Water quality modeling in the watershed-based approach for waste load allocation of the Des Moines River

by

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A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

Major: Civil Engineering (Environmental Engineering)
Major Professor: Ruochuan Gu

Iowa State University
Ames, Iowa
1997

Graduate College
Iowa State University

This is certify that the Master's thesis of

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thesis requirements of has met the Iowa State University

Dedication

This thesis is dedicated to my husband Song Li, mother Fangying Li, and father Xianglong Dong. Without their love and support I could not have achieved the success that I have. I thank them for their encouragement, devotion, and tireless dedication to my life.

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INTRODUCTION

Watershed-based Approach and Water Quality Modeling

The watershed approach for water quality management is not a new concept. It has been part of the Clean Water Act (CWA) scince 1972. The Clean Water Act (CWA) authorized funding for areawide planning under Section 208 (Flynn, 1994). However, during the past two decades, water quality controls mostly focused on wastewater treatment plant and industrial discharges to meet the 1972 Clean Water Act goal of fishable and swimmable waters. While wastewater treatment and surface water quality have been improved, water quality professionals now realize that further gains will require actions beyond control of discharges of point source pollutants. The initial implementation of the Clean Water Act concentrated on the creation of a federal permitting program, the National Pollutant Discharge Elimination System (NPDES). The subsequent workload in handling NPDES permits overwhelmed many state water quality programs to the point where the primary focus became response to NPDES applications, establishment of point source waste load allocations, issuance of NPDES permits and NPDES permit enforcement. Program resources were rarely allocated to the evaluation of non-point source loads, such as those from overland runoff or transport of pollutants through groundwater flow into surface waters. Despite the fact that federal, state, and local governments have spent billions of dollars to establish criteria, tools, and programs for protecting water quality, problems still remain, particularly non-point source pollution and habitat degradation. Currently, it is understood that different environmental issues are so much intertwined that they require a comprehensive approach, which incorporates ecological principles and collaboration among agencies. Many agencies and programs at all levels of government are now embracing the idea of using the geographic boundaries of a river basin or a watershed as the basis for coordinating and integrating environmental management efforts. This is known as the watershed protection approach (EPA, 1995).

Renewed interest in watershed management during the last 10 years resulted in part from CWA Section 303(d), which requires each state to identify waters in its boundaries for which technology-based, point-source effluent controls would not lead to compliance with water quality standards. The states then must establish the total maximum daily loads (TMDL) of contaminants for these water bodies that would achieve compliance. Hence the TMDL requirements forced regulatory agencies to begin viewing pollution control from a watershed perspective(EPA, 1995).

Since 1991, the Environmental Protection Agency (EPA) has embraced the watershed-based approach for waste load allocation (WLA) and permit issuance in the National Pollutant Discharge Elimination System (NPDES) as a major mechanism for achieving the next generation of water environmental protection. Many States throughout the USA have already developed and implemented or have been planning to implement the watershed-based approach for solving their water quality problems. This is because the watershed-based approach has many advantages over the traditional, fragmentary, point-source oriented way of dealing with water quality concerns. Implementation of watershed-based approach has significant economic and environmental benefits. Watershed-based WLAs provide a comprehensive evaluation of the combined effects of permitted discharges on surface water quality in a watershed.

Non-point source pollution is responsible for the majority of Iowa's waterbodies that are not meeting their designated use. Surface water runoff from agricultural fields and feed lots is the largest source of non-point pollution in Iowa. Water quality goals in Iowa definitely cannot be achieved only with point source control. The advantage of watershed scale assessment and the seriousness of non-point source pollution in Iowa, the Iowa Department of Natural Resource (IDNR) is also considering adoption of the watershed-based approach for waste load allocation and NPDES permits. The Environment Engineering Division of the Department of Civil and Construction Engineering at Iowa State University conducted a research project for IDNR to developed a statewide strategy for adopting the watershed-based approach for waste load allocation in Iowa.

Surface water quality modeling provides a means to predict the impacts of natural processes and human activities on physical, chemical, and biological characteristics of a water body. Models are used widely to evaluate the impacts of waste loads from wastewater treatment plants or pollutant loads from various other point sources and non-point sources. Surface water quality modeling is one of the essential tools for the development and implementation of a watershed-based approach for waste load allocations in Iowa. The water quality models are utilized to assess the impacts of all point and non-point pollution sources in the whole watershed on water quality, calculate the waste load allocation and to determine

NPDES permits. Models are used not only to evaluate current water quality conditions and predict future water quality conditions but also to aid implementing and evaluating the appropriate pollution control measures for the desirable water quality. This thesis will focus on to develop a surface water quality modeling strategy in a watershed-based approach for waste load allocation in Iowa and demonstrate it on the Des Moines River, a major river in central of Iowa.

Objectives

A strategy for surface water quality modeling in a watershed-based approach for waste load allocation was developed by the research group in the Environment Engineering Division of the Department of Civil and Construction Engineering at Iowa State University.

The objective of this study is to demonstrate the strategy by using a surface water quality simulation model in the watershed-based approach for waste load allocation on the Des Moines River below Des Moines City, including model calibration and verification with field data for Des Moines River and model application to evaluate different watershed management and water quality control.

Organization of Study

This study begins with a discussion on the watershed-based approach for waste load allocation and a brief summary of surface water quality modeling and its role in watershed-based approach. Two surface water quality simulation model, QUAL2E and WASP5 , are reviewed in detail. The model selection is made for the watershed-based approach for waste load allocation in Iowa, especially the Des Moines River.

Then, the main task of this study focus on applying WASP5 model to implement watershed-based approach for waste load allocation to Des Moines river below Des Moines City, evaluating basic characteristics of the Des Moines River basin below Des Moines City, collecting hydraulic data, water quality monitoring data, point source and non-point source data, analyzing flow data, point source and non-point source loadings and using field data to calibrate and verify the WASP5 model .

The final part of this study focus on using the verified model with calibrated coefficients and constants to simulate water quality problem in a watershed with watershed based approach and to calculate waste load allocation of the Des Moines river in watershed based approach, analyzing effects of point source loadings, non-point source loadings, flow conditions and determining WLA of point source and non-point source loadings, under various future management or control scenarios.

LITERATURE REVIEW

Watershed-based Approach

Environmental Protection Agency has been encouraging states and local governments to adopt watershed management plans and programs. Approximately thirty-six states in U.S. are in the process of developing or implementing watershed approach frameworks. Through EPA's involvement in over 120 watershed projects nationally, the economic and environmental benefits of this approach have been seen as described in an EPA report (EPA, 1996). "Scientists, engineering, planners, environmentalists, and regulators have embraced watershed management as a better, more cost-effective approach for achieving clean water goals." (Freedman, 1994).

The Nebraska Department of Environmental Quality (NDEQ) recently developed a watershed-based approach for surface and groundwater quality entitled the "Basin Management Approach" (BMA). The BMA divides Nebraska into 13 river basins and ultimately develops a basin management plan for each of the basins. Basin management plans incorporate water quality (WQ) monitoring, WQ modeling, load allocation, and waste load reduction measures for the river basins. The BMA program began in 1994 and operates in five year cycles through the next century. NDEQ is implementing the BMAs in a phased approach beginning with two river basins in 1994. The steady state MULSMP model is used for modeling dissolved oxygen and carbonaceous BOD. Steady state equations are used for determining the amount of dilution that nutrients such as ammonia, and toxic pollutants receive in the stream below a wastewater treatment facility discharge. The TOXIWASP model is also occasionally used for modeling toxic pollutants. Non-point source modeling for nutrients involves the use of the EUTROMOD and AGNPS models.

For Washington State, the Watershed Approach to Water Quality is intended to be the initial phase of a broader program entitled "A Watershed Approach to Environmental Management". The program, "A Watershed Approach to Environmental Management," integrates water rights planning and permitting; shorelines planning; flood hazard management; wetlands planning; financial management; and waste management with water quality considerations. The main elements of the watershed approach include: 1) Five-year rotating management cycle; 2) Water Quality Management Areas; 3) Water quality monitoring and assessments; 4) Technology-based Treatment Standards, Anti-degradation, and TMDL pollution control strategies; 5) point and non-point source pollution controls; and 6) implementation of a Baseline Program. Washington uses a phased approach to its water quality modeling. At the first stage the Streeter-Phelps DO model is used to determine if the assimilative capacity of a waterbody will be exceeded. If the Streeter-Phelps model indicates that the capacity will be exceeded, the QUAL2E model will be employed. The WASP water quality model is used for tidal rivers and estuaries, though departmental personnel describe that model as difficult to use and not user friendly. Mixing zone models, such as CORMIX, are used to determine mixing zones for NPDES permits. Non-point source pollution is occasionally modeled with the HSPF model but non-point pollution is usually determined for upstream water quality monitoring data (Washington Department of Ecology, 1993).

In “EPA TMDL Case Study, Modeling the Appoquinimink River”(EPA, 1994), WASP4 was applied to support TMDL development. The WASP4 model was used to predict the water quality impacts of various point and non-point source loading scenarios. The objectives of this study include characterization of the non-point source nutrient loads and their impact on water quality and description of further modeling studies necessary to refine the TMDL .

Water Quality Modeling with WASP5 Model

The Water Quality Analysis Simulation Program--5 (WASP5) is an enhancement of the original WASP model(Di Toro et al., 1983; Connolly and Winfield, 1984; Ambrose, R.B. et al., 1988). This model helps users interpret and predict surface water quality responses to natural phenomena and man-made pollution for various pollution management decisions. WASP5 is a dynamic compartment modeling program for aquatic systems, including both the water column and the underlying benthos(Ambrose, R.B. et al., 1993).

Earlier versions of WASP have been used to examine eutrophication and PCB pollution of the Great Lakes (Thomann, 1975; Thomann et al., 1976; Thomann et al, 1979; Di Toro and Matystik, 1980a; Di Toro and Connolly, 1980b), eutrophication of the Potomac Estuary (Thomann and Fitzpatrick, 1982), kepone pollution of the James River Estuary (O'Connor et al., 1983), volatile organic pollution of the Delaware Estuary (Ambrose, 1987), and heavy metal pollution of the Deep River, North Carolina (JRB Inc, 1984).

EUTRO5 is one of three components of WASP5, which is applicable to modeling eutrophication. It was used to develop the water quality model for the Upper Mississippi River and Lake Pepin by Lung and Larson(1995). In their study, EUTRO5 model was applied to evaluate phosphorous control alternatives.

Previous Studies in Des Moines River

The Des Moines River is the largest interior waterbody in Iowa. The Environmental Engineering Division of the Department of Civil and Construction Engineering at Iowa State University has conducted water quality monitoring along the Des Moines River under an ongoing contract with the United States Army Corps of Engineers, Rock island District since 1968. Okereke (1982) developed equations that would facilitate the prediction of the annual loading rate of seven of the more critical water quality parameters (BOD, DO, ammonia nitrogen, nitrite plus nitrate nitrogen, suspend solids, total phosphorus and ortho- phosphate) in the Des Moines River and Raccoon River basins by using water quality monitoring data for 1973-1980. Girton (1994) verified the previously determined relationship between the annual unit load of four non-point source parameters (BOD, nitrite plus nitrate nitrogen, suspend solids, total ammonia nitrogen) in Okereke's study by reworking and extending the time period to 1993.

WATERSHED-BASED APPROACH MODELING STRATEGY AND MODELING PROCEDURE

The Key components of watershed-based approach are considering and addressing water quality problems based on the entire watershed and incorporation of non-point sources. The implementation strategy of the watershed-based approach in Iowa recommended by the research group of the Environment Engineering Division of the Department of Civil and Construction Engineering at Iowa State University are:

1. Organize citizen advisory groups or committees to help identity water quality issues in each geographic management unit, to assist in developing watershed planning goals and objectives.

2. Develop basin plans for all management units and strategies to achieve identified goals and objectives.

3. Establish a five year watershed planning and management cycle. The stages in the cycle are (1) basin planning and organization, (2) data collection, (3) assessment, modeling and prioritization, (4) basin plan development, and (5) implementation.

4. Compile and review preliminary information and collect and analyze available data. Identify issues and prioritize watersheds based on factors such as beneficial use, state surface water designations, ecological value, severity of environmental impact, and risk to human health or wildlife. Allocate resources to those waterbodies according to factors such as cost, feasibility of management, potential of success, and degree of public support.

5. Design and implement the monitoring plan. Compile detailed information and data.

6. Conduct water quality modeling and perform waste load allocation (WLA) and total maximum daily loads (TMDLs) analyses for the watershed. Analyze and evaluate information/data and modeling results. Evaluate issues identified and watershed prioritization in step 4.

7. Implement the watershed-based management strategy, including development of strategies for prioritized watersheds and watershed management plans, agency and public review/hearings, approval of river basin plans, and implementation of the plan.

Surface modeling is used in different phases of the watershed-based management cycle. It is used in the assessment phase to analyze water quality impairments and to determine the sources of water standards violations. It also plays a key role in the development of strategies for water quality improvement, like waste load allocations, NPDES permits and Total Maximum Daily Loads (TMDLs). On watershed-based approach for waste load allocations, both point sources and non-point sources in the entire watershed must be considered in whole watershed scale. Running the surface water quality modeling should be in watershed unit.

Modeling procedure consists of four phases: data collection, calibration of the model, verification of the model and application of the model. The data collection stage includes dividing the waterbody into junctions, channels, segments, and collecting data for flow, weather, water quality, waterbody geometry, point, non-point loads data and water quality standard. Model calibration is made against a set of field data selected, in which according to the output of model adjust model parameter and constants until model results agree well with observed data from a watershed. The verification of a model uses a second set of data measured in the watershed, which is different from those used for calibration, without further adjustment of model parameters and constants. In model application, the verified model is used as a tool for developing and testing alternative water quality management strategies in a watershed that involve point source and non-point source discharges and water quality problems.

MODEL SELECTION

To develop and implement a watershed-based approach for waste load allocations in Iowa, both point sources and non-point sources in the entire watershed must be considered when surface water model is chosen. Non-point source pollutants enter surface waters at intermittent intervals that is related to meteorological events. The total pollutant concentration is contributed by both point and non-point sources. A dynamic model is needed to determine the highest concentration of pollutants in a river basin resulting from the combined non-point source and point source loading.

WASP5 and QUAL2E are the most often used surface water quality models. QUAL2E is a one dimentinal steady state model for conventional pollutants. Hydraulically, QUAL2E is limited to the simulation of time periods during which both the stream flow in a river basin and input waste loadings are essentially constant. By operating the model dynamically, the user only can study the effects of diurnal variations in meteorological data on water quality (primarily dissolved oxygen and temperature) and also can study diurnal dissolved oxygen variations due to alga growth and respiration. It cannot simulate toxic pollutants.

After reviewing several surface water quality models, WASP5 was chosen as the surface water quality model to be used for the watershed-based approach for waste load allocations. WASP5 is able to simulate flow, point source loading and non-point source loading dynamically and it can simulate sediment and toxic pollutants. WASP5 is a dynamic compartment modeling program for conventional pollutants (including DO, BOD, nutrients and eutrophication) and toxic pollutants (including organic chemicals, metals, and sediments). Pollutant concentrations and their variations with time and over space resulting from point source loading and non-point source loading and spatial and temporal variations in the entire watershed can be simulated. WASP5 permits the user to structure one, two or three dimensional models. It allows the specification of time-variable exchange coefficients, flows, point source loading and non-point source loading, and water quality boundary conditions (Ambrose, et al. 1993).

WASP5 is found to have some advantages. WASP5 is an unsteady state model for conventional pollutants and toxic pollutants. Hydraulically, it is not limited to simulations for periods during which both the stream flow and waste loading are essentially constant. WASP5 can be used to determine the highest concentration of pollutant in a river basin resulting from non-point loading as well as point source loading. WASP5 can simulate sediment and toxic pollutants. On the other side, WASP5 is more sophisticated in eutrophication simulation. Comparison of capabilities of WASP5 and QUAL2 Models is listed in Table 1.

WASP5 can provide sufficient information needed for NPDES permit program and water quality management. WASP5 model will be an effective tool for the development and implementation of a watershed-based approach to waste load allocations and point source and non-point source pollution controls in Iowa.

Table 1. Comparison of WASP5 and QUAL2 model

	QUAL2	WASP5
Branching Stream	YES	YES
Segmented stream	YES	YES
Steady state	YES	YES
Quasi-dynamic	YES	YES
Dynamic	NO	YES
Hydraulics	YES	YES
Dimension	1	1,2,3
Temperature	YES	NO
BOD-DO	YES	YES
Organic nitrogen	YES	YES
Organic phosphorus	YES	YES
Inorganic phosphors	YES	YES
Ammonia	YES	YES
Nitrate	YES	YES
Toxic pollution	NO	YES
Point loads	YES	YES
Non-point loads	YES	YES

DESCRIPTION OF WASP5 MODEL

General Description

WASP is generalized framework for modeling contaminant fate and transport in surface waters and is supported by the Environment Protection Agency's (EPA) environment research laboratory in Athens, Georgia. WASP5 is the latest version of a series of developments. The Water Quality Analysis Simulation Program--5 (WASP5) helps users interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decision's conditions (Ambrose, et al. 1993). WASP5 is a dynamic compartment modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program.

