United States
Environmental Protection
Agency

Permits Division
(EN-336)
Washington DC 20460

OWEP 83-03
August 1983

Water

EPA

Development of Improved Ammonia Fate Models for the State of Iowa

DEVELOPMENT OF IMPROVED AMMONIA FATE MODELS FOR THE STATE OF IOWA

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Permits Division (EN-336)

August 1983

DISCLAIMER

Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the Environmental Protection Agency. Similarly, publication of studies reporting better results from one model vis-a-vis others does not constitute endorsement.

FOREWARD

A major function of the Office of Water Enforcement and Permits is to provide technical assistance to the Regional Offices and States in the area of permit issuance. Water quality is an important aspect of permit issuance particularly as requests for waivers under section 301(g) of the Clean Water Act become more numerous. The project reported in this document was undertaken at the request of Region VII and the State of Iowa. It is being distributed so that other Regions and States may benefit from its findings.

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NOTE ON MODEL AVAILABILITY

The official EPA version of QUAL II is currently being revised, in part as a result of this study. In the interim, copies of the two models described in this report are available from the EPA Modeling Center with the understanding that no user's assistance can be provided for the models. Users should rely on "User's Manual for Modified Iowa DEQ Model" and "User's Manual for Vermont QUAL-II" also available from the Modeling Center. Inquiries should be addressed to Thomas Barnwell, USEPA Modeling Center, College Station Road, Athens, Georgia 30613.

ABSTRACT

The purpose of this study was to provide technical assistance to the State of Iowa to improve that State's ability to develop water quality-based NPDES permit limits through improved modeling techniques. A secondary purpose of this case study was to encourage other States to evaluate the effectiveness of their water quailty models.

The project evaluated three models for assessing the impacts of BOD and ammonia discharges on receiving water quality. The models included the current Iowa model which is a simple Streeter-Phelps DO sag equation; a version of the current Iowa model which was developed as part of this project to include algal photosynthesis-respiration effects on DO and preferential uptake of ammonia; and a version of Qual-II developed by the State of Vermont. The models were evaluated on the basis of predictive capabilities, data requirements, and costs. Predictive capability could not be fully examined because of the lack of data available for the study site. Descriptions of the modified Iowa and Vermont Qual-II models are included in this report, and User's Manuals are available under separate cover.

The improved ammonia predictions of the modified Iowa and Qual-II models led to significantly different water quality-based permit limits than the existing Iowa model. In contrast to the existing model, the modified Iowa and Qual-II models predicted that under both summer and winter ice cover conditions, discharges of ammonia at the study site POTW are limited by DO considerations and not toxicity concerns. Toxicity determined permit limits on total ammonia only during winter no ice conditions. While the permit limits derived with the existing model required year around operation of nitrification facilities, the modified Iowa and Qual-II models indicated that operation was only needed during winter conditions.

The study concluded that computer costs are comparable for all three models. Monitoring costs are comparable for both the existing and modified Iowa models but considerably higher for the Qual-II model. The report recommended that the modified Iowa model be used for preliminary water quality assessments to identify stream segements where the Qual-II model should be used to develop final permit limits.

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1. INTRODUCTION

1.1 BACKGROUND

The Iowa Department of Environmental Quality (DEQ) has evidence of potentially toxic levels of NH_3 occurring in some State streams. This has led to the imposition of stringent NPDES permit limits for NH_3 discharges and the establishment of compliance schedules for the upgrading of numerous wastewater treatment plants to include nitrification facilities. The U.S. Environmental Protection Agency (EPA) will approve funding of these advanced treatment projects only if it believes that the need for such facilities exists and that the environmental benefits justify the costs.

The Iowa DEQ uses a mathematical computer model developed by Stanley Consultants to establish waste load allocations (1). Model calibration and verification performed by TenEch Environmental Consultants in 1978 raised questions about the model's ability to predict accurately the assimilative capacity of Iowa's receiving waters (2). As a result, JRB Associates, in conjunction with a separate project being conducted in the State, evaluated the performance of the Iowa DEQ model and outlined an approach to improve its capabilities.

The ensuing technical assessment revealed several weaknesses in the model's ability to predict ammonia (NH_3) concentrations during winter and summer conditions and to predict dissolved oxygen (DO) concentrations during summer conditions. JRB concluded that the following modifications would significantly improve the model's performance:

- Use of a more widely accepted temperature correction function for nitrification in order to improve NH_3 simulation in winter
- Development of an expression to account for the uptake of NH_3 by aquatic plants in order to improve NH_3 simulation in summer
- Development of a "photosynthesis minus respiration" (P-R) term in order to improve DO simulation in summer

Subsequently, JRB Associates was contracted by the EPA, Permits Division, Washington, DC to evaluate alternative models, conduct case studies, and provide recommendations to the State. The existing Iowa model was modified to include the recommended improvements, and the more sophisticated Vermont Qual-II model was investigated for use by the State. The project was intended not only to assist the State of Iowa but also to serve as a case study to encourage other States to evaluate the effectiveness of their models.

1.2 ORGANIZATION OF THE FINAL REPORT

Chapter 2 describes the modified Iowa DEQ model and comments on the limitations of its simplified approach. The capabilities of the Vermont Qual-II model are described in Chapter 3. In Chapter 4, the existing Iowa, modified Iowa, and Qual-II models are compared in terms of simulation accuracy and cost, and recommendations for their use are made. Chapter 5 summarizes the waste load allocation analyses performed for the case study area. Stream monitoring requirements for model calibration and verification are included in Chapter 6. Chapter 7 contains the list of references for the report.

2. DESCRIPTION OF MODIFIED IOWA DEQ MODEL

2.1 BACKGROUND

JRB Associates used two approaches in investigating improved waste load allocation modeling techniques for the State of Iowa. The first approach was to modify the existing model to include better algorithms for NH_3 and DO predictions. The second approach was to evaluate the most comprehensive waste load allocation model currently available. After evaluating several versions of QUAL II, it was decided that the Vermont version was the most comprehensive model available. The advantage of the first approach is that the model remains simple and familiar -- only minimal time would be required to train State personnel in its use. The disadvantage of this approach is that the revised model is greatly improved but still too simple to simulate accurately all the water quality processes which determine receiving water concentrations of NH_3 and DO.

The revised Iowa model was constrained to follow the structure of the existing Iowa model in simulating only DO, BOD, and NH_3. In order to simulate the algal growth, which has such an influence on NH_3 and DO in Iowa's nutrient-enriched streams, a model must include, as a minimum, the reactions and transport of nitrate (NO_3) and inorganic phosphorus (PO_4). The revisions to the existing model attempt to circumvent the absence of NO_3 and PO_4 simulation by having the modeler calculate algal growth rates outside the model, using observed instream concentrations of NO_3, NH_3 and PO_4. This calculated value can then be entered in the model and used in subsequent algorithms that compute photosynthetic production of oxygen and preferential uptake of ammonia. The revised model cannot, however, overcome the need to simulate NO_3 in order to ensure that calibrated nitrification rates do not result in excessive conversion of NH_3 to NO_3. This deficiency in the model may lead to the overestimation of nitrification rates and the underestimation of preferential uptake of ammonia.

More detailed discussion of the limitations and appropriate use of the modified Iowa model will be provided in Chapter 4. In summary, JRB recommends that Iowa DEQ use this revised model as a screening tool to select those streams that appear to require advanced treatment facilities. The Vermont QUAL II model should then be used to develop waste load allocations for these potential AWT streams.

