Chesapeake Bay Program

Watershed Model Application to Calculate Bay Nutrient Loadings

Final Findings and Recommendations

Prepared by the Modeling Subcommittee
of the Chesapeake Bay Program

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WATERSHED MODEL APPLICATION TO CALCULATE BAY NUTRIENT LOADINGS

Final Findings and Recommendations

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FOREWORD

The EPA Chesapeake Bay Program (CBP) has sponsored a series of projects to develop and implement a 'Watershed Model' of the Chesapeake Bay drainage area that could be used effectively to estimate nutrient loadings to the Bay and to evaluate the impacts of agricultural Best Management Practices (BMPs). A phased approach was planned to develop the Watershed Model and implement its calibration and refinement. The U.S. EPA Hydrological Simulation Program - FORTRAN (HSPF) was selected as the framework for the CBP Watershed Model.

Phase I of the effort was designed to improve the nonpoint loading representation, refine the data input to the Model, and perform a preliminary calibration to available water quality data for the 1984-85 period. This period was used as the basis for the 40% nutrient loading reduction goal defined by the 1987 Chesapeake Bay Agreement.

Phase II was designed to focus on a better representation of the effects of agricultural BMPs, including application of the detailed Agrichemical Modules (AGCHEM) of HSPF to allow a more deterministic, process-oriented approach to BMP analysis and evaluation. AGCHEM provides a nutrient balance approach to modeling cropland areas so that sensitivity to nutrient inputs can be represented. In addition, HSPF code enhancements were performed to allow specific consideration of sediment-nutrient and bed interactions within the stream channel. The Phase II Watershed Model was then applied for the 1984-87 period to the Bay drainage area to include sediment erosion, sediment transport, and associated nutrients, in addition to the current modeled water quality constituents, to provide input to the Chesapeake Bay 3-D Water Quality Model.

This report presents the results of the combined Phase I/Phase II effort. Model calibration results are presented for hydrology, nonpoint loadings, and instream water quality for numerous sites throughout the Bay drainage. In addition, model estimates of Fall Line loads for various nutrient forms are compared with regression estimates used in the calibration of the Bay Model. The results indicate that the Watershed Model is a valid representation of nutrient loadings to the Bay, and provides a framework for assessing the impacts of land use changes and alternative nutrient and agricultural management practices.

Since the completion of Phase II, the Watershed Model has been used to: 1) determine the distribution of point and nonpoint source loads and the controllable and uncontrollable portions of the loads; 2)determine the quantity of loads reduced under different management actions; 3) determine the nutrient loads to the Bay under different Clean Air Act scenarios; and 4) quantify the loads under future (year 2000 conditions). These loads were used as input conditions for the Chesapeake Bay Water Quality Model. Following this Foreword is a brief technical summary of the status and use of the Watershed Model for management and planning in the Chesapeake Bay Region. Work is continuing in a current Phase III effort to extend the simulation period, investigate and improve the plant nutrient and reservoir simulations, and refine the calibration for recent water quality conditions.

THE CHESAPEAKE BAY WATERSHED MODEL

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ABSTRACT

The Chesapeake Bay Watershed Model is designed to simulate nutrient loads delivered to the estuary under different management scenarios. The nutrient loads are differentiated into anthropogenic loads amenable to management, and nonanthropogenic loads which are considered to be uncontrollable. The model divides the Bay basin into sixty-three model segments with an average area of 260,300 hectares. Hydrology, sediment and nonpoint source loads (including atmospheric deposition) are simulated on nine land uses. In the river reaches, sediment, nonpoint source loads, point source inputs, and water supply diversions are simulated on an hourly time-step. Particulate and dissolved nutrients are transported sequentially through each segment, and ultimately to the tidal Chesapeake Bay. The input data used for development of the Watershed Model water is reviewed. Model scenarios of existing loads, Chesapeake Bay Agreement loads, year 2000 loads, and loads under limit of technology controls are described. The model will be used to assist the Chesapeake Bay Program in the restoration of Chesapeake Bay water quality through nutrient load reductions.

INTRODUCTION

"Decision makers who assess which environmental control strategies to implement are particularly wary of two possibilities:

1. Reducing waste inputs to a water body and observing little or no improvement in water quality (the environmental engineering equivalent of building half a bridge) or,
2. Mandating control actions that are subsequently shown to be [excessive]...(the environmental engineering equivalent of building a bridge to nowhere)."

Robert V. Thomann

The Chesapeake watershed drains the waters (and nutrient loads) of seven mid-Atlantic States from New York to Virginia. Six major basins of the watershed are the Susquehanna, Potomac, Rappahannock/York, James, West Shore Chesapeake, and East Shore Chesapeake (Figure 1). Taken together, the three largest basins of the Susquehanna, Potomac, and James, comprise 80% of the total basin area. Land use in the watershed is predominately forest (60%), cropland (20%), pasture (9%), and urban land (10%) (Figure 2). By the year 2000, urban land in the watershed will increase to 13% due to the conversion of forest (2% decrease) and cropland (1% decrease).

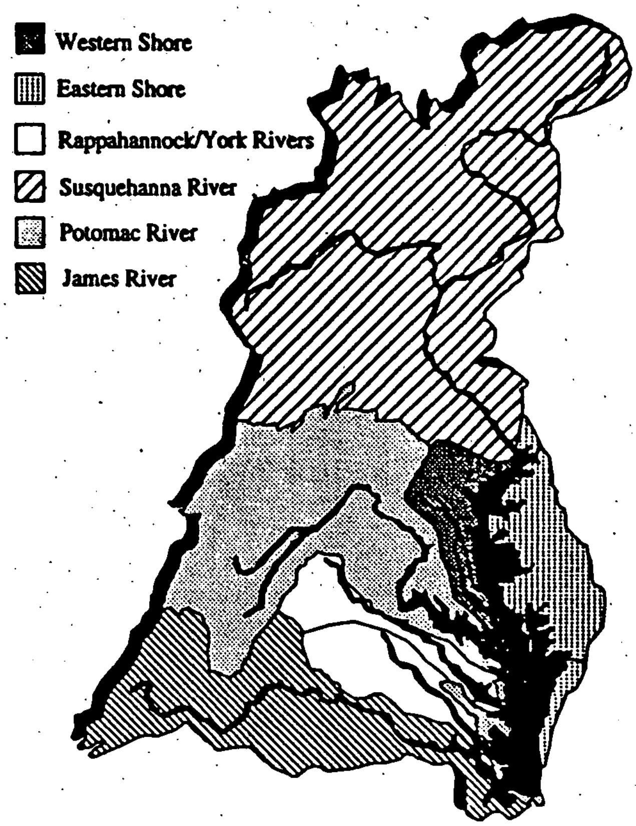

Figure 1. Chesapeake Bay watershed: major basins.

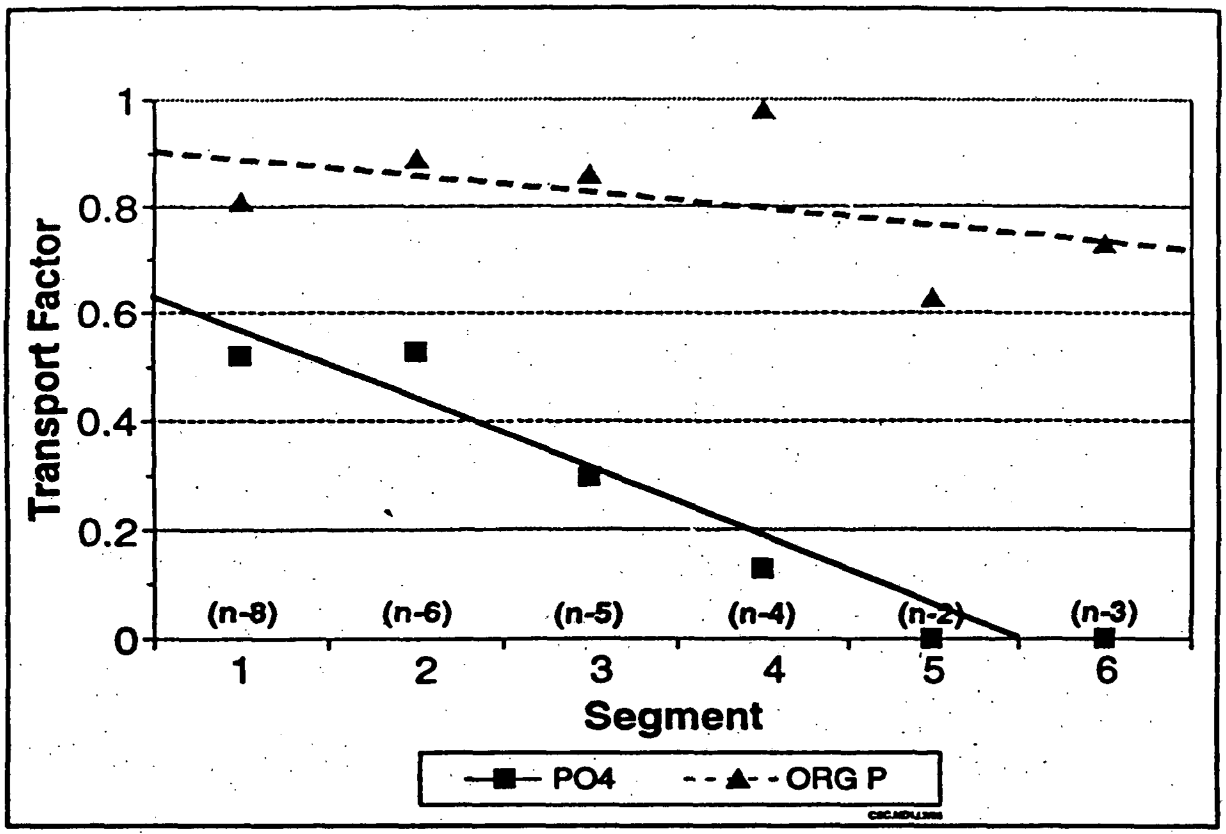

Figure 5. Watershed average phosphorus transport.

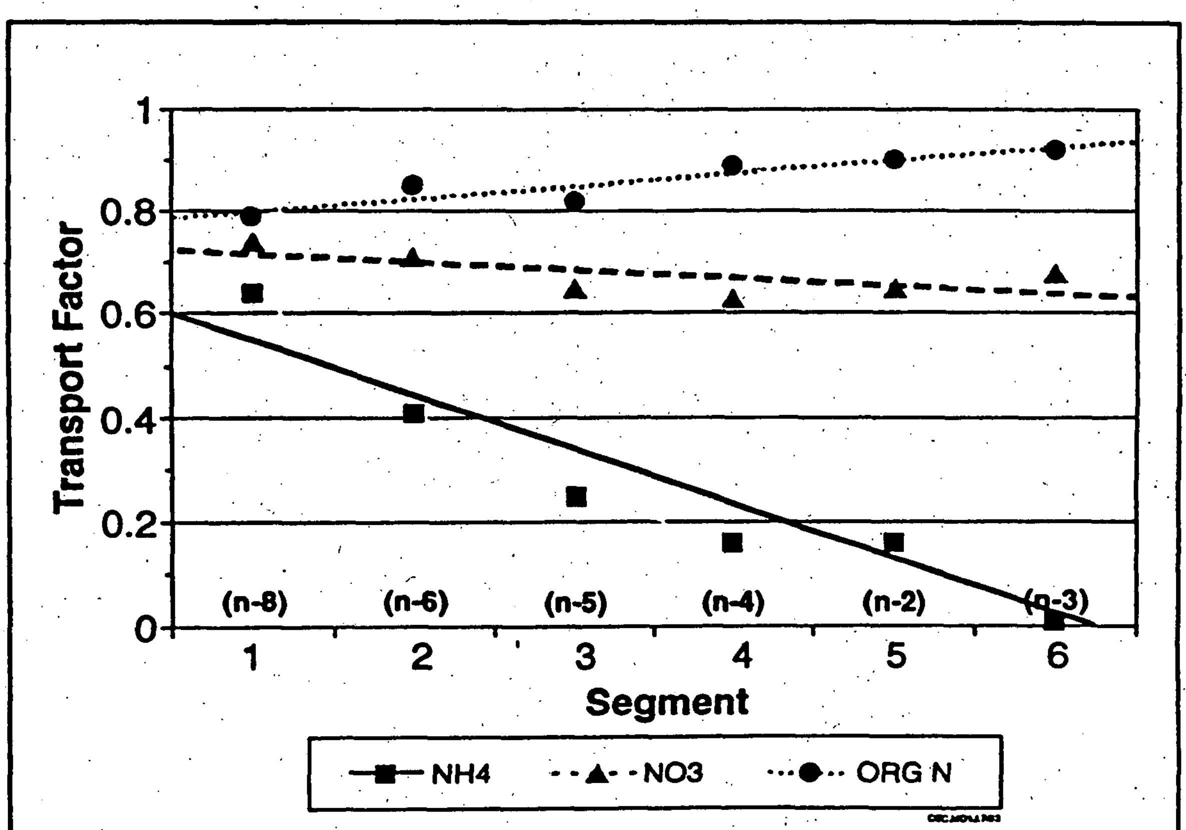

Figure 6. Watershed average nitrogen transport.

Susquehanna Basin

segment 6a->
->segment 5a->segment 4a->
segment 6b->

->segment 3—>segment 2—>segment 1—>discharge to tidal Bay

segment 6c->segment 5b->segment 4b->

segment 5c->segment 4c->

Segments 6a, 6b, 5a, and 4a represent the East Branch Susquehanna. Segments 6c, 5b, and 4b represent the West Branch Susquehanna. Segments 5c and 4c represent the Juniata Branch and Segments 3, 2, and 1 represent the Susquehanna main stem.

Not surprisingly, phosphate P is rapidly attenuated through incorporation into riverine sediment by phytoplankton uptake or adsorption to particulates. This removal mechanism is dramatically reversed during periods high flow and scour of sediments. During a high flow riod in November, 1985 (peak discharge 33 times the average discharge of the 1991 record) in the Upper Potomac segments, the phosphorus discharged was 1.8 times that amount input by annual edge-of-stream loads.

As can be seen from Figure 5, attenuation of nutrient loads is dependent on the nutrient form and the time or length of transport. Other factors of attenuation are nutrient limitation and the presence of reservoirs in the system which in some cases greatly increase the basin residence time. Examination of the nutrient concentrations reveals these systems to be consistently under phosphorus limitation. The slope of the phosphate P attenuation is -0.125. The slope of the organic P attenuation is -0.030.

Average transport losses of ammonia, nitrate, and organic nitrogen are diagramed in Figure 6. Organic nitrogen, as in the case of organic phosphorus, includes biomass, labile and refractory organic and particulate inorganic nitrogen. Ammonia is removed quickly (slope = -0.105) in riverine transport by incorporation into organic nitrogen through biomass uptake and adsorption to particulates. Ammonia is so removed through nitrification. Nitrate (slope = -.014) moval mechanisms include uptake by biomass and denitrification. The transport time in the basins is correlated with increasing organic nitrogen primarily through conversion of inorganic nitrogen.

MANAGEMENT SCENARIOS

Several key scenarios were completed in order to develop the basic inventory of loads under specific management conditions.

BASE CASE SCENARIO

This scenario is the base case year: 1985 loads to the Chesapeake Bay.

BAY AGREEMENT SCENARIO

This scenario represents the nutrient loads to be reduced by the year 2000 under the Bay Agreement. The reduction is a 40% reduction of controllable nutrient loads. Controllable loads were defined as the base case loads minus the loads delivered to the Bay under the conditions of an all forested watershed. In other words, controllable loads are defined as everything over and above the total phosphorus or total nitrogen loads that would have come from an entirely forested watershed. In this definition, point source loads are considered entirely controllable.

LIMIT OF TECHNOLOGY SCENARIO

The limit of technology scenario is defined as all cropland in conservation tillage; the Conservation Reserve Program fully implemented; nutrient management, animal waste controls, and pasture stabilization systems implemented where needed; a 20% reduction in urban loads; and point source effluent controlled to a level of 0.075 mg/l total phosphorus and 3.0 mg/l total nitrogen. An important aspect of the limit of technology scenario is that it determined the feasibility of the 40% nutrient reduction.

YEAR 2000 SCENARIO

This scenario represents the growth in population and the projected changes in land use by the year 2000. The controls in place in the base case scenario are applied to the year 2000 point source flows and land use representing the loading conditions without the nutrient reductions of the Bay Agreement.

1991 PROGRESS SCENARIO

This scenario applies the actual reductions made in nitrogen and phosphorus by the year 1991.

Figures 7 and 8 show the base case total phosphorus and total nitrogen loads relative to the Bay Agreement, the limit of technology, the year 2000, and the 1991 Progress loads.

In all basins, the limit of technology phosphorus loads are less than the Bay Agreement loads. For nitrogen loads only the point source dominated basins of the Potomac, James, and the West Shore have limit of technology loads appreciably less than Bay Agreement loads. For nonpoint source dominated basins of the Susquehanna, Rappahannock, York, and the East Shore, the limit of technology loads are essentially equivalent to the Bay Agreement loads.

The Year 2000 scenario has increased loads of phosphorus and nitrogen for all basins. The point source dominated basins of the Potomac, James, and West Shore, which experience the greatest urbanization in the Year 2000 scenario have the greatest increase in nutrient loads.

The 1991 Progress Scenario indicates that phosphorus reductions are on track to reach the year 2000 goal. The nitrogen reductions posted by the 1991 progress scenario are m... Overall progress in nitrogen reductions ... need to increase by a factor of 3.7 in order to reach the year 2000 goal.

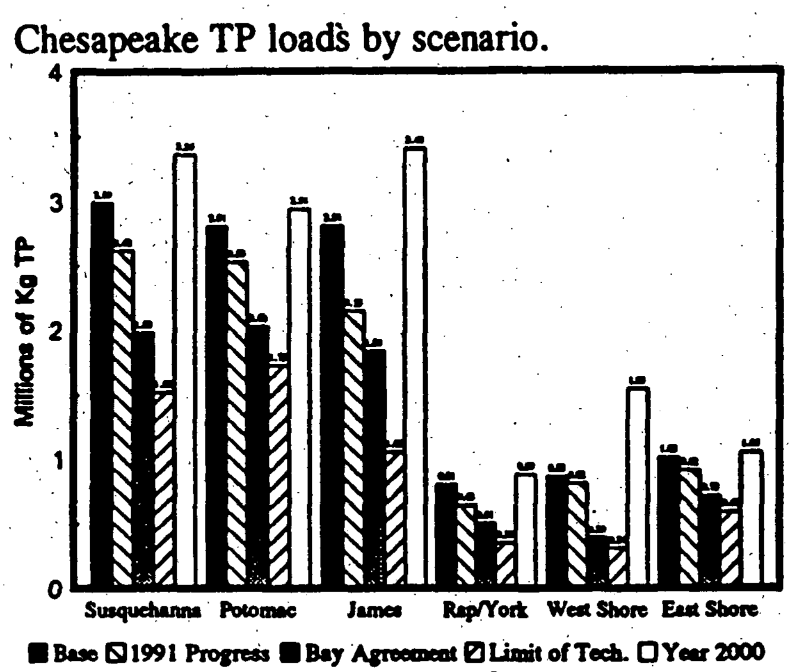

Figure 7. Chesapeake total phosphorus loads by scenario.

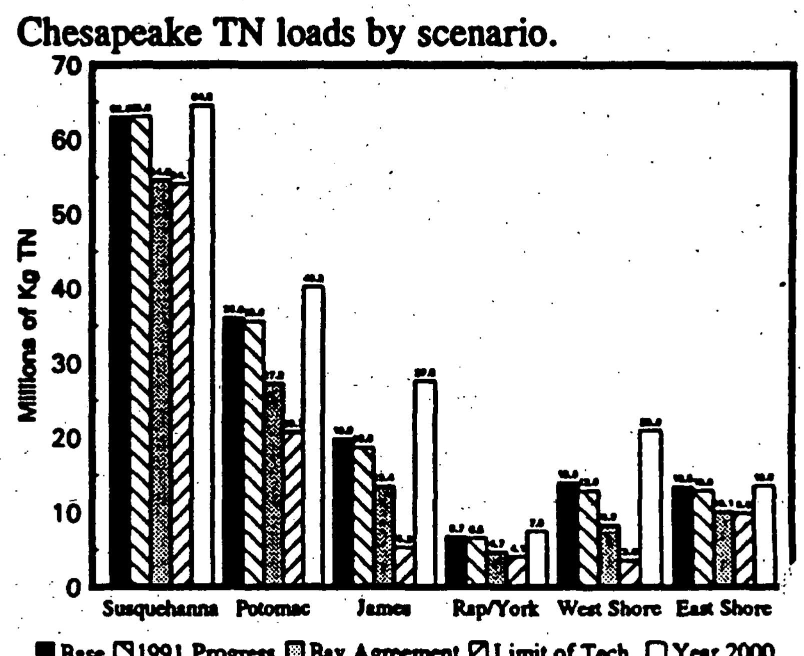

Figure 8. Chesapeake total nitrogen loads by scenario.

Another aspect of the Progress Scenario is that the Bay Agreement reductions become nutrient load caps after the year 2000. The Watershed Model is envisioned as the tool which will track the changes in watershed loads to ensure the caps are not exceeded in any basin.

CONCLUSION

The Watershed Model is a successful water quality simulation which quantifies the nonpoint source and point source nutrient loads from all basin sources. The model was essential in establishing a consistent method of accounting for the nutrient loads, among all sources, and among the basin jurisdictions of the Bay Program. The model is used to examine the level of controls achievable from different management practices. The model has examined management practices, which when combined into strategies of nutrient control, will meet the Chesapeake Bay Program water quality objective of a 40% reduction in controllable nutrients in the Chesapeake watershed and do so in a cost-effective and equitable manner.

ACKNOWLEDGMENTS

The authors wish to acknowledge the state, regional, and federal members of the Chesapeake Bay Program Modeling Subcommittee for their essential guidance and direction throughout the development of the Chesapeake Bay Watershed Model, and in particular Dr. Robert Thomann for his expertise and experience gained through 23 years of water quality modeling work on the Chesapeake and its tributaries.

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ABSTRACT

Since 1985 the EPA Chesapeake Bay Program (CBP) has sponsored a series of projects to convert the proprietary HSP-NPS model to the public domain HSPF model, make it operational on the CBP VAX computer system, and implement a number of model refinements so that the resulting 'Watershed Model' could be used effectively to estimate nutrient loadings to the Bay and to evaluate the impacts of agricultural Best Management Practices (BMPs). A comprehensive workplan developed in September 1987 proposed a two-phased approach to address Watershed Model deficiencies and produce an improved and re-calibrated model. Phase I was designed to improve the nonpoint loading representation, refine/re-evaluate the data input to the Model, and perform a preliminary re-calibration to available water quality data for the 1984-85 period. This period was used as the basis for the 40% nutrient loading reduction goal defined by the 1987 Chesapeake Bay Agreement.

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This report is submitted in fulfillment of Work Assignment No. 7(B) by AQUA TERRA Consultants under EPA Contract No. 68-C0-0019 with the EPA Athens Environmental Research Laboratory. Earlier work for Phase I of the CBP Watershed Model re-calibration was performed under EPA Contact No. 68-03-3513.

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ACKNOWLEDGMENTS

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The project was guided by a number of technical committees that met on a regular basis to provide thorough technical review of all aspects of the study. These committees included the Modeling Subcommittee, the Nonpoint Source Committee, the Nutrient Reduction Task Force (NRTF), and the Science and Technical Advisory Committee. It would be impossible to accurately acknowledge the specific contributions of all the individuals on these committees, but their participation, review, and input was a major factor in the conduct of this work. Mr. James Collier, as Chair of the Modeling Subcommittee, played a key coordination and oversight role among the various agencies and committees.

The NRTF deserves special mention because its various state members were instrumental in providing the information needed to develop appropriate input for the AGCHEM modeling of the cropland areas, including the nutrient application rates, crop cover values, tillage practices, etc. Mr. Jim Cox, as Chair of the NRTF, was a key force in this effort, in addition to the various state representatives including Dr. Robert Summers and Mr. John McCoy of MDE, Mr. Mike Flagg of VA DSWC, Dr. Elizabeth Casman of ICPRB, Ms. Veronica Kasi of PA BWSC and Mr. Fred Samadani of MDA. The AGCHEM model application would not have been possible without the valuable assistance from these individuals. The assistance of Joel Myers, SCS is acknowledged for his contributions to the Pennsylvania agricultural data. In addition, Mr. James Hannawald, SCS, played a major role in the land use evaluation, soil parameter assessment, and crop cover representation and provided invaluable knowledge of agricultural conditions and practices within the Bay drainage.

The CBP Watershed Model Evaluation Group was convened at various times throughout the study to provide expert technical review of the modeling procedures and results. Mr. Thomas Barnwell of Athens ERL, Dr. Alan Lumb of the USGS, and Dr. Robert Thomann of Manhattan College provided helpful and insightful review comments as members of this group. Their participation is sincerely appreciated.

In addition to the authors, various individuals at AQUA TERRA Consultants and the CBPO provided key technical and staff support roles throughout the study. At AQUA TERRA, Mr. John Imhoff was a key participant in the development of the sediment-nutrient interaction capabilities and assisted in the water quality parameter review and calibration; Mr. Jack Kittle assisted in the Conowingo Reservoir operation program, the rainfall generation program, and the ANNIE/WDM application; and Ms. Dorothy Inahara and Ms. Mary Shandonay provided administrative, word processing and graphics support.

At CBPO, in addition to the authors, several individuals provided guidance and assistance. Mr. Ed Stigall, Technical Programs Director, and Mr. Lynn Shuyler, Nonpoint Source Coordinator, assisted in bridging the gap between the technical aspects of the model and its application to water quality problems in the Chesapeake Bay. Their assistance is gratefully acknowledged. Many of the staff of the Computer Sciences Corporation were essential for the successful execution of a number of tasks throughout this project, with special appreciation to Scott McDiarmid and Lacy Williams for satisfying the variety of requisites, large and small, made of them by HSPF or it's modelers. Ms. Diane Allegre, the Modeling Intern, is thanked for her many contributions to the appendices and the report.

TABLE OF ACRONYMS AND ABBREVIATIONS

AFFIX	-	An HSPF parameter representing the incorporation of detached sediment into the soil matrix where it would be unavailable for transport.
AFL	-	Above Fall Line.
AGCHEM	-	Agricultural/Chemical section of HSPF. An HSPF module which simulates agricultural nutrient loads in detail in PERLND.
ARC-INC	-	A type of GIS software.
ARM	-	Agricultural Runoff Model.
ATEMP	-	An HSPF module used to adjust air temperature for adiabatic differences between the measuring station and the average altitude of the model segment.
BFL	-	Below Fall Line.
BMP	-	Best Management Practice.
BOD	-	Biochemical Oxygen Demand.
BTU	-	British Thermal Units heat metric.
BWSC	-	Bureau of Water and Soil Conservation (PA).
C	-	Centigrade temperature.
CBP	-	Chesapeake Bay Program.
CBPO	-	Chesapeake Bay Program Office.
COVER	-	An HSPF parameter used to specify the degree to which the soils are protected for rain splash soil detachment by vegetation, organic debris, or vegetative litter.
CNT	-	Conventional Tillage land use.
CSC	-	Computer Science Corporation.

CTIC	-	Conservation Technology Information Center.
CST	-	Conservation Tillage land use.
3-D Water Quality Model	-	The Chesapeake Bay Three-Dimensional Time-Variable Model, a coupled hydrodynamic and water quality model of the Chesapeake Bay. The Watershed Model simulates the nutrient loads used as input in the 3-D Water Quality Model.
DETS	-	An HSPF parameter used to represent detached sediment storage in SEDMNT.
DSWC	-	Department of Soil and Water Conservation (VA).
DO	-	Dissolved Oxygen concentration.
EPA	-	Environmental Protection Agency.
ERL	-	Environmental Research Laboratory (US EPA).
F	-	Fahrenheit temperature.
FHA	-	Federal Highway Administration.
FTABLE	-	An HSPF input file table which relates water volume to depth, surface area, and flow rate for a reach or reservoir.
GIS	-	Geographic Information System.
HSPF	-	Hydrologic Simulation Program - Fortran. Model code used as a basis for the Watershed Model.
HSP-NPS	-	Hydrologic Simulation Program - Nonpoint Source - A proprietary model code.
HTRCH	-	An HSPF module used to simulate heat exchange and water temperature in RCHRES.
HYDDAY	-	App D.
HYDHR	-	App D.
HYDR	-	An HSPF module used to simulate hydraulic behavior in RCHRES.
HYDSDY	-	App D.
IMPLND	-	Impervious Land simulation section of HSPF. An HSPF module used to simulate the pollutant loads from impervious land uses.
ICPRB	-	Interstate Commission of the Potomac River Basin.
IQUAL	-	An HSPF module which simulates water quality in IMPLND.

IWTGAS - An HSPF module which simulates water temperature and dissolved gas concentration in IMPLND.

K - A USLE parameter used to represent soil erodibility.

KPL - An HSPF parameter representing plant uptake rates of nutrients in AGCHEM.

KRER - An HSPF parameter representing the erodibility of soil.

KSER - An HSPF parameter used to adjust the amount of soil fines detached by raindrop impact.

LU/LC - Land Use/Land Cover.

MAGI - Maryland Geographic Information System.

MDA - Maryland Department of Agriculture.

MDE - Maryland Department of Environment.

MGD - Millions of Gallons per Day.

MSLAY - An HSPF module which simulates solute transport in AGCHEM.

N - Nitrogen nutrient.

NADP - National Atmospheric Deposition Program.

NASA - National Aeronautics and Space Administration.

NHAPP - National High-Altitude Photography Program.

NITR - An HSPF module which simulates nitrogen in AGCHEM.

NOAA - National Oceanographic and Atmospheric Administration.

NPDES - National Pollution Discharge Elimination System.

NPS - Nonpoint Source, a term describing pollutants from diffuse sources.

NRI - National Resource Inventory.

NRTF - Nutrient Reduction Task Force.

NUTRX - An HSPF module which simulates primary inorganic nitrogen and phosphorus reactions in RQUAL.

NVPDC - Northern Virginia Planning District Commission.

NVSI	-	An HSPF parameter used to represent net external additions or removals of sediment caused by atmospheric deposition or wind.
ORGN	-	Organic Nitrogen.
ORGP	-	Organic Phosphorus.
OXRX	-	An HSPF module used to simulate primary DO and BOD reactions in RQUAL.
P	-	Phosphorus nutrient.
PANEVAP	-	A FORTRAN subroutine used to develop pan evaporation rate time series for the Watershed Model.
PERLND	-	Pervious Land simulation section of HSPF. An HSPF module used to simulate the pollutant loads from pervious land uses.
PLANK	-	An HSPF module which simulates plankton in RQUAL.
PRECIP	-	A FORTRAN subroutine used to develop an hourly time series of rainfall data.
PQUAL	-	Water quality section of HSPF. An HSPF module which simulates water quality in PERLND.
PHOS	-	Detailed phosphorus simulation section of HSPF. An HSPF module which simulates phosphorus in AGCHEM.
PSTEMP	-	Soil temperature section of HSPF. An HSPF module which simulates soil temperature in PERLND.
PWATER	-	Water budget section of HSPF. An HSPF module used to simulate the water budget in PERLND.
PWTGAS	-	Water temperature section of HSPF. An HSPF module which simulates water temperature and gas concentrations in PERLND.
RADCLC	-	A FORTRAN subroutine used to develop solar radiation time series for the Watershed Model.
RCHRES	-	Reach and Reservoir section of HSPF. An HSPF module used to simulate transport and transformation in the river reaches and reservoirs.
RQUAL	-	An HSPF module used to simulate water quality constituents in RCHRES.
SCS	-	Soil Conservation Service.

SEDMNT	-	An HSPF module which simulates sediment to the edge of stream in PERLND.
SEDTRN	-	An HSPF module which simulates sediment transport in RCHRES.
SLSUR	-	An HSPF parameter that represents the average land slope of a model segment.
SLSED	-	HSPF parameter that represents external lateral input of sediment from an upland segment.
SNOW	-	Snow simulation section of HSPF. An HSPF module used to simulate snow accumulation and melt.
SOLIDS	-	An HSPF module which simulates the accumulation and removal of solids in IMPLND.
TAUCD	-	An HSPF parameter which specifies the critical shear stress for sediment deposition in SEDTRN.
TAUCS	-	An HSPF parameter which specifies the critical shear stress for sediment scour in SEDTRN.
TN	-	Total Nitrogen.
TOC	-	Total Organic Carbon.
TP	-	Total Phosphorus.
UAN	-	Urea, Ammonium, Nitrate liquid fertilizer.
USDA	-	United States Department of Agriculture.
USGS	-	United States Geological Survey.
USLE	-	Universal Soil Loss Equation model.
VIRGIS	-	Virginia Geographic Information System.
WDM	-	Watershed Data Management system. System data files by HSPF.

SECTION 1.0

INTRODUCTION

1.1 BACKGROUND

Since 1985 the EPA Chesapeake Bay Program (CBP) has sponsored a series of projects to convert the proprietary HSP-NPS model to the public domain HSPF model (Johanson et al, 1984), make it operational on the CBP VAX computer system, and implement a number of model refinements so that the resulting 'Watershed Model' could be used effectively to estimate nutrient loadings to the Bay and to evaluate the impacts of agricultural Best Management Practices (BMPs). A comprehensive workplan developed in September 1987 proposed a two-phased approach to address Watershed Model deficiencies. Phase I was designed to improve the nonpoint loading representation, refine/re-evaluate the data input to the Model, and perform a preliminary re-calibration to available water quality data for the 1984-85 period. This period was used as the basis for the 40% nutrient loading reduction goal defined by the Chesapeake Bay Agreement.

Phase II was designed to focus on a better representation of the effects of agricultural BMPs through application of the detailed Agrichemical Modules (AGCHEM) of HSPF which allow a more deterministic, process-oriented approach to BMP analysis and evaluation. In addition, HSPF code enhancements were performed to allow specific consideration of sediment-nutrient and bed interactions within the stream channel so that runoff, and subsequent delivery to the Bay, of dissolved and sorbed nutrient forms can be more accurately modeled. The Phase II Watershed Model was then applied to the Bay drainage area to include sediment erosion, sediment transport, and associated nutrients, in addition to the current modeled water quality constituents, to provide input to the Bay model.

This report presents the results of the combined Phase I/Phase II effort. The Phase II effort, in addition to the agricultural and sediment-nutrient emphasis noted above, also addressed the preliminary conclusions and recommendations resulting from the Phase I work as discussed in the Phase I report (Donigian et al, 1990). In summary, the Phase I effort identified the need for a longer simulation period (i.e. more observed data), more in-depth analysis of animal waste and point source contributions, and simulation problems with selected nutrient forms and phytoplankton as issues that needed to be addressed in Phase II. Thus, the results presented herein represent the integrated efforts of both phases of the Watershed Model refinement and re-calibration work. However, the detailed results of Phase I are not repeated in this report since they have been superseded by Phase II and were presented in the Phase I report.

The Watershed Model represents the entire drainage area to the Chesapeake Bay as a series of land segments each with relatively uniform climatic and soils conditions. Within each model segment a variety of different land use categories are each modeled with its own parameter values, and each land use provides surface and subsurface nonpoint loadings to the stream draining that model segment. Each model segment also corresponds to a single channel reach which are linked sequentially with other channel reaches in other segments to represent the major and minor river systems that comprise the Bay drainage. Figure 1.1 shows the primary subbasins for the areas above the Fall Line, which include the three major subbasins - Susquehanna, Potomac, James - and a number of smaller river systems. Figures 1.2 and 1.3 show the model segments for the Above Fall Line (AFL) and Below Fall Line (BFL) areas, respectively; Figure 1.2 also shows the primary model calibration stations. A complete list of the model segments is included in Table 1.1. This brief overview is provided to establish a common basis for the following sections on the Phase I/II efforts and associated conclusions and recommendations. The model segmentation is discussed further in Sections 4.0 and 5.0.

It should be noted that the entire Phase I/II project has been a joint effort between AQUA TERRA Consultants and the Chesapeake Bay Program Office (CBPO), including the support of Computer Sciences Corporation, in Annapolis, Maryland. AQUA TERRA was responsible for overall guidance and review of the modeling effort, with the lead on specific tasks such as meteorologic data update procedures, snowmelt/hydrology calibration, nonpoint parameter evaluation, AGCHEM application, water quality calibration guidance and review, and final model input sequence development. CBPO has taken the lead on database update for meteorologic data, diversions, point sources, and observed water quality data; land use re-evaluation; and urban nonpoint source loading assessment. The final water quality calibration was a joint effort with AQUA TERRA preparing final input sequences for all basins, developing a preliminary calibration for the Susquehanna basin, and providing essentially final calibrations for the remaining basins and below Fall Line areas. CBPO staff continued calibration of the Susquehanna, performed selected refinements on the other basins, executed the final runs, and prepared the statistical analyses and appendices of the final results. Through this joint effort CBPO staff have become thoroughly trained in the application and many of the intricacies of the Watershed Model.

1.2 OVERVIEW OF THE PHASE I/PHASE II EFFORTS

The primary tasks in the Phase I project involved selected model refinements, updating model input, and preliminary hydrology and water quality re-calibration; these primary tasks and major subtasks are listed below:

WATERSHED MODEL REFINEMENTS

- Incorporate snowmelt simulation
- Allow variable hydrology for each land use category
- Include animal waste contributions

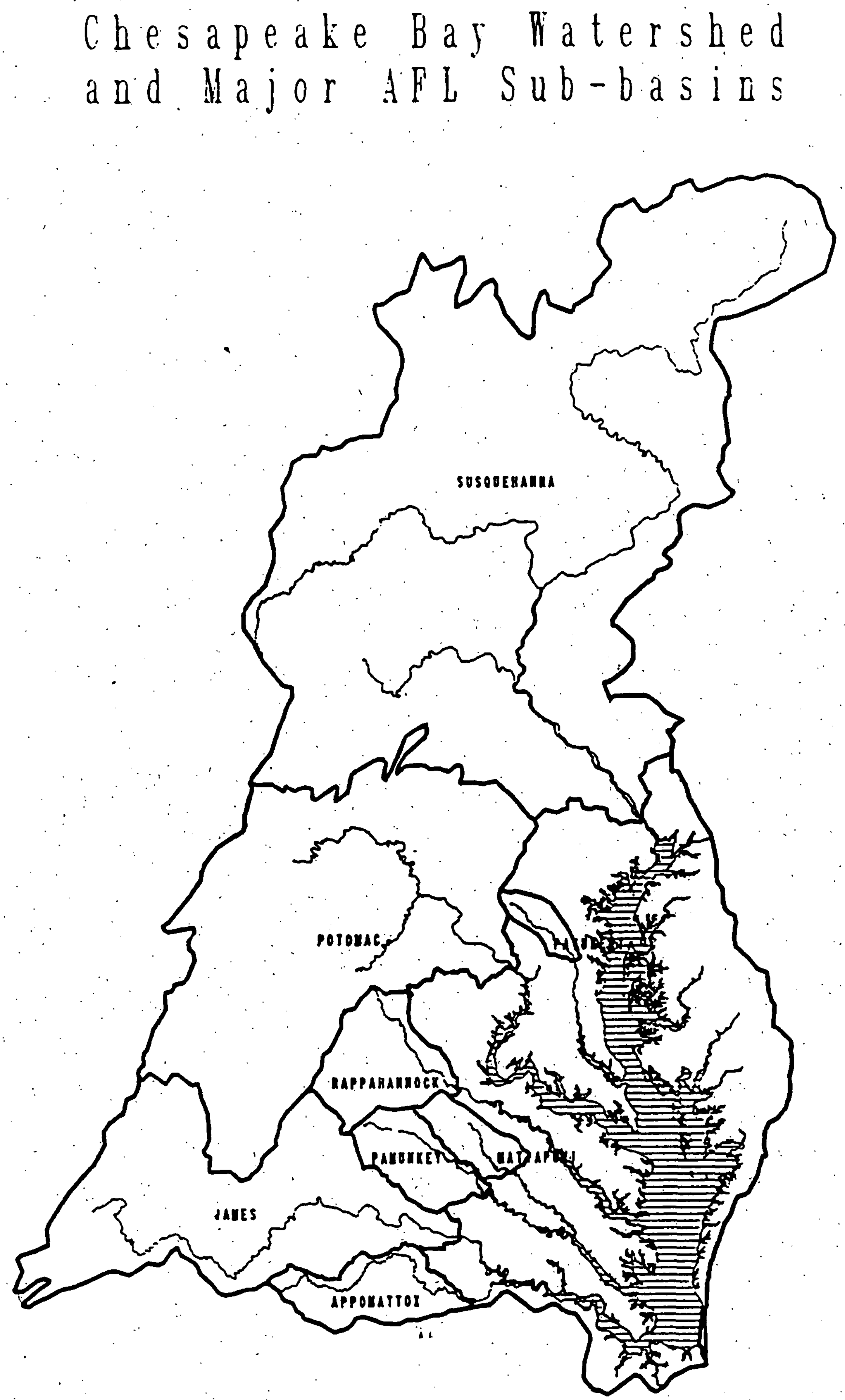


Figure 1.1 Chesapeake Bay watershed and major above fall line

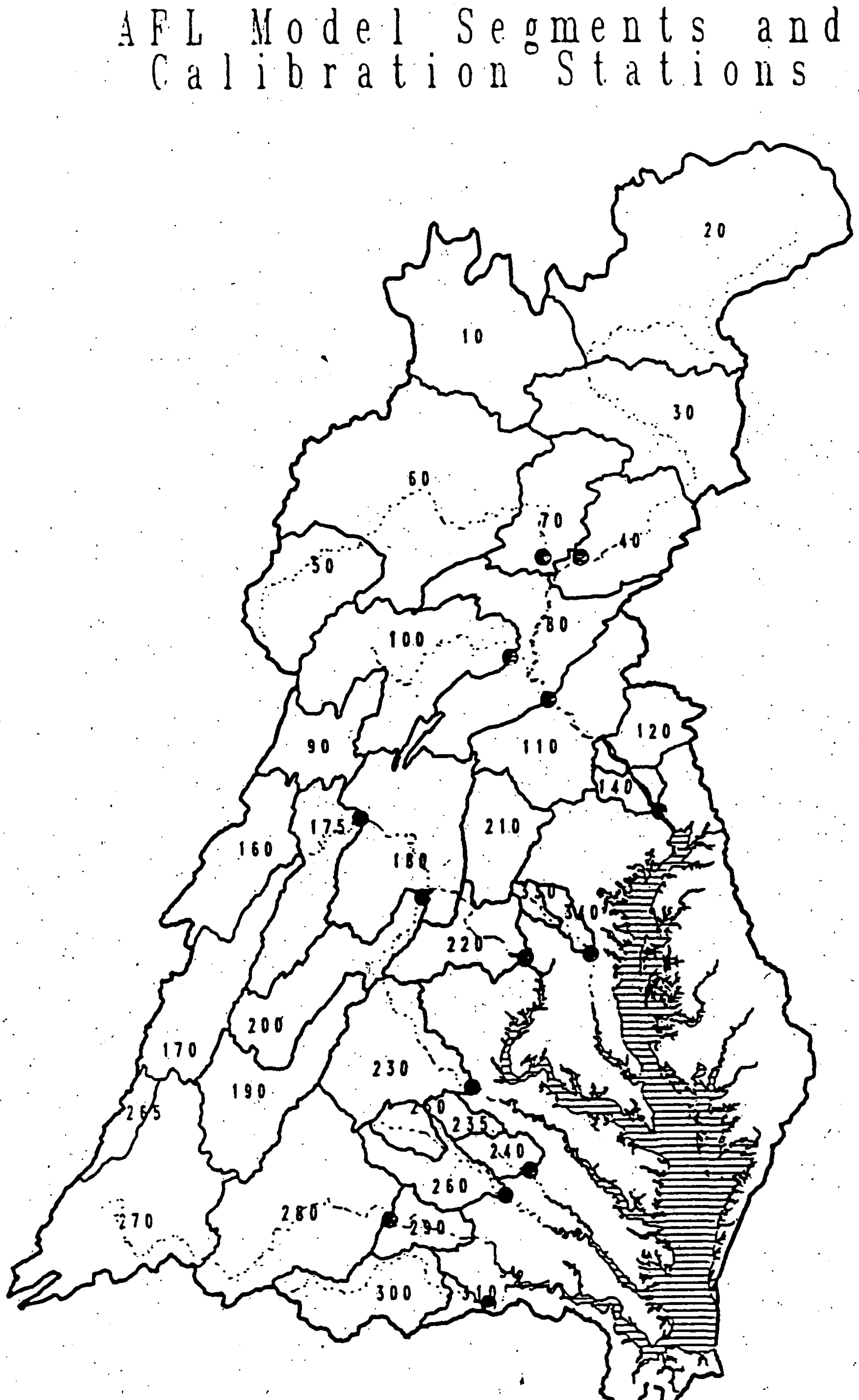


Figure 1.2 Above fall line watershed model segments.

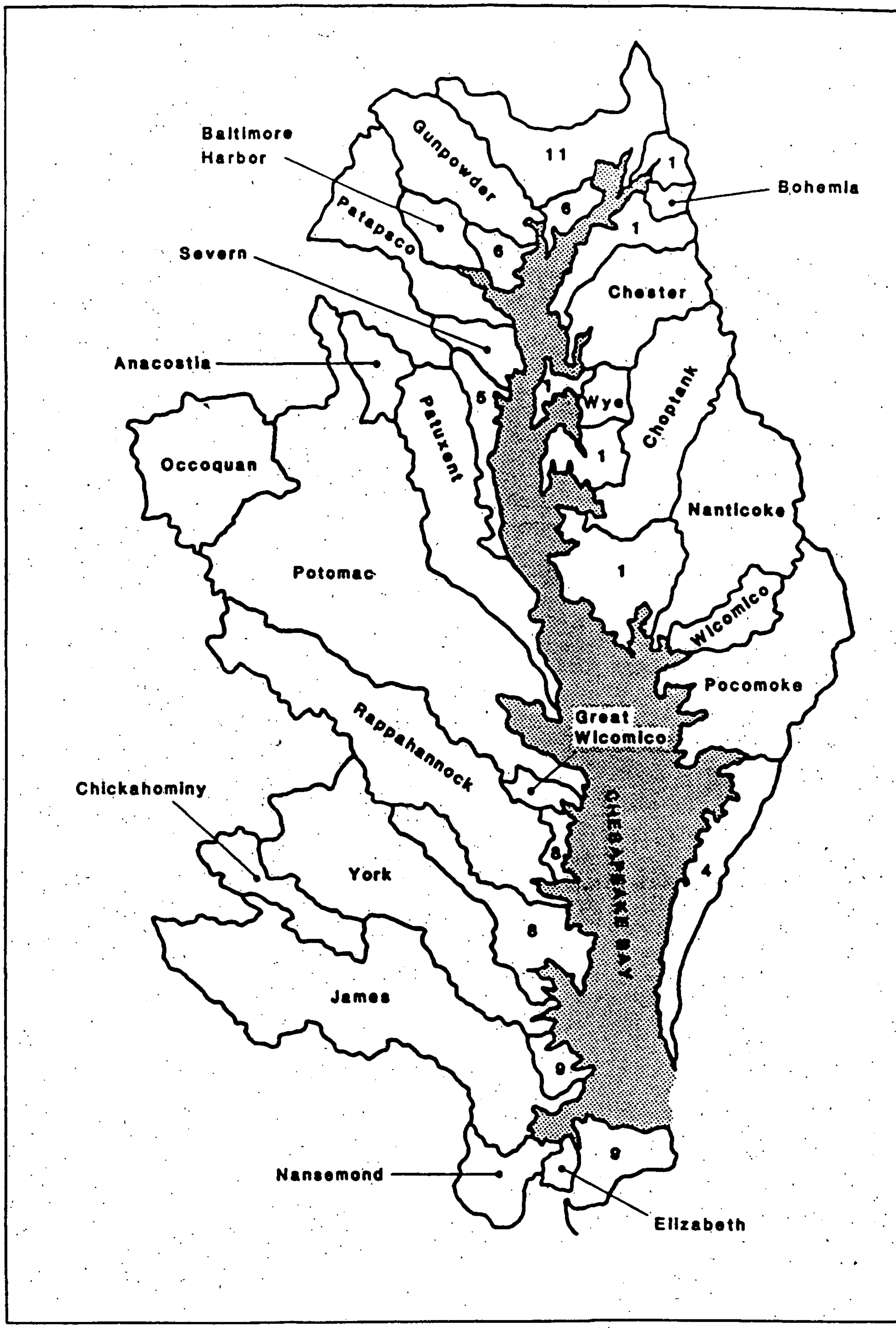


Figure 1.3 Below fall line watershed model segments.

TABLE 1.1 SUBBASIN, SEGMENT NAME, AND SEGMENT NUMBERS OF THE CHESAPEAKE BAY WATERSHED MODEL

SUBBASIN	SEGMENT NAME / GROUP	SEGMENT NUMBERS
<u>ABOVE FALL LINE</u>		
SUSQUEHANNA	East Branch Susquehanna (EBSUS)	10, 20, 30, 40
	West Branch Susquehanna (WBSUS)	50, 60, 70
	Juniata (JUNIATA)	90, 100
	Lower Susquehanna (LOSUS)	80, 110
	Conowingo (CONOW)	120, 140
POTOMAC	Upper Potomac (UPPOT)	160, 170, 175
	Shenandoah (SHENA)	190, 200
	Lower Potomac (LOPOT)	180, 210, 220
RAPPAHANNOCK	Rappahannock (RAPPA)	230
YORK	Mattaponi (MATTA)	235, 240
	Pamunkey (PAMUN)	250, 260
JAMES	James (JAMES)	265, 270, 280, 290
APPOMATTOX	Appomattox (APPOM)	300, 310
PATUXENT	Patuxent (PATUX)	330, 340
<u>BELOW FALL LINE</u>		
UPPER EASTERN SHORE		
BFL_1A	Coast_1	360
	Bohemia	370
BFL_1B	Chester	380
	Wye	390
	Choptank	400
LOWER EASTERN SHORE		
BFL_2	Nanticoke	410
	Wicomico	420
	Pocomoke	430
	Coast_4	440
WEST CHESAPEAKE		
BFL_3A	Coast_11	450
	Coast_6	460
BFL_3B	Gunpowder	470
	Baltimore	480
	Patapsco	490

TABLE 1.1 (Continued)

SUBBASIN	SEGMENT NAME / GROUP	SEGMENT NUMBERS
BELOW FALL LINE		
PATUXENT/MID CHESAPEAKE		
BFL_4	Patuxent	500
	Severn	510
	Coast_5	520
POTOMAC		
BFL_5	Potomac	530
	Anacostia	540
	Occoquan	550
RAPPAHANNOCK		
BFL_6	Rappahannock	560
	Coast_8	570
	Great Wicimico	580
	York	590
JAMES		
BFL_7A	James	600
	Chickahominy	610
BFL_7B	Nansemond	620
	Elizabeth	630
	Coast_9	640

UPDATE MODEL INPUT

- Update meteorology and precipitation to 1984-85
- Update diversions, point sources, and observed streamflow/water quality data to 1984-85
- Re-evaluate land use for 1974-78 and update to 1984-85

WATERSHED MODEL RE-CALIBRATION

- Re-evaluate nonpoint parameters and loadings
- Re-calibrate Watershed Model to 1984-85 with model refinements and updated input

The Watershed Model refinements in Phase I focused on areas that had been noted as specific deficiencies in the earlier applications. Snow accumulation and melt had not been included in the first Watershed Model formulation, and thus was not included in the HSPF version resulting from the HSP-NPS model conversion study (Donigian et al, 1986). Since snow accumulation is significant in much of the northern portions of the watershed, simulating snow processes was considered an important element in year-round simulations produced by the Watershed Model.

Also, the converted Watershed Model used the same hydrologic parameters for all land uses within a specific hydrologic segment; this was a limitation of the NPS model which was eliminated when the Watershed Model was converted to HSPF. Thus, allowing a different set of hydrologic parameters for each land use was considered important to representing the impacts of land use changes. Furthermore, animal waste had not been specifically considered in earlier efforts and contributions from this source needed to be evaluated.

A major portion of the Phase I effort involved evaluating, refining, and updating the required input data to the Watershed Model. This effort was severely hampered by the lack of detailed documentation and loss of back-up information for the original Watershed Model (NVPDC, 1983), especially for the diversions, point sources, and meteorologic data. Also, the accuracy and validity of the land use information used in the original model was questioned, leading to the need to re-evaluate the land use for both the 1974-78 period and the 1984-85 period. Although not originally envisioned as part of Phase I, direct atmospheric deposition of nitrogen was an added input to the model (for water surfaces only) to allow for this source. To avoid future problems, such as those experienced in this study in updating the model, special efforts were expended to develop detailed documentation and back-up for all procedures and analyses performed in this model development effort.

The Watershed Model re-calibration effort involved both hydrology and water quality. The hydrology re-calibration was needed because of the inclusion of snow simulation and the parameter adjustments and refinement for better land use representation; addition of an animal waste land segment and changes to the land use also required a re-assessment of the hydrology. The water quality re-calibration involved re-evaluation of the nonpoint parameters (i.e. potency factors, subsurface concentrations, accumulation/washoff rates) and the expected loadings from each land use represented in the Model, and then adjustment of these parameters and selected instream water quality parameters was performed as part of the calibration process. Although the model had been previously calibrated to the 1974-78 period, differences in the point loads and the additional effects of animal waste and atmospheric contributions required considerable re-calibration for the 1984-85 period in Phase I. Problems identified during the re-calibration were discussed in the Phase I report, and, as noted above, helped to focus the Phase II effort.

The emphasis in the Phase II work was directed to more detailed modeling of agricultural BMPs, addition of sediment erosion and instream transport modeling, and incorporation of instream sediment-nutrient interactions in order to better represent nutrient delivery to the Bay. This effort involved replacing the empirical potency factor/subsurface concentration approach with the process-oriented Agrichemical modules in HSPF for the cropland areas of the watershed. In addition, the instream module (RCHRES) of HSPF was enhanced to include sediment-nutrient interactions, and the resulting enhanced version was re-applied/re-calibrated to the drainage area. The original workplan for Phase II identified the following major tasks and subtasks:

DETAILED EVALUATION OF AGRICULTURAL PRACTICES

- Identify/inventory current practices/BMPs
- Identify/evaluate field site data
- Apply detailed agricultural models
- Adapt Watershed Model to reflect field site results

SEDIMENT/NUTRIENT INTERACTIONS IN HSPF RQUAL

- Enhance HSPF RQUAL to include sediment/nutrient interactions
- Test model enhancements on selected subwatersheds

APPLICATION/RECALIBRATION OF ENHANCED WATERSHED MODEL

- Calibrate erosion and instream sediment transport
- Apply/calibrate enhanced RQUAL
- Integrate Task A results into Watershed Model
- Apply/Calibrate Enhanced Watershed Model to 1984-87 data

1.3 PHASE I PRELIMINARY FINDINGS AND RECOMMENDATIONS

In this section we briefly summarize the primary conclusions and recommendations resulting from the Phase I work, in terms of hydrology, nonpoint loadings, and water quality simulation, in order to set the stage for describing the Phase II efforts and final results. These findings and recommendations were discussed in greater detail in the Phase I report.

1.3.1 Hydrology Conclusions and Recommendations

a. Overall, the hydrology calibration results for 1974-78 were very good to excellent. The agreement in mean annual flow volumes and flow frequency results was excellent. Although some differences remained in the daily timeseries flow comparison, the basic conclusion was that the model was a good representation of the observed data for that time period.

b. The hydrology results for 1984-85 were not nearly as close to observed data values as in the earlier 1974-78 period. Both the daily and monthly R^2 values were considerably lower at most stations, and the frequency curves generally showed greater deviations with lower peak flows and higher base flows than observed.

c. The agreement could have been considerably improved for 1984-85 if a complete re-calibration had been performed, instead of limiting our adjustments to the input evaporation. The Phase I recommendations for additional efforts in Phase II included the following:

   1. Extend the data base and simulation through 1988 or 1989 to provide a better basis for evaluating the model performance for this latter period.

   2. Snow depth data should be developed for the 1984-89 period to check and evaluate the snow simulation, and allow for any additional calibration if needed.

   3. The Conowingo Reservoir simulation needs to be investigated and re-evaluated because the rule curve needed to be adjusted during the 1974-78 calibration.

   4. The storm of November 1985 in the Upper Potomac was not well simulated, in terms of peak flow, by the Watershed Model, although the monthly volume was accurate. Further efforts should be made to investigate the problems with simulating this event once the simulation period has been extended.

1.3.2 Phase I Nonpoint Loading Conclusions and Recommendations

a. The simulated annual nonpoint loading rates were within the range of expected values, with some deviations such as the rates for PO_4 and NH_4 from forest, and PO_4 rates from pasture.

b. Comparing Conventional and Conservation tillage segments, Conventional produced higher loading rates for all pollutants except NO_3, where Conservation is the higher rate.

c. The highest rates shown were for the manure segment, followed by urban and/or conventional tillage, conservation tillage, pasture, and forest. The order changed slightly for individual pollutants. The manure segment loading rates need to be further evaluated to ensure they provide a reasonable means of representing animal waste inputs.

d. Analysis of Total Segment Loads indicate that agricultural cropland (i.e. both conventional and conservation) tended to be the highest loader of both Total N and Total P; however, the percent contributions varied from segment to segment, and other sources dominated in selected segments. Both urban and animal waste contributions were significant, generally varying between 10% and 30% of TN and/or TP.

e. Point sources are still a major source of TP, often in the range of 20% to 30% or more, and a moderate source of TN. The assumptions in developing the point source loads should be re-assessed to insure their representation is accurate.

f. The atmospheric contribution tends to be only a few percent or less for most areas, since only direct deposition to water surfaces is considered. Atmospheric deposition to land surfaces is assumed to be implicitly included in the nonpoint calibration.

g. It should be noted that these results from Phase I were based on only two years of simulation. Loading rates from nonpoint sources are notoriously variable from year to year. Thus, the recommendation to extend the simulation in Phase II through 1988 or 1989 (as discussed above for hydrology) is also supported by the need to better define the simulated range and mean of the nonpoint loading rates.

1.3.3 Phase I Water Quality Simulation Conclusions and Recommendations

a. Water temperature and DO simulation was generally very good to excellent throughout the Bay drainage.

b. The majority of the nutrient concentrations were simulated quite well, reflecting the general range of the observed data values, especially for Total N and Total P at the major Fall Line stations.

c. Larger deviations were seen in the individual nutrient forms, such as PO_4 in the Upper Susquehanna and the James rivers. The focus of Phase II, on sediment simulation and sediment-nutrient interactions, should help to improve the phosphate simulation and should be further investigated.

d. The Potomac simulation results were significantly better than the results for the Susquehanna and James, especially for the phosphorus components and Chl a. The Potomac data is more extensive than in the other basins, allowing a better representation of the expected variability in the observations.

e. The river systems show considerable variability within the Bay drainage. Differences in PO_4, Chl a, and other parameter between regions and individual subbasins need to be further investigated as part of Phase II.

f. The storm of November 1985 in the Upper Potomac was also under-simulated in terms of particulate associated nutrients. In Phase II, the water quality simulation should be further investigated especially in terms of the nonpoint loadings contributions.

g. Phase II should also focus on some of the smaller subbasins (e.g. Patuxent, Appomattox) where further investigation and calibration is needed to present a consistent level of simulation throughout the Bay drainage.

h. For Total N and Total P loads at the Fall Line, the model and regression annual loads generally agreed within about 20%; problems with Organic P in 1985 (partly due to the November 1985 storm) lead to greater differences for that year.

i. Nitrate showed the closest agreement between the two load estimates, at least for the three major Fall Line stations. Interestingly, nitrate dominates the Total N and all other nutrient loads in terms of total mass, especially for the Susquehanna, Rappahannock, and the Patuxent, and to a lesser extent, the Potomac. In the James, Organic N dominates the Total N load and is significantly greater than the nitrate load.

j. The differences between the simulated and regression loads were generally much greater for the minor tributaries for most nutrient forms, than for the major Above Fall Line basins.

k. Monthly load timeseries showing the simulated and regression loads (plus Standard Error Bounds) indicate that the model estimates, especially for TN and TP, generally fell within the envelope defined by the two error bounds.

l. Simulation of Total Organic Carbon (TOC) should be considered in Phase II, either to replace BOD or supplement it.

1.4 PHASE II FINDINGS AND RECOMMENDATIONS

The general conclusions of the Phase II effort are discussed below in terms of hydrology, nonpoint loadings and AGCHEM simulation, and water quality simulation:

1.4.1 Phase II Hydrology Conclusions and Recommendations

The Phase II hydrology calibration results indicate the following:

a. The agreement between mean annual flow volumes is excellent; simulated values are within 6% of observed values. The year-to-year variations shown in the appendix are greater but they still indicate good agreement.

b. The daily R^2 values for simulated and observed streamflow are generally 0.70 or greater, and usually in the range of 0.75 to 0.84 for the three major basins. The monthly R^2 values are consistently in the range of 0.77 to 0.90 for all subbasins.

c. The daily R^2 values for 1984-87 are consistently higher than the corresponding values for 1974-78, possibly due to the greater number of rain gages used in Phase II.

d. Both the timeseries and flow frequency comparisons for all calibration sites show good to very good agreement. Although differences exist, the daily simulated timeseries and frequency curves track the observed timeseries quite well for most all sites. The largest deviations are consistently at the smaller subbasins where more detailed spatial representation of precipitation may be needed. Also, these differences are greater when reservoirs are present in the smaller subbasins (e.g. Pamunkey, Patuxent); further study of the reservoir operating rules and finer spatial segmentation may be needed.

e. Very little improvement was possible in Phase II for simulation of the November 1985 storm in the Potomac. The storm was well simulated in the Upper Potomac and Shenandoah model segments, but the recorded rainfall amounts, intensities, and spatial distribution in the Lower Potomac could not sustain the extreme observed storm flows.

f. In Phase II, the Conowingo Reservoir hydraulic simulation was investigated and adjusted to include a minimum summer release rate of 5000 cfs and minor adjustments to the weekly outflow coefficients Both the daily timeseries and the frequency results show very good agreement between simulated and observed values, with some deviation in the low flow simulation since these flows are controlled entirely by the operating procedures of the reservoir.

g. Seasonal R^2 values were calculated by CBPO based on the following seasons:

Season 1	January - February
Season 2	March - May
Season 3	June - September
Season 4	October - December

The results show that the winter (Season 1) is consistently simulated worst than the other three seasons, and that the summer and fall (Seasons 3 and 4) are usually the best, at least for the three major basins. For most of the smaller basins, the spring (Season 2) is often the best simulated.

Overall, the Phase II hydrology calibration results are a very good representation of the Chesapeake Bay basin hydrology and provide a sound basis for nonpoint load generation and delivery of pollutant loads to the Bay. Ongoing updating of the meteorologic, diversion, and land use information is recommended to allow for complete verification of the hydrology using the 1988-91 period.

1.4.2 Phase II Nonpoint Loading Conclusions and Recommendations

a. Generally, the simulated annual loading rates are within the range of expected values, with some deviations. Annual rates for PO_4 from forest and pasture, and NH_4 from forest occasionally tend to be toward the lower end of the defined range. Annual PO_4 rates from the cropland areas are somewhat higher than the defined range.

b. For non-cropland categories, the Total N and Total P simulated values compare favorably with both the expected means and ranges.

c. For the cropland categories of Conventional Tillage, Conservation Tillage, and Hay, the Total N and Total P simulated values are generally close to the mean lumped cropland data; the Hay values are generally less than the mean, while the tillage categories are usually greater than the mean but well within the observed range.

d. Comparing Conventional and Conservation tillage segments, Conventional produces higher loading rates for most model segments for all pollutants except NO_3, where Conservation is sometimes the higher rate.

e. The highest rates for Total N and Total P are for the manure segment, followed by conventional tillage, conservation tillage, urban, hay land, pasture, and forest. The order changes slightly for individual pollutants.

f. The manure segment loading rates are the most uncertain since there is very little information on which to assess their validity.

g. For NH_3 and PO_4 from cropland, the simulated ranges are generally 0.5 to 4.0 lb/ac and 0.2 to 2.0 lb/ac, respectively; these ranges are generally higher than the limited observed data for these forms, but they are not unrealistic based on the general literature.

h. Urban pervious and impervious areas provide loadings which are comparable to the Hay and Pasture categories, and for some nutrient species (e.g., NH_3) the loadings are similar to the tillage categories. Thus, urban land can be a significant source of total nonpoint loadings in urbanized model segments.

1.4.2.1 AGCHEM Conclusions and Recommendations

The AGCHEM application to the cropland areas of the Chesapeake Bay drainage has satisfied the objectives outlined at the beginning of Phase II, namely to (1) represent nutrient balances for the major cropland categories in each model segment, (2) allow investigation of sensitivity to climate variations and agricultural practices, and (3) provide a mechanism to project impacts of nutrient management alternatives for agricultural cropland. The results are consistent with expected nutrient balances, observed ranges of runoff concentrations, and expected ranges of nutrient loadings from cropland areas.
The AGCHEM approach to modeling the nutrient balances on agricultural cropland is exactly the type of approach recommended by the Chesapeake Bay Nonpoint Source Evaluation Panel in their report to the U.S. EPA and the CBP Executive Council. In March 1990, the EPA Administrator convened the Panel to "assess the effectiveness of current efforts to reduce nonpoint source loadings of nutrients entering the Bay system". They reviewed and evaluated the effectiveness of a wide range of nonpoint source programs, including program design, implementation, budgets, modeling and assessment methods, and research efforts. One of the key

recommendations of the Panel related to new approaches to nutrient control was as follows:

> "The Panel recommends that the Bay jurisdictions and the federal agencies develop a mass balance accounting system, where nutrient loadings are balanced by the nutrients removed from the system plus those which are introduced and stored" (Chesapeake Bay Nonpoint Source Evaluation Panel, 1990).

The AGCHEM application provides an initial assessment of this 'mass balance' for cropland areas, a tool for assisting in the 1991 Re-evaluation of the 40% nutrient reduction goal of the Bay Agreement, and a framework for future efforts on nutrient management based on the mass balance approach. Recommendations to improve the use and application of AGCHEM by CBP include the following:

a. A detailed review and refinement of the current fertilizer and manure application rates, and changes expected under nutrient management alternatives should be initiated since these rates are the starting point for nutrient reduction from cropland.

b. Detailed site applications of AGCHEM, such as in the Patuxent, Nomini, and Owl run watersheds, should be diligently pursued by either CBLO and/or state agencies to further refine and improve the simulated nutrient balances and regional differences.

c. Variations in soil nutrient storages, throughout the Bay drainage and for different land uses, should be included in future model improvements. Use of GIS capabilities and soils databases should be used to improve spatial definition and regional variations in model parameters.

d. In line with the CBP NPS Evaluation Panel recommendations, future Watershed Model refinements should include application of mass balance and soil process modeling procedures for <u>all land uses</u> to represent nutrient balances in all areas.

e. Recommended improvements to the AGCHEM module to facilitate Watershed Model application and operation, and refinement of selected nutrient processes include:

    1. Capability to simulate NH_3 volatilization from soils and manure applications.

    2. Modifications to simplify specification of nutrient application rates and agricultural operations; more than one-half of the current model input sequences are devoted to defining this input for cropland areas.

    3. Capability to specify wet and dry atmospheric deposition rates for all nutrient forms.

4. Refinement of soil phosphorus cycle and processes to allow a better representation of sorption, fixation, and plant uptake mechanisms. Additional research and algorithm development may be needed to accurately model the soil phosphorus cycle.

1.4.3 Phase II Water Quality Simulation Conclusions and Recommendations

Review of the water quality calibration results indicates the following general conclusions and recommendations, some of which were also presented in the Phase I report:

a. Water temperature and DO simulation is generally very good to excellent throughout the Bay drainage. In Phase I, water temperature was calibrated at three instream sites within the basin, where continuous water temperature data was available, and then extrapolated to the other model segments. The simulation was extended and refined in Phase II.

   The DO simulation is generally very good for most calibration sites but with some deviations at selected sites for low summer DO observations. At most sites, the simulation is quite good except for one or two extreme points whose observed values may be questionable. Some of the low summer values may be due to benthal demands which are not currently calculated in the model.

b. The majority of the nutrient constituents are simulated quite well at most sites, reflecting the general range of the observed data values, especially for Total N and Total P at the major Fall Line stations, with the notable exception of the Susquehanna Basin (discussed below). Peak simulated concentrations are often somewhat higher than observed values, as would be expected when comparing a continuous simulated timeseries with discrete, individual observations.

c. The Phase II results are a significant improvement over the Phase I results due to the water quality parameter re-evaluation, the AGCHEM nutrient loading simulations, and the additional calibration effort. Although some problems remain, the results show improved simulation of seasonal variations in nitrate and Chl a, closer representation of individual nutrient species, and better agreement with most observed concentrations and loads.

d. Large deviations are still seen in the individual nutrient forms at some sites, such as PO_4 in portions of the Susquehanna and inorganic nutrients in the minor tributaries. Chl a observations were limited at many calibration sites, thus restricting the calibration process.

e. The Potomac simulation results are the best of all the major basins and are generally a good to very good representation of nutrient concentrations throughout the Bay basin. This could be partially due to the fact that the Potomac data is more extensive than in any of the other basins, allowing a better representation of the expected variability in the observations and a better calibration. The total nutrient concentrations, and the individual species, are well simulated throughout the entire period. Concentration peaks do exceed individual observations, especially for NH_3 and PO_4, but they are generally within the range of the observed data.

f. The Susquehanna simulation also shows good agreement between simulated and observed concentrations, but this was accomplished only after intensive calibration effort of the entire basin, with particular focus on the reservoir simulation. Generally, Total N and component concentrations at Conowingo are somewhat under-simulated. PO_4 and Total P concentrations are somewhat over-simulated throughout the Susquehanna, possibly due to interactions with sediment and metal oxides, and increased sorption under low pH conditions.