The flexibility afforded by the Water Quality Analysis Simulation program is unique. WASP5 allows the specification of time-variable exchange coefficients, advective flows, waste loads and water quality boundary conditions. WASP5 allows users to specify point source and non-point source loading to water bodies. It is a dynamic compartment model that can be used to analyze a variety of water quality problems in such diverse water bodies as ponds, streams, lades, reservoirs, rivers, estuaries, and coastal waters. The equations solved by WASP5 are based on the conservation of mass. WASP5 traces each water quality constituent from the point of spatial and temporal input to its final point of export, conserving mass in space and time.

Overview of the Model System

The WASP5 system consists of two stand-alone computer programs, DYNHYD5 and WASP5, that can be run in conjunction or separately. (Ambrose, et al. 1993). The hydrodynamics program, DYNHYD, simulates the movement and interaction of pollutants within the water. WASP5 is supplied with two kinetic sub-models to simulate two of the major classes of water quality problems: conventional pollutants(including dissolved oxygen, biochemical oxygen demand, nutrients and eutrophication) and toxic pollutants (including organic chemicals, metals, and sediments).

EUTRO5 can simulate 8 variables. Table 2 summarizes these variables and their use in six discrete levels of complexity.The user may choose to simulate any combination of these variables using any combination of parameter functions and values described in manual, the user may choose to simulate only one variable, such as CBOD, while bypassing (and thus holding constant) all other variables.

TOXI5 can simulate 6 variables. Table 3 summarizes these variables and their use in several discrete levels of complexity. These levels of complexity describe possible approaches to simulating solids, equilibrium reactions, and kinetic reactions. They are suggestive. The user may choose to simulate any combination of these variables using any combination of the parameter functions and values described in manual. Table 4-5 summarized available display variable for EUTRO5 and TOXI5.

Table 2. EUTRO5 systems and levels of complexity (Ambrose, et al. 1993)

System			Use in Complexity Level[a]					
Number	variables	Name	1	2	3	4	5	6
1	NH3	Ammonia nitrogen		x	x	x	x	x
2	NO3	Nitrate nitrogen			x	x	x	x
3	PO4	Inorganic phosphorus				x	x	x
4	PHYT	Phytoplankton carbon				x	x	x
5	CBOD	Carbonaceous BOD	x	x	x	x	x	x
6	DO	Dissolved oxygen	x	x	x	x	x	x
7	ON	Organic nitrogen			x	x	x	x
8	OP	Organic phosphorus				x	x	x

[a] Complexity Level Explanation:

1: "Streeter-Phelps" BOD-DO with SOD
2: "Modified Streeter-Phelps" with NBOD
3: Linear DO balance with nitrification
4: Simple eutrophication
5: Intermediate eutrophication
6: Intermediate eutrophication with benthos

Table 3. TOXI5 systems and levels of complexity (Ambrose, et al. 1993).

System Number	variables	Name	Levels of Complexity[a] for: Solids			Kinetics	
			1-2	3	4	1-3	4
1	C1	Chemical 1	x	x	x	x	x
2	S1	Solid 1		x	x		
3	S2	Solid 2			x		
4	S3	Solid 3			x		
5	C2	Consists Chemical 2					x
6	C3	Chemical 3					x

[a] Complexity Level Explanation

Solids1: Descriptive solids concentration field
Solids2: Descriptive solids concentration field with specific solids transport rates
Solids3: Simulated total solids
Solids4: Three simulated solids types
Kinetic1: Constant half lives or rate constants
Kinetic2: Spatially-variable rate constants
Kinetic3: Second order rates
Kinetic4: Transformation products

Table 4. EUTRO5 display variables (Ambrose, et al. 1993)

Number	Variable	Definition
1	DEPTHG(I)	Segment Depth, m
2	STP	Water Temperature, C
3	WIND	Wind Speed, m/sec
4	VEL	Water Velocity, m/sec
5	DO	Dissolved Oxygen, mg/L
6	DOMIN	DO Minimum, mg/L
7	DOMAX	DO Maximum, mg/L
8	CS	DO Saturation, mg/L
9	PERSAT	Percent DO Saturation, %
10	KA	Effect Reaeration rate, 1/day
11	K2WSAVE	Wind Driven Reaeration , 1/day
12	K2HSAVE	Current Driven Reaeration , 1/day
13	SOD1D(I)	Sediment Oxygen Demand, g/m2/day
14	CBOD	CBOD, mg/L
15	BOD5	BOD5, Mg/l
16	UBOD	Ultimate BOD, mg/L
17	TEMPBOD	BOD decay rate constant, 1/day
18	PHYT	Phytoplankton Carbon Biomass, mg/L
19	TCHLAX	Phytoplankton Chlorophyll a, mg/L
20	GP1	Phytoplankton Growth Rate, 1/day
21	DP1	Phytoplankton Death Rate, 1/day
22	SR19P	Phtoplankton DO Production, mg/L/day
23	SK19P	Phtoplankton DO Consumption , mg/L/day
24	CCHL1	Phyt. Carbon to Chl.a Ratio, mg/mg
25	RLGHTS(I,I)	Light Limit for Phyt. Growth
26	RNUTR	Nutrient Limit for Phyt. Growth
27	XEMP1	Phosphorus Limit for Phyt. Growth
28	XEMP2	Nitrogen Limit for Phyt. Growth
29	ITOTMP	Light at Segment Surface, langleys/day
30	IS1	Saturating light Intensity, langleys/day
31	IAV	Light at Top of Segment, langleys/day
32	IAVBOT	Light at Bottom of Segment, langleys/day
33	NH3	Ammonia Nitrogen, mg/L
34	NO3	Nitrate Nitrogen, mg/L
35	CN	Available Inorganic Nitrogen, mg/L
36	TON	Total Organic Nitrogen, mg/L
37	TIN	Total Inorganic Nitrogen, mg/L
38	TN	Total Nitrogen, mg/L
39	OPO4	Available Inorganic Phosphorus , mg/L
40	TIP	Total Inorganic Phosphorus , mg/L
41	TOP	Total Organic Phosphorus , mg/L
42	OP	Nonliving Organic Phosphorus , mg/L

Table 5. TOXIC5 display variables (Ambrose, et al. 1993)

Constant Number				
C1	C2	C3	Variable	Definition
1			TOTSOSL	Total solids concentration ,mg/L
2			SOLID 1	Solids type 1 concentration, mg/L
3			SOLID 2	Solids type 2 concentration, mg/L
4			SOLID 3	Solids type3 concentration, mg/L
5			STEMP	Segment temperature, °C
6			ITYPE	Segment type (1,2,3,or 4)
7	19	31	TOTCHEM	Total chemical concentration (1, 2, 3), g/L
8	20	32	TOTTDIS	Dissolved chemical concentration, g/L
9	21	33	TOTDOC	DOC-sorbed chemical concentration, g/L
10	22	34	TOTPAR	Total sorbedchemical concentration, g/L
11	23	35	TOTPAR 1	Total sorbed chemical concentration, g/kg
12	24	36	TOTION	Total ionic chemical concentration, g/L
13	25	37	KBIO	Biodegradation rate constant,1/day
14	26	38	KHYD	Total hydrolysis rate constant, 1/day
15	27	39	KFOT	photolysis rate constant, 1/day
16	28	40	KVOL	Volatilization rate constant, 1/day
17	29	41	KOX	Oxidation rate constant, 1/day
18	30	42	KEXT	Extra rate constant, 1/day

Governing Equation

The general mass balance equation is:

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}(E_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(E_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial C}{\partial z}) + S_L + S_B + S_K \qquad \textbf{1}$$

where the x- and y-coordinates are in the horizontal plane, and the z-coordinate is in the vertical plane (Ambrose, et al. 1993).

C = concentration of the water quality constituent, *mg/L* or g/m^3

t = time, days

U_x, U_y, U_z = longitudinal, lateral, and vertical advective velocities, *m/day*

E_x, E_y, E_Z = longitudinal, lateral, and vertical diffusion coefficients, m^2/day

S_L = direct and diffuse loading rate, g/m^3-day

S_B = boundary loading rate (including upstream, downstream, benthic, and atmospheric), g/m^3 day

S_K = total kinetic transformation rate; positive is source, negative is sink, g/m^3-day

By expanding the infinitesimally small control volumes into larger adjoining "segments," and by specifying proper transport, loading, and transformation parameters, WASP implements a finite-difference form of equation 1. For brevity and clarity, however, the derivation of the mass balance equation will be for a one-dimensional reach. Assuming vertical and lateral homogeneity, we can integrate equation 1 over y and z to obtain

$$\frac{\partial}{\partial t}(AC) = \frac{\partial}{\partial x}(-U_x AC + E_x A\frac{\partial C}{\partial x}) + A(S_L + S_B) + AS_K \qquad 2$$

where:

A = cross-sectional area, m^2

This equation represents the three major classes of water quality processes -- transport (term 1), loading (term 2), and transformation (term 3) (Ambrose, et al. 1993).

Summary

WASP5 is a dynamic compartment modeling program for conventional pollutants (including DO, BOD, nutrients and eutrophication) and toxic pollutant (including organic chemicals, metals, and sediments). It can provides a complete characterization of the hydrological, chemical and biological processes that occur in a watershed afte linked it with a hydrologic and non-point pollution model.

WASP5 can be used to describe present water quality condition where and when there are no monitoring data when constants and coefficients for the model are available, to determine the severity of water quality impairment, to identify sources of impairment, to analyze relationship between pollutant loading and water quality, and to predict water quality. WASP5 provides sufficient information needed for NPDES permit program and water quality management. WASP5 can help IDNR to establish TMDLs or waste load allocations, and to evaluate water quality management strategies and to establish a watershed management plan. WASP5 model will be an effective tool for the development and implementation of a watershed-based approach to waste load allocations and point source and non-point source pollution controls in Iowa.

WATER QUALITY MODELING OF THE DES MOINES RIVER

Introduction

A 24 mile reach of the Des Moines River below the City of Des Moines receives wastewater from the Des Moines Sewage Treatment Plant (point source) and from non-point sources that mainly come from agricultural cropland. Both point source and non-point source discharges affect the water quality of the river. Discharging of point source and non-point sources into the reach of river causes biochemical processes. For the watershed-based approach, the combined effects of the wastewater effluent from the Des Moines Sewage Treatment Plant and the non-point source discharges need to be assessed. WASP5 Model was calibrated and verified for study reach. The verified WASP5 Model was applied to simulate some of the biochemical processes and calculate the waste load allocation. The study reach is from the outfall of the treatment plant(river mile 198.5) to downstream distance of about 24 miles. Figure 1 show the location of simulation domain in the study. The study reach is divided to 24 segments with each segment length is 1 mile.

The water quality model was applied to simulate the instream concentration of dissolved oxygen, carbonaceous biochemical oxygen demand, and total ammonia as nitrogen. For these three parameters, WASP5 Model was calibrated and verified. The verified model was applied to various combinations of different discharges from point sources and non-point sources, and different flow conditions. The potential of failing to meet water quality standardis greatest during lower streamflows, higher stream temperatures or both, or during

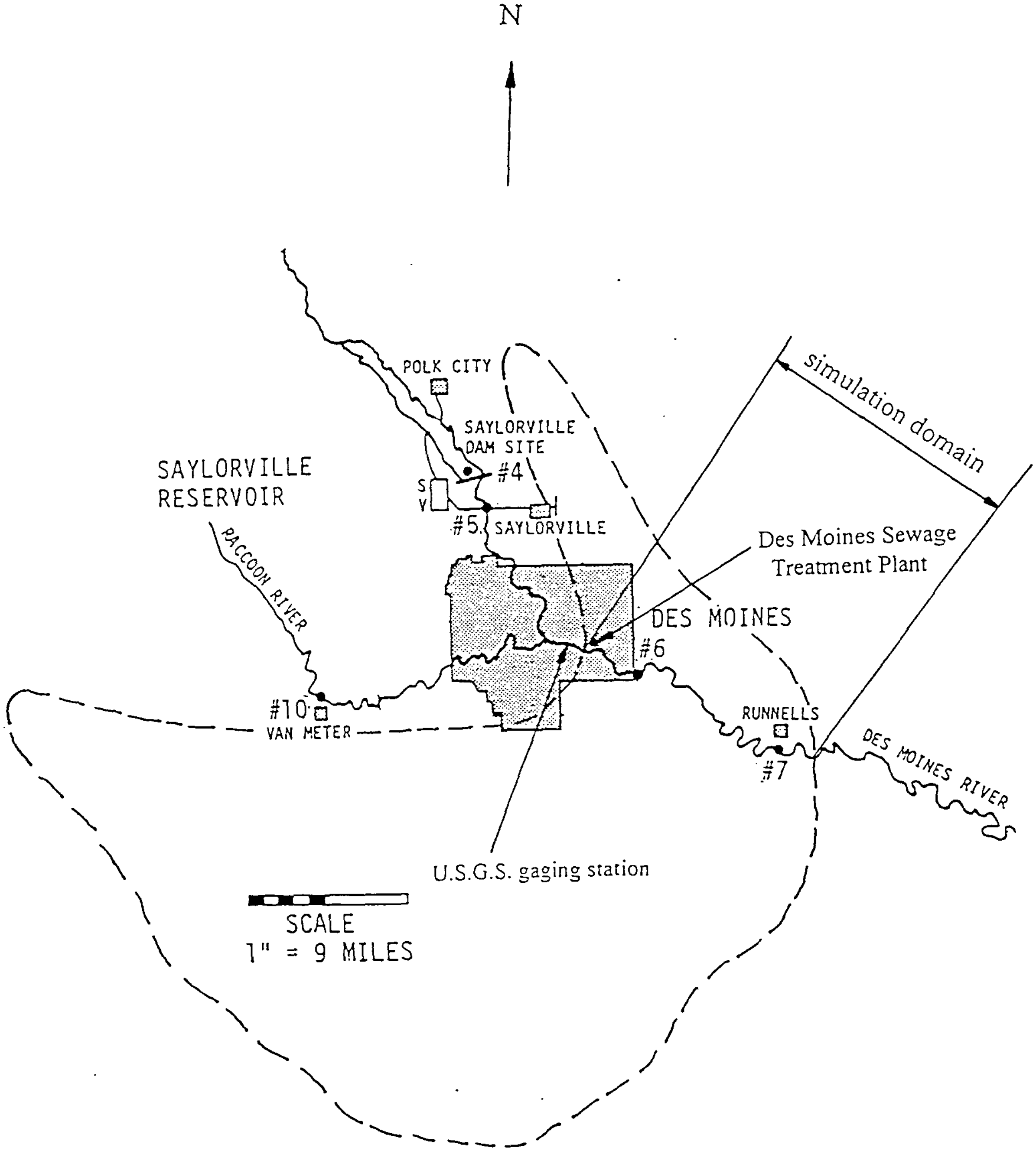

Figure 1. Location map of simulation domain in the study

highest concentration of pollutants from runoff. The water quality model was used as a tool to evaluate the effects of discharging from treated wastewater from Des Moines Sewage Treatment Plant and discharging from non-point sources mainly coming from cropland and the water quality model was used as a tool to identify the waste assimilation capacities of the river.

The Environmental Engineering Division of the Department of Civil and Construction Engineering at Iowa State University has conducted water quality monitoring along the Des Moines River under an ongoing contract with the United States Army Corps of Engineers, Rock island District since 1968. Figure 2 shows a vicinity map and the locations of regular sampling stations (Lutz, 1995). In order to investigate the effects of the Des Moines Sewage Treatment Plant discharge on the water quality of the Des Moines River, three special profile studies were conducted on 24 September 1975, 15 October 1975, and 13 July 1977. In these special profile studies, more sampling sites were set from above the of the treatment plant to distance of about 22 miles below the treatment plant. The data obtained on 13 July 1977 were used to calibrate the WASP5 Model. The data obtained on 24 September 1975, and on 15 October 1975 were used to verify the WASP5 Model.

This section describes the results of the modeling study to evaluate the effects of point source and non-point source discharges on instream water quality conditions with the watershed-based approach. The model simulates the water quality condition and process involved process with the verified reaction coefficients.