2.2 MODEL THEORY

The existing Iowa DEQ model is a steady-state model which predicts receiving water dissolved oxygen (DO), carbonaceous biochemical oxygen demand (BOD), and ammonia (NH_3) concentrations, assuming completely mixed conditions in each stream reach. DO deficit is calculated using a modified Streeter-Phelps equation which includes only instream microbial nitrification and biological oxidation. No benthic oxygen demands or photosynthesis-respiration effects on DO are included. The rates of oxygen utilization due to both carbonaceous and nitrogenous biochemical oxygen demand are expressed as first order equations. Data supplied to the program as input include the first order decay rate constants for BOD (K_1) and ammonia (K_n). The travel time and reaeration rate constant (K_2) are calculated within the model.

JRB modified the existing DEQ model by improving algorithms for NH_3 and DO and adding new ones to simulate previously neglected instream processes. New algorithms were added to revise the first order nitrification rate constant K_N as a function of temperature and stream DO concentration, and to simulate the uptake of NH_3 by algae. Unlike nitrification, algal uptake of NH_3 involves ammonia removal without oxygen utilization; therefore, the simulation of algal NH_3 uptake will also affect the DO simulation. The relationship between NH_3 and nitrogenous BOD was changed to reflect a more reasonable oxygen demand for NH_3, and a photosynthesis-respiration term was added to improve DO simulation in enriched streams. The following subsections describe the revised modeling expressions in detail. JRB has also prepared a detailed User's Manual for the modified model which is available under separate cover.

2.2.1 Predictive Equations

The equations which predict stream concentrations of carbonaceous BOD, nitrogenous BOD, and DO deficit are listed below:

$$L(t) = L_o e^{-K_1 t} \tag{1}$$

where

$L(t)$ = ultimate carbonaceous BOD at time t (mg/l)

L_o = initial ultimate carbonaceous BOD concentration (mg/l)

K_1 = carbonaceous deoxygenation rate constant (day^{-1})

t = time of travel through reach (day)

$$N(t) = N_o e^{-K_N t} \qquad (2)$$

where

$N(t)$ = nitrogenous BOD concentration at time t (mg/l)

N_o = initial nitrogenous BOD concentration (mg/l)

K_N = nitrogenous deoxygenation rate constant (day^{-1})

$$D(t) = \frac{K_1 L_o}{K_2 - K_1}\left(e^{-K_1 t} - e^{-K_2 t}\right) + \frac{K_N N_o}{K_2 - K_N}\left(e^{-K_N t} - e^{-K_2 t}\right) + D_o e^{-K_2 t} + \frac{(R-P)\left(1 - e^{-K_2 t}\right)}{K_2} \qquad (3)$$

where

$D(t)$ = DO deficit at time t (mg/l)

K_2 = reaeration rate constant (day^{-1})

D_o = initial DO deficit (mg/l)

R = algal respiration oxygen utilization (mg/l/day)

P = photosynthetic oxygen production (mg/l/day)

Only the DO deficit equation differs from those in the existing model.

The equations used to calculate P and R are taken from the MS-ECOL fresh water stream model.[3] They are:

$$P = \frac{(OP)(GP - DP)(CHLA)}{AP} \qquad (4)$$

where

OP = mg oxygen produced by algae/mg algae

AP = ug chlorophyll-a/mg algae

GP = algal growth rate (day^{-1})

DP = algal death rate (day^{-1})

CHLA = chlorophyll a concentration (ug/l)

and

$$R = 0.025 \text{ CHLA} \tag{5}$$

The values of OP, AP, and DP must be selected from the literature by the modeler. It is essential that chlorophyll-a measurements be available from the sampling data. If not, chlorophyll-a values must be estimated by field observation and calibration, which detracts from the credibility of the calibration. Since nitrate and inorganic phosphorus are not included in the model, the growth rate (GP) must be calculated outside the model using the equation:

$$GP = \bar{u} \left(\frac{N}{N + K_{MN}}\right)\left(\frac{P}{P + K_{MP}}\right)\left(\frac{LI}{LI + K_{LI}}\right) \tag{6}$$

where

GP = local algal growth rate at 20°C (day^{-1})

$\bar{u}$ = maximum specific algal growth rate at 20°C (day^{-1})

N = sum of observed instream concentrations of NH_3-N and NO_3-N (mg/l)

K_{MN} = Michaelis-Menton half-saturation constant for total inorganic N (mg/l)

P = observed instream concentration of inorganic phosphorus (mg/l)

K_{MP} = Michaelis-Menton half-saturation constant for inorganic P (mg/l)

LI = average incident light intensity ($kcal/m^2$-sec)

K_{LI} = Michaelis-Menton half-saturation constant for light ($kcal/m^2$-sec)

The values of OP and AP are input as constants for the entire stream, while GP, DP, and CHLA are specified for each reach. The Michaelis-Menton constants are used to adjust the maximum potential algal growth rate by the amounts of light, nitrogen, and phosphorus that can limit algal growth. Each constant is the concentration at which that particular constituent limits algal growth to half the maximal or "saturated" value.

The relationship between NH_3-N and nitrogenous BOD (NOD) has also been revised. In the existing model, the value of NOD is calculated by multiplying the simulated instream NH_3-N concentration by 4.57. This constant, which represents the grams of oxygen required to convert one gram of ammonia to nitrate, was calculated using the oxidation-reduction equations for nitrification. As long as nitrification is not limited by insufficient inorganic carbon, some oxygen will be obtained from inorganic carbon sources. When this is taken into account, the synthesis-oxidation equations show that only 4.33 grams of oxygen are required to convert one gram of ammonia to nitrate. Thus, the revised model uses the constant 4.33 instead of 4.57.

Another new feature in the revised model is the simulation of algal uptake of NH_3-N. The instream concentrations of inorganic nutrients are reduced by phytoplankton consumption. Phytoplankton requirements for inorganic N may involve both ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3-N). The fraction of consumed nitrogen which is NH_3-N must be known if instream concentrations of NH_3-N are to be properly simulated. This fraction is the preferential NH_3 uptake factor.

The amount of NH_3-N removed by algae in a reach is calculated by the following equation taken from the MS-ECOL model (3):

$$UP = \frac{(GP)(ANP)(NF)(CHLA)\left(e^{(GP-DP)(t)} - e^{-(K_N)(t)}\right)}{(GP - DP + K_N)} \tag{7}$$

where

UP = amount of NH_3-N removed in a reach (mg/l)
ANP = mg N / ug chlorophyll-a
NF = fraction of NH_3 preferred for algal uptake (0 - .9)
t = time of travel through reach (day)

The model calculates t internally, the value of ANP must be input by the modeler, and the value of NF is calibrated. The model assumes that algal uptake of ammonia occurs until the instream concentration of NH_3-N is equal to the inorganic N half-saturation constant K_{MN}. If the instream concentration of NH_3 is below the half-saturation constant, the technical literature indicates that algae will switch to NO_3 as the sole source of nitrogen.

2.2.2 Rate Constants

The predictions of equations (1)-(3) depend upon the values of rate constants K_1, K_N, and K_2, which represent the carbonaceous deoxygenation rate, nitrogenous deoxygenation rate, and reaeration rate, respectively. The modeler sets initial values of K_1 and K_N; final values of these rate constants are established through calibration and verification of the model. Unlike K_1 and K_N, the reaeration rate constant K_2 is calculated internally in the model by the equation:

$$K_2 = \frac{(ICE)(C)(\Delta h)}{t} \qquad (8)$$

where

ICE = factor reflecting effect of ice cover on reaeration rate

C = escape coefficient (ft^{-1})

Δh = difference in water surface elevation between upstream and downstream ends of reach (ft)

t = time of travel through reach (day)

The value of C is specified by the modeler, and the appropriate value is refined through calibration and verification. TenEch recommends ICE factors ranging from 0.05 for complete ice cover to 1.0 for zero cover (2).