USGS data for pH show extremely low values for two main stem stations in the East and West Branch subbasins, with mean monthly values in the 3.0 to 4.0 range. Detenbeck and Brezonik (1991) show greatly increased P binding by lake sediments for pH in the range of 4.5 to 6.0, with greatly decreased diffusive P fluxes under these conditions. Consequently, increased sorption and retention, and possibly precipitation of PO_4 from the overlying water may be a reason for most of the observed concentrations being close to detection limits.

Clearly, further investigation is warranted and should focus on instream processes in the Upper and Lower basins for both nitrogen and phosphorus delivered to the Conowingo Reservoir, and processes within the reservoir. This should be performed in conjunction with a thorough loadings analysis to confirm the relative loadings contributions from all sources. Further calibration of the reservoir water quality is needed to improve the sediment and Chl a simulations, which may also assist in improving the phosphorus simulation.

g. The simulations for the James River are a significant improvement over the Phase I results. Although the concentration agreement is not as good as in the Potomac, the Total N and Total P are consistently within the range of the observations, and the component nutrient species are reasonably well simulated. The data base for the James was much more limited compared to the other sites, thus limiting the calibration effort.

h. The river systems show considerable variability within the Bay drainage, as noted above concerning the PO_4 simulation problems in the Susquehanna. In general, the smaller tributaries and those with reservoirs are not simulated as well as the larger basins with free-flowing reaches. When both these conditions occur, such as in the Pamunkey and Appomattox basins, the differences between simulated and observed values usually increase. In these cases, finer segmentation and more investigation into reservoir operations is needed. For the short-term, simulation differences in the smaller basins should have minimal impact on the Bay simulation since they are a small fraction of the delivered nutrient load.

i. Although the Patuxent River falls in the category of a small basin with reservoirs, the simulation results are exceptionally good due to the wealth of observed data for calibration and the point source monitoring that accurately defined the point source loads in the Watershed Model. The Total P simulation reflects the impact of the phosphorus ban in December 1985, with the 1986-87 concentrations being significantly lower than in 1984-85. The few instances where simulated values are high are due primarily to under-simulation of extreme low flows during late summer.

j. The storm of November 1985 in the Upper Potomac was under-simulated in terms of peak flow, and many of the particulate associated nutrients were also under-simulated for this event. In Phase II, the HSPF code was modified to allow user-specified particulate NH_4 and PO_4 concentrations for scouring of the bed sediments; however, much of the scoured material is organic. Consequently, the particulate N and P concentrations are under-simulated for this event in both the Potomac and James basins, and since these components dominate during a major scour event, Total N and P concentrations are also under-simulated. Future efforts should consider adding the capability to allow user-specified bed concentrations for organic components.

k. Simulation of Total Organic Carbon (TOC) was included in Phase II because TOC is a required input for the Bay model and observed TOC values were more readily available at more sites than BOD. BOD is still simulated by the Watershed Model because it is a required parameter. BOD is used in the current version as an indicator of TOC, i.e. BOD nonpoint and point source loadings are converted to TOC by a conversion factor which was used as a calibration factor to adjust the TOC simulation. The simulation results for TOC are generally quite good for most sites, and are similar in appearance to the organic N and organic P simulations.

l. The sediment simulation results are generally adequate but could be improved with further calibration. The model tends to over-simulate large storms, and under-simulate small storms and concentrations during low flow periods. Additional sediment calibration should concentrate on evaluation of the simulated sediment loadings and the target values derived from the NRI data. Also, reservoir sediment simulations should be further investigated with additional calibration. Finer model segmentation and spatial detail of both land segments and stream reaches is probably needed for improved sediment simulation.

The following general conclusions are derived from comparison of the simulated Fall Line loads with regression estimates:

a. For Total N and Total P, the model and regression annual loads generally agree within about 25% to 30%. Problems with Organic P and, to a lesser extent Organic N, in th Potomac in 1985 (partly due to the November 1985 storm) lead to greater differences for that year.

b. In the Patuxent and the Potomac, the closeness of the concentration comparison is also reflected in the Fall Line load ratios. For both these rivers, extensive data was available for developing the regression and performing the model calibration.

c. Nitrate generally shows the closest agreement between the two estimates, at least for the three major Fall Line stations. Interestingly, nitrate dominates the Total N and all other nutrient loads in terms of total mass, especially for the Susquehanna, Rappahannock, and the Patuxent.

d. The differences between the two estimates are generally much greater for the minor tributaries for most nutrient forms (with the exception of the Patuxent), than for the major Above Fall Line basins. For the minor tributaries and the James, significantly less data was available for developing the regression. Consequently, the uncertainty of the regression is greater for these basins.

1.5 GENERAL WATERSHED MODEL RECOMMENDATIONS

The Watershed Model provides a framework for quantifying and evaluating nutrient loadings to the Bay, and a mechanism for assessing the impacts of land use changes and alternate nutrient and agricultural management practices. However, the watershed modeling component of the Chesapeake Bay Program should be an ongoing, evolving process with continuing data collection, model development and testing, and calibration/validation efforts. The current Watershed Model, although providing a sound basis for current decision-making, needs continuing updating and refinement in a number of areas. As all planning tools, the Watershed Model should not be <u>static</u>. Continuing efforts should be devoted to the following areas:

a. Further calibration and validation with new data (e.g. 1988-90) with specific focus on problems areas, such as animal waste, reservoir modeling, and PO_4 in the Susquehanna.

b. Further investigation and refinement of reservoir hydrology and water quality simulation for model segments with major reservoirs.

c. Refinement and improvement in urban and animal waste simulation procedures and management alternatives.

d. Refinement of AGCHEM nutrient balances based on field site applications, regional conditions, and seasonal variations.

e. Finer spatial segmentation and representation of land areas and stream reaches to provide more detailed input to regional water quality issues and problems.

f. Direct linkage between the CBLO capabilities with geographic information systems (GIS) and model parameter/input development. This is a major focus of current development efforts in watershed management and nonpoint source modeling.

g. Extend nutrient balance concepts of AGCHEM to simulation of <u>all</u> land uses to provide a consistent mass balance approach for all portions of the Watershed Model.

h. **Develop improved capabilities in the Watershed Model for user interface, output analysis, and specification of nutrient applications and agricultural management practices.**

1.6 FORMAT OF THIS REPORT

Section 2 describes the procedures used to update the meteorologic and precipitation data for the 1984-87 period, while Section 3 briefly describes the land use and waste load development techniques. Section 4 describes the nonpoint loading simulation procedures used for both cropland and non-cropland land categories, including an overview of the AGCHEM module and the application procedures used for cropland areas; nonpoint simulation results are also presented in Section 4 for all land uses. Section 5 provides an overview of the RCHRES module sections used in the Phase II effort, along with discussion of the sediment-nutrient capabilities incorporated into the HSPF code. Sections 6 and 7, respectively discuss the hydrology and water quality results, with the primary focus on the Phase II results. As noted above, due to the vast amount of data and information, developed for and generated by the Phase II watershed modeling work, the majority of the results and input related information are provided in the Appendices.

SECTION 2.0

METEOROLOGIC AND PRECIPITATION DATA BASE DEVELOPMENT PROCEDURES

2.1 INTRODUCTION

This section documents the procedures that were used to update the regional meteorologic data base and hourly precipitation data base for 1984-1985 and subsequently, 1986-1987. The regional meteorologic data base consists of wind speed, air temperature, dewpoint temperature, evaporation, cloud cover, and solar radiation. The goal of this task was to produce a data base that was both valid and, insofar as possible, consistent with the 1974-78 data with regard to the observation stations, computation and disaggregation methods, and level of detail. Because documentation of the existing (1974-78) regional data base was not available, this data base was exhaustively analyzed and compared to observed and generated data in an attempt to determine data sources and computational methods. Based on this analysis, observation stations were selected and procedures were developed to update the data base for the 1984-85. Development of the hourly precipitation data was accomplished using modified versions of the Thiessen procedure, aggregation software, and observed data base used to develop the 1974-78 data base. The same procedures were also followed in completing the data base for the 1986-1987 period; however, small changes in the network of observed stations were necessitated by the discontinuance of several stations.

The final data base is stored in Watershed Data Management (WDM) System files. WDM files are unformatted, direct access files that may contain several types of data and many individual data sets of each type. The data sets are identified by unique data set numbers and other attributes such as a name, descriptive information, and time interval. WDM file format is the primary data storage format for the HSPF program. In addition, several intermediate data formats were utilized in developing the data base. These formats are ASCII, HSPF-readable, hourly and daily formats that are identified in this document as HYDDAY, HYDSDY, and HYDHR, respectively. The formats are described in Appendix D.1

2.2 REGIONAL METEOROLOGIC DATA

The 1974-78 regional met data was compared with published data for major stations in the basin. As a result of these comparisons, the cloud cover and dewpoint temperature data sets were found to exactly match the published data as shown in Table 2.1

TABLE 2.1 CORRESPONDENCE BETWEEN 1974-78 REGIONAL DATA AND PUBLISHED DATA

REGION	CLOUD COVER STATION	DEWPOINT TEMPERATURE STATION
1	Binghamton, NY	Binghamton, NY
2	Williamsport, PA	Binghamton, NY (2)
3	Harrisburg, PA	Harrisburg, PA
4	Roanoke, VA (1)	Roanoke, VA
5	National Airport	National Airport
6	Roanoke, VA	Roanoke, VA
7	Richmond, VA	Richmond, VA

(1) Region 4 cloud cover data are computed from Roanoke data and monthly factors.

(2) Region 2 dewpoint temperatures for March-November are the Binghamton data multiplied by 1.1.

The other regional met data sets (wind speed, air temperature, potential evaporation, and solar radiation) did not match these stations, but were found to exhibit other relationships. Generally, these relationships involved constant monthly factors between the regions. Since the methodology used to develop these factors is unknown, it was decided to base the regional data entirely upon observed data from representative stations in or near each of the regions. The stations selected were those that were used in the 1974-78 data base for dewpoint and cloud cover, with two exceptions. The weather stations at Elkins, WV and Dulles Airport were chosen as more representative of Regions 4 and 5, respectively, than Roanoke, VA and National Airport. Table 2.2 contains the stations used to develop the 1984-87 regional data base, and Figure 2.1 shows the seven meteorologic regions and the locations of their corresponding stations.

TABLE 2.2 STATIONS USED TO DEVELOP 1984-87 REGIONAL METEOROLOGIC DATA

REGION	STATION	STATION NUMBER
1	Binghamton, NY	300687
2	Williamsport, PA	369728
3	Harrisburg, PA	363699
4	Elkins, WV	462718
5	Dulles Airport	448903
6	Roanoke, VA	447285
7	Richmond, VA	447201

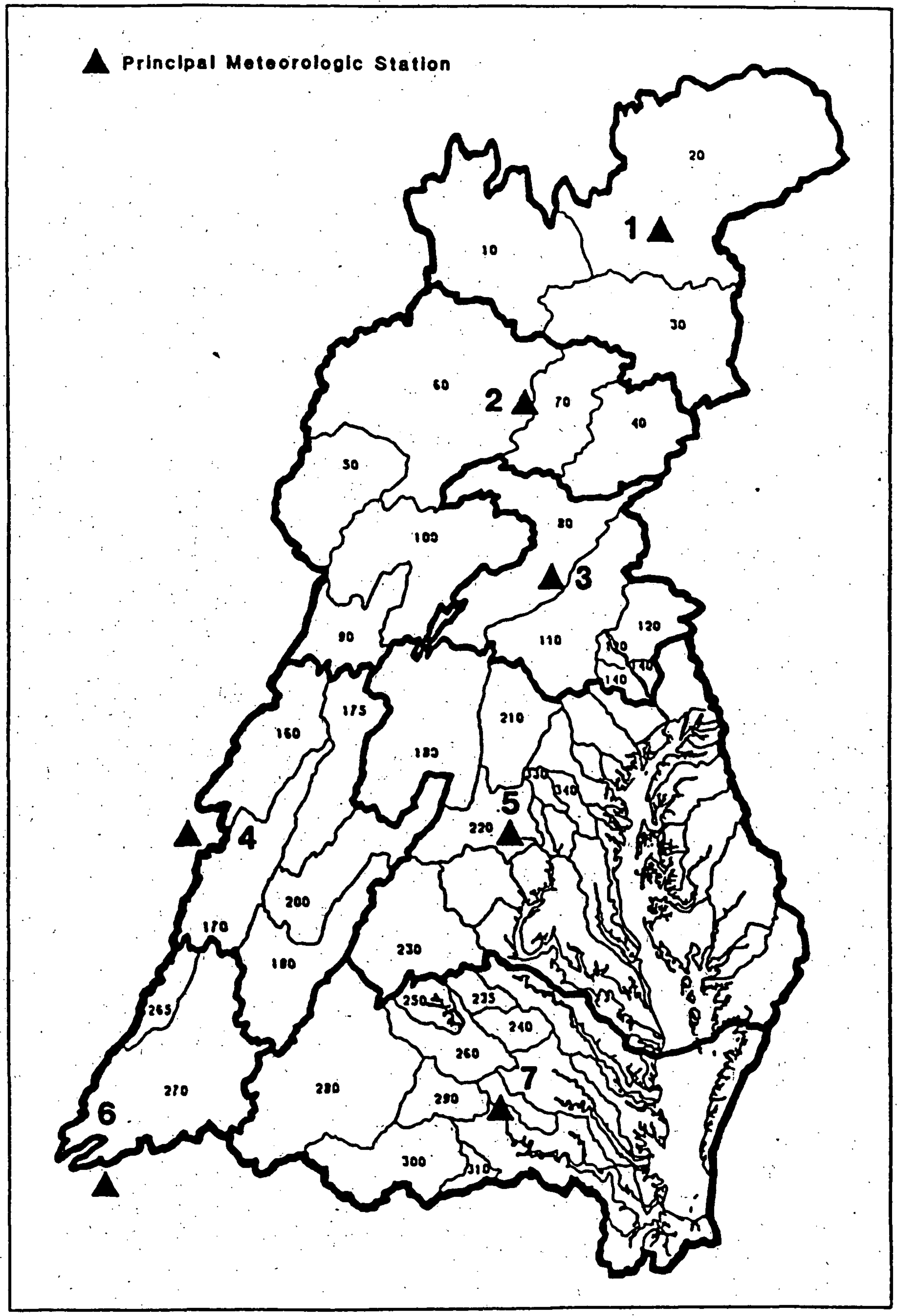


Figure 2.1 Meteorologic regions and principal stations in the Chesapeake Bay watershed model.

2.2.1 Cloud Cover and Dewpoint Temperature

The Watershed Model utilizes daily values of cloud cover and dewpoint temperature. The daily records for the stations listed in Table 2.2 were downloaded from the NOAA data tape, reformatted, and transferred into the WDM files without any modification of the data.

2.2.2 Air Temperature and Wind Speed

The Basin model utilizes hourly values of wind speed (miles/hour) and air temperature (deg F). The daily records for the stations listed in Table 2.2 were 1) downloaded from NOAA data tapes, 2) reformatted, 3) distributed to hourly values using customized software, and 4) transferred into the WDM files.

The daily max-min air temperatures were converted to hourly values based on a smooth variation with the daily minimum at 6 AM and daily maximum at 4 PM. This variation is illustrated in Figure 2.2. The program TMPDIS, which is included in Appendix D.2, was used to perform this distribution. TMPDIS reads a daily data file containing maximum and minimum temperatures in HYDSDY format and the daily observation hour (1 to 24). The output hourly air temperature data are written to the output file in the HYDHR format.

The daily wind movement (miles/day) data were distributed to hourly values using a slight diurnal variation having a minimum value from midnight to 7 AM and a maximum at 3 PM. Figure 2.3 illustrates this variation. The program WNDDIS (Appendix D.3) was used to perform the distribution. This program reads the total daily wind movement (miles per day) from an input file, using the format HYDDAY, and outputs the hourly wind speed (miles per hour) to the output file in the HYDHR format.

2.2.3 Solar Radiation

Analysis of the solar radiation data and the corresponding cloud cover time series indicates that the 1974-78 radiation used by the Watershed Model was computed using a model based on latitude and cloud cover. Such radiation models generally use curves of clear sky radiation as a function of latitude and day of the year, along with an empirically derived correction factor based on cloud cover or percent sunshine. Since measured solar radiation data are no longer readily available, it was decided to generate the 1984-87 radiation data using a model.

Two simple solar radiation models were compared to the 1974-78 clear sky data in an attempt to match the 1974-78 regional data. The model that more closely matched the 1974-78 data was the RADIATION generation utility contained in the HSP QUALITY program (Hydrocomp, 1977). Using approximate area-weighted latitudes for each of the regions, this program generated curves that were nearly identical to the 1974-78 clear sky data. Small differences (1 to 4%) occurred in the spring and autumn months depending on the latitude used in the computation. While neither the clear sky radiation nor the cloud cover correction factor were reproduced exactly, the differences in generated radiation are negligible.

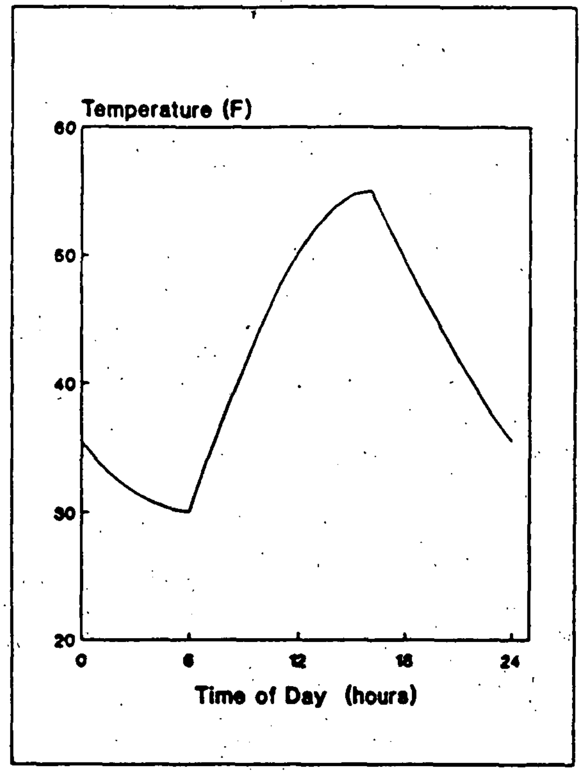


Figure 2.2 Diurnal variation of air temperature.

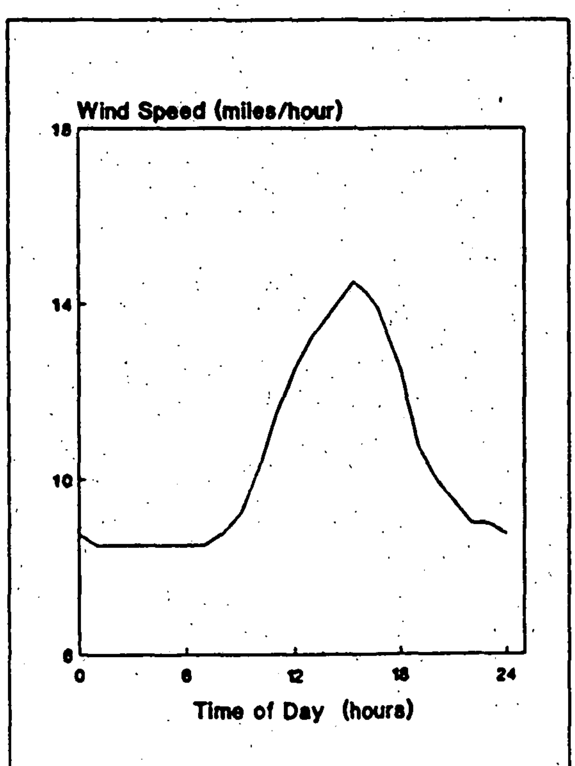


Figure 2.3 Diurnal variation of wind speed.

A FORTRAN subroutine (RADCLC) was developed to implement this model. The algorithm is based on empirical curves developed by Hamon et al., (1954), and documented in the HSP II Manual (Hydrocomp, 1978)). Also, since the daily radiation must be distributed to hourly values for input to HSPF, the subroutine RADDST was adapted from the HSP QUALITY program to perform this distribution. This routine generates hourly radiation values using the daily total, the month, and the day. These two routines were implemented in a program that reads the daily cloud cover data and the latitude for a region, and generates the daily and hourly solar radiation for each day of the year. Listings of the subroutines are included in Appendix D.4 along with a table of inputs and outputs of the routines.

The area-weighted latitudes for the regions are based on the following model segment groupings:

Region	Segments	Latitude
1	10 20 30	41.75
2	40 50 60 70 90 100	40.9
3	80 110 120 140	40.8
4	160 170 175 190 200	39.25
5	180 210 220 230 330 340	39.75
6	265 270	39.1
7	235 240 250 260 280 290 300 310	37.8

2.2.4 Potential Evaporation

Daily and monthly totals of potential evaporation from the regional data sets were compared to observed data from the pan evaporation stations located in the Chesapeake Bay watershed. No definitive relationships were observed between the regional and recorded data in these comparisons. However, comparisons between the individual regional data sets showed that the daily values are related to each other by monthly factors. Since the evaporation data were not derived from observed pan data, but are apparently related to each other, it was hypothesized that the data for one region were computed using an evaporation model; and then the other regions were obtained from the computed time series and long term relationships between the regions. This hypothesis was reinforced by comparison of the Region 5 data to daily pan evaporation data that was estimated using the Penman equation. Dewpoint, air temperature, wind speed, and solar radiation data from Region 5 were used as parameters in the Penman model. When these estimated values were compared with the Region 5 data set, it was found that the daily values were related by constant monthly factors for the years 1974-76.

The Penman (1948) method is a simple, commonly-used algorithm for estimation of pan evaporation. The method, as described by Kohler et al. (1955), uses daily inputs of solar radiation (Langleys), wind speed (miles/day), dewpoint (F), and average air temperature (F). The average air temperature is defined here as the mean of the maximum and minimum daily values. The output from the model is daily pan evaporation in inches. This algorithm was implemented in a FORTRAN subroutine entitled PANEVP that reads the appropriate input data files, and outputs the daily data in the HYDDAY format. The PANEVP subroutine is listed in Appendix D.5.

Development of the regional potential evapotranspiration data sets was accomplished using the following two-step procedure:

1. Regional daily pan evaporation totals were computed using the Penman method as implemented in the subroutine PANEVP.

2. Factors were developed to account for the pan coefficient and apparent overprediction by the Penman method during winter months. These factors were applied to the Penman data to obtain the final potential evapotranspiration.

2.3 HOURLY PRECIPITATION DATA

Significant effort was devoted to development of the hourly rainfall data for the watershed model because this data is the principal driving force for the model and because of the quantity of data involved. This task included three principal subtasks. First, a large amount of observed hourly and daily data was reformatted from NOAA tapes to WDM format using the ANNIE program and associated utility software. Second, an iterative procedure, using GIS software (ARC-INFO), coordinate locations of the observed stations, and digitized model segments was used to develop the precipitation segmentation and weighting factors needed to combine the data. Third, the observed data were combined and distributed to hourly values utilizing software adapted from the procedures used to generate the 1974-78 data base. The resulting data base consists of 32 data sets of generated hourly rainfall corresponding to individual model segments or, in some cases, several aggregated model segments.

2.3.1 Development of Observed Rainfall Data Base

This task involved reformatting the 1984-85 and 1986-1987 daily and hourly data for all rainfall stations located within or near the basin to WDM format (Figure 2.4 and Figure 2.5). This data was obtained from standard NOAA tape files for each of the states in the basin, i.e., NY, PA, WV, DE, MD, and VA. The ANNIE program and several additional stand-alone utility programs were employed in this effort, which involved reading and obtaining an inventory of the NOAA tape files, selecting stations to extract based on coordinate locations, breaking the large data files into smaller files, and transferring the data to a WDM file. Details of the procedures and software are documented in Appendix D.6.

2.3.2 Basin Segmentation and Development of Weighting Factors

A Thiessen analysis was performed to determine the weighting factors to use in the rainfall generation. The stations and Thiessen weights from the original 1974-78 rainfall generation were reviewed, and it was decided to redo the analysis since several of the original stations were no longer available, and the model areas and segments associated with several of the generated rainfall records were not documented. Also, it was likely that the availability of additional observed stations would improve the analysis.

The final 1984-85 Thiessen analysis was based on the digitized model segment boundaries and the coordinate locations (latitude and longitude) of a selected

AFL Daily and Hourly Precipitation Stations

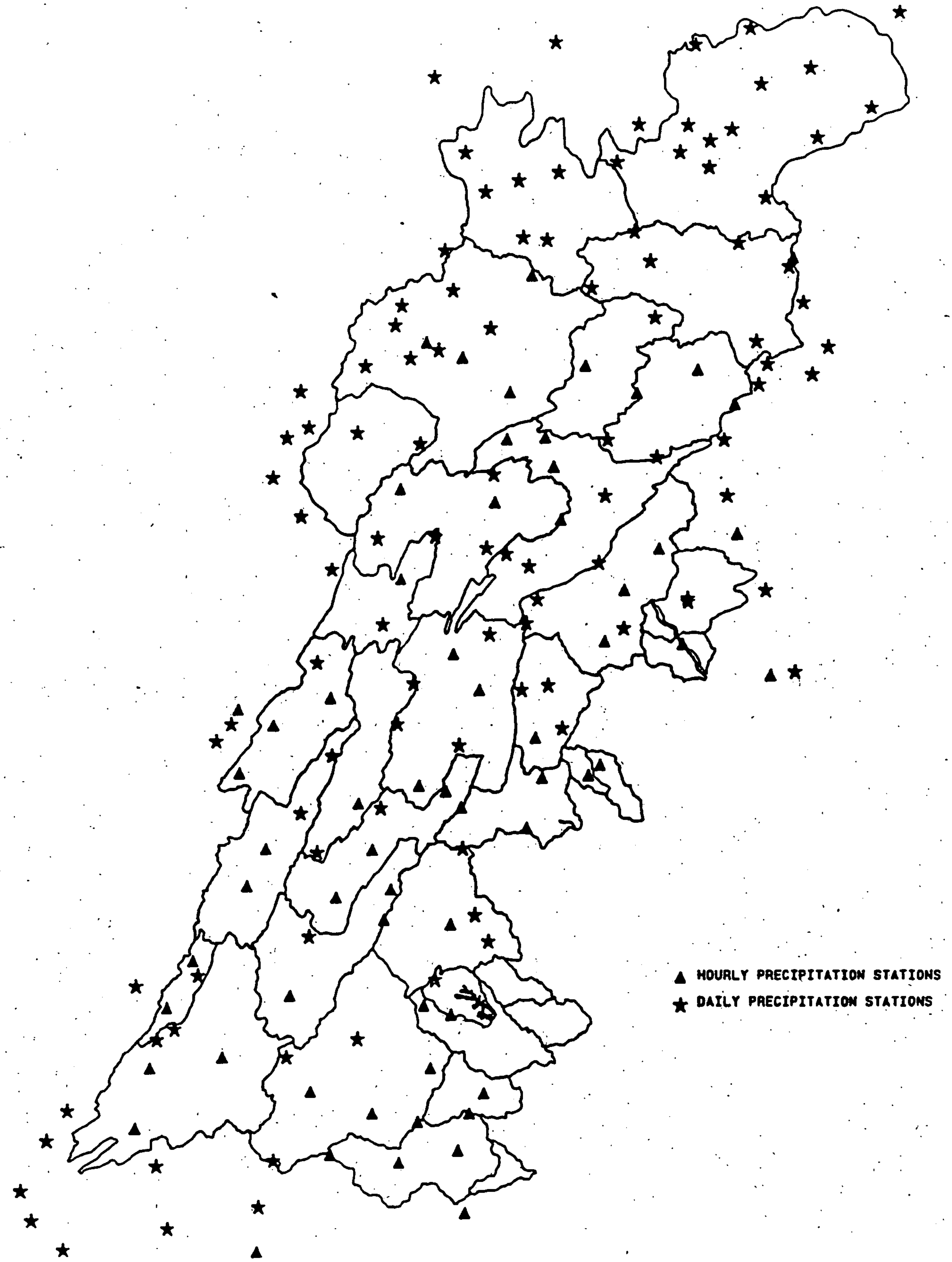


Figure 2.4 AFL daily and hourly precipitation stations.

BFL Daily and Hourly Precipitation Stations

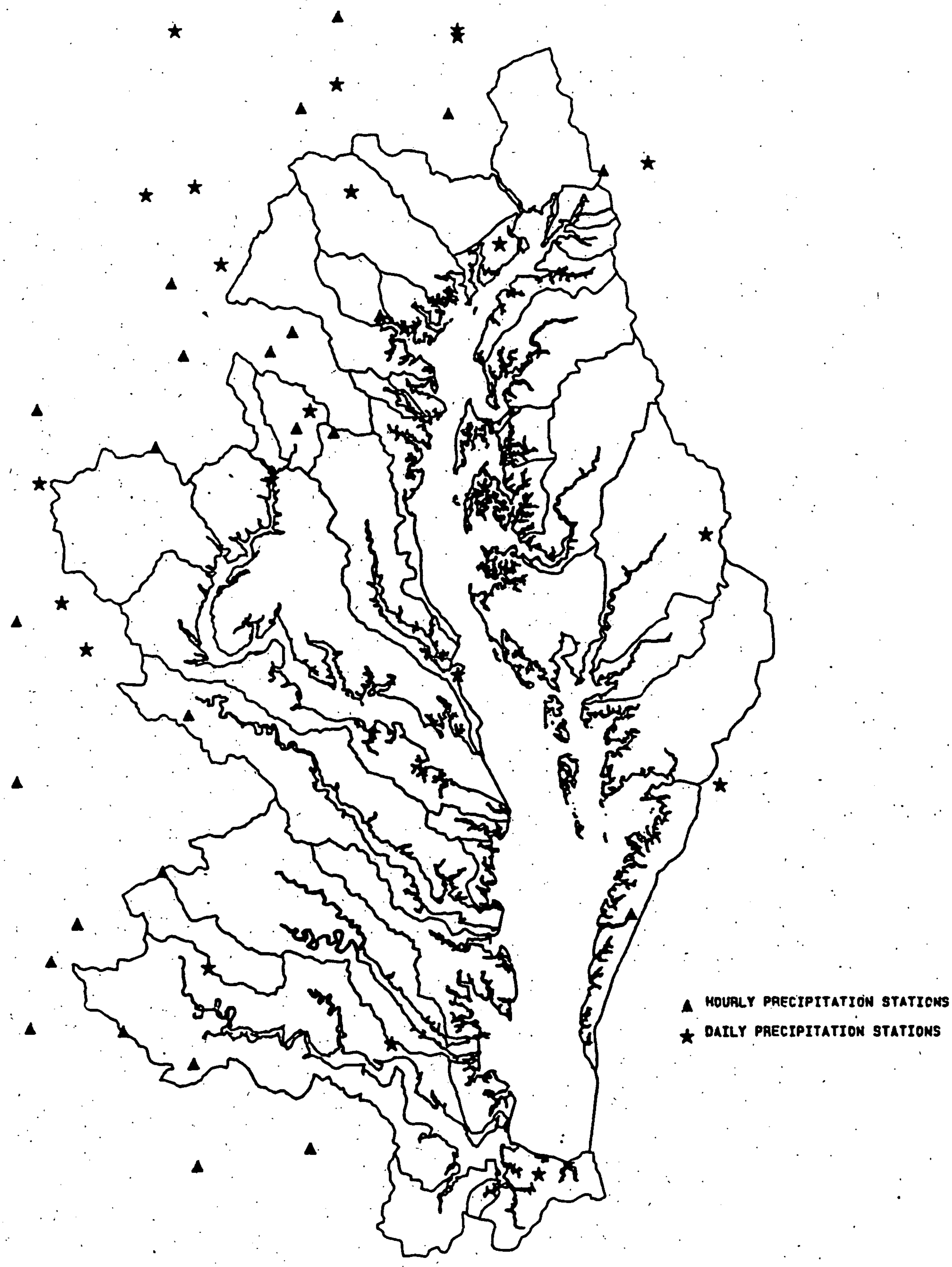


Figure 2.5 BFL daily and hourly precipitation stations.

subset of the observed stations. It was performed using the ARC-INFO GIS software. The outputs from the procedure were the observed stations and the corresponding area-based weights for each model segment. The procedure required a sequence of steps as described in Appendix D.7. The resulting Thiessen network consisted of 32 separate rainfall segments and utilized a total of 173 individual stations.

When the 1986-87 data were being generated, it was discovered that several stations included in the 1984-85 Thiessen network had been discontinued or had significant missing data. Therefore, these stations were removed from the network and their Thiessen weightings were added to the nearest station in the set of stations for that segment. The differences between the 1984-85 and 1986-87 Thiessen networks are documented in Appendix D.7. Generally, these differences are very small.

2.3.3 Generation of Weighted Hourly Rainfall Records

The final step in creating the hourly precipitation was to run the PRECIP program to generate the data using the Thiessen network and the data base of observed hourly and daily stations. The PRECIP program is a FORTRAN program designed to generate an hourly time series of rainfall that is a weighted average of several observed time series. For each execution of the program, which generates one hourly time series, the following inputs are required:

- Between one and ten observed time series of hourly rainfall
- Between zero and ten observed time series of daily rainfall
- Weighting factor for each of the above time series (sum of all factors must be 1.0)

The program then proceeds daily through the following steps to produce an hourly time series:

1. Computes the daily totals for all input (observed) time series (daily and hourly). (Data are obtained from the WDM file.)

2. Computes the weighted daily total rainfall using the weighting factors and the daily totals computed in Step 1. (Note that any station having missing data during the day is eliminated from the computations on that day, and the weighting factor for that station is distributed among the remaining stations in proportion to their original weights.)

3. Compares the weighted daily total with each of the daily totals of the observed hourly time series. Selects the observed hourly station having the closest daily total to the weighted daily total.

4. Computes the generated hourly time series by distributing the weighted daily total using the hourly distribution of the station selected in Step 3.

5. Stores the resulting hourly time series in the WDM file.

6. Writes a summary of the data generation for each day that data were generated. If the program experiences difficulty because of too much missing data, it also writes an explanatory message to the output file, and skips the current day.

During generation of several of the rainfall records, the PRECIP program skipped a number of days on which precipitation occurred because none of the hourly stations had data on that day. When the total quantity of skipped precipitation was judged to be non-negligible, the skipped rainfall was distributed manually over the day, and the hourly values were inserted into the WDM file using ANNIE.

Additional documentation of the PRECIP program, including operational details, input formats and a program listing, may be found in Appendix D.8.

SECTION 3.0

LAND USE DATA AND WASTE LOAD INPUTS

3.1 LAND USE DATA

This section documents the methods used to provide a 1985 base year land use data set for use in the Watershed Model. The 1985 base year was chosen to be consistent with the 1987 Bay Agreement, and because it was a recent year that had sufficient land use information coverage from the different sources used. The Phase II Watershed Model land uses are forest, conventional till cropland, conservation till cropland, cropland in hay, pasture land, animal waste areas, and water areas. The hay cropland was defined as a separate category in Phase II and extracted from the total cropland acreages used in Phase I.

There are several methodologies, developed at the state level, for the assessment of land use. These methodologies focus on different planning and assessment issues and at differing levels of detail. As a consequence, their methods, land use definitions, and base years vary from state to state. Some excellent examples of state level land use assessments include Maryland's Geographic Information System (MAGI), Virginia's Geographic Information System (VIRGIS), and Pennsylvania's detailed County Level National Resources Inventory (NRI) data base.

Another methodology with partial basin coverage is the USGS Land Use and Land Cover System (USGS LU/LC). The USGS LU/LC has consistent coverage for the basin for the 1972-73 period, except for the basin area within New York. Other basin-wide land use assessments include the U.S. Census Bureau which has surveyed agricultural land use since the 1800's. The U.S. Forest Service has been conducting state forestry surveys since the 1940's. More recently, the U.S. Soil Conservation Service has conducted the National Resources Inventory, a data base of land use and geographic characteristics. To the extent possible, consistent with the objective of obtaining a basin-wide methodology, all of the above land use methodologies have been utilized in the development of the 1978 and 1985 data sets.

A consistent methodology of determining land use for the entire Bay basin was developed which obtained particularly detailed information on agricultural cropland. The principle sources of information used provided data on land use at a county level throughout the basin. Principle sources were the U.S. Census Bureau, the U.S Forestry Service, and the U.S. Department of Agriculture. Also used to advantage were the U.S. Geological Survey LU/LC data for areas of water (rivers, lakes, and reservoirs) and urban land.

3.1.1 Land Use for 1978

The first step in the creation of the 1985 data base was to review the 1978 data set used by the early versions of the model. The refined 1978 land use data set provided a base for the update to 1985 land use.

Refinement of the preliminary 1978 land use data was achieved through utilizing several existing sources. These sources include the series, Census of Agriculture for 1978 and Census of Agriculture for 1982, Volume 1, Geographic Area Series (U.S. Census Bureau, 1980, 1984) published for each state the by the U. S. Department of Commerce, Bureau of the Census. The 1978 Census of Agriculture provided consistent, reliable data on land areas of cropland, and pasture. Combining the major cropland categories from the 1978 Census of Agriculture produced cropland acreage figures by county. Major categories of pasture land were also aggregated to obtain the total pasture area. The 1982 Census of Agriculture was used to determine the total land area of each county in the basin.

Woodland area was derived from USDA Forest Service Timber Surveys (U.S. Forest Service, 1974, 1978, 1978, 1980, and 1982). The latest available publications of the Timber Surveys were used to obtain woodland area by county. Total "other land" found in the Ag Census was aggregated with the woodland area to create a land use defined as natural woodlots, planted woodlots, timber tracts, cutover land, and land not harvested, grazed, or used for buildings or roads.

Neither the Census of Agriculture nor the Forestry Surveys quantify urban land use. Urban land area for the preliminary 1978 land use data was determined by subtracting the cropland, pasture, and woodland acreage from the total acreage of each county. Any negative differences resulted in the assumption of zero urban land area. Negative differences were then reconciled to the total county land area by adjustment of the woodland acreage.

The resulting preliminary 1978 land use data set was then sent to the State Offices of the USDA, Soil Conservation Service for revision and/or confirmation. All states made revisions. Each state used its own methods to revise the county data set. Among the methods used were work load analysis studies, National Resources Inventory data, state planning agencies, and local county field offices of the Soil Conservation Service. The 1978 data set after the State revisions, is presented in Appendix E.1. This data set has four categories of land use on a county basis, cropland, pasture land, woodland and urban land.

Assisting with review and corrections to the refined 1978 land use data base were:

David Benner, Asst. State Conservationist, Delaware
Jeffery Loser, State Resource Conservationist, Maryland
Phillip Nelson, Asst. State Conservationist, New York
Robert Heidecker, State Resource Conservationist, Pennsylvania
Willis Miller, Asst. State Conservationist, Virginia
Bruce Julian, State Resource Conservationist, Virginia
Ken Carter, Soil Conservationist, Virginia
Dixie Shreve, State Resource Conservationist, West Virginia
Ernest L. Moody, District Conservationist, District of Columbia

3.1.2 Land Use for 1985

To obtain the 1985 land use data, the 1978 data were further processed. The 1978 data were sent to the State Offices of the Soil Conservation Service for updating to 1985. The state contacts reviewed and updated the land use to 1985 as shown in Appendix E.2. Pennsylvania land use data were updated by the Pennsylvania Department of Environmental Resources.

Assisting with review and corrections to the 1985 land use data base were:

- David Benner, Asst. State Conservationist, Delaware
- Jeffery Loser, State Resource Conservationist, Maryland
- Phillip Nelson, Asst. State Conservationist, New York
- Robert Heidecker, State Resource Conservationist, Pennsylvania
- Timothy Murphy, Hydraulic Engineer, Pennsylvania
- Bruce Julian, State Resource Conservationist, Virginia
- Dixie Shreve, State Resource Conservationist, West Virginia
- Ernest L. Moody, District Conservationist, District of Columbia

The 1985 land use data were further refined as described below.

3.1.3 Cropland Tillage

The Watershed Model has three categories of cropland; conventional tillage, conservation tillage, and hay land. Conventional tillage represents fall plowed and/or spring plowed conventional tilled cropland. Conservation tillage represents those tillage practices that result in a residue cover of at least 30% at the time of planting.

Tillage information on a county level for the 1985 data base was obtained from the Conservation Technology Information Center (CTIC), West Lafayette, Indiana. The CTIC is a clearinghouse for information on soil conservation and, in particular, cropland tillage practices. The CTIC conducts an annual survey by county of acres of crops grown under different tillage systems. CTIC data for 1985 was the basis for the conventional and conservation cropland distribution in the 1985 land use data set (CTIC, 1986).

The CTIC tillage data were processed to eliminate area overestimation due to double cropping. Percent of cropland under conservation tillage was calculated for each county (Appendix E.3).

Hay acres were compiled from the 1982 Census of Agriculture from the category of harvested, "hay, alfalfa, and other tame, small grain, wild, grass silage, or green chop". The hay acres were transformed to a percentage of the Census of Agriculture total harvested crop acres, and the area of hay acres was determined by this proportion applied to total model cropland area.

3.1.4 Water Acres

Water acres are defined as the area in rivers, creeks, streams, canals, lakes, and reservoirs. Only nontidal waters of the basin are considered to be in this land use category. Tidal waters are included in the simulation of the 3-D Water Quality Model.

The water land use area was obtained from the CBPO Geographical Information System (GIS), USGS Land Use/Land Cover (LU/LC) compiled from NASA high-altitude aerial photographs and National High-Altitude Photography Program (NHAPP) photographs. The GIS was used to directly determine the acres of water in each segment, with the exception of the area of New York state which was not available. Data from the National Resources Inventory (NRI) were used to determine acres of water for New York.

3.1.5 Manure Acres

Manure acres is a derived land use which represents the production of nutrients from manure produced in a segment. These acres do not represent acres of concentrated animals, nor do they represent manure piles or manure stacking facilities, rather the manure acres are used to represent the aggregate of all of these activities.

Animal units in each model segment were estimated from the livestock numbers in the 1982 Census of Agriculture. An animal unit is defined as 1000 pounds of animal weight. For the purpose of this analysis, this corresponds to 0.71 dairy cows, 1 beef cow, 5 swine, 250 poultry layers, 500 poultry broilers, or 100 turkeys. Table 3.1, modified from Animal Waste utilization on Cropland and Pastureland (U.S. EPA, 1979) tabulates the voided manure of different animal types. The tabulated wet weight of manure does not include the wet weight of bedding material, spilled food, or soil.

TABLE 3.1 ESTIMATED QUANTITIES OF VOIDED MANURE FROM LIVESTOCK AND POULTRY. NORMALIZED TO 1,000 POUNDS BODY WEIGHT. FROM, ANIMAL WASTE UTILIZATION ON CROPLAND AND PASTURELAND (U.S. EPA, 1979)

Animal Type	Animals/ Animal Unit	Tons of Wet Manure Voided	P (lbs)	N (lbs)	COD (lbs)
Dairy	0.71	14.9	21	123	3,340
Beef	1.0	6.7	18	61	1,510
Swine	5.0	11.7	37	160	2,080
Poultry layers	250	9.7	100	235	4,353
Poultry broilers	500	13.1	110	390	5,915
Turkeys	100	10.2	84	304	4,599

Animal units of poultry, swine, beef, and dairy were adjusted to account for the predominant manure handling practices. Poultry are usually raised in houses. The houses are cleaned out completely once a year and the manure is spread on fields. As the spread manure is already accounted for in the land uses of conventional cropland, conservation cropland, and hayland, manure from poultry are not counted in the manure land use.

Likewise, swine are housed during a significant portion of the year in finishing sheds. Manure is washed daily from the finishing pens to storage ponds and ultimately applied to cropland as liquid manure. As for poultry, spread manure is already accounted for in the (mostly) county level estimates of manure applications to conventional tilled, conservation tilled, and haylands. Only the period that swine are allowed on ground for breeding and gestation (115 days) are accounted for as manure acres.

Following Casman (1990), a ratio of indoor weight to outdoor weight can be estimated. Assumptions are 10 sows per boar, an adult pig weight is 350 lbs, two litters of 10 pigs per sow per year, and that piglets increase weight from 30 to 250 lbs in 6 months with an estimated annualized weight of 140 lbs per finished pig. Therefore:

$$\frac{\text{indoor weight}}{\text{outdoor weight}} = \frac{(140\ \text{lb})*(10\ \text{finished pigs})+(350\ \text{lb})*(250/365\ \text{days})}{(350\ \text{lbs})*(1.1\ \text{adults})*(115/365\ \text{days})} = 13.6$$

Therefore, swine animal units were adjusted down by the factor of 0.0735.

Animal units of cattle were segregated into two categories. The first category is beef cattle, defined here as beef cattle, heifers, heifer calves, steers, steer calves, bulls and bull calves. Animal units of beef cattle are decreased by a factor of 0.7 to account for the large proportion of cattle that are for most of the year, unconfined to small pastures or enclosures. The second category is dairy cows. No adjustments are made in animal units of dairy cows.

The total adjusted animal units were divided by a "compromise animal density" of 145 animal units per acre, yielding the number of manure acres. Manure acres are listed by model segment in Appendix E.4.

Manure acres were originally taken from the pasture land use acres. As manure is stored and treated through the implementation of a control program, a portion of these acres will revert back to pasture acres for simulation purposes. As control actions of guttering, diversions, and manure containment are not totally effective, some proportion of each manure acre will revert to pasture for the full implementation of controls and some smaller proportion will remain in the manure land use to account for control efficiencies less than 100%.

The overall simulation of manure land use allows the model to track agricultural waste storage practices, and show any increases due to increases in animal populations or decreases due to control actions.

3.1.6 Urban Land Subcategories

The GIS system was used to differentiate the urban land into five sub-categories. The urban land uses are listed below as described by Anderson et al. (1976).

Residential - ranging in density from very high in urban cores to low density with units on more then one acre.

Commercial - including urban central business districts, shopping centers, commercial strip developments, warehouses, etc.

Industrial - including light and heavy manufacturing as well as mining operations, stockpiles, and spoil areas.

Transportation - roads, railroads, airports, seaports, and facilities associated with the transportation of water, gas, oil, electricity, and communications.

Institutional - urban parks, cemeteries, open land, playgrounds, golf courses, zoos, and undeveloped urban land in an urban setting.

Urban land imperviousness was determined for each model segment based on the five subcategories of urban land. The model simulates one urban land use based on the area-weighted parameter of imperviousness of the above five subcategories. The following lists the five classes of urban land with the reported range of imperviousness and the single impervious value chosen for use in the model. The range of imperviousness is from the EPA report, National Urban Runoff Program (U.S. EPA, 1982) except for the transportation subcategory, which was obtained from the Federal Highway Administration report, Retention, Detention, and Overland Flow for Pollutant Removal From Highway Stormwater Runoff (FHA, 1988).

Land Use	Reported Range of Imperviousness	Impervious Value Used in Model
residential	5-60%	30%
commercial	65-85%	75%
industrial	75-85%	80%
transportation	5-20%	10%
institutional	27-100%	50%

Using the proportion of the total urban area in the different subcategories and the value of imperviousness described above, a single area-weighted imperviousness was determined for the single aggregate urban land use modeled. Appendix E.5 lists the percentage of urban land in each of the subcategories and the calculated imperviousness for the area-weighted total.

The area weighted imperviousness was used to determine the expected urban load in each model segment. The degree of imperviousness of the urban area determined the expected annual urban load using the method described by Schueler (1987):

$$L = [(P)(Pj)(0.05 + 0.9)(I)/12] (C)(2.72)$$

where:

- L = expected annual load
- P = rainfall depth over an annual period
- Pj = fraction of rainfall events that produce runoff
- I = imperviousness

C - mean concentration of pollutant based on national NURP average (C values were obtained for phosphate, total phosphorus, ammonia, nitrate, total nitrogen and BOD)

Following Schueler, the annual loads were adjusted to include baseflow loads and a curve of expected annual urban loads was generated for the range of imperviousness encountered. The urban land uses in each model segment were calibrated to the expected urban load.

3.1.7 Land Use by County

The county land use data were converted to a model segment basis. Consistent with the level of spatial detail of the model, it is assumed that all land uses are evenly distributed within a county. Counties within the Bay basin are shown in Figures 1-6 (Appendix E.6).

3.1.8 Land Use by Model Segment

Land uses by county are proportioned by percent of the county in each model segment (Appendix E.7). The percent of county area in each segment was determined by GIS. With few exceptions, model segments are larger than counties in area. Usually several counties were aggregated up to compile the model segment data. Figures 7 through 26 in Appendix E.8 show the relationship of model segments to county boundaries throughout the Bay basin. Appendices E.9 and E.10 list the land uses by model segment for 1978 and 1985, respectively.

3.1.9 Land Surface Cover and Erodibility Parameters - COVER, SLSUR, KRER

COVER represents the fraction of the land surface that is covered by canopy, crop residue, leaf litter, etc. and is subsequently protected from raindrop erosion. Cover is a one of the primary determinates of the generation of sediment fines that can be transported by runoff as part of the erosion process. The twelve monthly values used in the model represent the land cover on the FIRST day of the month. Cover is interpolated daily in the model between the user-defined monthly cover values. COVER values for conventional cropland and conservation cropland are based on the crop types grown in the segment. Major crop types aggregated from harvested acres in the 1987 Ag Census were used to obtain unique cover values for conventional and conservation cropland in each model segment. Aggregated crop categories obtained from the 1987 Ag Census include corn for grain, sorghum for grain, wheat for grain, barley for grain, buckwheat, oats for grain, rye for grain, sunflower seed, tobacco, soybeans, potatoes, sweet potatoes, corn for silage, sorghum for silage, and vegetables. Section 4.3.3 discusses the development of the COVER values used for the cropland categories in each model segment. COVER values for pervious land areas are tabulated by land use in Appendix E.11.

Appendix E.11 also includes the values of the SLSUR parameter for each land use. SLSUR represents the slope for overland flow. This parameter influences the simulation of hydrology and sediment erosion. Land slope data were derived from the National Resources Inventory (NRI) data base. The county-based NRI distribution of slopes was combined with the proportion of different county land uses to develop an average slope for cropland, woodland and pasture in each segment. Urban data were not available from this data set. The slope of the urban land was set equal to that of cropland.

The parameter KRER, a coefficient in the model soil fines detachment equation is also listed in Appendix E.11. KRER, in conjunction with the COVER parameter controls the amount of fine sediment detached by raindrop impact and is then available to be transported by overland flow. It is usually estimated by assuming it is equal to the erodibility factor, K, in the Universal Soil Loss Equation (USLE).

3.1.10 Crop distributions for Conventional (CNT) and Conservation (CST) Tillage

Due to computational limitations for modeling at the scale of the Bay drainage, the Watershed Model required the concept of a 'composite crop' representation for the CNT and CST categories in order to evaluate land cover, nutrient application rates, and expected plant uptake rates. The 'composite crop representation' is introduced and discussed in Section 4.3.3 as part of the nonpoint load modeling for the cropland categories. In order to develop a 'composite crop' for each cropland model segment, the crop distribution in the CNT and CST categories is needed. These distributions were developed as follows:

1. Total Cropland was determined as the sum of the Phase I CNT and CST categories after they had been adjusted for removal of the hayland acres (as discussed in Section 3.1.3 above).

2. The 1987 Ag census information was used to develop the crop distributions (for the cropland total) for the following aggregated crop categories for each model segment:

   Corn-grain, Corn-silage, Sorghum, 'bad actors'
   Soybeans
   Small Grains

   The 'bad actors' category essentially included all other types of crops i.e. other than corn, sorghum, soybeans, and small grains. This usually represented only a few percent of the total cropland for areas above the Fall Line, but was more significant for selected model segments below the Fall Line.

3. Multiplying the Total Cropland by the crop category percentages in Step 2 (above) produced the total acreages for each crop category.

4. The CTIC 1985 Survey reports for each state provided statewide values for the percentage of each crop in Conservation Tillage (i.e. aggregate of various types of conservation tillage practices). These percentages were used to distribute the total acres in each crop into CNT and CST categories in each model segment. The percentages used for Conservation Tillage were as follows:

	Corn	Soybeans	Grains
PA	50.9 %	52.6 %	29.6 %
MD	74.0 %	79.8 %	54.1 %
VA	67.4 %	66.0 %	50.0 %
WV	54.0 %	73.6 %	29.1 %
NY	20.6 %	7.2 %	6.6 %

5. The acres in each crop/tillage category were then adjusted to maintain the same split of conventional and conservation acres as the original Phase I cropland acres.

6. The Ag Census information was then used to determine the breakdown of corn-grain and corn-silage acres (and percentages) so that separate parameter values, especially COVER (see Section 4.3.3), could be used for each corn type.

The final percentages for the crop distributions for the four major categories listed above for Conventional and Conservation Tillage are shown in Table 3.2 for each model segment, both above and below the Fall Line.

3.1.11 Comparison of Forest Land

Forest acreage for 1950, 1978, and 1985 were compiled from the 1950 Timber Survey Data and from the 1978 and 1985 County Land Use Data submitted by SCS State Offices. Appendix E.12 contains a summary of this data by county and the totals for each state.

The CBPO Cultural Data file for 1950 does not have data for all counties in the basin. Forest land estimates include idle land and wetlands. This was done because the model has a limited number of land uses available.

These data give an indication of changes in forest land from 1950 to 1985. Since the data for 1950 are limited, however, it is difficult to show total changes in basin acreage between 1950 and 1978.

From the data available, forest acreage increased overall in the basin by 8% between 1950 and 1978. Forest acreage in the Bay basin decreased by 3% between 1978 and 1985. These estimates are consistent with previous reports (U.S. EPA, 1983) which ascribe an increase in forest land between 1950 and 1978 to a decrease in cropland acreage due to changes in agricultural practices. The decrease in forest land between 1978 and 1985 may be due, in part, to increases in urban land acreage.

3.2 POINT SOURCES

Point source inputs to the Watershed Model were developed for the 1984-87 period. These data represent all loadings from municipal wastewater and industrial facilities which discharge to channel reaches in the basin. Point sources discharging below the Fall Line were considered to be a direct discharge to the tidal Bay and were not included as part of the Watershed Model input data.

TABLE 3.2 CROP DISTRIBUTIONS FOR CONVENTIONAL AND CONSERVATION TILLAGE FOR EACH WATERSHED MODEL SEGMENT

	CONVENTIONAL TILLAGE					CONSERVATION TILLAGE				
SEGMENT	CORN GRAIN	CORN SILAGE	SOYBEANS	GRAINS	TOTAL	CORN GRAIN	CORN SILAGE	SOYBEANS	GRAINS	TOTAL
10	33.7%	34.3%	0.6%	31.4%	100.0%	42.0%	42.7%	0.5%	14.7%	100.0%
20	31.5%	54.2%	0.0%	14.3%	100.0%	34.9%	60.1%	0.0%	5.0%	100.0%
30	37.1%	45.7%	0.3%	16.8%	100.0%	41.3%	50.8%	0.4%	7.6%	100.0%
40	52.9%	5.9%	11.1%	30.1%	100.0%	63.9%	7.1%	14.4%	14.7%	100.0%
50	46.2%	12.7%	1.5%	39.7%	100.0%	60.4%	16.6%	2.0%	21.0%	100.0%
60	51.3%	19.6%	4.1%	24.9%	100.0%	60.0%	23.0%	5.2%	11.8%	100.0%
70	49.7%	11.2%	11.8%	27.2%	100.0%	58.7%	13.3%	15.0%	13.0%	100.0%
80	42.6%	18.1%	6.9%	32.4%	100.0%	52.5%	22.3%	9.0%	16.2%	100.0%
90	41.6%	33.2%	1.2%	24.0%	100.0%	48.4%	38.7%	1.5%	11.3%	100.0%
100	46.3%	25.3%	2.8%	25.6%	100.0%	54.4%	29.8%	3.5%	12.2%	100.0%
110	46.1%	15.5%	9.8%	28.6%	100.0%	55.1%	18.6%	12.5%	13.8%	100.0%
120	49.2%	24.9%	7.5%	18.5%	100.0%	55.0%	27.8%	8.9%	8.4%	100.0%
140	47.9%	14.7%	7.5%	29.9%	100.0%	56.1%	17.2%	12.2%	14.5%	100.0%
160	36.3%	31.5%	0.6%	31.6%	100.0%	44.6%	38.7%	1.2%	15.6%	100.0%
170	35.5%	56.5%	0.8%	7.2%	100.0%	36.8%	58.6%	1.9%	2.7%	100.0%
175	40.1%	35.4%	1.8%	22.7%	100.0%	45.8%	40.4%	3.9%	9.9%	100.0%
180	37.7%	28.3%	4.1%	29.9%	100.0%	44.8%	33.7%	6.4%	15.1%	100.0%
190	19.7%	57.2%	0.8%	22.4%	100.0%	22.3%	64.7%	0.8%	12.2%	100.0%
200	25.6%	43.8%	3.8%	26.9%	100.0%	29.8%	51.0%	4.4%	14.9%	100.0%
210	34.3%	21.5%	9.4%	34.9%	100.0%	41.5%	26.0%	14.4%	18.1%	100.0%
220	47.9%	17.1%	17.5%	17.5%	100.0%	52.4%	18.7%	20.0%	8.8%	100.0%
230	34.9%	39.3%	8.0%	17.7%	100.0%	38.7%	43.5%	8.3%	9.5%	100.0%
235	24.2%	13.5%	40.8%	21.5%	100.0%	28.0%	15.6%	44.4%	12.0%	100.0%
240	23.8%	2.0%	48.2%	26.1%	100.0%	28.4%	2.4%	54.1%	15.1%	100.0%
250	30.8%	32.3%	16.9%	20.1%	100.0%	34.7%	36.4%	17.9%	11.0%	100.0%
260	21.3%	10.2%	40.2%	28.3%	100.0%	25.7%	12.3%	45.5%	16.5%	100.0%
265	30.9%	67.4%	0.0%	1.7%	100.0%	31.2%	68.0%	0.0%	0.8%	100.0%
270	30.5%	54.1%	0.0%	15.4%	100.0%	33.2%	58.8%	0.0%	8.1%	100.0%
280	24.5%	20.1%	33.4%	22.0%	100.0%	28.3%	23.2%	36.2%	12.3%	100.0%
290	9.6%	23.1%	44.3%	23.0%	100.0%	11.2%	27.1%	48.7%	13.0%	100.0%
300	17.2%	24.1%	29.3%	29.5%	100.0%	20.7%	29.0%	33.2%	17.2%	100.0%
310	34.8%	10.5%	22.3%	32.5%	100.0%	42.5%	12.8%	25.6%	19.2%	100.0%
330	47.4%	7.2%	15.2%	30.2%	100.0%	53.7%	8.2%	23.9%	14.2%	100.0%
340	54.1%	8.0%	13.6%	24.2%	100.0%	59.4%	8.8%	20.7%	11.0%	100.0%
ANACOSTIA	55.5%	5.8%	19.2%	19.5%	100.0%	57.8%	6.0%	27.7%	8.4%	100.0%
BALT_HAR	51.4%	6.0%	11.5%	31.1%	100.0%	59.6%	6.9%	18.5%	15.0%	100.0%
BOHEMIA	54.0%	7.1%	15.6%	23.3%	100.0%	58.4%	7.7%	23.4%	10.5%	100.0%
CHESTER	49.2%	3.3%	21.1%	26.3%	100.0%	53.1%	3.5%	31.6%	11.8%	100.0%
CHICKAHOM	25.6%	5.0%	34.6%	34.8%	100.0%	27.5%	5.3%	51.6%	15.5%	100.0%
CHOPTANK	31.2%	2.4%	27.7%	38.8%	100.0%	35.4%	2.7%	43.6%	18.3%	100.0%
COASTAL1	37.2%	2.1%	30.5%	30.2%	100.0%	39.5%	2.2%	45.0%	13.3%	100.0%
COASTAL11	49.8%	16.0%	13.1%	21.0%	100.0%	54.9%	17.7%	17.4%	10.0%	100.0%
COASTAL4	25.2%	0.0%	45.2%	29.6%	100.0%	30.7%	0.0%	51.8%	17.5%	100.0%
COASTAL5	59.4%	3.3%	24.2%	13.2%	100.0%	58.4%	3.2%	33.0%	5.4%	100.0%
COASTAL6	52.7%	9.4%	11.7%	26.2%	100.0%	59.0%	10.6%	18.2%	12.2%	100.0%
COASTAL8	24.7%	0.4%	47.0%	27.9%	100.0%	29.8%	0.4%	53.4%	16.3%	100.0%
COASTAL9	20.0%	0.7%	60.2%	19.1%	100.0%	23.1%	0.8%	65.4%	10.7%	100.0%
ELIZABETH	0.2%	0.0%	55.0%	44.8%	100.0%	0.2%	0.0%	70.3%	29.5%	100.0%
GREAT_WIC	21.4%	0.0%	41.0%	37.6%	100.0%	27.4%	0.0%	49.3%	23.3%	100.0%
GUNPOWDER	49.4%	7.3%	11.5%	31.7%	100.0%	57.5%	8.5%	18.6%	15.4%	100.0%
JAMES	31.6%	3.1%	46.8%	18.4%	100.0%	36.1%	3.6%	50.2%	10.2%	100.0%
NANSEMOND	56.2%	1.0%	27.3%	15.5%	100.0%	62.2%	1.1%	28.4%	8.3%	100.0%
NANTICOKE	40.2%	2.2%	17.9%	39.7%	100.0%	48.1%	2.6%	29.6%	19.7%	100.0%
OCCOQUAN	35.2%	27.6%	10.2%	27.0%	100.0%	41.2%	32.3%	11.2%	15.3%	100.0%
PATAPSCO	43.8%	9.7%	12.2%	34.4%	100.0%	51.7%	11.5%	19.9%	16.9%	100.0%
PATUXENT	52.4%	2.2%	25.0%	20.5%	100.0%	53.6%	2.3%	35.4%	8.7%	100.0%
POCOMOKE	33.3%	0.9%	42.3%	23.5%	100.0%	32.9%	0.9%	56.5%	9.7%	100.0%
POTOMAC	31.5%	1.7%	34.9%	31.9%	100.0%	36.3%	2.0%	45.3%	16.5%	100.0%
RAPPAHANN	22.3%	0.6%	43.1%	34.0%	100.0%	27.9%	0.7%	50.8%	20.6%	100.0%
SEVERN	40.7%	3.3%	15.7%	40.3%	100.0%	49.3%	4.0%	26.4%	20.3%	100.0%
WICOMICO	28.4%	0.6%	49.0%	22.0%	100.0%	26.8%	0.6%	64.0%	8.6%	100.0%
WYE	41.6%	2.5%	26.4%	29.5%	100.0%	44.7%	2.6%	39.5%	13.2%	100.0%
YORK	24.2%	2.4%	44.8%	28.6%	100.0%	29.3%	2.9%	51.0%	16.8%	100.0%

The Point Source Atlas was used as the universe of possible point sources. Municipal dischargers were selected based on a flow of 0.4 million gallons per day (MGD) or greater. This criteria captured more than 96% of the municipal point source flow. The remaining (approximately) 4% of point source flow was from numerous small discharges.

Industrial dischargers have highly variable concentrations of discharged nutrients, ranging from zero to many times the concentrations associated with municipal discharges. Accordingly, Industrial dischargers were included in the point source data set if the load from the industrial source was equivalent to the TN, TP, or BOD load of a 0.4 mgd municipal point source with secondary treatment. Industrial dischargers were selected if any of the following were true: total phosphorus load greater than or equal to 12 lb per day; or, total nitrogen load greater than or equal to 40 pounds per day; biological oxygen demand greater than or equal to 100 pounds per day.

Data for all facilities that discharge to streams within a model segment were aggregated to obtain a single set of point source loads for the corresponding model reach. The constituents and units are listed below:

CONSTITUENT	UNIT
flow	ac-ft
BOD	lbs
DO	lbs
ammonia (NH_3)	lbs
nitrate (NO_3)	lbs
organic-N	lbs
phosphate (PO_4)	lbs
organic-P	lbs
heat	BTU

The data sets consist of monthly total loads for each reach for the 1984-87 period. It was determined that monthly values represented the most appropriate resolution for the available data.

Data for these parameters were derived in the following manner. If State (National Pollution Discharge Elimination System, NPDES) data were available, they were used preferentially. When no State NPDES data were available, data from the 1985 Point Source Atlas were used. As a last resort, defaults were calculated for missing data, as described below. Permit Compliance System data were found to contain many errors and were not used to compile the initial data set.

Defaults for municipal dischargers were based on default concentrations applied to the municipal flows. The record of flows for municipal dischargers was good, and only measured values of flow were used. The default value for dissolved oxygen assumed a dissolved oxygen concentration of 6.25 milligrams per liter for municipal dischargers. A flow-weighted load was calculated from the default. Tables 3.3 and 3.4 summarize nitrogen and phosphorus default concentrations and chemical-species percentages used when nutrient data were missing from municipal flows.

TABLE 3.3 MUNICIPAL NITROGEN DEFAULT PERCENTAGES OF AMMONIA, NITRATE AND ORGANIC NITROGEN, AND THE DEFAULT CONCENTRATIONS OF TOTAL NITROGEN. DEFAULTS BASED ON LEVELS OF SECONDARY TREATMENT

	Maryland		Virginia **		Pennsylvania	
Year	Ammonia/ Nitrate/ Org. N, percent	Default Total Nitrogen mg/l	Ammonia/ Nitrate/ Org. N, percent	Default Total Nitrogen mg/l	Ammonia/ Nitrate/ Org.N, percent	Default Total Nitrogen mg/l
1984	50/35/15	18.0	73/11/16	18.7	50/35/15	18.5
1985	50/35/15	18.0	73/11/16	18.7	50/35/15	18.5
1986	50/35/15	18.0	73/11/16	18.7	50/35/15	18.5
1987	50/35/15	18.0	73/11/16	18.7	50/35/15	18.5
1988	50/35/15	18.0	75/09/16	18.7	50/35/15	18.5

** Virginia default concentrations and percentages were based on Hampton Roads Sanitation District processes.

Note: Tabulated point source data for 1988 are not currently included in the Watershed Model.

TABLE 3.4 MUNICIPAL PHOSPHORUS DEFAULT PERCENTAGES OF PHOSPHATE AND ORGANIC PHOSPHORUS, AND THE DEFAULT CONCENTRATIONS OF TOTAL PHOSPHORUS. DEFAULTS BASED ON LEVELS OF SECONDARY TREATMENT **

	Maryland		Virginia		Pennsylvania	
Year	Default Ortho-P/ Org. P, percent	Total Phos., mg/l	Default Ortho-P/ Org. P, percent	Total Phos., mg/l	Default Ortho_P/ Org. P, percent	Total Phos. mg/l
1984	85/15	7.0	85/15	6.4	85/15	8.0
1985	85/15	7.0	85/15	6.4	85/15	8.0
1986	85/15	3.0	85/15	6.4	85/15	8.0
1987	85/15	3.0	85/15	6.4	85/15	8.0
1988	85/15	3.0	81/19	2.5	85/15	8.0

** Primary or tertiary treatment level ratio of ortho-phosphate to organic phosphate is 45/55.

Note: The tabulated point source data for 1988 data are not currently included in the Watershed Model.

The shift in default values of TP for Maryland in 1985 and for Virginia in 1988 reflects the phosphate ban on detergents that went into effect for Maryland in December 1985 and for Virginia in January, 1988.

Missing municipal biochemical oxygen demand (BOD) values were replaced with the average of values for the months for which data was available. No defaults were applied if all BOD data was missing.

A different procedure was developed for industrial load defaults. Industrial flows are highly variable and, when nutrients are discharged, are characterized by low volume and high concentrations. In addition, some industrial flows are very large, such as water used for condenser cooling or hydroelectric generation, and have no nutrient loads whatsoever. As a consequence, industrial flows are assumed to have zero flow (and are, of course, not counted as surface water diversions). Nutrients from industrial sources were input to the channel as a load based on the dischargers' reported values.

Since industrial flow is not quantified, dissolved oxygen loads for industrial dischargers are not required. Industrial loads are primarily BOD, PO4, organic P, or NH4. Industrial loads of nitrate and organic N are negligible and not included. The total industrial nitrogen load is assumed to be entirely ammonia. The industrial phosphorus load is assumed to be 85% ortho-phosphorus and 15% organic phosphorus.