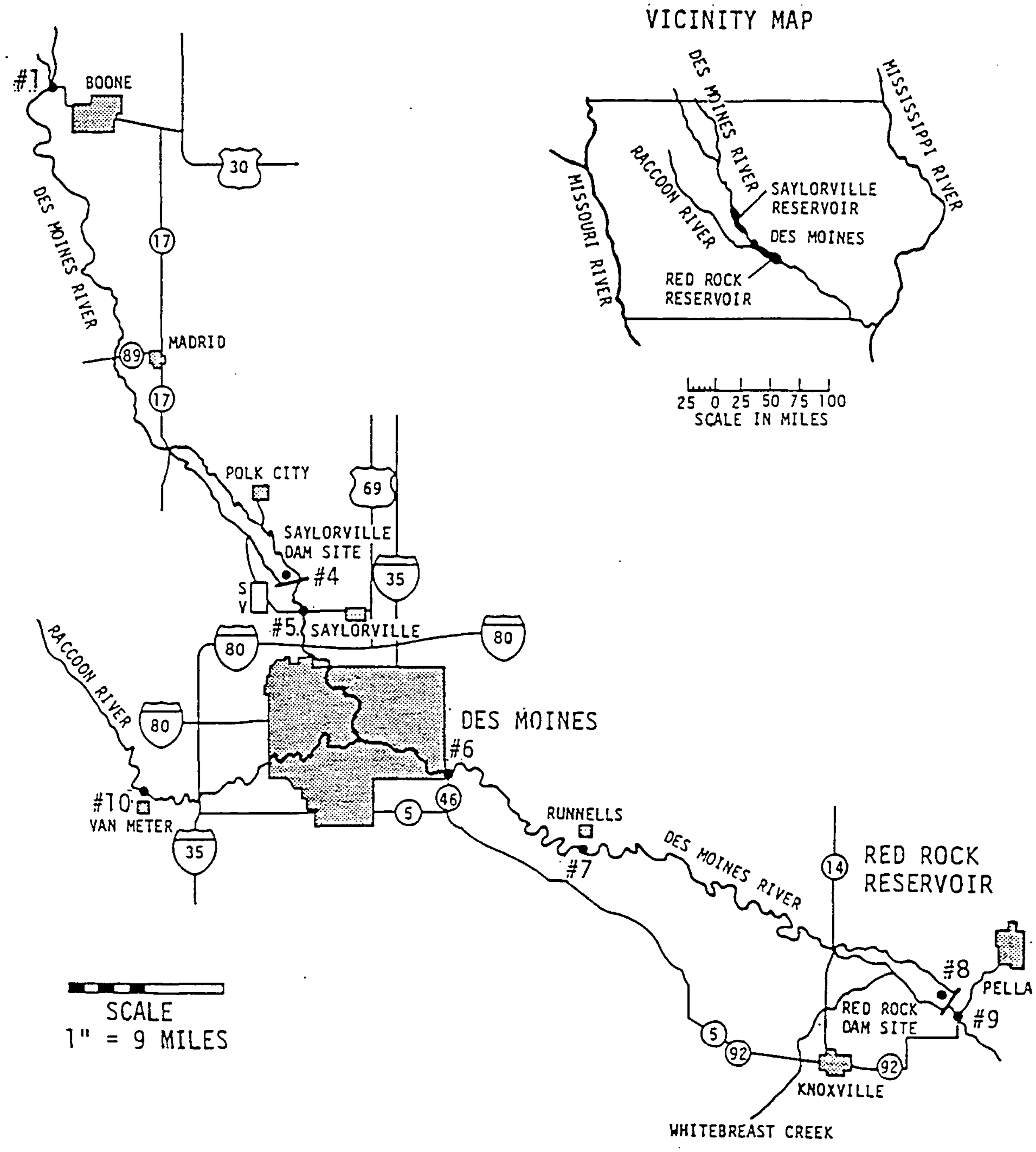

Figure 2. Location map for sampling stations on Des Moines River, and Raccoon River (Lutz, 1995)

Water Quality Standards

The chapter 60, 61, and 62 of the Iowa Administrative Code specify state surface designations, surface water quality Criteria, and effluent quality standards. In the Iowa Administrative Code, the reach of the Des Moines River below Des Moines City is identified as class A (Primary contact recreation) and class B(WW) (Significant resource warm water) by Environmental Protection Commission of State of Iowa. The class B(WW) water is defined as. "water in which temperature, flow and other habitat characteristics are suitable for maintenance of a wide variety of reproducing populations of warm water fish and associated aquatic communities, including sensitive species" (Iowa Administrative Code, sec61.3(1)). The class A water is to be protected for primary contact recreation, and defined as "water in which recreational or other uses may result in prolonged and direct contact with the water, involving considerable risk of ingesting water in quantities sufficient to pose a health hazard." (Iowa Administrative Code, sec61.3(1).) No criteria for Dissolved Oxygen and Ammonia Nitrogen are specified for class A water. The criteria for Dissolved Oxygen of class B(WW) is more than 5.0 mg/L (IAC, sec.61.3(3) b(1)), Criteria for ammonia nitrogen for class B(WW) are listed in Table 6 (IAC, P.8, sec61.3(3) b(3)).

General Hydrology

The watershed drainage area of the 24 mile reach is about 1776 $mi.^2$ The U. S. Geological Survey gaging station (05485500) is located at river mile 200.7, which is 2.2 mile upstream of the study reach. The streamflow in the Des Moines River is quite variable from

Table 6. Criteria for ammonia nitrogen -- warm water stream and lake (IAC: State of Iowa) (all values expressed in milligrams per liter as Nitrogen)

Temp . °C		PH											
		6.5	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0
1.0	Acute	49.0	39.5	33.8	27.6	21.4	15.8	11.2	7.1	4.5	2.9	1.8	1.2
	chronic	9.8	7.9	6.8	5.5	4.3	3.2	2.2	1.4	0.9	0.6	0.4	0.2
5.0	Acute	46.4	37.4	32.1	26.2	20.3	15.0	10.6	6.8	4.3	2.8	1.8	1.2
	chronic	9.3	7.5	6.4	5.2	4.1	3.0	2.1	1.4	0.9	0.6	0.4	0.2
10.0	Acute	44.0	35.5	30.5	24.9	19.3	14.3	10.1	6.5	4.1	2.7	1.8	1.2
	chronic	8.8	7.1	6.1	5.0	3.9	2.9	2.0	1.3	0.8	0.5	0.4	0.2
15.0	Acute	42.3	34.1	29.3	24.0	18.6	13.8	9.8	6.3	4.1	2.7	1.8	1.2
	chronic	8.5	6.8	5.9	4.8	3.7	2.8	2.0	1.3	0.8	0.5	0.4	0.2
20.0	Acute	41.2	33.3	28.6	23.4	18.2	13.5	9.7	6.2	4.1	2.7	1.8	1.2
	chronic	8.2	6.7	5.7	4.7	3.6	2.7	1.9	1.2	0.8	0.5	0.4	0.2
25.0	Acute	40.7	32.9	28.3	23.2	18.1	13.5	9.7	6.3	4.2	2.7	1.8	1.2
	chronic	8.1	6.6	5.7	4.6	3.6	2.7	1.9	1.3	0.8	0.5	0.4	0.2
30.0	Acute	20.4	16.5	14.2	11.7	9.1	6.8	5.0	3.3	2.2	1.5	1.1	0.8
	chronic	4.1	3.5	2.8	2.3	1.8	1.4	1.0	0.7	0.4	0.3	0.2	0.2

year to year and season to season. The variability and duration of streamflow in the Des Moines River are an important water quality consideration.

Based on the historical flow record from 1941 to 1976, at gaging station (05485500), the median value of annual mean discharges was 3580 cfs, or 4.9 in/yr (Water Resources Data, Iowa, Water Year 1989). The 7-day 10-year low streamflow was 98 cfs, the 7-day 5-year low streamflow was 135 cfs, the 7-day 2-year low streamflow was 264 cfs, the 84% low streamflow was 399 cfs (the U. S. Geological Survey, 1979).

Data Collection for the Model Calibration and Verification

Before the model was applied to simulate water quality conditions in the study reach, it was calibrated and verified with independent sets of field data. The model was calibrated so that simulated data for one set were in an acceptable agreement with field data. The reaction coefficient of the model was calibrated. Two sets of field data was used to verify the calibrated reaction coefficients. Dissolved oxygen, biochemical oxygen demand and total ammonia as nitrogen, important indicator of water quality in the Des Moines River, were simulated.

In the special profile studies e conducted by The Environmental Engineering Division of the Department of Civil and Construction Engineering at Iowa State University, two special profile studies were conducted from the outfall of the treatment plant to distance of about 11 miles to 22 miles below the treatment plant on September 24,1975 and October 15,1975. the streamflow on September 24,1975 and October 15,1975 are 555 cfs and 437 cfs.

Among the data of September 24,1975, the data of five sampling station was used to verify the model. Among the data of October 15,1975, the data of five sampling station was used to verify the model. Severe drought conditions experienced in central Iowa during the summer of 1977. The low flow condition in 1977 offers an excellent opportunity to calibrate the water quality model as water column kinetics becomes more pronounced during low flow periods. A special profile study was conducted on July 13,1977, the streamflow was 88 cfs. Sampling was conducted at eight river locations from above the outfall of the treatment plant to distance of about 27 miles below the treatment plant. Because the very low flow condition, the oxygen sag is much greater with the minimum in the sag occurring farther upstream than two profile studies on September 24,1975 and October 15,1975. Among the data of July 13,1977, the data of six sampling stations were used to calibrate the model because no other point source information except the Des Moines Sewage Treatment Plant. The water quality data used in this study were are listed in Tables 7- 9. They are from reports entitled "Water Quality Studies --Red Rock and Saylorville Reservoirs, Des River Moines, Iowa" (Baumann, et al. 1977a, 1977b).

Model Calibration and Verification

The one dimensional steady state model was calibrated and verified. The first upstream sampling station data was used as boundary condition. The loading rate from the Des Moines Sewage Treatment Plant is a major input to the model, and incorporated into the EUTRO5 input files via the boundary condition group. The water temperature data at

Table 7. Water quality data from the July 13,1977 profile study

Station	River Miles	DO (mg/L)	BOD_5 (mg/L)	Ammonia (mg/L)
1	197.5	3.60	10.5	5.98
2	195.8	2.25	9.3	7.61
3	193.4	1.90	7.5	5.91
4	188.0	2.88	6.6	3.47
5	179.5	3.88	5.4	2.33
6	175.2	3.78	5.7	1.73

Table 8. Water quality data from the September 24,1975 profile study

Station	River Miles	DO (mg/L)	BOD_5 (mg/L)	Ammonia (mg/L)
1	197.5	11.16	9.1	0.99
2	195.8	10.49	9.4	0.73
3	193.4	9.65	9.1	0.78
4	190.8	9.77	8.6	0.71
5	187.8	9.92	9.9	0.77

Table 9. Water quality data from the October 15,1975 profile study

Station	Station River Miles	DO (mg/L)	BOD_5 (mg/L)	Ammonia (mg/L)
1	195.8	8.22	10.55	1.19
2	187.8	7.13	8.85	1.18
3	179.5	8.91	7.55	0.61
4	176.8	10.59	8.70	0.54

monitoring stations were used for input. The calibration parameters are denitrification rate, the half-saturation constant for nitrification-oxygen limitation and the CBOD deoxygenation rate. In the model calibration, adjustments were made to the reaction coefficients within appropriate range until simulation output has the best match with the field observations onJuly 13,1977. Appropriate range for each parameter was defined by a literature value. In the model verification, calibration coefficients were used as inputs, and different sets of field data were used. As the results of the calibration and verification of the model, the coefficients identified for this reach of the Des Moines River are presented in Table 10. The literature values are from "Principles of Surface Water Quality Modeling and Control" (Thomann and Mueller, 1987).

The standard error (S_e) and normalized standard error (S_e^*) are calculated by Equation 3 and 4.

$$S_e = \frac{\sqrt{\sum (C_{predicted} - C_{observed})^2}}{n} \qquad 3$$

Table 10. Kinetic coefficient values for calibration and verification of EUTRO5 model

Coefficient	Code	Calibration Value	Literature value
Nitrification rate at 20°C	K12C	0.5 day^{-1}	0.1-3.0 day^{-1}
Half-saturation constant for nitrification-oxygen limitation	KNIT	0.2 mg O_2/L	
CBOD deoxygenation rate	KDC	0.4 day^{-1}	0.1-1.0 day^{-1}

$$S_e^* = \frac{S_e}{\bar{C}_{observed}} \qquad 4$$

Figure 3 shows the result of ammonia nitrogen in calibration (S_e^* = 9%) with data on July 13,1977. Figure 4 shows the result of BOD5 in calibration (S_e^* = 7%) with data on July 13,1977. Figure 5 shows the result of DO in calibration (S_e^* = 12%) with data on July 13,1977. The predicted DO, BOD, and ammonia nitrogen concentration profiles in the reach of the Des Moines River below Des Moines City were examined and compared favorably with field data of first four sample points but not for last two sample points. The predicted BOD of the last two sample points is lower than the filed data and the predicted DO of the last two sample points is higher than the filed data. There is a tributaries entering the Des Moines River before the last two sampling points, which may be the cause of the discrepancy. The water quality data for these tributaries is not available. The predicted results for the last two sample points are reasonable because the possible inputs of pollutants from the tributaries are not considered in the simulations. Figure 6 shows the results of model verification for ammonia nitrogen (S_e^* = 7%) against data on September 24,1975, Figure 7 shows the results of model verification for BOD5 (S_e^* = 6%) against data on September 24,1975, Figure 8 shows the results of model verification for DO (S_e^* = 4%) against data on September 24,1975, Figure 9 shows the result of verification for ammonia nitrogen (S_e^* = 9%) against data on October 15, 1975. Figure 10 shows the result of verification for BOD5 (S_e^* = 6%) against data on October 15,1975. Figure 11 shows the result of verification for

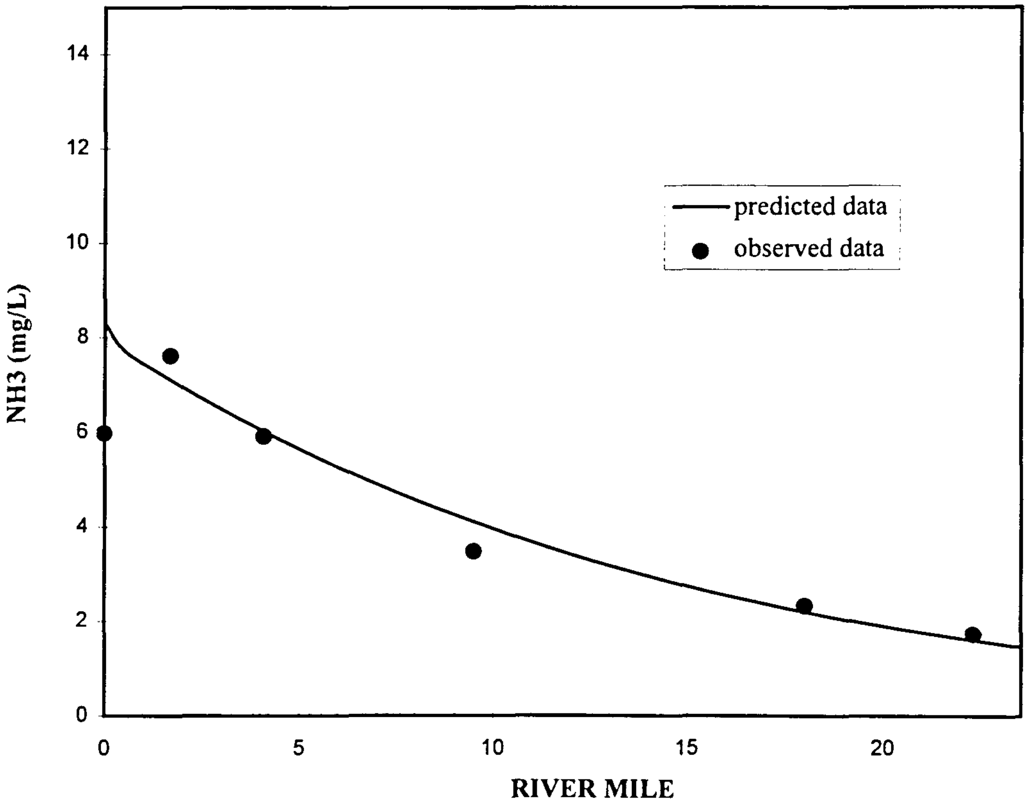

Figure 3. Predicted and observed ammonia nitrogen
in calibration with data on July 13,1977