The modified model alters the value of K_N within each reach as a function of the stream DO concentration. Because nitrifying bacteria are very sensitive to DO levels, K_N is reduced when low DO conditions exist. The following equation, which accounts for the effect of DO concentrations on nitrification rates, is taken from the Wisconsin Qual III Model (4):

$$PN = 1-e^{-(.52)(DO)} \qquad (9)$$

where

PN = nitrification reduction factor
DO = dissolved oxygen concentration (mg/l)

The K_N value input to the model is multiplied by the reduction factor PN. The product is the value of K_N which is used in equations (2) and (3).

2.2.3 Temperature Effects

Each rate constant is affected by changes in stream temperature. The equations within the model which simulate the effect of temperature are:

$$K_{1(T)} = K_{1(20)} \times 1.047^{T-20} \quad (10)$$

$$K_{2(T)} = K_{2(20)} \times 1.0159^{T-20} \quad (11)$$

$$K_{N(T)} = K_{N(20)} \times 1.080^{T-20} \quad (12)$$

$$GP_{(T)} = GP_{(20)} \times 1.047^{T-20} \quad (13)$$

where,

T = temperature (°C)

Equation (10) is commonly used to simulate the effect of temperature on the rate constant K_1, and it is unchanged from the existing model. Equations (11) and (12) differ from those in the existing model; the new equations are more accepted functions used in the Vermont Qual II Model (5). Equation (13) is taken from the MS-ECOL model.

3. DESCRIPTION OF VERMONT QUAL-II MODEL

3.1 BACKGROUND

The QUAL-II model is an extension of the stream model, QUAL-I, developed by F. D. Masch and Associates, and the Texas Water Development Board in 1971. QUAL-I was originally designed to simulate the dynamic behavior of conservative materials, temperature, BOD and DO in streams.

Water Resources Engineers, Inc. (WRE) revised the QUAL-I model to include the steady-state simulation of ammonia, nitrite, nitrate, dissolved phosphorus, algae and coliforms, as well as BOD and DO. This WRE QUAL-II model has since undergone numerous revisions to incorporate additional parameters and changes in constituent interactions. The version of QUAL-II which JRB used on the North Raccoon River is the Vermont version of QUAL-II.

The Vermont QUAL-II is basically a version developed by Meta Systems, Inc. (June 1979), with later modifications by Walker (1980, 1981) and the Vermont Department of Water Resources and Environmental Engineering. The changes Meta Systems introduced in 1979 to USEPA's version of QUAL-II includes the following:

- Incorporation of the simulation of organic nitrogen
- Provision for algal uptake of ammonia as a nitrogen source
- Steady state calculation of diurnal oxygen variations due to algal photosynthesis and respiration based on diel curve analysis
- Changes in the model to delete the dynamic simulation of DO, thus allowing dynamic simulation of temperature only
- Inclusion of dam reaeration
- Changes in the methods used to calculate the reaeration coefficient, K_2.

To this Meta Systems version of QUAL-II, Vermont has added the simulation of organic phosphorus and has modified the expressions for algal kinetics.

In order to develop a useful manual which incorporates all of the recent changes made to the Vermont model, JRB had to consolidate the material from four separate reports into one User's Manual. The new manual is provided under separate cover as part of this project for the State of Iowa.

3.2 MODEL THEORY

The Vermont Qual-II is a steady state water quality model that can simulate any completely mixed branching stream or river system. It can handle multiple waste discharges, water withdrawals, tributary flows, and incremental inflows, all of which are considered constant. Advection and dispersion are the major pollutant transport mechanisms. Stream channel geometry and velocity are held constant in each reach. The following constituents are simulated in the model:

- Dissolved oxygen (DO)
- Carbonaceous biochemical oxygen demand (CBOD)
- Nitrogenous biochemical oxygen demand (NBOD)
- Temperature
- Algae
- Organic Nitrogen
- Ammonia (NH_3-N)
- Nitrite (NO_2-N)
- Nitrate (NO_3-N)
- Organic phosphorus
- Dissolved phosphorus
- Coliforms
- Up to three conservative substances.

The Vermont Qual-II model assumes first order decay for CBOD and also allows for CBOD settling. The effects on DO of benthic oxygen demand, algal production, and nitrification are included in the model. The model utilizes a simplified nutrient-algal model with MONOD kinetics and includes the cycling of nitrogen and phosphorus forms between inorganic and organic forms. Local algal growth rates are computed as being limited by light and either nitrogen or phosphorus, but not both. An ammonia preference factor is input to the model so that algae can use ammonia and/or nitrate as a source of nitrogen. When oxygen is simulated, and photosynthesis is considered either by simulating algae or by inputing P and R values, a diel curve analysis is performed after the steady state solution is reached. This analysis estimates for each computational element in the system the daily minimum and maximum DO concentrations resulting from photosynthesis and respiration.

4. COMPARISON OF MODELS

Sampling data from a summer and a winter period were used to compare the predictive capabilities and costs of the existing Iowa, modified Iowa, and Vermont QUAL-II models. Figure 4.1 is a map of the study area, which extends from the City of Storm Lake on Outlet Creek to Sac City on the North Raccoon River. Only two point source discharges are included in the modeling analysis: the City of Storm Lake's wastewater treatment plant, a two-stage trickling filter system, and the IBP Meat Packing Company's aerobic lagoon system. Both of these treatment facilities discharge to Outlet Creek. This study area was selected by the State of Iowa because additional nitrification is currently scheduled for the Storm Lake municipal plant based on waste load allocation analyses performed using the existing Iowa DEQ model.

4.1 LIMITATIONS IN AVAILABLE DATA

The data from both the September 1981 and the January 1978 sampling events were obtained from reports prepared by the Hygienic Laboratory at the University of Iowa (6,7). Both the trickling filter plant and the lagoon were discharging during the September sampling, but only the Storm Lake facility was active during the January period.

The September sampling involved grab samples at the two dischargers and in the stream every six hours, beginning at noon on September 14 and ending at 6 a.m. September 15. Two more samples were then taken at 6 a.m. September 16 and 6 a.m. September 17. JRB calibrated the models using the mean values for the September 14 to 15 period.

During the January sampling period, single grab samples were taken at the three instream stations on January 16 and at the Storm Lake effluent on January 13, 16, 17 and 18. The January 16 instream values were used for model verification purposes. However, since BOD was not measured in the effluent on January 16, JRB was forced to use data from January 18 as the best estimate for effluent quality preceding the stream sampling.