All of the data sets generated as described above were then reviewed by the States of Virginia, Maryland, and Pennsylvania for accuracy. The reviewed data sets were then further processed for use as model input.

State contacts who provided input to the collection and review of the point source data are:

Maryland:	Narendra Pandy Maryland Department of the Environment 2500 Broening Highway Baltimore, Md. 21224
Pennsylvania:	Ken Bartel / Cedric Karper / George Fetchko Pennsylvania Bureau of Water Quality Management Fulton Building, 12th Floor Harrisburg, Pa. 17120
Virginia:	Alan Pollock / John Kennedy / Arthur Butt Virginia State Water Control Board 2111 North Hamilton Street Richmond, Va. 23230

The point source dischargers were assigned to appropriate model segments by the NPDES record latitude and longitude of each discharger. Point source loads by model segment were then reformatted and stored in the WDM files for the appropriate river basins. During model simulations, the monthly values were divided evenly over all simulation intervals (hourly) in the month. The following tables are included in Appendix F:

- Appendix F.1 details the total basin-wide point source loads by year.
- Appendix F.2 displays loads by model segment for each year.
- Appendix F.3 displays loads by basin for each year.
- Appendix F.4 lists the total municipal loads for each parameter by State.
- Appendix F.5 lists the total industrial loads for each parameter by State.
- Appendix F.6 lists the point source discharges for which data was compiled.

3.3 SURFACE WATER DIVERSIONS

Major surface water diversions from channel reaches are represented in the Watershed Model for the 1984-1987 simulation period. Data were obtained from U.S. Geological Survey offices in Pennsylvania, Maryland, and Virginia (USGS, 1988) and from the U.S. Army Corps of Engineers report Water Needs Assessment of the Susquehanna River Basin (COE, 1988).

The data were reported in monthly or annual diversions for each water user. If only annual diversions were available, then equal monthly divisions of the annual total were assumed.

Categories of water use included as surface water diversions were:

domestic water use - water for household purposes.

industrial water use - water used for industrial fabrication, processing, washing and cooling.

irrigation water use - water used to assist in growing crops or to maintain vegetative growth.

public supply - water withdrawn by public and private water suppliers and delivered to groups of users.

Several categories of water uses were assumed to involve a "once through" nonconsumptive use and were not included in the model data of surface water diversions. These categories are hydroelectric, thermoelectric, and industrial cooling. Mining is assumed to be a water use which provides its own source of wash or process water and does not involve consumptive use. Ground water sources and water that is continually recycled in industrial use or in mineral processing were also not included in the surface water diversion data.

Commercial water use is a subcategory of the public supply water use and is not included to avoid double-counting. National figures (USGS Circular 1004, Estimated Use of Water in the United States in 1985) show that 93% of commercial water is from public supply (82%) or ground water sources (11%).

The surface water diversions are assigned to model segments by the reported latitude and longitude and summed for each segment. The surface water diversion data is reformatted and stored in WDM files in time steps of one day and in units of cfs. The WDM files are the total surface water diversions in each model segment. Appendix F.7 lists the average annual surface water diversions in cfs in each model segment.

3.4 ATMOSPHERIC SOURCES

The Watershed Model accounts for the atmospheric deposition of nitrogen and phosphorus directly onto water surfaces for the 1984-87 period of simulation. Deposition to water surfaces is explicitly modeled.

Deposition of inorganic nitrogen to land surfaces is explicitly included in the AGCHEM land uses (conventional cropland, conservation cropland, and hayland) through the inclusion of atmospheric loads with nutrient applications of fertilizer and manure (see Section 4.3.4). Atmospheric deposition to PQUAL land uses (forest, urban, pasture) is implicitly included by calibration to the annual loads observed in field measurements.

The wetfall ammonia and nitrate loads for each model segment were determined by the use of annual isopleths produced by the National Atmospheric Deposition Program (NADP, 1982 - 1987). The wetfall nitrate and ammonia loads vary spatially by model segment with the highest deposition generally in the northwest areas of the bay basin, (West Branch Susquehanna and Juniata), and the lowest deposition in the southeast area of the basin (lower James, lower Eastern Shore). The year-to-year variation of the wetfall nitrate assigned to model segments for the 1982-87 period is about 16%. The year-to-year variation in wetfall ammonia is about 44% for the same period.

Following Tyler (1988), the dryfall nitrate loads are assumed to be equal to the wetfall nitrate. Accordingly, the dryfall nitrate was set to the long term (1982-1987) average of the wetfall nitrate. The dryfall nitrate is spatially distributed by model segment, but has no year-to-year variation. Dryfall ammonia is assumed to be negligible.

Orthophosphate, organic nitrogen and organic phosphorus are not typically monitored by NADP. Annual loads of these constituents were derived from the report Chesapeake Bay Program Technical Studies: A Synthesis (U.S. EPA, 1982). The Synthesis Report gives no indication of year-to-year or spatial variation of these parameters, so constant loads are used for all years. Table 3.5 lists the basin-wide average annual atmospheric deposition loads.

TABLE 3.5 BASIN-WIDE AVERAGE ANNUAL ATMOSPHERIC DEPOSITION LOADS (LB/AC/YR)

YEAR	NH3	NO3	ORGANIC NITROGEN	TOTAL NITROGEN	ORTHO PHOSPHORUS	TOTAL PHOSPHORUS
1984	1.95	6.94	6.07	15.0	.143	.566
1985	1.50	6.70	6.07	14.3	.143	.566
1986	1.68	6.86	6.07	14.6	.143	.566
1987	1.70	6.41	6.07	14.2	.143	.566

The average total nitrogen load compares favorably with other estimates of atmospheric deposition in the basin (Jaworski and Linker, 1991):

The data was reformatted as a monthly load to the total model segment water area and added to the WDM files. The data is input to the model in the same manner as the point source inputs, i.e., the monthly totals are divided evenly over each hour of the month. Atmospheric loads by year and model segment are included in Appendix F.8.

SECTION 4.0

NONPOINT LOADING SIMULATION MODULES AND SIMULATION RESULTS

This section discusses the HSPF modules used to simulate the nonpoint loadings from each of the land uses considered in the Phase II Watershed Model. Table 4.1 shows the land use categories in the model, while Table 4.2 lists the water quality and nonpoint loading constituents simulated in Phase I. Note that TOC (Total Organic Carbon) and Chlorophyll A are simulated only as instream constituents.

The focus in Phase II was to provide a more detailed simulation of agricultural cropland areas so that a cause-effect relationship could be represented between the nutrient applications (fertilizer and manure) on these areas and the subsequent runoff loadings from these land uses. Consequently, the empirical approach to nonpoint simulation used in Phase I was replaced with the more detailed mechanistic approach provided by the Agrichemical Module sections of HSPF. Also, a significant element of the Phase II work was the discovery that hay cropland was a major portion of the total agricultural cropland as defined in Phase I. Hay cropland represents 50% of the total cropland above the Fall Line, and 10% of the cropland below the Fall Line. Since the nutrient loadings from hay areas are expected to be significantly lower than from cultivated croplands, the acreage of hay cropland was removed from the total cropland and simulated as a separate land use category.

The procedures used in simulating the nonpoint loadings from both cropland and non-cropland areas are discussed in the following subsections, along with the estimation of selected input parameters needed for model application at the scale of the Chesapeake Bay drainage area. The loading simulation results for all land uses are discussed in the final subsection, Section 4.4. Further details on the model equations and algorithms are contained in the HSPF Users Manual (Johanson et al., 1984) and the HSPF Application Guide (Donigian et al., 1984).

4.1 OVERVIEW OF CROPLAND AND NON-CROPLAND SIMULATION

Within the HSPF framework, the PERLND and IMPLND module sections are used to simulate hydrologic, sediment, and water quality processes that produce nonpoint loadings to a stream from both surface and subsurface pathways. The structure charts for the PERLND and IMPLND module sections are shown in Figures 4.1 and 4.2, respectively. Each module section is comprised of subroutines, or groups of subroutines, that perform the simulation of individual processes. For example, the SNOW module in Figures 4.1 and 4.2 performs the snow accumulation and melt simulation for both pervious and impervious land areas, while the PWATER module in Figure 4.1 performs the hydrologic simulation for all pervious land

TABLE 4.1 LAND USE CATEGORIES IN THE WATERSHED MODEL

Simulated Land Uses:

Pervious

- Forest
- High Tillage Cropland
- Low Tillage Cropland
- Hay Cropland
- Pasture
- Urban

Impervious

- Animal Waste
- Urban

Urban Categories:

- Residential
- Commercial and Services
- Industrial
- Transportation
- Institutional

TABLE 4.2 WATER QUALITY CONSTITUENTS SIMULATED IN THE WATERSHED MODEL

Dissolved Oxygen (DO)	
Water Temperature	
Sediment	
Biochemical Oxygen Demand (BOD)	
Nitrate-Nitrogen (NO3-N)	Total N
Ammonia-Nitrogen (NH3-N)	Total N
Organic Nitrogen	Total N
Orthophosphorus (PO4-P)	Total P
Organic Phosphorus	Total P
Total Organic Carbon (TOC)	
Chlorophyll A (CHL A)	

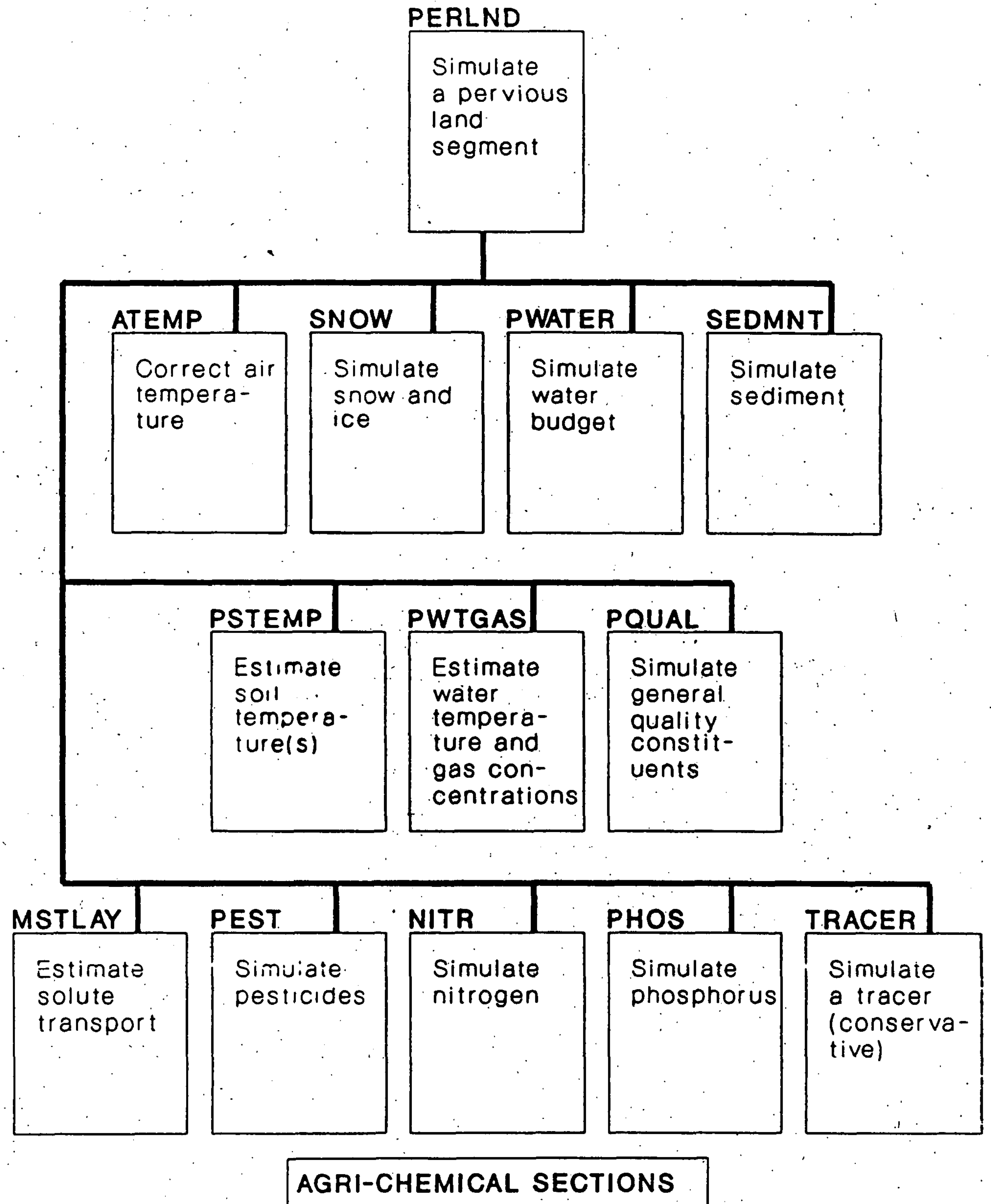


Figure 4.1 PERLND structure chart.

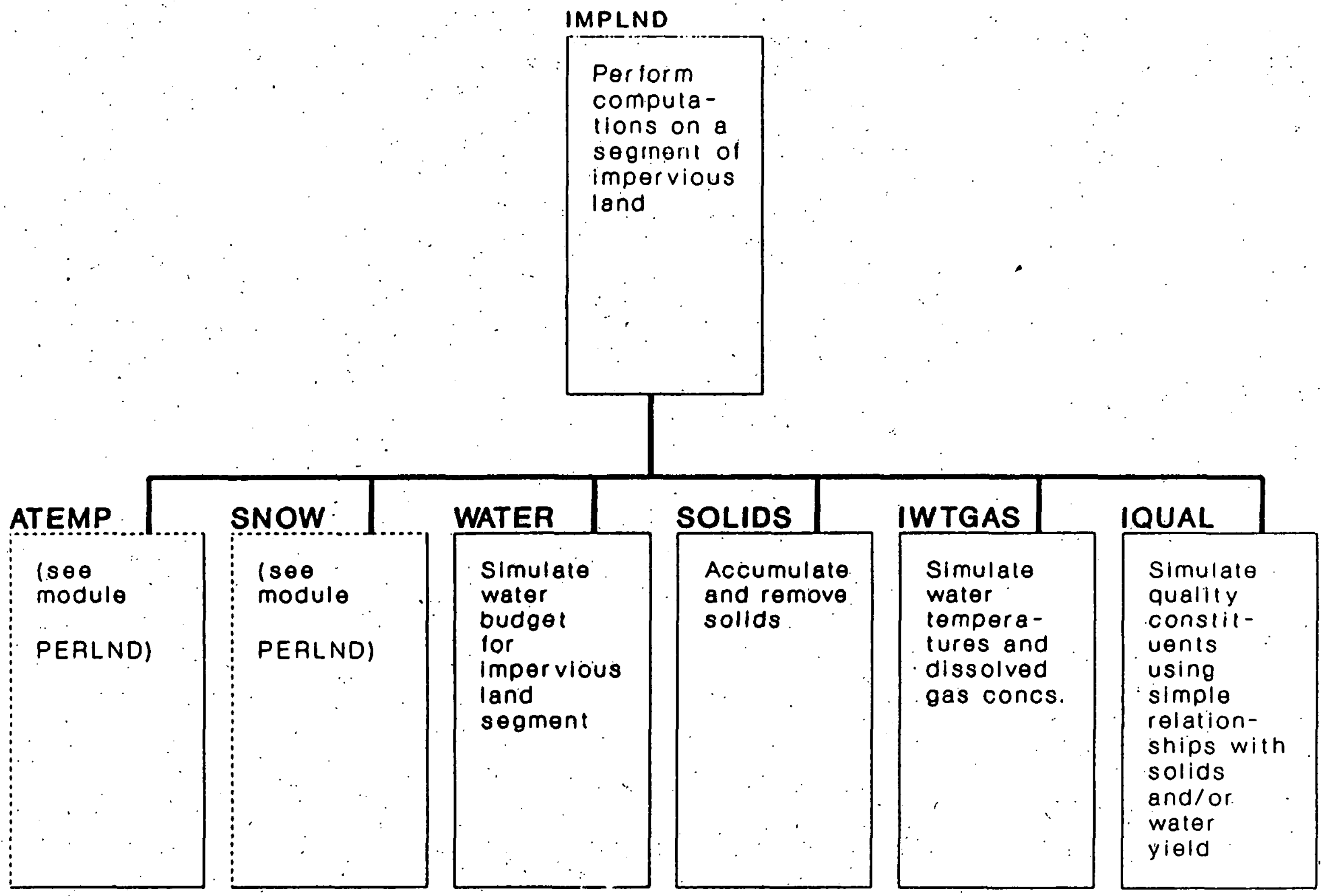


Figure 4.2 Structure chart - impervious land-segment application module.

areas. The specific processes simulated by each module are identified in the figures.

Since HSPF has the ability to use either simple or detailed (i.e., AGCHEM) approaches for nonpoint loading simulation, different modules were used for different land use categories to combine the simplified simulation approach from Phase I for non-cropland areas with the detailed AGCHEM approach for the cropland categories. Table 4.3 lists the specific HSPF modules used to simulate the individual nonpoint loading constituents from each land use category.

Typically, nonpoint loadings are calculated in nonpoint models by using one or more of three basic approaches, which include the following:

a. Potency factors and subsurface concentrations
b. First-order washoff and subsurface concentrations
c. Detailed modeling of land surface and soil processes

In the 'potency factor' approach, nonpoint loadings from the land surface are calculated as a function of the sediment loading rate, which in turn may be calculated from the Universal Soil Loss Equation (Wischmeier and Smith, 1978), or one of its modifications, or by detailed modeling of storm runoff and soil erosion. The potency factor approach has been used in a number of nonpoint loading estimation techniques and models, including the NPS model (Donigian and Crawford, 1976b) which was the basis for the original NVPDC and Phase I CBP watershed modeling efforts.

The 'first-order washoff' approach includes a daily calculation of pollutant accumulation/deposition on the land surface, and a subsequent washoff of pollutants for storm events as a first-order function of the storm runoff rate. This approach was originally developed for urban areas where impervious surfaces provide the major fraction of surface nonpoint loadings; the well-known EPA Storm Water Management Model (SWMM) (Huber and Dickinson, 1988), the Modified NPS Model used in the NVPDC Study, HSPF, and numerous other models use the first-order washoff approach.

Both the potency factor and first-order washoff approaches are used exclusively for surface loadings; they rely on user-specified subsurface concentrations to define the subsurface pollutant contributions.

The 'detailed modeling' approach involves the representation of soil chemical and biochemical processes that, in conjunction with hydrologic and erosion modeling, calculate both the surface and subsurface nonpoint loading contributions. For modeling nonpoint nutrient loadings, this often involves the calculation of mineralization, nitrification/denitrification, immobilization, sorption/desorption, plant uptake, and other soil nutrient processes as impacted by nutrient applications (fertilizer and manure), agronomic practices, hydrologic conditions, and soil moisture and temperature.

Although this approach requires more data and input than the other empirical methods, detailed modeling allows a direct linkage between nutrient application rates and agricultural practices, and resulting runoff loadings. The HSPF AGCHEM modules, CREAMS (Knisel et al., 1980), CREAMS-NT (Deizman and Mostaghimi, 1991),

TABLE 4.3 HSPF MODULES USED TO SIMULATE NONPOINT LOADINGS FROM EACH LAND USE IN PHASE II

	Conventional Tillage	Conservation Tillage	Hay	Forest	Pasture	Urban Pervious	Urban Impervious	Manure Acres
Hydrology	PWATER/SNOW	PWATER/SNOW	PWATER/SNOW	PWATER/SNOW	PWATER/SNOW	PWATER/SNOW	IWATER/SNOW	IWATER/SNOW
Dissolved Oxygen	PWTGAS	PWTGAS	PWTGAS	PWTGAS	PWTGAS	PWTGAS	IWTGAS	--
Water Temperature	STEMP	STEMP	STEMP	STEMP	STEMP	STEMP	IWTGAS	--
Sediment Loading	SEDMNT	SEDMNT	SEDMNT	SEDMNT	SEDMNT	SEDMNT	--	--
Organics Loading	PQUAL	PQUAL	PQUAL	PQUAL	PQUAL	PQUAL	IQUAL	--
NO_3-N	AGCHEM	AGCHEM	AGCHEM	PQUAL	PQUAL	PQUAL	IQUAL	--
NH_3-N	AGCHEM	AGCHEM	AGCHEM	PQUAL	PQUAL	PQUAL	IQUAL	--
Organic N	AGCHEM	AGCHEM	AGCHEM	--	--	--	--	--
PO_4-P	AGCHEM	AGCHEM	AGCHEM	PQUAL	PQUAL	PQUAL	IQUAL	--
Organic P	AGCHEM	AGCHEM	AGCHEM	--	--	--	--	--

and other agricultural models use this general approach to varying degrees of process representation.

The PQUAL and IQUAL modules of HSPF allow both the potency factor and first-order washoff approaches to nonpoint loading simulation. As shown in Table 4.3, these modules were used in Phase II to simulate the nonpoint loadings for all constituents from forest, pasture, and urban (pervious and impervious) land uses, and for the BOD/organics loading from the cropland categories. The AGCHEM modules were used for nutrient loadings from the cropland areas. The nutrient loadings from the animal waste 'manure acres' were derived from the runoff and defined waste concentrations as described below in Section 4.2. That section also discusses additional details of the non-cropland loading simulation.

4.1.1 Hydrologic, Sediment Loading, DO, and Water Temperature Simulation

As shown in Table 4.3, the hydrology, sediment, DO (Dissolved Oxygen), and runoff water temperature simulations are based on the same procedures, utilizing the same HSPF modules, for all pervious land categories. The hydrology for impervious land categories (i.e., urban impervious and manure acres) uses a different module, although the snow simulation is identical. Since these modules are common to all the land uses, a brief overview of the simulation approaches is provided below with further details available in the HSPF User Manual.

The hydrologic submodel, PWATER, in HSPF was derived originally from the Stanford Watershed Model (Crawford and Linsley, 1966), and subsequent refinements through the HSP (Hydrocomp, Inc., 1976), ARM (Donigian and Crawford, 1976a; Donigian et al., 1977), and NPS models. Figure 4.3 is a flowchart of the hydrologic processes simulated in PWATER; the snowmelt processes are simulated in the separate SNOW modules of HSPF. PWATER calculates a complete water balance for each land use category within the watershed, or model segment, by converting input rainfall and evaporation data into the resulting surface runoff, changes in soil moisture storages for various portions of the soil profile, infiltration of water, actual evapotranspiration, and subsequent discharge of subsurface flow (both interflow and baseflow) to the stream channel. During storm events, rainfall is distributed among surface runoff and soil moisture storage compartments based on nominal storage capacities and adjusted infiltration rates. Between storm events, water storage in the soil profile is depleted by evapotranspiration and subsurface recharge, thereby freeing up soil moisture capacity for rainfall inputs from the next storm (NVPDC, 1983).

The SNOW module requires input of additional meteorologic timeseries, that is in addition to precipitation and evaporation, including solar radiation, air temperature, wind, and dewpoint. Energy balance calculations, in terms of heat fluxes, are performed to evaluate melt components associated with radiation (solar and terrestrial), heat exchange due to condensation and convection, rainfall temperatures, and subsurface heat. In conjunction with the melt calculations, air temperatures are used to determine whether precipitation is falling as rain or snow, and snowpack characteristics are simulated including snow density and compaction, areal coverage, albedo, evaporation, heat loss, and liquid water storage. The end result is a continuous simulation of snow depth, water equivalent, liquid water storage, and subsequent release of melt water to the land surface. This melt water release is then received by the PWATER modules

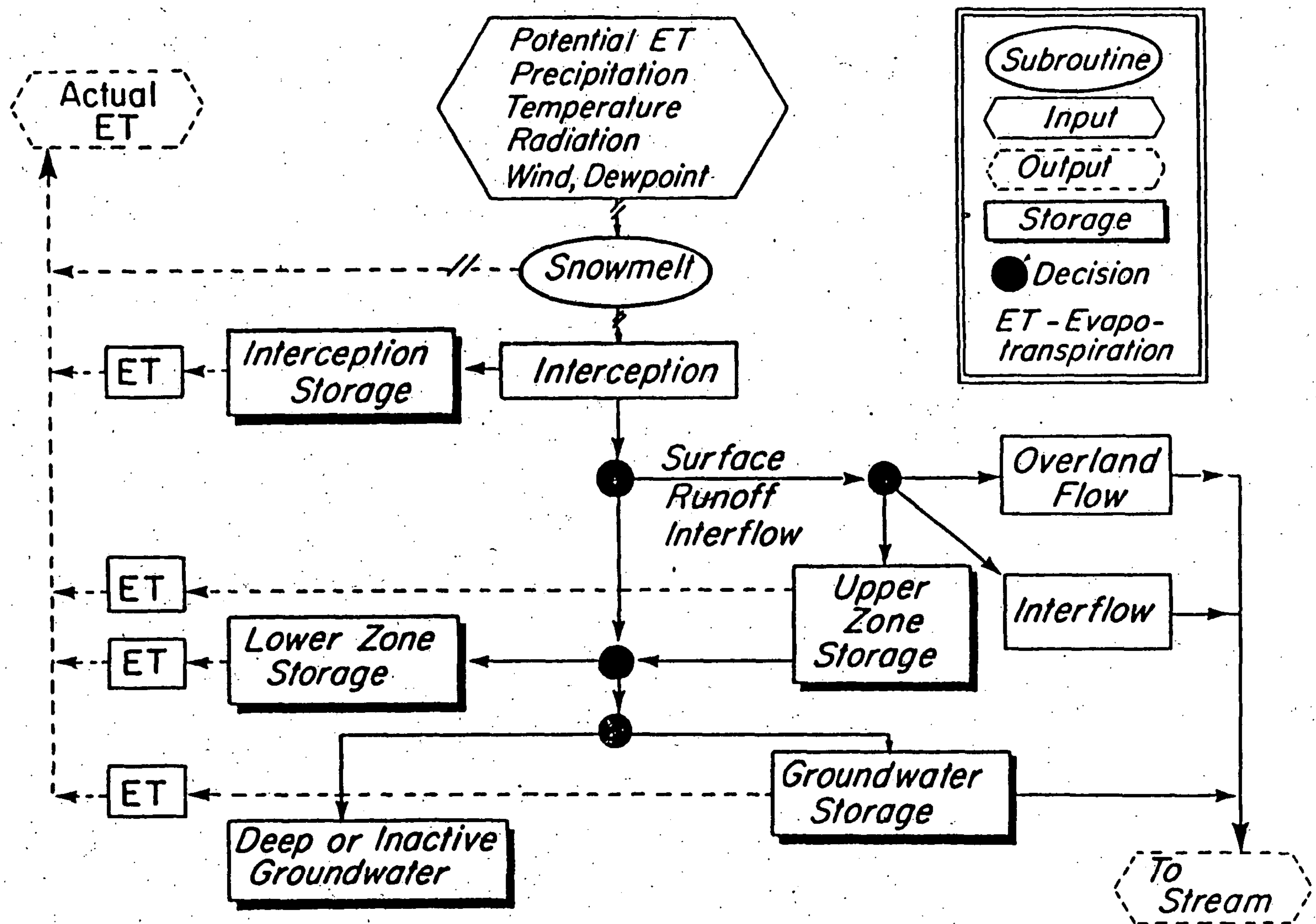


Figure 4.3 Hydrologic processes simulated by the PWATER module of HSPF.

as input for the soil hydrologic processes shown in Figure 4.3. The equations used in SNOW are based on work by the U.S. Army Corps of Engineers (1956), Anderson and Crawford (1964), and Anderson (1968); they are identical to the equations used in the HSP, ARM, and NPS models.

For impervious land surfaces, the IWATER module of HSPF performs the hydrologic simulation which includes only the processes of detention or retention of incident rainfall, evaporation from retention storage, and overland flow routing of the rainfall excess. Retention accounts for surface depressions and ponding on various impervious surfaces (e.g., roof tops, parking lots, road side depressions) from which the retained water can then evaporate. Thus, impervious runoff simulation would be analogous to including only the 'interception' and 'overland flow' portions of the hydrologic processes shown in Figure 4.3 (for pervious surfaces).

The SEDMNT module of HSPF performs the sediment loading simulation for all pervious land use categories, i.e., all land uses except urban-impervious and manure acres. Figure 4.4 shows the sediment processes and fluxes simulated by SEDMNT, including detachment of sediment particles by raindrop impact, net vertical sediment input (or export), attachment or aggregation of fine sediment particles, washoff of detached sediment, and scour of the soil matrix by overland flow. All these processes are simulated in the Watershed Model except for scour of the soil matrix which requires information at finer spacial scale than was available for the model segments.

The equations used to produce and remove sediment are based on the ARM and NPS Models (Donigian and Crawford 1976 a,b). The algorithms representing land surface erosion in these models were derived from a sediment model developed by Moshe Negev (Negev 1967) and influenced by Meyer and Wischmeier (1969) and Onstad and Foster (1975). The equation which represents the scouring of the matrix soil, which is not included in ARM or NPS, was derived from Negev's method for simulating gully erosion.

Two of the sediment fluxes shown in Figure 4.4, SLSED and NSVI, are added directly to the detached sediment storage variable DETS. SLSED represents external lateral input from an upslope land segment. It is a time series which the user may optionally specify, this option was not implemented in the Watershed Model. NVSI is a parameter that represents any net external additions or removals of sediment caused by human activities or wind.

Impacts of tillage operations on sediment availability are affected in SEDMNT by re-setting the value of DETS to represent an increased amount of sediment fines available for erosion, at the time of the tillage operation.

The washoff process involves two parts: the detachment/attachment of sediment from/to the soil matrix and the transport of this sediment. Detachment (DET) occurs by rainfall. Attachment occurs only on days without rainfall; the rate of attachment is specified by parameter AFFIX. Transport of detached sediment is by overland flow.

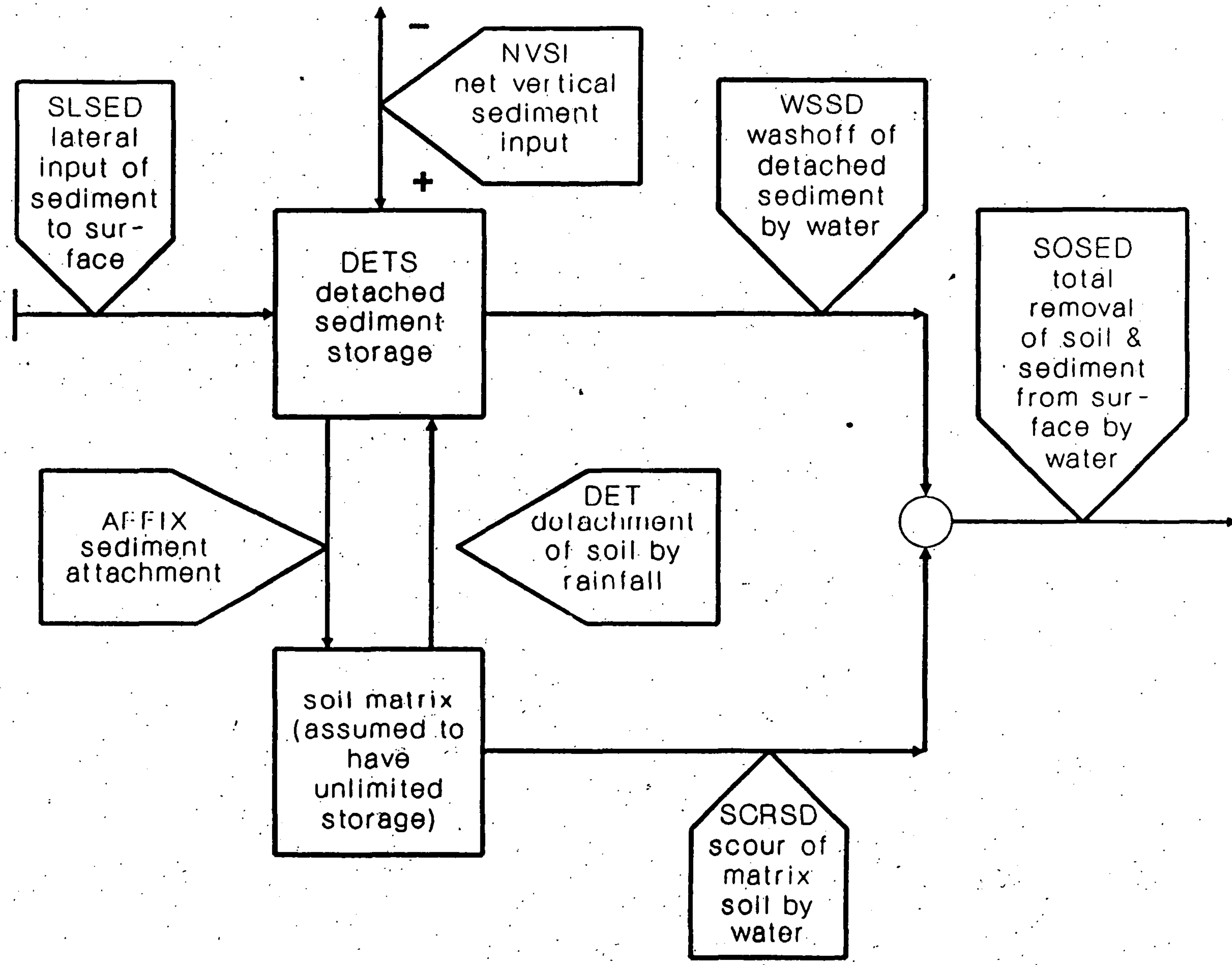


Figure 4.4 Flow diagram for SEDMNT section of PERLND application module.

Kinetic energy from rain falling on the soil detaches particles which are then available to be transported by overland flow. The equation that simulates detachment is:

DET = DELT60*(1.0 - CR)*SMPF*KRER*(RAIN/DELT60)**JRER (4.1)

where:

DET = sediment detached from the soil matrix by rainfall in tons/acre per interval
CR = fraction of the land covered by snow and other cover
SMPF = supporting management practice factor
KRER = detachment coefficient dependent on soil properties
RAIN = rainfall in in./interval
JRER = detachment exponent dependent on soil properties

The variable CR is the sum of the fraction of the area covered by the snowpack (SNOCOV), if any, and the fraction that is covered by anything else but snow (COVER). SNOCOV is computed by section SNOW. COVER is a parameter which for pervious areas will typically be the fraction of the area covered by vegetation and mulch. It can be input on a monthly basis.

When simulating the washoff of detached sediment, the transport capacity of the overland flow is estimated and compared to the amount of detached sediment available. The transport capacity is calculated by the equation:

STCAP = DELT60*KSER*((SURS + SURO)/DELT60)**JSER (4.2)

where:

STCAP = capacity for removing detached sediment in tons/acre per interval
DELT60 = hr/interval
KSER = coefficient for transport of detached sediment
SURS = surface water storage in inches
SURO = surface outflow of water in in./interval
JSER = exponent for transport of detached sediment

When STCAP is greater than the amount of detached sediment in storage, washoff is calculated by:

WSSD = DETS*SURO/(SURS + SURO) (4.3)

If the storage is sufficient to fulfill the transport capacity, then the following relationship is used:

WSSD = STCAP*SURO/(SURS + SURO) (4.4)

where:

WSSD = washoff of detached sediment in tons/acre per interval
DETS = detached sediment storage in tons/acre

WSSD is then subtracted from DETS.

SEDMNT also simulates the re-attachment of detached sediment (DETS) on the surface due to soil compaction, particle aggregation, etc. Attachment to the soil matrix is simulated by merely reducing DETS by a daily rate input by the user. Since the soil matrix is considered to be unlimited, no addition to the soil matrix is necessary when this occurs. DETS is diminished at the start of each day that follows a day with no precipitation by multiplying it by (1.0 - AFFIX), where AFFIX is the user defined parameter. This represents a first order rate of reduction of the detached soil storage.

Water temperature of runoff and the DO concentration are calculated by the PSTEMP and PWTGAS modules, respectively, for the pervious land categories. Actually, the PSTEMP module calculates <u>soil temperatures</u> for each of the defined soil layers - surface, upper zone, lower zone, and groundwater zone - and the flow component originating from that zone is assumed to be at the calculated soil temperature, except that the water temperature cannot be less than freezing. Thus, surface runoff occurs at the calculated surface soil temperature, interflow occurs at the calculated upper zone temperature, and groundwater occurs at the calculated groundwater zone temperature. In addition, these calculated temperatures are used to perform adjustments to the input soil nutrient reaction rates in the AGCHEM module (see Section 4.3 below)

For the Watershed Model, the surface and upper zone soil temperatures are based on a linear regression with air temperature in each time interval. The lower zone and groundwater temperatures are assumed to be the same and are input monthly values defined by the user; these temperatures correspond to the lower root zone and shallow groundwater that contributes baseflow to the stream.

The surface soil temperature and surface runoff temperature is then used in the PWTGAS module to calculate the DO concentration of the overland flow, which is assumed to be at saturation. PWTGAS uses the following empirical nonlinear equation to relate dissolved oxygen at saturation to water temperature (Committee on Sanitary Engineering Research, 1960):

$$SODOX = (14.652 + SOTMP*(-0.41022 + SOTMP*(0.007991 - 0.000077774*SOTMP)))*ELEVGC \quad (4.5)$$

where:

SODOX - concentration of dissolved oxygen in surface outflow in mg/l
SOTMP - surface outflow temperature in degrees C
ELEVGC - correction factor for elevation above sea level

The concentration of dissolved oxygen in the interflow and the active groundwater flow cannot be assumed to be at saturation. Values for these concentrations are provided by the user. He may specify a constant value or 12 monthly values for the concentration of each of the gases in interflow and groundwater. If monthly values are provided, daily variation in values will automatically be obtained by linear interpolation between the monthly values.

For impervious surfaces, the procedures for runoff water temperature and DO are identical to those used for pervious surfaces; the IWTGAS module uses a linear regression to calculate impervious overland flow temperature, which is then used with Equation 4.5 (above) to calculate the DO concentration.

4.2 SIMULATION OF NON-CROPLAND AREAS

Based on the hydrology and sediment loading simulations, the PQUAL module simulates the nonpoint pollutant loadings from the non-cropland areas of forest, pasture, and urban-pervious, while the IQUAL module simulates these loadings for the urban-impervious land use category. Animal waste contributions from manure acres are derived from IWATER/SNOW modules and user-defined concentrations, as discussed in Section 4.2.2 (below).

4.2.1 Forest, Pasture, Urban Area Procedures

Both PQUAL and IQUAL allow use of either the potency factor or first-order washoff approach for any of the nonpoint constituents that are simulated. In the Watershed Model, the potency factor approach was selected for all constituents from pervious land areas, while the first-order washoff approach was selected for all constituents from impervious land areas within the non-cropland categories. This was the approach used in Phase I and is consistent with current nonpoint modeling procedures.

Figure 4.5 is the flow chart for the PQUAL module. The corresponding diagram for the IQUAL module is identical to the top half of Figure 4.5, since pollutant contributions from scour, interflow and groundwater are not allowed from impervious land areas.

The potency factor approach simply assumes that the contaminant loading is a direct function of the sediment load, as simulated by the SEDMNT module in each simulation timestep. The relationship is shown as follows:

$$WASHQS = WSSD*POTFW$$

where:

WASHQS = flux of quality constituent associated with detached sediment washoff in quantity/acre per interval
WSSD = washoff of detached sediment in tons/acre per interval
POTFW = washoff potency factor in quantity/ton

In Figure 4.5, the pollutant contribution calculated by the above equation is shown as 'associated with detached sediment'. Potency factors indicate the pollutant strength relative to the sediment removed from the land surface. Certain constituents that are strongly adsorbed to sediment particles, such as metals, phosphates, organics, etc., actually move with the eroded sediment; whereas, for other less-highly attached contaminants, (e.g., ammonia, nitrate, BOD) this approach simply means that sediment loadings are a reasonable indicator of the expected contaminant load in surface runoff.

Potency factors are specified separately for each land use category, and can be input on a monthly basis for pollutants that demonstrate a definite seasonal variability. In conjunction with the potency factors, subsurface (i.e., interflow and baseflow) concentrations are needed to define the subsurface contributions; these concentrations can also be defined on a monthly basis for seasonal variation.

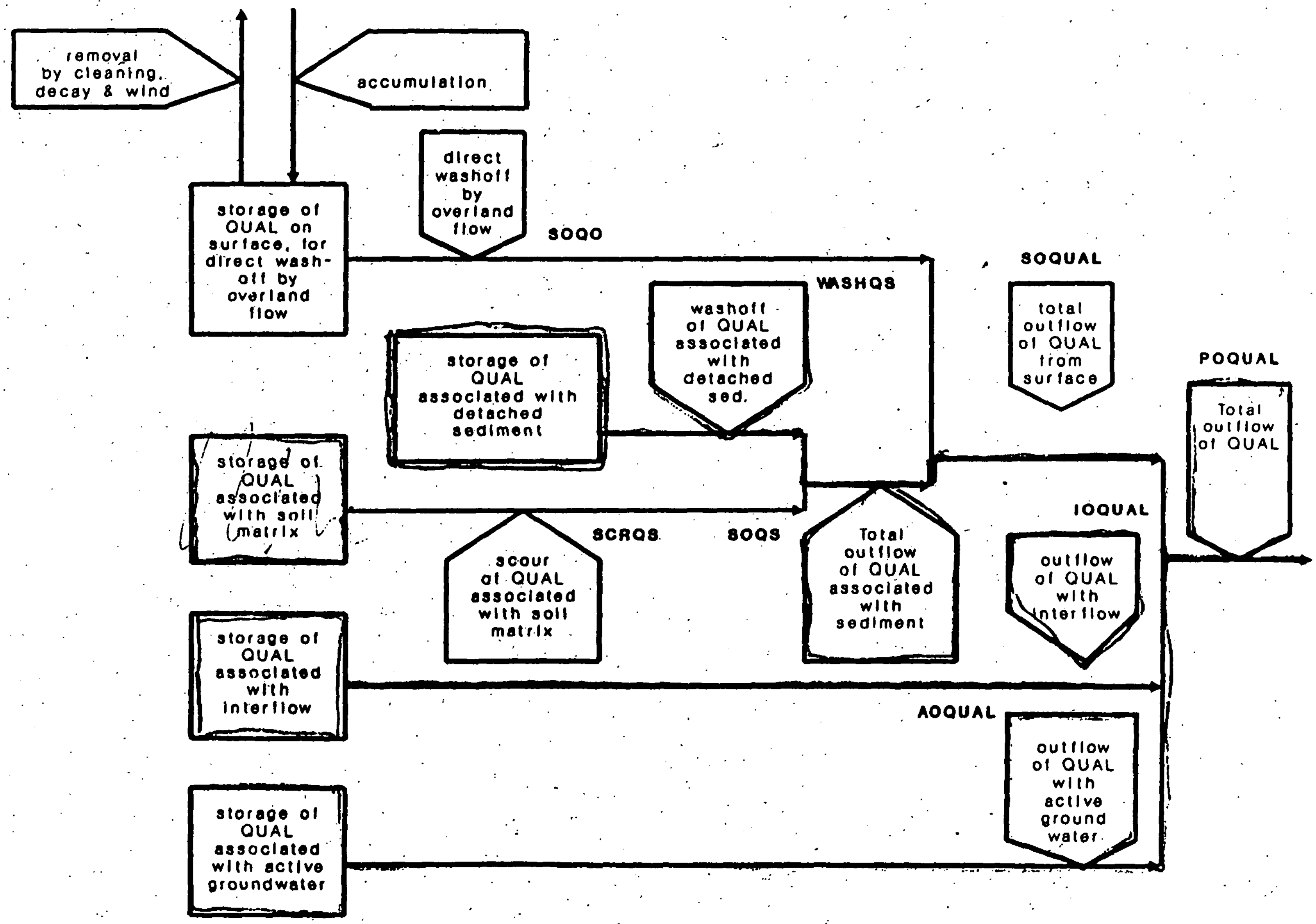


Figure 4.5 Flow diagram for PQUAL section of PERLND application module.

In the first-order washoff approach, simulation of surface runoff pollutant loads involves two components: daily accumulation and depletion (non-runoff related) of contaminants on the land surface, and washoff by overland flow during storm events. The constituent can be accumulated and removed by processes which are independent of storm events such as street cleaning, decay, and wind erosion and deposition, or it can be washed off by overland flow. The accumulation and removal rates can have monthly values to account for seasonal fluctuations.

When there is surface outflow and some quality constituent is in storage, washoff is simulated using the commonly used relationship:

$$SOQO = SQO*(1.0 - EXP(-SURO*WSFAC)) \tag{4.6}$$

where:

- SOQO - washoff of the quality constituent from the land surface in quantity/acre per interval
- SQO - storage of available quality constituent on the surface in quantity/acre
- SURO - surface outflow of water in in./interval
- WSFAC - susceptibility of the quality constituent to washoff in units of 1/in.
- EXP - Fortran exponential function

The storage is updated once a day to account for accumulation and removal which occurs independent of runoff by the equation:

$$SQO = ACQOP + SQOS*(1.0 - REMQOP) \tag{4.7}$$

where:

- ACQOP - accumulation rate of the constituent, quantity/acre per day
- SQOS - SQO at the start of the interval
- REMQOP - unit removal rate of the stored constituent, per day

The module computes REMQOP and WSFAC for this subroutine according to:

$$REMQOP = ACQOP/SQOLIM \tag{4.8}$$

where:

- SQOLIM - asymptotic limit for SQO as time approaches infinity (quantity/acre), if no washoff occurs

and

$$WSFAC = 2.30/WSQOP \tag{4.9}$$

where:

- WSQOP - rate of surface runoff which results in a 90 percent washoff in one hour, in./hr

Since the unit removal rate of the stored constituent (REMQOP) is computed from two other parameters, it does not have to be supplied by the user.

As with the potency factor approach, subsurface concentrations which can be input on a monthly basis are used to define the subsurface contributions.

4.2.2 Animal Waste Procedures

To represent animal waste contributions within the Watershed Model, the CBPO developed estimates of 'manure acres' for each model segment (see Section 3.0) which are used to calculate runoff and associated pollutant loads from animal waste. These areas are included in the Watershed Model as 'impervious' land surfaces in order to conceptually model a rain-driven source of pollutants with constant concentrations. The available literature was reviewed to estimate reasonable hydrologic parameters and concentrations to use in calculating the waste contributions. The following hydrologic parameters are currently used in the model:

Retention parameter	-	0.35 in.
Roughness factor	-	0.15
Slope	-	2.0 % Above Fall Line
		1.0 % Below Fall Line
Slope Length	-	150 ft.

The most critical of these parameters is the retention parameter which specifies the surface storage to be satisfied prior to runoff. Since evaporation occurs from this storage, it also determines the total fraction of rainfall that becomes runoff. The value of 0.35 inches is consistent with the limited available literature from Edwards et al. (1985, 1983) and Phillips and Overcash (1976) for paved animal feedlots; this value results in about 70% runoff of precipitation. The remaining parameters are consistent with small feedlot size areas, and they have no significant impact on runoff volumes.

The calculated runoff volumes are multiplied by assumed constant concentrations to calculate the pollutant loadings to the stream channel from the 'manure acres'. Initial values for concentrations were derived from a review of the available literature on animal waste runoff; these initial values were then adjusted, primarily reduced, during the calibration process based on instream concentrations and relative contributions from all sources. The final concentrations used in both Phase I and Phase II are listed below, along with annual per acre loadings corresponding to 25 inches of runoff:

	Concentration (mg/l)	Annual Loading (lb/ac/yr)
Organic N	300	1698
Ammonia N	40	226
Nitrate N	10	57
Total N	350	1981
Organic P	60	340
Phosphate P	10	57

Total P	70	397
BOD (ultimate)	700	3962

Actual segment loadings are based on the actual runoff volumes for each segment; the above loadings based on 25 inches of runoff are shown to provide some perspective on the general magnitude of loadings associated with animal waste in the Watershed Model. These concentrations are considerably lower than those expected from feedlots, primarily because the manure acres concept does not represent feedlot areas, manure piles, or manure stocking facilities. It is simply a means of accounting for animal waste nutrient contributions, and allowing for this contribution to be reduced as treatment and storage programs are implemented (See Section 3.1.5).

4.3 SIMULATION OF CROPLAND AREAS

The primary objectives in applying the AGCHEM modules for simulating nonpoint nutrient loadings from the cropland areas were as follows:

a. Represent nutrient (nitrogen and phosphorus) balances, including applications (fertilizer and manure), crop uptake, soil transformations, and runoff loadings for the major cropland categories in each model segment.

b. Provide a mechanism for investigating and representing sensitivity to climate variations and agricultural practices.

c. Provide a means of evaluating the water quality impacts of current nutrient application rates and practices, and projecting impacts of changes in rates and practices as potential nutrient management alternatives.

This section provides an overview of the processes simulated by the AGCHEM modules of HSPF, and discusses the general application procedures used in applying the modules to the model segments within the Watershed Model. Details of the equations used are provided in the HSPF User Manual (Johanson et al., 1984). Following the overview of AGCHEM processes, we discuss some of the key issues involved in applying the AGCHEM module at the scale of the Watershed Model segments, including the development of a 'composite crop' representing a weighted combination of the major crops grown within the Basin, and specification of current fertilizer and manure application rates, chemical forms, and application procedures for defining model input. The final subsection, Section 4.3.6, summarizes the AGCHEM simulation results.

4.3.1 AGCHEM Overview

The AGCHEM modules of HSPF attempt to represent the major nitrogen and phosphorus processes occurring within the soil profile that determine and control the fluxes of soil nutrients within the soil/plant/terrestrial environment. Figure 4.6 shows the soil nutrient storages, nutrient application modes, and subsequent movement of soil nutrients modeled by the AGCHEM module. Runoff, soil moisture, and sediment values calculated by the corresponding sections of HSPF are used

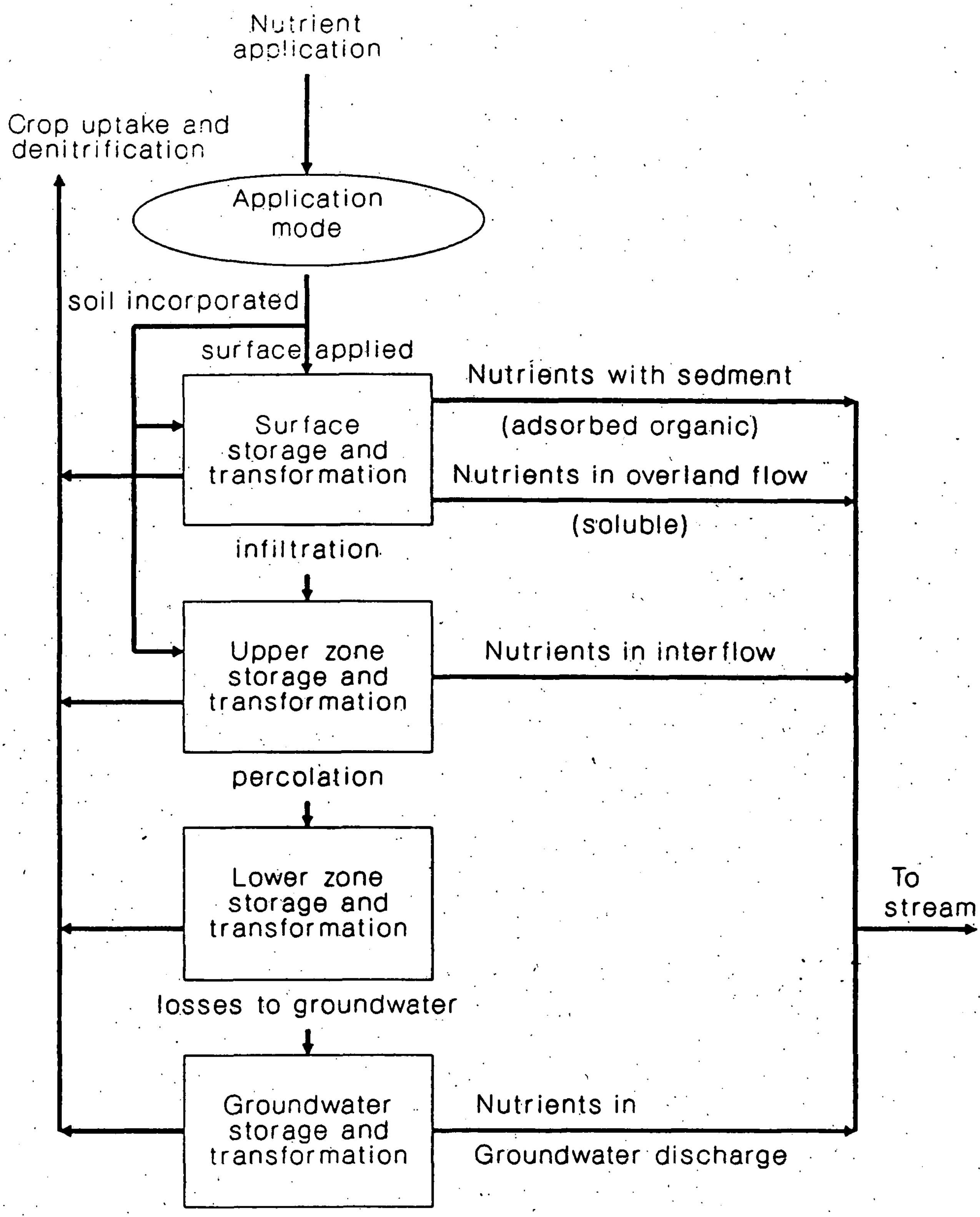


Figure 4.6 Nutrient storages and transport modeled by the AGCHEM module.

by the AGCHEM module to provide the moisture storage and transport values needed for the nutrient simulation. Fertilizers, animal wastes, plant residues, and other nutrient inputs (e.g., atmospheric deposition, sludge application) are applied in their chemical form (i.e., NH_4, NO_3, PO_4, Organic N, Organic P) either as a surface application or incorporated into the soil.

Figure 4.7 shows the AGCHEM conceptualization of the soil profile. Nutrients are stored in four depth layers: surface zone, upper zone, lower zone, and groundwater zone. The depths of each zone are defined by input parameters estimated by the model user. The shallow surface layer is a continuous mixing zone which may be defined functionally as the zone of interaction of surface applied chemicals, from which surface runoff, sediment erosion, and associated chemicals are transported to a waterbody. The surface zone depth is typically estimated at about one centimeter, although values ranging from 0.5 to 2.0 cm have been used in specific applications with AGCHEM and other agricultural runoff models.

The upper zone extends from the bottom of the surface zone to a depth often ranging from 10 to 20 cm. This usually corresponds to the depth of major tillage operations and/or incorporation of applied nutrients. It also defines the depth used to calculate the mass of soil and nutrients through which interflow and percolating water pass to reach the lower zone regardless of the method of chemical application.

The lower zone is the primary source of plant evaporation, and it regulates the amount of soluble chemicals that can be introduced into groundwater since the chemicals must pass through this layer. For agricultural applications, the lower zone depth is typically set to the maximum depth of the crop root zone, usually ranging from 50 to 150 cm.

The groundwater layer represents the depth of shallow groundwater that actively contributes baseflow to the stream channel. It can also be visualized as a shallow mixing depth within the surface aquifer that controls the chemical transformations and associated contributions to baseflow concentrations. In reality, this depth is highly variable and difficult to define; for watershed modeling purposes, depths of 1 to 3 m are typically used.

In Phase II, the soil depths for these layers were set to the following values for all model segments:

Soil Layer	Thickness	Bottom Depth from Soil Surface
Surface	1 cm	1 cm
Upper Zone	14 cm	15 cm
Lower Zone	105 cm	120 cm
Groundwater Zone	152 cm	272 cm

Although variations in the depth of the groundwater zone for each model segment may be appropriate, and should be considered in any future studies, the use of a constant value was consistent with the both the objectives and resources available for the Phase II effort.

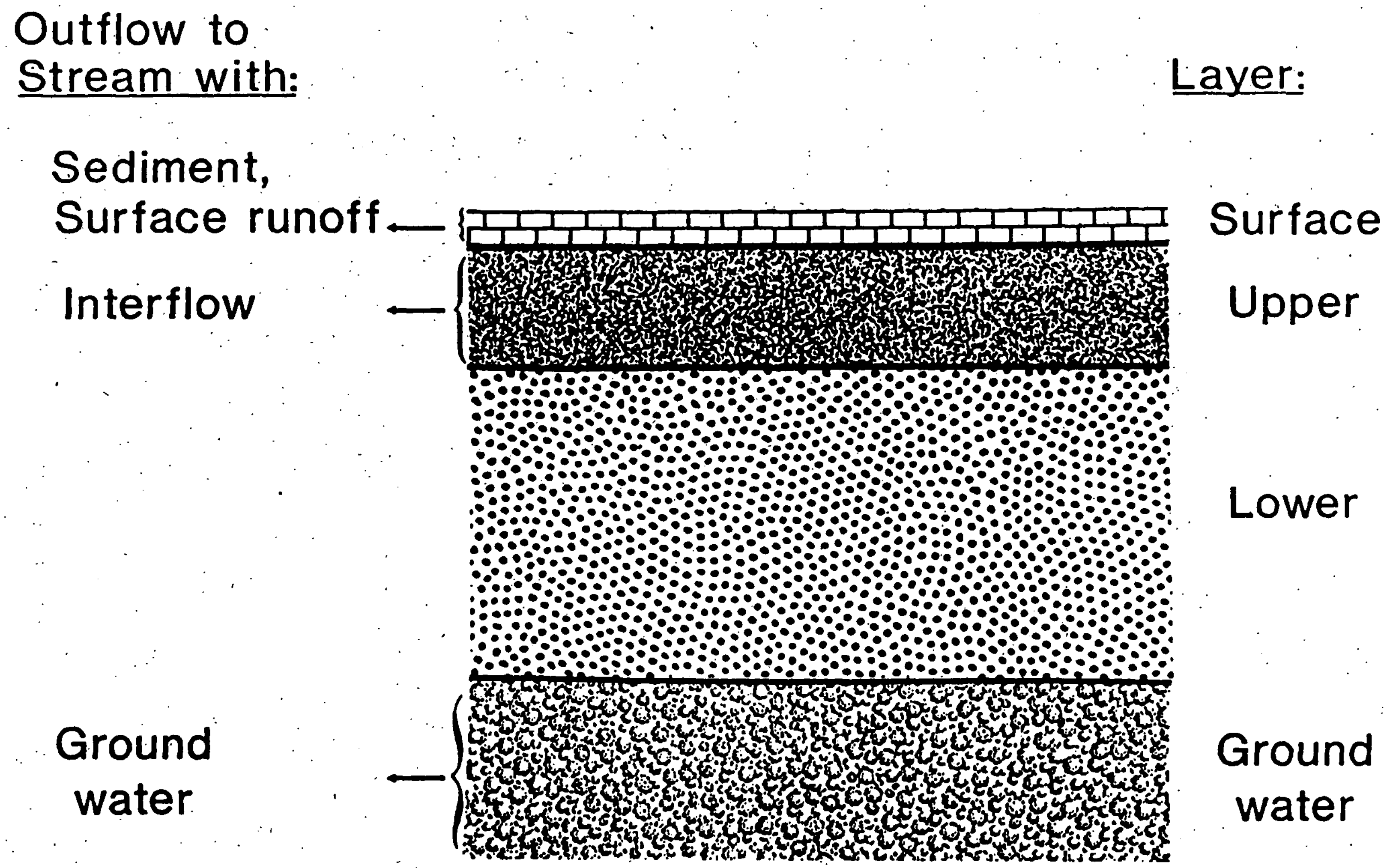


Figure 4.7 Soil profile representation by the AGCHEM Module.

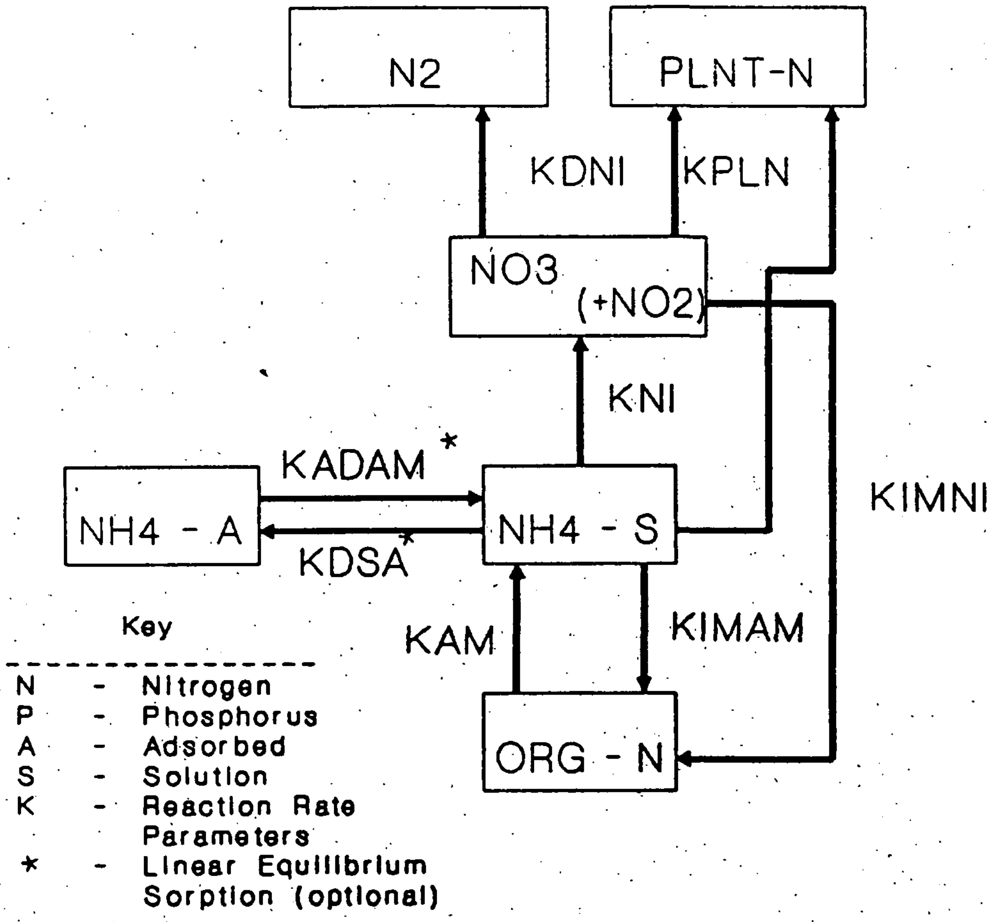
4.3.2 Soil Nutrient Processes Modeled by AGCHEM

Within the AGCHEM module, the NITR and PHOS sections perform the reactions and transformations of nitrogen and phosphorus compounds, respectfully, in the soil profile as a basis for predicting the nutrient content of agricultural runoff. The transformations, nutrient storages, and reaction rates considered by NITR and PHOS are shown in Figure 4.8. The nutrient simulation primarily assumes first-order reaction rates and is derived from work by Mehran and Tanji (1974), and Hagin and Amberger (1974). The AGCHEM module is a translation and enhancement of the soil nutrient capabilities of the Agricultural Runoff Management (ARM) Model (Donigian and Crawford, 1976b; Donigian et al., 1977; Donigian and Davis, 1978). The processes simulated include immobilization, mineralization, nitrification/denitrification, plant uptake, and adsorption/ desorption (for which an equilibrium isotherm option is available).

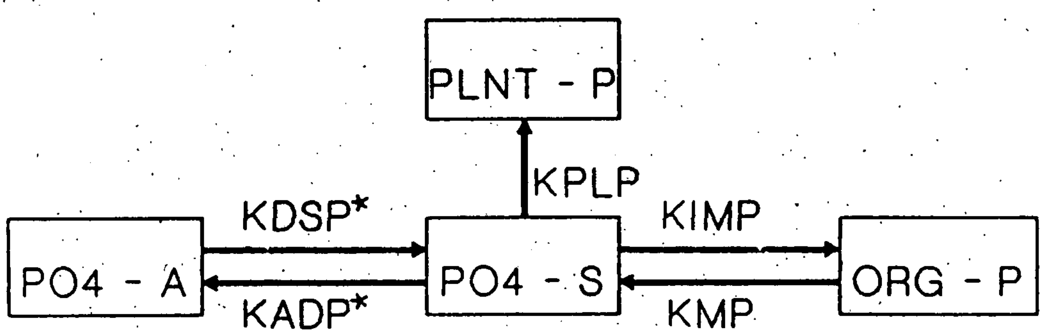
The nutrient module simulate both nutrient transformations and movement in the watershed by water or sediment. Transformations of nutrients determine the nutrient forms in each soil layer and their resulting susceptibility to movement. Nutrient transport processes are simulated only to the extent that is needed to predict runoff quality and quantity. The model does not consider the generally secondary movement of soil chemicals by concentration and thermal gradients. However, it does model the lateral and downward transport of chemicals by water from the soil zones. Lateral transport of nutrients towards the stream can occur from the surface and upper zone storages. Inflow of nutrients to the groundwater zone and nutrient transformations in the groundwater are modeled as a basis for predicting the outflow of dissolved constituents with groundwater flow.

The diagrams in Figure 4.8 show the transformation pathways, storages, and names of the reaction rate input parameters. Reaction rates are input on a per day basis for each soil layer. Nitrite (NO^2) transforms so quickly in most agricultural soils that it is not considered separately. The adsorbed phase represents the nutrients in a complex form along with those adsorbed on the soil. The plant uptake rates (KPL) are input monthly as a function of the stage of crop growth. These monthly uptake parameters are adjusted to represent the crop uptake of N and P from the soil storages and to distribute it throughout the growing season.

Soil temperature is presently the only environmental factor that is modeled as affecting the reaction rates, with the exception that the transformations are stopped entirely at very low moisture levels as often occurs in the surface layer. Soil temperatures for the surface and upper zones are determined by regression equations based on air temperature, while the daily soil temperature for the lower zone and groundwater is interpolated from average monthly input values. The input first-order rate parameters are defined as the maximum, or optimum, rates at 35 degrees C. Using the calculated soil temperature for each soil layer in each model time-step, the input rate parameter is corrected for soil temperatures below 35 degrees C by the generalized equation:



Nitrogen transformations in NITR module



Phosphorus transformations in PHOS module

Figure 4.8 Nutrient transformations simulated by the AGCHEM Module.

$$KK = K*TH**(TMP-35.0) \tag{4.10}$$

where:

KK - temperature corrected first order transformation rate in units of per simulation interval

K - optimum first order reaction rate parameter

TH - temperature coefficient for reaction rate correction (typically about 1.06)

TMP - soil layer temperature in degrees C

When temperatures are greater than 35 degrees C, the rate is considered optimum, that is KK is set equal to K. When the temperature of the soil layer is below 4 degrees C or the layer is dry, no biochemical transformations occur.

The corrected reaction rate parameters are determined every biochemical reaction interval and multiplied by the respective storages as shown in Figure 4.8 to obtain the reaction fluxes. Plant uptake can vary monthly and can be distributed between nitrate and ammonium by a user-specified input parameter which designates the fraction of plant uptake from each species of N.

Other factors deemed as having a constant influence during the simulation period, such as soil pH, are represented by adjustments to the input reaction rates. Also, all input parameters are specified separately for each soil layer; thus, variations in characteristics of the soil profile can be accommodated by using different reaction rates for the different soil layers.

Although HSPF has been applied to hundreds of watersheds across the United States and abroad, the detailed agricultural runoff simulation provided by the AGCHEM modules has not had the same degree of application experience. However, initial testing and application was performed on field sites in Georgia and Michigan as part of the ARM model development work (Donigian and Crawford, 1976; Donigian et al., 1977), and subsequent applications including both field and watershed-scale sites have been conducted in Iowa (Donigian et al., 1983; Imhoff et al., 1983), Nebraska (Gilbert et al., 1982), Florida (Nichols and Timpe, 1985), and Tennessee (Moore et al., 1988).