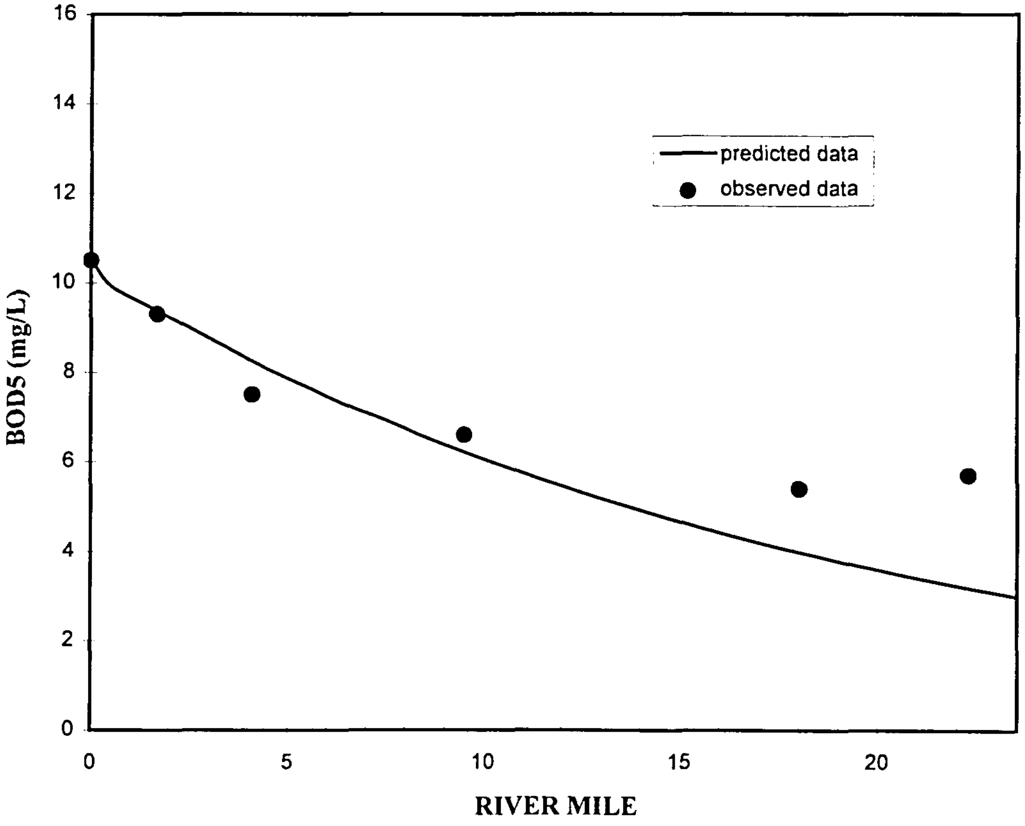

Figure 4. Predicted and observed BOD5 in calibration with data on July 13,1977

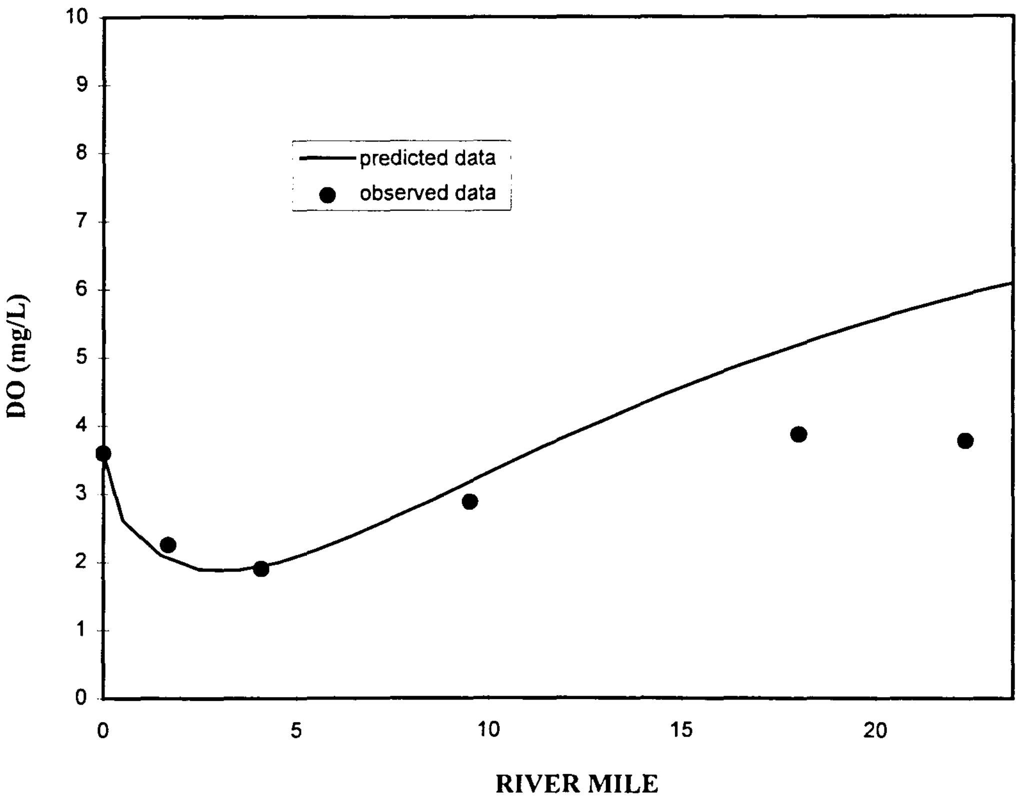

Figure 5. Predicted and observed DO in calibration with data on July 13,1977

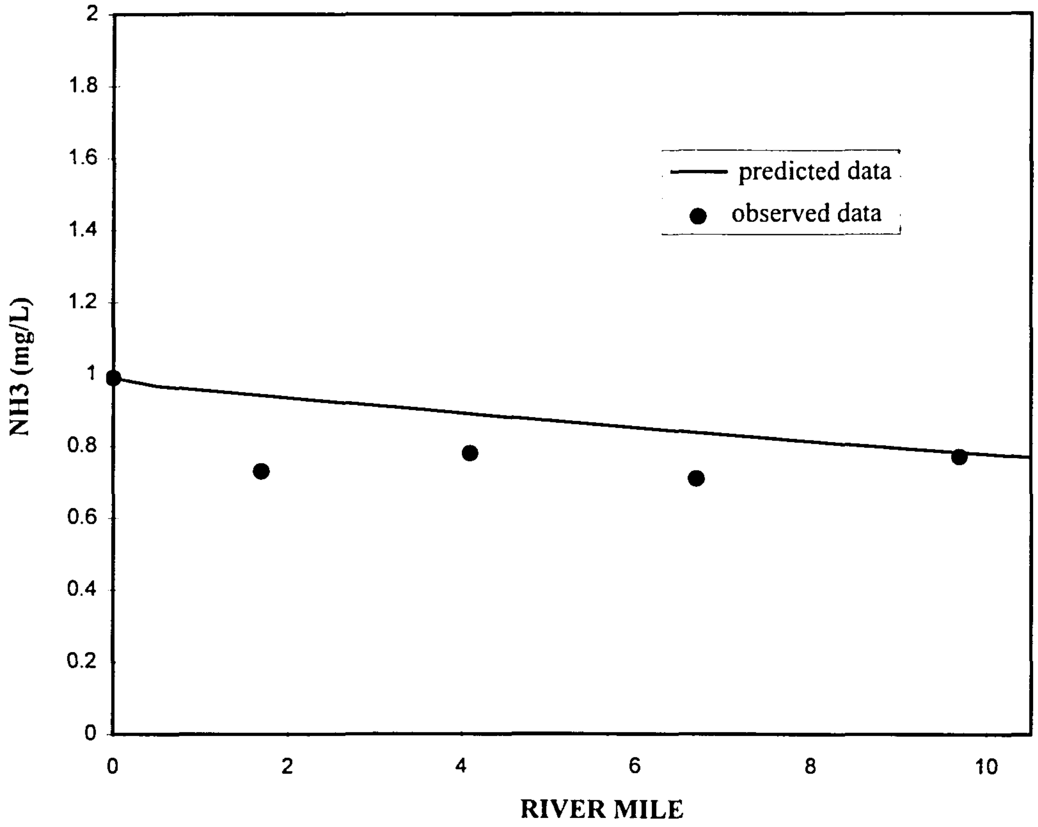

Figure 6. Predicted and observed ammonia nitrogen in verification with data on September 24,1975

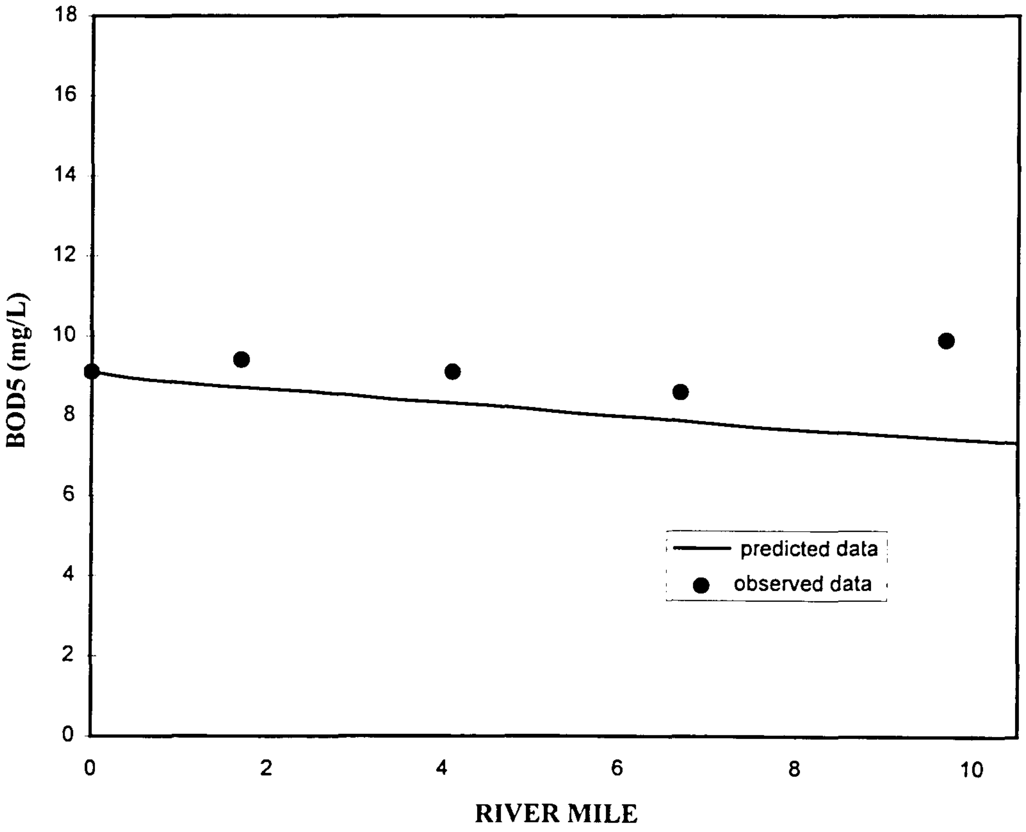

Figure 7. Predicted and observed BOD5 in verification with data on September 24,1975

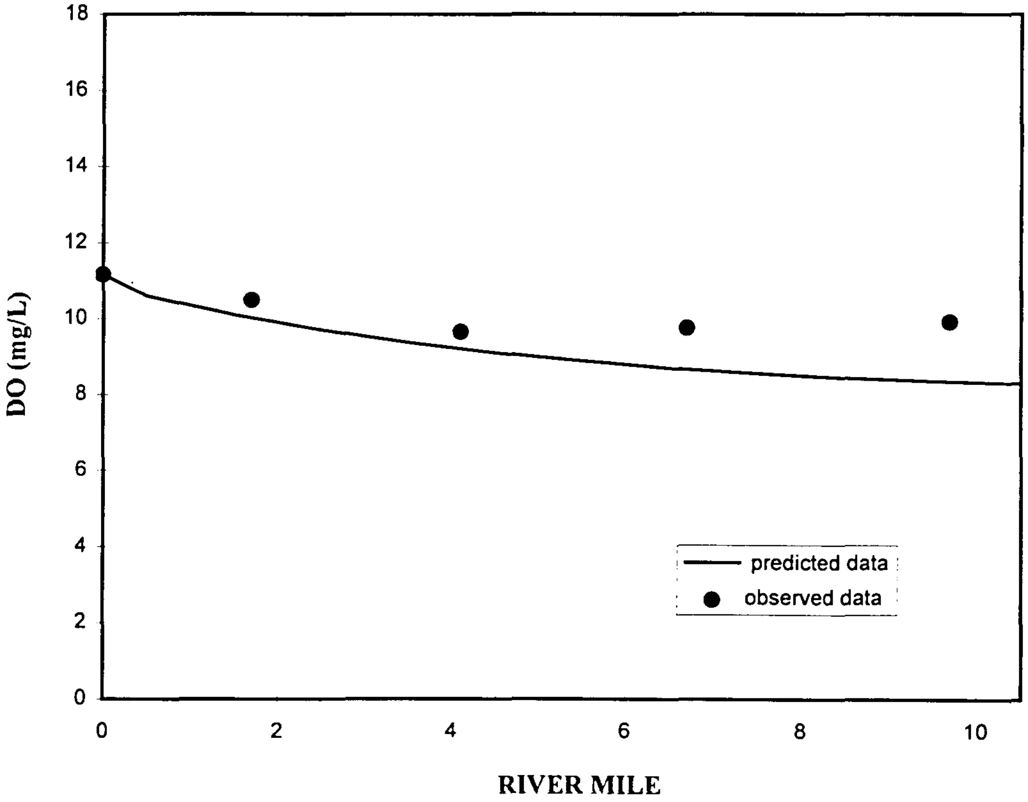

Figure 8. Predicted and observed DO in verification
with data on September 24,1975

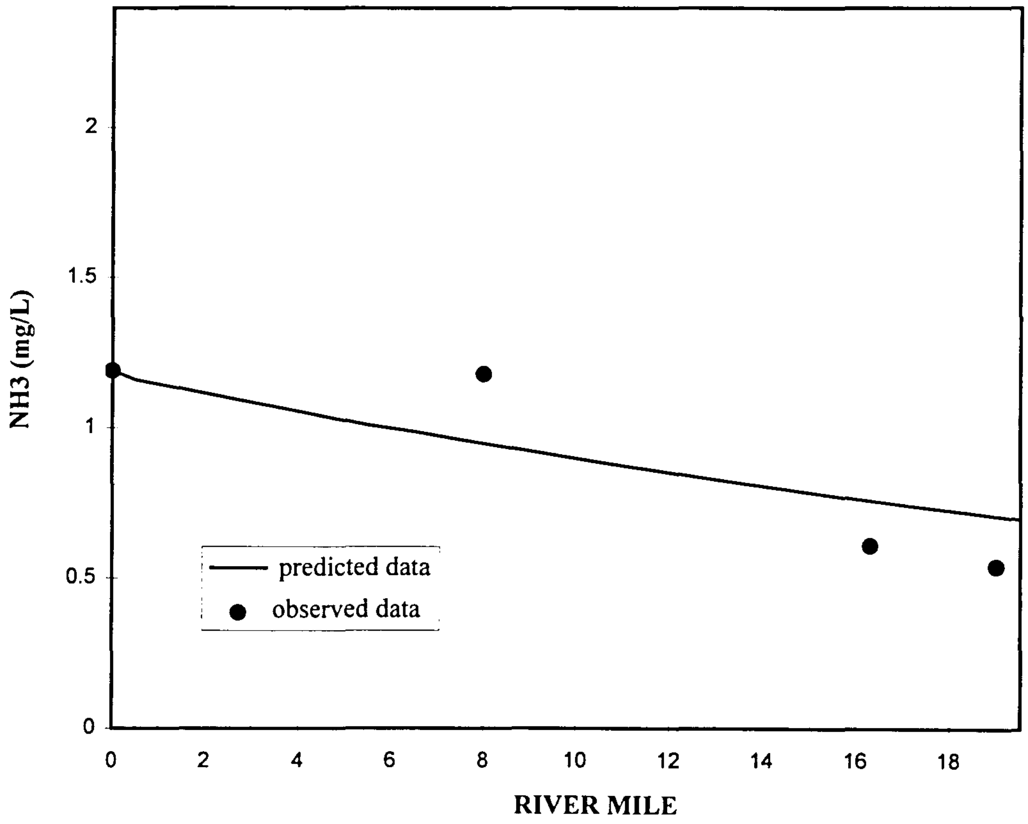

Figure 9. Predicted and observed Ammonia Nitrogen in verification with data on October 15,1975

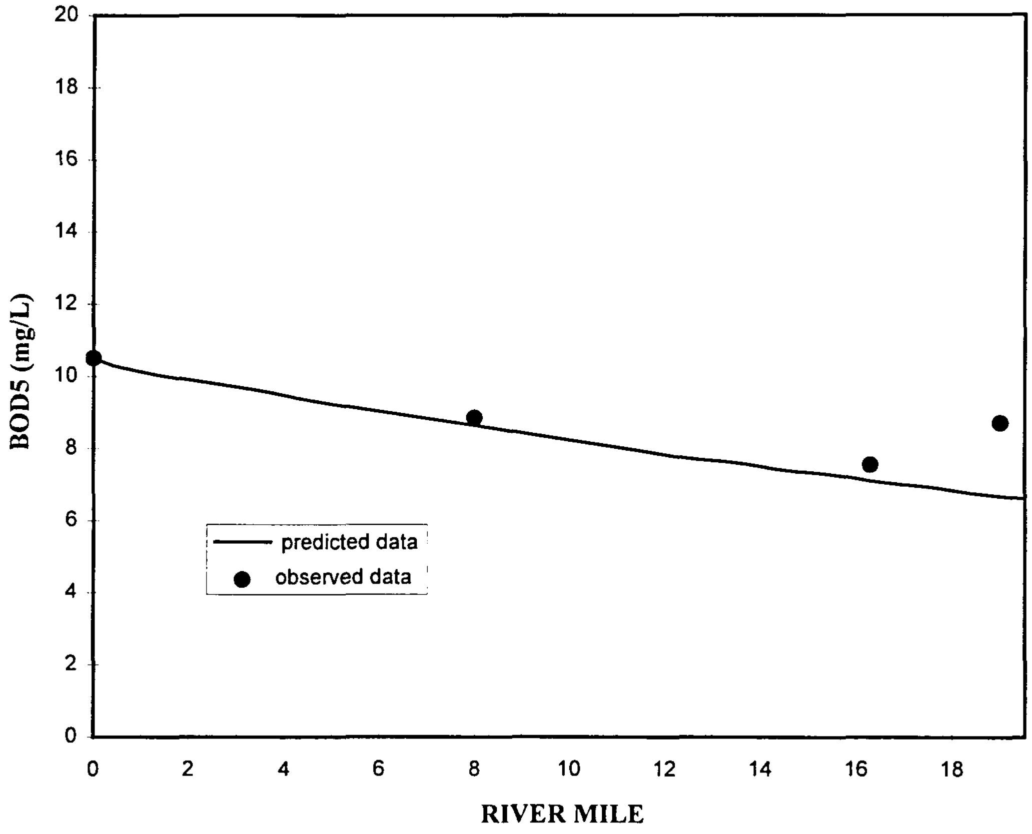

Figure 10. Predicted and observed BOD5 in verification with data on October 15,1975