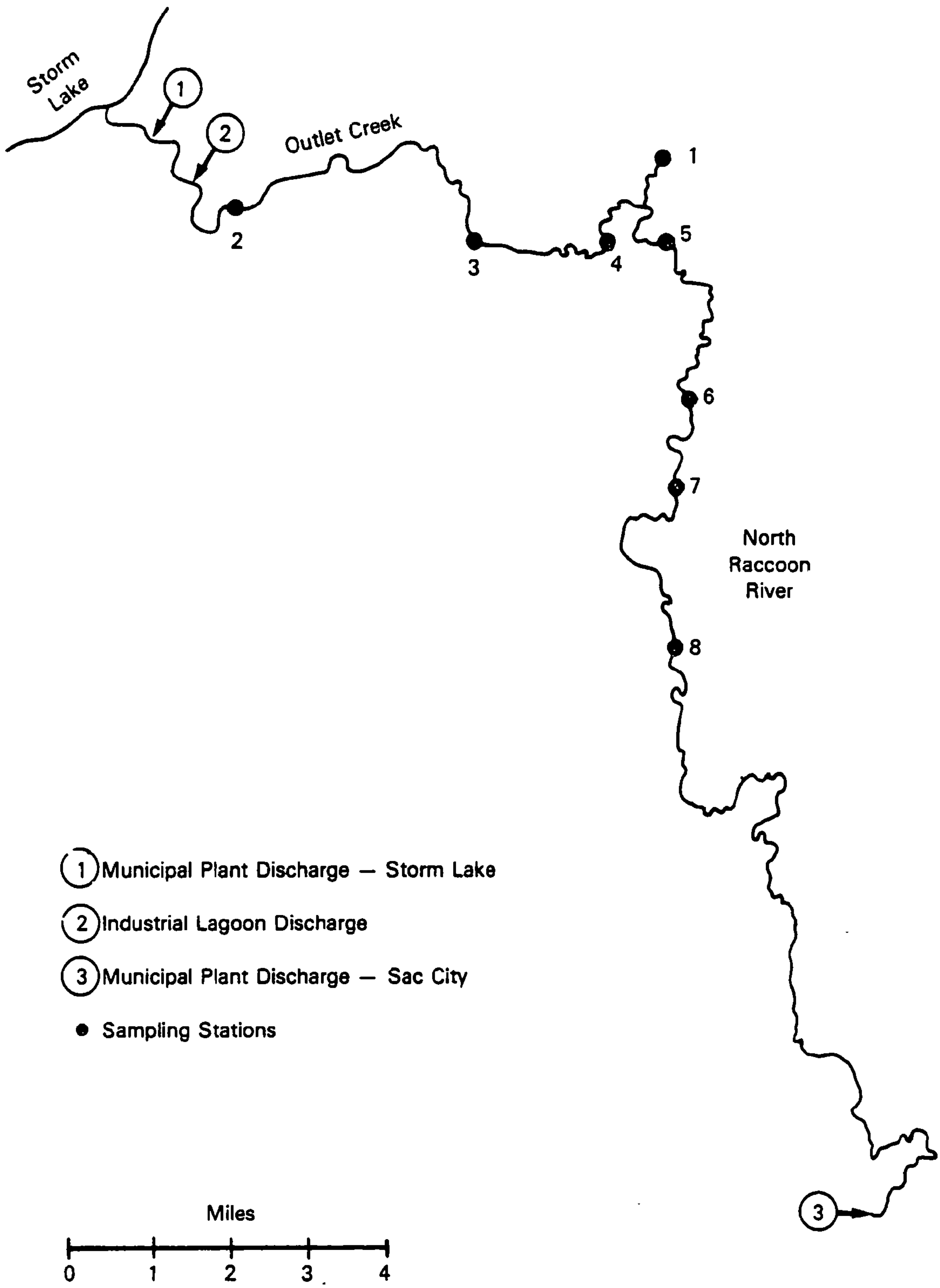


Figure 4.1
Map of Study Area

The sampling methods employed for both September and January are not the most appropriate for model calibration and verification. The ideal monitoring program consists of plug flow sampling, in which the sampling of each station is staggered in accordance with the travel time between stations. Any tributaries or point sources contributing to the slug of water being sampled should be monitored as the slug passes these points. In the case of the Outlet Creek dischargers, situated at the headwaters of the modeled stream, 24-hour composite sampling of the effluent should have been performed one day prior to the instream sampling in order to allow for the monitored discharge to affect receiving water concentrations.

The other major deficiency in the calibration sampling program involved the inclusion of a period in which the industrial lagoon was discharging. The lagoon is not permitted to discharge during flows at or below the 7Q10 level. Consequently, waste load allocation analyses are not supposed to include this discharge. The lagoon discharge has such an overwhelming effect on receiving water quality in the summer time that all the algal growth parameters and related reaction rate coefficients established during model calibration will reflect the impact of the lagoon and not be appropriate for use in the wasteload allocation modeling.

Table 4.1 summarizes the gaps that existed in the sampling data available compared to the data required for each model's calibration. The effluent data was deficient from the very beginning because the sampling was performed on the same day as instream sampling. The measured discharge had no time to influence the receiving water. Monitoring data indicate that effluent concentrations at the two treatment plants varied significantly from day to day, thus making it even more important that the effluent be monitored one day before instream sampling. Another significant limitation in the effluent data was that it only included DO, BOD and NH_3. No measurements were made of chlorophyll-a concentrations or of any nutrients other than NH_3.

Table 4.1 indicates that appropriate instream data were also lacking. The most serious deficiencies include the lack of chlorophyll-a data during the summer sampling period and the absence of flow, velocity and ice cover

TABLE 4.1

COMPARISON OF DATA NEEDS FOR MODEL
CALIBRATION/VERIFICATION

	REQUIRED SAMPLING DATA						AVAILABLE SAMPLING DATA			
	QUAL-II		EXISTING IOWA		MODIFIED IOWA		9/81		1/78	
PARAMETER	POINT SOURCE DISCHARGE	STREAM	POINT SOURCE DISCHARGE	STREAM	POINT SOURCE DISCHARGE	STREAM	POINT SOURCE DISCHARGE	STREAM	POINT SOURCE DISCHARGE	STREAM
DO	X	X	X	X	X	X	X	X	X	X
BODu	X	X	X	X	X	X	X	X	X	X
ORGANIC N	X	X						X		X
NH_3-N	X	X	X	X	X	X	X	X	X	X
NO_2-N	X	X				X				
NO_3-N	X	X				X		X		X
DISSOLVED P	X	X				X		X		X
ORGANIC P	X	X						X		X
TEMPERATURE	X	X	X	X	X	X	X	X	X	X
CHLOROPHYLL-A	X	X			X	X				
FLOW	X	X	X	X	X	X	X	X	X	
VELOCITY		X		X		X		X		
CHANNEL GEOMETRY		X						X		

measurements during the winter period. In addition, there were no measurements made of pollutant concentrations in the Outlet Creek waters above the dischargers, or in the agricultural tile drainage that contributes much of the incremental inflow to both Outlet Creek and North Raccoon River.

The lack of chlorophyll-a data was a critical deficiency in calibrating both the modified Iowa and the Vermont QUAL-II models for the September sampling period. The instream concentration of chlorophyll-a is used in both of these models to calculate photosynthetic oxygen production, algal respiration, and algal uptake of ammonia. During the September 1981 monitoring, the field crew observed a dark green coloration extending from the lagoon discharge to the confluence with the North Raccoon River. The lagoon was apparently seeding Outlet Creek with algae. The wide range of diurnal DO values monitored during this period also confirmed the presence of high instream concentrations of algae.

The absence of flow, velocity and ice cover data during the winter period greatly hindered verification of all the models. The flow could be estimated by proportioning USGS flows at Sac City by the appropriate drainage area, but the missing velocity and ice cover data could not be easily replaced. Since velocity determines travel time, poor estimation of this parameter has a detrimental effect on the prediction of all water quality parameters. Without documented estimates of the extent of ice cover, the reaeration capacity of the receiving waters during the January sampling period is completely open to question.

The lack of data on the background concentrations for Outlet Creek headwaters and the incremental inflow is not as critical as the other deficiencies because these components make up such a small percentage of the total flow during the sampling events. However, studies by EPA's OR&D which involved calibrating the HSPF model to Iowa watersheds indicate that nitrate concentrations in tile drainage may be quite high. In the future BOD, DO and nutrients should be measured in both headwaters and tile drainage during waste load allocation monitoring studies.

JRB attempted to work around all these data limitations by supplementing the sampling information with reasonable assumptions and appropriate values from the technical literature. It is important to note, however, that the lack of essential data is so significant that none of the models can be considered calibrated or verified. JRB thus recommends that this project be viewed only as a modeling exercise to investigate the relative advantages and disadvantages of the existing Iowa, modified Iowa, and Vermont QUAL-II models. The statistical tests used to compare the predictive accuracy of the models are only included to demonstrate how proper goodness-of-fit measurements should be conducted in addition to graphical comparisons of observed and simulated data. Consequently, the waste load allocation analyses included in Chapter 5 are presented only as a theoretical demonstration of how improved waste load allocation models can lead to cost savings in the design and operation of treatment facilities.

The following two subsections of this chapter describe in detail the various assumptions JRB made to fill in the data gaps and proceed with the model comparisons.