4.3.2.1 General Limitations of AGCHEM

As with any model, AGCHEM has a number of inherent limitations in representing soil nutrient processes that need to be discussed in order to fully appreciate the model results and their use in the Phase II effort. Some limitations are due to current capabilities of the HSPF code, others are due to the scale of the Chesapeake Bay application, while others are a reflection of the current state-of-the-art of modeling soil nutrient processes. Each limitation and its potential impact is discussed below:

a. Ammonia volatilization is not currently simulated by the AGCHEM model. Volatilization can be a significant loss of nitrogen when applied as manure or as urea-based fertilizers. In order to account for this loss, ammonia losses from manure applications were estimated separately and deducted from the total manure N application (see Section 4.3.4.4). Subsequent ammonia losses, i.e., following the applications, from the soil were represented by increased immobilization/fixation. Although this did not eliminate the volatilized N from the soil, it did reduce soil ammonia values and subsequent runoff, and the resulting increase in soil organic N was minimal.

b. Urea is not modeled as a separate form of nitrogen in AGCHEM. Consequently, the urea component of fertilizer was assumed to be readily hydrolyzed to ammonia so that all nitrogen fertilizer in the urea form was input to the model as ammonia (see Section 4.3.4). This is expected to have very little impact on the simulation results, and would only affect storms occurring within a few days of a fertilizer application.

c. Plant uptake is represented as a first-order process in AGCHEM, based on the soil nutrient storages in the various soil zones. As described above, monthly rates are input by the user for each soil zone to mimic the time-variation in root development and associated plant nutrient uptake from the various soil zones. The input rates are corrected for soil temperature and uptake is stopped when moisture levels are zero; this primarily occurs in the surface layer. Thus, uptake is a direct function of soil nutrient storages and application rates; plant growth, root development, stresses associated with environmental conditions, etc. are not represented. Consequently, uptake rates are primarily determined through calibration to expected annual crop uptake (see Section 4.3.5). The rates and resulting annual uptake need to be re-evaluated whenever application rates are changed in order to ensure that crop needs are satisfied.

d. The soil phosphorus cycle and processes represented in AGCHEM are considerably simplified compared to the complex reality of how phosphorus behaves in the soil environment. Chemical fixation and precipitation reactions that produce iron and aluminum complexes with phosphate are not represented, and the distinction between sorbed phosphate and organic P is difficult to model, and somewhat arbitrary, since these forms are not usually reported in field studies due to the difficult analytical problems they present. In effect, the sorbed PO_4 in the model represents an 'exchangeable PO_4' which controls the amount in solution, while the organic P effectively represents both organic P and tightly-bound PO_4 not available for desorption. Section 4.3.5.3 discusses the estimation of model parameters based on this view of the phosphorus state variables. Very few agricultural models currently available attempt to represent the complex phosphorus cycle in soils; further model development and testing work is needed.

e. Only sediment-bound organic N and P are simulated by AGCHEM; no dissolved organics are modeled. This is generally considered to be a reasonable approximation for surface runoff contributions, where dissolved organics are usually small components of the total nutrient load. In Phase II, a BOD component from the cropland areas is included in the model simulations providing a source of dissolved organic material for the instream processes.

f. Crop rotations are not explicitly represented by AGCHEM in the Watershed Model. AGCHEM is designed to represent a constant annual land cover/land use pattern for each model segment throughout the simulation period. Consequently, crop rotations and associated practices at the field scale are not directly represented. The implicit assumption is that, at the scale of a model segment ranging from 100 sq. mi. to 1000 sq. mi. or more, rotations within a segment will offset each other so that the total area in each land use and crop will remain approximately constant throughout the period. That is, although crops and practices on an individual field may change from year to year, the net change in crops and practices within a model segment will be minimal.

Other limitations of AGCHEM, primarily related to the large scale of the Watershed Model application, are discussed below in Sections 4.3.4 and 4.3.5. Recommendations for improvements to AGCHEM, based on the above limitations, and refinements of the Watershed Model application are discussed in Section 4.3.7.

4.3.3 Composite Crop Representation

The Phase II Watershed Model includes 63 individual model segments, comprised of 34 segments above the Fall Line (AFL) and 29 segments below the Fall Line (BFL). The AFL segments include simulation of nonpoint loadings from all the land use categories plus the instream flow and water quality constituents, while the BFL segments provide the nonpoint loadings directly to the estuaries and main Bay segments modeled by the 3-D Water Quality Model. In each segment of the Watershed Model, each of the eight land use categories (pervious and impervious) are modeled for flow, sediment, and all nonpoint loadings; over 500 combinations of model segments and land use categories (i.e., 63 segments times 8 land use categories equals 504 combinations) are simulated. This is a significant computational burden even with the modern increases in computer processing speed. Moreover, the computations increased in Phase II due to the addition of the 'hay' land use category and the use of the more detailed computations of the AGCHEM module for all the cropland categories.

Due to this computational burden and limitations inherent in the spatial representation of land use within a model segment at the scale of the Bay drainage, it was necessary to develop the concept of a 'composite crop' in order to evaluate segment-wide parameter values for the Conventional Tillage and Conservation Tillage categories. The 'composite crop' concept is simply a means of calculating selected parameter values for a model segment by weighting crop-specific values by the relevant percentages in each crop category. The crop percentages, or crop distributions, for both tillage land use categories were developed as described in Section 3.1.10; the percentages shown in Table 3.2 were used to calculate the segment parameters.

The key model parameters affected by the cropping patterns include monthly land surface cover (i.e., the COVER parameter), nutrient application rates, and expected composite crop nutrient uptake values. This section discusses the calculation of COVER values for the model segments. Section 4.3.4 (below) discusses the development of the nutrient application rates and the associated influence of the composite crop approach, while Section 4.3.5 describes the expected crop uptake values and how they were used in the application of the AGCHEM simulations.

The COVER parameter represents the fraction of the land surface protected from direct raindrop impacts by either crop canopy or residue on the surface. Its primary influence in the AGCHEM model is on the calculated sediment loadings for each land use category within each model segment. Monthly COVER values are input to the sediment model representing the land surface cover on the first day of each month; values for days during the month are linearly interpolated from the neighboring monthly values. Figure 4.9 shows the division of the Bay drainage area into three regions for definition and variation of the monthly COVER values; the COVER values for each major crop for both Conventional and Conservation Tillage, and for the hay cropland are shown in Table 4.4. Figures 4.10 and 4.11 show the weighting procedure used to calculate the composite crop COVER values for model segment number 100 (within the Juniata Basin) for the Conventional (CNT) and Conservation (CST) Tillage categories, respectively.

The monthly COVER values for CNT, CST, and Hay for all model segments are provided in Appendix E.11, and were estimated as follows:

a. Monthly COVER values for each of the four major crop categories and hay were estimated for Region 2 in conjunction with the Soil Conservation Service (J. Hannawald, 1990, Personal Communication).

b. Values for Region 1 and Region 3 were estimated by adjusting the expected planting dates <u>two weeks earlier</u> for Region 3 and <u>two weeks later</u> for Region 1, based on data from U.S.D.A. Handbook No. 628 (USDA,1984) and from State representatives on the CBP Nutrient Reduction Task Force (NRTF). The resulting monthly values were reviewed by the NRTF members.

c. The composite crop COVER values for CNT and CST were then calculated using the corresponding crop distributions for each tillage practice, as shown in Figures 4.10 and 4.11 for CNT and CST in model segment 100. The hay COVER values are used directly by the model since it is represented as a separate land use category. The final numbers were reviewed by the NRTF.

In reviewing the COVER values, please note the following:

1. As noted above, all COVER values are for the first day of each month, and values between months are linearly interpolated.

2. There are only slight differences between the CNT and CST values for Corn-Silage, primarily in March and April, since the stover is removed in both practices.

3. The values for Grains in June-September are 'dashed' because they are not included in the weighting, under the assumption that they will be followed by one of the other crops.

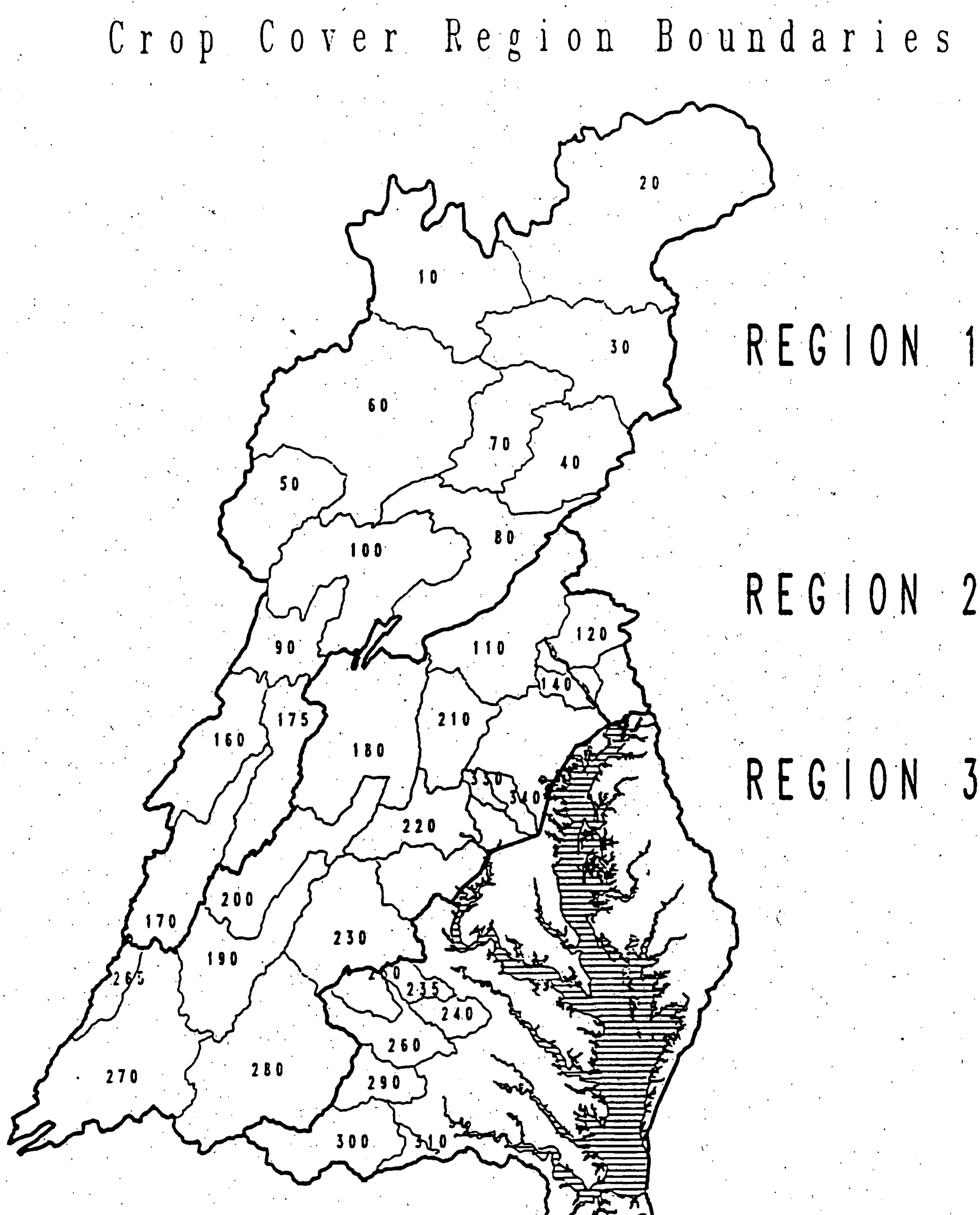


Figure 4.9 Crop COVER region boundaries.

TABLE 4.4 CROP COVER VALUES FOR ALL REGIONS AND PRACTICES

COVER VALUES FOR CONVENTIONAL TILLAGE

CORN GRAIN

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	50	45	0	0	5	45	70	88	93	80	55	55
REGION 2	50	45	0	0	10	50	75	93	93	85	70	55
REGION 3	50	45	0	5	45	70	88	93	93	90	85	55

CORN SILAGE

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	5	4	0	0	5	45	70	88	93	10	8	6
REGION 2	5	4	0	0	10	50	75	93	93	10	8	6
REGION 3	5	4	0	5	45	70	88	93	93	20	15	10

SOYBEAN

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	10	5	4	5	0	3	60	82	87	65	15	15
REGION 2	10	5	3	4	0	5	65	87	87	75	15	15
REGION 3	10	5	6	0	5	60	80	87	87	80	15	12

GRAINS

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	40	40	60	80	90	--	--	--	--	35	40	40
REGION 2	45	50	65	75	90	--	--	--	--	40	45	45
REGION 3	50	65	80	90	90	--	--	--	--	45	50	50

COVER VALUES FOR CONSERVATION TILLAGE

CORN GRAIN

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	65	60	55	50	50	60	70	88	93	85	75	70
REGION 2	65	60	55	50	55	65	75	93	93	90	80	70
REGION 3	65	60	55	50	60	70	88	93	93	93	85	70

CORN SILAGE

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	5	3	3	3	5	45	70	88	93	10	8	6
REGION 2	5	4	4	4	10	50	75	93	93	10	8	6
REGION 3	5	5	5	5	45	70	88	93	93	20	15	10

TABLE 4.4 CROP COVER VALUES FOR ALL REGIONS AND PRACTICES (continued)

SOYBEAN

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	10	9	8	8	8	15	60	87	87	60	20	15
REGION 2	15	12	10	10	10	20	65	87	87	75	25	20
REGION 3	20	15	10	10	15	60	87	87	87	80	30	25

GRAIN

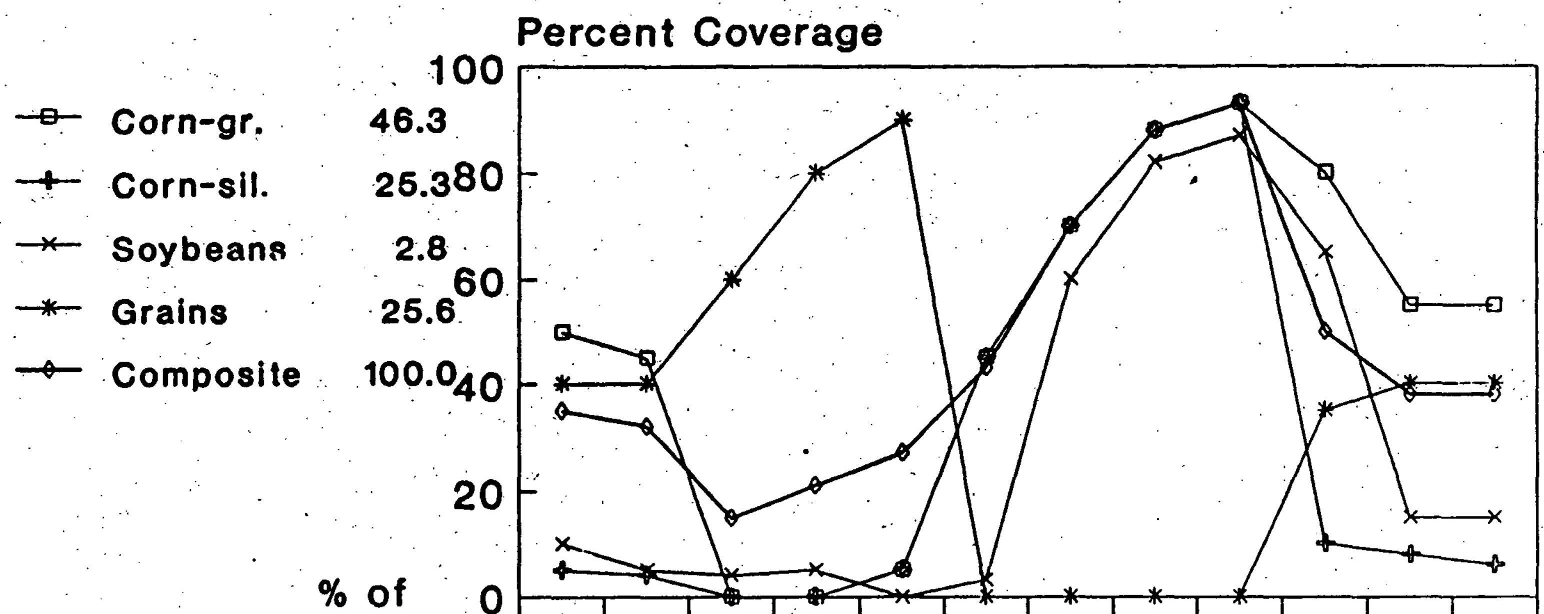
	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	50	55	60	75	90	--	--	--	--	45	50	50
REGION 2	55	60	70	80	90	--	--	--	--	50	55	55
REGION 3	60	65	80	90	90	--	--	--	--	55	60	60

COVER VALUES FOR HAY

HAY

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
REGION 1	85	85	88	65	65	93	93	93	88	85	85	85
REGION 2	85	85	88	93	93	93	65	65	73	85	85	85
REGION 3	85	85	88	93	93	93	65	65	73	85	85	85

Percent Coverage - Conventional Tillage
Juniata Segment 100

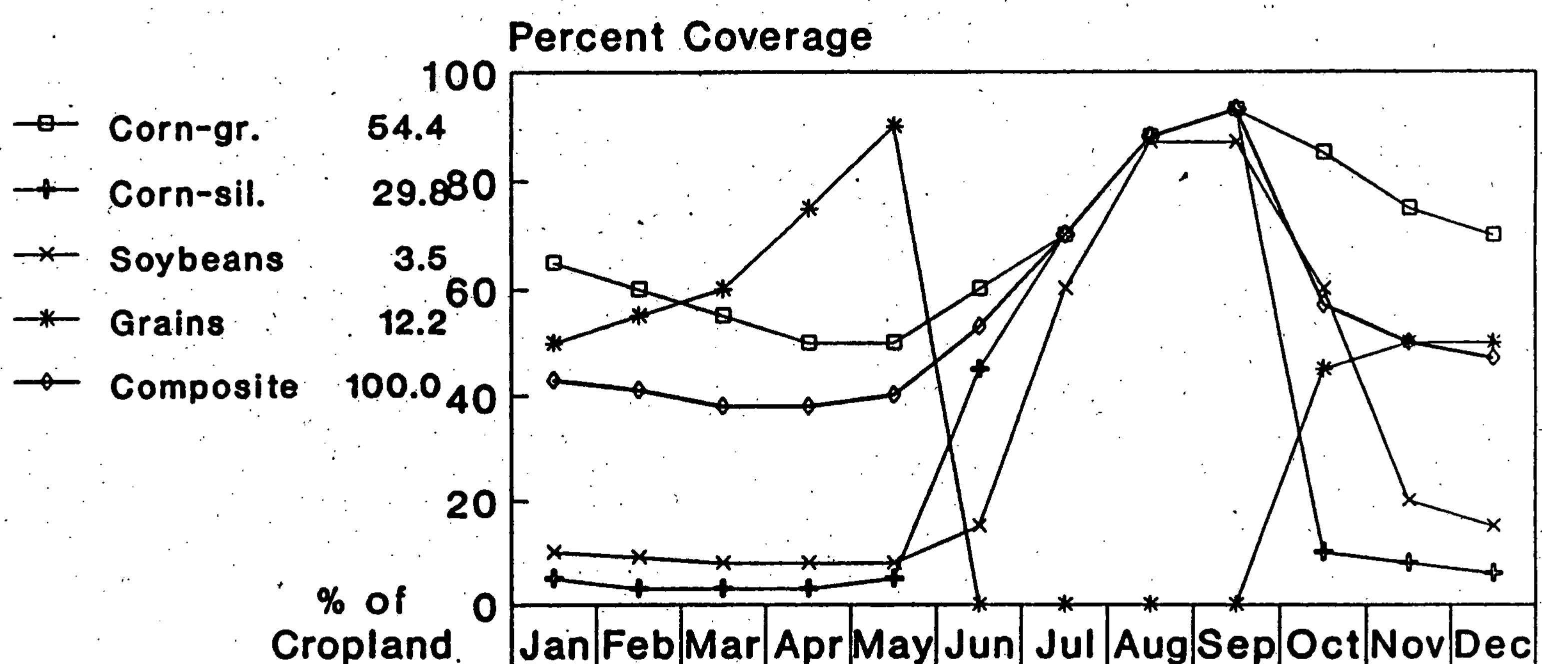


	% of Cropland	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Corn-gr.	46.3	50	45	0	0	5	45	70	88	93	80	55	55
Corn-sil.	25.3	5	4	0	0	5	45	70	88	93	10	8	6
Soybeans	2.8	10	5	4	5	0	3	60	82	87	65	15	15
Grains	25.6	40	40	60	80	90	0	0	0	0	35	40	40
Composite	100.0	35	32	15	21	27	43	70	88	93	50	38	38

Time (Months)

Figure 4.10 Composite crop COVER values for Segment 100 - Conventional Tillage.

Percent Coverage - Conservation Tillage
Juniata Segment 100



	% of Cropland	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Corn-gr.	54.4	65	60	55	50	50	60	70	88	93	85	75	70
Corn-sil.	29.8	5	3	3	3	5	45	70	88	93	10	8	6
Soybeans	3.5	10	9	8	8	8	15	60	87	87	60	20	15
Grains	12.2	50	55	60	75	90	0	0	0	0	45	50	50
Composite	100.0	43	41	38	38	40	53	70	88	93	57	50	47

Time (Months)

Figure 4.11 Composite crop COVER valu for Segment 100 - Conservation Tillage.

4. We've reduced the maximum values (e.g., 96 and 100) which are commonly used for some crops to account for borders, non-cropped areas, spatial variability (e.g., dry spots), etc.

5. Values on the scale of the size of the model segments will likely be somewhat different than those measured in a single field since we need to use average values that are adjusted for variations in practices, e.g., 20% fall plowing in CNT, or 75% of CST areas leave residues.

6. Differences of a few percentage points (i.e., 3 to 5) will have little or no significant impact on the simulation; the COVER values primarily affect the simulated sediment loading rates. Differences of 10 to 20 points for specific crops in specific months could have a significant impact if the changes also result in similar differences in the calculated Composite Crop COVER values.

4.3.4 Development of Model Segment Nutrient Application Rates

The 'key' element in the application of the AGCHEM model to the cropland areas of the model segments was the development of the nutrient (fertilizer and manure) application rates used as input to the model. This information was developed over a period of 6 months with continuous interaction and discussions among Aqua Terra staff, CBPO, and the NRTF members. The outcome of this effort was the specific values of fertilizer and manure nutrients, including composition and methods of application, that were used to model the expected nutrient balances for each cropland category. Moreover, this effort also demonstrated the relatively high degree of uncertainty in the information available in each state to categorize these rates. This is a critical issue since any efforts to reduce nutrient loadings from agricultural cropland must consider current application rates and procedures as a starting point. In other words, application rates are the means of implementing nutrient reduction from nonpoint source loadings from cropland. Thus, accurate information on <u>current</u> fertilizer and manure nutrient applications is essential to any management approach attempting to reduce nutrient loadings from agriculture.

Development of the model input application rates involved aggregating input from each of the major CBP states (i.e., PA, MD, VA), developing assumptions appropriate to the <u>scale</u> of the Bay drainage, and calculating rates corresponding to the 'composite crop' discussed in Section 4.3.3 (above). Figure 4.12 is a flowchart that demonstrates the information used and steps performed in calculating the model segment nutrient application rates. The items in 'boxes' are the input data and assumptions used, while the 'ovals' represent the calculations performed in developing the input rates. The major data needs and issues involved in these calculations included the following:

a. Fertilizer and manure application rates, procedures, and timing for each major crop, plus atmospheric deposition estimates.

b. Crop distributions for Conventional and Conservation Tillage.

c. Composition (i.e., organic and inorganic fractions) of fertilizer and manure nutrients.

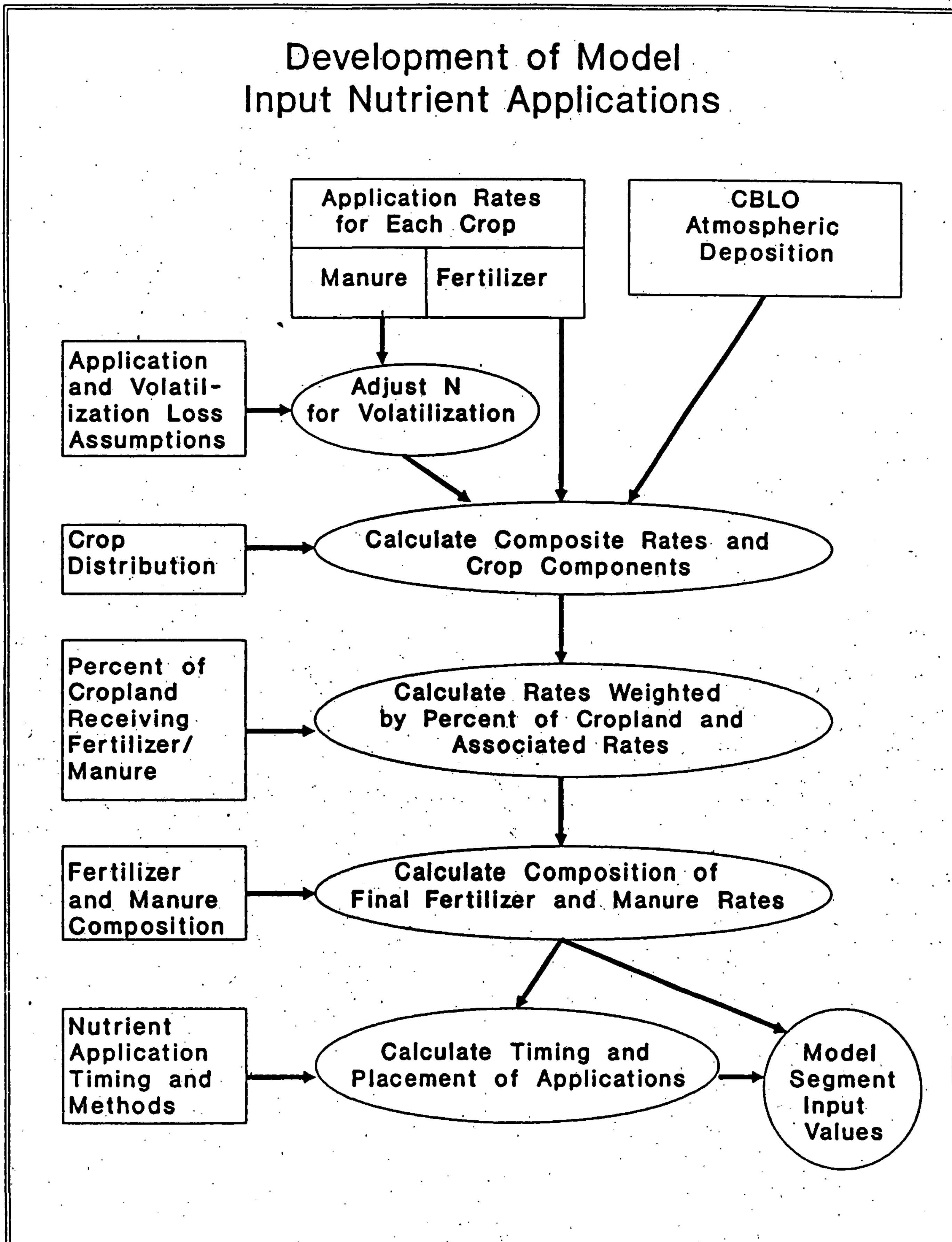


Figure 4.12 Flowchart for development of model input nutrient application rates.

d. Application/volatilization losses of manure nitrogen.

e. Model representation of application procedures and timing.

The following sections discuss each of these issues, except the crop distributions which were discussed in Section 3.1.10, followed by a description of the Lotus spreadsheet used to calculate the application rates and input values for each model segment. Appendix C provides copies of the spreadsheets for all model segments; the spreadsheets are also available on diskette from CBPO.

In reviewing the following sections, the reader should note that many of the problems and issues of applying AGCHEM (or any other detailed agricultural runoff model) at the scale of the model segments would not exist if the model was being applied at the field-scale. At the field level, farmers would be able to specify (or data could be obtained to define) fertilizer and manure compositions, timing and methods of applications, application rates for individual crops, etc. For model segments with croplands approaching hundreds of square miles, field and farm level practices must be adapted to define what is 'typical' or 'representative' of practices throughout the entire model segment. Much of the effort in developing the application rates and procedures involved the definition of representative conditions and practices, and resolution of conflicting information from individual agencies in order to prepare consistent and compatible model input for all portions of the Bay drainage.

4.3.4.1 State-supplied application rates

Table 4.5 lists the fertilizer application rates for each major crop category for each model segment which were developed by the state representatives on the NRTF. The corresponding manure application rates are shown in Table 4.6, while Table 4.7 shows the estimated percentages for each crop category receiving applications of fertilizer only, manure only, and both fertilizer and manure.

As noted above, this information was initially supplied by the states and subsequently refined in NRTF meetings and telephone/fax communications in order to clarify how the rates (and percentages) would be used and interpreted within the framework of the AGCHEM modeling calculations. In reviewing this information, please note the following:

a. All nitrogen (N) and phosphorus (P) rates are in terms of the elemental nutrients, i.e., N and P. P is calculated as 0.44 x P_2O_5.

b. Application rates are usually the same for corn-grain and corn-silage, with a few exceptions.

c. The rates for corn, soybeans, and grains were used to calculate the weighted rate for the composite crop, while the hay rate was used unchanged (except as discussed below for manure N volatilization) as input to the 'hay' cropland category.

TABLE 4.5 FERTILIZER APPLICATION RATES SUPPLIED BY THE NRTF (lb/ac)

MODEL	CORN		BEANS		GRAINS		HAY	
SEGMENT	N	P	N	P	N	P	N	P
10	120	24	34	8	34	8	60	29
20	120	24	34	8	34	8	60	29
30	120	24	34	8	34	8	60	29
40	120	24	34	8	34	8	60	29
50	120	26	34	8	34	8	60	26
60	120	26	34	8	34	8	60	26
70	120	26	34	8	34	8	60	26
80	90	37	34	8	34	8	15	35
90	95	59	34	8	34	8	0	16
100	95	59	34	8	34	8	0	16
110	120	44	20	18	34	18	20	26
120	120	44	20	18	34	18	20	26
140	120	44	20	18	34	18	20	26
160	140/31[a]	22/0[a]	20	26	100	0	0	79
170	150/105[b]	26/22[b] 35/26[d]	20/18[b]	29/22[b]	100/80[b]	35/26[b]	36/20[b]	30/16[b]
175	150/105[b]	26/22[b] 35/26[d]	20/18[b]	29/22[b]	100/80[b]	35/26[b]	36/20[b]	30/16[b]
180	142	30	25	19	76	2	7	63
190	150/105[b]	26/22[b] 35/26[d]	20/18[b]	29/22[b]	100/80[b]	35/26[b]	36/20[b]	30/16[b]
200	150/105[b]	26/22[b] 35/26[d]	20/18[b]	29/22[b]	100/80[b]	35/26[b]	36/20[b]	30/16
210	144	29	23	35	43	21	5	39
220	148	23	20	31	82	29	24	33
230	150	22	20	24	100	21	60	21
235	150/160[c]	22/35[c] 31/44[d]	20[c]	24/29[c]	100[c]	31/26[c]	36/30[c]	30/25[c]
240	160/150[c]	35/22[c] 44/31[d]	20[c]	29/24[c]	100[c]	26/31[c]	30	25
250	150	22 31[d]	20	24	100	31	36	30
260	150/160[c]	22/35[c] 31/44[d]	20[c]	24/29[c]	100[c]	31/26[c]	36/30[c]	30/25[c]
265	150	26 35[d]	20	29	100	35	36	30
270	150/105[b]	26/22[b] 35/26[d]	20/18[b]	29/22[b]	100/80[b]	35/26[b]	36/20[b]	30/16[b]
280	150[c]	22/26[c] 31/35[d]	20[c]	24/29[c]	100[c]	31/35[c]	30/36[c]	25/30[c]
290	150/160[c]	22/35[c] 31/44[d]	20[c]	24/29[c]	100[c]	31/26[c]	30/36[c]	25/30[c]
300	150	22	20	24	100	31	30	25
310	150	22	20	24	100	31	30	25
330	160/49[a]	18/0[a]	20	13	50	13	30	13
340	160/50[a]	18/0[a]	20	13	50	13	30	13

TABLE 4.5 FERTILIZER APPLICATION RATES SUPPLIED BY THE NRTF (lb/ac) (continued)

MODEL SEGMENT	CORN N	CORN P	BEANS N	BEANS P	GRAINS N	GRAINS P	HAY N	HAY P
Anacostia	143/25[a]	25/0[a]	20	44	45	26	0	40
Baltimore	160	18	20	13	50	13	30	13
Bohemia	120	18	20	18	80	18	20	26
Chester	130	16	20	35	60	18	30	26
Coast_1	130	16	20	35	60	18	30	26
Coast_4	160	35	20	29	100	26	30	25
Coast_5	160	18	20	13	50	13	30	13
Coast_6	180	42	0	26	30	26	0	31
Coast_8	160	35 44[d]	20	29	100	26	36	25
Coast_9	160	35 44[d]	20	29	100	26	30	25
Coast_11	158	43	7	23	26	23	7	27
Chicka.	160/150[c]	35/22[c] 44/31[d]	20[c]	29/24[c]	100[c]	26/31[c]	30/26[c]	25/30[c]
Choptank	130	16	20	35	60	18	30	26
Elizabeth	160	35 44[d]	20	29	100	26	30	25
Gr. Wicomico	160	35 44[d]	20	29	100	26	36	25
Gunpowder	160	18	20	13	50	13	30	13
James	160/150[c]	35/22[c] 44/31[d]	20[c]	29/24[c]	100[c]	26/31[c]	30	25
Nansemond	160	35 44[d]	20	29	100	26	30	25
Nanticoke	145	30	17	13	74	20	30	26
Patapsco	160/43[a]	18/0[a]	20	13	50	13	30	13
Patuxent	135/21[a]	35/6[a]	7	11	90	20	30	13
Pocomoke	145	30	17	13	74	20	30	26
Potomac	144	34	13	18	95	25	30	19
Occoquan	150	22 31[d]	20	24	100	31	36	30
Rappahannock	160	35 44[d]	20	29	100	26	36	25
Severn	160	18	20	13	50	13	30	13
Wicomico	145	30	17	13	74	20	30	26
Wye	130	16	20	35	60	18	30	26
York	160/150[a]	35/22[a] 44/31[d]	20[a]	29/24[a]	100[a]	26/31[a]	30/36[a]	25/30[a]

a - Two fertilizer rates used, manure applied with both fertilizer rates;
b - Two fertilizer rates used, manure applied with second fertilizer rate only;
c - Two fertilizer rates used, in cases where the second rate separated by a slash (/) is not shown means it is same as the first rate;
d - Phosphorus fertilizer application for corn-silage (Nitrogen application is same as Corn Grain)

TABLE 4.6 MANURE NUTRIENT APPLICATION RATES SUPPLIED BY THE NRTF (lb/ac)

MODEL	CORN		BEANS		GRAINS		HAY	
SEGMENT	N	P	N	P	N	P	N	P
10	100	18	140	25	140	25	0	0
20	100	18	140	25	140	25	0	0
30	100	18	140	25	140	25	0	0
40	100	18	140	25	140	25	0	0
50	180	32	140	25	140	25	0	0
60	180	32	140	25	140	25	0	0
70	180	32	140	25	140	25	0	0
80	180	32	140	25	140	25	0	0
90	150	26	140	25	140	25	150	26
100	150	26	140	25	140	25	150	26
110	180	32	180	32	180	32	180	32
120	180	32	180	32	180	32	180	32
140	180	32	180	32	180	32	180	32
160	109	27	0	0	109	27	109	27
170	265	60	265	60	265	60	50	16
175	265	60	265	60	265	60	50	16
180	107	23	121	25	121	25	71	16
190	265	60	265	60	265	60	50	16
200	265	60	265	60	265	60	50	16
210	104	22	113	24	113	24	81	18
220	37	9	37	9	37	9	37	9
230	0	0	0	0	0	0	0	0
235	0	0	0	0	0	0	0	0
240	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	0	0
260	0	0	0	0	0	0	0	0
265	0	0	0	0	0	0	0	0
270	265	60	265	60	265	60	50	16
280	0	0	0	0	0	0	0	0
290	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0
310	0	0	0	0	0	0	0	0
330	111	26	111	26	111	26	111	26
340	110	25	110	25	110	25	110	25

TABLE 4.6 MANURE NUTRIENT APPLICATION RATES SUPPLIED BY THE NRTF (lb/ac) (continued)

MODEL SEGMENT	CORN N	CORN P	BEANS N	BEANS P	GRAINS N	GRAINS P	HAY N	HAY P
Coast_1	173	36	173	36	173	36	30	26
Bohemia	109	23	109	23	109	23	20	26
Chester	155	38	155	38	155	38	155	38
Wye	170	37	170	37	170	37	170	37
Choptank	197	40	197	40	197	40	205	42
Nanticoke	245	51	236	50	244	52	252	53
Wicomico	241	51	246	52	238	51	253	54
Pocomoke	230	49	231	50	227	49	238	51
Coast_4	0	0	0	0	0	0	0	0
Coast_11	135	27	135	27	135	27	135	22
Coast_6	121	26	121	26	121	26	121	26
Gunpowder	109	25	109	25	109	25	109	25
Baltimore	124	27	124	27	124	27	124	27
Patapsco	117	28	117	28	117	28	117	28
Patuxent	114	29	114	29	114	29	114	29
Severn	126	23	126	23	110	25	126	23
Coast_5	110	27	110	27	110	27	110	27
Potomac	67	19	67	19	67	19	67	19
Anacostia	118	31	118	31	118	31	118	31
Occoquan	0	0	0	0	0	0	0	0
Rappahannock	0	0	0	0	0	0	0	0
Coast_8	0	0	0	0	0	0	0	0
Gr. Wicomico	0	0	0	0	0	0	0	0
York	0	0	0	0	0	0	0	0
James	0	0	0	0	0	0	0	0
Chicka.	0	0	0	0	0	0	0	0
Nansemond	0	0	0	0	0	0	0	0
Elizabeth	0	0	0	0	0	0	0	0
Coast_9	0	0	0	0	0	0	0	0

TABLE 4.7 PERCENTAGE OF CROPLAND RECEIVING FERTILIZER AND/OR MANURE AS SUPPLIED BY THE NRTF

CROP PERCENT (%)

MODEL	CORN			BEANS			GRAINS			HAY		
SEGMENT	F	M	F+M	F	M	F+M	F	M	F+M	F	M	F+M
10	70	10	20	70	10	20	80		20	50		
20	70	10	20	70	10	20	80		20	50		
30	70	10	20	70	10	20	80		20	50		
40	70	10	20	70	10	20	80		20	50		
50	70	10	20	70	10	20	80		20	50		
60	70	10	20	70	10	20	80		20	50		
70	70	10	20	70	10	20	80		20	50		
80	70	15	20	60	15	25	80		20	50		
90	70	15	20	65	15	20	80		20	50	30	
100	65	15	20	65	15	20	80		20	50	30	
110	45	25	30	45	25	30	80		20	50	30	
120	45	25	30	45	25	30	80		20	50	30	
140	45	25	30	45	25	30	80		20	50	30	
160	77		12	100			64	24	12	30	15	
			11[a]									
170	85		15	85		15	85		15	89		11[a]
175	85		15	85		15	85		15	89		11[a]
180	70		30	73		27	70		30	30	22	
190	49		51[a]	49		51[a]	49		51[a]	58		42[a]
200	51		49[a]	51		49[a]	51		49[a]	58		42[a]
210	68		32	76		24	64		36	30	24	
220	93		7	94		6	91		9	30	6	
230	100			100			100			100		
235	79			79			79			79		
	21[b]			21[b]				21[b]				21[b]
240	97			97			97			100		
	3[b]			3[b]				3[b]				
250	100			100			100			100		
260	93			93			93			91		
	7[b]			7[b]			7[b]			9[b]		
265	100			100			100			100		
270	91		3[a]	91		3[a]	91		3[a]	91		1[a]
	6[b]			6[b]			6[b]			8[b]		
280	98			98			98			44		
	2[b]			2[b]			2[b]			56[b]		
290	94			94			94			97		
	6[b]			6[b]			6[b]			3[b]		
300	100			100			100			100		
310	100			100			100			100		
330	65		30	70		30	60		30	30	30	
			5[a]						10[a]			
340	80		16	84		16	75		16	30	16	
			4[a]						9[a]			

TABLE 4.7 PERCENTAGE OF CROPLAND RECEIVING FERTILIZER AND/OR MANURE AS SUPPLIED BY THE NRTF (continued)

MODEL	CROP PERCENT (%)											
	CORN			BEANS			GRAINS			HAY		
SEGMENT	F	M	F+M	F	M	F+M	F	M	F+M	F	M	F+M
Anacostia	77		20	69	11	20	69	11	20	30	20	
			3[a]									
Baltimore	83		17	81	2	17	81	2	17	30	17	
Bohemia	96		4	95	1	4	95	1	4	30	4	
Chester	91	2	7	88	5	7	89		11[a]	30	7	
Chickahominy	73			73			73			73		
	27[b]			27[b]			27[b]			27[b]		
Choptank	84		16	80		20	84		16	30	14	
Coast_1	92	1	7	92	1	7	92	1	7	30	4	
Coast_4	100			100			100			100		
Coast_5	87		13	87		13	87		13	30	13	
Coast_6	97		3	96	1	3	96	1	3	30	3	
Coast_8	100			100			100			100		
Coast_9	100			100			100			100		
Coast_11	26	9	65	26	9	65	39		61	38	55	
Elizabeth	100			100			100			100		
Gr. Wico.	100			100			100			100		
Gunpowder	71	4	25	56	19	25	68	7	25	30	25	
James	73			73			73			100		
	27[b]			27[b]			27[b]					
Nanticoke	31		69	22		78	30		70	30	34	
Nansemond	100			100			100			100		
Occoquan	100			100			100			100		
Patapsco	82		16	77	7	16	82	16	4	30	16	
			2[a]									
Patuxent	91		8	92		8	90	2	8	30	16	
			1[a]									
Pocomoke	19		81	21		79	15		85	30	3	
Potomac	94		6	97		3	94		6	63	4	
Rappahannock	90			90			90			90		
	10[b]			10[b]			10[b]			10[b]		
Severn	65		35	65		35	75	9	16	30	35	
Wicomico	26		74	31		69	23	2	75	30	61	
Wye	85	2	13	86	1	13	77	10	13	30	14	
York	85			85			85			85		
	15[b]			15[b]			15[b]			15[b]		

TABLE 4.7 PERCENTAGE OF CROPLAND RECEIVING FERTILIZER AND/OR MANURE AS SUPPLIED BY THE NRTF (continued)

CROP PERCENT (%)

MODEL SEGMENT	CORN F	CORN M	CORN F+M	BEANS F	BEANS M	BEANS F+M	GRAINS F	GRAINS M	GRAINS F+M
SEGMENTS WHERE PERCENTAGES WERE DIFFERENT FOR CONSERVATION TILLAGE									
160	78		12	100			40	18	12
			10[a]						
175	83		17	83		17	83		17
180	66		34	73		27	60		40
210	70		30	76		24	52		48
220	93		7	94		6	89		11
330	65		30	70		30	50		30
			5[a]						20[a]
340	81		16	84		16	64		16
			3[a]						20[a]
Baltimore	83		17	80	3	17	82	1	17
Chester	91	2	7	90	3	7	85		15
Choptank	84		16	84		16	82		18
Gunpowder	72	3	25	63	12	25	61	14	25
Nanticoke	32		68	28		72	23		77
Patapsco	83		16	80	4	16	79	5	16
			1[a]						
Patuxent	92		8	92		8	88	4	8
Pocomoke	19		81	23		77	100		
Severn	65		35	65		35	65	20	16
Wicimico	5		95	32		68	2		98
Wye	86	1	13	86	1	13	80	7	13

a - Receives manure with the second fertilizer rate
b - Receives second fertilizer rate
F - Crop receives fertilizer only
M - Crop receives manure only
F+M - Crop receives both fertilizer and manure

d. The fertilizer application rates for corn are relatively consistent among the various states and model segments, whereas manure application rates and fertilizer rates for the other crops are much more variable, even between neighboring model segments and within model segments that cross state boundaries (see discussion below).

e. In Maryland and Virginia, different fertilizer rates were provided by the states when fertilizer was used alone, and when it was applied in addition to manure. The second (usually smaller) number shown in Table 4.5 is the rate used when manure was also applied.

The basic information available to the state representatives on which to base these application rates varied in detail from state to state. In general, the rates for fertilizers, especially for corn, are probably more reliable than the manure rates. Much of the information was extracted from county-level SCS or Extension Service data, supplemented by 'best estimates' when information was not available. In many cases, estimates were used when a particular crop represented a minor fraction of the cropland in a specific model segment, e.g., rates for soybeans in the Upper Susquehanna were often estimated due to lack of data, but they often represented less than 5% of the cropland.

The rates were then adapted to model segments prior to being transmitted to Aqua Terra and CBPO; the only exception was for Virginia which provided rates for subregions within the state which were then transformed into the model segment values shown in the tables.

For model segments that crossed state boundaries, a weighing procedure was used to estimate application rates when the appropriate information was available from the adjoining states and the areas were significant (e.g., more than 10% of the model segment). Table 4.8 shows the estimated percentages of the multi-state model segments in the various states. The weighting was performed for each crop application rate prior to calculating the model segment composite rate for the composite crop. The percentages of croplands receiving fertilizer, manure, and both were usually consistent and values for one state were adopted.

Although Delaware, New York, and West Virginia include portions of the Chesapeake Bay drainage area, they are not active members of the Chesapeake Bay Program. Consequently, information was not available for nutrient applications in these states and the rates had to be estimated from the rates in the other CBP member states.

The specific approach and relevant issues in individual model segments were as follows:

<u>Segments 10 and 20:</u> PA rates were used since application rate information for NY was not available. Although 67% and 91% of the area of these two segments respectively reside in NY, the cropland (CNT, CST, Hay) comprises 20% and 18%, respectively, of the model segments.

TABLE 4.8 ESTIMATED PERCENTAGES OF MULTI-STATE SEGMENTS IN VARIOUS STATES

MODEL SEGMENTS	NY	PA	DE	MD	VA	WV
10	67.0%	33.0%				
20	91.0%	9.0%				
160		19.0%		36.0%		45.0%
170					7.0%	93.0%
175		13.0%		19.0%	1.0%	67.0%
180		36.0%		23.0%	19.0%	22.0%
200					92.0%	8.0%
210		23.0%		77.0%		
220				33.0%	67.0%	
Bohemia			20.0%	80.0%		
Chester			10.0%	90.0%		
Choptank			17.0%	83.0%		
Coastal 1			2.0%	98.0%		
Coastal 11		37.0%		63.0%		
Gunpowder		2.0%		98.0%		
Nanticoke			63.0%	37.0%		
Pocomoke			6.0%	89.0%	5.0%	
Pocomoke				95.0%	5.0%	
Potomac				53.0%	47.0%	
Wicomico			1.0%	99.0%		

Segment 160: MD rates were used for the entire segment because no information was available for WV, MD comprised the next largest portion, and MD provided detailed information on % of cropland receiving fertilizer, manure, and both. The overall impact should be small since only 3.3% of the segment is in Cropland and 6.7% is in Hay.

Segments 170 and 175: Rates from the neighboring segments in VA, Shenandoah Segments 190 and 200, were used with some adjustment of the '% receiving manure', because it was felt that the nature of agriculture in these segments would be more similar to that in VA than in the other states. Based on animal populations reported by Lugbill (1990), the percentages of cropland receiving manure were reduced to 30% of the values in Segment 200. The overall impact of these assumptions should be small since only 1.0% of Segment 170 and 3.0% of Segment 175 are in Cropland, while 4.0% and 5.0%, respectively, are in Hay.

Segment 200: VA rates were used for the entire segment since only 8% is in WV where no data was available.

Segments 180, 210, and 220: The rates for these segments were weighted between two states: PA and MD for Segments 180 and 210, VA and MD for Segment 220. The segment rates were calculated from the percentages for each state shown in Table 4.8. MD information on '% receiving fertilizer only, and both fertilizer and manure', was used for all three segments since values were provided for every model segment, and the values were reasonably consistent with the information from PA and VA.

Coastal 11 and Potomac (BFL): Weighting of PA and MD rates for Coastal 11, and VA and MD rates for the Potomac BFL segment, was performed. MD information on percentages receiving fertilizer and/or manure was used.

Remaining BFL Segments: For the remaining multi-state BFL model segments shown in Table 4.8, MD data was used since the majority of the model segment area was contained in MD and no information was available for the portions in DE.

Although the assumptions described above are reasonable, and were necessary to complete the AGCHEM modeling within the project schedule, any future efforts should include an attempt to verify the application rates and percentages used especially for areas in the non-member states of NY, WV, and DE.

4.3.4.2 Atmospheric deposition

At the request of the NRTF, atmospheric deposition of nitrogen was included in the nutrient balance of the cropland areas simulated by AGCHEM by adding in deposition estimates as part of the nutrient input to the land surface. The Phase I Watershed Model included atmospheric deposition directly on water surfaces as input to the stream channel simulation in each model segment. In Phase II, these deposition values for nitrogen were also added to the nutrient input to the cropland areas. Although the HSPF code does not currently contain a capability for daily wet or dry deposition values, the estimated annual nitrogen deposition for each model segment was included as an addition to the fertilizer/manure applications so that it could be considered in the annual nutrient balance. Table 4.9 shows the model segment values for 1982-87 along with the annual average; the annual average value for each segment (rounded to whole numbers) was included in calculating the total nutrient applications to the cropland areas (see Section 4.3.4.6 below). The development of the atmospheric deposition values was described earlier in Section 3.4; the same values are used for the cropland areas and the deposition onto water surfaces in each model segment.

4.3.4.3 Composition of nutrient inputs

All nutrients that are input to the AGCHEM model must be in one of the specific nutrient forms simulated. As discussed in Section 4.3.1, the nutrient forms simulated by AGCHEM include NO_3, NH_4 (adsorbed and dissolved), Organic N, PO_4 (adsorbed and dissolved), and Organic P. Thus, all fertilizer, manure, and atmospheric deposition inputs are defined as one or more of these five nutrient forms. Figure 4.13 shows the assumed forms of each of these three nutrient sources.

For fertilizers, information provided by the NRTF indicated that the primary forms of nitrogen fertilizers are applied as urea, ammonium nitrate, and so-called 'nitrogen solutions' which are typically referred to as UAN (urea ammonium nitrate) solutions (Tisdale et al., 1985). For all three primary CBP states, UAN solutions dominate the nitrogen fertilizer use. Similarly, phosphorus fertilizers are almost exclusively applied in some form of phosphate material, either alone or in a combination with other nutrients such as ammonium or potash.

Based on the above information, all phosphorus fertilizer inputs were assumed to be in the phosphate (PO_4) form. For nitrogen, we assumed a typical <u>30% nitrogen UAN solution</u> as defined by Tisdale et al. (1985), which contains a 50%/25%/25% distribution of nitrogen as urea/ammonium/nitrate, respectively. Since 'urea' is not a nutrient form simulated by AGCHEM, all the urea nitrogen was input to the model in the ammonium (NH_4) form. Consequently, all fertilizer was input as 75% NH_4, and 25% NO_3. Tisdale et al. (1985) discuss the soil reactions (i.e., hydrolysis and biomediated decomposition) that breakdown urea in the soil to ammonia; they note that the reactions occur rapidly, continue to occur at significant rates even at temperatures of 2° C and lower, and often completely transform urea to ammonia within a few days in warm moist soils. Thus, inputting all urea as ammonia appears to be a reasonable approximation.

For atmospheric deposition, the loading estimates developed by CBPO indicated that about 80% of the nitrogen was in the nitrate form, with the remaining 20% as ammonia. Due to the relatively rapid nitrification that occurs in surface soils, all the deposition was input as nitrate in the model. Phosphorus loadings in atmospheric deposition were assumed to be insignificant.

For manure nutrients, nutrient composition is much more variable, being a function of animal type, diet, storage/handling, season, etc. The primary issue in terms of modeling is the distribution between the organic and inorganic nutrient components because the inorganic fraction is partitioned between the adsorbed and dissolved forms, while the organic fraction is assumed (in the AGCHEM model) to be entirely bound to soil particles and sediment. Also, for

TABLE 4.9 ANNUAL NITROGEN ATMOSPHERIC DEPOSITION LOADS

MODEL SEGMENT	1982	1983	1984	1985	1986	1987	Average Total N
10	8.95	8.75	10.23	9.15	8.70	9.38	9.19
20	8.10	8.77	9.87	8.91	9.65	9.12	9.07
30	8.51	8.50	9.39	8.77	9.38	8.58	8.86
40	8.80	8.81	9.56	9.01	9.22	10.22	9.27
50	10.92	9.89	11.72	10.15	11.51	11.79	11.00
60	11.39	9.82	11.78	10.22	11.65	11.86	11.12
70	9.21	8.87	10.23	9.35	9.83	9.69	9.53
80	9.78	8.67	10.10	8.87	9.15	8.75	9.22
90	10.27	9.52	10.94	9.92	10.06	11.07	10.30
100	10.72	9.55	11.17	9.75	10.70	10.91	10.47
110	9.57	8.34	9.15	8.40	8.81	8.21	8.75
120	8.30	8.10	8.78	7.96	8.10	7.77	8.17
140	8.61	7.87	8.75	7.93	8.07	7.74	8.16
160	9.66	9.45	10.34	9.52	10.87	9.52	9.89
170	10.80	8.55	9.43	8.94	10.43	8.21	9.39
175	10.13	8.98	10.00	9.51	11.67	9.59	9.98
180	9.97	8.61	9.29	8.87	9.76	8.68	9.20
190	9.72	8.28	8.55	8.21	9.02	7.73	8.58
200	9.19	8.38	9.26	8.91	10.19	8.58	9.08
210	9.53	8.11	8.92	8.44	8.78	8.17	8.66
220	9.33	8.11	8.92	8.44	8.78	8.17	8.62
230	8.96	7.94	8.75	8.14	8.21	7.67	8.28
235	8.38	7.50	8.38	7.63	7.70	7.50	7.85
240	8.35	7.47	8.28	7.60	7.47	7.40	7.76
250	8.59	7.50	8.38	7.70	7.84	7.50	7.92
260	8.32	7.43	8.24	7.56	7.43	7.36	7.73
265	9.90	7.71	8.52	8.04	8.72	7.43	8.39
270	8.85	7.34	7.88	7.33	7.47	7.06	7.66
280	8.03	7.13	7.88	7.20	7.34	6.59	7.36
290	7.88	7.07	7.81	7.13	7.20	6.39	7.24
300	7.45	6.63	7.17	6.62	6.76	5.95	6.76
310	7.24	6.56	7.10	6.62	6.62	5.95	6.68
330	8.91	8.17	8.85	8.23	8.24	7.77	8.36
340	8.91	8.17	8.85	8.23	8.24	7.77	8.36
ANACOSTIA	8.58	7.83	8.72	7.83	7.83	7.56	8.06
BALT_HARBOR	8.58	7.83	8.72	7.83	7.77	7.63	8.06
BOHEMIA	8.58	7.70	8.72	7.83	7.77	7.63	8.04
CHESTER	8.48	7.66	8.41	7.73	7.46	7.26	7.83
CHICKAHOMINY	8.31	7.57	7.77	7.63	7.23	6.35	7.48
CHOTANK	8.44	7.56	8.11	7.62	7.36	7.23	7.72
COASTAL_1	8.48	7.60	8.01	7.66	7.66	7.53	7.82
COASTAL_11	8.58	7.77	8.72	7.83	7.77	7.70	8.06
COASTAL_4	7.97	7.02	7.44	6.88	6.95	6.42	7.12
COASTAL_5	8.38	7.63	8.04	7.36	7.29	6.96	7.61

TABLE 4.9 (continued)

MODEL SEGMENT	1982	1983	1984	1985	1986	1987	Average Total N
COASTAL_6	8.51	7.77	8.38	7.76	7.70	7.37	7.91
COASTAL_8	8.34	7.40	7.81	7.12	7.19	7.26	7.52
COASTAL_9	7.13	6.93	7.13	6.25	6.38	5.98	6.63
ELIZABETH	7.60	6.99	7.20	6.31	6.58	6.05	6.79
GREAT_WICOMICO	8.28	7.53	7.81	7.05	7.12	6.59	7.40
GUNPOWDER	8.54	7.80	8.28	7.79	7.86	7.60	7.98
JAMES	7.67	7.13	7.27	6.65	6.92	6.12	6.96
NANSEMOND	7.60	6.99	7.20	6.31	6.58	6.05	6.79
NANTICOKE	8.38	7.49	7.84	7.36	7.43	6.96	7.58
OCCOQUAN	8.54	7.80	8.08	7.93	7.86	7.74	7.99
PATAPSCO	8.54	7.80	8.28	7.79	7.86	7.74	8.00
PATUXENT	8.38	7.63	7.84	7.36	7.29	7.09	7.60
POCOMOKE	8.28	7.39	7.74	6.99	7.12	6.52	7.34
POTOMAC	8.41	7.67	7.94	7.39	7.46	7.13	7.67
RAPPAHANNOCK	8.31	7.30	7.77	7.36	7.16	6.82	7.45
SEVERN	8.51	7.77	8.25	7.69	7.70	7.57	7.91
WICOMICO	8.31	7.43	7.77	7.09	7.23	6.82	7.44
WYE	8.38	7.36	7.84	7.56	7.29	7.16	7.60
YORK	7.94	7.20	7.34	6.99	7.06	6.18	7.12

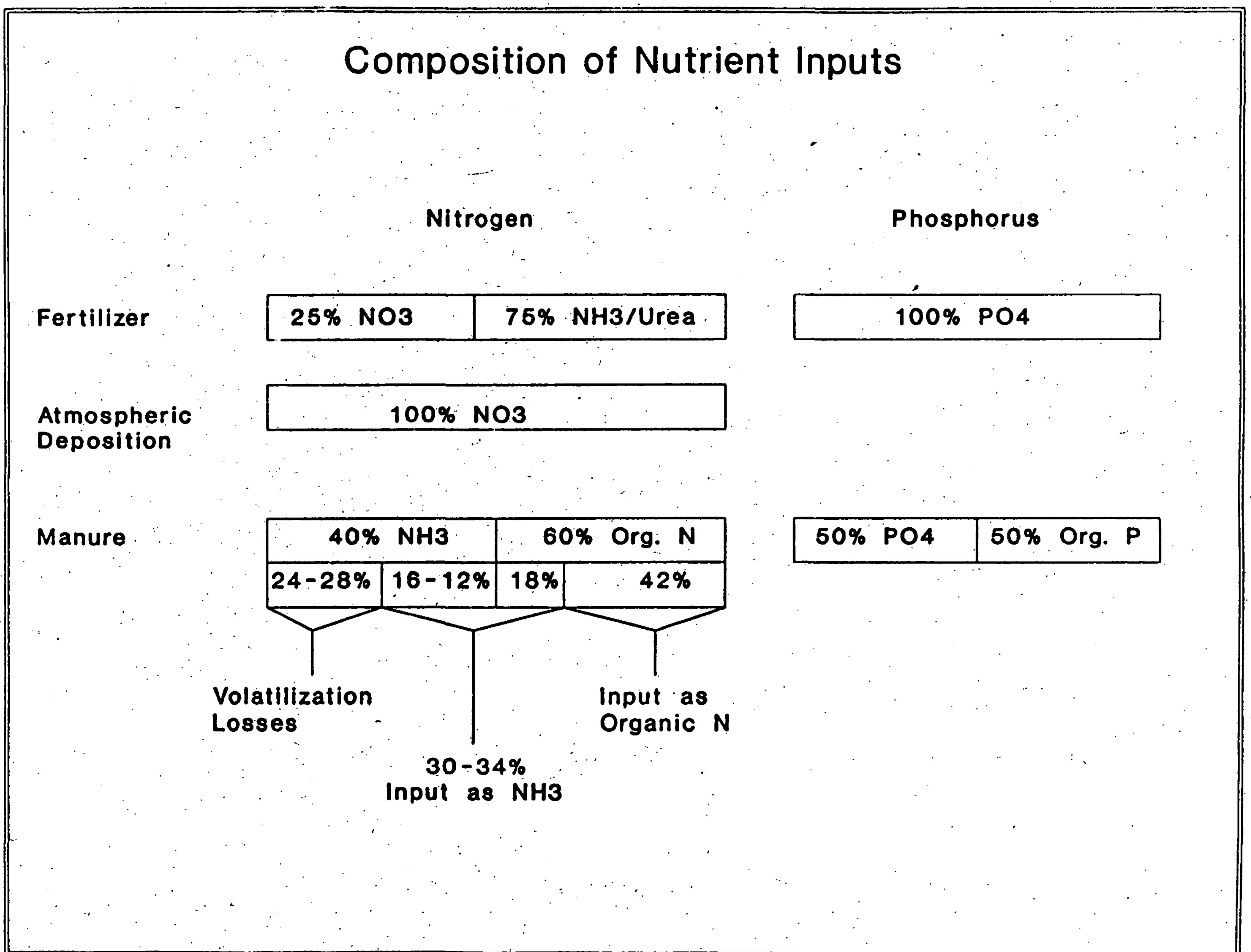


Figure 4.13 Composition of nutrient inputs to AGCHEM model.

nitrogen, volatile losses for the inorganic component (primarily NH_3) can be a significant fraction of the total manure nitrogen application.

A variety of articles and reports were reviewed in order to estimate a reasonable value of percent inorganic nitrogen for manure applications to cropland. The following table summarizes the range and mean of values found in the literature, along with the literature source and the manure type:

Percent Inorganic N	Manure Type	Reference
6 to 59 % Mean: 26%	Beef	Reddy et al., 1979
24 to 62 % Mean: 33%	Dairy	"
15 to 75 % Mean: 38%	Swine	"
39 %	Dairy	Loehr, 1984
45 %	Dairy	VA DSWC (Flagg, 1990 personal communication)
37 %	Dairy, liquid	PA DER Manual by R.E. Wright (1990)
55 %	Swine, liquid	"
30 to 48 % Mean: 39 %	Dairy, Liquid	Fox and Piekielek, 1990

Although a number of the references are general in nature, the information from the VA Department of Soil and Water Conservation, the PA Department of Environmental Resources, and the work of Fox and Piekielek (1990) are all specific to the Chesapeake Bay region. Based on this review and with primary emphasis on beef and dairy wastes, a value of 40% inorganic N was assumed for all nitrogen applied as manure. This assumption then provided the basis for subsequent calculations of volatile ammonia losses from manure applications, as discussed below in Section 4.3.4.4.

The remaining 60% organic N fraction in manure is comprised of both unstable and stable organic compounds, with the unstable portion derived from urea-type materials. Consequently, the unstable organic nitrogen will become available as inorganic species (primarily NH_4) through mineralization processes much more quickly than the stable fraction. Based on information from Banvel (1990), the Maryland Department of Agriculture (F. Samadani, 1990, personal communication, and the Virginia Department of Soil and Water Conservation (M. Flagg, 1990, personal communication), about 30% to 50% of the organic N can become available to the crop as inorganic N during the first year; 30% to 40% can become available relatively quickly within 3 to 4 weeks. The remaining portion of the organic N is either non-mineralizable or slowly mineralizes over subsequent years; about 20% of the organic N is in this latter category based on the sources noted above. Since AGCHEM includes only one mineralization rate for organic N, we assumed that 30% of the organic N is quickly converted to NH_4 for input to the model with the remaining fraction added to the soil organic N storage. In Figure 4.13, this 30% is shown as the 18% of Total N (i.e., 30% x 60% Organic N = 18% NH_4) added to the non-volatilized ammonia.

For the phosphorus composition in manure, very little useful information was found due largely to the complex chemistry and associated analytical problems in measuring the various organic and inorganic forms of P. Sommers and Sutton (1980) provide a brief overview of some of these problems, indicating that most of the P in animal wastes is part of relatively insoluble compounds and that much of the organic P is not well defined and of unknown chemical structure. They cite work by Townshend et al. (1969) where swine, beef cattle, and dairy cattle wastes were found to have soluble P (expressed as a percentage of Total P) values of 43 %, 54 %, and 46 %, respectively. Based on this limited data, we assumed a 50/50 split between the inorganic and organic P fractions of manure P input to the model, as shown in Figure 4.13. Clearly, this split is not quite as critical as the corresponding one for N, since PO_4 does not undergo volatilization losses during and following application to the land.

4.3.4.4 Application/volatilization losses of manure nitrogen

Since AGCHEM does not account for volatilization losses of nitrogen, these losses associated with manure application were estimated and the application rates were reduced accordingly to subtract the volatilized fraction. Ammonia volatilization from manure applications is highly variable, and depends on animal waste type and characteristics, meteorologic conditions (e.g., wind, air temperature), application procedures, etc. Since the inorganic (primarily ammonia) fraction is the volatile component, various literature sources were reviewed in order to estimate the fraction of the inorganic component that would likely be lost by volatilization. The following summarizes the results obtained from this review:

Percent NH3 Loss	Reference
4 to 96 % loss, dairy, surface applied (mostly in 60 to 80% range)	Reddy et al.,1979
39 % (incorporated within 24 hrs)	Stevens and Logan, 1987
over 50 % (incorporated within 24 hrs)	Thompson et al., 1987
over 50 % (from surface within 24 hrs)	Lauer et al., 1976
over 50 % (loss within 24-48 hrs, incorp.)	Fox and Piekielek, 1990

Casman (1989) reviewed a number of literature sources on animal waste volatilization losses associated with collection, storage and handling, and application, and found that application losses were generally in the range of 10 to 60 % of Total N. In a spreadsheet for calculating animal waste application for croplands in Maryland, Banvel (1990) provides the user with options ranging from 20% loss of NH_3 for incorporation within 1 day, to 80% loss for incorporation within 5 days. He also allows an option for 100% loss (by both volatilization and leaching) if the manure is not incorporated at all, or later than 5 days.

Information on manure application procedures were provided by the state members of the NRTF. In VA manure is either incorporated after 7 days or not at all. In PA, the practice is to incorporate within 2 days about 40% of the time, and after 2 days about 60% of the time. Practices in MD typically fell between these two extremes: incorporation within 2 to 5 days. In discussions with the NRTF, and considering the literature information cited above, the following 'percent ammonia losses' were assumed for each state:

Pennsylvania	60 % loss
Maryland	65 % loss
Virginia	70 % loss

These percent losses were applied to the manure application rates specified by each state as shown in Table 4.6; the state-supplied rates represented the amounts applied to the land surface, accounting for any collection, handling, and storage losses, so that application and volatilization losses were the only additional mechanisms to be considered.

4.3.4.5 Nutrient application methods and timing

Once fertilizer and manure application amounts were estimated, application practices and procedures were studied in order to define the appropriate timing and placement of the nutrient applications for input to the AGCHEM model for each model segment. 'Timing' refers to the period during the year when nutrients are applied for each major crop, and 'placement' refers to how the nutrients are applied, usually either surface application or soil-incorporated. The USDA Handbook No. 628 (USDA, 1984) provided information on usual planting dates for the major crops; information from the NRTF, and subsequent discussions with state representatives, helped to further refine typical application practices. Table 4.10 summarizes the <u>protocols</u> used to distribute the estimated nutrient application amounts, in both time and space, for both fertilizer and manure applications to each major crop, along with assumptions on the atmospheric deposition component.

For fertilizer applications, both surface application and soil incorporation were considered typical procedures depending on whether the application is at, or prior to, planting or during the growing season as a side-dressing. For surface applications, the application amount was added, in the model, to the <u>1 cm</u> surface zone. For soil incorporation, different assumptions were used for Conventional Tillage (CNT) versus Conservation Tillage (CST). For CNT, we assumed that 10% of the application would remain in the surface zone, and 90% would be added to the <u>14 cm</u> upper zone; this is based on the assumption that incorporation would produce a <u>uniform distribution</u> of the chemical in the top 10 to 15 cm of the soil. For CST, we assumed 15% would remain in the surface, and 85% would be in the upper zone, derived from assuming a <u>linear distribution</u> of chemical from the surface to zero at the depth of incorporation of 10 to 15 cm. These assumptions were based on reviews of literature to evaluate the impacts of BMPs on model parameters (Donigian, et al., 1983).

For manure applications, we assumed a 50/50 split between the surface and upper zones for all nutrient components of the animal waste. Although manure applications are typically surface-applied, some incorporation does occur. Also, the small depth of the 1 cm surface zone relative to the large mass of manure applied (typically 10-15 tons/ac) would lead to some natural mixing of manure with native soil below the 1 cm depth, which the model represents as the upper zone. Since the AGCHEM model assumes all organic N and P is sediment bound, any organics applied to the surface remain in the surface except for losses by mineralization and attached to eroded sediment. For these reasons, the 50/50 split was needed to more closely represent manure nutrient applications within the model framework.

For the Hay segment, we also assumed a 50/50 split for fertilizer applications because re-seeding would likely involve soil incorporation of applied fertilizer but this would occur only once every two to three years. In the other years, the fertilizer would be surface applied. Since some fraction of the farmers would be re-seeding hay fields every year, we assumed the 50/50 split would be a reasonable compromise for the complex combinations of practices that would occur each year.

Based on discussions with the NRTF, the frequency of manure applications can vary from daily spreading in winter, to weekly or monthly applications for hay, to one or two spring or fall applications for field crops. Unfortunately, the current procedures for specifying nutrient applications in AGCHEM are too cumbersome to allow daily or weekly applications at the scale of this modeling effort; each application must be defined explicitly for each model segment and each year of the simulation, and each specific state variable impacted by the application. Consequently, the minimum frequency used in the model is monthly applications for the hay segment and bi-monthly (i.e., every two months) for the other crops, during the typical application period appropriate for each crop.

In general, the application protocols described in Table 4.10 produced a reasonable representation of nutrient application procedures throughout the Bay drainage. Some compromises between practices in different states were needed in order to maintain consistency in the model representation. Any future studies with the Watershed Model by the CBPO and/or individual states should consider refining the assumptions and practices as needed to better represent local and regional conditions.