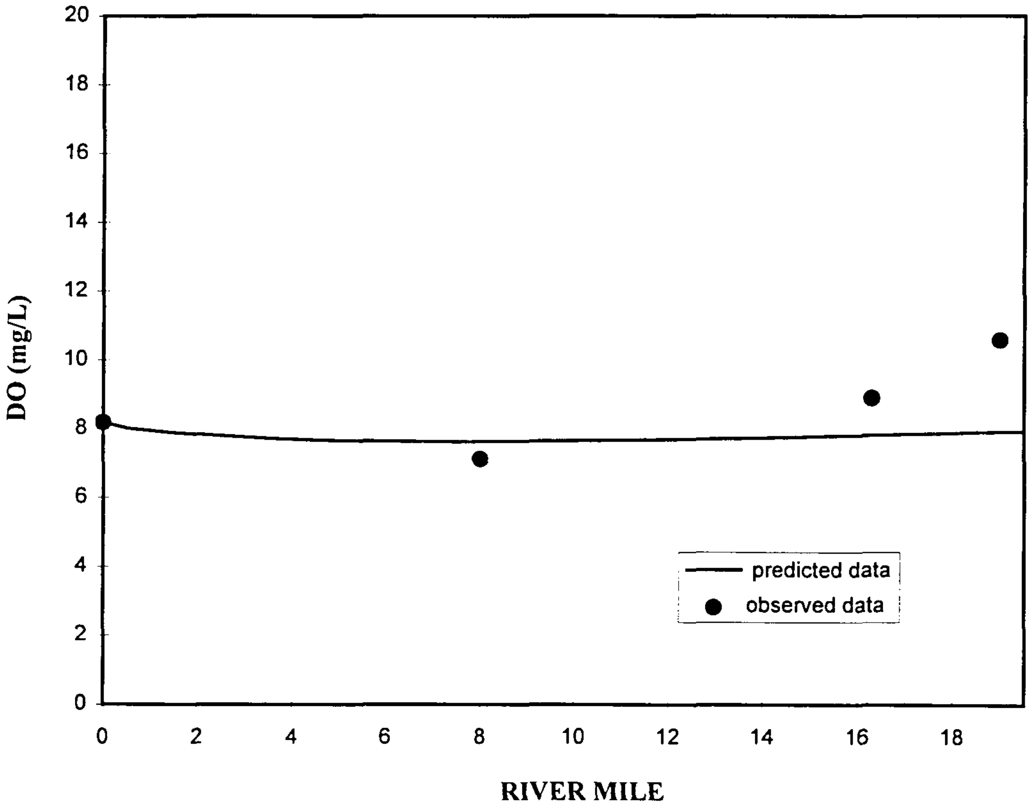

Figure 11. Predicted and observed DO in verification with data on October 15,1975

DO (S_e* = 8%) against data on October 15,1975. The predicted DO, BOD and ammonia nitrogen concentrations in the two verifications agree well with the field data.

Model Application

In the watershed-based approach, the verified model can be used as a tool for evaluating alternative water quality management strategies in a watershed that involve point source and non-point source discharges. To demonstrate the potential use of the model, the verified model for this study reach was used to simulate water quality in the Des Moines River, including dissolved oxygen, biochemical oxygen demand and total ammonia as nitrogen which results from different hypothetical point source loading, non-point source loading and different streamflow scenarios. Because there is no large point source above the outfall of the Des Moines Sewage Treatment Plant, very clean water quality conditions were assumed. The first upstream station data was used as boundary condition. The loading rate from the Des Moines Sewage Treatment Plant is major input to the river, it is incorporated into the EUTRO5 model input files via the boundary condition group. Loading from non-point sources is included in the non-point sources loading section of model input.

The criteria of total ammonia as nitrogen from Iowa State Standard depends on the temperature and pH. Base on the records of monitoring water quality data, a maximum pH of 8.0 and a maximum water temperature of 25°C were used. The criteria of total ammonia as nitrogen from Iowa State Standard is less than 1.9 mg/L for pH = 8.0 and T=25°C.

Figure 12-25 show the application results for the different streamflow and point source loading conditions. The results are also summarized in Table 11. These results can be

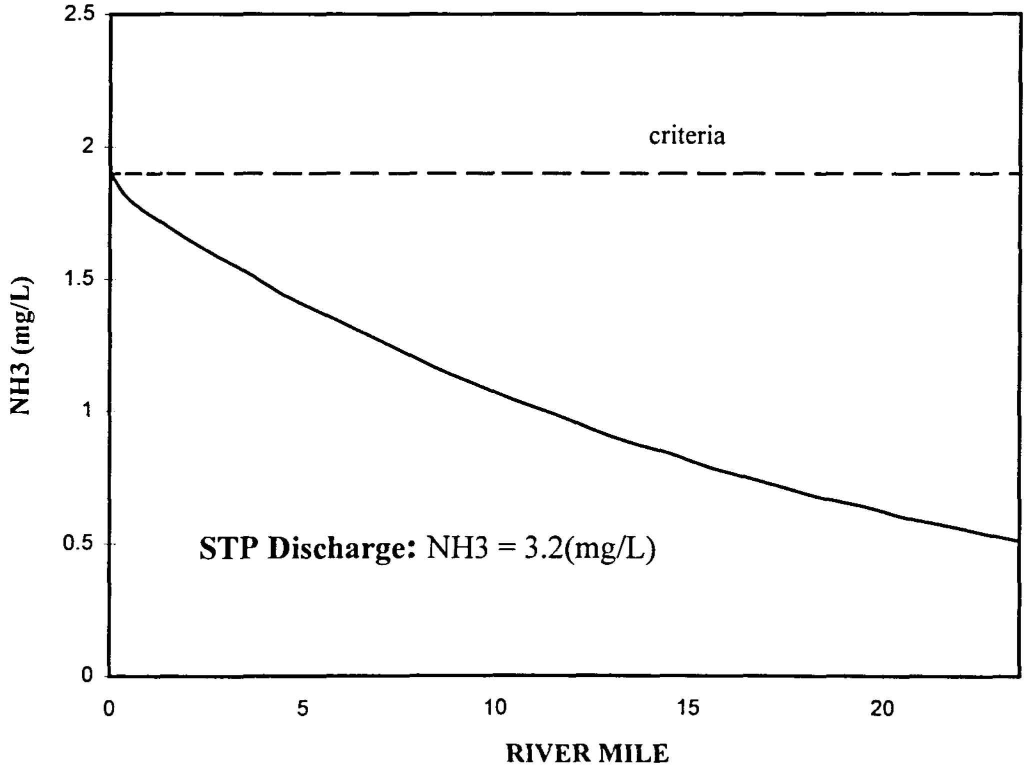

Figure 12. Predicted ammonia nitrogen with STP discharge:
BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L at Q7,10

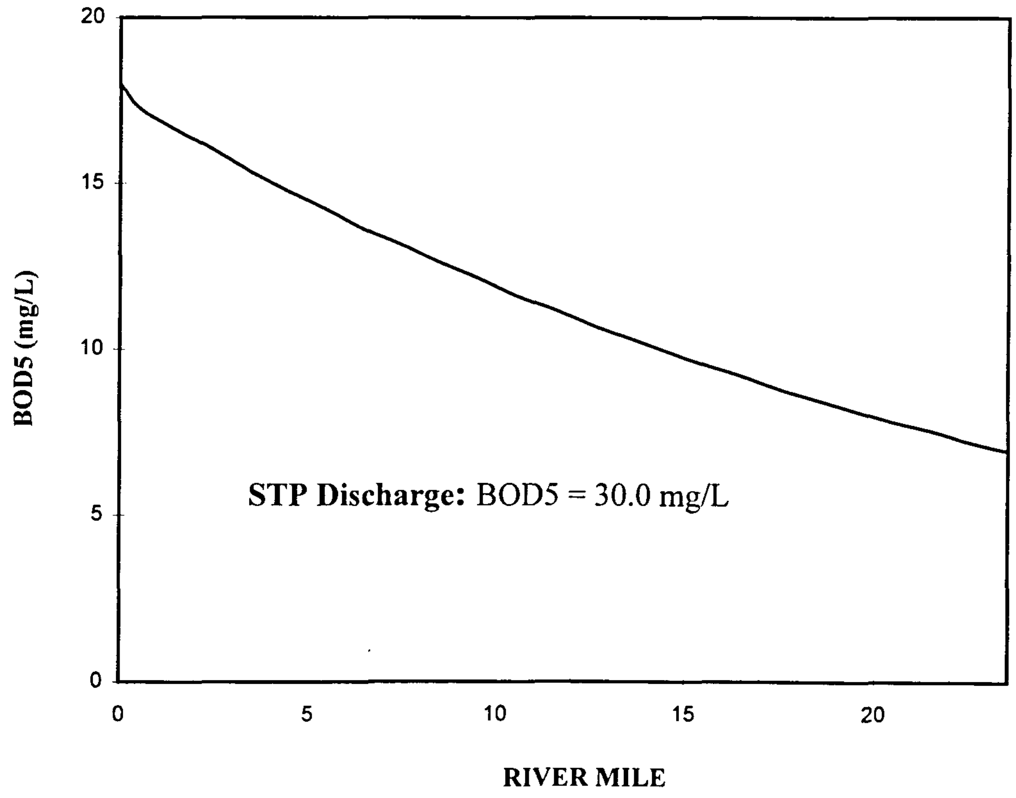

Figure 13. Predicted BOD5 with STP discharge: BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L at Q7,10

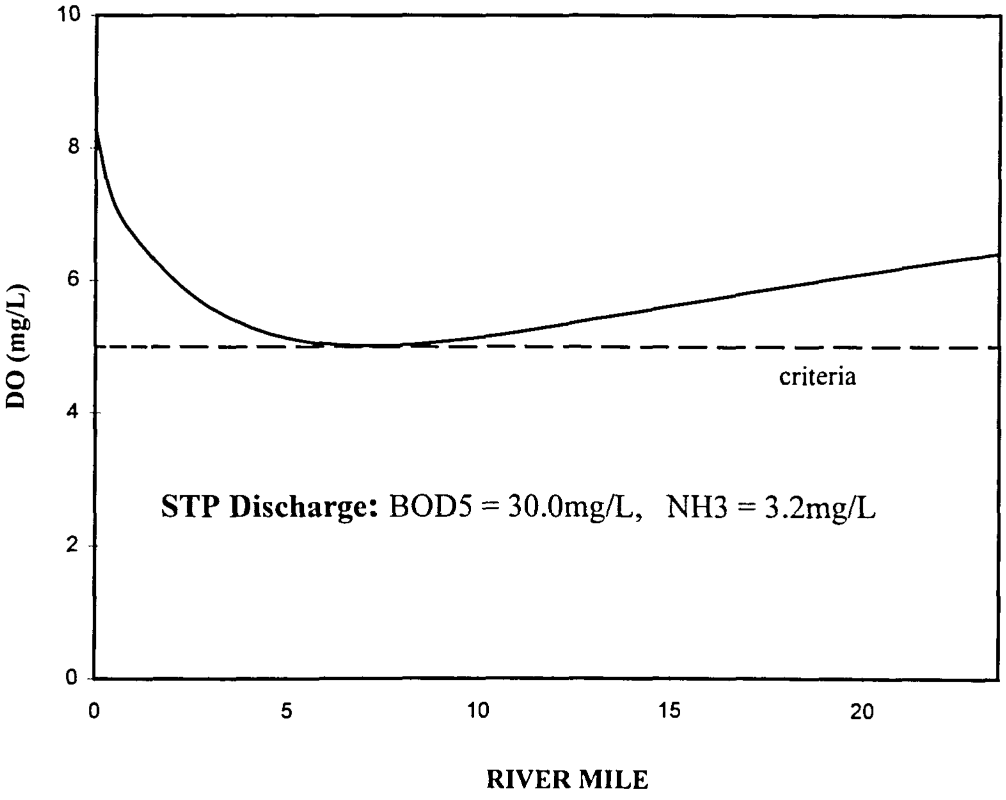

Figure 14. Predicted DO with STP discharge: BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L at Q7,10