4.1.1 Modified Iowa Model--Assumptions for Missing Data

As explained in Chapter 2, the modified Iowa model only simulates DO, BOD and NH_3. The modified Iowa model is not a deterministic model like QUAL-II, which routes all forms of N and P and calculates the algal growth rate in each reach, using simulated inorganic N and P concentrations. Instead the growth rate calculation is performed by hand using observed instream inorganic N and P data. The computed algal growth rate is then input to the model, where it is used to calculate photosynthetic oxygen production and uptake of ammonia. As a result, the calibration of the modified Iowa model is not affected by the lack of effluent nutrient data.

Model calibration for the September period is, however, significantly harmed by the absence of instream chlorophyll-a measurements. These chlorophyll-a data are required for model calculations of photosynthetic oxygen production, algal respiration oxygen demand, and preferential uptake of ammonia.

Since the field crew observed that the discharge from the industrial lagoon was seeding Outlet Creek and the North Raccoon River with algae, JRB referred to the technical literature on aerobic ponds to estimate chlorophyll-a concentrations in the lagoon effluent. The literature suggests that algae in an aerobic lagoon must be maintained at a level from 40 to 100 mg/l for effective operation (8). Assuming a typical value of 50 ug chlorophyll-a/mg algae, the IBP lagoon on Outlet Creek can be expected to contain chlorophyll-a concentrations of at least 2,000 ug/l. In the absence of corroborating sampling data, JRB assumed a discharge of less than half this amount (800 ug/l). The use of this chlorophyll-a discharge resulted in an instream concentration after dilution of about 400 ug/l. This assumed instream concentration is reasonable, based on the situation, and may be quite conservative.

Because chlorophyll-a is not routed through the system like NH_3-N, BOD, and DO, the modeler must specify the chlorophyll-a concentrations for each reach. The value of 400 ug/l was specified for all reaches of Outlet Creek downstream from the lagoon discharge. The concentrations in the North Raccoon reaches downstream from the river's confluence with Outlet Creek were based on simple dilution calculations, considering the flow and chlorophyll-a concentrations contributed by both the Creek and the River. Headwater chlorophyll-a concentrations for Station #1 in the North Raccoon River above the confluence with Outlet Creek, and in Outlet Creek above the lagoon discharge, were estimated at 25 ug/l, a reasonable value for enriched streams during summer conditions. Measured concentrations of DO, BOD and the nutrients from Station #1, above the confluence with Outlet Creek, were used to represent the headwaters of the North Raccoon River. Since there were no samples taken in the Outlet Creek headwater, JRB made use of a combination of estimates from the State of Iowa, and the measured values from the North Raccoon headwaters. The DO and BOD values input to the model were those recommended by the Iowa DEQ, while the nutrient concentrations came from Station #1. Groundwater inflow values were obtained from TenEch estimates for the North Raccoon River (2). Neither the headwaters or groundwater inflow values exerted any significant effect on simulated instream concentrations since their contribution to the total September flow is so small.

The absence of flow and velocity data in the January 1978 sampling prevented verification of the modified Iowa model. The flow values were estimated using data from the Sac City USGS gaging station, located on the North Raccoon River 30 miles below the confluence with Outlet Creek. The sum of the point source discharges above the gage was subtracted from the measured flow to estimate the natural inflow to the stream system. This inflow was then proportioned by drainage area to Outlet Creek, North Raccoon River, and Big Cedar Creek. The flows estimated for Outlet Creek and the North Raccoon River were converted to velocities in the modified Iowa model with the Leopold-Maddock equation. The empirical coefficients, "a" and "b", used in the equation were those determined from the September dataset.

The extent of ice cover during the January 1978 sampling was not documented in the monitoring report. Estimates from the field crew indicate that the North Raccoon had complete ice cover and that Outlet Creek was at least partially covered with ice during the sampling event. The modified Iowa model retained the ICE variable from the existing model. The reaeration rate constant (K_2) is multiplied by the ICE factor to calculate a reduced reaeration capacity due to ice cover conditions. In a modeling study for the Iowa DEQ, TenEch Environmental Consultants found that calibrated ICE values for complete ice cover ranged from 0.01 to 0.40, with 0.05 resulting in good DO calibrations for the majority of streams (2). Due to the uncertainty of the extent of ice cover during the January monitoring period, the value of ICE was calibrated for Outlet Creek. ICE was assumed to be 0.05 for the North Raccoon River, because the field crew recalled that complete ice cover existed at that time.

The estimation of headwater and groundwater quality was another consideration in the January verification. The only existing headwater data was from a grab sample taken approximately 8 miles upstream of the confluence of Outlet Creek and the North Raccoon River. Those conditions were used as headwater conditions for both the Creek and the River. Groundwater inflow values recommended by TenEch for winter conditions for both the Creek and the River were used for the January verification (2).

Table 4.2 lists all the input data developed for both the existing and the modified Iowa model from the assumptions discussed in this section of the report.

4.1.2 Vermont QUAL-II Model--Assumptions for Missing Data

The Vermont QUAL-II model must route all inorganic and organic forms of nitrogen and phosphorus in order to calculate the effects of algal growth on DO and NH_3. Therefore, it could not be calibrated for the September sampling event without data on the effluent concentrations of organic nitrogen, nitrate, dissolved phosphorus and organic phosphorus. In order to estimate these concentrations, JRB consulted the following sources:

- Literature values of typical nutrient concentrations in the effluent of secondary treatment plants
- Effluent data from similar trickling filter plants and lagoons in Iowa
- Historical data from the Storm Lake POTW and IBP Meat Packing Lagoon.

After reviewing all the available data on trickling filter plants, JRB decided to utilize the Storm Lake POTW data from April 1972 to estimate organic nitrogen, nitrate and phosphorus values for the September 1981 sampling period. Secondary treatment plant data from the literature were used to distribute measured total P concentrations between organic and dissolved P. The April 1972 data was selected because its concentrations of NH_3 and BOD were similar to those monitored in September 1981. Both sets of data were provided by the State of Iowa and are listed below:

POTW Effluent Concentrations (mg/l)	September 1981	April 1972
BOD_u	30.0	35.0
DO	2.23	--
NH_3-N	14.0	13.0
Organic N	--	3.8
Nitrate	--	2.9
Total Phosphorus	--	11.0

TABLE 4.2

INPUT DATA
EXISTING AND MODIFIED IOWA MODELS

Input Data	Calibration		Verification	
	Outlet Creek	North Raccoon River	Outlet Creek	North Raccoon River
Storm Lake POTW				
Flow (cfs)	2.74	--	1.33	--
BOD_u (mg/l)	30.0	--	27.0	--
DO (mg/l)	2.2	--	7.3	--
NH_3-N (mg/l)	14.0	--	21.0	--
IBP Lagoon				
Flow (cfs)	2.46	--	0.0	--
BOD_u (mg/l)	19.1	--	--	--
DO (mg/l)	14.9	--	--	--
NH_3-N (mg/l)	1.04	--	--	--
Headwater				
Flow (cfs)	0.10	4.20	0.10	4.20
BOD_u (mg/l)	6.00	6.0	1.5	1.5
DO (mg/l)	8.2	10.2	6.5	6.5
NH_3-N (mg/l)	0.02	0.02	0.29	0.29
Chlorophyll-a (ug/l)*	25.00	10.0	5.0	5.0
Inflow				
Flow (cfs)	0.0	0.28	0.06	0.10
BOD_u (mg/l)	6.0	6.0	2.0	2.0
DO (mg/l)	2.0	2.0	2.0	2.0
NH_3-N (mg/l)	0.02	0.02	0.05	0.05
Chlorophyll-a (ug/l)*	0.0	0.0	0.0	0.0
Receiving Water				
Chlorophyll-a (ug/l)*	400.00	259.00	5.0	5.0

*Chlorophyll-a values are not included in existing model.