4.3.4.6 Calculation of model input values

Calculation of the final model input nutrient application amounts was performed with a Lotus spreadsheet for each model segment, following the flowchart shown in Figure 4.12 and the assumptions discussed in the above sections. Tables 4.11 and 4.12 show portions of the spreadsheet for Model Segment 100 (Juniata model segment) to demonstrate the format of the spreadsheet and the steps in the final calculations.

Table 4.11 shows the calculations of the annual application amounts for the CNT category within Model Segment 100; separate portions of the spreadsheet are used to calculate the rates for CST and Hay. These portions are not shown, but they follow the same steps as in Table 4.11 except that the calculations for Hay are simpler since no compositing is involved.

Table 4.10 MODEL PROCEDURES FOR TIMING AND PLACEMENT OF FERTILIZER/MANURE APPLICATIONS AND ATMOSPHERIC DEPOSITION

CORN:

Fertilizer- 50% N and 100% P applied at planting and incorporated
50% N sidedressed 5-6 weeks after planting

Manure - Bimonthly (i.e., every 2 months) applications, November through April, with a 50/50 split between Surface and Upper Zone

SOYBEANS:

Fertilizer- 100% of N and P applied at planting, incorporated, about 3-4 weeks after corn planting dates

Manure- Bimonthly (i.e., every 2 months) applications November through April, same as corn; if amounts are small, use double applications in November and April (for Fall and Spring). Split 50/50 between surface and upper zone.

NOTE: If total application amount is small, less than 5 pounds/ac, add to the corn application, i.e., don't put in as separate applications.

GRAINS:

Fertilizer- 100% P and 20% N application in Fall (September), incorporated, and 80 % N application top-dressed in Spring (March)

Manure- Bimonthly summer applications, June through September, 50/50 split incorporation in Surface and Upper Zone

HAY:

Fertilizer- Use 40/30/30 split applications between August, mid-March, and June to account for different seeding times (August and March, incorporated 50/50 split between Surface and Upper zones) and single top-dressing in June.

Manure- Monthly application April through October, with 50/50 split between surface and upper zone.

ATMOSPHERIC DEPOSITION:

Apply all deposition amounts as NO_3 (since NH_3 will be nitrified quickly) and add to the fertilizer component, but only to the SURFACE zone.

TABLE 4.11 EXAMPLE CALCULATION OF FINAL NUTRIENT APPLICATION RATES

CALCULATION OF NUTRIENT APPLICATION RATES - SEGMENT 100 — Model Segment Number
Date: 03/08/91
State-Supplied Fertilizer and Manure Appl. Rates and CBLO ATM. Depos.

				State Nutrient Application Rates						
		CNT	CST	Fertilizer # 1		Manure		ATM. DEP	Fertilizer # 2	
		CROP %	CROP %	N	P	N	P	N	N	P
Crop Distribution, State-Supplied Application RAtes, and Atmos. Dep.	Corn	46.3%	54.4%	95	59	150	26	10	0	0
	Corn-sil	25.3%	29.9%	95	59	150	26	10	0	0
	Soybeans	2.8%	3.5%	34	8	140	25	10	0	0
	Grains	25.6%	12.2%	34	8	140	25	10	0	0
	Totals	100.0%	100.0%							

Cropland Category — Conventional Tillage

		Fertilizer		Manure (less NH3 vol. losses)		ATM. DEP	TN	TP
		N	P	N	P	N		
Initial Composite Based on Crop Distribution	Composite	77.7	44.5	111.8	25.7	10.0	199.5	70.2
	Corn	68.0	42.2	81.6	18.6	7.2	156.8	60.9
	Soybeans	1.0	0.2	3.0	0.7	0.3	4.2	0.9
	Grains	8.7	2.0	27.2	6.4	2.6	38.5	8.4

	Area Weighted Application Rates - CNT		Corn	Beans	Grains
State-Supplied Fractons for Application Rates	Fraction of area receiving fertilizer # 1 and manure		0.20	0.20	0.20
	Fraction of area receiving fertilizer # 1		0.65	0.65	0.80
	Fraction of area receiving fertilizer # 2 and manure		0.15	0.15	0.00
	Fraction of area receiving fertilizer # 2		0.00	0.00	0.00
NH_3 Volatilization and Nutrient Composition Assumptions	Fraction of manure available as NH3	0.34			
	Fraction of manure available as ORGN	0.42			
	Fraction of manure available as PO4	0.50			
	Fraction of manure available as ORGP	0.50			
	Fraction of fertilizer available as NH3	0.75			
	Fraction of fertilizer available as NO3	0.25			

		Fertilizer		Manure		ATM. DEP	TN	TP
		N	P	N	P	N		
FINAL Composite Rates and Crop Components	Composite	67.3	38.1	35.1	8.0	10.0	112.4	46.2
	Corn	57.8	35.9	28.6	6.5	7.2	93.5	42.4
	Soybeans	0.8	0.2	1.0	0.2	0.3	2.1	0.4
	Grains	8.7	2.0	5.4	1.3	2.6	16.7	3.3

FINAL SEGMENT RATES

Fertilizer and Manure Composition of TN and TP

		Fertilizer + ATMOS. Dep.				Manure					
				ATM.							
		NH3	NO3	NO3	PO4	NH3	ORGN	PO4	ORGP	TN	TP
Composition of Final Segment Application Rates	Composite	50.5	16.8	10.0	38.1	15.5	19.1	4.0	4.0	112.4	46.2
	Corn	43.4	14.5	7.2	35.9	12.8	15.8	3.3	3.3	93.5	42.4
	Soybeans	0.6	0.2	0.3	0.2	0.5	0.6	0.1	0.1	2.1	0.4
	Grains	6.5	2.2	2.6	2.0	2.4	3.0	0.6	0.6	16.7	3.3

TABLE 4.12 EXAMPLE CALCULATION OF TIMING AND PLACEMENT OF NUTRIENT APPLICATION

Timing and Placement of Fertilizer Applications

FERTILIZER TIMING AND PLACEMENT SEGMENT 100 — Model Segment Number

		Spr. Gr.	Plant C.		Plant B.		S.Dr. C	Fall Gr.		Total Fertilizer Applications	
		SZ	SZ	UZ	SZ	UZ	SZ	SZ	UZ	TN	TP
Conventional Tillage	CNT										
	N:NH3	5.22	2.17	19.51	0.06	0.55	21.68	0.13	1.18	77.33	38.15
	N:NO3	3.79	4.30	6.50	0.30	0.18	10.81	0.56	0.39		
	P:PO4	0.00	3.59	32.32	0.02	0.17	0.00	0.20	1.84		
Conservation Tillage	CST										
	N:NH3	2.49	3.83	21.70	0.11	0.64	25.53	0.09	0.53	83.23	43.49
	N:NO3	1.81	5.49	7.23	0.39	0.21	12.72	0.28	0.18		
	P:PO4	0.00	6.34	35.93	0.04	0.20	0.00	0.15	0.83		

		March		June	August		Total Fertilizer Applications	
		SZ	UZ	SZ	SZ	UZ	TN	TP
Hay land	HAY							
	N:NH3	0.00	0.00	0.00	0.00	0.00	10.00	8.00
	N:NO3	3.00	0.00	3.00	4.00	0.00		
	P:PO4	1.20	1.20	2.40	1.60	1.60		

Timing and Placement of Manure Applications

MANURE TIMING AND PLACEMENT SEGMENT 100 — Model Segment Number

		CORN/SOY (3 appl.) Nov/Jan/Mar		GRAINS (3 appl.) May/Jul/Sep		Total Manure Applications	
		SZ	UZ	SZ	UZ	TN	TP
Conventional Tillage	CNT						
	NH3	2.21	2.21	0.41	0.41	35.06	8.04
	ORGN	2.73	2.73	0.50	0.50		
	PO4/ORGP	0.56	0.56	0.11	0.11		
Conservation Tillage	CST						
	NH3	2.61	2.61	0.19	0.19	37.54	8.59
	ORGN	3.22	3.22	0.24	0.24		
	PO4/ORGP	0.66	0.66	0.05	0.05		

		HAY (6 appl.) May/Jun/Jul/Aug/Sep/Oct		Total Manure Applications	
		SZ	UZ	TN	TP
Hay land	HAY				
	NH3	1.28	1.28	34.20	7.80
	ORGN	1.58	1.58		
	PO4/ORGP	0.33	0.33		

SZ - Surface Soil Zone
UZ - Upper Soil Zone

At the top of the spreadsheet, the input values for the cropping distributions, the state-supplied rates for each crop, and the atmospheric deposition amounts are shown. In the next section, the initial composite value and the individual crop components are calculated based on the input cropping distribution. These rates also allow for NH_3 volatilization losses using the value for 'fraction of manure available as NH_3', which is shown in the middle portion of the table. For example, the value shown in Table 4.11 is 0.34; this accounts for 60% loss by volatilization of the inorganic N, plus the fraction of organic N available as NH_3 (as shown in Figure 4.13 and discussed above).

The middle section of Table 4.11 shows the state-supplied fractions of each crop (i.e., corn, beans, grains) which receives the various combinations of manure and up to two different fertilizer rates; this middle section also shows the fractions used to calculate volatilization losses and nutrient composition. The initial composited crop component rates are then weighted by the crop fractions for the various combinations in order to calculate the final segment rates, and the crop components, shown in the second to last block near the bottom of Table 4.11. The final block in Table 4.11 shows the composition of the final segment rates, i.e., the distribution of the final rates into organic and inorganic forms.

The components of the final segment rates attributable to each crop is carried through the calculations so that the protocols for timing and placement for each crop can be represented. In Table 4.12, the final segment rates from Table 4.11 are then distributed in time and space for specific applications on each cropland category. The top half of Table 4.11 shows the values for fertilizer applications, while the bottom half shows the manure applications for CNT, CST, and Hay. The values shown in this table (which are the same as in the spreadsheet) are the specific values input to the model and can be identified in the model segment input sequence.

For fertilizer applications, the values in Table 4.12 include the NH_3, NO_3, and PO_4 amounts applied to the surface zone (SZ in the table), and the upper zone (UZ) for applications associated with spring grains, planting of corn and soybeans, side dressing of corn, and fall grains. For the Hay segment, the fertilizer amounts associated with the three separate applications (discussed in Table 4.10) are shown.

For manure applications, the bottom half of Table 4.12 shows the inorganic and organic amounts, the number and timing of the applications, and the placement in the surface and upper zones.

The final application rates for all model segments for the CNT, CST, and Hay cropland categories are summarized in Tables 4.13, 4.14. and 4.15, respectively. Appendix C includes copies of the individual spreadsheets for each model segment, which are also available from the CBPO as Lotus files.

4.3.5 AGCHEM application procedures for Model Segments

As noted in the introduction to Section 4.3, the primary goal of the AGCHEM application in Phase II was to represent nutrient balances on the cropland areas so that the impacts of climate, agricultural practices, and nutrient management

TABLE 4.13 FINAL CALCULATED MODEL SEGMENT NUTRIENT APPLICATION RATES FOR CONVENTIONAL TILLAGE (lb/ac)

MODEL	FERTILIZER		MANURE		ATMOS. DEP.	TOTAL	
SEGMENT	N	P	N	P	N	N	P
10	84.3	17.2	22.4	5.3	9	115.7	22.5
20	97.4	19.7	22.6	5.3	9	129.0	25.0
30	95.3	19.3	22.6	5.3	9	126.8	24.6
40	77.1	15.9	23.4	5.5	9	109.5	21.4
50	77.5	17.1	33.1	7.7	11	121.6	24.8
60	86.3	18.9	35.7	8.4	11	133.1	27.2
70	78.7	17.3	34.6	8.1	10	123.2	25.4
80	59.4	22.2	43.0	10.1	9	111.5	32.2
90	68.9	39.5	35.4	8.1	10	114.3	47.6
100	67.3	38.1	35.1	8.0	10	112.4	46.2
110	62.6	26.8	61.5	14.4	9	133.2	41.2
120	71.5	28.8	66.4	15.5	8	145.9	44.3
140	63.4	27.1	60.9	14.3	8	132.4	41.3
160	110.9	13.4	21.8	7.3	10	142.7	20.7
170	138.9	30.7	28.6	9.0	9	176.6	39.7
175	130.5	30.2	28.6	9.0	10	169.1	39.2
180	117.5	21.2	24.7	7.1	9	151.2	28.3
190	117.9	29.1	97.3	30.6	9	224.2	57.7
200	113.7	28.7	93.5	29.4	9	216.2	58.1
210	97.5	26.8	26.1	7.5	9	132.6	34.3
220	114.1	25.5	1.9	0.6	9	125.0	26.1
230	130.7	22.0	0.0	0.0	8	138.7	22.0
235	87.0	27.2	0.0	0.0	8	95.0	27.2
240	76.8	29.8	0.0	0.0	8	84.8	29.8
250	118.0	27.0	0.0	0.0	8	126.0	27.0
260	83.8	26.6	0.0	0.0	8	91.8	26.6
265	149.2	32.2	0.0	0.0	8	157.2	32.2
270	138.6	31.6	5.7	1.8	8	152.3	33.4
280	95.6	26.5	0.0	0.0	7	102.6	26.5
290	81.1	27.4	0.0	0.0	7	88.1	27.4
300	97.2	27.4	0.0	0.0	7	104.2	27.4
310	104.8	26.3	0.0	0.0	7	118.8	26.3
330	101.0	14.8	29.4	9.3	8	138.3	24.1
340	110.4	15.4	16.8	5.2	8	135.2	20.5

TABLE 4.13 FINAL CALCULATED MODEL SEGMENT NUTRIENT APPLICATION RATES FOR CONVENTIONAL TILLAGE (lb/ac) (continued)

MODEL	FERTILIZER		MANURE		ATMOS. DEP.	TOTAL	
SEGMENT	N	P	N	P	N	N	P
Anacostia	96.7	26.9	22.8	8.1	8	127.5	35.0
Baltimore	109.3	15.8	16.4	4.8	8	133.7	20.6
Bohemia	94.9	17.9	3.5	1.0	8	106.4	18.9
Chester	85.4	19.8	11.7	3.9	8	105.0	23.7
Chickahominy	89.9	29.2	0.0	0.0	7	96.9	29.2
Choptank	72.4	22.0	24.4	6.7	8	104.9	28.8
Coast_1	74.6	22.2	10.2	2.9	8	92.8	25.1
Coast_4	79.0	29.6	0.0	0.0	7	86.0	29.6
Coast_5	111.7	16.1	10.6	3.5	8	130.3	19.6
Coast_6	119.6	35.8	3.0	0.9	8	130.6	36.7
Coast_8	77.5	29.7	0.0	0.0	8	85.5	29.7
Coast_9	64.3	29.7	0.0	0.0	7	71.3	29.7
Coast_11	100.9	33.3	72.1	19.2	8	181.1	52.6
Elizabeth	56.1	27.7	0.0	0.0	7	63.1	27.7
Gr. Wico.	80.0	29.2	0.0	0.0	7	87.0	29.2
Gunpowder	103.7	14.9	25.6	7.9	8	137.3	22.8
James	82.4	29.2	0.0	0.0	7	89.4	29.2
Nansemond	112.5	32.1	0.0	0.0	7	119.5	32.1
Nanticoke	93.9	23.0	127.6	36.4	8	229.5	59.3
Occoquan	123.5	27.1	0.0	0.0	8	131.2	27.1
Patapsco	101.4	14.7	16.7	5.4	8	126.1	20.2
Patuxent	92.8	25.7	7.6	2.6	8	108.4	28.3
Pocomoke	74.2	20.5	137.8	40.1	7	219.0	60.5
Potomac	82.7	25.5	2.4	0.9	8	93.1	26.5
Rappahannock	79.0	29.1	0.0	0.0	7	86.0	29.1
Severn	91.9	14.7	27.7	7.3	8	127.6	22.1
Wicomico	66.7	19.5	130.4	37.4	7	204.1	56.9
Wye	77.3	20.8	21.5	6.3	8	106.8	27.2
York	79.7	29.3	0.0	0.0	7	86.7	29.3

TABLE 4.14 FINAL CALCULATED MODEL SEGMENT NUTRIENT APPLICATION RATES FOR CONSERVATION TILLAGE (lb/ac)

MODEL	FERTILIZER		MANURE		ATMOS. DEP.	TOTAL	
SEGMENT	N	P	N	P	N	N	P
10	96.7	19.5	22.6	5.4	9	128.3	24.9
20	104.3	20.9	22.7	5.4	9	132.8	25.7
30	102.1	20.5	22.7	5.4	9	133.9	25.9
40	86.1	17.5	23.9	5.6	9	118.9	23.2
50	90.9	19.8	36.7	8.6	11	138.6	28.4
60	95.2	20.7	38.2	8.9	11	144.5	29.7
70	86.8	19.0	37.1	8.7	10	133.9	27.7
80	65.3	25.4	48.2	11.3	9	122.5	36.7
90	74.6	44.7	37.8	8.6	10	122.4	53.3
100	73.2	43.5	37.5	8.6	10	120.8	52.1
110	71.0	28.5	68.6	16.1	9	148.6	44.5
120	77.5	30.0	71.3	16.7	8	156.8	46.7
140	70.7	28.4	68.3	16.0	8	147.0	44.4
160	115.8	16.8	22.3	7.5	10	148.1	24.3
170	139.7	30.5	28.6	9.0	9	177.3	39.5
175	133.0	29.5	32.4	10.2	10	175.5	39.7
180	124.5	25.1	28.1	8.1	9	161.6	33.1
190	121.6	28.9	97.3	30.6	9	227.9	59.5
200	117.6	28.4	93.5	29.4	9	220.1	57.8
210	108.3	28.4	25.7	7.4	9	143.0	35.8
220	116.5	25.1	1.9	0.6	9	127.4	25.8
230	134.5	22.1	0.0	0.0	8	142.5	22.1
235	87.2	26.9	0.0	0.0	8	95.2	26.9
240	75.1	30.4	0.0	0.0	8	83.1	30.4
250	121.2	26.6	0.0	0.0	8	129.2	26.6
260	82.9	25.9	0.0	0.0	8	90.9	25.9
265	149.6	32.2	0.0	0.0	8	157.6	32.2
270	142.1	31.4	5.7	1.8	8	155.9	33.2
280	96.8	26.0	0.0	0.0	7	103.8	26.0
290	80.4	27.0	0.0	0.0	7	87.4	27.0
300	98.3	26.8	0.0	0.0	7	105.3	26.8
310	107.2	25.4	0.0	0.0	7	114.2	25.4
330	106.1	15.2	29.5	9.3	8	143.6	24.5
340	115.4	15.8	16.5	5.1	8	139.9	20.8

TABLE 4.14 FINAL CALCULATED MODEL SEGMENT NUTRIENT APPLICATION RATES FOR CONSERVATION TILLAGE (lb/ac) (continued)

MODEL	FERTILIZER		MANURE		ATMOS. DEP.	TOTAL	
SEGMENT	N	P	N	P	N	N	P
Anacostia	97.3	28.3	22.6	8.0	8	127.9	36.3
Baltimore	117.4	16.2	16.2	4.8	8	141.7	21.0
Bohemia	92.2	17.9	3.6	1.0	8	103.8	18.9
Chester	84.4	21.6	11.5	3.8	8	103.9	25.4
Chicka.	77.5	29.3	0.0	0.0	7	84.5	29.3
Choptank	69.2	24.7	23.7	6.5	8	100.9	31.2
Coast_1	70.3	24.5	10.6	3.0	8	88.9	27.5
Coast_4	77.0	30.3	0.0	0.0	7	84.0	30.3
Coast_5	107.9	16.1	10.6	3.5	8	126.4	19.6
Coast_6	128.9	37.1	3.0	0.9	8	139.9	37.9
Coast_8	75.4	30.4	0.0	0.0	8	83.4	30.4
Coast_9	62.0	30.2	0.0	0.0	7	69.0	30.2
Coast_11	108.1	34.4	73.6	19.6	8	189.7	54.0
Elizabeth	43.9	28.1	0.0	0.0	7	50.9	28.1
Gr. Wico.	77.0	29.9	0.0	0.0	7	84.0	29.9
Gunpowder	112.3	15.4	25.3	7.8	8	145.6	23.2
James	82.6	29.5	0.0	0.0	7	89.6	29.5
Nansemond	115.3	32.6	0.0	0.0	7	122.3	32.6
Nanticoke	93.1	23.0	127.5	36.4	8	228.7	59.4
Occoquan	127.8	26.5	0.0	0.0	8	135.8	26.5
Patapsco	112.2	15.8	15.8	5.1	8	136.0	20.9
Patuxent	85.5	25.1	7.0	2.4	8	100.5	27.6
Pocomoke	65.8	19.4	136.9	39.6	7	209.7	59.1
Potomac	76.6	25.3	2.3	0.9	8	86.9	26.2
Rappahannock	76.2	29.6	0.0	0.0	7	83.2	29.6
Severn	98.7	15.1	32.0	8.2	8	138.6	23.4
Wicomico	57.0	18.3	136.8	39.6	7	200.8	57.9
Wye	76.1	23.4	18.6	5.5	8	102.7	28.9
York	78.0	29.8	0.0	0.0	7	85.0	29.8

TABLE 4.15 FINAL CALCULATED MODEL SEGMENT NUTRIENT APPLICATION RATES FOR HAY (lb/ac)

MODEL	FERTILIZER		MANURE		ATMOS. DEP.	TOTAL	
SEGMENT	N	P	N	P	N	N	P
10	30.0	14.5	0.0	0.0	9	39.0	14.5
20	30.0	14.5	0.0	0.0	9	39.0	14.5
30	30.0	14.5	0.0	0.0	9	39.0	14.5
40	30.0	14.5	0.0	0.0	9	39.0	14.5
50	30.0	13.0	0.0	0.0	11	41.0	13.0
60	30.0	13.0	0.0	0.0	11	41.0	13.0
70	30.0	13.0	0.0	0.0	10	40.0	13.0
80	7.5	17.5	0.0	0.0	9	16.5	17.5
90	0.0	8.0	34.2	7.8	10	44.2	15.8
100	0.0	8.0	34.2	7.8	10	44.2	15.8
110	10.0	13.0	41.0	9.6	9	60.0	22.6
120	10.0	13.0	41.0	9.6	8	59.0	22.6
140	10.0	13.0	41.0	9.6	8	59.0	22.6
160	0.0	23.7	12.1	4.1	10	22.1	27.8
170	34.2	28.5	4.0	1.8	9	47.2	30.2
175	34.2	28.5	4.0	1.8	10	48.2	30.2
180	2.1	18.9	11.6	3.5	9	22.7	22.4
190	29.3	24.1	15.1	6.7	9	53.4	30.8
200	29.3	24.1	15.1	6.7	9	53.4	30.8
210	1.5	11.7	14.4	4.3	9	24.9	16.0
220	7.2	9.9	1.6	0.5	9	17.8	10.4
230	60.0	21.0	0.0	0.0	8	68.0	21.0
235	34.7	29.0	0.0	0.0	8	42.7	29.0
240	30.0	25.0	0.0	0.0	8	38.0	25.0
250	36.0	30.0	0.0	0.0	8	44.0	30.0
260	35.5	29.6	0.0	0.0	8	43.5	29.6
265	36.0	30.0	0.0	0.0	8	44.0	30.0
270	34.6	28.7	0.4	0.2	8	42.9	28.9
280	33.4	27.8	0.0	0.0	7	40.4	27.8
290	30.2	25.2	0.0	0.0	7	37.2	25.2
300	30.0	25.0	0.0	0.0	7	37.0	25.0
310	30.0	25.0	0.0	0.0	7	37.0	25.0
330	9.0	3.9	24.6	7.8	8	41.6	11.7
340	9.0	3.9	13.0	4.0	8	30.0	7.9

TABLE 4.15 FINAL CALCULATED MODEL SEGMENT NUTRIENT APPLICATION RATES FOR HAY (lb/ac) (continued)

MODEL	FERTILIZER		MANURE		ATMOS. DEP.	TOTAL	
SEGMENT	N	P	N	P	N	N	P
Anacostia	0.0	12.0	17.5	6.2	8	25.5	18.2
Baltimore	9.0	3.9	16.9	4.6	8	33.9	8.5
Bohemia	6.0	7.8	3.2	0.9	8	17.2	8.7
Chester	9.0	7.8	8.0	2.7	8	25.0	10.5
Chicka.	31.6	26.4	0.0	0.0	7	38.6	26.4
Choptank	9.0	7.8	21.2	5.9	8	38.2	13.7
Coast_1	9.0	7.8	5.1	1.4	8	22.1	9.2
Coast_4	30.0	25.0	0.0	0.0	7	37.0	25.0
Coast_5	9.0	3.9	10.6	3.5	8	27.6	7.4
Coast_6	0.0	9.3	2.7	0.8	8	10.7	10.1
Coast_8	30.0	25.0	0.0	0.0	8	37.0	25.0
Coast_9	30.0	25.0	0.0	0.0	7	37.0	25.0
Coast_11	2.7	10.3	55.7	14.9	8	66.3	25.1
Elizabeth	30.0	25.0	0.0	0.0	7	37.0	25.0
Gr. Wico.	30.0	25.0	0.0	0.0	7	37.0	25.0
Gunpowder	9.0	3.9	20.2	6.3	8	37.2	10.2
James	30.0	25.0	0.0	0.0	7	37.0	25.0
Nansemond	30.0	25.0	0.0	0.0	7	37.0	25.0
Nanticoke	9.0	7.8	63.4	18.0	8	80.4	25.8
Patapsco	9.0	3.9	13.9	4.5	8	30.9	8.4
Patuxent	9.0	3.9	13.5	4.6	8	30.5	8.5
Pocomoke	9.0	7.8	5.3	1.5	7	21.3	9.3
Potomac	18.9	12.0	2.0	0.8	8	28.9	12.7
Occoquan	36.0	30.0	0.0	0.0	8	44.0	30.0
Rappa.	30.6	25.5	0.0	0.0	7	37.6	25.5
Severn	9.0	3.9	32.6	8.0	8	49.6	12.0
Wye	9.0	7.8	17.6	5.2	8	34.6	13.0
Wicomico	9.0	7.8	114.2	32.9	7	130.2	40.7
York	30.9	25.8	0.0	0.0	7	37.9	25.8

alternatives on NPS nutrient loadings and water quality could be evaluated. The AGCHEM modules were originally designed for application to areas ranging from field-size to small-to-moderate size watersheds on the order of the size of a single model segment. For these size areas <u>when</u> the relevant soil, crop, and runoff data are available, the AGCHEM calibration involves the establishment of a reasonable simulation of soil nutrient storages through adjustment of plant uptake rates, soil transformations, partition coefficients, and percolation parameters, followed by evaluation of the nutrient runoff simulation (in comparison with observed values) and parameter refinement as needed. The general guidance provided for nutrient calibration as described in the HSPF Application Guide (Donigian, et al., 1983) is as follows:

1. Evaluate initial soil nutrient parameters from information available in the literature, and include fertilizer manure and rainfall sources of nutrients as input to the model.

2. Calibrate initial mineralization rates so that annual amounts of plant-available nutrients correspond to expected values.

3. Adjust leaching factors based on any data available for a tracer such as chloride.

4. Adjust plant uptake rates to develop the expected nutrient uptake distribution during the growing season and the estimated total uptake amount expected for the crop.

5. Adjust nutrient partition coefficients based on available soil core and runoff data.

6. Refine the leaching, uptake, and partition parameters based on observed runoff data and the expected sources of nutrient runoff, i.e., surface, interflow, groundwater.

Due to both data and resource limitations, the type of detailed AGCHEM calibration described by the above steps could not be performed in Phase II. Even if the data were available for selected sites within the Bay drainage, the calibrated model parameters would still need to be refined or adjusted to the scale of the model segments and to represent the 'composite crop' within each model segment. AGCHEM model calibrations were initially planned as part of the Phase II effort for sites in the Patuxent, Rappahannock (Owl Run), and Potomac (Nomini Creek) model segments; however, schedule and data constraints precluded completion of these efforts. Plans are to complete these applications in future studies either by the CBPO, the individual states, or through joint efforts.

Because of the above constraints and limitations, the focus of the AGCHEM simulations was a 'regional' scale application designed to represent the expected nutrient balances on each of the cropland categories. The literature was reviewed to define typical nutrient balances for each of the major crop categories, and the AGCHEM simulations were calibrated to represent these nutrient balances while maintaining the nonpoint nutrient loadings within the range of expected values.

4.3.5.1 Expected crop nutrient balances

Tables 4.16 and 4.17, respectively show the typical nitrogen and phosphorus balances expected for the major crops when the nutrients are applied at agronomic rates meeting crop needs. Although there is a fairly large range in many of the components of the nutrient balances, it is clear that nutrient applications and crop uptake are the dominant portions of the balance. This is especially true for corn which generally comprises more than half of the cropland (excluding hay) for the model segments above the Fall Line; below the Fall Line, soybeans and grains are more extensive but corn still comprises about 30% to 60% of the cropland in most segments.

Moreover, current total nutrient application rates including both fertilizer and manure, as shown in Tables 4.5 and 4.6, are considerably larger than expected crop nutrient needs. Table 4.18 shows the expected mean and range of crop uptake rates along with the assumed crop yields on which the rates are based. The uptake rates were initially derived from the general literature sources shown in the table, and then adjusted through discussions with the NRTF based on subsequent information provided by state representatives on actual crop yields experienced in the individual states.

Because of the dominance of the application rates and crop uptake on the nutrient balance, these two components were the primary focus of our efforts with AGCHEM to simulate these balances. The extensive efforts to develop reasonable and realistic nutrient application rates were described above in Section 4.3.3. The critical importance of the application rates cannot be over-stated; these rates defined the source and quantity of nutrients available for crop uptake and runoff loadings. Based on the defined application rates, the steps in the AGCHEM calibration were as follows:

1. Estimate soil nutrient storages and parameters from available literature and state-supplied data.

2. Calibrate uptake, mineralization, and immobilization (fixation) rates to reflect expected nutrient balances.

3. Compare simulated runoff loadings and concentrations to available literature data.

Initial estimates of both soil nutrients and parameters were derived from past modeling studies using AGCHEM at a variety of field and watershed sites in Georgia and Michigan as part of the ARM model development work (Donigian and Crawford, 1976; Donigian et al., 1977), and in Iowa (Donigian et al., 1983; Imhoff et al., 1983), Nebraska (Gilbert et al., 1982), Florida (Nichols and Timpe, 1985), and Tennessee (Moore et al., 1988). However, many of these studies focussed on small field sites with little or no subsurface nutrient components, and phosphorus modeling was either not attempted or de-emphasized due to limited data availability. In fact, the current application of AGCHEM is the most comprehensive and extensive application to date, requiring more detailed assessment of cropland nutrient processes than any previous study.

TABLE 4.16 TYPICAL NITROGEN BALANCE FOR MAJOR CROPS WHEN NITROGEN IS APPLIED AT AGRONOMIC RATES (lb/ac)

	Corn	Soybeans	Grains	Hay
Inputs:				
Fertilizer/Manure	100-160	25-35	50-100	30-60
Atmos. Deposition	7-10	7-10	7-10	7-10
Mineralization	25-40	25-40	25-40	25-40
Totals	132-210	57-85	82-150	62-110
Outputs:				
Plant Uptake	120-150	25-40*	60-90	30-55
Surface Runoff	2-5	1-3	2-4	1-3
Leaching & Subsurface Runoff	10-25	10-15	5-15	5-15
Volatilization & Dinitrification	15-25	5-15	10-20	10-20
Totals	147-205	41-73	77-129	46-91
Δ Storage	-15 to +5	+16 to +12	+5 to +21	+16 to +10

* - Represents uptake from the soil, approximately 25% of total uptake, with 75% supplied by fixation (Tisdale et al., 1985).

TABLE 4.17 TYPICAL PHOSPHORUS BALANCE FOR MAJOR CROPS WHEN PHOSPHORUS IS APPLIED AT AGRONOMIC RATES (lb/ac)

	Corn	Soybeans	Grains	Hay
Inputs:				
Fertilizer/Manure	20-40	10-30	10-30	10-30
Atmos. Deposition	0-1	0-1	0-1	0-1
Mineralization	2-5	2-5	2-5	2-5
Totals	22-46	12-36	12-36	12-36
Outputs:				
Plant Uptake	20-30	12-20	12-22	12-25
Surface Runoff	1-2	0-1	0-1	0-1
Leaching & Subsurface Runoff	0-1	0-1	0-1	0-1
Totals	21-33	12-22	12-24	12-27
Δ Storage	+1 to +13	0 to +14	0 to +12	0 to +9

4.3.5.2 Initial soil nutrient storages

Soil nutrient storages required by AGCHEM include initial values for all nutrient forms (i.e., organic and inorganic) for each soil zone, including the surface, upper, lower and groundwater zones as described in Section 4.3.1. Although a variety of soil nutrient data was supplied by the state representatives on the NRTF, the data was generally sporadic, incomplete for selected nutrient forms, often based on different analytical techniques, and did not provide the vertical spatial definition needed for the model soil zones. In addition, limited resources precluded efforts to establish different nutrient storage values for each model segment. Consequently, the nutrient storages were developed from a few selected detailed studies, past experience with AGCHEM, and general soils information, and then compared with available state information to insure consistency.

Parker et al. (1946) prepared national maps of Total N and P_2O_5 for the surface foot of soil which showed percentages of 0.05 to 0.19 for these two forms, respectively. Cunningham (R.L. Cunningham, 1991, personal communication) noted that Total N was typically in the range of 0.13 to 0.16 % for Pennsylvania. Data from Fox and Piekielek (1983) for a variety of cropland sites throughout Pennsylvania were consistent with the earlier information. Bandel et al. (1975) reports detailed information for N content at three research sites in Maryland for different soil depths. Ibison (1990) reported Total N, Total P, and Inorganic P soil concentrations for a variety of Maryland and Virginia sites in coastal regions of the Bay as part of an effort to assess nutrient contributions from eroding banks.

The above data indicated extreme variability in soil nutrient concentrations at individual sites as a function of native soil characteristics, cropping practices, historical fertilizer and manure applications, etc. Lacking the resources to develop segment-specific values, we developed initial nutrient storages that were consistent with the general range of reported literature data and state-supplied information. Brady (1990) reports that the vast majority of nitrogen (i.e., 90-95% or more) is in the organic form, while for phosphorus the inorganic form tends to dominate especially in subsurface soils. Moreover, for our cropland categories, nutrient applications and crop uptake primarily impact the <u>inorganic</u> nutrient forms leading to significant variations in soil storages during the annual simulations; this is consistent with the reported data for field sites.

Based on the above information and data sources, we developed the following organic (ON, OP) and inorganic (IN, IP) nutrient storages which were used, with only slight adjustments, for all model segments:

The initial nutrient storages shown above provided a reasonable basis for simulating the regional nutrient balances as part of the AGCHEM application. Although the resources available for this effort were inadequate to analyze the universe of available soil nutrient data and develop nutrient storages specific to each model segment, any future efforts to refine or improve the AGCHEM modeling should include a more detailed assessment of the variation in soil nutrients throughout the region.

4.3.5.3 Estimation of AGCHEM model parameters

In addition to the initial soil nutrient storages, the AGCHEM nutrient parameters can be grouped into the transformation rates, sorption parameters, and plant uptake rates. Initial values for most parameters were obtained from selected literature sources and past applications of AGCHEM in Georgia and Michigan as part of the ARM model development work (Donigian and Crawford, 1976; Donigian et al., 1977), and applications in Iowa (Donigian et al., 1983; Imhoff et al., 1983), Nebraska (Gilbert et al., 1982), and Tennessee (Moore et al., 1988).

Stanford and Smith (1972) and Reddy et al. (1979) provided ranges of values for nitrogen mineralization rates, along with temperature adjustment factors. Reddy et al. (1979) and Reddy and Patrick (1984) also discussed expected values for nitrification, denitrification, and volatilization rates for soils and sediments. Recently, Deizman (1989) summarized literature values on rates for mineralization, nitrification, and ammonia volatilization for soils amended with organic wastes. Gilliam and Hoyt (1987) discuss the impacts of conservation tillage on nitrogen soil processes and summarize much of the available literature.

To represent the sorption process, a modified Freundlich isotherm is used in the AGCHEM application in Phase II whereby a permanently bound concentration of the chemical must be exceeded prior to partitioning by the Freundlich isotherm parameters. Thus, for each soil layer three parameters are required to represent NH_4 and PO_4 sorption: the permanently bound concentration, XFIX (ppm), and the Freundlich coefficient, K1, and exponent, 1/N1 (N1 is the input parameter). The literature on sorption was much more limited for NH_4 than for PO_4, but a wide range of values was reported based on soil conditions, sampling procedures, and analytical procedures, especially for PO_4. Work by Ardakani and McLaren (1977), Simon (1989), Reddy (1989; 1990, personal communication), and Reddy et al. (1988) provided values from field observations for NH_4. For the more highly sorptive PO_4, a number of articles for a wide range of soils and conditions were reviewed, including Berkheiser et al. (1984), Reddy et al. (1980), Sharpley et al. (1981), Mansell et al. (1977), Fitter and Sutton (1971), Oloya and Logan (1980), Taylor and Kunishi (1971), and McDowell et al. (1980).

In spite of the extensive literature available on soil nutrient processes, information on rate values that could be used directly in AGCHEM without calibration was limited. In addition, the regional scale of the modeling and the 'composite crop' representation precluded the direct use of literature values developed from specific field and plot-scale data collection efforts for specific crops, soils, practices, etc. Consequently, the final AGCHEM parameter values were determined primarily through calibration to represent the expected nutrient

TABLE 4.19 NUTRIENT TRANSFORMATION AND SORPTION PARAMETERS USED IN THE AGCHEM SIMULATIONS

NITROGEN:*	Surface	Upper	Lower	G.W.
Mineralization	0.001	0.00015	0.00015	0.00
Nitrification	10.0	5.0	3.0	0.50
Dinitrification	0.0	0.0/0.005	0.005	0.03
Mobilization/ Fixation	5.0/6.0	2.0/3.0	0.20	0.00
PHOSPHORUS:*				
Mineralization	0.0007	0.00003	0.00005	0.00
Immobilization/ Fixation	10.0	2.0	0.10	0.00

FREUNDLICH SORPTION PARAMETERS:

NH_4^+ Sorption	Surface	Upper	Lower	G.W.
XFIX (ppm)	5.0	5.0	0.7	0.3
K1	1.0	1.0	0.5	0.5
N1	1.5	1.2	1.2	1.1
PO_4 Sorption				
XFIX (ppm)	25.0	15.0	10.0	12.0
K1	5.0	5.0	5.0	6.0
N1	1.5	1.5	1.5	1.5

* - Rates are in units of 'per day'

d. The P parameters and representation of the P balance are the most uncertain aspects of the AGCHEM simulations. Most previous AGCHEM applications were limited to nitrogen simulations, largely because the nitrogen cycle is much better documented and understood than the phosphorus cycle in soils. The complexity of the phosphorus cycle and PO_4 chemistry is well documented, but poorly understood quantitatively (e.g., see Sample et al. (1980), Olsen and Khasawneh (1980), and sorption references cited above). Some of the limitations of AGCHEM for phosphorus simulation were discussed in Section 4.3.2. In calibrating the phosphorus balance, it was necessary to use high plant uptake rates, relatively low sorption parameters, and high immobilization/fixation rates. The sorption parameters are consistent with the low end of the range of values in the literature, while rapid fixation of applied PO_4 fertilizer (as bound or precipitated complexes of iron, aluminum, calcium, etc.) is generally accepted.

4.3.6 AGCHEM Simulation Results

The AGCHEM model provides storages and fluxes of each nutrient form for each soil zone and each simulated process for every timestep of the simulation. Consequently, an extensive volume of information is produced for each model segment. Tables 4.21, 4.22, and 4.23 summarize the simulation results for the Conventional Tillage, Conservation Tillage, and Hay land categories, respectively for model segment 100 in the Juniata Basin. The tables provide annual totals and the annual average for the four-year simulation period, for the following variables and fluxes:

- Nutrient applications
- Runoff and components
- Sediment loading
- NO_3 and Ammonia loadings and components
- Sediment N loadings (ammonia and organic N)
- PO_4 loadings and components
- Sediment P loadings (PO_4 and organic P)
- N and P plant uptake from each soil zone
- N and P mineralization
- Denitrification
- Ammonia and PO_4 immobilization

The results for model segment 100 in the Juniata Basin are representative of the AGCHEM results throughout the Bay drainage. Appendix C.2 includes AGCHEM summary tables for the three cropland categories for selected model segments within each subbasin.

Figures 4.14, 4.15, and 4.16 graphically show the inputs, losses, and runoff losses of N and P for the Juniata model segment 100. Figure 4.14 shows the composition of the nutrient inputs of N and P; Figure 4.15 shows the composition and amounts of the N and P losses; and Figure 4.16 shows the composition of the nutrient runoff losses. Finally, Table 4.24 summarizes the Total N and Total P, and components, in runoff losses from selected model segments for relative comparisons. All the information in these tables and figures are partial extracts of model results included in the tables in Appendix C.2.

TABLE 4.22 AGCHEM RESULTS FOR JUNIATA SEGMENT 100 (LT COMPOSITE CROP)

	1984	1985	1986	1987	Mean
Fert. + Manure	122lb N/a	122lb N/a	122lb N/a	122lb N/a	122lb N/a
Application	53lb P/a	53lb P/a	53lb P/a	53lb P/a	53lb P/a
Runoff (in)					
Surface	5.98	4.73	4.26	2.18	4.29
Interflow	6.67	4.73	5.78	3.93	5.28
GW	8.15	6.36	6.59	6.48	6.90
Total	20.80	15.82	16.63	12.59	16.46
Sed. Loss (t/a)	0.61	0.56	0.29	0.12	0.40
Nutrient Loss (lb/a)					
NO3					
Surface	0.31	0.63	0.43	0.05	0.36
Interflow	13.23	8.15	7.66	7.94	9.25
GW	4.87	3.33	3.25	3.08	3.63
Total	18.41	12.11	11.34	11.07	13.23
NH3					
Surface	1.12	2.24	1.14	0.38	1.22
Interflow	1.25	0.81	0.89	0.41	0.84
GW	0.05	0.01	0.01	0.01	0.02
Total	2.42	3.06	2.04	0.80	2.08
NH3 Sed. (lb/a)	6.53E-03	7.33E-03	3.53E-03	1.28E-03	4.67E-03
ORG. N Sed. (lb/a)	2.57	2.36	1.21	0.50	1.66
Total N (lb/a)	23.41	17.54	14.59	12.37	16.98
PO4					
Surface	0.65	0.86	0.91	0.34	0.69
Interflow	0.57	0.48	0.73	0.29	0.52
GW	0.00	0.00	0.00	0.00	0.00
Total	1.22	1.34	1.64	0.63	1.21
PO4 Sed. (lb/a)	2.69E-02	2.71E-02	1.33E-02	5.56E-03	1.82E-02
ORG. P Sed. (lb/a)	0.68	0.63	0.32	0.13	0.44
Total P (lb/a)	1.93	2.00	1.97	0.77	1.67
Plant Uptake (lb/a)					
Nitrogen					
Surface	0.01	0.04	0.06	0.03	0.03
Upper	59.53	67.48	67.58	67.61	65.55
Lower	32.57	27.78	29.21	30.49	30.01
Total	92.11	95.30	96.85	98.13	95.60
Phosphorus					
Surface	0.04	0.04	0.07	0.05	0.05
Upper	20.01	19.37	21.14	20.94	20.37
Lower	9.82	2.56	1.89	1.79	4.02
Total	29.87	21.97	23.10	22.78	24.43
Net Mineralization (lb/a)					
Nitrogen	33.03	32.26	32.54	32.52	32.59
Phosphorus	2.44	2.13	2.23	2.19	2.25
Denitrification (lb/a)	1.48	1.20	1.16	1.16	1.25
NH3 IMMOB. (lb/a)	19.73	20.77	21.46	21.26	20.81
PO4 IMMOB. (lb/a)	29.50	27.42	25.56	27.47	27.49

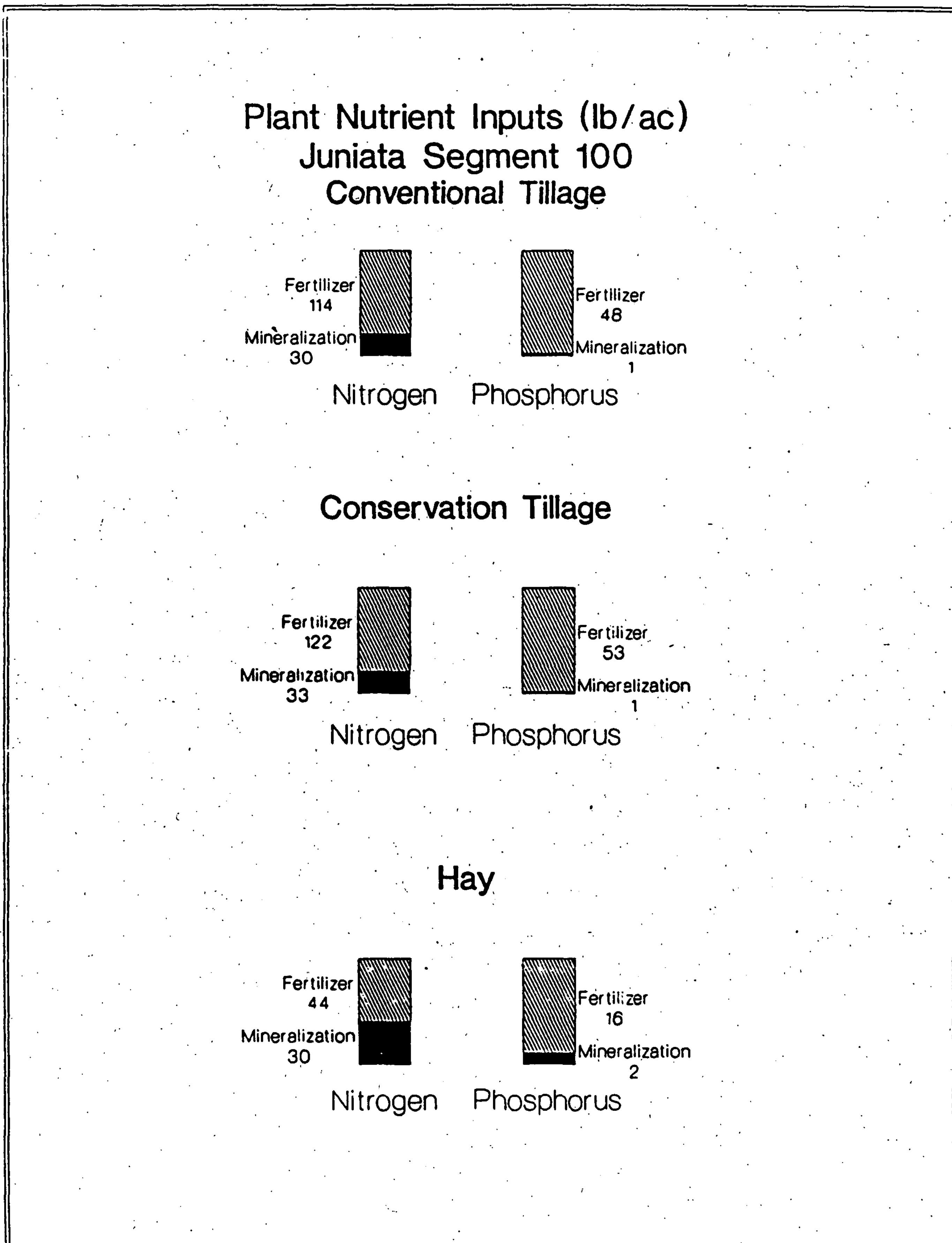


Figure 4.14 Plant nutrient inputs - Juniata Segment 100.

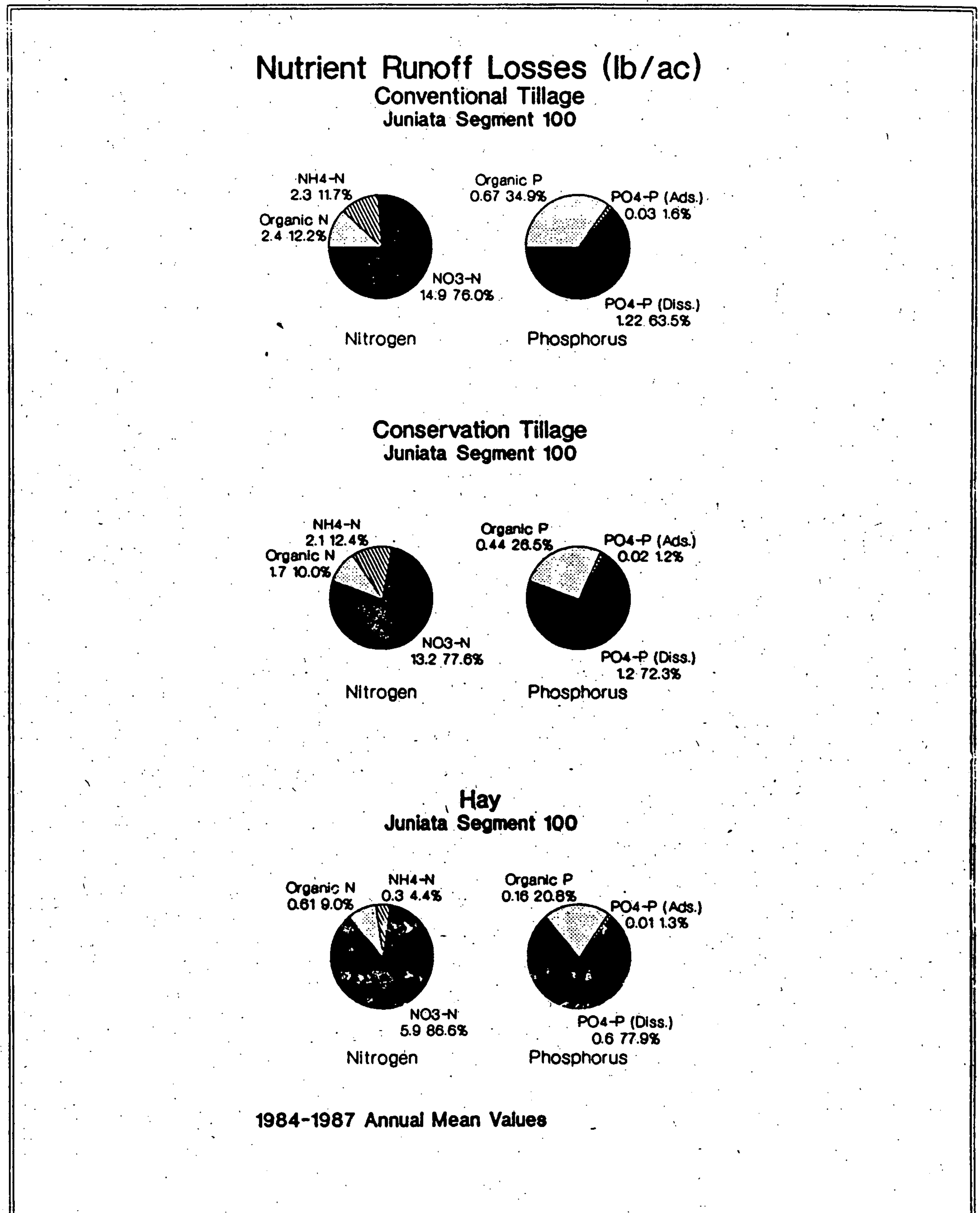


Figure 4.16 Nutrient runoff losses - Juniata Segment 100.

Review of the AGCHEM model results presented in these tables and figures, and included in Appendix C, indicate the following:

a. The nutrient applications of fertilizer and manure and the associated plant uptake of N and P dominate the input and output portions, respectively, of the nutrient balance of the croplands.

b. Mineralization is a significant source of plant available N, but not a significant source for plant available P in these simulations.

c. Plant uptake is a direct function of the nutrient application rates on each segment and land use category. Annual uptake of N is typically 70% to 90% of the application, while for P the uptake is typically about 50% of the application amount. However, there is considerable variation from segment to segment due to variations in the application rates.

d. Uptake amounts were generally less than calculated 'composite target' amounts when the segment application rates were similar to or less than the targets, and greater than the targets when the application rates were greater than the targets by a significant amount. This simply indicated that on individual segments higher application rates than expected (or required by the crop) produced higher yields and uptake than was used in our calculation of the 'composite' target uptake.

e. Plant available N is generally reduced by the processes of denitrification, NH_3 volatilization, fixation, immobilization, and leaching; plant available P is reduced primarily by fixation and immobilization. Since NH_3 volatilization and N and P fixation are not specifically modeled, immobilization was used as the primary mechanisms for losses of plant available nutrients. NH_3 immobilization was typically in the range of 15% to 30% of application amounts, while PO_4 immobilization was typically about 50% of the application. Denitrification was assumed to be small.

f. The calibration process focused on maintaining plant uptake amounts close to target levels, representing reasonable losses of plant available nutrients, and keeping NO_3, NH_3, and PO_4 runoff losses in the range of expected values.

g. Total N and Total P runoff losses are generally in the range of 10% to 30%, and 5% to 15% of application amounts, respectively. NO_3 is the largest component of Total N losses, followed by soluble NH_3, Organic N and sorbed NH_3. For Total P, soluble PO_4 is the largest, followed by Organic P and sorbed PO_4. The loadings of sediment associated organics, and sorbed NH_3 and PO_4 are direct functions of the calibrated sediment loading rate, which includes the impact of the assumed delivery ratio of 15%. Consequently, the sediment associated loadings are considerably less than expected edge-of-field values due to deposition processes affecting delivery at the scale of the model segments.

Table 4.25 SUMMARY OF OBSERVED CONCENTRATIONS FROM SELECTED FIELD MONITORING STUDIES (Means and Ranges, mg/l)

	NH4-N		NO3-N		Total N		Ortho-P		Total P		TN/TP ratio
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
Owl Run Watershed (in Segment 230) - 7.8 sq. mi.											
QOA - 4.5 sq. mi.	2.44	0.098-28.9	2.90	0.0-9.78	12.60	1.7-89.5	0.68	0.02-4.9	2.96	0.29-17.6	4.3
QOB - 0.2 sq. mi.	0.61	0.0-2.6	1.61	0.07-6.5	7.92	2.4-33.1	0.55	0.05-1.38	1.48	0.29-2.95	5.4
QOC - 1.8 sq. mi.	0.32	0.0-1.2	1.17	0.0-3.9	6.29	0.0-15.2	0.04	0.0-.15	0.94	0.0-16.2	6.7
QOD - 1.3 sq. mi.	0.43	0.0-1.35	2.60	0.0-7.75	8.40	0.0-28.9	0.26	0.0-1.56	1.60	0.0-9.4	5.3
Nomini Cr. Watershed (in Potomac Basin, Below Fall Line) - 6.7 sq. mi.											
QN1 - 5.8 sq. mi.	0.33	0.01-1.48	0.63	0.11-1.86	5.75	1.80-15.1	0.03	0.0-0.14	0.91	0.05-12.9	6.3
QN2 - 0.9 sq. mi.	0.30	0.0-1.58	1.15	0.12-2.09	7.85	2.46-39.7	0.03	0.0-0.16	1.57	0.10-16.7	5.0
Jug Bridge, Monocacy River (in Segment 210) - 817 sq. mi.											
Base Flow data	0.37	0.05-0.98	2.10	0.05-3.57	3.23	0.65-5.37	0.23	0.08-0.52	0.44	0.14-0.88	7.3
Storm Event	0.25	0.11-0.65	1.77	0.05-3.10	4.32	0.95-9.1	0.16	0.01-.44	1.10	0.06-1.9	3.9
Patuxent Watershed - Field Sites (Segment 340)											
Station H01 - 5 ac.	0.09	0.0-0.26	0.88	0.07-5.3	3.87	0.77-18.8	0.63	0.01-1.50	1.21	0.30-5.2	3.2
Station CA1 - 8 ac.	0.07	0.02-0.24	0.33	0.02-0.70	7.49	1.60-45.0	0.13	0.03-0.40	1.54	0.40-3.6	4.9

Table 4.27 SUMMARY OF PATUXENT (SEGMENT 340) SIMULATED CONCENTRATIONS by AGCHEM (Means and Ranges, mg/l)

	NH4-N		NO3-N		Total N		PO4-P		Total P		TN/TP ratio
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
CONVENTIONAL TILLAGE											
Surface & Interflow	0.38	0.04-2.51	2.58	0.0-17.60	9.96	1.83-37.10	0.41	0.12-1.90	2.34	0.35-10.80	4.3
Total	0.02	0.01-2.33	1.41	0.05-14.60	1.60	0.50-36.10	0.009	0.00-1.54	0.056	0.0-10.50	28.6
CONSERVATION TILLAGE											
Surface & Interflow	0.45	0.06-4.74	2.30	0.01-16.40	10.30	1.68-35.10	0.41	0.15-2.61	2.42	0.35-6.31	4.3
Total	0.02	0.02-4.25	1.26	0.07-14.90	1.41	0.44-31.60	0.007	0.0-2.12	0.042	0.0-6.03	33.6
HAY											
Surface & Interflow	0.13	0.01-1.53	0.35	0.0-1.16	5.38	0.31-14.20	0.26	0.04-1.20	1.57	0.11-3.96	3.4
Total	0.01	0.0-1.42	0.99	0.06-2.96	1.07	0.45-13.40	0.004	0.0-1.03	0.023	0.0-3.72	46.5

Notes:

1. Surface & Interflow concentrations are calculated as daily load/daily flow for these components when the daily flow (surface and interflow only) exceeds 0.1 in.
2. Total concentrations are based on both storm (i.e. surface and interflow) and baseflow values for the entire simulation period

The extreme values of the ratio, in the range of 100 to 500, for total concentrations in the Rappahannock (Segment 230) in Table 4.26 are due to extremely low mean TP concentrations as reflected in the observed water quality data. Since baseflow will have higher N and lower P than storm runoff, the TN/TP ratio will increase as baseflow and subsurface contributions increase as reflected in the AGCHEM results.

4.3.7 AGCHEM Conclusions and Recommendations

The AGCHEM application to the cropland areas of the Chesapeake Bay drainage has satisfied the objectives outlined at the beginning of Section 4.3, namely to (1) represent nutrient balances for the major cropland categories in each model segment, (2) allow investigation of sensitivity to climate variations and agricultural practices, and (3) provide a mechanism to project impacts of nutrient management alternatives for agricultural cropland. The results are consistent with expected nutrient balances, observed ranges of runoff concentrations, and expected ranges of nutrient loadings from cropland areas (discussed below in Section 4.4).

The AGCHEM approach to modeling the nutrient balances on agricultural cropland is exactly the type of approach recommended by the Chesapeake Bay Nonpoint Source Evaluation Panel in their report to the U.S. EPA and the CBP Executive Council. In March 1990, the EPA Administrator convened the Panel to "assess the effectiveness of current efforts to reduce nonpoint source loadings of nutrients entering the Bay system". They reviewed and evaluated the effectiveness of a wide range of nonpoint source programs, including program design, implementation, budgets, modeling and assessment methods, and research efforts. One of the key recommendations of the Panel related to new approaches to nutrient control was as follows:

> "The Panel recommends that the Bay jurisdictions and the federal agencies develop a mass balance accounting system, where nutrient loadings are balanced by the nutrients removed from the system plus those which are introduced and stored" (Chesapeake Bay Nonpoint Source Evaluation Panel, 1990).

The AGCHEM application provides an initial assessment of this 'mass balance' for cropland areas, a tool for assisting in the 1991 Re-evaluation of the 40% nutrient reduction goal of the Bay Agreement, and a framework for future efforts on nutrient management based on the mass balance approach. Recommendations to improve the use and application of AGCHEM by CBP include the following:

a. A detailed review and refinement of the current fertilizer and manure application rates, and changes expected under nutrient management alternatives should be initiated since these rates are the starting point for nutrient reduction from cropland. Plant uptake amounts under reduced nutrient application rates will need to be investigated to ensure that crop needs are met; plant uptake rates may need to be adjusted.

b. Detailed site applications of AGCHEM should be diligently pursued by

In the Phase I, the first steps in the nonpoint calibration effort involved a review and evaluation of nonpoint loading rates associated with individual land uses and nonpoint parameters used in the original Watershed Model. The goal was to define the expected range of loading rates from the available literature, as a basis for evaluating and calibrating the model predicted loading rates, and determine if any changes or adjustments to the original nonpoint parameters could be justified. The State representatives on the CBP Nonpoint Source Workgroup provided data summaries of monitoring projects and studies conducted in their respective regions to supplement the efforts of the CBPO and AQUA TERRA on this task. Table 4.29, developed in Phase I, provides a brief summary of the results of this effort, with ranges of loading rates for individual nutrient forms for the major land use categories in the Watershed Model.

Unfortunately, the available data was not sufficiently extensive or detailed to allow delineation of different loading rates for different portions of the Bay drainage area. As shown in Table 4.29 and in the original literature, the rates are quite variable with cropland showing the greatest variability and forest the least variation. For urban pervious and impervious areas, the average annual National Urban Runoff Program (NURP) loads, as complied by Schueler (1987) were used to supplement the information in Table 4.29 and guide the calibration adjustments. In summary, as shown in Table 4.29, the model predicted rates could fall within a relatively large range and still be consistent with the literature data.

In fact, the second part of this effort involved an assessment of consistency between the original model rates and the literature. In order to assess whether refinements to the potency factors and washoff parameters were justified, we compared the model predicted loading rates (which are based on the input potency factors and washoff parameters) with the loading ranges shown in Table 4.29. Our reasoning was that if the model loading rates were consistent with the literature values, we did not have a basis for changing the parameters except through calibration. The comparison showed that the model rates were consistent with the literature values, partly due to the wide range in the literature. Consequently, no changes in potency factors or washoff rates were made initially until the calibration indicated that changes were justified.

However, the subsurface concentrations used in the original Watershed Model were based on calibration at instream sites during low flow periods. Thus, the same concentrations were used for all land uses. In the Phase I work, we developed different subsurface concentrations for each land use for consistency with the hydrologic/land use variability and to better represent effects of land use changes. Initial subsurface concentrations were estimated for NH_3, NO_3, PO_4, BOD, and DO from a variety of sources including past HSPF applications within the Bay drainage, data from sites within the Patuxent and Monocacy rivers, and selected literature review articles. Generally, the highest pollutant values were estimated for cropland areas, with conservation tillage having somewhat higher values than conventional tillage. Urban subsurface concentrations were the next highest, followed by pasture, with forest areas having the lowest concentrations. Subsurface DO values were assumed to be the same for all land uses, and the same seasonal (i.e. monthly) variations as used in the original model were imposed. These initial values were then adjusted as needed during the calibration process based on the observed data and model predictions for the calibration sites throughout the drainage area.

In Phase II, Table 4.30 was developed by the CBPO from further analyses of field studies specific to the Chesapeake Bay drainage area; many of the studies were provided by members of the NRTF. Note that a number of the entries in Table 4.30 indicate 'no data' due to insufficient information for selected land uses and individual nutrient species. Table 4.31 from Beaulac (1980) and Reckhow et al (1980) show the range and median of expected loading rates (or export coefficients) only for Total N and Total P based on nation-wide data from field studies. Typically, Total N and Total P are better defined than the individual components of NH_3, PO_4, and organics; NO_3 loading rates are usually better defined than the other species since it is the most commonly measured nutrient form.

Tables 4.32, 4.33, and 4.34 are tabulations of the simulated loading rates from the Phase II simulations for each nutrient form, plus BOD, for each year of the simulation, along with the mean annual value, for model segments 60, 180, and 280, respectively. These three segments are the largest segments in each of the three major basins - Susquehanna, Potomac, and James. Similar tabulations are provided for additional model segments in Appendix C. Note that Total N and Total P are <u>calculated</u> from the other nutrient forms and BOD as described in Section 5.0 and the table footnote.

Table 4.35 summarizes the mean annual rates for 17 model segments throughout the Bay drainage area, including both above and below Fall Line segments; the detailed tabulations for these model segments are included in Appendix C.1. Table 4.36 provides a capsule summary of the mean and ranges of loading rates for the segments listed in Table 4.35; although this summary is not based on <u>all</u> model segments (segment tabulations are being currently compiled), it does provide a good indication of the simulated mean and range for each land use and selected nutrient forms. Comparing the mean annual rates in Table 4.36 with the expected means and ranges from Tables 4.29 through 4.31 indicates the following general conclusions:

a. Generally, the simulated annual loading rates are within the range of expected values shown in Table 4.29 with some deviations. Annual rates for PO_4 from forest and pasture, and NH_4 from forest occasionally tend to be toward the lower end of the defined range. Annual PO_4 rates from the cropland areas are somewhat higher than the defined range.

b. For non-cropland categories, the Total N and Total P simulated values compare favorably with both the expected means and ranges.

c. For the cropland categories of Conventional Tillage, Conservation Tillage, and Hay, the Total N and Total P simulated values are generally close to the mean lumped cropland data; the Hay values are generally less than the mean, while the tillage categories are usually greater than the mean but well within the observed range.

TABLE 4.31 NUTRIENT EXPORT COEFFICIENTS FROM BEAULAC (1980) AND RECKHOW ET AL. (1980)

Land Use	Minimum	Phosphorus Median	Maximum
	<------	lbs/acre/year	------>
Forest	0.017	0.18	0.74
Pasture	0.12	0.72	4.37
Cropland	0.09	0.89	1.96
Urban	0.17	0.98	5.56

Land Use	Minimum	Nitrogen Median	Maximum
	<------	lbs/acre/year	------>
Forest	1.23	2.32	5.58
Pasture	1.32	4.63	27.52
Cropland	1.96	8.03	71.0
Urban	1.32	4.91	34.3

Source: Nutrient export coefficients from (Beaulac (1980) and Reckhow et al. (1980).