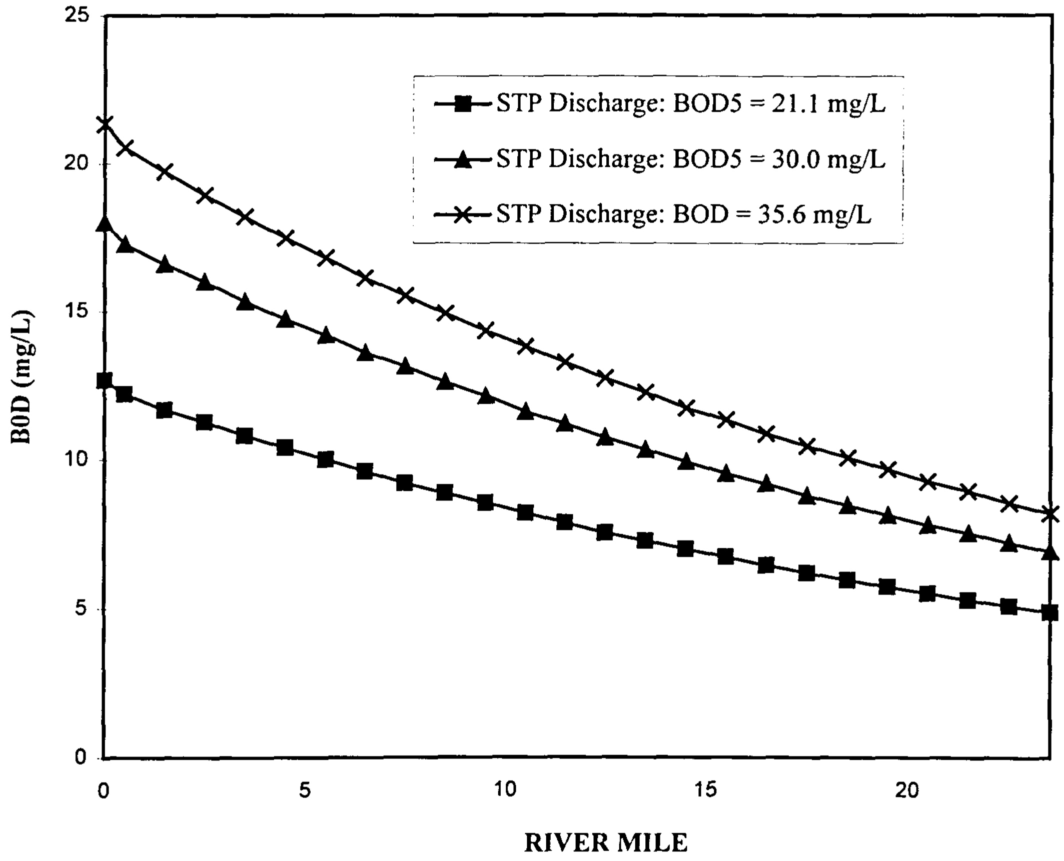

Figure 15. Predicted BOD5 at Q7,10 for different STP loadings

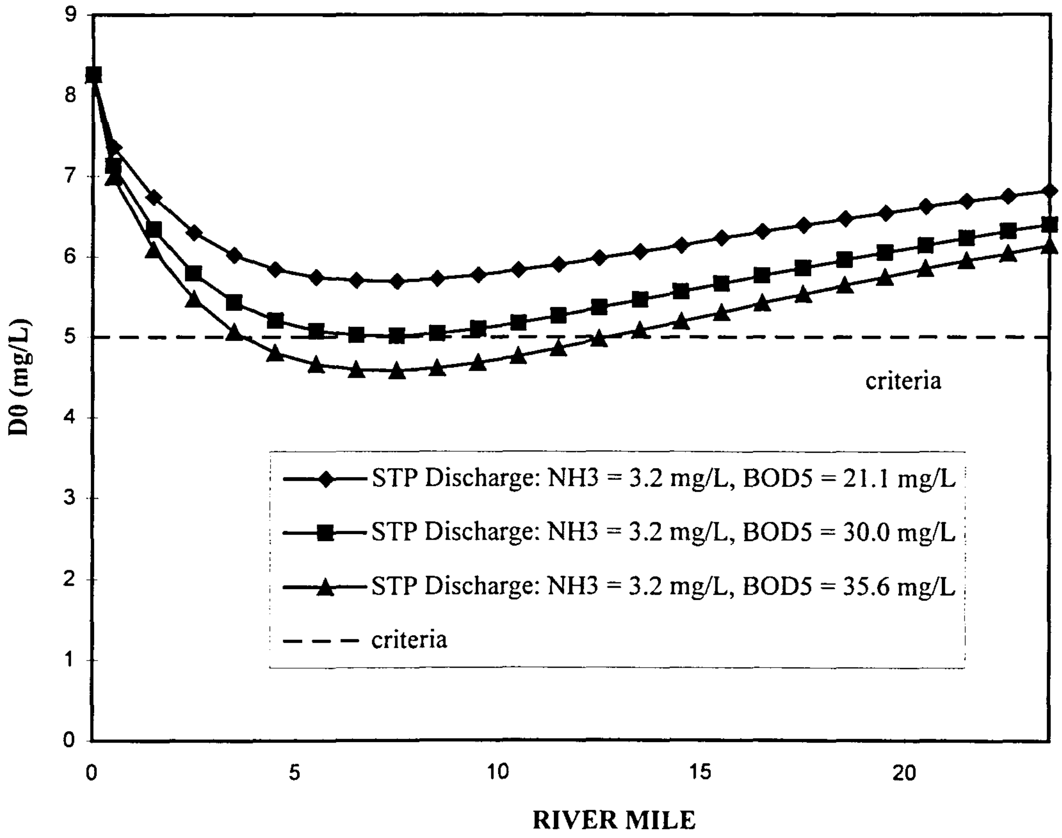

Figure 16. Predicted DO at Q7,10 for different STP loadings

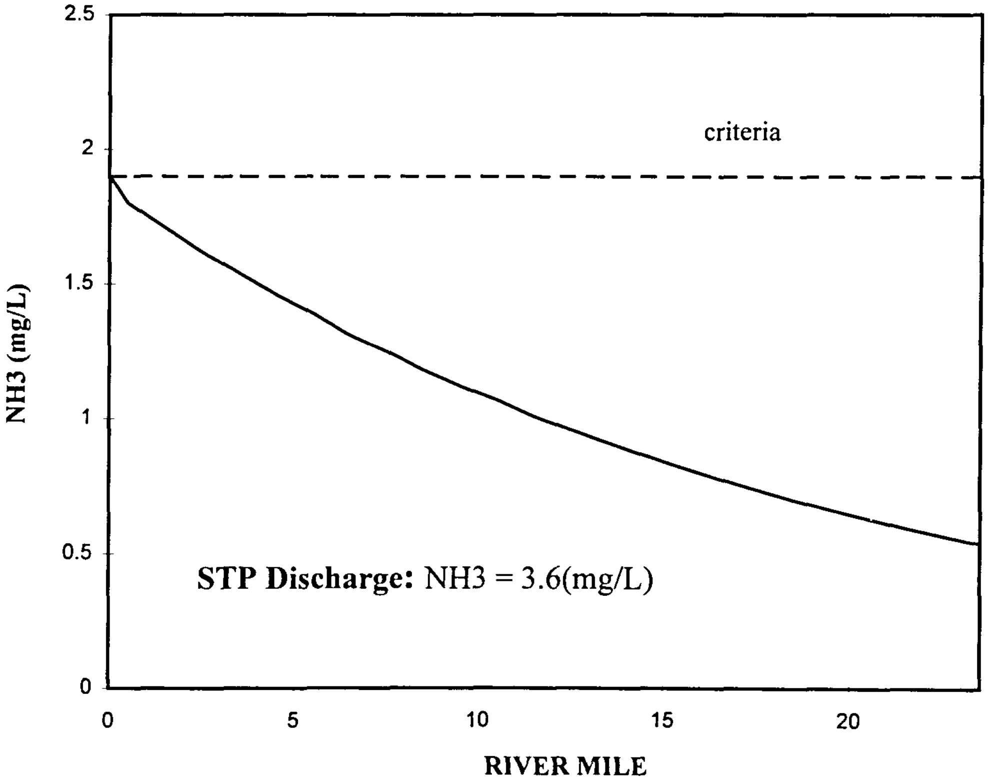

Figure 17. Predicted ammonia nitrogen with STP discharge:
BOD5 = 34.2 mg/L,NH3 = 3.6 mg/L at Q7,5

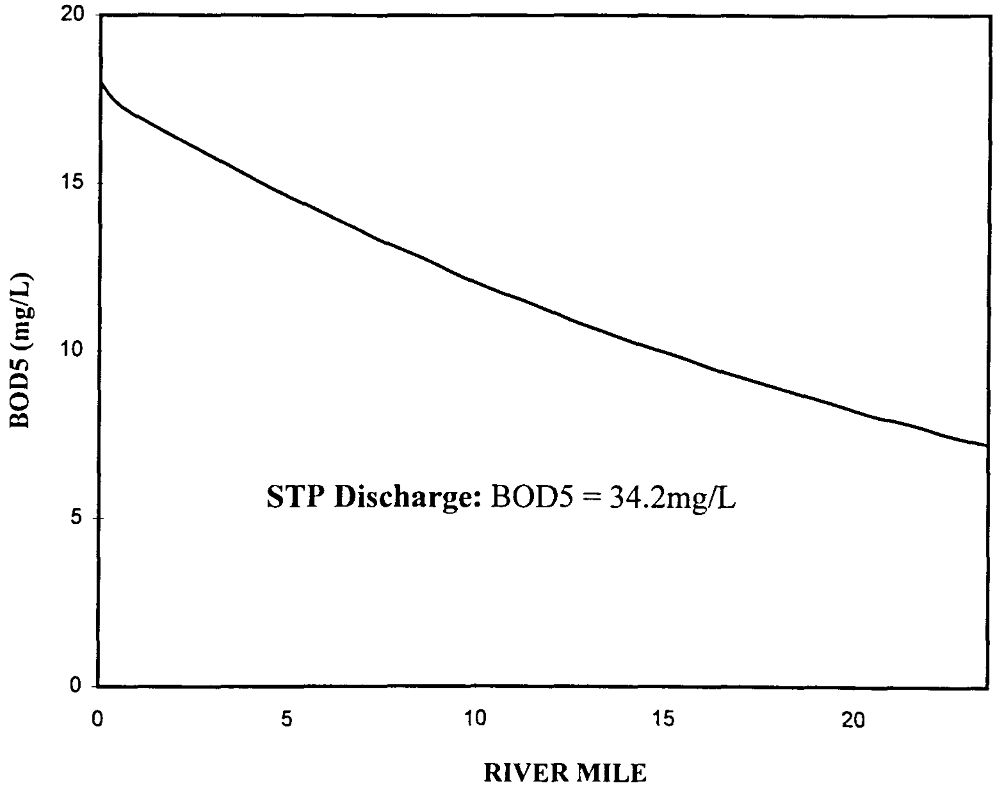

Figure 18. Predicted BOD5 with STP discharge: BOD5 = 34.2 mg/L, NH3 = 3.6 mg/L at Q7,5

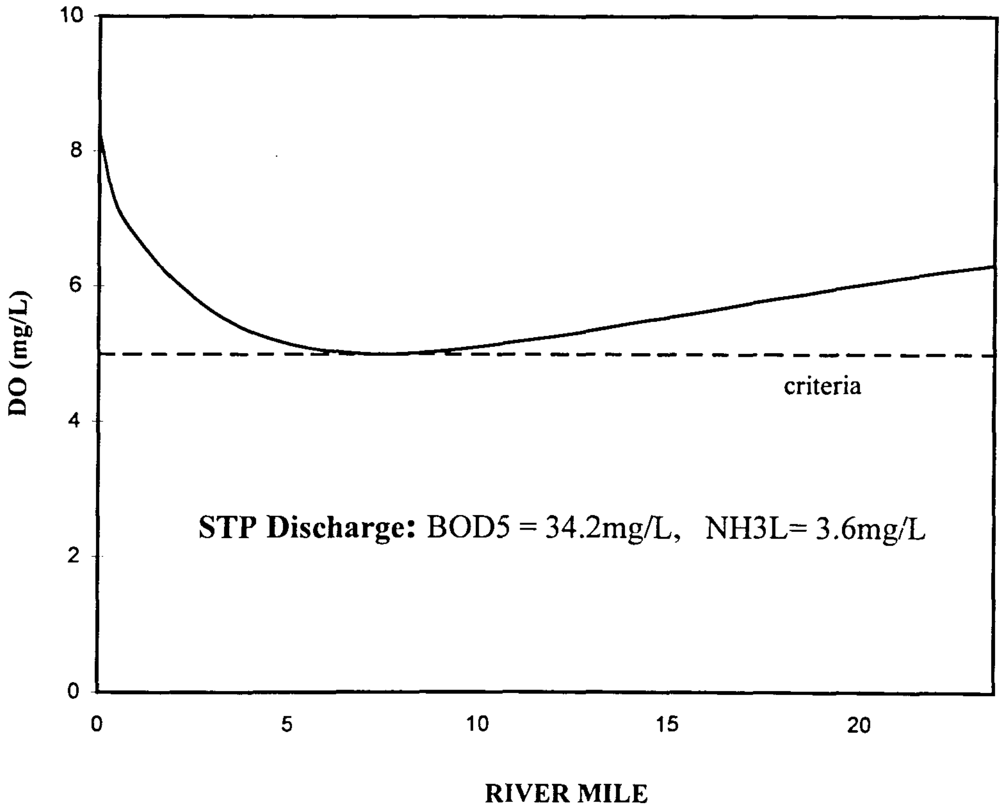

Figure 19. Predicted DO with STP discharge: BOD5 = 34.2 mg/L, NH3 = 3.6 mg/L at Q7,5

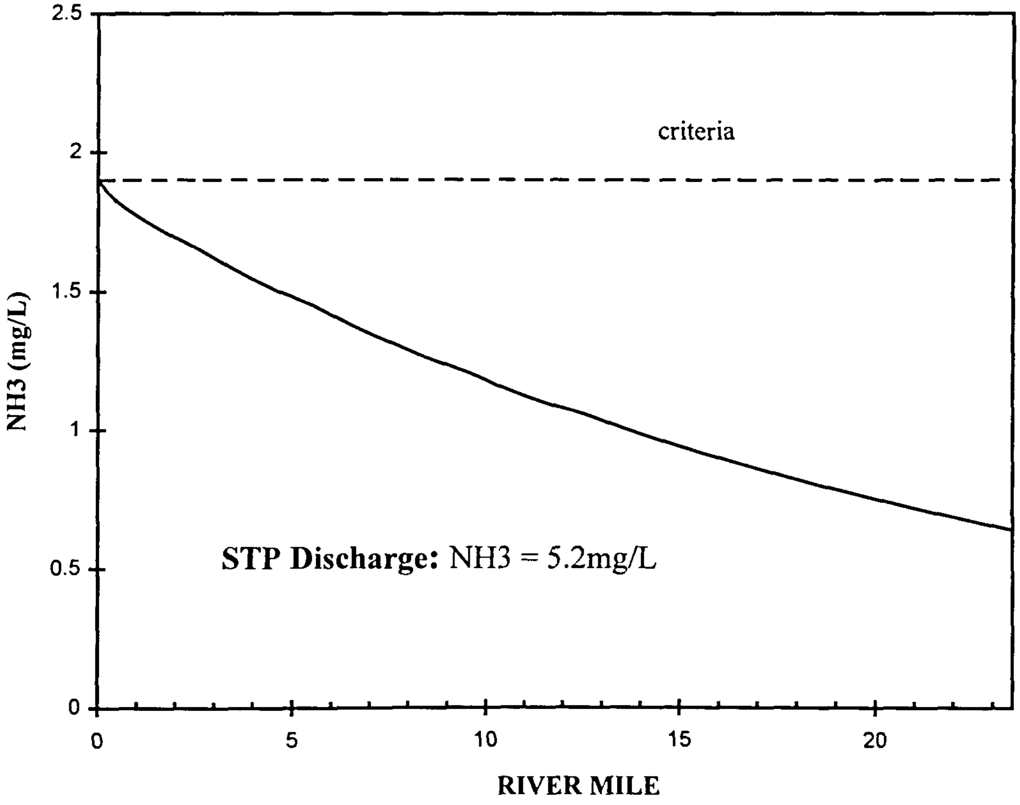

Figure 20. Predicted ammonia nitrogen with STP discharge:
BOD5 = 49.7 mg/L, NH3 = 5.2 mg/L at Q7, 2

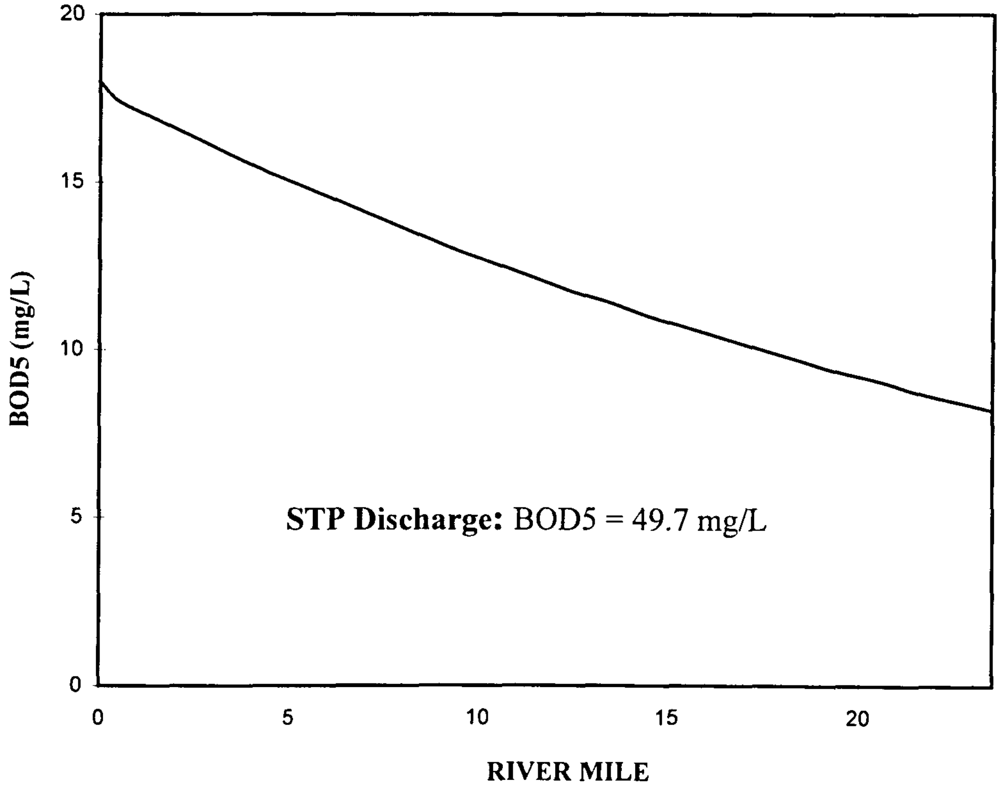

Figure 21. Predicted BOD5 with STP discharge: BOD5 = 49.7 mg/L, NH3 = 5.2 mg/L at Q7, 2

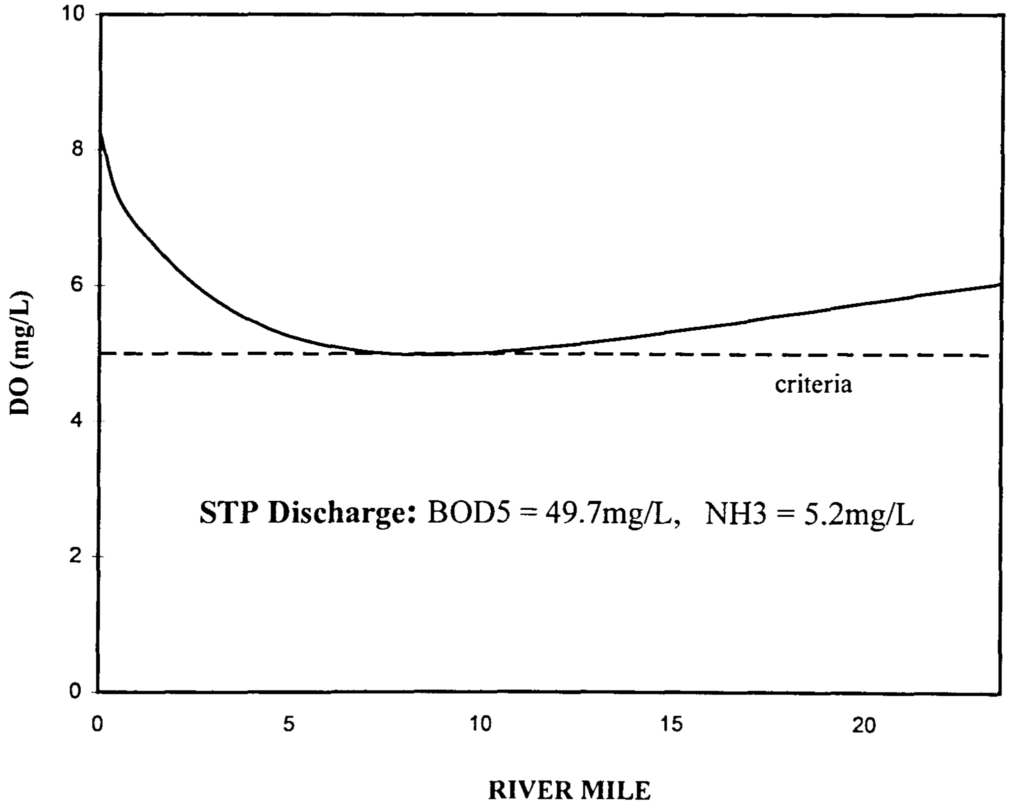

Figure 22. Predicted DO with STP discharge: BOD5 = 49.7 mg/L, NH3 = 5.2 mg/L at Q7, 2