No historical data were found for the IBP lagoon or similar lagoon systems in Iowa. To estimate lagoon effluent quality, JRB was forced to use literature values for the mean concentration of organic N, NO_3, and phosphorus discharged from "moderately well-operated" secondary treatment systems. These values compare to the measured effluent concentrations as follows:

Lagoon Effluent Concentrations (mg/l)	IBP data	Literature Values
BOD_u	19.1	30-45
DO	14.9	--
NH_3-N	1.04	1.0
Organic N	--	1.0
NO_3-N	--	16.9
Total Phosphorus	--	7-9

The same assumptions regarding the lagoon discharge of chlorophyll-a, the headwater concentrations, and groundwater inflow concentrations were made for QUAL-II as were made for the modified Iowa model (See Section 4.1.1). Unlike the modified Iowa model, the QUAL-II model does route chlorophyll-a through the reach system. The dilution calculations performed externally for input to the modified Iowa model are done internally by the QUAL-II model.

The January 1978 sampling program also failed to measure the concentrations of organic N, NO_3, dissolved P and organic P in the POTW effluent. This was not as critical a deficiency for model verification as it was for model calibration since algal growth does not affect receiving water quality during the winter. The lack of NO_3 effluent data did, however, prevent an evaluation of the nitrification rate. NO_3 concentrations should be simulated along with NH_3 in order to ensure that calibrated nitrification rates do not lead to an excess of NO_3. Because of the lack of effluent data and the insignificance of winter algal growth, JRB decided not to simulate algae and phosphorus in the verification model run. The Vermont QUAL-II program requires that all nitrogen components be simulated when any individual parameter is to be modeled. All nitrogen constituents except NH_3 were set to zero, and QUAL-II was operated like the modified Iowa model to simulate only BOD, DO and NH_3.

The same assumptions regarding flow and velocity, ice cover factors, and headwater/inflow concentrations were made for QUAL-II as were made for the modified Iowa model (see Section 4.1.1).

Table 4.3 lists all the input data developed for the Vermont QUAL-II model from the assumptions discussed in this section of the report.

4.2 PREDICTIVE ACCURACY COMPARISONS

The ultimate goal of the calibration process is to obtain an assessment of stream system behavior that can be used to support decision making. Such an assessment is realized by defining reaction rates which, when combined with the measured inputs, yield constituent values that are consistent with the observed data (9). As discussed in the preceding section, the lack of appropriate data prevented any real calibration of the models. JRB thus recommends that the following discussion regarding calibration/verification results be viewed only as a comparative exercise to illustrate the relative capabilities of each model.

In order to evaluate the predictive accuracy of each model, JRB used graphical comparisons of observed versus simulated data and statistical measurements of goodness-of-fit. The use of statistical tests is not really appropriate for this study because of the inadequacy of the input data. Despite these problems, JRB decided to include the analyses in order to demonstrate how visual comparisons should be supplemented with statistics during the calibration/verification process. A number of statistical measurements are recommended for use as goodness-of-fit indicators, including the student's t-test comparison of means, regression analysis, and relative error calculations. Relative error and standard error measurements are used in this study.

Relative error is calculated for each parameter at each sampling station using the following equation:

$$e_i = \frac{X_i - C_i}{X_i}$$

TABLE 4.3

INPUT DATA
VERMONT QUAL II MODEL

	Calibration		Verification	
Input Data	Outlet Creek	North Raccoon River	Outlet Creek	North Raccoon River
Storm Lake POTW				
Flow (cfs)	2.74	--	1.33	--
BOD_u (mg/l)	30.0	--	27.00	--
DO (mg/l)	2.2	--	7.3	--
NH_3-N (mg/l)	14.0	--	21.00	--
Chlorophyll-a (ug/l)	0.0	--	0	--
ORG-N (mg/l)	3.8	--	0	--
NO_3-N (mg/l)	2.9	--	0	--
DISS-P (mg/l)	8.9	--	0	--
ORG-P (mg/l)	2.1	--	0	--
IBP Lagoon				
Flow (cfs)	2.46	--	0	--
BOD_u (mg/l)	19.1	--	--	--
DO (mg/l)	14.9	--	--	--
NH_3-N (mg/l)	1.04	--	--	--
Chlorophyll-a (ug/l)	800.00	--	--	--
ORG-N (mg/l)	1.01	--	--	--
NO_3-N (mg/l)	16.9	--	--	--
DISS-P (mg/l)	7.86	--	--	--
ORG-P (mg/l)	0.14	--	--	--
Headwater				
Flow (cfs)	0.10	4.20	0.10	4.20
BOD_u (mg/l)	6.0	6.0	1.5	1.5
DO (mg/l)	8.2	10.2	6.5	6.5
NH_3-N (mg/l)	0.02	0.02	0.29	0.29
Chlorophyll-a (ug/l)	25.0	10.0	5.00	5.00
ORG-N (mg/l)	0.93	0.93	0.34	0.34
NO_3-N (mg/l)	0.05	0.05	7.8	7.8
DISS-P (mg/l)	0.06	0.06	0.12	0.12
ORG-P (mg/l)	0.06	0.06	0.0	0.0
Inflow				
Flow (cfs)	0.0	0.28	0.06	0.10
BOD_u (mg/l)	6.0	6.0	2.00	2.00
DO (mg/l)	2.0	2.0	2.00	2.00
NH_3-N (mg/l)	0.02	0.02	0.05	0.05
Chlorophyll-a (ug/l)	0.0	0.0	0.00	0.00
ORG-N (mg/l)	0.93	0.93	0.34	0.34
NO_3-N (mg/l)	0.05	0.05	7.8	7.8
DISS-P (mg/l)	0.06	0.06	0.12	0.12
ORG-P (mg/l)	0.06	0.06	0.0	0.0

where,

e_i = Relative error at the sampling station

X_i = Measured value at the sampling station

C_i = Simulated value at the sampling station

Standard error combines relative errors at all the stations for each parameter using the following equation:

$$S_e = \sqrt{\frac{(X_i - C_i)^2}{n-2}}$$

where,

S_e = Standard error of the estimate
n = Number of paired values

Relative error calculations are very sensitive when the concentrations of a parameter are low. Small differences between observed and simulated values can lead to relatively large relative error calculations. As long as the modeler is aware of this problem, it should not lead to erroneous interpretation of results.

4.2.1 Existing Iowa Model Calibration/Verification

Table 4.4 shows the final calibration dataset of instream process parameters for the existing Iowa model. Figures 4.2 and 4.3 contain the plots of observed versus predicted concentrations of BOD_u, NH_3-N, and DO for Outlet Creek and the North Raccoon River during the September 1981 sampling event. Tables 4.5 and 4.6 present the statistical measurements of goodness-of-fit. A good calibration of BOD_u was achieved using reasonable deoxygenation rate coefficients of 0.60 on Outlet Creek (where stream flow is almost 100 percent effluent), and 0.05 on the North Raccoon River (which is over 10 miles downstream of the two discharges). The good results for BOD_u were expected since JRB's technical evaluation of the existing model did not indicate any problems with the BOD algorithms. In contrast, observed NH_3 concentrations were approximated only by using unusually high nitrification rates of 4.0 on Outlet

TABLE 4.4

INSTREAM PROCESS PARAMETER VALUES
EXISTING IOWA MODEL

	Calibration		Verification	
	Outlet Creek	North Raccoon	Outlet Creek	North Raccoon
Carbonaceous Oxygenation Rate	0.60	0.05	0.60	0.05
Nitrogenous Deoxygenation Rate	4.00	2.50	4.00	2.50
Tsivoglou Coefficient	0.32	2.00	0.32	2.00
ICE Factor	1.00	1.00	0.70	0.05
O_2 uptake by Nitrification (mg O_2/mg NH_3)	4.57	4.57	4.57	4.57