TABLE 4.33 WATERSHED MODEL SEGMENT 180 ANNUAL LOADING RATES (LB/AC/YR)

LAND USE	YR	NH4	NO3	PO4	BOD	ORG-N	ORG-P	TN *	TP *
FOREST	84	0.072	4.12	0.012	7.91			4.61	0.072
	85	0.053	3.41	0.005	2.81			3.61	0.026
	86	0.046	2.99	0.004	2.93			3.19	0.026
	87	0.059	3.47	0.009	5.09			3.80	0.048
	AVERAGE	0.057	3.50	0.008	4.69			3.80	0.043
CONV.TILL	84	2.73	22.71	1.46	400.00	5.86	1.61	37.66	3.98
	85	3.05	12.74	1.29	86.00	1.20	0.33	18.36	1.82
	86	1.38	9.15	0.92	84.90	1.47	0.41	13.35	1.52
	87	2.79	13.70	0.97	174.00	2.44	0.67	21.70	2.04
	AVERAGE	2.49	14.58	1.16	186.23	2.74	0.76	22.77	2.34
CONSER. TILL	84	3.82	21.85	2.06	181.00	4.66	1.23	33.21	3.70
	85	2.08	11.20	1.36	44.80	0.89	0.24	14.88	1.70
	86	1.42	7.06	1.00	31.10	0.67	0.18	9.64	1.25
	87	2.98	11.63	1.16	80.20	1.78	0.47	17.67	1.81
	AVERAGE	2.58	12.94	1.40	84.28	2.00	0.53	18.85	2.12
PASTURE	84	0.10	6.08	0.06	48.00			8.72	0.42
	85	0.07	5.16	0.04	29.80			6.81	0.27
	86	0.06	4.40	0.03	25.00			5.79	0.22
	87	0.08	5.10	0.04	35.30			7.05	0.31
	AVERAGE	0.08	5.19	0.04	34.53			7.09	0.31
URBAN-PERV.	84	0.31	7.61	0.25	54.90			10.83	0.67
	85	0.20	6.23	0.14	29.50			7.99	0.37
	86	0.16	5.20	0.11	22.40			6.55	0.28
	87	0.22	6.19	0.17	36.60			8.35	0.45
	AVERAGE	0.22	6.31	0.17	35.85			8.43	0.44
HAY	84	0.42	4.68	2.14	203.00	1.97	0.53	10.30	3.13
	85	0.13	1.72	0.69	42.70	0.36	0.09	2.89	0.88
	86	0.15	1.78	0.88	27.40	0.27	0.07	2.63	1.01
	87	0.30	2.18	1.49	89.10	0.79	0.21	4.69	1.90
	AVERAGE	0.25	2.59	1.30	86.25	0.85	0.23	5.13	1.73
URBAN-IMPV.	84	1.42	3.04	0.66	86.50			9.04	1.31
	85	1.34	2.85	0.62	81.00			8.48	1.23
	86	1.36	2.89	0.63	82.30			8.61	1.25
	87	1.39	2.95	0.64	84.00			8.79	1.28
	AVERAGE	1.38	2.93	0.63	83.45			8.73	1.27
MANURE SEG.	84	243.0	60.7	60.7	4,251.6	1,822.1	364.4	2,125.8	425.2
	85	198.2	49.5	49.5	3,468.5	1,486.5	297.3	1,734.2	346.8
	86	170.7	42.7	42.7	2,987.8	1,280.5	256.1	1,493.9	298.8
	87	202.0	50.5	50.5	3,535.7	1,515.3	303.1	1,767.9	353.6
	AVERAGE	203.5	50.9	50.9	3,560.9	1,526.1	305.2	1,780.5	356.1

* For all land uses, except CNT, CST, HAY and MANURE land uses, TN and TP are calculated by:
TN = NH3 + NO3 + 0.053*BOD TP = PO4 + 0.0076*BOD

For CNT, CST, and HAY land uses, TN and TP are calculated by:
TN = NH3 + NO3 + ORGN + 0.3*0.053*BOD TP = PO4 + ORGP + 0.3*0.0076*BOD

For the MANURE land use, TN and TP are calculated by:
TN = NH3 + NO3 + ORGN TP = PO4 + ORGP

TABLE 4.35 SUMMARY OF AVERAGE ANNUAL LOADING RATES FOR EACH LAND USE IN SELECTED MODEL SEGMENTS (LB/AC/YR)

SEGMENT	LANDUSE	NH4	NO3	PO4	ORG-N	ORG-P	TN	TP
SEGMENT 10	Conv. Till	2.39	13.80	0.95	3.91	0.76	20.10	1.71
E. Branch Susquehanna	Cons. Till	2.12	12.10	0.93	2.48	0.49	16.70	1.42
	Hay	0.76	8.84	1.10	1.20	0.23	10.80	1.33
	Pasture	0.08	3.00	0.02	1.06	0.15	4.14	0.17
	Manure Seg	212	53	53	1,593	319	1,858	372
	Forest	0.04	1.91	0.01	0.27	0.04	2.22	0.05
	Urban	0.59	4.53	0.31	3.28	0.42	8.40	0.73
SEGMENT 30	Conv. Till	2.31	13.00	0.96	3.49	0.69	18.80	1.65
E. Branch Susquehanna	Cons. Till	2.83	12.80	1.07	2.37	0.46	18.00	1.53
	Hay	1.02	10.00	1.17	1.08	0.21	12.10	1.38
	Pasture	0.09	5.89	0.02	1.39	0.20	7.37	0.22
	Manure Seg	255	64	64	1,915	383	2,234	447
	Forest	0.05	5.10	0.01	0.34	0.05	5.49	0.06
	Urban	1.07	7.17	0.38	3.56	0.50	11.80	0.88
SEGMENT 40	Conv. Till	3.21	12.60	1.12	5.79	1.14	21.60	2.26
E. Branch Susquehanna	Cons. Till	3.15	11.20	0.96	3.35	0.70	17.70	1.66
	Hay	1.13	8.58	1.65	1.29	0.25	11.00	1.90
	Pasture	0.09	5.88	0.02	1.88	0.27	7.85	0.29
	Manure Seg	287	72	72	2,155	431	2,514	503
	Forest	0.05	6.02	0.01	0.43	0.06	6.50	0.07
	Urban	1.34	7.03	0.66	4.13	0.58	12.50	1.24
SEGMENT 50	Conv. Till	6.95	22.00	1.38	4.25	0.79	33.20	2.17
W. Branch Susquehanna	Cons. Till	8.77	20.50	1.38	3.43	0.51	32.70	1.89
	Hay	1.41	15.00	1.30	1.29	0.23	17.70	1.53
	Pasture	0.11	4.26	0.02	1.06	0.15	5.43	0.17
	Manure Seg	301	75	75	2,257	452	2,633	527
	Forest	0.10	3.00	0.01	0.35	0.05	3.45	0.06
	Urban	0.65	5.97	0.26	3.88	0.56	10.50	0.82
SEGMENT 60	Conv. Till	4.93	20.80	1.19	4.82	0.95	30.55	2.14
W. Branch Susquehanna	Cons. Till	5.14	19.40	1.22	3.98	0.58	28.52	1.80
	Hay	1.33	14.20	1.06	1.36	0.26	16.89	1.32
	Pasture	0.10	5.16	0.02	1.62	0.23	6.88	0.25
	Manure Seg	261	65	65	1,962	393	2,287	458
	Forest	0.09	4.62	0.01	0.33	0.05	5.04	0.06
	Urban	0.72	7.74	0.33	3.64	0.52	12.10	0.85
SEGMENT 110	Conv. Till	2.08	11.60	1.31	18.02	3.06	31.70	4.37
Lower Susquehanna	Cons. Till	2.39	11.90	1.37	9.71	1.73	24.00	3.10
	Hay	0.49	4.79	0.75	5.92	0.97	11.20	1.72
	Pasture	0.21	7.60	0.01	3.39	0.49	11.20	0.50
	Manure Seg	221	55	55	1,657	332	1,933	387
	Forest	0.09	6.04	0.01	0.35	0.04	6.48	0.05
	Urban	0.95	8.26	0.36	5.99	0.85	15.20	1.21
SEGMENT 160	Conv. Till	4.64	13.20	0.96	6.76	1.16	24.60	2.12
N. Branch Potomac	Cons. Till	3.34	9.83	1.09	4.03	0.70	17.20	1.79
	Hay	0.31	3.83	2.29	1.93	0.33	6.07	2.62
	Pasture	0.11	6.98	0.08	2.26	0.32	9.35	0.40
	Manure Seg	240	60	60	1,799	360	2,099	420
	Forest	0.06	3.61	0.01	0.24	0.04	3.91	0.05
	Urban	0.66	5.58	0.38	3.72	0.54	9.96	0.92

TABLE 4.35 (Continued)

SEGMENT	LANDUSE	NH4	NO3	PO4	ORG-N	ORG-P	TN	TP
SEGMENT 310	Conv. Till	1.90	12.50	0.93	8.60	1.62	23.00	2.55
Appomattox	Cons. Till	1.68	11.50	0.89	5.02	0.99	18.20	1.88
	Hay	0.57	4.33	1.01	2.82	0.54	7.72	1.55
	Pasture	0.05	1.51	0.03	2.31	0.33	3.87	0.36
	Manure Seg	242	61	61	1,815	363	2,118	424
	Forest	0.05	0.68	0.01	0.28	0.04	1.01	0.05
	Urban	0.69	2.35	0.30	2.93	0.42	5.97	0.72
SEGMENT 340	Conv. Till	1.55	10.20	0.63	6.75	1.72	18.50	2.35
Patuxent	Cons. Till	1.22	8.69	0.46	4.59	1.15	14.50	1.61
	Hay	0.11	2.47	0.15	2.18	0.53	4.76	0.68
	Pasture	0.07	2.64	0.03	0.53	0.07	3.24	0.10
	Manure Seg	216	54	54	1,623	325	1,893	379
	Forest	0.04	1.33	0.01	0.22	0.03	1.59	0.04
	Urban	0.64	4.72	0.28	3.98	0.57	9.34	0.85
SEGMENT 380	Conv. Till	1.59	11.20	0.42	4.71	0.93	17.50	1.35
Chester	Cons. Till	1.14	9.92	0.35	3.14	0.62	14.20	0.97
	Hay	0.25	3.59	0.18	1.60	0.29	5.44	0.47
	Pasture	0.07	4.73	0.04	1.04	0.15	5.84	0.19
	Manure Seg	190	48	48	1,425	285	1,663	333
	Forest	0.04	2.20	0.01	0.26	0.03	2.50	0.04
	Urban	0.45	4.69	0.22	2.11	0.30	7.25	0.52
SEGMENT 400	Conv. Till	1.88	11.90	0.53	3.82	0.68	17.60	1.21
Choptank	Cons. Till	1.18	10.20	0.44	2.52	0.46	13.90	0.90
	Hay	0.30	3.80	0.22	0.92	0.16	5.02	0.38
	Pasture	0.07	4.69	0.04	0.95	0.13	5.71	0.17
	Manure Seg	190	48	48	1,425	285	1,663	333
	Forest	0.04	2.28	0.003	0.10	0.02	2.42	0.02
	Urban	0.48	4.83	0.23	2.20	0.31	7.51	0.54
SEGMENT 430	Conv. Till	3.20	17.80	1.34	3.80	0.68	24.80	2.02
Pocomoke	Cons. Till	2.19	16.60	1.22	2.41	0.44	21.20	1.66
	Hay	0.16	2.94	0.21	0.74	0.13	3.84	0.34
	Pasture	0.07	4.54	0.04	1.74	0.25	6.35	0.29
	Manure Seg	190	48	48	1,425	285	1,663	333
	Forest	0.04	2.30	0.004	0.13	0.02	2.47	0.02
	Urban	0.55	4.74	0.26	2.13	0.30	7.42	0.56
SEGMENT 450	Conv. Till	1.55	11.00	0.89	3.75	0.86	16.30	1.75
Lower Susquehanna	Cons. Till	1.16	10.20	0.63	2.94	0.65	14.30	1.28
	Hay	0.21	3.10	0.35	1.71	0.31	5.02	0.66
	Pasture	0.08	5.55	0.03	0.89	0.13	6.52	0.16
	Manure Seg	212	53	53	1,594	319	1,859	372
	Forest	0.05	2.35	0.003	0.10	0.02	2.50	0.02
	Urban	0.68	5.25	0.31	2.31	0.34	8.24	0.65
SEGMENT 500	Conv. Till	1.15	8.27	0.56	9.58	2.33	19.00	2.89
Lower Patuxent	Cons. Till	0.71	6.42	0.39	6.07	1.44	13.20	1.83
	Hay	0.13	2.57	0.15	4.91	0.89	7.61	1.04
	Pasture	0.08	4.95	0.04	1.25	0.18	6.28	0.22
	Manure Seg	211	53	53	1,583	316	1,847	369
	Forest	0.05	2.35	0.003	0.14	0.02	2.54	0.02
	Urban	0.58	5.00	0.27	2.29	0.33	7.87	0.60

TABLE 4.36 OVERALL SIMULATED MEAN AND RANGE of LOADING RATES FROM SELECTED SEGMENTS LISTED IN TABLE 4.35 (LB/AC/YR)

	NH3-N	NO3-N	PO4-P	TN	TP
FOREST					
Mean	0.06	2.77	0.01	3.09	0.04
Range	0.04-0.10	0.55-6.04	0.003-0.03	0.81-6.50	0.02-0.09
CONVENTIONAL TILL					
Mean	2.57	13.19	0.95	22.04	2.18
Range	0.90-6.95	8.27-22.00	0.42-2.17	15.20-33.20	1.21-4.37
CONSERVATION TILL					
Mean	2.24	11.69	0.91	17.90	1.68
Range	0.71-8.77	6.42-20.50	0.35-1.97	11.0-32.70	0.90-3.10
PASTURE					
Mean	0.10	4.70	0.06	6.47	0.29
Range	0.05-0.25	1.01-8.53	0.01-0.28	2.28-11.20	0.10-0.91
URBAN*					
Mean	0.65	5.49	0.33	9.27	0.78
Range	0.21-1.34	1.27-9.73	0.16-0.66	3.43-15.20	0.42-1.24
HAY					
Mean	0.51	6.13	0.87	8.72	1.26
Range	0.11-1.41	2.47-15.00	0.15-2.29	3.84-17.70	0.34-2.62
MANURE					
Mean	230	57	57	2010	402
Range	190-301	48-75	48-75	1663-2633	333-527

* - Includes area weighted totals from both pervious and impervious segments.

SECTION 5.0

RIVER TRANSPORT AND TRANSFORMATION SUBMODEL

This section discusses the HSPF modules used to simulate the instream transport and water quality processes considered in the Phase II Watershed Model. Each Above Fall Line (AFL) Watershed Model segment is associated with a corresponding river channel/reservoir which receives nonpoint, point, and atmospheric deposition loadings. These inputs of flow, heat, sediment, and inorganic and organic nutrients then undergo the various instream processes, including phytoplankton growth, and are transported downstream toward the Bay. Table 4.2 lists the water quality constituents simulated in Phase II.

A major focus of Phase II was to include a more detailed representation of instream nutrient processes, particularly with respect to sediment-nutrient interactions. With the exception of a simple organic N and P settling algorithm, previous versions of the Watershed Model have not considered sediment transport and the associated sediment-nutrient interactions that are critical to an accurate representation of the water quality of the rivers in the basin. Consequently, the Phase II effort included significant modifications to the nutrient simulation routines in HSPF to allow inorganic N (ammonium) and P (orthophosphate) to adsorb to sediment and undergo settling, resuspension, and transport. Also, the denitrification algorithm was modified to provide a more flexible representation of nitrate losses via this process.

The methods used to simulate instream processes in run-of-the-river and reservoir reaches are described in the following subsections. Additional details of the model equations and algorithms are contained in the HSPF Users Manual (Johanson et al, 1984).

5.1 OVERVIEW OF THE INSTREAM MODEL

Within the HSPF program, the RCHRES module sections are used to simulate hydraulics, sediment transport, water temperature, and water quality processes that result in delivery of flow and loadings to the Bay. The structure chart of the RCHRES module sections is shown in Figure 5.1. Each module section consists of a group of subroutines that perform the individual process simulations. For example the HYDR module performs the flow/hydraulic simulation that drives the sediment transport and pollutant advection. The water quality processes in the Watershed Model are performed by the RQUAL module, which is further subdivided into submodules for performing simulation of different water quality processes as shown in Figure 5.2. All processes in the Watershed Model are simulated using a one hour time step.

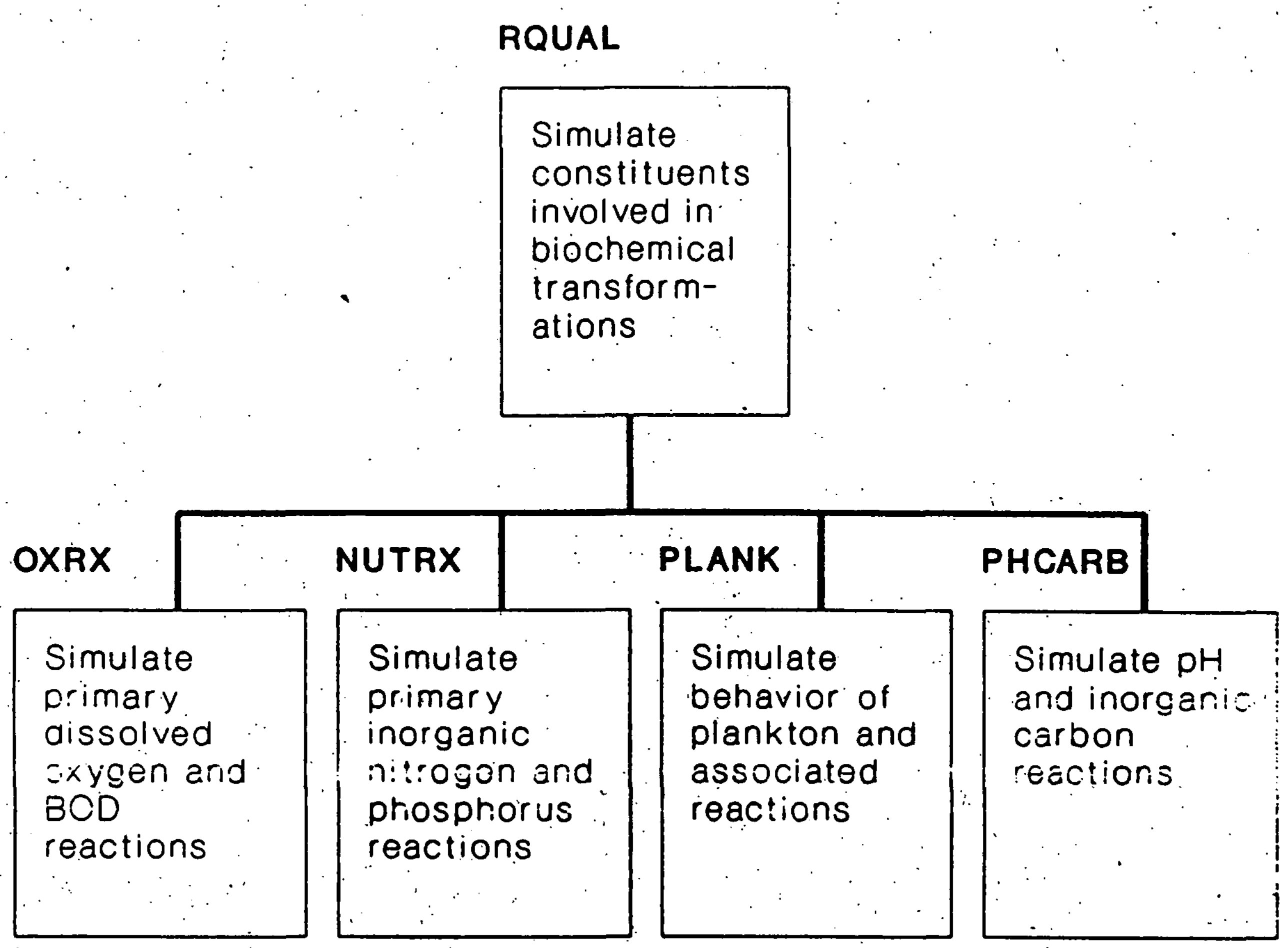


Figure 5.2 Structure chart of the RQUAL section of the RCHRES module.

Geological Survey (Armbruster, 1977) and the Susquehanna River Basin Commission (Jackson, 1979).

5.2.2 Water Temperature

Water temperature is simulated in the Watershed Model because of its fundamental effect upon water quality processes. Dissolved oxygen saturation level and the rates of BOD decay, nitrification, and phytoplankton growth are all directly affected by water temperature.

Instream water temperature processes are simulated by the HTRCH module, shown in Figure 5.3. Changes in heat content of a reach result primarily from advective transport, runoff and rainfall entering the reach, and heat transfer processes across the air-water interface. The advective transport is simulated by treating water temperature as a thermal concentration. This allows use of the standard method within the model for computing advective transport of dissolved constituents.

The mechanisms affecting heat transfer across the air-water interface are absorption of solar (shortwave) radiation, absorption/emission of infrared (longwave) radiation, conduction-convection, and evaporation. Each mechanism is evaluated separately, and the net transfer is the sum of the individual effects. Solar radiation absorption is computed by the following equation:

$$QSR = 0.97 * CFSAEX * SOLRAD * 10. \qquad (5.1)$$

where:

- QSR = radiation absorbed ($kcal/m^2/hr$)
- 0.97 = fraction of incident radiation absorbed
- CFSAEX = fraction of gage radiation that is incident to the surface
- SOLRAD = solar radiation (langleys/hr)
- 10. = conversion from langleys to $kcal/m^2$

The net infrared radiation transfer, considering both atmospheric radiation and back radiation from the water surface, is dependent on temperature and cloud cover. It is computed using the following equation:

$$QB = SIGMA * (TWKELV^4 - KATRAD * 10^6 * CLDFAC * TAKELV^4) \qquad (5.2)$$

where:

- QB = net transport of infrared radiation ($kcal/m^2/hr$)
- SIGMA = Stefan-Boltzmann constant multiplied by 0.97 ($kcal/m^2/hr/K^4$)
- TWKELV = water temperature (°K)
- KATRAD = atmospheric longwave radiation coefficient
- CLDFAC = cloud factor = $1.0 + (0.0017 * CLOUD^2)$
- CLOUD = cloud cover (tenths)
- TAKELV = air temperature corrected for elevation (°K)

Air temperature is corrected for elevation by application of a lapse rate to the gage temperature. If it is raining, the lapse rate is 0.00194 C/ft; otherwise, the lapse rate is selected from a table of 24 hourly values ranging from 0.0019 to 0.0028 C/ft.

Conductive-convective heat transfers are caused by the temperature difference between the air and the water; the net transfer is computed as follows:

$$QH = CFPRES * KCOND * 10^{-4} * WIND * (TW - AIRTMP) \quad (5.3)$$

where:

- QH = net conductive-convective heat transfer (kcal/m²/hr)
- CFPRES = pressure correction factor dependent on elevation
- KCOND = adjustable coefficient
- WIND = wind speed (m/hr)
- TW = water temperature (°C)
- AIRTMP = air temperature (°C)

Evaporative heat losses occur when water evaporates from the water surface. HSPF uses the following equation to compute the evaporative heat losses:

$$QE = HFACT * KEVAP * 10^{-9} * WIND * (VPRESW - VPRESA) \quad (5.4)$$

where:

- QE = heat loss due to evaporation (kcal/m²/hr)
- HFACT = latent heat of vaporization multiplied by density
- KEVAP = evaporation coefficient
- VPRESW = saturation vapor pressure at water surface; dependent on water temperature (mbar)
- VPRESA = vapor pressure of air above water surface; dependent on dewpoint temperature (mbar)

Since three of the above mechanisms depend on water temperature, the final water temperature is actually computed using the partial derivatives of QB, QH, and QE with respect to water temperature. Calibration of the four air-water interface processes is accomplished using the adjustable parameters CFSAEX, KATRAD, KCOND, and KEVAP.

In addition to the processes discussed above, significant heat inputs to the Watershed Model result from the nonpoint and point source inflows. Five time series of meteorologic data are utilized by the Watershed Model to simulate heat processes. These time series, which are obtained from the regional meteorologic database, are:

1. Hourly solar radiation (langleys/hour)
2. Hourly air temperature (°F)
3. Hourly wind speed (miles/hr)
4. Daily dewpoint temperature (°F)
5. Daily cloud cover (tenths)

5.2.3 Sediment Transport

Sediment transport simulation was added to the Phase II Watershed Model because of the need to simulate sediment-nutrient processes. Sediment transport is simulated in HSPF by the SEDTRN module, which computes scour, deposition, and advection of three sediment size fractions. Figure 5.4 shows the principal quantities and fluxes represented in this module.

Since sediment migration characteristics and adsorptive properties of sediment vary with particle size, SEDTRN considers three size fractions (sand, silt, and clay), each with its own set of parameters. The silt and clay fractions are categorized as cohesive sediments, and are simulated differently from the sand or noncohesive fraction. The module maintains storages of each size fraction in the bed and in suspension, and computes scour and deposition fluxes between these storages. It also computes a bed depth based on sediment porosities and width and length of the bed. SEDTRN assumes a single bed layer, so that all sediment is available for scour; burial and armoring are not considered.

Scour and deposition of cohesive sediments depends on the bed shear stress computed in the HYDR module, and is based on equations developed by Krone (1962) and Partheniades (1962). Whenever bed shear stress in the reach is less than the user-defined critical shear stress for deposition, sediment settles to the bed. Conversely, whenever the shear is greater than the critical shear stress for scour, erosion of sediment from the bed occurs. The following two equations are used for each size fraction to compute the deposition and scour fluxes, respectively.

$$DEPCNC = CONC * (1.0 - EXP(-W/AVDEPM) * (1.0 - TAU/TAUCD)) \qquad (5.5)$$

where:

DEPCNC = concentration of suspended sediment lost to deposition (mg/L/hr)
CONC = concentration of suspended sediment at start of interval (mg/L)
W = settling velocity of size fraction (m/hr)
AVDEPM = average depth of reach (m)
TAU = bed shear stress (kg/m^2)
TAUCD = critical shear stress for deposition (kg/m^2)

$$SCRCNC = M/AVDEPM * 1000 * (TAU/TAUCS - 1.0) \qquad (5.6)$$

where:

SCRCNC = concentration of suspended sediment added to suspension by scour (mg/L/hr)
M = erodibility coefficient ($kg/m^2/hr$)
1000 = conversion from kg/m^3 to mg/L
TAUCS = critical shear stress for scour (kg/m^2)

The principal calibration parameters for cohesive sediments are the settling velocity (W), erodibility coefficient (M), and the critical shear stresses (TAUCD and TAUCS). The critical stresses affect the timing of deposition and scour, while W and M are useful in adjusting the magnitudes. In the Watershed Model, initial values of TAUCD and TAUCS were determined from time series plots of the simulated bed shear stresses in each reach. These adjustments were made so that occurrence of scour and deposition was restricted to extremely high and low stress periods, respectively. As an example, based on the plot of shear stress shown in Figure 5.5, the TAUCS and TAUCD values for REACH 290 in the James River were set to the following values:

Critical Shear Stresses for REACH 290
(lbs/ft^2)

	DEPOSITION	SCOUR
SILT	0.030	0.137
CLAY	0.029	0.135

Values of M and KSER (the soil erosion parameter for pervious areas) were then calibrated by comparing simulated and observed suspended sediment concentrations during scour events and periods of high loading.

Sand transport in SEDTRN is simulated by one of three optional methods. The Toffaleti and Colby methods are detailed formulations primarily applicable to wide rivers, while the user-specified power function (of velocity) is simpler and more generally applicable. The power function method is used in the Watershed Model because of the variety of channel types encountered in the basin, and because of the greater degree of control over the sand simulation that this option provides.

Sand scour and deposition in SEDTRN depends on the amount of material the flow is capable of carrying. If the amount of sand being transported is less than the flow can carry for the hydrodynamic conditions of the reach, sand will be scoured from the bed. Conversely, deposition occurs if the sand in suspension exceeds the flow's capacity. The potential sandload or sand carrying capacity for the power function method is computed directly as:

$$PSAND = KSAND * AVVELE^{EXPSND} \tag{5.7}$$

where:

PSAND - sand carrying capacity of the flow (mg/L)
KSAND - coefficient in the sandload equation
EXPSND - exponent in the sandload equation
AVVELE - average velocity of the flow (ft/s)

5.2.4 Water Quality Processes

Water quality simulation in the Watershed Model is performed by the RQUAL module which consists of four interacting submodules. Three of these submodules are used in the Watershed Model: 1) OXRX, which simulates oxygen and BOD dynamics; 2) NUTRX, which simulates inorganic nitrogen and phosphorus reactions; and 3) PLANK, which handles phytoplankton and other organic materials. These submodules are executed sequentially in the order listed, and each submodule requires the execution of those above it. For example execution of NUTRX requires that OXRX be executed, and PLANK requires execution of both OXRX and NUTRX. OXRX execution does not require any other submodule.

In this section, overviews of the nitrogen and phosphorus cycles are described first, and then the individual processes simulated in each submodule are described under the corresponding section below. Table 5.1 provides a summary of all of the water quality constituents and processes simulated in the Watershed Model along with the submodules that handle them.

The complete schematic of instream nitrogen cycling in the Watershed Model is shown in Figure 5.6. The distinct forms of nitrogen are nitrate (NO_3), dissolved ammonia (NH_3), particulate ammonia (ads-NH_3), degradable organic N (BOD), living organic N (phytoplankton), and dead refractory organic N (ORN). The principal changes made as part of Phase II are the addition of the particulate ammonia and a more flexible algorithm for denitrification of NO_3.

The parallel schematic for phosphorus is shown in Figure 5.7. As for nitrogen, improvements made to the Phase II model are the addition of the particulate orthophosphate constituent and its associated processes sorption/desorption and settling/resuspension.

5.2.4.1 Dissolved oxygen and BOD dynamics

The primary reactions of dissolved oxygen and BOD simulated in the Watershed Model are performed by OXRX, while processes simulated in the NUTRX and PLANK submodules also affect oxygen and BOD concentrations. Figures 5.8 and 5.9 are the flow diagrams for oxygen and BOD; the processes simulated in the Watershed Model are delineated by dashed lines.

Reaeration is computed as the product of a coefficient dependent on hydraulic conditions, and a driving force which is the difference between the actual dissolved oxygen concentration and the saturated value for the current conditions. The general expression is:

$$DELDOX = KOREA * (SATDO - DOXS) \quad (5.8)$$

where:
- DELDOX = change in oxygen concentration over the interval (mg/L)
- KOREA = reaeration coefficient
- SATDO = oxygen saturation level at the current water temperature (mg/L)
- DOXS = oxygen concentration at start of interval (mg/L)

The saturation value is based on temperature as follows:

$$SATDO = 14.652 + TW*(-.4102 + TW*(.00799 - .7777E\text{-}4*TW)) * CFPRES \quad (5.9)$$

where:
- TW = water temperature (°C)
- CFPRES = ratio of atmospheric pressure to pressure at sea level

Estimation of the reaeration coefficient for free flowing river channels uses a modified version of Churchill's empirical relationship of depth and velocity which has the following form:

$$KOREA = 0.726 * AVVELE^{0.969} * 1.024^{(TW - 20.)}/AVDEPE^{1.673} \quad (5.10)$$

where:
- AVVELE = average velocity (ft/s)
- AVDEPE = average depth (ft)

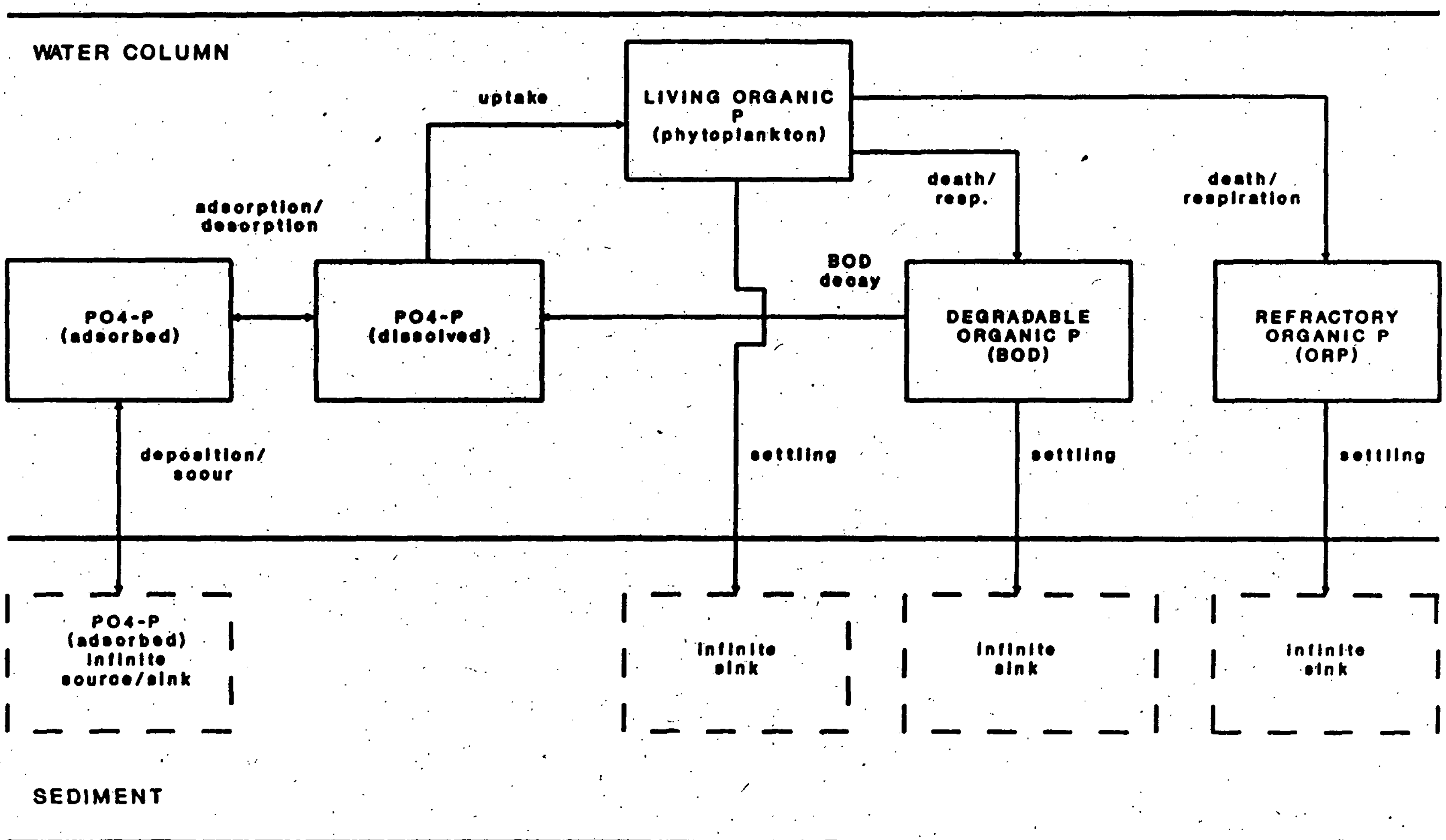


Figure 5.7 Insteam phosphorus dynamics in the Watershed Model.

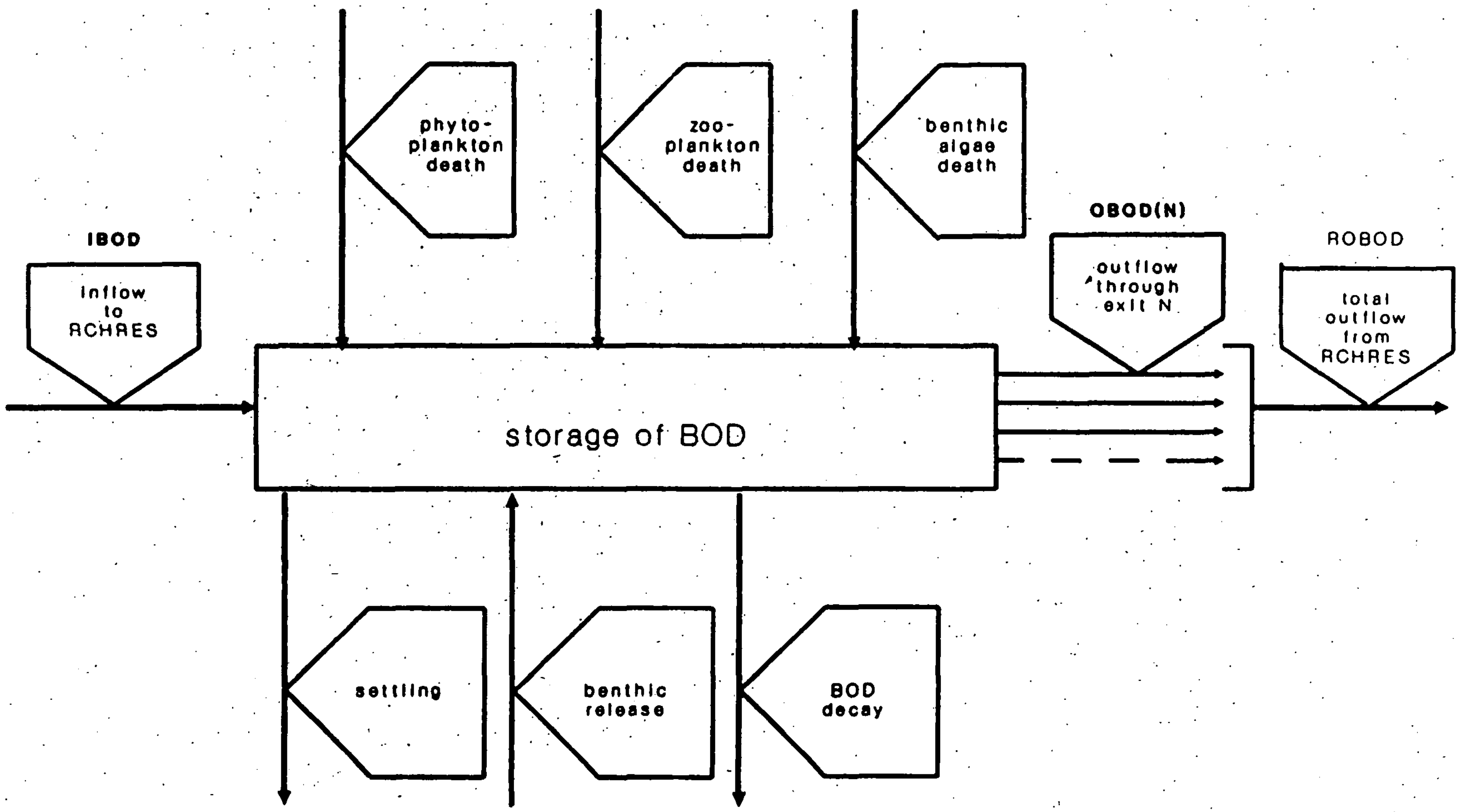


Figure 5.9 Flow diagram of BOD in the OXRX section of the RCHRES module.

TW - water temperature (°C)
TAM - total dissolved ammonia-N concentration (mg/L)

This process is dependent upon a suitable supply of dissolved oxygen; i.e., nitrification is set to zero if the DO concentration is below 2 mg/L. In HSPF, the amount of oxygen used during nitrification is 4.33 mg oxygen per mg NH_3-N oxidized completely to NO_3-N.

Denitrification is the reduction of nitrate by facultative anaerobic bacteria such as Pseudomonas, Micrococcus, and Bacillus. These bacteria can use NO_3 for respiration in the same manner that oxygen is used under aerobic conditions. Facultative organisms use oxygen until the environment becomes nearly or totally anaerobic, and then switch over to NO_3 as their oxygen source. The end product of denitrification is assumed to be nitrogen gas.

Denitrification does not occur unless the dissolved oxygen concentration is below a user-specified threshold value (DENOXT). If that situation occurs, denitrification is assumed to be a first-order process based on the NO_3 concentration. The amount of denitrification is calculated by the following equation:

$$DENNO_3 = KNO_320 * (TCDEN**(TW-20)) * NO_3 \quad (5.13)$$

where:
$DENNO_3$ - amount of NO_3 denitrified (mg N/L per hour)
KNO_320 - NO_3 denitrification rate coefficient at 20°C (/hr)
TCDEN - temperature correction coefficient for denitrification
NO_3 - nitrate concentration (mg N/L)

NUTRX simulates the exchange of ammonium between the dissolved state and adsorption on suspended sediment, i.e., adsorption/desorption is not simulated in the bed sediment. The sorbents considered are sand, silt, and clay, which are simulated in section SEDTRN. The adsorption/desorption process for each sediment fraction is represented with an equilibrium linear isotherm (K_d) which is described as follows:

$$ADSNH_3 = DISNH_3 * KDNH_3 \quad (5.14)$$

where:
$ADSNH_3$ - equilibrium concentration of adsorbed ammonia on sediment fraction J (mg/kg)
$DISNH_3$ - equilibrium concentration of dissolved ammonia (mg/L)
$KDNH_3$ - adsorption parameter (or K_d) (L/kg)

The advective processes for ammonia adsorbed to a sediment size fraction are:

1. Inflow to the RCHRES of ammonia attached to suspended sediment.

2. Migration of ammonia from suspension to the bed as a result of deposition of the sediment to which the ammonia is adsorbed.

TALGRH, no growth occurs. Between TALGRL and TALGRM, the correction factor increases linearly from 0 to 1, and between TALGRM and TALGRH, the correction factor is 1. In the Watershed Model, the high temperature threshold is 95°F, and the optimum temperature (TALGRM) is 86°F. The low temperature threshold was set to 26.7°F for most of the basin, except for James and other Virginia tributaries, where lower values (> -10°F) are needed to produce sufficient algal growth during winter.

Algae depend on uptake of orthophosphorus to provide the phosphorus necessary for growth. In situations where phosphorus is the limiting factor, the growth rate depends on both phosphate and nitrate as follows:

$$GROP = \frac{MALGRT * PO_4 * NO_3}{(PO_4 + CMMP) * (NO_3 + CMMNP)} \qquad (5.15)$$

where:

GROP - unit growth rate based on P-limitation (/hr)
MALGRT - temperature-corrected maximum growth rate (/hr)
CMMP - phosphate Michaelis-Menten constant for P-limited growth (mg/L)
CMMNP - nitrate Michaelis-Menten constant for P-limited growth (mg/L)

Nitrogen, which is also essential to algal growth, is obtained from the total pool of dissolved NH_3 and NO_3 in the reach. The ratio of NO_3 uptake to total inorganic N ($NO_3 + NH_3$) uptake is governed by a preference factor (ALNPR) which ranges from 0.25 to 0.35 in the Watershed Model. The nitrogen-limited growth rate is calculated by the following equation:

$$GRON = \frac{MALGRT * (NH_3 + NO_3)}{CMMN + (NH_3 + NO_3)} \qquad (5.16)$$

where:

GRON - unit growth rate based on N-limitation (/hr)
CMMN - Michaelis-Menten constant for N-limited growth (mg/L)

During each time step, the model computes the amount of radiation available to support algal growth by applying light absorption rates to the incident light available at the surface, and assuming that all phytoplankton are at the mid-depth of the reach. The overall light extinction is the sum of the base extinction coefficient, a chlorophyll A factor, and a sediment factor. Finally, the light-limited growth rate is computed as:

$$GROL = \frac{MALGRT * LIGHT}{CMMLT + LIGHT} \qquad (5.17)$$

where:

GROL - unit growth rate based on light-limitation (/hr)
CMMLT - Michaelis-Menten constant for light-limited growth (Ly/min)
LIGHT - light intensity available to algae (Ly/min)

parameter used in the Watershed Model to adjust algal losses from the system.

5.2.4.4 Organic nitrogen, organic phosphorus, and total organic carbon

Dead refractory organic matter is simulated as three state variables in the model. ORN, ORP, and ORC are the nitrogen, phosphorus, and carbon species, respectively. These constituents undergo advection, they are generated as a result of phytoplankton death (see above), and they are lost from the system via settling. They are constituents in the respective <u>total</u> organic quantities (TORN, TORP, TORC) which are also made up of contributions from BOD and phytoplankton. It is these simulated total organic state variables that are compared directly with the "observed" organics concentrations (organic N, organic P, and TOC). The following expressions, based on the Watershed Model stoichiometry, define the total organic state variables:

$$TORN = ORN + 0.0863 * PHYTO + 0.0529 * BOD \quad (5.19)$$

$$TORP = ORP + 0.0123 * PHYTO + 0.00756 * BOD \quad (5.20)$$

$$TORC = ORC + 0.49 * PHYTO + 0.301 * BOD \quad (5.21)$$

where:

PHYTO = phytoplankton concentration (mg/L as biomass)
BOD = biochemical oxygen demand (mg/L as oxygen)

In the Phase II Model, total organic carbon (TOC) replaces BOD as the primary indicator of carbon species. This change was implemented because of the greater availability of observed TOC data for direct comparison with the simulation. However, in order to simulate TOC, it was necessary to characterize the loadings of carbon since the Phase I model did not account for the total carbon loadings. Previously, loading of nonliving carbon species occurred entirely through the BOD loading. In the Phase II model, refractory organic carbon (ORC) loadings from point and nonpoint sources are explicitly included by assuming that ORC loads are proportional to the existing BOD loads. Therefore, the BOD loads are multiplied by a factor and input to the system as refractory organic carbon.

5.2.4.5 Review and adjustment of instream water quality parameters

The chemical and biological parameters were reviewed and adjusted in Phase II. Some of the parameter values were atypical of the ranges used in surface water modeling. This may have been due to the magnification or reduction of certain parameters in order to compensate for phenomenon that are not simulated by the model. For example, in the initial versions of the model, temperature endpoints of the smoothing functions were set at atypical levels to permit phytoplankton growth in all four seasons. In addition, in previous versions of the model maximal algal growth rate may have been set artificially high to account for both free-floating and benthic algae as well as adsorption-sedimentation mechanisms for reducing inorganic P and N during instream transport.

A series of steps, following the hierarchy of model sections were executed during the process of adjusting the water quality parameters. For instance, hydraulics simulation was finalized before temperature was adjusted and the dissolved oxygen simulation was completed before proceeding to the adjustment of inorganic nutrients.

TABLE 5.2 INSTREAM WATER QUALITY PARAMETERS

Parameter	Description	Value	Unit	Ref.
TCBOD	Temperature Coefficient for BOD decay	1.047	N/A	1,2
TCGINV	Temperature Coefficient for gas invasion	1.024	N/A	1,2
TCNIT	Temperature Coefficient for nitrification	1.045	N/A	1,2
TALGRH	Temperature above which algal growth ceases	95.0	*F	2
TALGRL	Temperature below which algal growth ceases	26.7	*F	2
TALGRM	Temperature below which algal growth is retarded	86.0	*F	2
CMMLT	Half-saturation constant for light	0.040	(ly/min)	1,2
CMMN	Half-saturation constant for nitrate	0.025	(mg/L)	1,2
CMMNP	NO3 Concentration for Phosphorus limiting growth	0.0001**	(mg/L)	1,2
CMMP	PO4 Concentration for Phosphorus limiting growth	0.005	(mg/L)	1,2
KBOD20	BOD Decay rate at 20 *C	0.004	(1/hr)	1,2
KODSET	BOD settling rate	0.021***	(ft/hr)	1,2
KNH320	Nitrification rate at *C	0.004	(1/hr)	1,2
MALGR	Maximal algal growth rate	0.142	(1/hr)	1,2
EXTB	Base light extinction coefficient	0.575	(1/ft)	*
ALR20	Algae respiration rate at 20 *C	0.005	(1/Hr)	1,2
ALDH	High algal death rate	0.003	(1/hr)	1,2
PHYSET	Phytoplankton settling rate	0.027***	(ft/hr)	1
REFSET	Dead refractory settling rate	0.021***	(ft/hr)	1
RATCLP	Chlorophyll-a to P ratio in biomass	0.68	N/A	1,2
ALNPR	Fraction of NO3 as nitrogen source for algal growth	0.35	N/A	1

1. Reference 1 - Bowie et al., 1985
2. Reference 2 - Potomac Model, Thomann and Fitzpatrick, 1982
* calculated from tidal fresh monitoring data.
** Set at a value as to make the parameter inoperative.
*** Adjusted by calibration for each reach.

TABLE 5.3 CHANNEL REACH INFORMATION

SUBBASIN REPRESENTED	REACH	LENGTH (MI)	TRIBUTARY AREA (MI^2)	TYPE*	PRIMARY TRIBUTARY
SUSQUEHANNA					
EAST BRANCH	10	108.0	2647	S	EAST BRANCH
	20	184.4	4991	S	EAST BRANCH
	30	94.9	2440	S	EAST BRANCH
	40	68.4	1492	S	EAST BRANCH
WEST BRANCH	50	91.0	1428	S	WEST BRANCH
	60	88.2	4262	S	WEST BRANCH
	70	42.1	1330	S	WEST BRANCH
JUNIATA	90	27.0	937	L	RAYSTOWN RESERVOIR
	100	111.9	2418	S	JUNIATA RIVER
LOWER	80	50.6	2286	S	SUSQUEHANNA RIVER
	110	24.2	1922	S	SUSQUEHANNA RIVER
CONOWINGO	120	19.6	743	L	CONOWINGO RESERVOIR
	140	14.0	295	L	CONOWINGO RESERVOIR
PATUXENT	330	12.0	133	L	PATUXENT RESERVOIRS
	340	21.0	215	S	PATUXENT RIVER
POTOMAC					
UPPER	160	92.3	1349	S	N. BRANCH POTOMAC
	170	126.6	1481	S	S. BRANCH POTOMAC
	175	43.3	1257	S	POTOMAC RIVER
SHENANDOAH	190	139.0	1623	S	SHENANDOAH RIVER
	200	57.8	1406	S	SHENANDOAH RIVER
LOWER	180	78.6	2507	S	POTOMAC RIVER
	210	64.5	971	S	MONOCACY RIVER
	220	41.0	955	S	POTOMAC RIVER
RAPPAHANNOCK	230	73.0	1604	S	RAPPAHANNOCK RIVER
YORK					
MATTAPONI	235	27.6	257	S	MATTAPONI RIVER
	240	35.7	338	S	MATTAPONI RIVER
PAMUNKEY	250	16.3	334	L	LAKE ANNA
	260	44.5	737	S	PAMUNKEY RIVER
JAMES	265	12.0	348	L	JAMES RIVER
	270	114.0	2917	S	JAMES RIVER
	280	107.3	2989	S	JAMES RIVER
	290	39.0	512	S	JAMES RIVER
APPOMATTOX	300	108.4	1194	S	APPOMATTOX RIVER
	310	13.8	158	L	LAKE CHESDIN

* S - River reach
L - Lake/reservoir reach

SECTION 6.0

HYDROLOGY CALIBRATION RESULTS

This section discusses the results of the hydrology calibration, including discussion of tasks performed in both Phase I and Phase II. Much of the text from the Phase I report is retained in order to provide a complete description of the hydrology calibration effort; however, only the results from Phase II are presented here since they supersede the Phase I results for the 1984-87 simulation period. Readers interested in the 1974-78 hydrology results are referred to the Phase I report (Donigian et al, 1990).

6.1 OVERVIEW AND STEPS IN THE HYDROLOGIC CALIBRATION PROCESS

The purpose and justification for the Phase I hydrology re-calibration was to include snow simulation, evaluate any changes resulting from the revised land use data and addition of the animal waste segments, and incorporate any changes necessitated by allowing different hydrologic parameters for each land use category. In Phase I, the 1974-78 period was chosen for the primary re-calibration effort because the existing data base covered this period and the model had been previously verified for the same period. In effect, the goal of the effort was to evaluate the cumulative impact of all the changes to the hydrologic parameters, and then perform the parameter adjustments needed to 're-calibrate' the model. The model was then run on the 1984-85 period and the results were analyzed, evaluated, and provided the basis for the recommended focus of the hydrology calibration tasks in Phase II.

As discussed in Section 1.3, the Phase I recommendations included extending the simulation and calibration through 1988 in order to provide a more realistic evaluation of the Watershed Model's ability to represent the hydrology during the critical 1984-88 period. This period was used as a basis for both the Bay model and the 40% Chesapeake Bay Agreement. Additional Phase I recommendations included evaluation of the snow simulation for 1984-88, investigation of the Conowingo Reservoir operation and simulation, and further investigation of the simulation of the November 1985 storm. Due to limitations on data availability for 1988 at the time the meteorologic was needed, the simulation could only be extended through 1987.

The steps performed in the combined Phase I/II efforts were as follows:

a. Identify watershed areas needing snow simulation.

b. Perform snow calibration for 1974-78 to observed snow depth data.

c. Evaluate hydrologic parameters for each land use category.

TABLE 6.1 ELEVATION, TEMPERATURE AND SNOW DEPTHS FOR WATERSHED MODEL LAND SEGMENTS

Subbasin		Average+	DECEMBER			JANUARY			FEBRUARY		
RCH	Elev	Elev	Normal	Snow on Ground*		Normal	Snow on Ground*		Normal	Snow on Ground*	
	(feet)	(feet)	Temp	Max	Min	Temp	Max	Min	Temp	Max	Min
10(1)	3300-650	1860	27.3	10.3	T	22.5	13.5	3.3	23.5	13.9	4.8
20(1)	3300-650	1512	25.9	9.7	T	20.8	14.8	3.1	22.0	15.7	4.3
30(1)	2000-650	1368	27.2	8.5	T	22.5	12.8	3.1	23.8	14.9	4.1
40(2)	1640-650	930	27.3	4.4	T	23.3	5.5	T	25.0	6.4	T
50(1)	3300-650	1980	26.4	6.0	0.0	22.1	11.9	1.3	23.2	15.2	3.1
60(1)	3300-650	1260	28.9	6.9	0.0	24.4	10.5	1.1	25.7	11.7	2.6
70(2)	3300-500	524	30.7	3.3	0.0	26.2	8.1	T	28.2	7.4	1.1
80(2)	1640-330	680	32.3	1.9	0.0	28.3	6.7	T	30.3	7.7	1.6
90(2)	3300-650		30.9			26.9			28.5		
100(2)	3300-300	772	31.5	2.2	T	27.5	6.2	T	29.2	7.0	T
110(2)	1640-330	469	33.3	1.7	0.0	29.3	5.7	T	31.2	6.1	T
120(2)	1000-500	510	32.2	3.2	0.0	28.5	8.1	0.0	30.5	9.6	T
140(3)	1000-	40	34.4	1.5	0.0	30.4	4.0	0.0	32.2	6.9	0.0
160(1)	2400-650	1693	31.4	4.7	0.0	27.8	11.3	1.0	29.7	12.9	2.2
170(2)	3300-650	1868	34.7	3.2	0.0	31.3	9.5	T	33.3	9.0	T
175(2)	1640-650	1288	33.3	1.9	0.0	29.5	8.1	T	31.2	8.6	1.5
180(2)	2000-400	547	33.4	1.6	0.0	26.6	6.9	0.0	31.8	7.1	T
190(3)	3600-650	1880	35.4	2.2	0.0	32.1	6.3	0.0	34.1	6.5	T
200(3)	1640-400	460	34.5	1.0	0.0	30.8	5.1	0.0	32.8	4.9	T
210(2)	2000-300	710	33.3	1.8	0.0	29.4	6.3	T	31.6	9.2	T
220(3)	2000-	910	35.8	1.8	0.0	31.4	6.3	0.0	33.6	5.9	T
230(4)	1000-	500	34.5	1.2	0.0	31.2	4.9	0.0	33.0	4.7	T
250(4)	1000-	220	37.9	1.3	0.0	34.7	4.0	0.0	36.4	2.9	0.0
260(4)	1000-	320	38.7	1.6	0.0	35.8	5.5	0.0	38.1	4.0	0.0
265(4)	3300-1640	2579	33.9	2.3	0.0	30.8	6.2	0.0	32.8	5.4	T
270(4)	3300-650	1060	40.0	T	0.0	35.3	4.2	0.0	37.8	4.3	0.0
280(4)	1000-	916	38.5	T	0.0	35.4	3.8	0.0	37.4	3.9	0.0
290(4)	500 -	164	39.9	T	0.0	36.6	3.2	0.0	38.9	2.7	0.0
300(4)	500 -	164	39.4	T	0.0	37.0	3.2	0.0	39.2	2.7	0.0

+ - Average of snow measuring stations elevation (ft) in that Subbasin (see attached Notes).
* - Average maximum snow on ground and average minimum snow on ground (see attached Notes).
T - Trace of snow.

Segment Categories:

(1)-Temperature below 30 (F) and max snow on ground above 10 (in) for two or more winter months.
(2)-Temperature below 32 (F) and max snow on ground below 10 (in) and above 6 (in) for two or more winter months.
(3)-Temperature below 32 (F) and max snow on ground below 10 (in) and above 6 (in) for one month.
(4)-Temperature above 32 (F) and/or max snow on ground below 6 (in) for two or more months.

NOTE For subbasins 40, 110 and 200 the snow gages are located at the lower end of the elevation range. So, an exception is made to include these subbasins under the next highest category.

extreme, segments under Category #4 do not require snow simulation due to above freezing temperatures and minimal observed snowfall.

With regard to the 'marginal' segments under Categories #2 and #3, the actual snow depth records were reviewed (as discussed under step c. above) to assess both the maximum depths achieved and the typical duration of snow cover during the winter months. Based on this assessment, segments under Category #3 were eliminated from contention because maximum depths rarely exceeded 10 to 12 inches and usually lasted only a few days. Similarly, under Category #2, segments 110, 120, 140, 180, and 210 were eliminated due to depth and duration of snow cover; depths rarely exceeded 12 inches and cover occasionally lasted up to two weeks at the most.

However, segments 40, 70, 80, 90, 100, 170, and 175, under Category #2 frequently showed snow cover lasting a month or more, and depths often exceeded 12 to 18 inches. Consequently, we felt that these segments would have significant snow depths, and subsequent storage and carry-over of moisture from one month to another; in our opinion, this justified the need for snow simulation.

Based on these analyses, the dividing line for snow simulation (as shown in Figure 6.1) occurs about midway through the Lower Susquehanna, at the northern boundary of the Lower Potomac, and at the southern boundary of the Upper Potomac. Since each segment is simulated with one set of input and parameters, the dividing line follows segment boundaries. To add or delete areas for snow simulation, an <u>entire</u> segment would need to be added or deleted. Additional areas can be added for snow simulation in future efforts to those currently simulated, if justified. However, the overall hydrologic calibration results (discussed below) appear to confirm the snow segment selection.

6.2.2 <u>Snow Calibration and Simulation Results</u>

In both Phase I and Phase II, snow calibration was performed on Segment 20 in the East Branch of the Susquehanna, Segment 50 in the West Branch of the Susquehanna, and Segment 160 in the Upper Potomac. These segments were chosen to specifically span the geographic extent of the snow simulation region and include segments with some snow depth measurements; see Figure 6.1 for the segment locations within the snow region. Since snow depth is highly variable between locations within a segment, we included as many observations as possible in the calibration.

The primary goals of the calibration were to capture the general time period of snow cover, the magnitude of the depth of the snow pack, and the general time frame for disappearance or melt of the pack in the spring. Parameters relating to the 'catch' of the precipitation gage (SNOWCF), the magnitude of the melt components (CCFACT), the snow density/moisture content (RDCSN), and the ground-associated melt (MGMELT) were adjusted in Phase I to obtain the best overall agreement between the observed and simulated timeseries and frequency of snow depth values.

The Phase I report included the calibrated frequency curves for snow depth for Segments 20, 50, and 160, and the daily observed and simulated snow depths for Segment 20 for each winter period from 1974-78 starting in January 1974. Both the

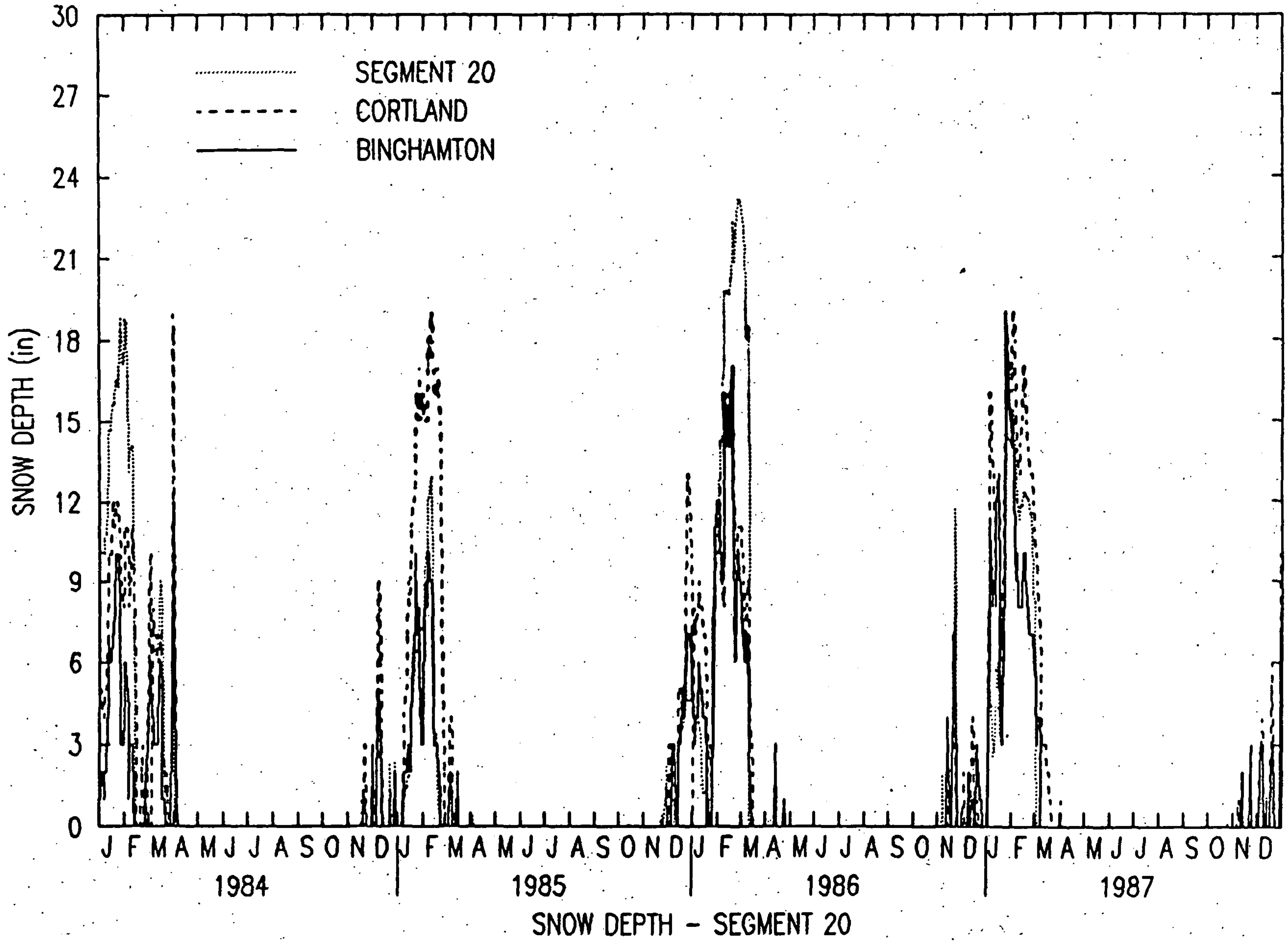


Figure 6.2 Simulated and observed snow depth for Model Segment 20, 1984-87.

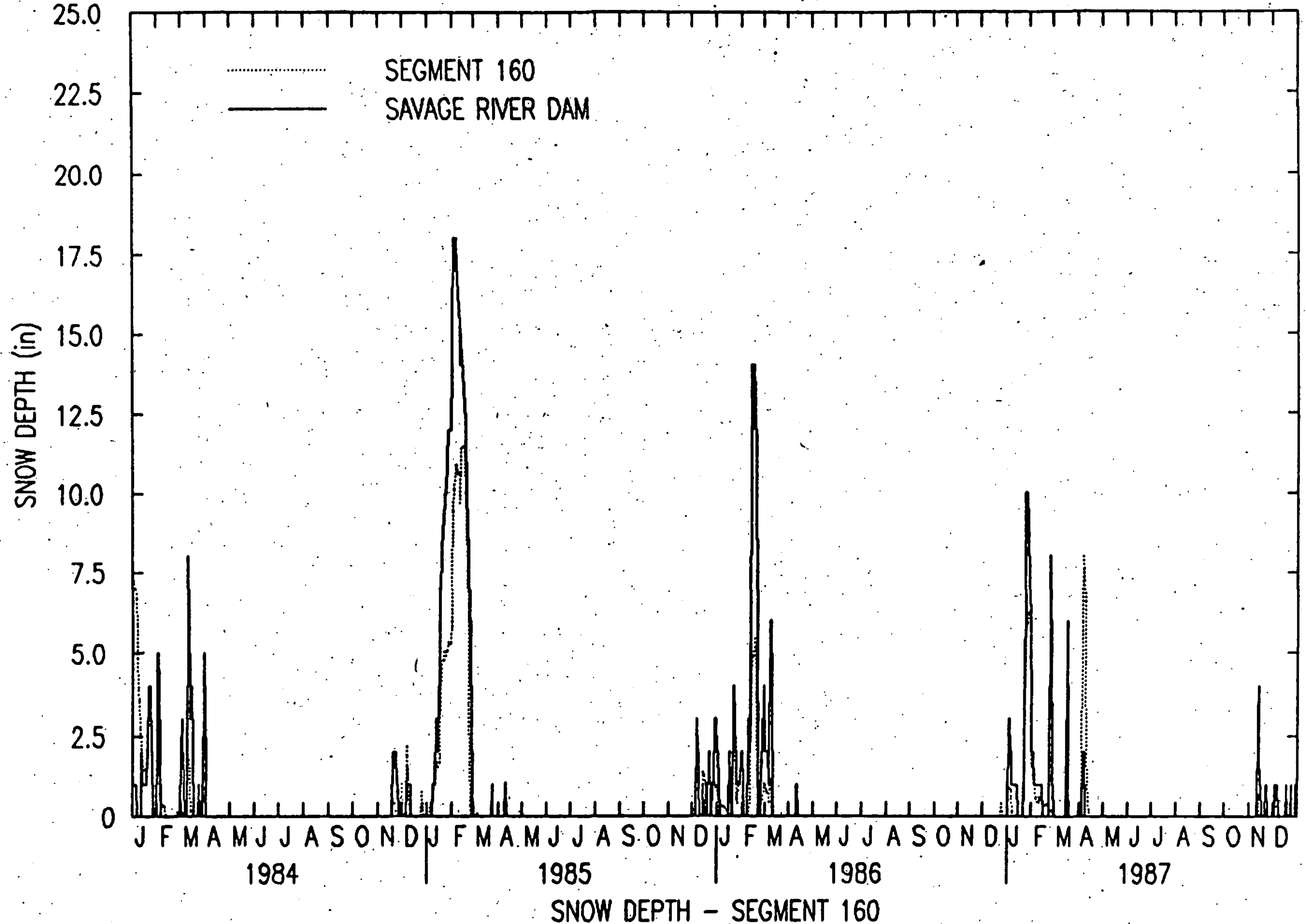


Figure 6.4 Simulated and observed snow depth for Model Segment 160, 1984-87.

TABLE 6.2 LAND USE COVER VALUES USED IN THE WATERSHED MODEL FOR NON-CROPLAND AREAS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
FOREST	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
PASTURE	0.90	0.90	0.90	0.91	0.91	0.91	0.93	0.93	0.93	0.91	0.90	0.90
URBAN	0.90	0.90	0.90	0.91	0.93	0.93	0.93	0.93	0.93	0.91	0.90	0.90

hydrologic simulation, the monthly rainfall interception values in the Model were adjusted to be consistent with the seasonality and magnitude of the COVER value for each land use.

Values for SLSUR and KRER were provided by CBPO based on soils information for all segments in the watershed. Slope values for SLSUR were derived from knowledge of the land use categories typically associated with different soil classifications. Values for KRER were estimated by the 'erodibility factor' in the Universal Soil Loss Equation based on tabulations from the SCS.

LSUR values were estimated with respect to corresponding slope values for each land use; areas with high slopes were assigned low values of LSUR and low slopes were assigned higher values, based on experience with the model.

NSUR is the Manning's roughness factor for overland flow. The following values assigned to each land category were initially developed in Phase I and subsequently revised in Phase II based on information in Knisel et al (1980), Engman (1986), and Donigian et al (1983):

Forest	0.35
Pasture	0.15
Urban Pervious	0.10
Conventional Tillage	0.05 - 0.06
Conservation Tillage	0.16 - 0.185
Urban Impervious	0.03

INFILT values are primarily based on calibration. For each land segment, we imposed a distribution of values based on experience that had the highest values for forest areas, the lowest values for cropland, and intermediate values for urban pervious and pasture. During the calibration effort, this ordering of values was maintained with individual segment values adjusted as dictated by the calibration process.

TABLE 6.3 WATERSHED MODEL HYDROLOGY AND WATER QUALITY CALIBRATION STATIONS

Model Seg.	Sta. #	Station Name	Status	Hydro.	Water Qual.	Cont. Temp.	Cont. Sed.
SUSQUEHANNA RIVER BASIN							
20	01515000	Sus. R. nr Waverly, NY	P	X			
40	01540500	Sus. R. nr Danville, PA	C	X	X		
70	01553500	WB Sus. R. @ Lewisburg, PA	C	X	X		
100	01567000	Juniata R. @ Newport, PA	C	X	X	X	X
80	01570500	Sus. R. @ Harrisburg,PA	C	X	X		
110	01576000	Sus. R. @ Marietta, PA	P	X			
140	01578310	Sus. R. @ Conowingo, MD	C	X	X	X	X
POTOMAC RIVER BASIN							
175	01613000	Potomac R. @ Hancock, MD	C	X			
220	06146580	Pot. R. @ Chain Bridge, DC	C	X	X		
200	01636500	Shenandoah R. @ Millville, WV	C	X	X		
180	01618000	Potomac R. @ Shepardstown, WV	P	X	X		
JAMES RIVER BASIN							
280	02035000	James R. @ Cartersville, VA	C	X	X		
290	02037500	James R. nr Richmond, VA	P	X			
270	02025500	James R. @ Holcombs Rock, VA	C	X		X(Buchanan)	
OTHER SITES							
310	02041650	Appomattox R. @ Matoaca, VA	C/P	X	X		
220	01646500	Pot. R. @ Lit. Falls Dam, DC	P	X			
180	01638500	Pot. R. @ Point of Rocks, MD	C	X		X	X
210	01643000	Monocacy R. @ Jug Bridge, MD	P	X		X	X
230	01668000	Rappahannock R. nr Fred., VA	C	X	X		
240	01674500	Mattaponi R. nr Beulah., VA	C	X	X		
260	01673000	Pamunkey R. nr Hanover, VA	C	X	X		
340	01594440	Patuxent R. nr Bowie, MD	C	X	X	X	X
330	01592500	Patux. R. nr Laurel, MD	P	X			

Proposed Stations for Hydrology and Water Quality Phase I Recalibration
C = calibration station; P = potential calibration stations.

TABLE 6.4 (continued)

Model Seg. Number	USGS Station Number	Station Name	1974-78 Mean Obs. Annual Flow (in)	1974-78 Mean Sim. Annual Flow (in)	1974-78 R^2 Ave. Daily	1974-78 R^2 Ave. Monthly	1984-87 Mean Obs. Annual Flow (in)	1984-87 Mean Sim. Annual Flow (in)	1984-87 R^2 Ave. Daily	1984-87 R^2 Ave. Monthly
260	01673000	Pamunkey R. @ Hanover, VA.	-	-	-	-	14.26	14.10	0.7170	0.8323
310	02041650	Appomattox R. @ Matoaca, VA.	-	-	-	-	13.31	13.88	0.7328	0.8153
340	01594440	Patux. R. nr. Bowie, MD.	11.48	11.43	0.3658	0.9392	11.34	11.75	0.5928	0.7729

The end result of these differences and inconsistencies between the two periods was to preclude the use of the 1984-85 as an effective period for verification of the hydrology simulation in Phase I. Since the evaporation difference was the major concern, the only calibration efforts performed for the 1984-85 simulation were constant adjustments to the input evapotranspiration timeseries. That is, we adjusted a single number, usually in the range of 0.8 to 0.95, multiplying the input data to obtain improvement in annual flow volumes. These were the only adjustments during the Phase I calibration for the 1984-85 period.