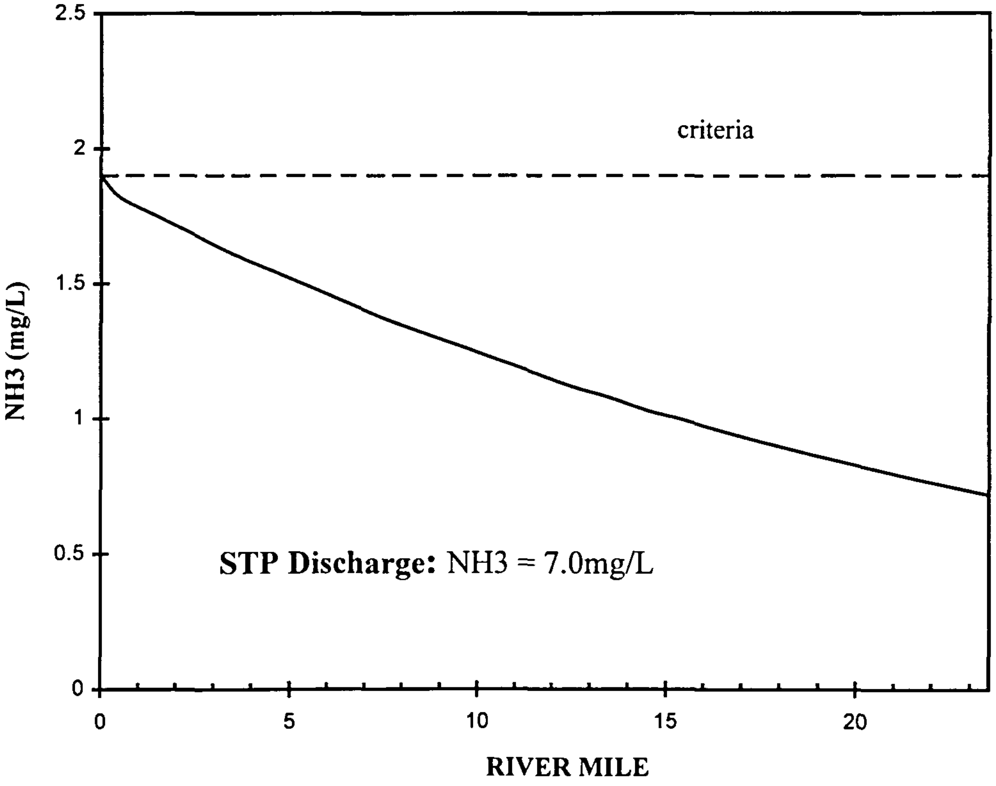

Figure 23. Predicted ammonia nitrogen with STP discharge:
BOD5 = 66.0 mg/L, NH3 = 7.0 mg/L at Q84%

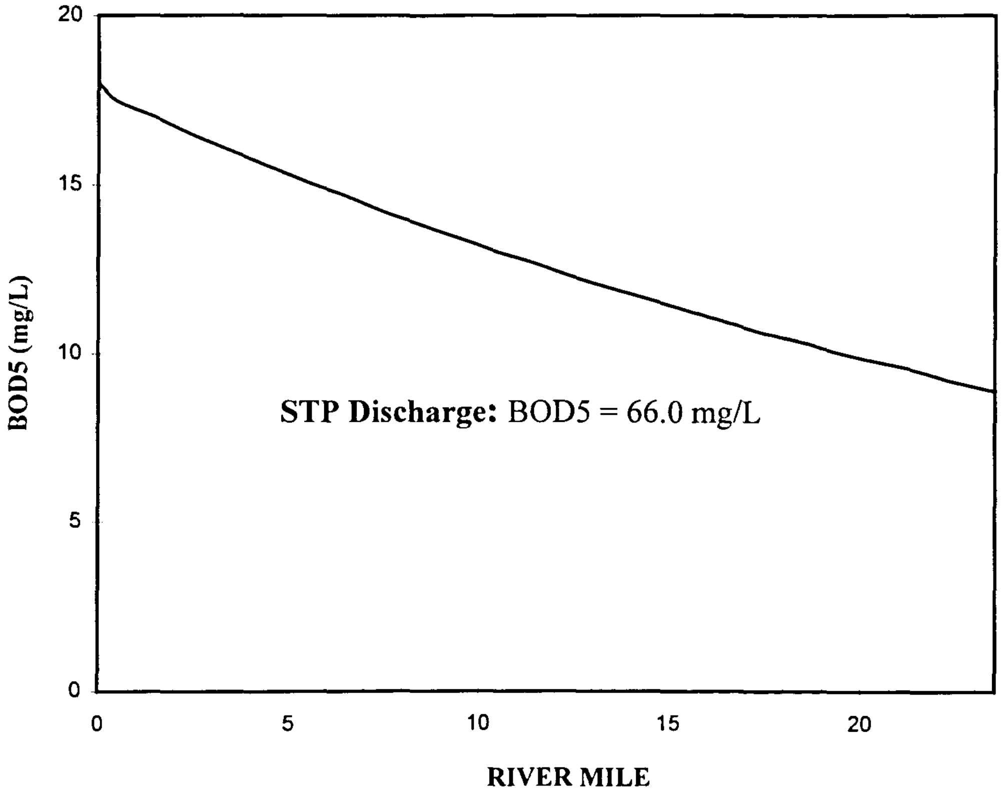

Figure 24. Predicted BOD5 with STP discharge: BOD5 = 66.0 mg/L, NH3 = 7.0 mg/L at Q84%

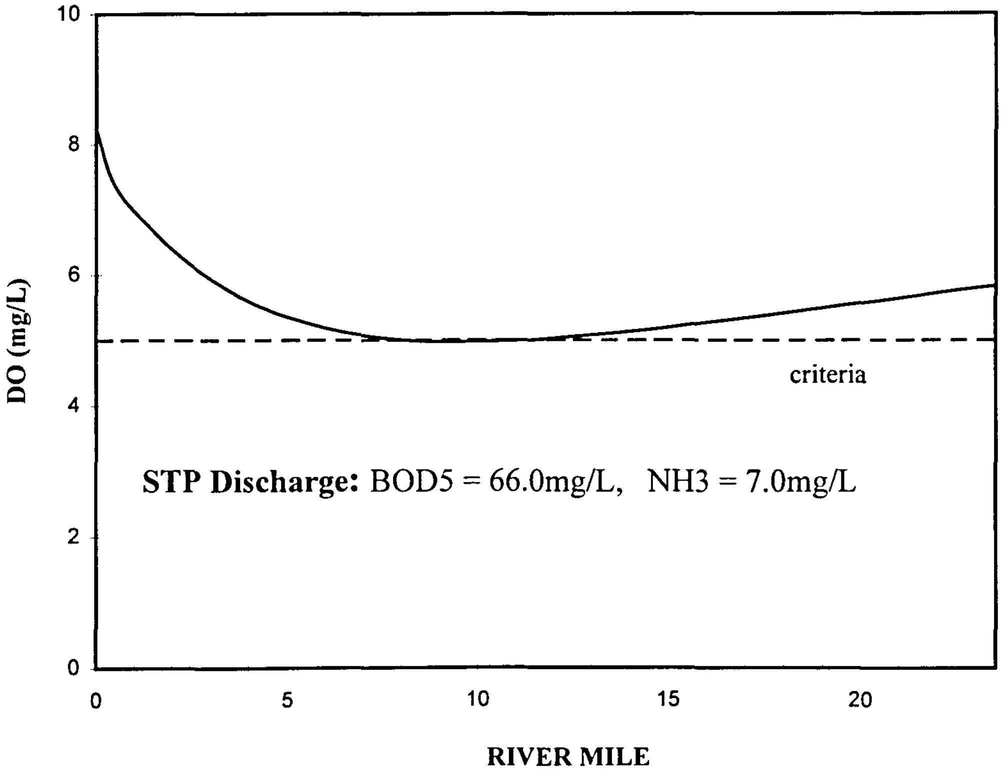

Figure 25. Predicted DO with STP discharge: BOD5 = 66.0 mg/L, NH3 = 7.0 mg/L at Q84%

Table 11. Summary of model results for the different streamflows and point source loading conditions

	streamflow	point source loading (from Des Moines Sewage Treatment Plant)
Figure 12-14	Q7, 10	BOD_5 = 30.0 mg/L,
	(98 cfs)	NH_3 = 3.2 mg/L
Figure 15-16	Q7, 10	A: BOD_5 = 21.1 mg/L,
	(98 cfs)	NH_3 = 3.2 mg/L.
		B: BOD_5 = 30.0 mg/L,
		NH_3 = 3.2 mg/L.
		C: BOD_5 = 35.6 mg/L,
		NH_3 = 3.2 mg/L.
Figure 17-19	Q7, 5 (135 cfs)	BOD_5 = 34.2 mg/L,
		NH_3 = 3.6 mg/L
Figure 20-22	Q7, 2 (264 cfs)	BOD_5 = 49.7 mg/L,
		NH_3 = 5.2 mg/L
Figure 23-25	Q84%	BOD_5 = 66.0 mg/L,
	(399 cfs)	NH_3 = 7.0 mg/L

used to determine the allowable amount of waste which can be discharged into the study reach so that the water quality standards are meet, considering only point source at the Des Moines Sewage Treatment Plant under various low streamflow condition.

Non-point sources are also considered in model application. Because no non-point source pollution modeling study was conducted on the Des Moines River watershed, detailed non-point source pollution data for different streamflow conditions are not available. In this study, the empirical equations relating the annual unit non-point load to the annual unit discharge of the watershed were used for non-point source input. The non-point source loading rates used in the model application are estimated from previous study. Girton (1994) reported results from his non-point source study on upper Des Moines River and Raccoon River. The regression equation for annual unit load as a function of annual discharge was: $BOD_5 = 0.46q+1.41$ (lbs/ac/yr); $NH_3 = 0.035q+0.052$ (lbs/ac/yr). Because median value of annual mean discharges was 3580 cfs (4.9 in/yr) (Water Resources Data, Iowa, Water Year 1989), therefore average BOD_5 discharge from non-point source is computed as 3.7 (lbs/ac/yr); average NH_3 discharge from non-point source is computed as 0.22 (lbs/ac/yr).

Figure 26-31 show the application results for the different streamflow and point source loading and non-point source loading conditions. Assume the point source discharge from the Des Moines Sewage Treatment is same as the limited discharge from Q7, 10 streamflow condition. Plant Summary is list in Table 12. These results give the allowable amount of waste discharges into the study reach that do not cause exceed of the water quality standards, considering the point source at the Des Moines Sewage Treatment Plant and non-point sources under higher streamflow conditions.

Summary

The calibrated and verified WASP5 model for Des Moines River can be used as a tool in the watershed based approach to evaluate various water quality management strategies in a subwatershed that involves point source and non-point source discharge and water quality in the Des Moines River. The model of WASP5 has been demonstrated for Des Moines River to

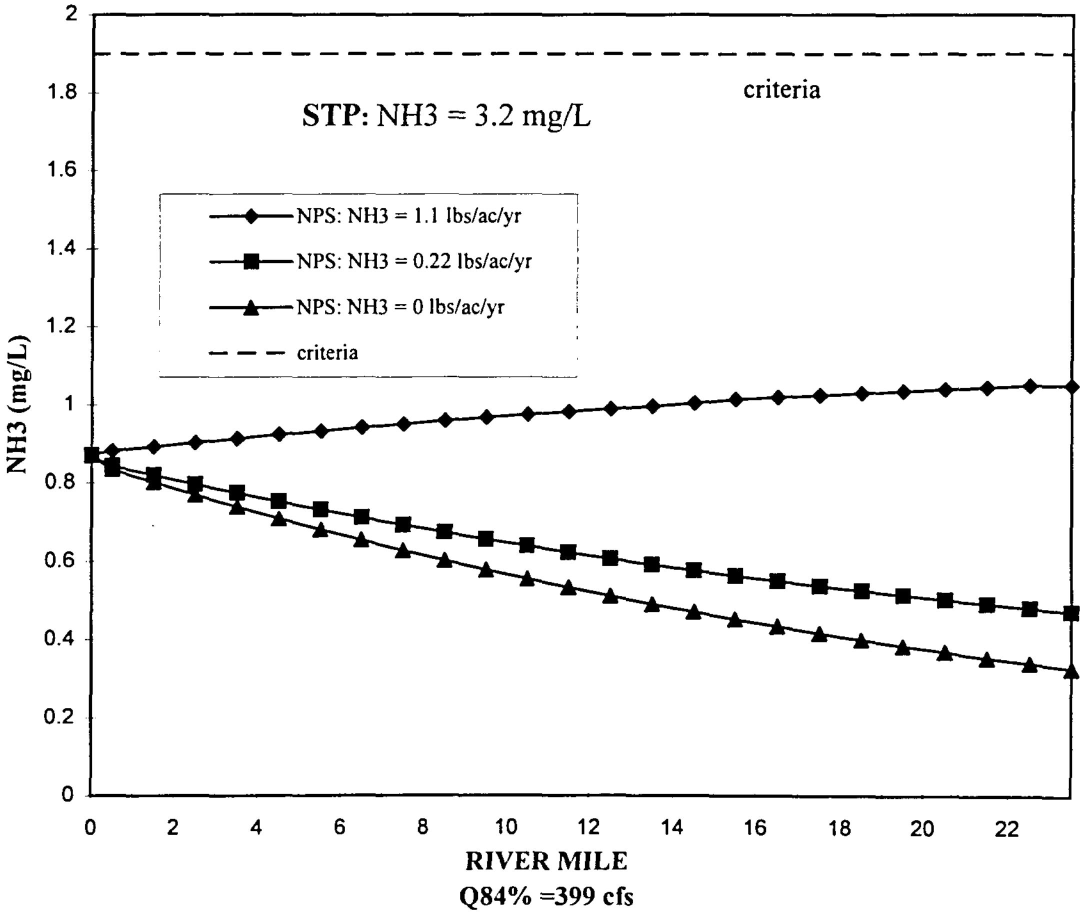

Figure 26. Predicted ammonia nitrogen with STP discharge: BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L and different non-point source loadings at Q84%

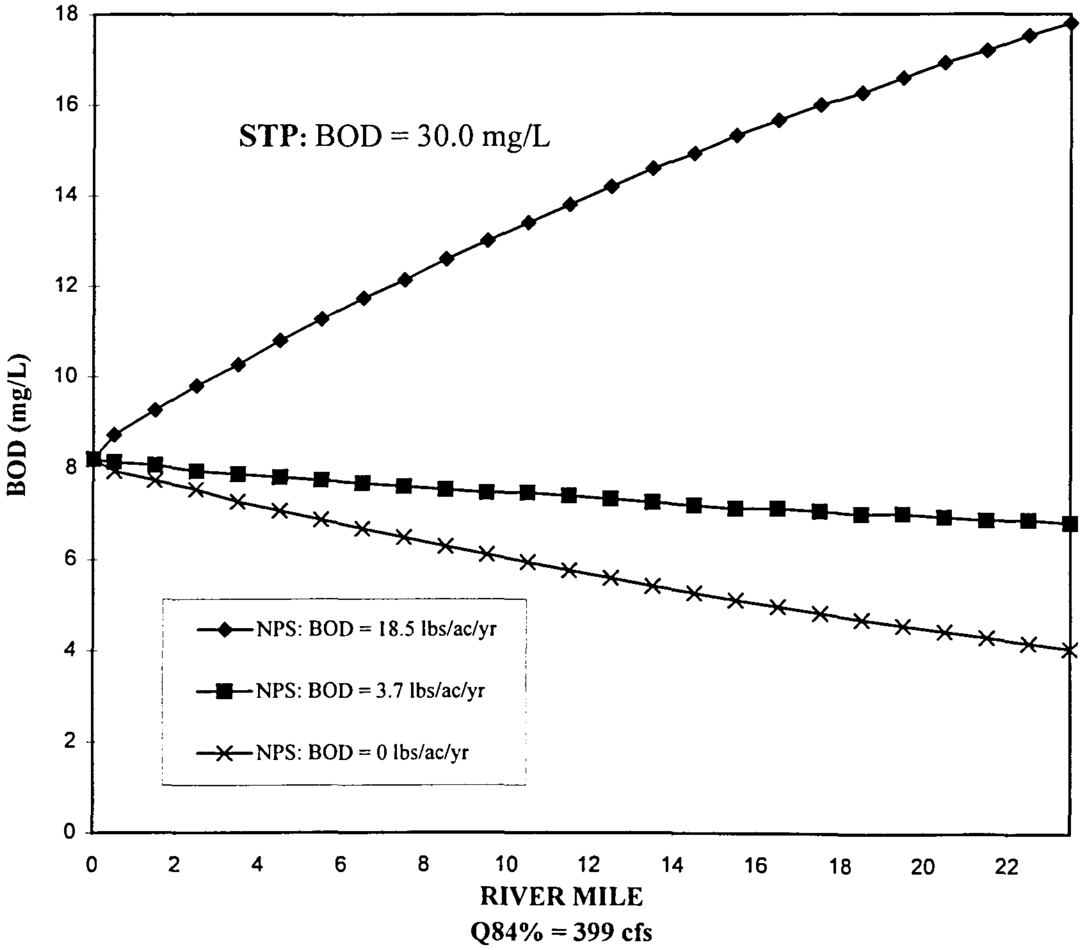

Figure 27. Predicted BOD5 with STP discharge: BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L and different non-point source loadings at Q84%