Figure 4.2.
Outlet Creek
Calibration
September 1981 Data
Existing Iowa Model

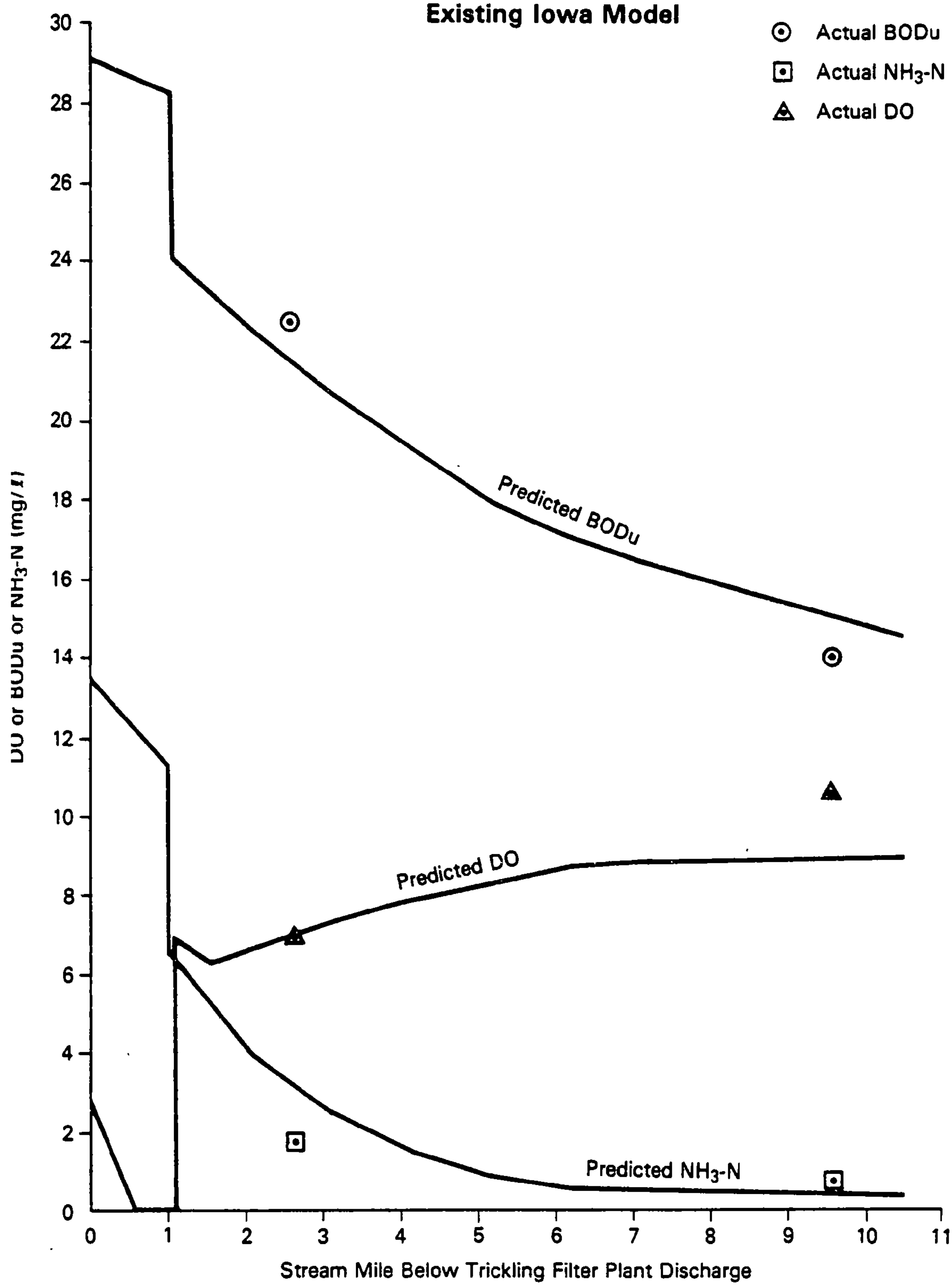


Figure 4.3.
North Raccoon River
Calibration
September 1981 Data
Existing Iowa Model