As reported in the Phase I report, the results for 1984-85 were not nearly as close to observed data values as in the earlier 1974-78 period. Although mean annual flow volumes were calibrated with the evaporation adjustment to maintain close agreement, both the daily and monthly R^2 values were considerably lower at most stations. In addition, the frequency curves generally show much greater deviations, such as the lower peak flows and the higher base flows than observed. However, the daily flow comparison still showed good tracking between the simulated and observed values, except for selected peak flow events and during winter snowmelt periods.

Due to the need for a better flow simulation for the 1984-85 period, our recommendations for additional efforts in Phase II were presented in Section 1.3 and are briefly listed below:

a. Extend the data base and simulation through 1988 or 1989, and calibrate as needed to improve the flow simulation.

b. Obtain snow depth data for the 1984-89 period to check and evaluate the snow simulation (as discussed above).

c. Re-evaluate and investigate the Conowingo Reservoir simulation for 1984-89.

d. Investigate the storm of November 1985 in the Upper Potomac since it was not well simulated, in terms of peak flow, in the Phase I effort.

In Phase II, all these tasks were performed, except that the meteorologic data base could only be extended through 1987 since the 1988 data was not available at that time. With the extended data base, the model required only minor adjustments to the evaporation for most subbasins to produce the final results shown in Table 6.4. This, in effect, was a pseudo-verification of the Phase I calibration, since the same model parameters were used except for minor changes to the evaporation multiplier. For the smaller subbasins and portions of the Susquehanna Basin, additional minor adjustments were needed to the infiltration (INFILT) and groundwater recession (AGWRC) parameters to improve the seasonal flows and frequency curves.

Figures 6.5 through 6.12 show the flow frequency and daily timeseries curves, respectively, for the four major basin stations: Susquehanna River at Harrisburg, Susquehanna River at Conowingo Reservoir, Potomac River at Washington, D.C., and James River at Cartersville. Complete results for all simulation years and all

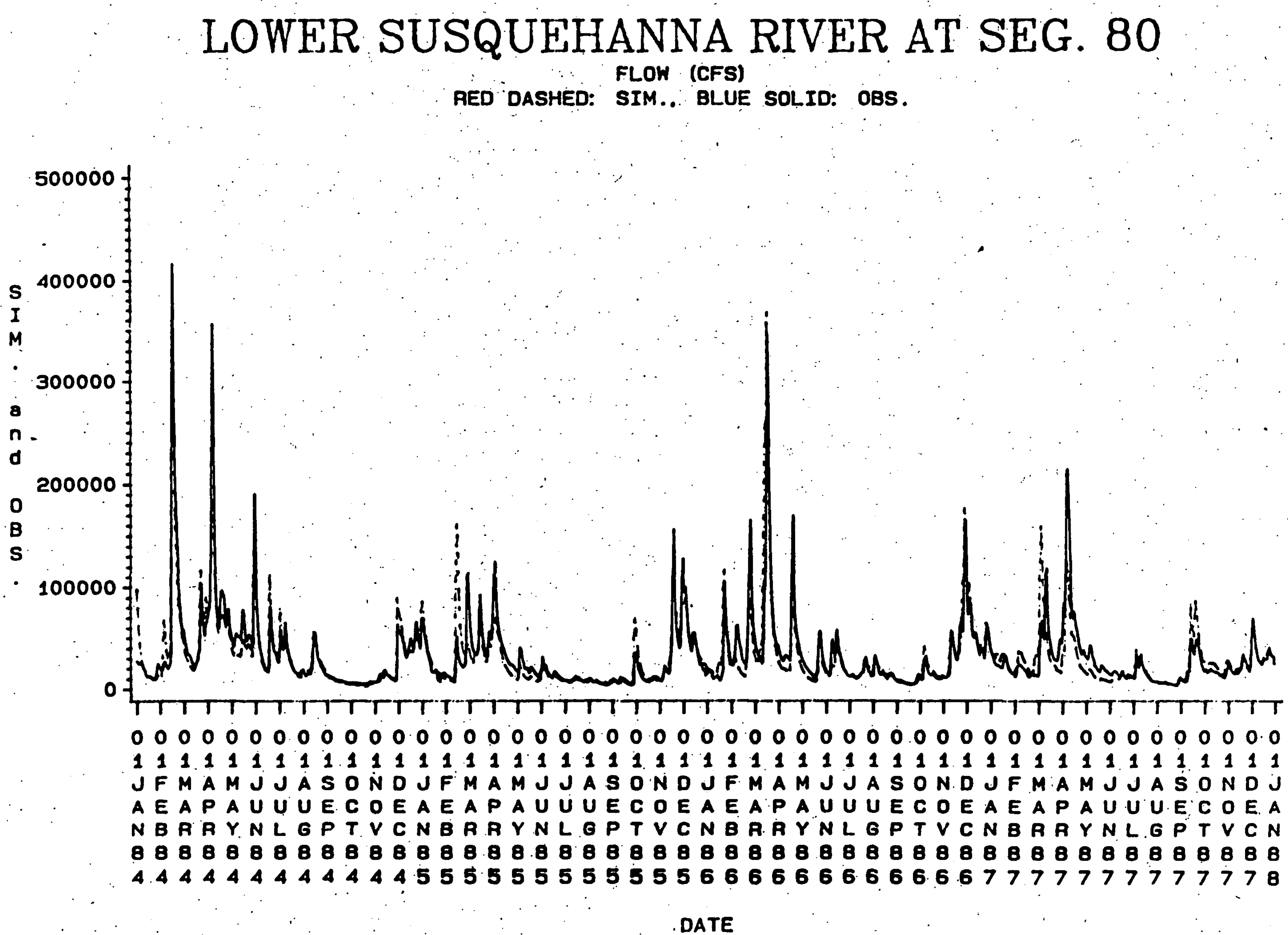


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Figure 6.6 Simulated and observed daily flow for Harrisburg, PA, Segment 80, 1984-87.

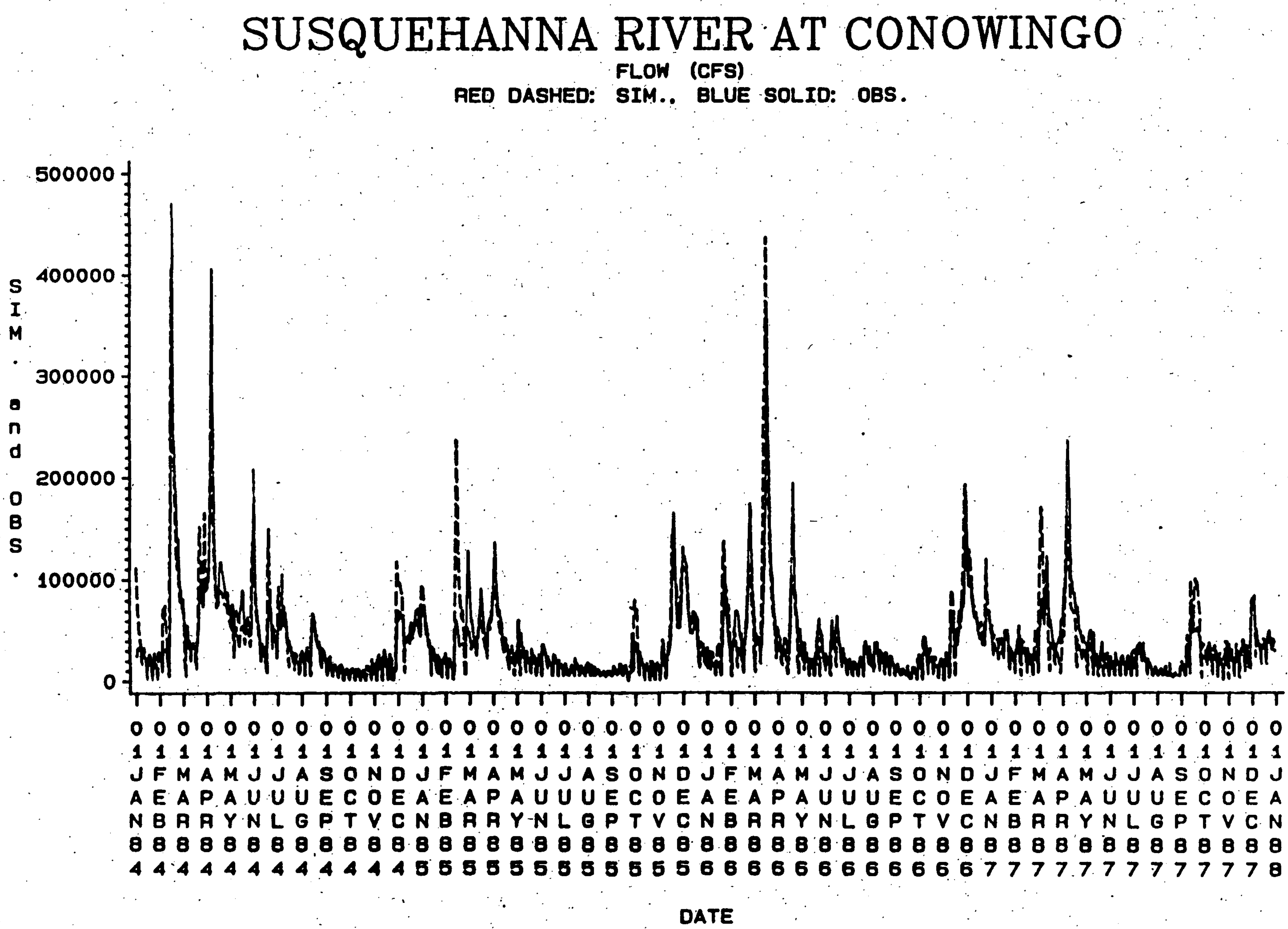

Figure 6.8 Simulated and observed daily flow for Conowingo Reservoir, MD, Segment 140, 1984-87.

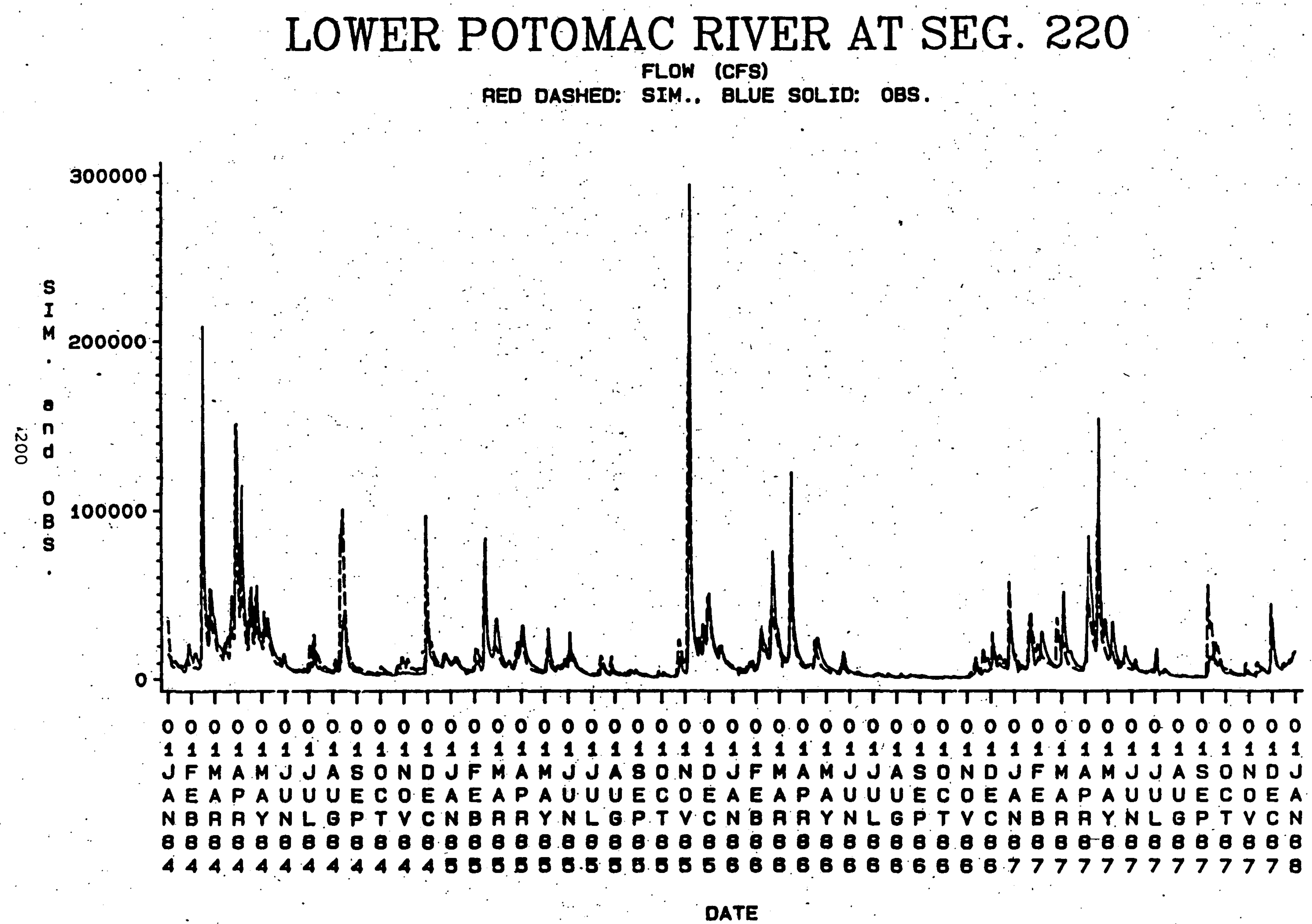

Figure 6.10 Simulated and observed daily flow for Potomac River, Washington, DC, Segment 220, 1984-87.

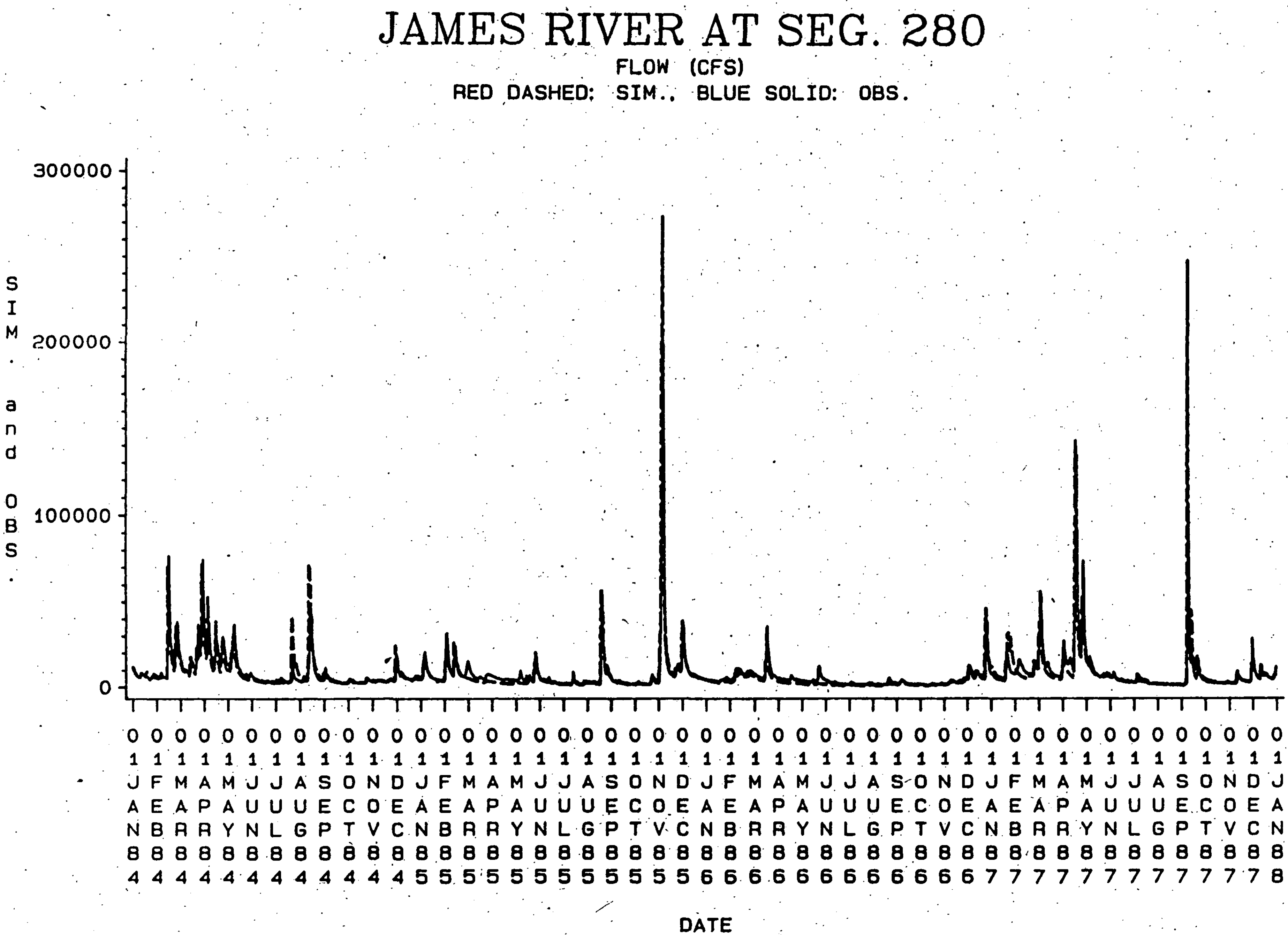

Figure 6.12 Simulated and observed daily flow for James River, Cartersville, VA, Segment 280, 1984-87.

f. In Phase II, the Conowingo Reservoir hydraulic simulation was investigated and adjusted to include a minimum summer release rate of 5000 cfs and minor adjustments to the weekly outflow coefficients (see Section 5.2.1.1). Both the daily timeseries (Figure 6.8) and the frequency (Figure 6.7) results show very good agreement between simulated and observed values, with some deviation in the low flow simulation since these flows are controlled entirely by the operating procedures of the reservoir.

g. Seasonal R^2 values calculated by CBPO are shown in Table 6.5 and in Appendix A. The seasons were defined as follows:

Season 1	January - February
Season 2	March - May
Season 3	June - September
Season 4	October - December

The results in Table 6.5 show that the winter (Season 1) is consistently simulated worst than the other three seasons, and that the summer and fall (Seasons 3 and 4) are usually the best, at least for the three major basins. For most of the smaller basins, the spring (Season 2) is often the best simulated.

Overall, the Phase II hydrology calibration results are a very good representation of the Chesapeake Bay basin hydrology and provide a sound basis for nonpoint load generation and delivery of pollutant loads to the Bay. Ongoing updating of the meteorologic, diversion, and land use information is recommended to allow for complete verification of the hydrology using the 1988-91 period.

SECTION 7.0

WATER QUALITY CALIBRATION RESULTS

This section discusses the results of the water quality calibration, including discussion of tasks performed in both Phase I and Phase II. Much of the text from the Phase I report is retained in order to provide a complete description of the water quality calibration effort; however, only the results from Phase II are presented here since they supersede the Phase I results for the 1984-87 simulation period. Readers interested in the preliminary 1984-85 results are referred to the Phase I report (Donigian et al., 1990).

7.1 OVERVIEW AND STEPS IN THE WATER QUALITY CALIBRATION PROCESS

In both Phase I and Phase II, water quality calibration was begun after completion of the hydrology simulation. However, in Phase I the land use revisions were also important for the water quality modeling, and in Phase II additional input updates were required for point sources, atmospheric deposition, and animal waste contributions. Although the water quality portions of the Watershed Model had been calibrated in the original NVPDC effort, all these revisions to the input for 1984-87 required re-assessment and re-calibration of the water quality parameters.

Whereas flow modeling deals with a single constituent - water quantity - and a single primary source - precipitation, water quality modeling must consider numerous constituents, various forms or species, and multiple sources. Thus, nutrient modeling must consider various forms of nitrogen and phosphorus, their interactions and transformations, and other parameters or constituents (e.g., DO, BOD, water temperature, sediment) that affect these interactions. In the current version of the Watershed Model, the sources considered include point (municipal and industrial) discharges, watershed land uses, atmospheric deposition, and animal waste contributions. Nutrient contributions from all these sources are <u>estimated</u>, hydrologic transport processes are superimposed, and then water quality modeling is performed to allow adjustments in parameters and sources as part of the calibration process.

Water quality calibration is an <u>iterative</u> process; the model predictions are the integrated result of <u>all</u> the assumptions used in developing the model input and in representing the modeled processes. Differences in model predictions and observations require the model user to re-evaluate these assumptions, in terms of both the estimated model input and model parameters, and consider the accuracy and uncertainty in the observations. At the current time, water quality calibration is more an art, than a science, especially for integrated simulations of nonpoint, point, and instream water quality.

2. Calibrate sediment delivery from each land use by adjusting the KSER parameter.

3. Develop initial values of instream parameters (critical shear stresses for scour and deposition) based on simulated shear stresses in each channel reach.

4. Adjust KSER and instream parameters to calibrate sediment at selected sites where observed data are available.

The sediment loading calibration was based on "expected sediment loading rates" (in units of tons/acre/year) for pervious land areas. Expected loading rates for pasture, cropland, and forest areas were developed for each model segment by applying the USLE (using county soil data from the 1982 NRI survey), and assuming a uniform delivery ratio of 0.15 for all areas. The loading rates for conservation tillage cropland were assumed to be 60% of the conventional tillage rates, and values for hay areas were estimated by adding one third of the difference between pasture and conservation tillage cropland to the pasture rates. A constant value of 0.16 tons/acre/year was assumed for all urban areas in the watershed, based on NURP data. The resulting expected sediment loading rates for all model segments are compiled in Appendix C.3.

The sediment erosion model, which is described in Section 4.1.1, involves sediment detachment/attachment from the soil matrix and transport of the detached sediment. Parameters for the sediment detachment (by rainfall impact) and attachment were developed (in Phase I) from soil data, while calibration was largely performed by adjusting the parameter, KSER, which is the coefficient in the transport equation. The sediment loading for all segments was calibrated so that the average of the simulated annual sediment loads for 1984-87 approached the expected sediment loading rates. Appendix C.3 contains the final calibrated average annual loading rates and the corresponding KSER values by model segment and land use.

The instream sediment simulation (described in Section 5.2.3) considers loading, scour, deposition, and advective transport of three sediment size fractions, sand, silt, and clay. Since the loading model considers a single sediment size fraction, the total load was apportioned into three size fractions using constant factors estimated from soil composition data and different delivery ratios for the three sizes.

Initial values of the instream scour/deposition parameters for silt and clay were developed by examination of daily time series plots of simulated velocity and shear stress in each reach. The sand transport parameters were set so that sand always settles to the bed, except at high flow velocities. The critical shear stress for scour (TAUCS) was set so that channel scour would occur only during extreme flow events, while the critical shear stress for deposition (TAUCD) was set so that silt and clay deposition would occur only at very low flows. The net effect is that the channels are not eroded over time, and loadings of silt and clay generally remain suspended, while sand deposits.

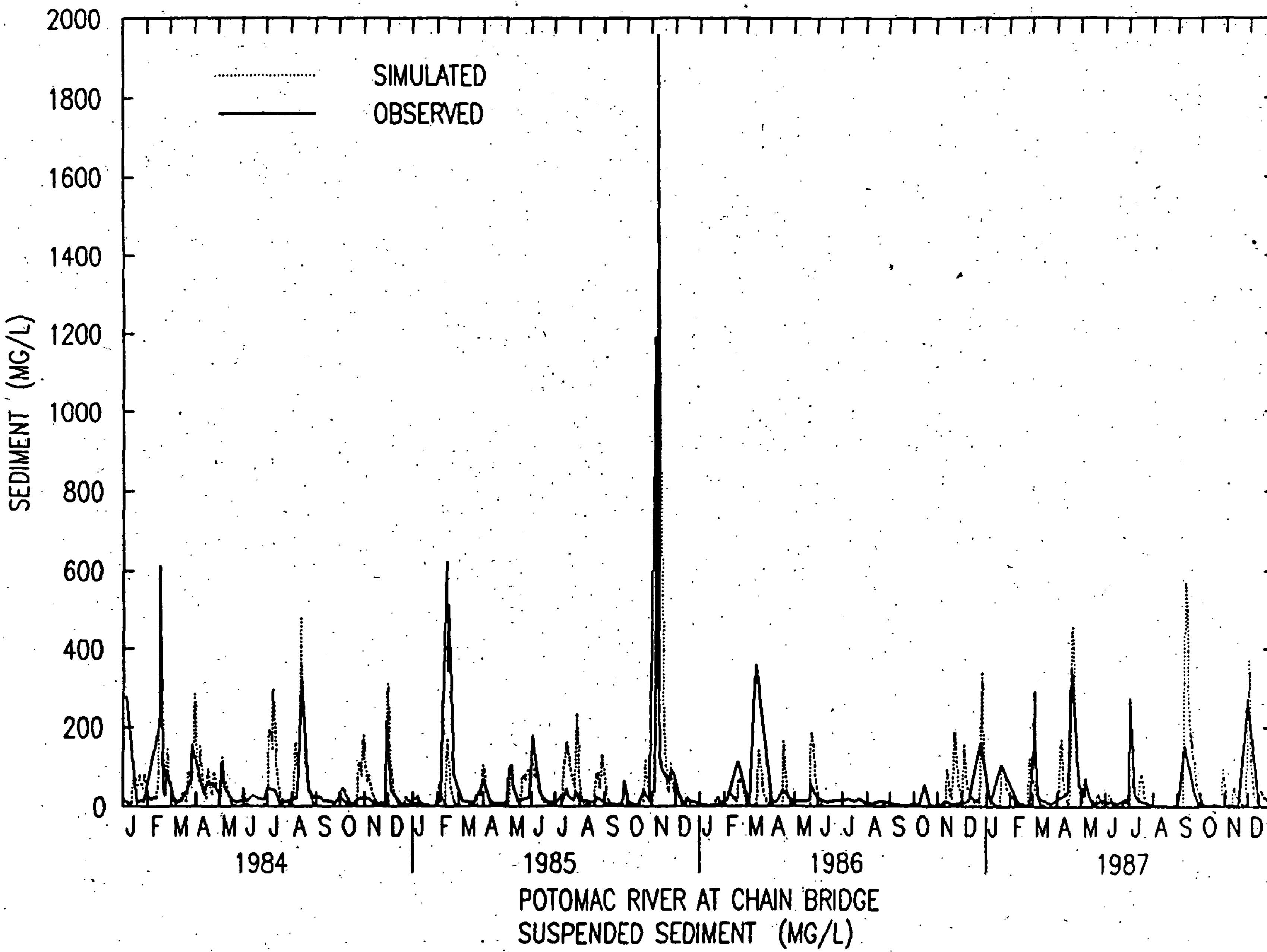

Figure 7.1 Suspended sediment concentration - Susquehanna River at Conowingo.

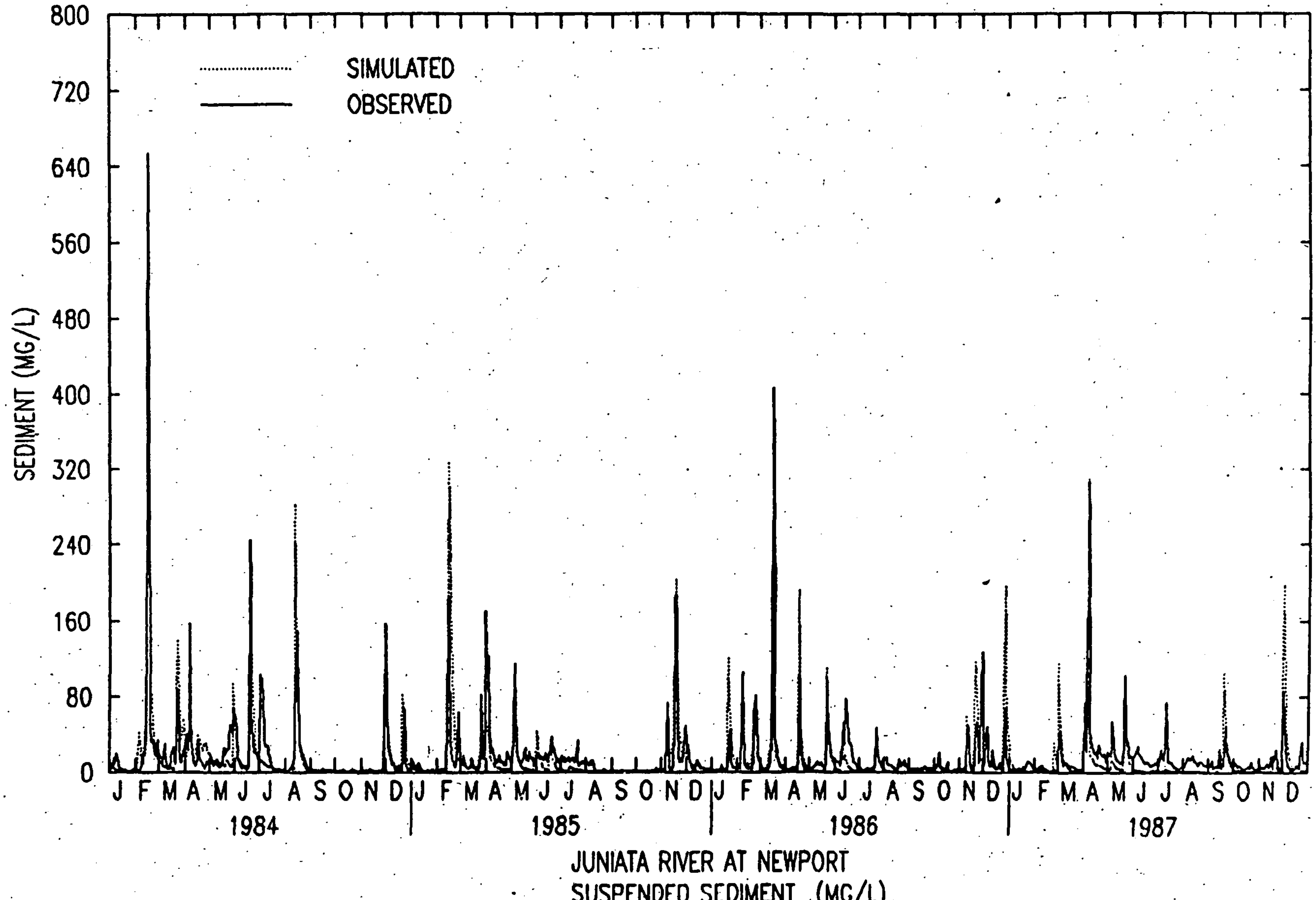

Figure 7.3 Suspended sediment concentration - Juniata River at Newport.

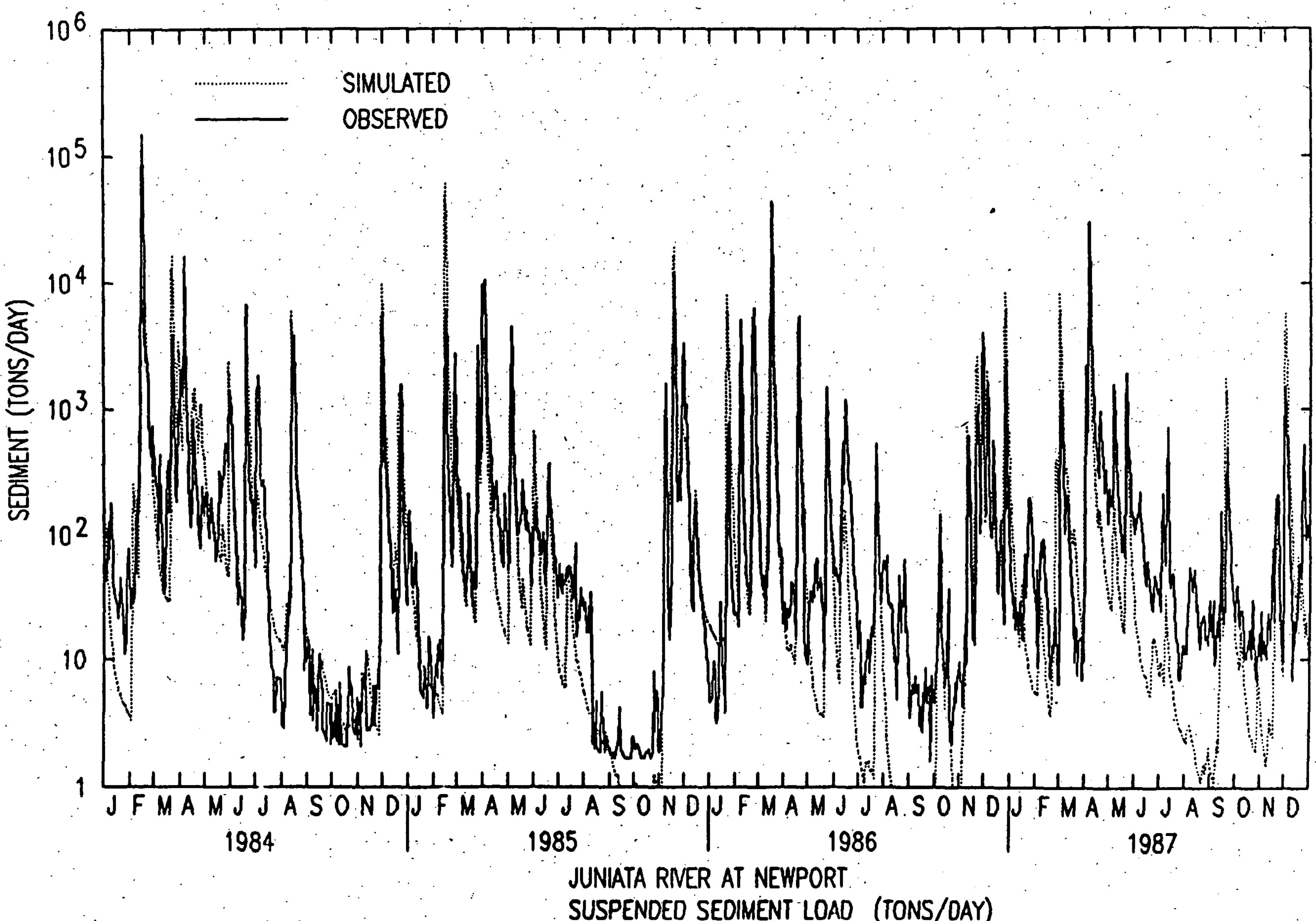

Figure 7.5 Suspended sediment load - Juniata River at Newport.

The calibration involved numerous model runs and iterations at each selected calibration site in order to maintain parameter consistency within and among the basins. In the sections below we present and discuss the final Phase II results of the comparisons performed in steps d and e above for the concentration and Fall Line loads. In Phase I, the greatest effort was devoted to the three Fall Line stations due to the need to provide preliminary Basin loads to the Bay model. In Phase II, calibration was performed on the Fall Line stations, numerous subbasins, and the minor tributaries, comprising 13 separate calibration sites. Due to the large number of plots produced by this effort, the model results presented below will focus primarily on the Fall Line sites, but the discussion will include issues relevant to all sites. Complete results for all water quality calibration sites are provided in Appendix B.

7.3.1 Instream Water Quality Concentrations

Once nonpoint and point source loading rates were deemed to be reasonable, the instream water quality calibration focused on adjustments to selected instream parameters to improve agreement with observed concentrations. The primary parameters of concern were the settling rates for phytoplankton and BOD, nitrification rates, phytoplankton growth rates, algal nutrient uptake parameters, and partition coefficients and bed concentrations for NH_4 and PO_4. Final model parameters were discussed in Section 5.2.4.

The figures provided at the end of this section include the water quality simulation results for four major stations in the basin, including the three Fall Line Stations on the Susquehanna, Potomac, and James rivers. The four stations and corresponding figures are as follows:

Model Segment	Station	Figures
80	Susquehanna R. @ Harrisburg, PA	7.6 - 7.17
140	Susquehanna R. @ Conowingo, MD	7.18 - 7.28
220	Potomac R. @ Washington, D.C.	7.29 - 7.39
280	James R. @ Cartersville, VA	7.40 - 7.51

In these figures, daily simulated and observed values are provided for the following water quality constituents for each station in the order shown below:

Water temperature (°C)
Dissolved oxygen (mg/l)
Suspended sediment (mg/l)
Nitrate plus nitrite (mg/l)
Ammonia, dissolved (mg/l)
Particulate nitrogen (mg/l)
Total nitrogen (mg/l)
Phosphate, dissolved (mg/l)
Particulate phosphorus (mg/l)
Total phosphorus (mg/l)
Total organic carbon (mg/l)
Chlorophyll a (ug/l)

timeseries with discrete, individual observations.

c. The Phase II results are a significant improvement over the Phase I results due to the water quality parameter re-evaluation, the AGCHEM nutrient loading simulations, and the additional calibration effort. Although some problems remain, the results show improved simulation of seasonal variations in nitrate and Chl a, closer representation of individual nutrient species, and better agreement with most observed concentrations and total loads.

d. Large deviations are still seen in the individual nutrient forms at some sites, such as PO_4 in portions of the Susquehanna and inorganic nutrients in the minor tributaries. Chl a observations were limited at many calibration sites, thus restricting the calibration process.

e. The Potomac simulation results are the best of all the major basins and are generally a good to very good representation of nutrient concentrations throughout the Bay basin. This could be partially due to the fact that the Potomac data is more extensive than in any of the other basins, allowing a better representation of the expected variability in the observations and a better calibration. The total nutrient concentrations, and the individual species, are well simulated throughout the entire period. Concentration peaks do exceed individual observations, especially for NH_3 and PO_4, but they are generally within the range of the observed data.

f. The Susquehanna simulation shows good agreement between simulated and observed concentrations, but this was accomplished only after intensive calibration effort of the entire basin, with particular focus on the reservoir simulation. Generally, Total N and component concentrations at Conowingo are somewhat under-simulated. PO_4 and Total P concentrations are somewhat over-simulated throughout the Susquehanna, possibly due to interactions with sediment and metal oxides, and increased sorption under low pH conditions.

USGS data for pH show extremely low values for two main stem stations in the East and West Branch subbasins, with mean monthly values in the 3.0 to 4.0 range. Detenbeck and Brezonik (1991) show greatly increased P binding by lake sediments for pH in the range of 4.5 to 6.0, with greatly decreased diffusive P fluxes under these conditions. Consequently, increased sorption and retention, and possibly precipitation of PO_4 from the overlying water may be a reason for most of the observed concentrations being close to detections limits.

Clearly, further investigation is warranted and should focus on instream processes in the Upper and Lower basins for both nitrogen and phosphorus delivered to the Conowingo Reservoir, and processes within the reservoir. This should be performed in conjunction with a thorough loadings analysis (see Section 7.4) to confirm the relative loadings contributions from all sources. Further calibration of the reservoir water quality is needed to improve the sediment and Chl a simulations, which may also assist in improving the phosphorus the TOC simulation. The simulation results for TOC are generally quite good for most sites, and are similar in appearance to the organic N and organic P simulations.

7.3.2 Fall Line Load Simulation and Regression Comparison

The Phase I water quality calibration included comparison of simulated nutrient loads at the Fall Line stations with regression loads developed by the U.S. Geological Survey (L. Zynjuk, R. Summers, and T. Cohn, 1989., personal communication) and HydroQual, Inc. (1989). The U.S.G.S. regression was used for all stations except the Rappahannock, James, Mattaponi, and Pamunkey rivers, where the HydroQual regression was used. In Phase II, regression loads for 1984-86 were provided by the U.S. Army Corps of Engineers so that the same regression loads would be used by both the Watershed Model and the Bay model. In both phases, the calibration effort considered both the available observed concentrations (as discussed above) and the regression loads whenever parameter adjustments were proposed. If parameter changes would improve one comparison at the expense of the other, we placed greater emphasis and priority on the actual observed concentrations.

Tables 7.2 through 7.5 show a comparison of annual simulated and regression Fall Line loads for the three major basins, and the Patuxent, along with their ratios for each year, 1984 through 1986, and for the entire three-year period.

Review of the comparisons in the tables indicates the following general conclusions and recommendations:

a. For Total N and Total P, the model and regression annual loads generally agree within about 10-20%; for the Potomac, the maximum difference is closer to 25%. Problems with Organic P and, to a lesser extent Organic N, in the Potomac and James in 1985 (partly due to the November 1985 storm) lead to greater differences for that year.

b. In the Potomac and to some extent the Patuxent, the closeness of the concentration comparison is also reflected in the Fall Line load ratios. For both these rivers, extensive data was available for developing the regression and performing the model calibration.

c. Nitrate generally shows the closest agreement between the two estimates, at least for the three major Fall Line stations. Interestingly, nitrate dominates the Total N and all other nutrient loads in terms of total mass, especially for the Susquehanna, Rappahannock, and the Patuxent, and to a lesser extent, the Potomac. In the James, Organic N dominates the Total N load and is significantly greater than the nitrate load.

d. The differences between the two estimates are generally much greater for the minor tributaries for most nutrient forms (with the exception of the Patuxent), than for the major Above Fall Line basins. For the minor tributaries and the James, significantly less data was available for developing the regression. Consequently, the uncertainty of the regression is greater for these basins.

TABLE 7.2 Susquehanna River Fall Line Loads: Comparison of Regression and Model Estimates - (Millions of Pounds)

Constituent	Year	Regression Estimate	Model Estimate	Model Est. / Regr. Est.
NO3	84	123	128	1.04
	85	80	74	0.93
	86	108	94	0.87
	87	-	77	-
	84-86 Mean	104	99	0.95
NH3	84	11.0	14.6	1.33
	85	7.3	7.4	1.01
	86	9.5	9.4	0.99
	87	-	7.3	-
	84-86 Mean	9.3	10.5	1.13
Org N	84	60	52	0.86
	85	33	27	0.81
	86	46	36	0.78
	87	-	29	-
	84-86 Mean	46	38	0.82
Tot N	84	194	194	1.00
	85	120	108	0.90
	86	163	139	0.85
	87	-	113	-
	84-86 Mean	159	147	0.93
PO4	84	1.6	1.0	0.63
	85	0.9	0.8	0.89
	86	1.0	0.8	0.80
	87	-	0.8	-
	84-86 Mean	1.2	0.9	0.74
Org P	84	7.9	8.5	1.08
	85	3.1	4.3	1.39
	86	5.5	5.8	1.05
	87	-	4.6	-
	84-86 Mean	5.5	6.2	1.13
Tot P	84	9.5	9.5	1.00
	85	4.1	5.1	1.24
	86	6.5	6.6	1.02
	87	-	5.4	-
	84-86 Mean	6.7	7.1	1.05
TOC	84	417	634	1.52
	85	209	235	1.13
	86	299	336	1.12
	87	-	263	-
	84-86 Mean	308	402	1.30

To compare model estimates with regression estimates, the following model outputs were used:

1. NO3 = NO2 + NO3
2. NH4 = Dissolved NH4 + Adsorbed NH4
3. Organic N = ORG-N + (0.08631 * PHYTO) + (0.05295 * BOD)
4. Total Nitrogen = 1 + 2 + 3
5. PO4 = Dissolved PO4
6. Organic P = ORG-P + (0.01233 * PHYTO) + (0.00756 * BOD) + Adsorbed PO4
7. Total Phosphorous = 5 + 6
8. Total Organic Carbon = ORG-C + (0.49 * PHYTO) + (0.3006 * BOD)

TABLE 7.4 James River Fall Line Loads: Comparison of Regression and Model Estimates - (Millions of Pounds)

Constituent	Year	Regression Estimate	Model Estimate	Model Est. / Regr. Est.
NO3	84	6.2	7.8	1.26
	85	4.4	4.9	1.11
	86	2.3	3.4	1.48
	87	-	7.0	-
	84-86 Mean	4.3	5.4	1.25
NH3	84	0.73	0.57	0.78
	85	0.64	1.08	1.69
	86	0.36	0.60	1.67
	87	-	1.10	-
	84-86 Mean	0.58	0.75	1.30
Org N	84	7.9	6.9	0.88
	85	5.6	7.8	1.40
	86	3.2	1.3	0.40
	87	-	11.8	-
	84-86 Mean	5.6	5.3	0.96
Tot N	84	15	15.3	1.02
	85	12	13.8	1.15
	86	6	5.3	0.88
	87	-	19.9	-
	84-86 Mean	11	11.5	1.04
PO4	84	1.2	1.1	0.92
	85	1.2	1.6	1.33
	86	1.0	0.4	0.40
	87	-	1.5	-
	84-86 Mean	1.1	1.0	0.91
Org P	84	2.7	1.5	0.56
	85	5.2	1.4	0.27
	86	0.7	0.3	0.43
	87	-	2.0	-
	84-86 Mean	2.9	1.1	0.37
Tot P	84	3.9	2.6	0.67
	85	6.4	3.0	0.47
	86	1.7	0.7	0.41
	87	-	3.5	-
	84-86 Mean	4.0	2.1	0.53
TOC	84	130	101	0.78
	85	165	169	1.02
	86	44	17	0.38
	87	-	231	-
	84-86 Mean	113	96	0.85

To compare model estimates with regression estimates, the following model outputs were used:

1. NO3 = NO2 + NO3
2. NH4 = Dissolved NH4 + Adsorbed NH4
3. Organic N = ORG-N + (0.08631 * PHYTO) + (0.05295 * BOD)
4. Total Nitrogen = 1 + 2 + 3
5. PO4 = Dissolved PO4
6. Organic P = ORG-P + (0.01233 * PHYTO) + (0.00756 * BOD) + Adsorbed PO4
7. Total Phosphorous = 5 + 6
8. Total Organic Carbon = ORG-C + (0.49 * PHYTO) + (0.3006 * BOD)

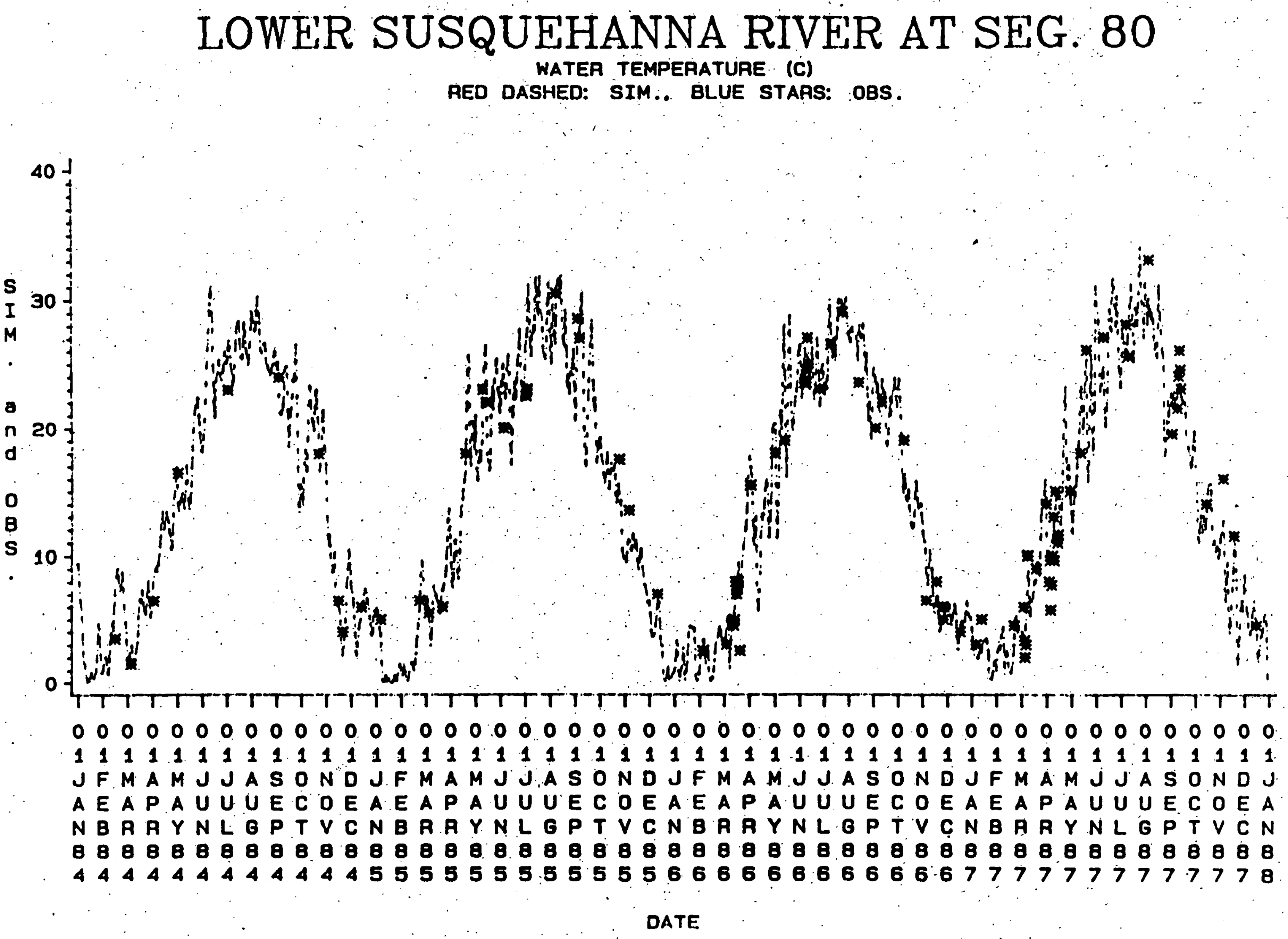

Figure 7.6 Simulated and observed water temperature (°C), Susquehanna River at Harrisburg, PA, 1984-87.

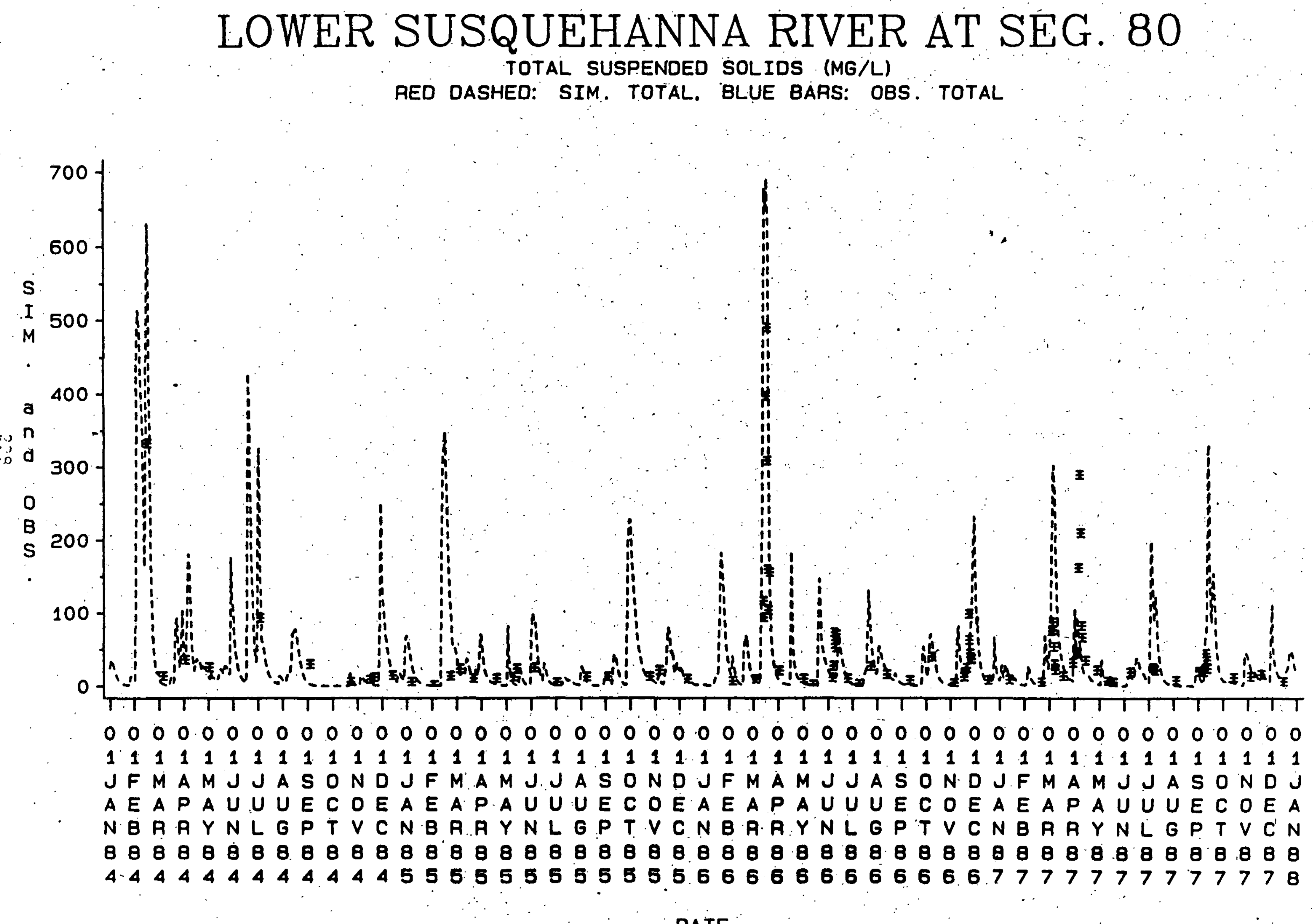

Figure 7.8 Simulated and observed suspended sediment (mg/l), Susquehanna River at Harrisburg, PA, 1984-87.

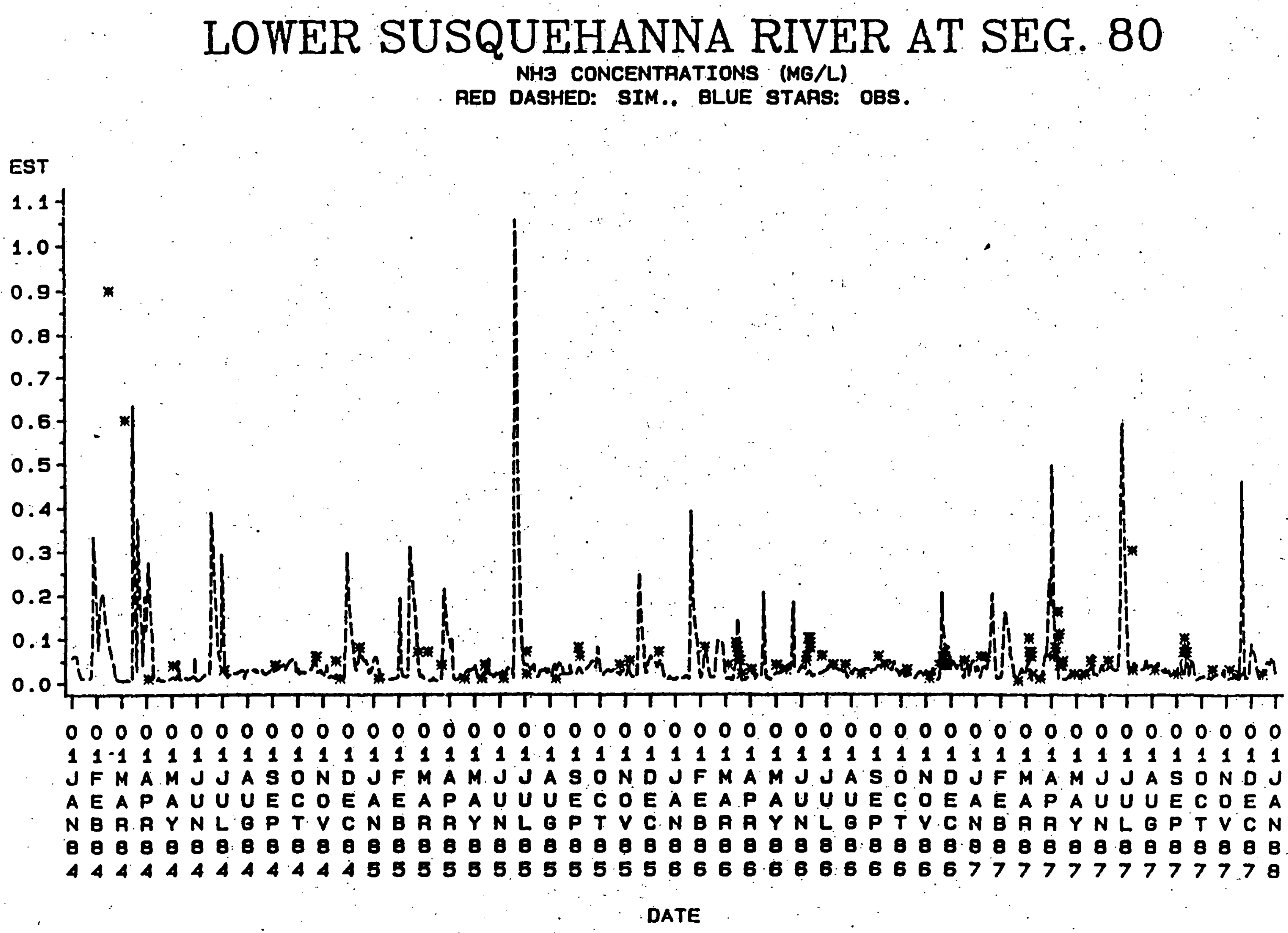

Figure 7.10 Simulated and observed ammonia (mg/l), Susquehanna River at Harrisburg, PA, 1984-87.

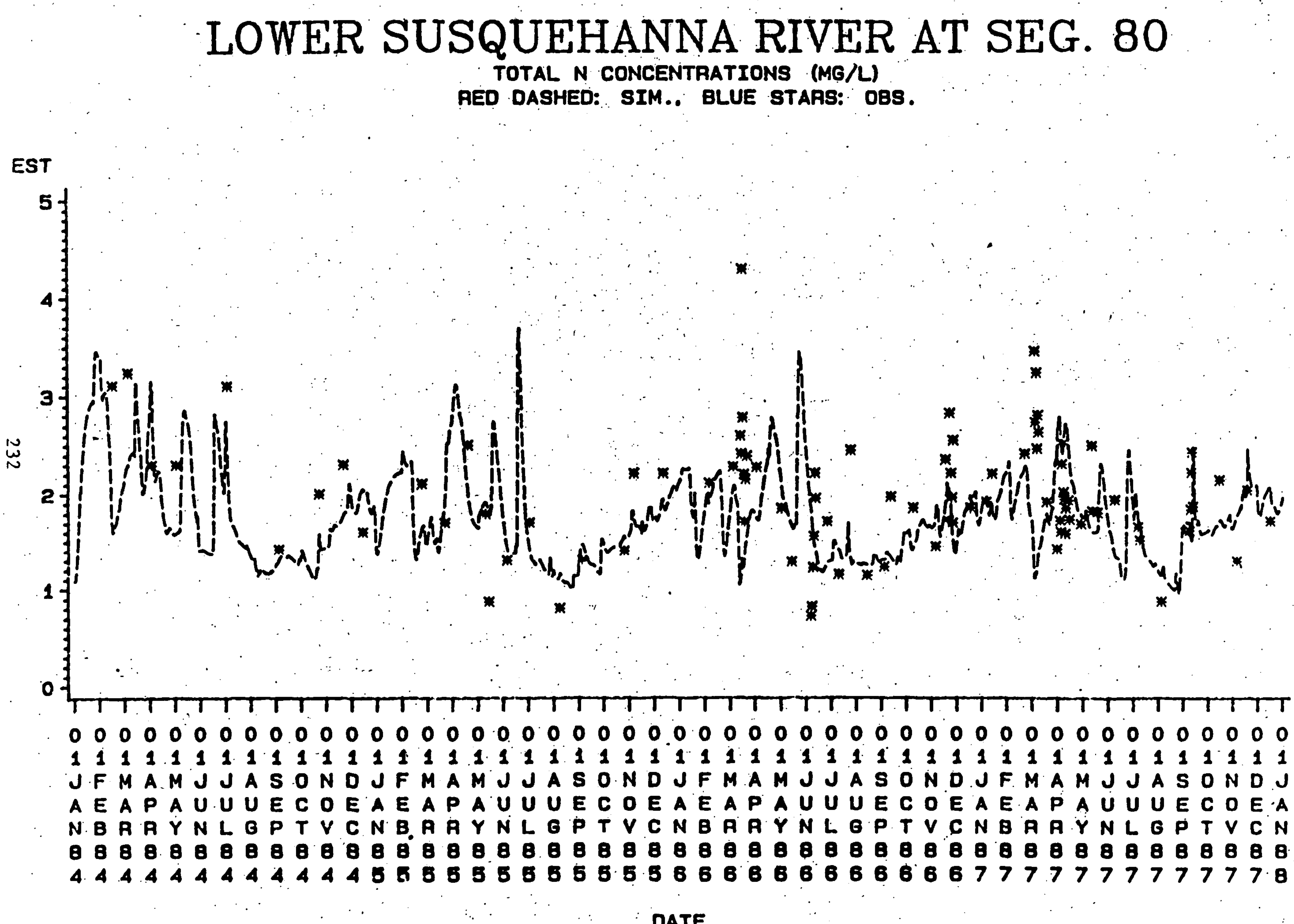

Figure 7.12 Simulated and observed total nitrogen (mg/l), Susquehanna River at Harrisburg, PA, 1984-87.

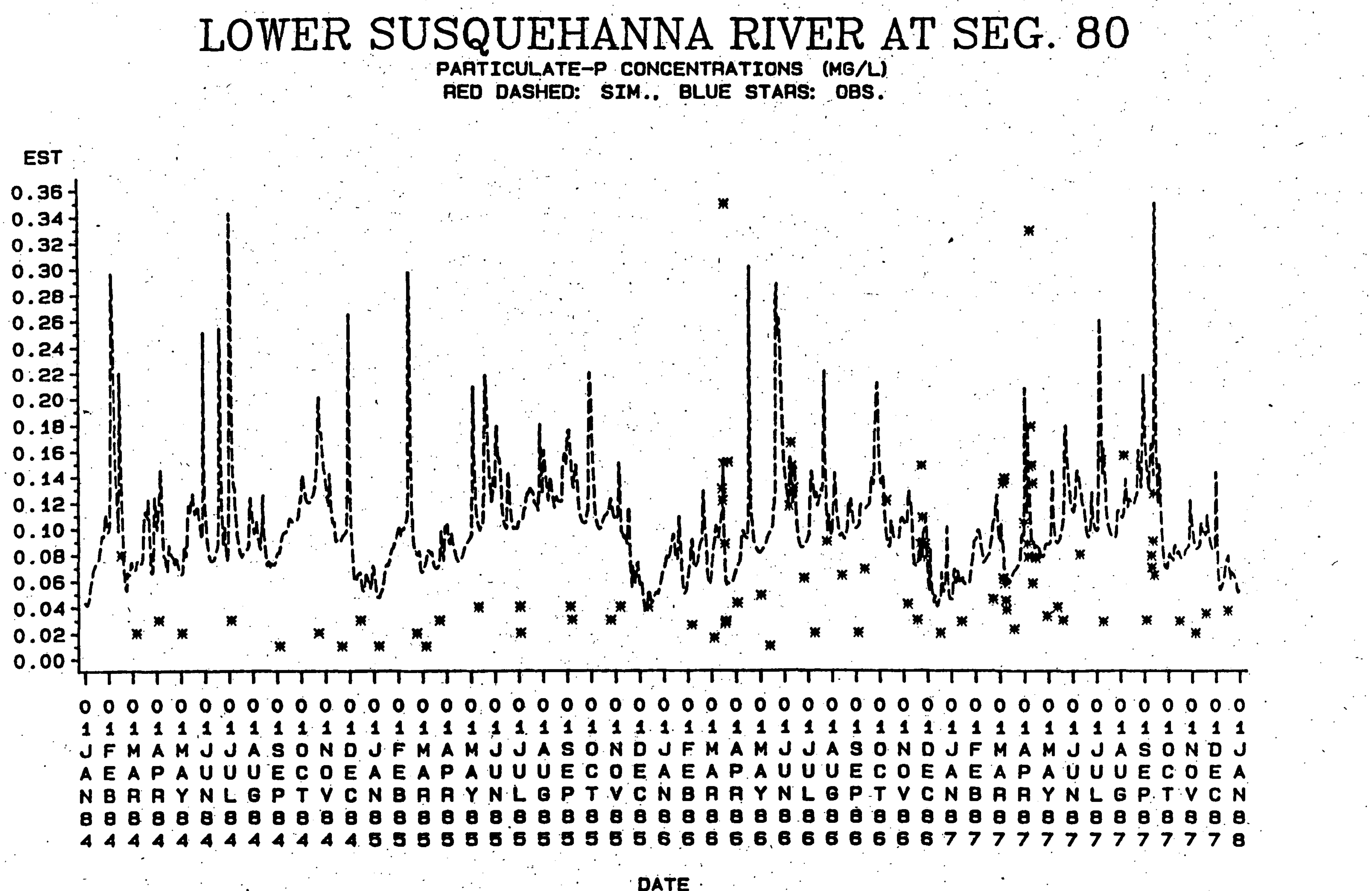

Figure 7.14 Simulated and observed particulate phosphorus (mg/l), Susquehanna River at Harrisburg, PA, 1984-87.

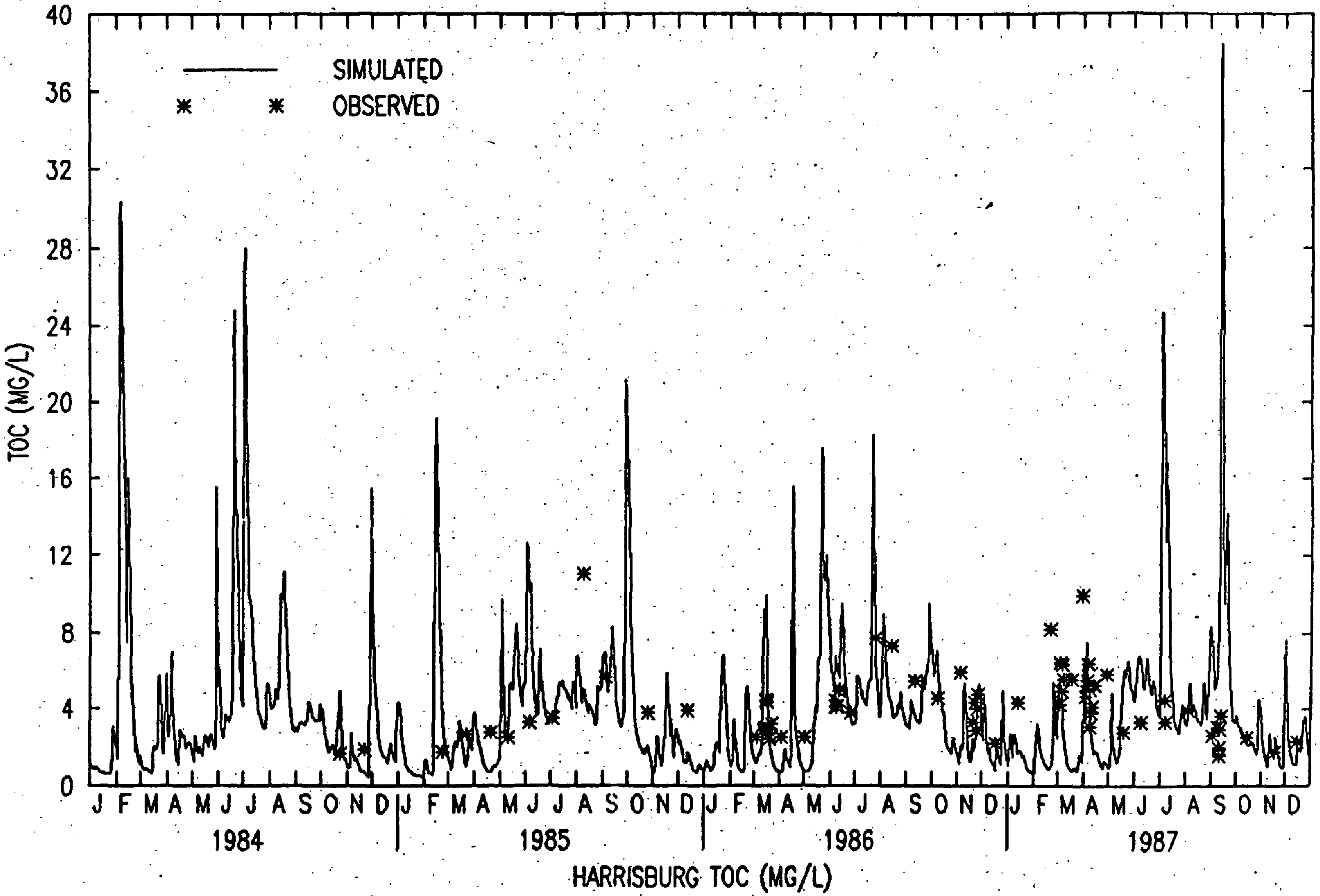

Figure 7.16 Simulated and observed total organic carbon (mg/l), Susquehanna River at Harrisburg, PA, 1984-87.