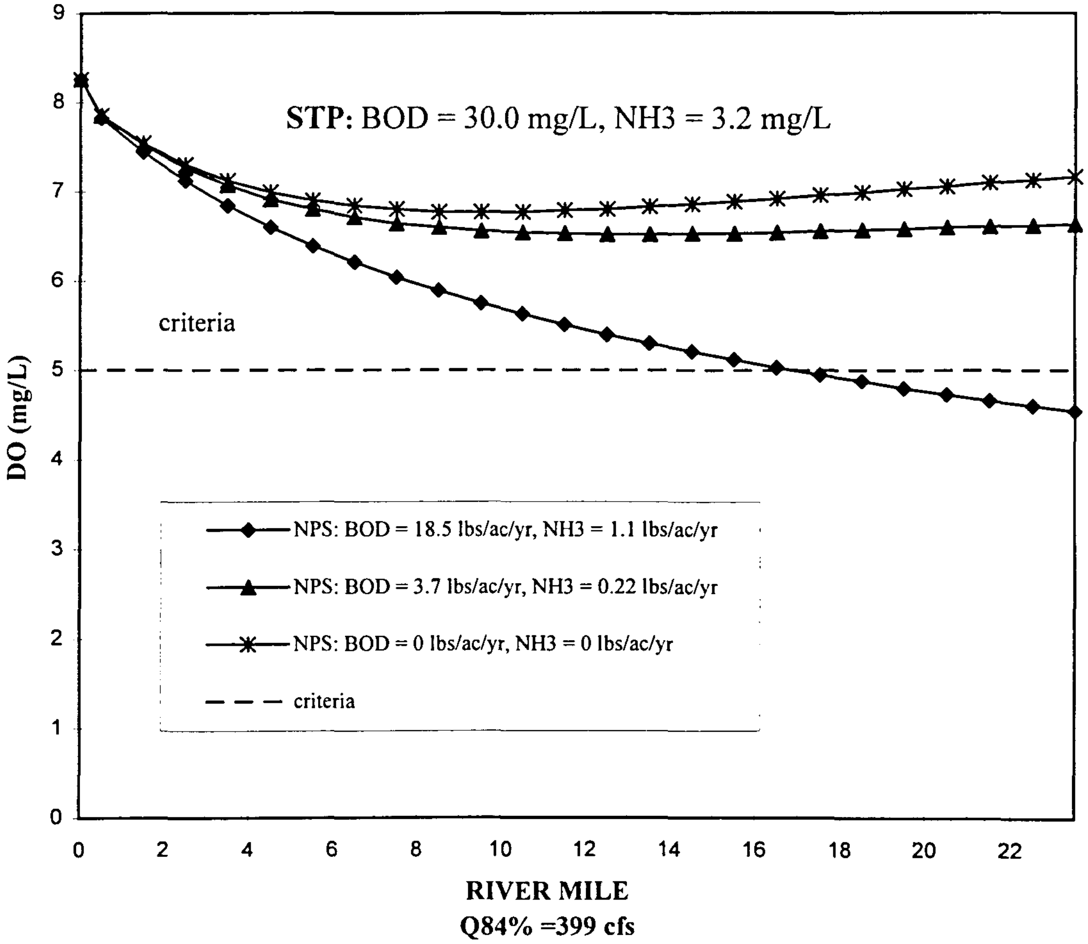

Figure 28. Predicted DO with STP discharge: BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L and different non-point source loadings at Q84%

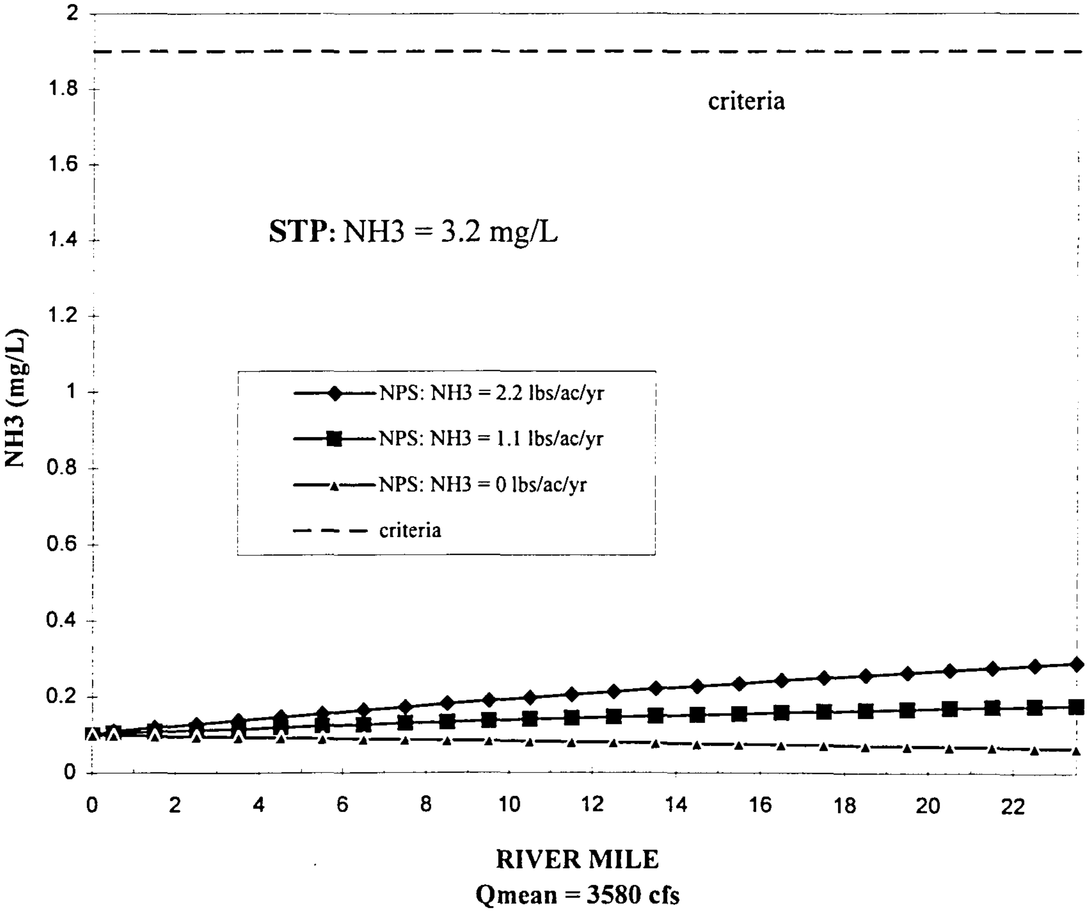

Figure 29. Predicted ammonia nitrogen with STP discharge: BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L and different non-point source loadings at Qmean

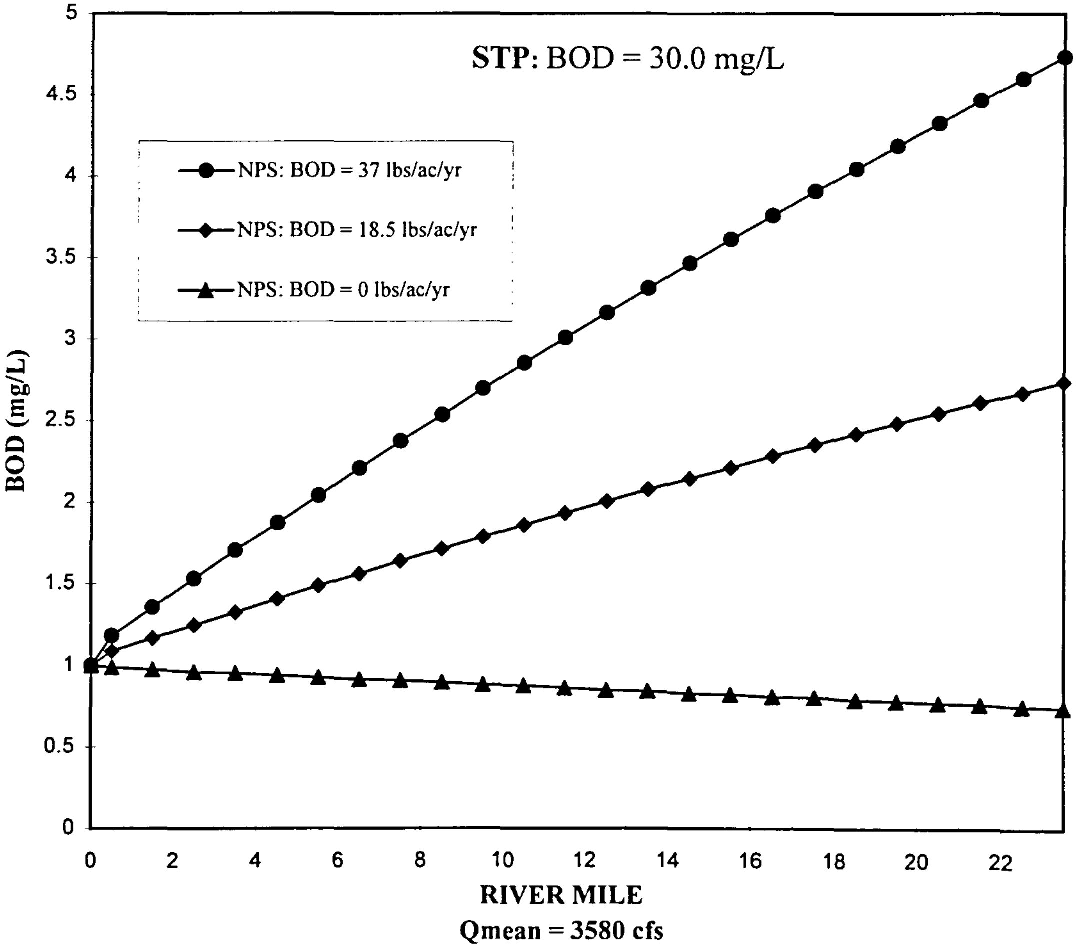

Figure 30. Predicted BOD5 with STP discharge: BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L and different non-point source loadings at Qmean

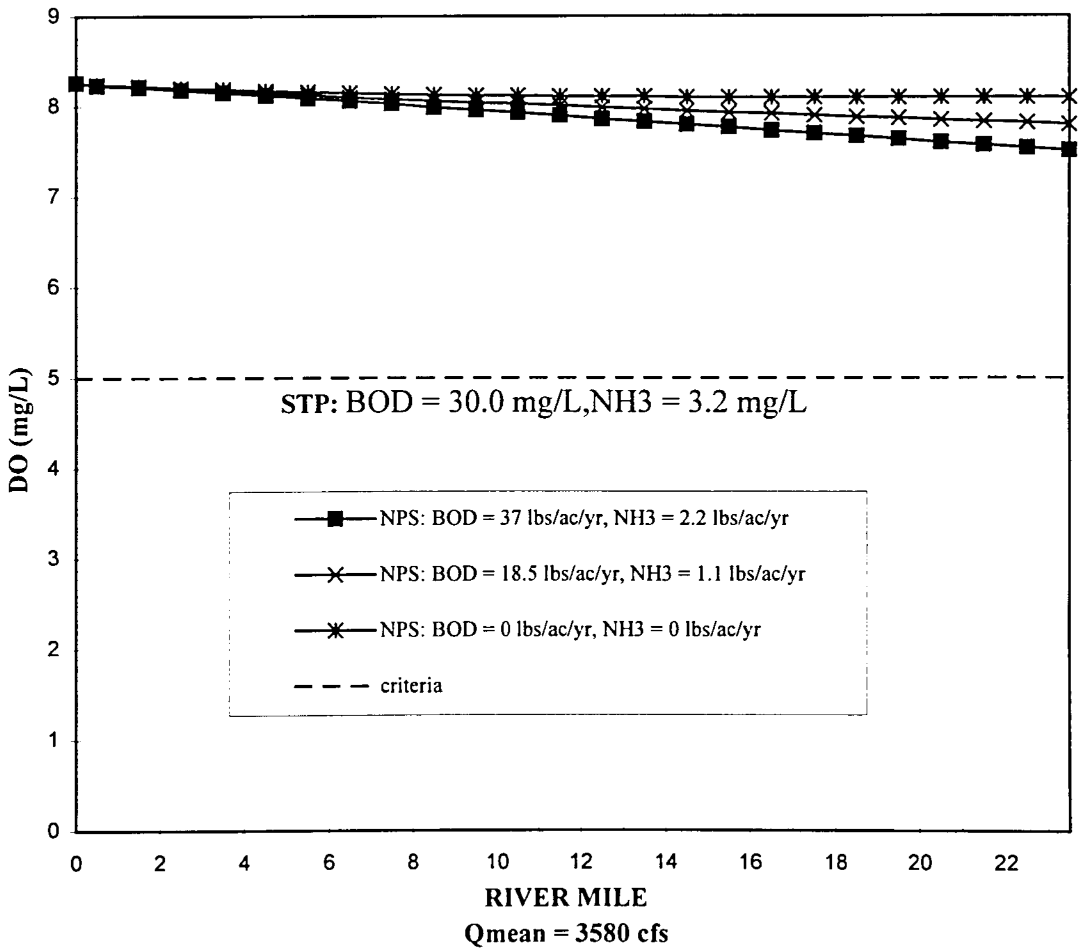

Figure 31. Predicted DO with STP discharge: BOD5 = 30.0 mg/L, NH3 = 3.2 mg/L and different non-point source loadings at Qmean

Table 12. Summary of model results for the different streamflows and point source loading and non-point source loading conditions

	streamflow	point source loading from Des Moines Sewage Treatment Plant	non-point source loading
Figure 26-28	Q84% (399 cfs)	BOD_5 = 30.0 mg/L, NH_3 = 3.2 mg/L	Scenario: A: BOD_5 = 0 lbs/ac/yr; NH_3 = 0 lbs/ac/yr B: BOD_5 = 3.7 lbs/ac/yr; NH_3 = 0.22 lbs/ac/yr C: BOD_5 = 18.5 lbs/ac/yr; NH_3 = 1.1 lbs/ac/yr
Figure 29-31	Qmean (3580 cfs)	BOD_5 = 30.0 mg/L, NH_3 = 3.2 mg/L	Scenario: A: BOD_5 = 0 lbs/ac/yr; NH_3 = 0 lbs/ac/yr B: BOD_5 = 18.5 lbs/ac/yr; NH_3 = 1.1 lbs/ac/yr C: BOD_5 = 37 lbs/ac/yr; NH_3 = 2.2 lbs/ac/yr

give accurate predictions of water quality (DO, BOD5 and ammonia). Given appropriate field data, this approach is expected to provide accurate results for other watershed.

Under low streamflow conditions, water qualities are very sensitive to the concentration of BOD_5 and NH_3 from the point source. Under high streamflow, water quality is more influenced by the concentration of NH_3 from non-point sources. BOD_5 in non-point sources is not an important parameter because its value is very low compared to the point source. Higher stremflow and more waste discharging can yield the longer distance from the discharge point to the lowest point of DO sag.

CONCLUSIONS AND RECOMMENDATIONS

Watershed-based approach for water quality considers and addresses water quality problems based on the entire watershed and incorporates non-point sources. Surface modeling is used in different phases of the watershed-based management cycle. Modeling procedure consists of four phases: data collection, calibration of the model, verification of the model and application of the model. When surface water model is chosen, implement of watershed scale and incorporate of non-point sources is important considering factor. Based on the application results of WASP5 to the Des Moines River demonstrated above, WASP5 is recommended to be used as surface water quality model for watershed-based approach in Iowa, although other models(such as QUAL-2E) may be selected.

As a demonstration of the surface water modeling strategy for the watershed-based approach, a 24-mile reach of the Des Moines River was studied. This reach of river receives wastewater from both point and non-point sources. WASP5 model was calibrated and verified with independent data sets of special profile studies, simulating some of the biochemical processes that result from wastewater discharges into the study reach. DO, BOD5, and ammonia nitrogen are chosen as water quality parameter to be simulated because data for other parameters are not available. As described above, the model result matched well with field data in calibration and verification of the WASP5 model. To demonstrate the potential use of the WASP5 model as a tool for evaluating alternate water quality management strategies that involve wastewater discharges and water quality in the Des

Moines River, the model and the verified reaction-coefficient values were used to simulate DO, BOD, ammonia nitrogen under different streamflow, point source and non-point source loading scenarios. The results can be used to determine WLA and NPDES permits for the Des Moines River.

From this study, it is clear that under low streamflow condition water quality is very sensitive to the concentration of BOD_5 and NH_3 from the point source, and under high streamflow, water quality is more influenced by the concentration of NH_3 from non-point sources. BOD_5 in non-point sources is not an important parameter because its value is very low compared to the point source. Higher streamflow and more waste discharging can yield the longer distance from the discharge point to the lowest point of DO sag.

Because no non-point source pollution modeling study was conducted on the Des Moines River watershed, detailed non-point source pollution data for different streamflow conditions are not available. In this study, the empirical equations relating the annual unit non-point load to the annual unit discharge of the watershed were used for non-point source input. If non-point source pollution model could be applied to same watershed, more detailed application of surface quality modeling could be made for to simulate water quality problem in a watershed to find the worst situation, considering point source and non-point source loading, streamflow, and storm runoff conditions.

The seasonal variation of streamflow in the Des Moines River stream is significant. In the study reach, Q7,10 is 98 cfs and Q mean is 3580 cfs. A singer constant discharge standard based on low flow may be too stringent and not economic for most stremflow conditions.

Seasonal discharge standards based on seasonal streamflow Q variations for waste load allocation in the watershed could be studied in the future using risk analysis method and may have engineering advantages and benefits.

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ACKNOWLEDGMENTS

I would like to express my appreciation for all the people and organizations who assisted me in my research and development of this thesis.

I would like to thank Dr. Rouchuan Gu for all his help and guidance throughout my research project and in the writing this thesis. I would like to thank Dr. T. A. Austin for giving me support and guidance throughout my research project and for his review and comments on this thesis. I would also like to thank Dr. Giora Slutzki for serving my committee and his wonderful teaching.

The Iowa Department of Natural Resources and EPA provided the financial support that made this study possible. I would also like to thank Donna Lutz for her help in data collection. The U. S. Army Corps of Engineers, Rock Island District for sponsored the water quality monitoring project on that the data of this research is based.