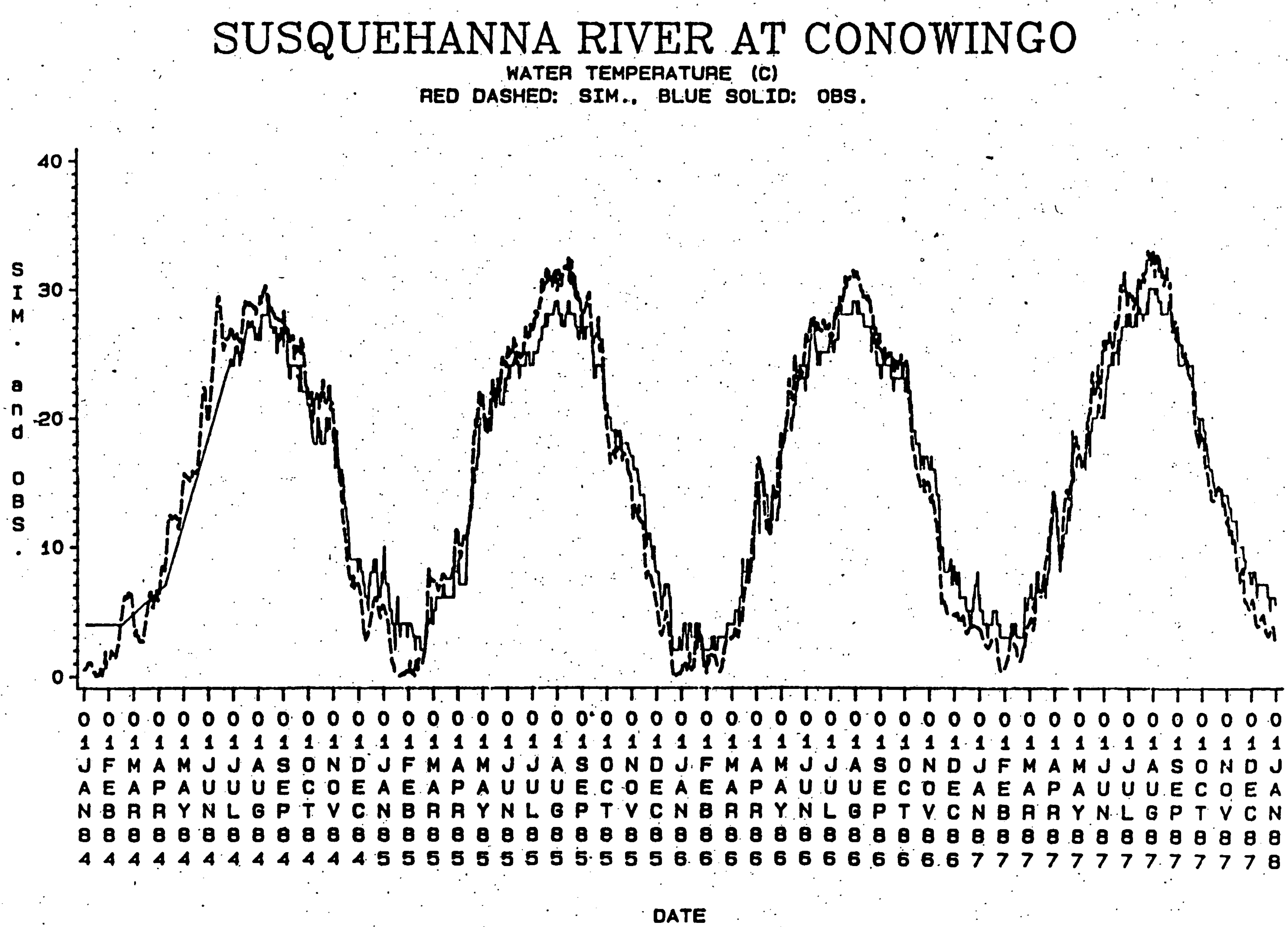

Figure 7.18 Simulated and observed water temperature (°C), Susquehanna River at Conowingo, MD, 1984-87.

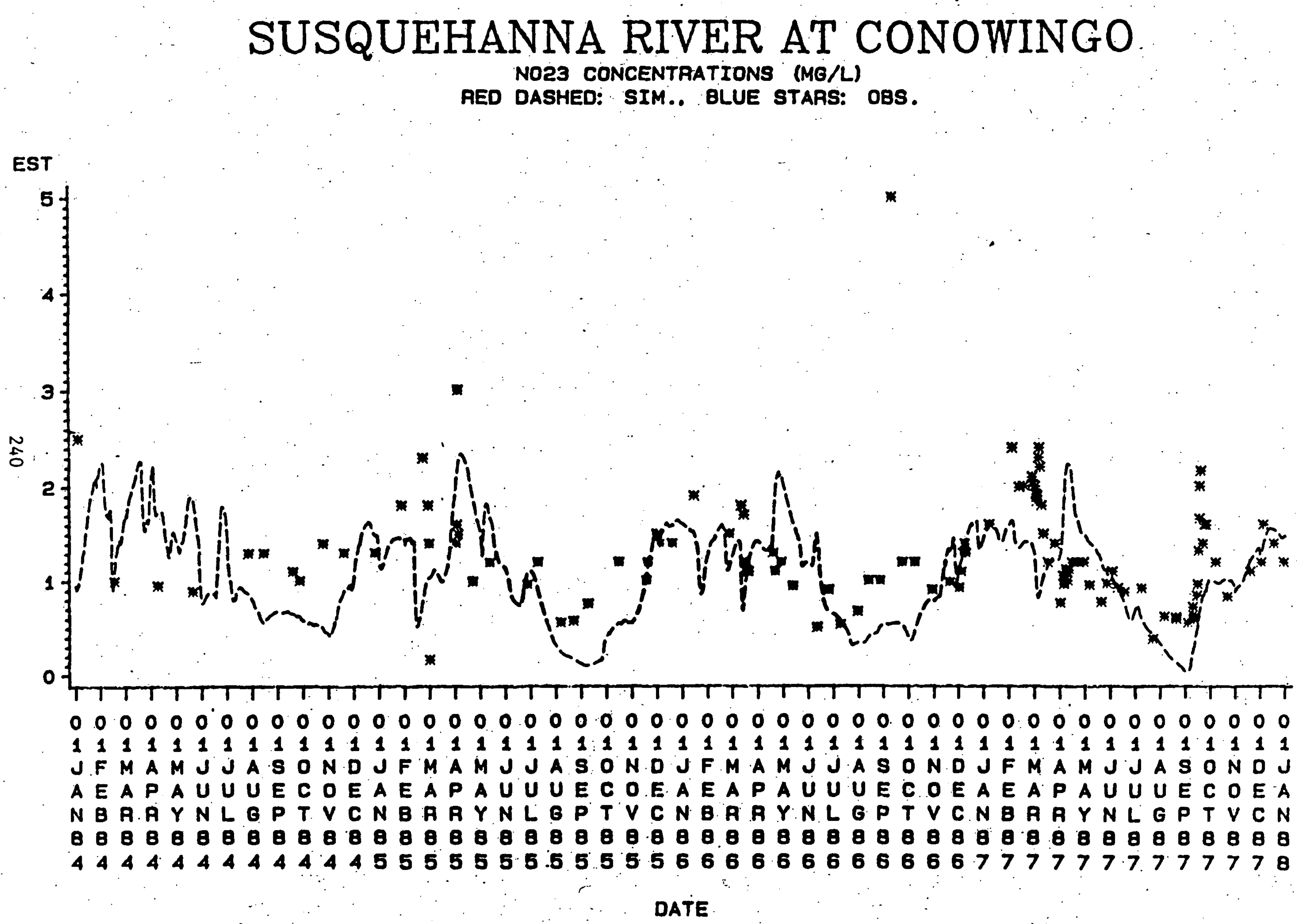

Figure 7.20 Simulated and observed nitrate (mg/l), Susquehanna River at Conowingo, MD, 1984-87.

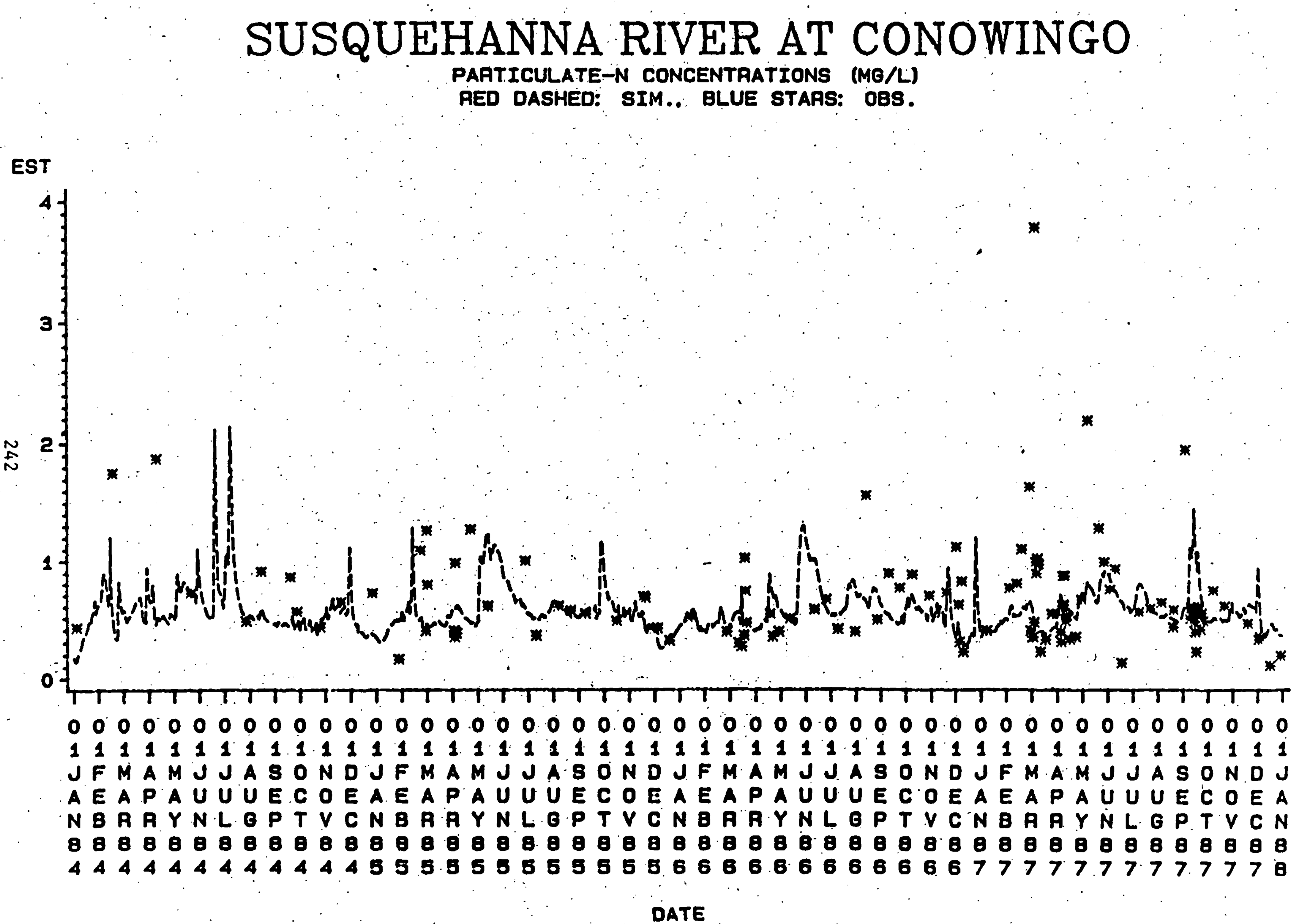

Figure 7.22 Simulated and observed particulate nitrogen (mg/l), Susquehanna River at Conowingo, MD, 1984-87.

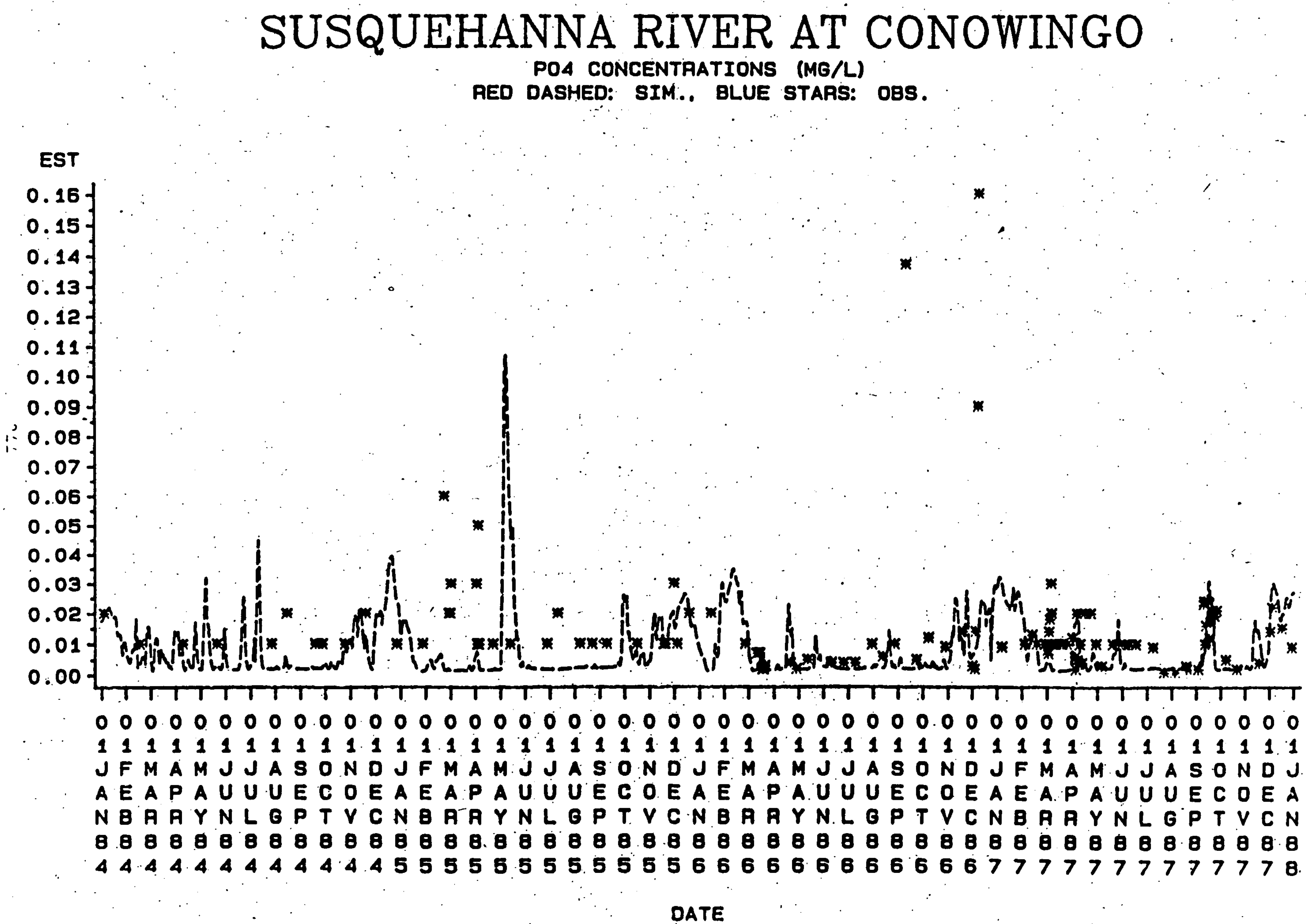

Figure 7.24 Simulated and observed phosphate (mg/l), Susquehanna River at Conowingo, MD, 1984-87.

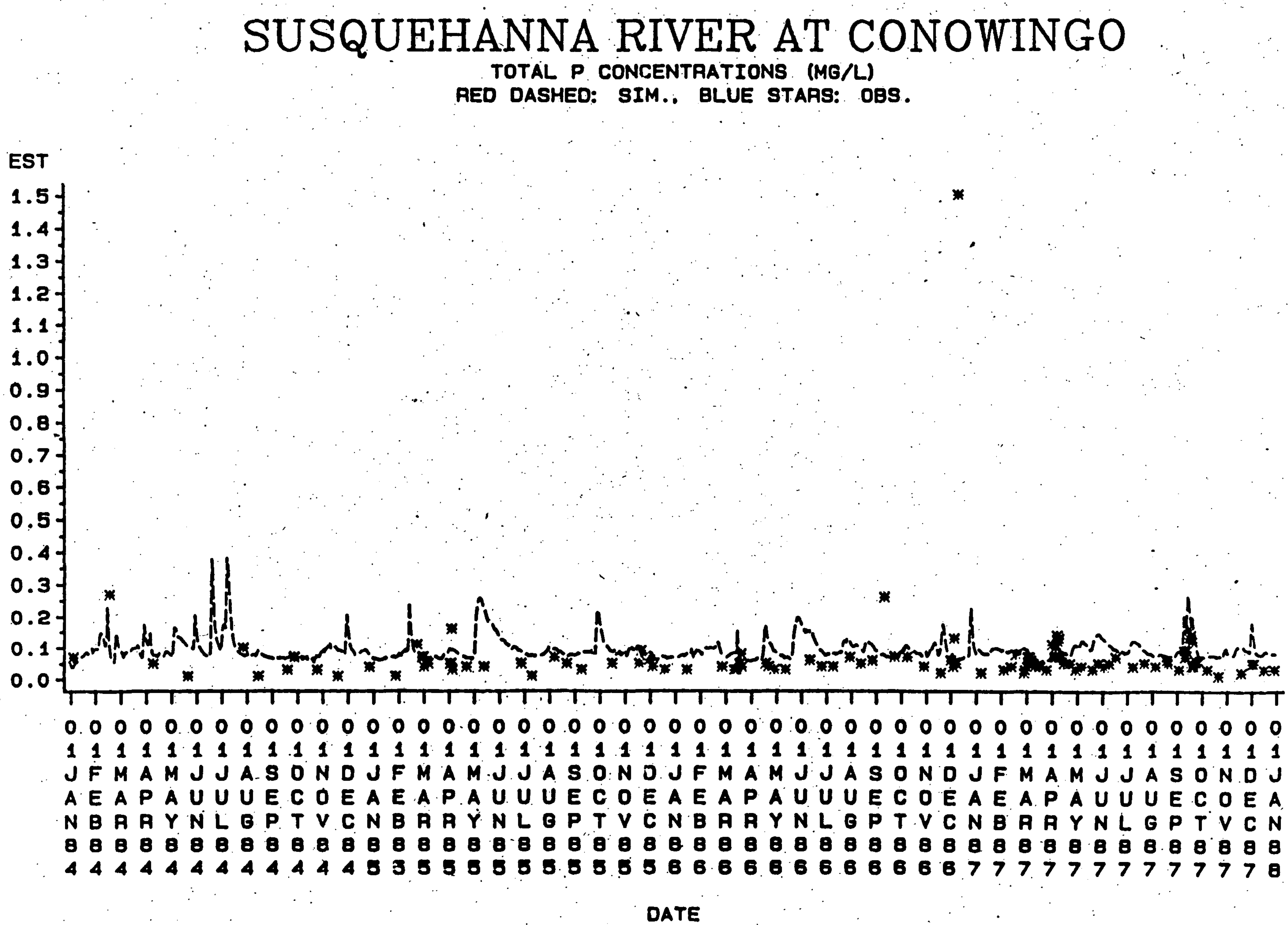

Figure 7.26 Simulated and observed total phosphorus (mg/l), Susquehanna River at Conowingo, MD, 1984-87.

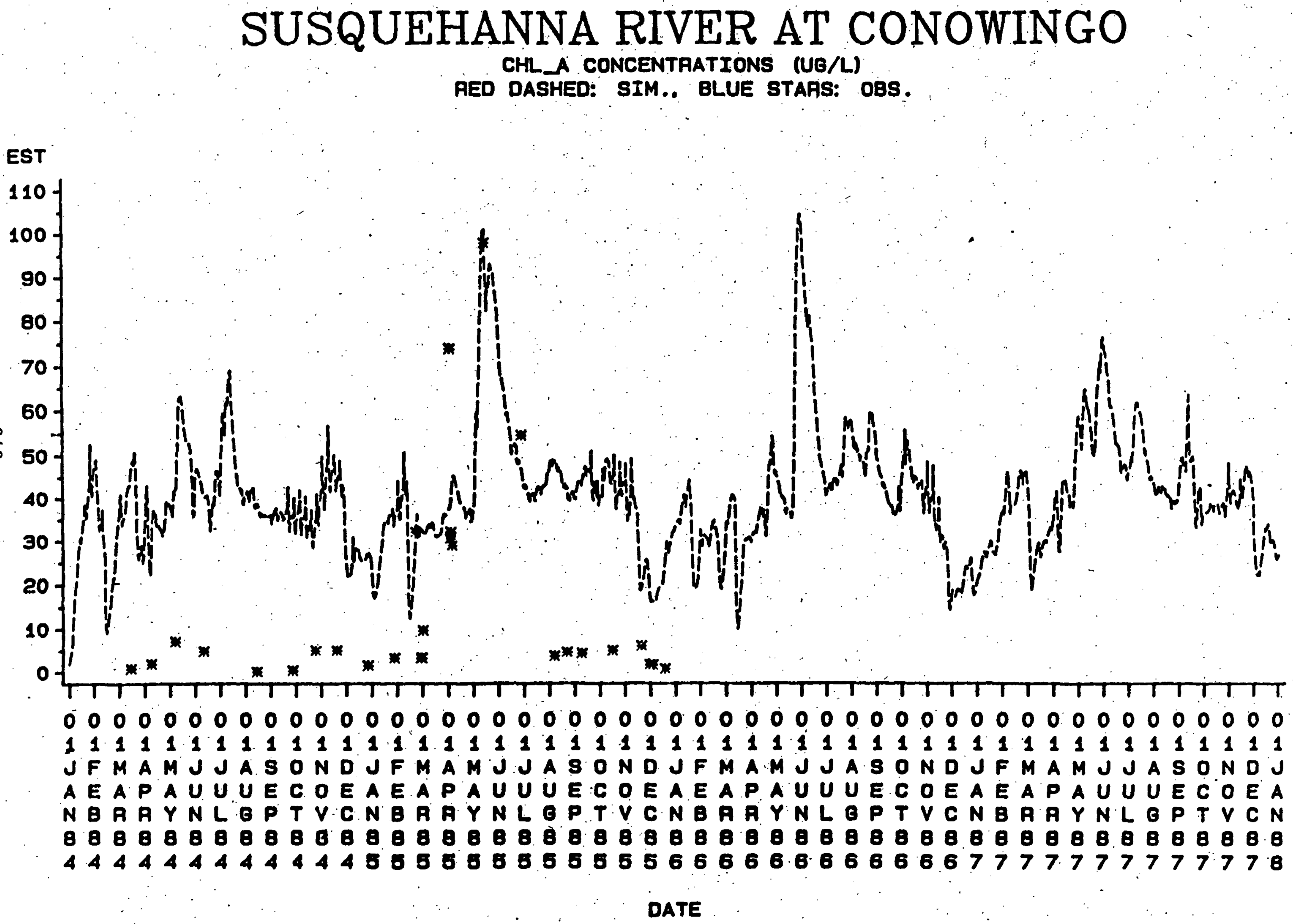

Figure 7.28 Simulated and observed chlorophyll A (ug/l), Susquehanna River at Conowingo, MD, 1984-87.

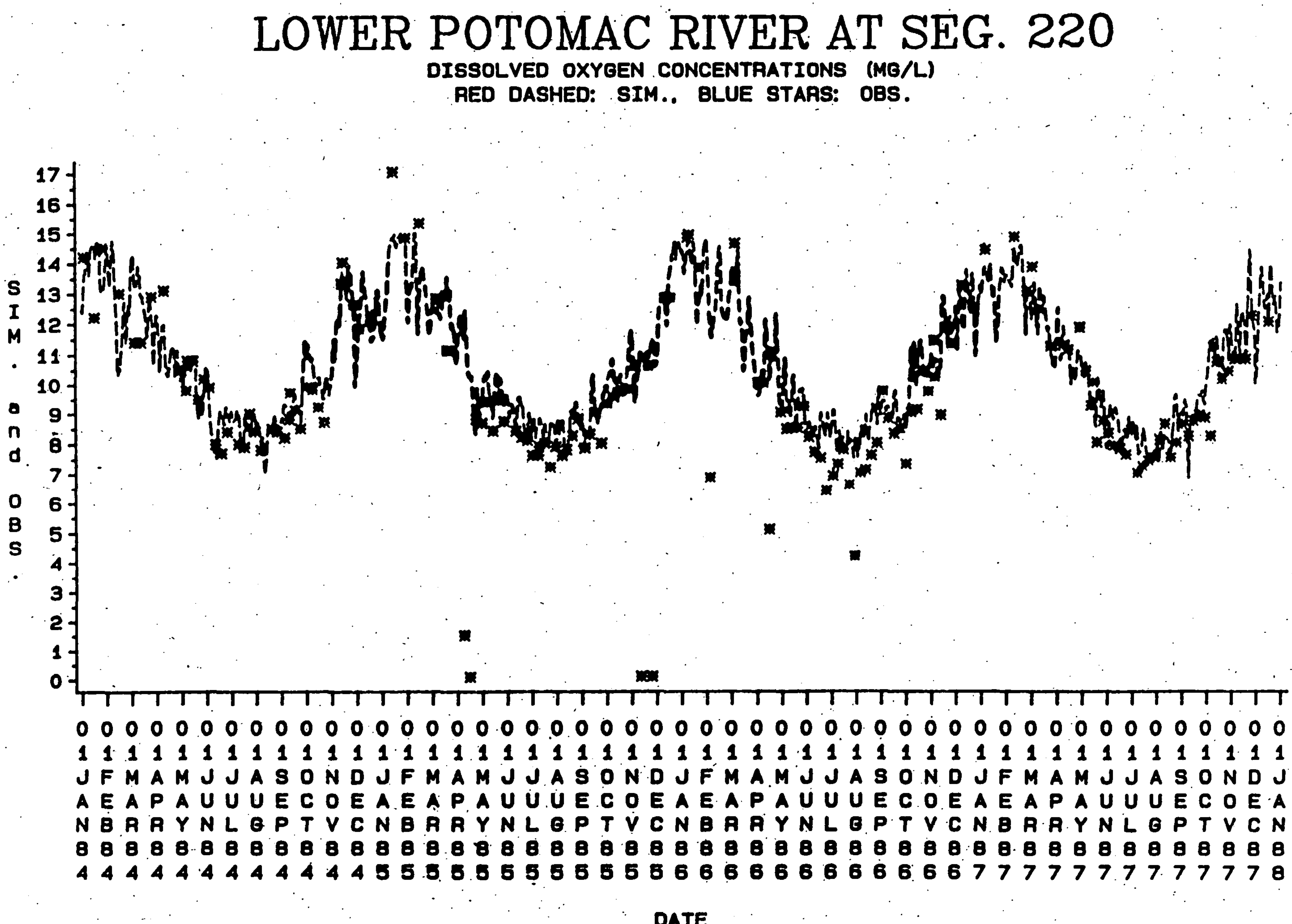

Figure 7.30 Simulated and observed dissolved oxygen (mg/l), Potomac River at Washinton, D.C., 1984-87.

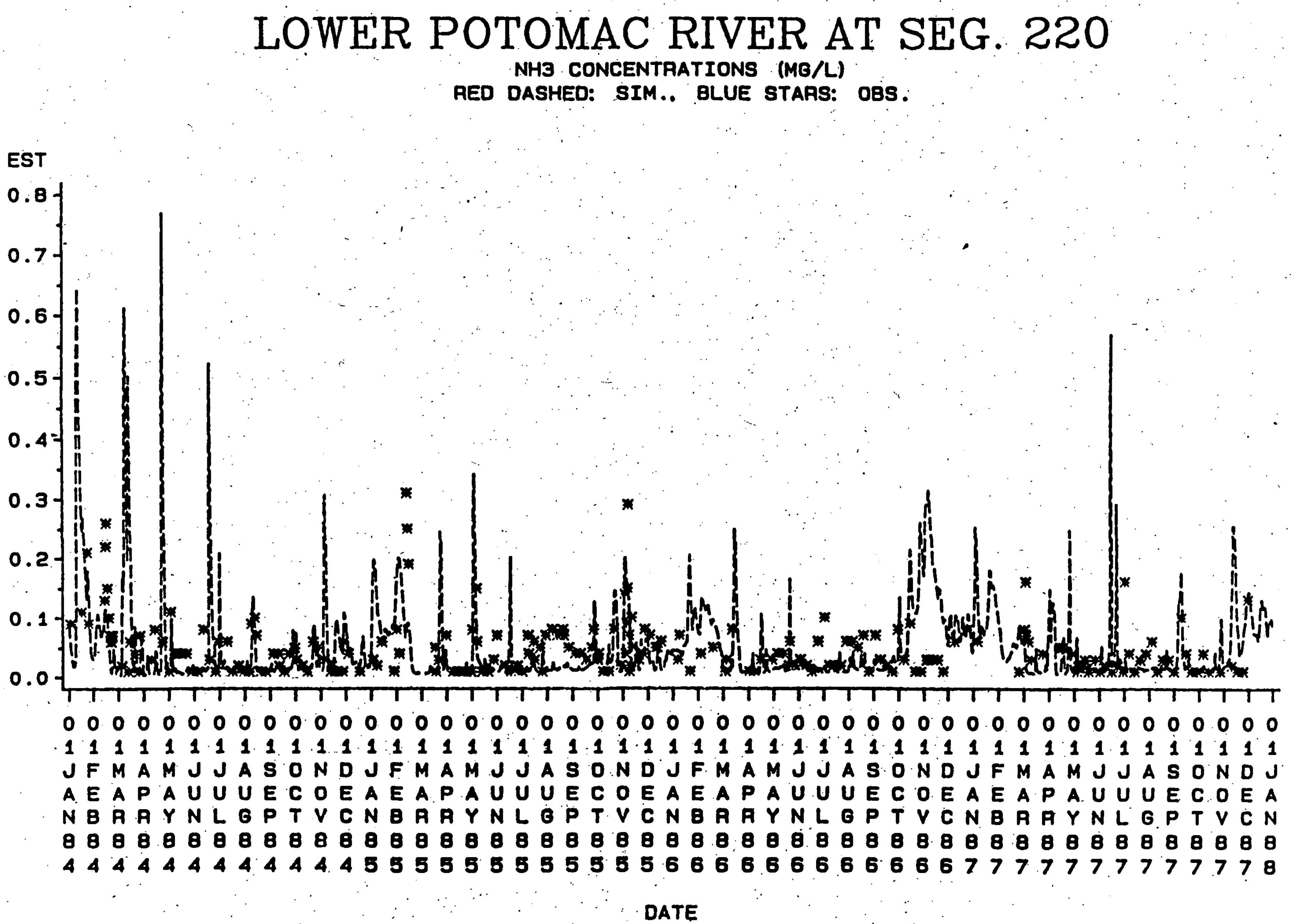

Figure 7.32 Simulated and observed ammonia (mg/l), Potomac River at Washington, DC, 1984-87.

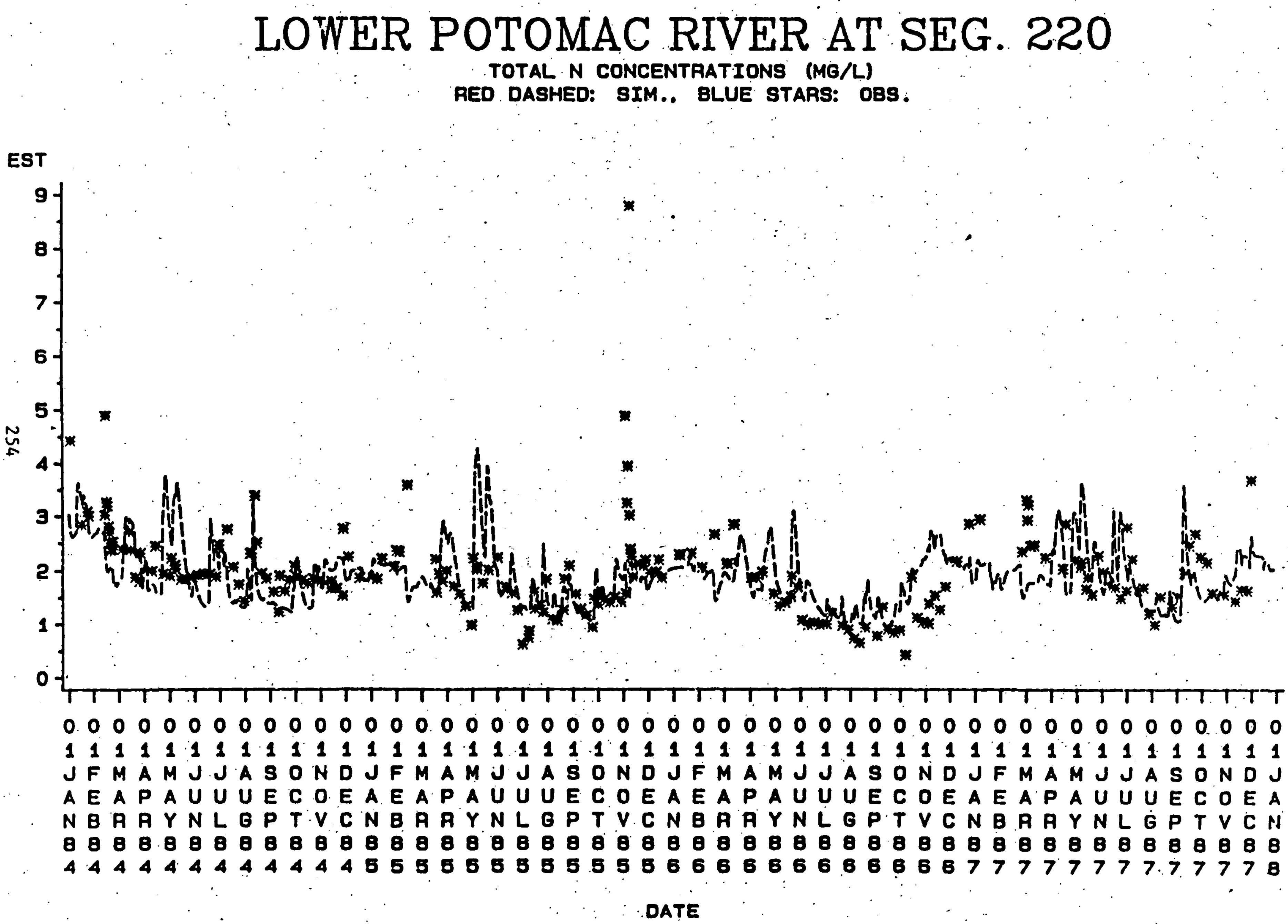

Figure 7.34 Simulated and observed total nitrogen (mg/l), Potomac River at Washington, DC, 1984-87.

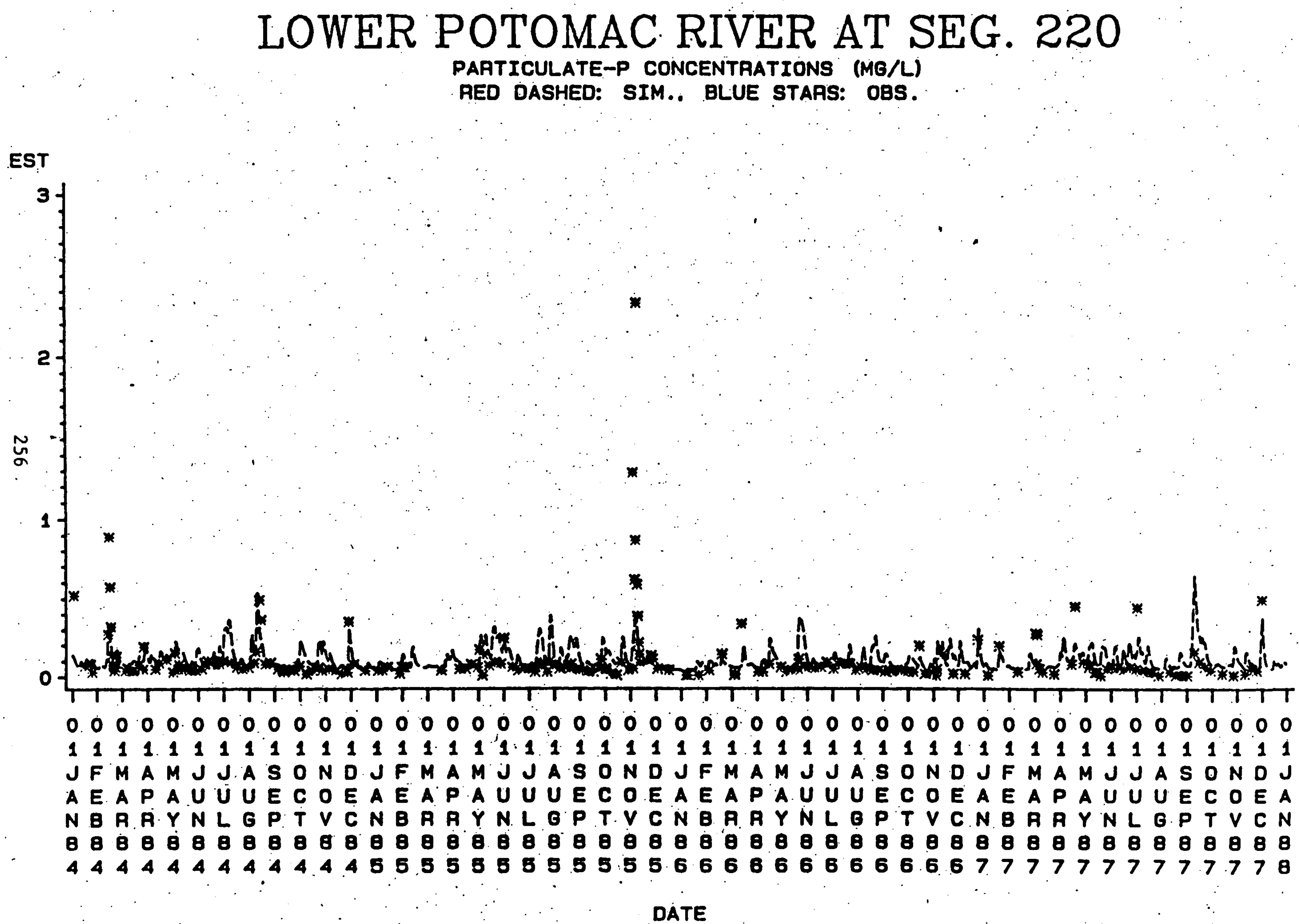

Figure 7.36 Simulated and observed particulate phosphorus (mg/l), Potomac River at Washington, DC, 1984-87.

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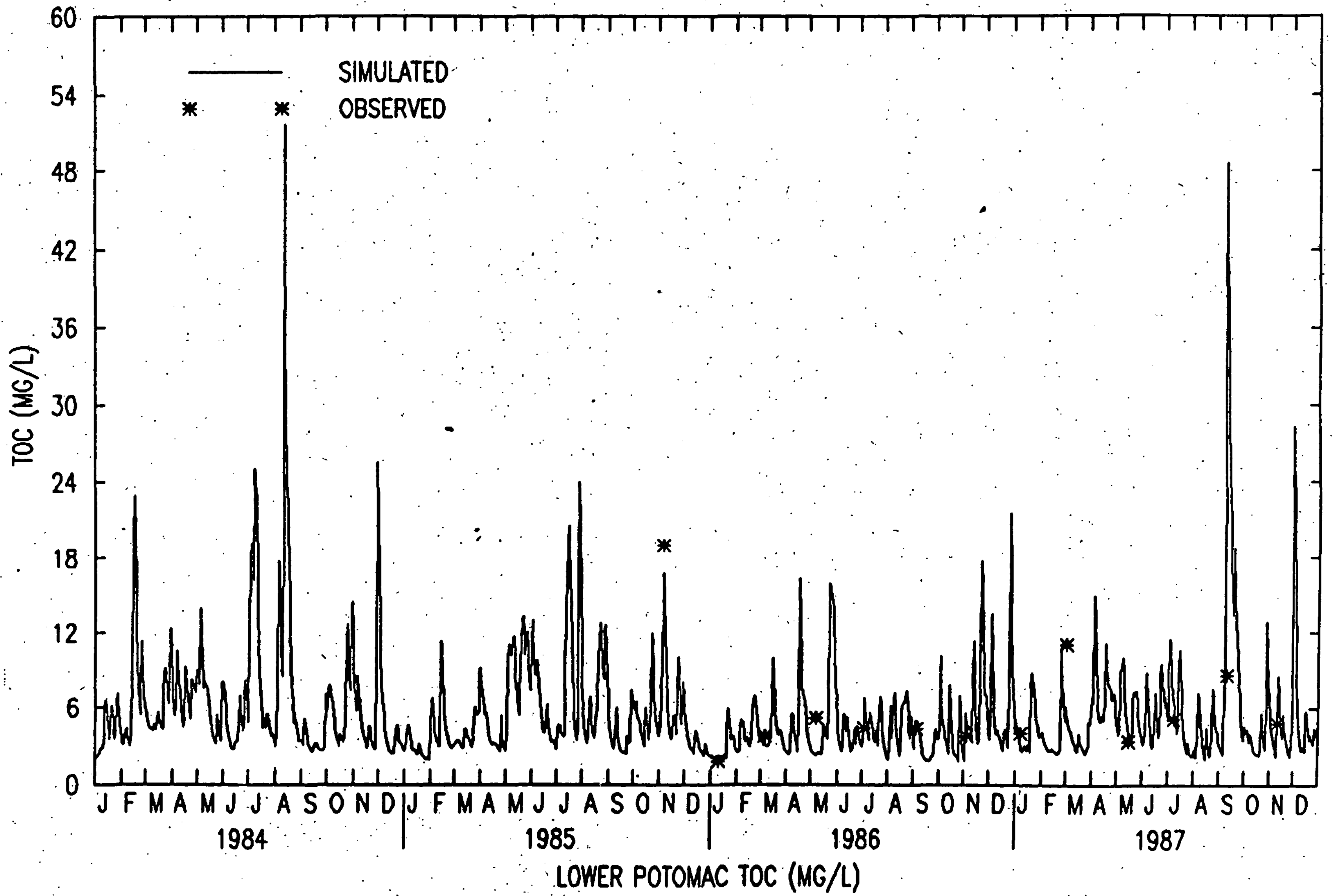

Figure 7.38 Simulated and observed total organic carbon (mg/l), Potomac River at Washington, D.C., 1984-87.

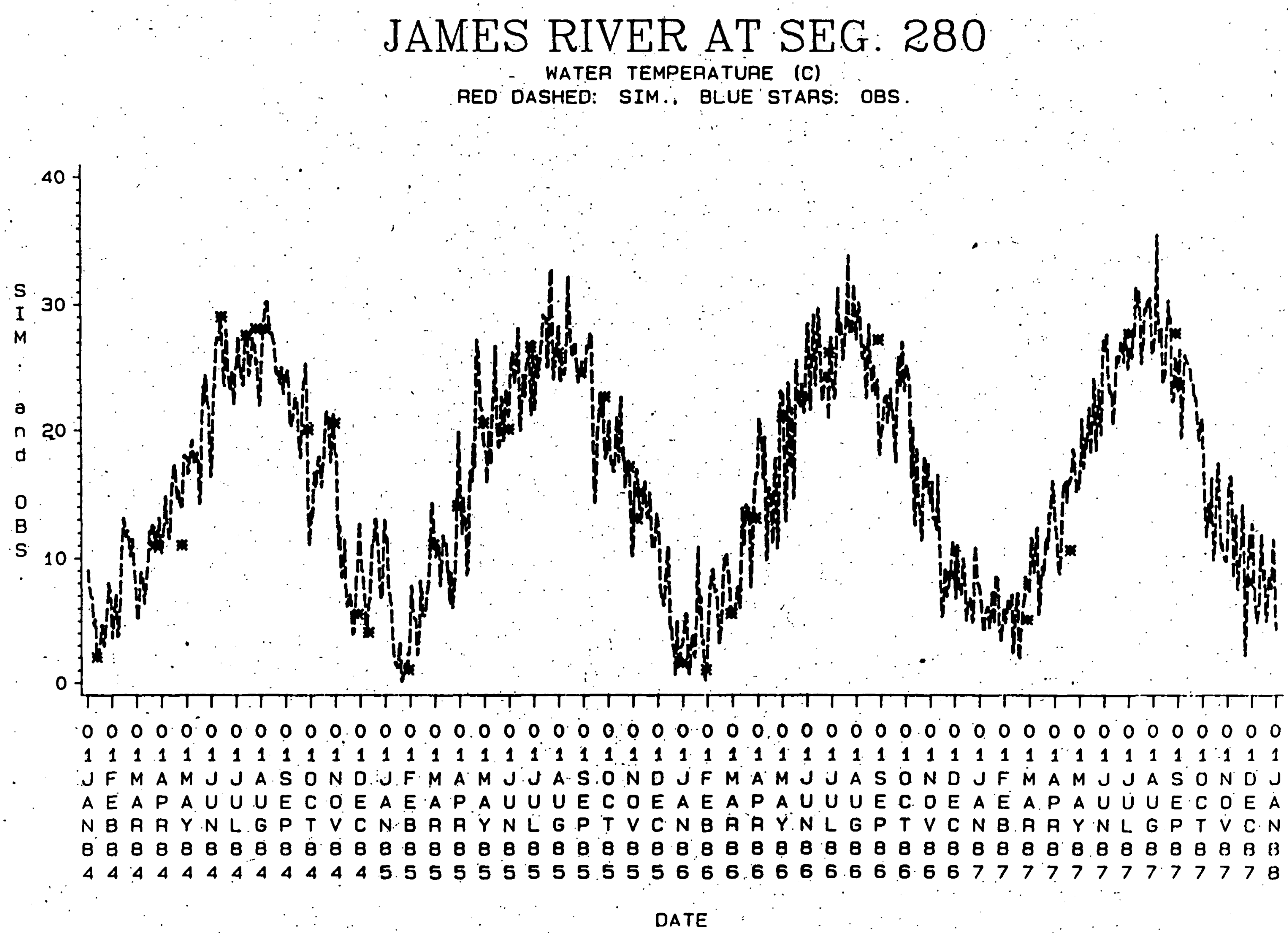

Figure 7.40 Simulated and observed water temperature (°C), James River at Cartersville, VA, 1984-87.

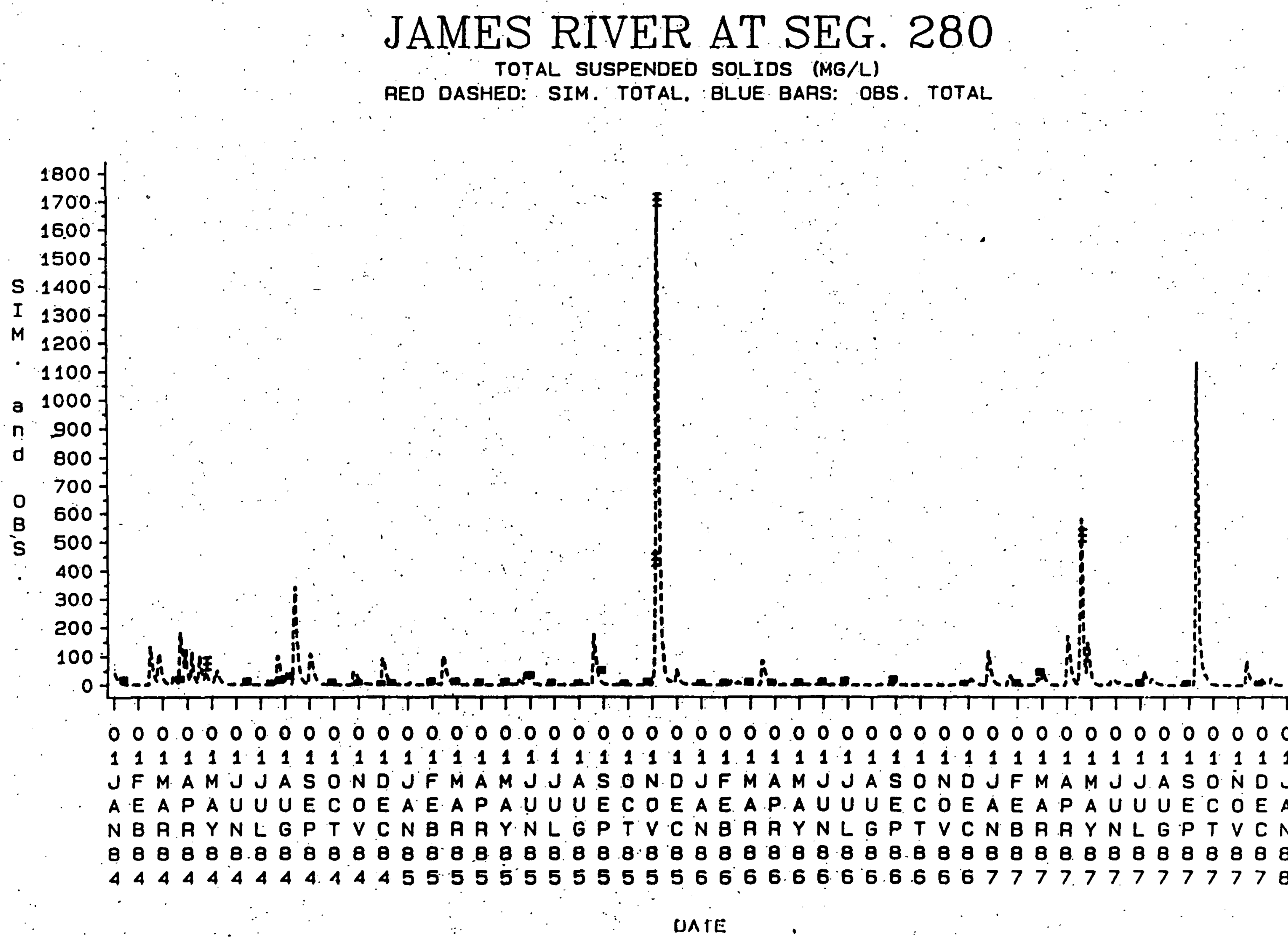

Figure 7.42 Simulated and observed suspended sediment (mg/l), James River at Cartersville, VA, 1984-87.

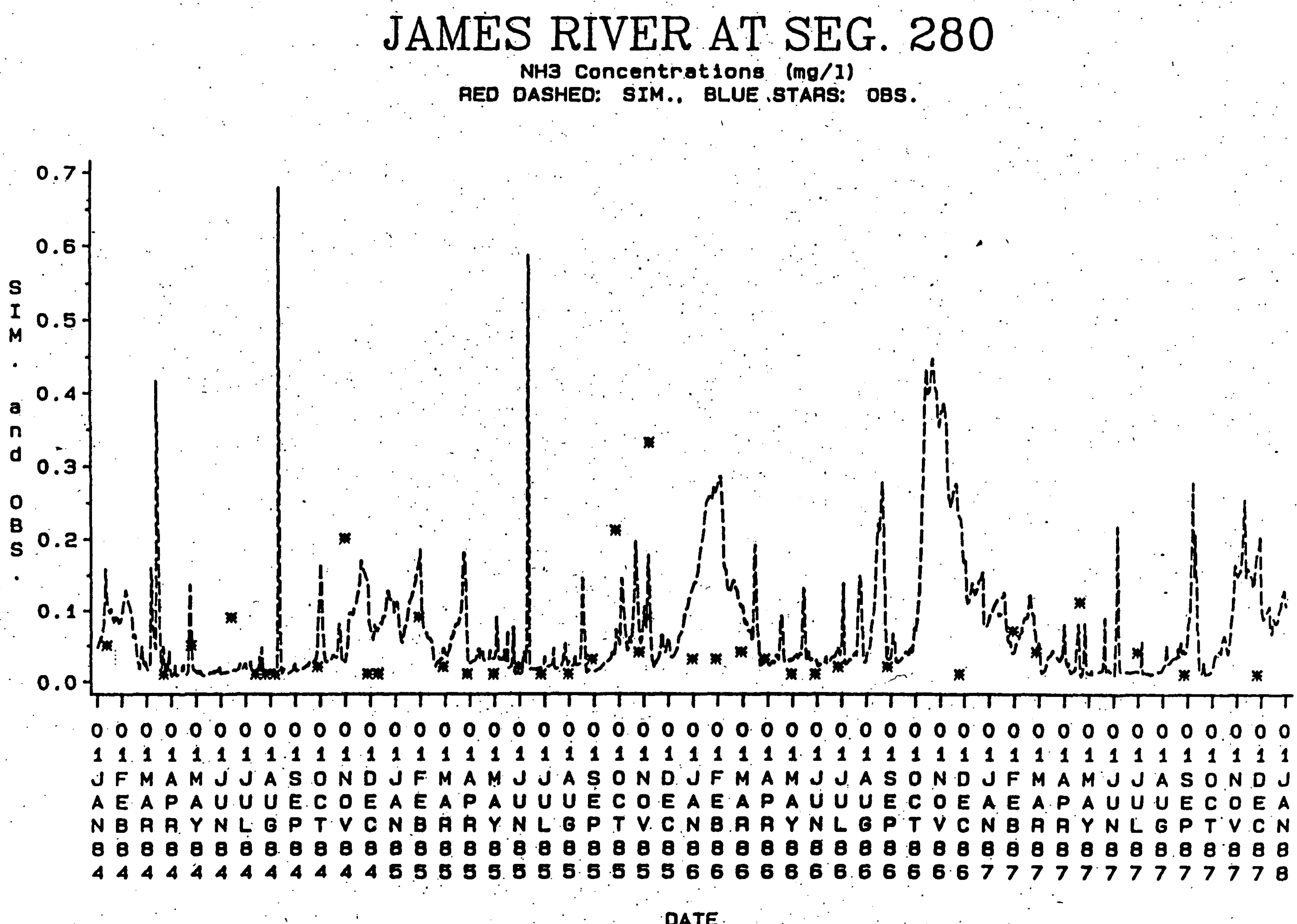

Figure 7.44. Simulated and observed ammonia (mg/l), James River at Cartersville, VA, 1984-87.

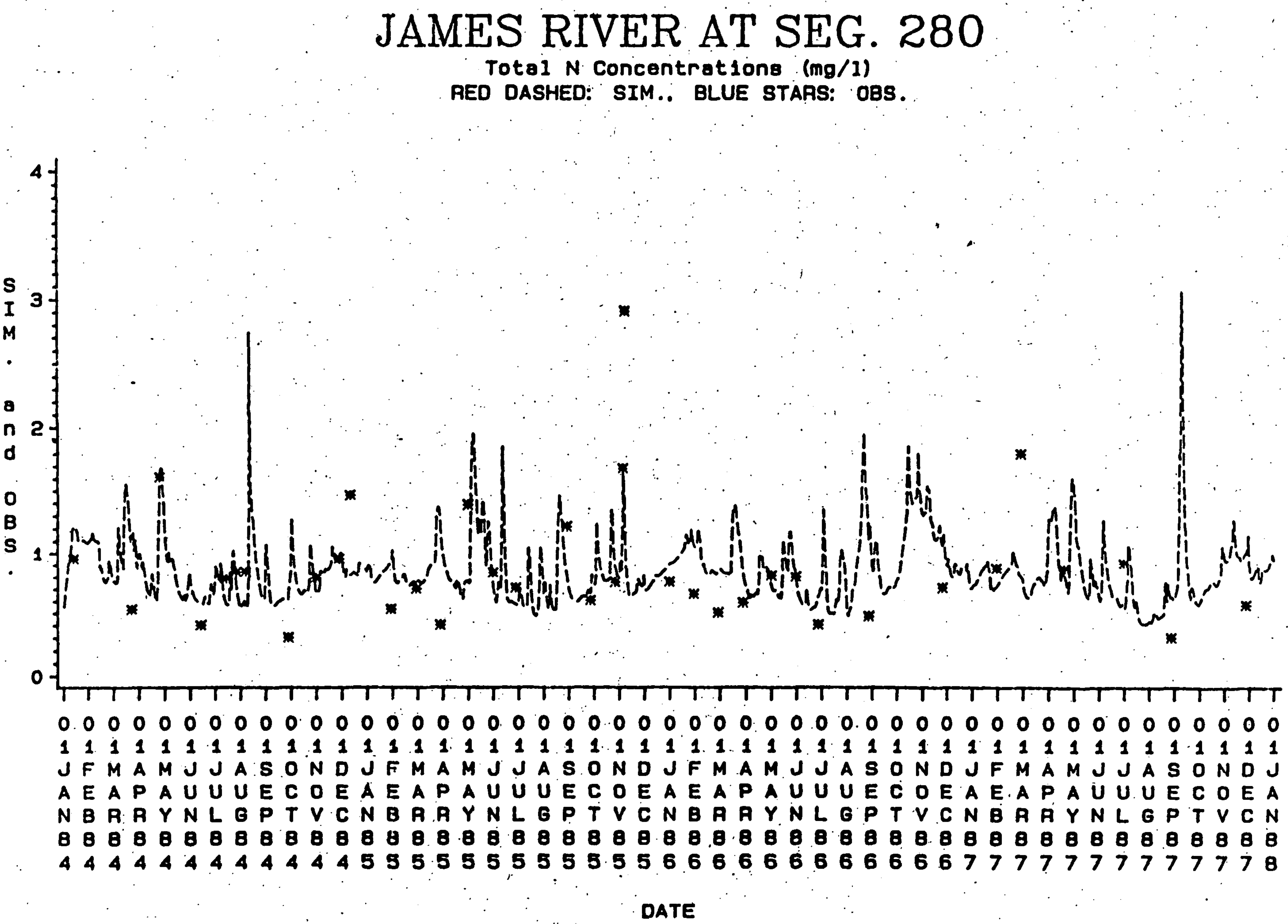

Figure 7.46 Simulated and observed total nitrogen (mg/l), James River at Cartersville, VA, 1984-87.

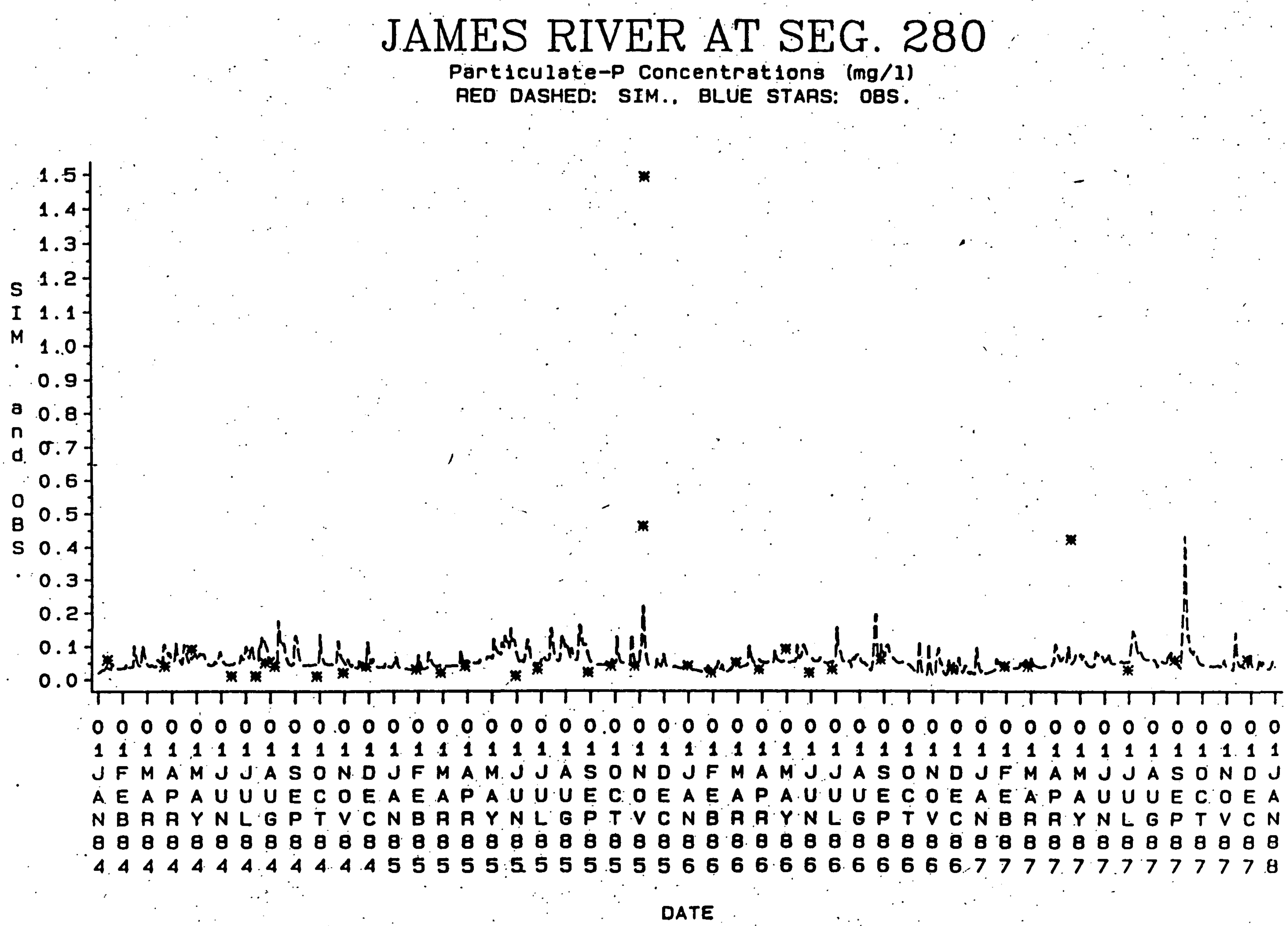

Figure 7.48 Simulated and observed particulate phosphorus (mg/l), James River at Cartersville, VA, 1984-87.

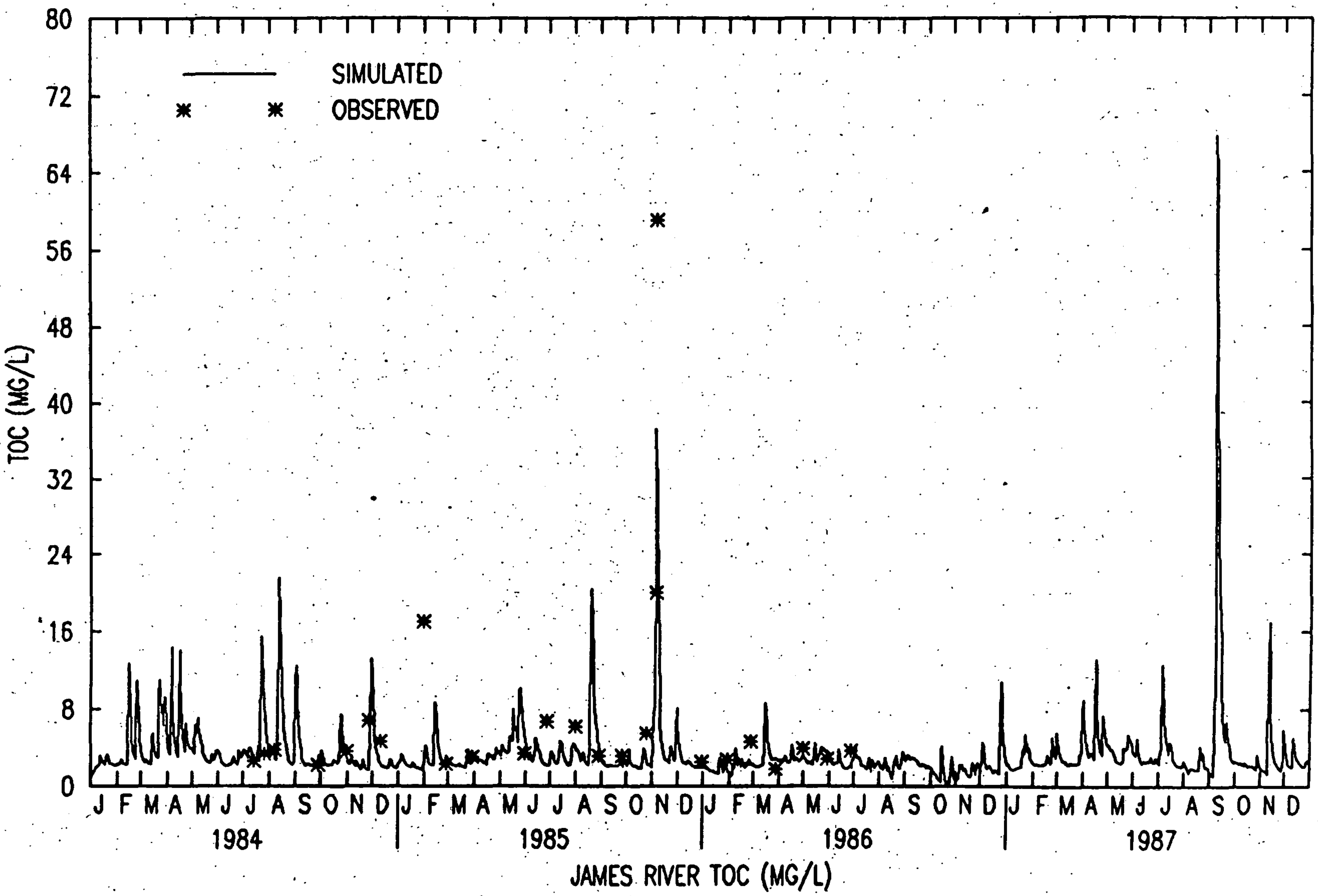

Figure 7.50 Simulated and observed total organic carbon (mg/l), James River at Cartersville, VA, 1984-87.

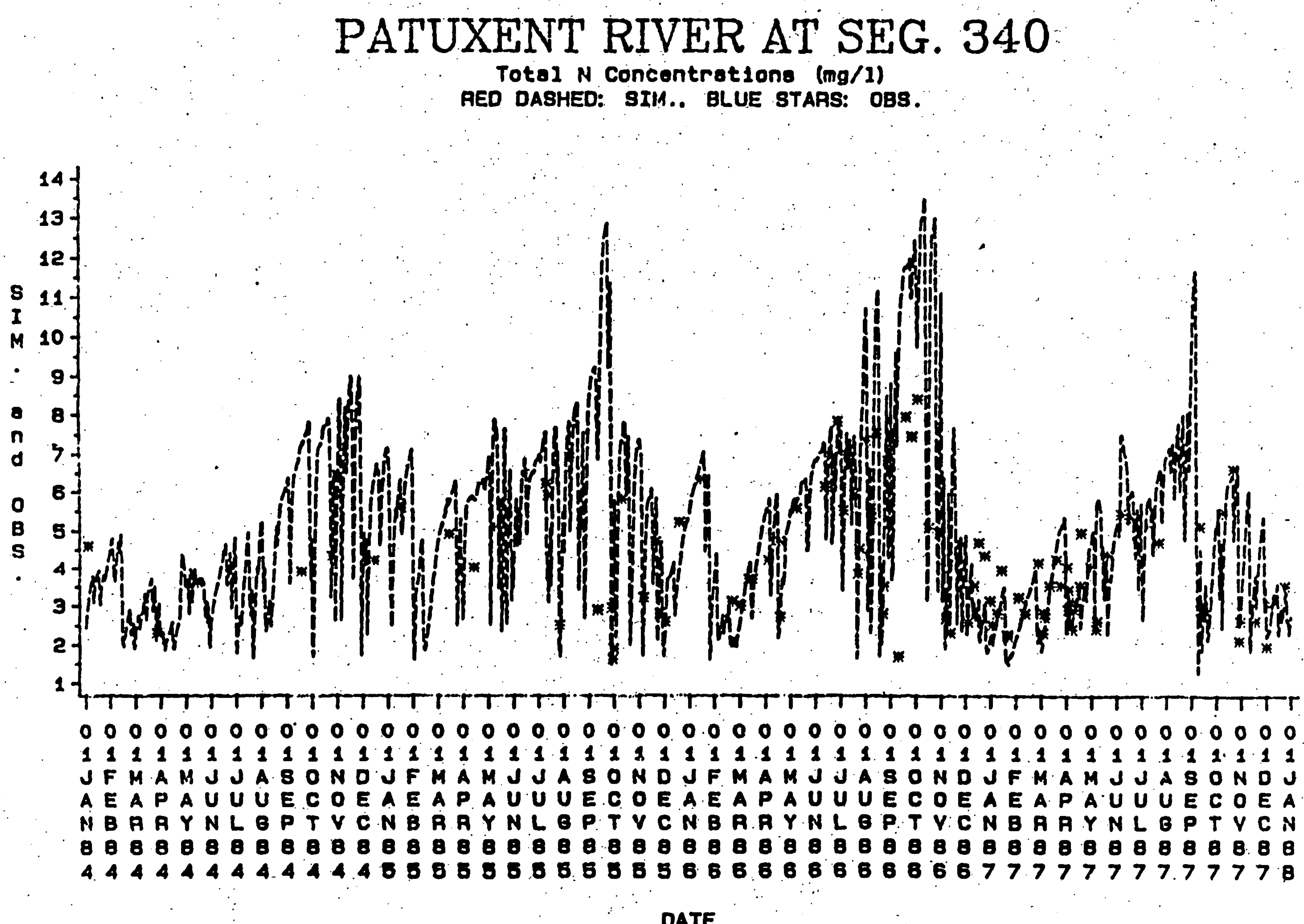

Figure 7.52 Simulated and observed total nitrogen (mg/l), Patuxent River at Bowie, MD, 1984-87.

SECTION 8.0

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