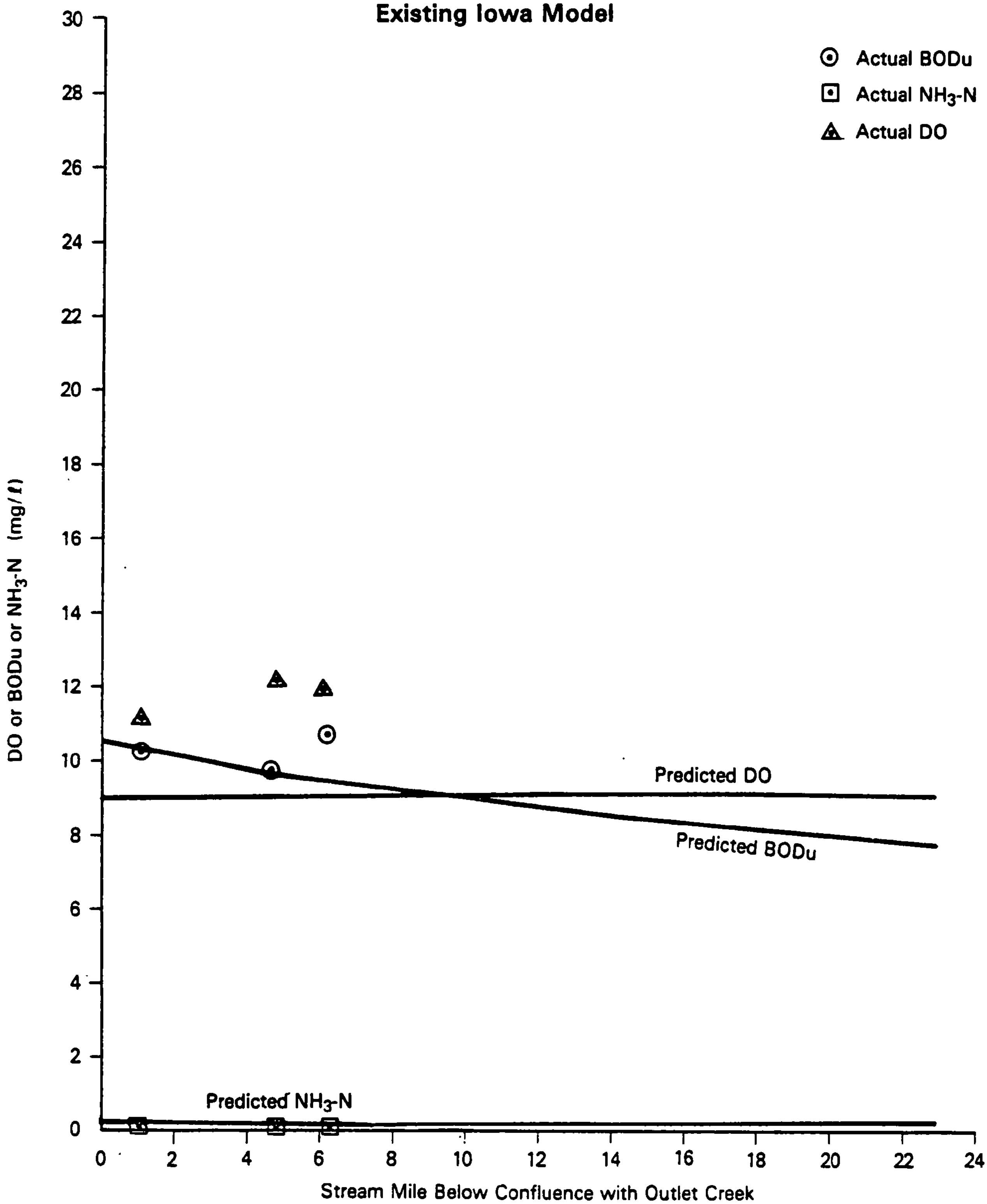


TABLE 4.5
COMPARISON OF RELATIVE ERROR
STATISTICS FOR EACH MODEL

		CALIBRATION						VERIFICATION		
		SAMPLING STATION						SAMPLING STATION		
PARAMETER	MODEL	1	2	4	5	6	7	3	5	8
DO	Existing Iowa	0.0	.013	.161	.185	.259	.240	.365	1.11	1.55
	Modified Iowa	0.0	.134	.098	.056	.008	.075	.022	.165	.011
	QUAL II	.001	.146	.164	.094	.006	.084	.050	.165	.138
BOD_u	Existing Iowa	.143	.040	.070	.040	.033	--	.074	.697	2.09
	Modified Iowa	.143	.053	.057	.020	.016	--	.089	.697	2.09
	QUAL II	.123	.033	.032	0.0	.047	--	.004	.658	1.96
NH_3-N	Existing Iowa	0.0	.742	.582	1.00	.231	.655	.350	1.17	1.03
	Modified Iowa	0.0	1.10	.766	.400	.025	.310	.285	0.0	.255
	QUAL II	.176	1.03	.239	2.85	.974	.172	.430	.126	.441

TABLE 4.6
COMPARISON OF STANDARD ERROR
STATISTICS FOR EACH MODEL

	CALIBRATION			VERIFICATION		
PARAMETER	EXISTING IOWA	MODIFIED IOWA	QUAL II	EXISTING IOWA	MODIFIED IOWA	QUAL II
DO	2.49	0.89	1.24	12.1	1.12	1.44
BOD_u	0.94	0.95	0.67	3.93	3.95	3.54
NH_3-N	0.70	1.03	0.94	5.01	3.17	4.82

Creek and 2.5 on the North Raccoon River. This force-fitting of NH_3 values resulted in a significant undersimulation of DO, even when extremely high Tsivoglou C values were used to increase the reaeration rate beyond expected levels. Previous modeling studies in Iowa determined that the Tsivoglou C coefficient should be set at 0.11 when flows are below 15 cfs, as in this case (2).

The unrealistic rate coefficients established during the calibration of the existing model resulted in extremely poor model verification results. In accordance with proper procedures, all rate coefficients were held constant for both the calibration and verification model runs (see Table 4.4). The only instream process parameters that had to change were ice cover factors and, of course, flow, velocity and water temperature data. During the January 1978 verification period, the existing Iowa model significantly overpredicted BOD_u, NH_3 and DO in both Outlet Creek and the North Raccoon River (see Figures 4.4 and 4.5). The poor BOD_u simulation can be attributed more to the absence of effluent BOD data for the day preceding instream sampling than to errors in the calibrated deoxygenation rate coefficient or its temperature correction function. Daily effluent data collected from the POTW on January 16, 17, and 18 showed wider variations in BOD_u concentrations (27 to 48 mg/l) than in NH_3 (21 to 24 mg/l) or DO (7.3 to 9.1 mg/l). Consequently, the BOD simulation should be the most affected by the lack of appropriate model input data. The oversimulation of NH_3, even though the nitrification rate was probably calibrated too high, can be explained by the inadequate temperature correction function in the existing model. The 0°C water temperatures observed during the January sampling event resulted in zero nitrification being simulated by the model. The observed data indicate, however, that nitrification was occurring since concentrations of NH_3 declined more than could be explained by dilution processes. The existing model's calibration/ verification results confirm JRB's conclusions that the existing model needs to be improved by: 1) including algal uptake of NH_3 in order to simulate the rapid decline in NH_3 without exerting an unrealistic oxygen demand; 2) adding the effects of algal photosynthesis and respiration on DO concentrations; and 2) using a more up-to-date temperature correction function for nitrification rates.

Figure 4.4.
Outlet Creek
Verification
January 1978 Data
Existing Iowa Model
Ice Cover

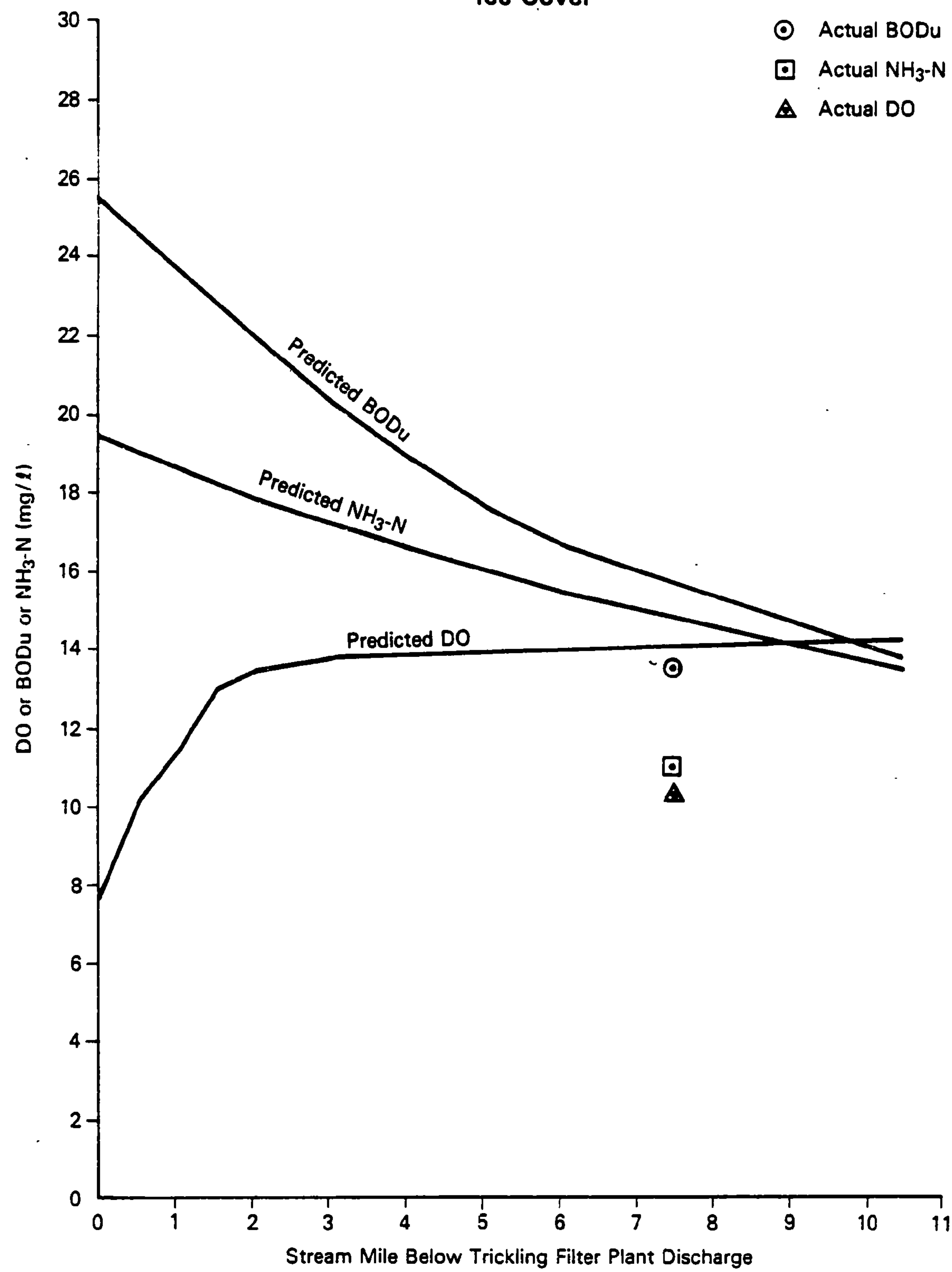
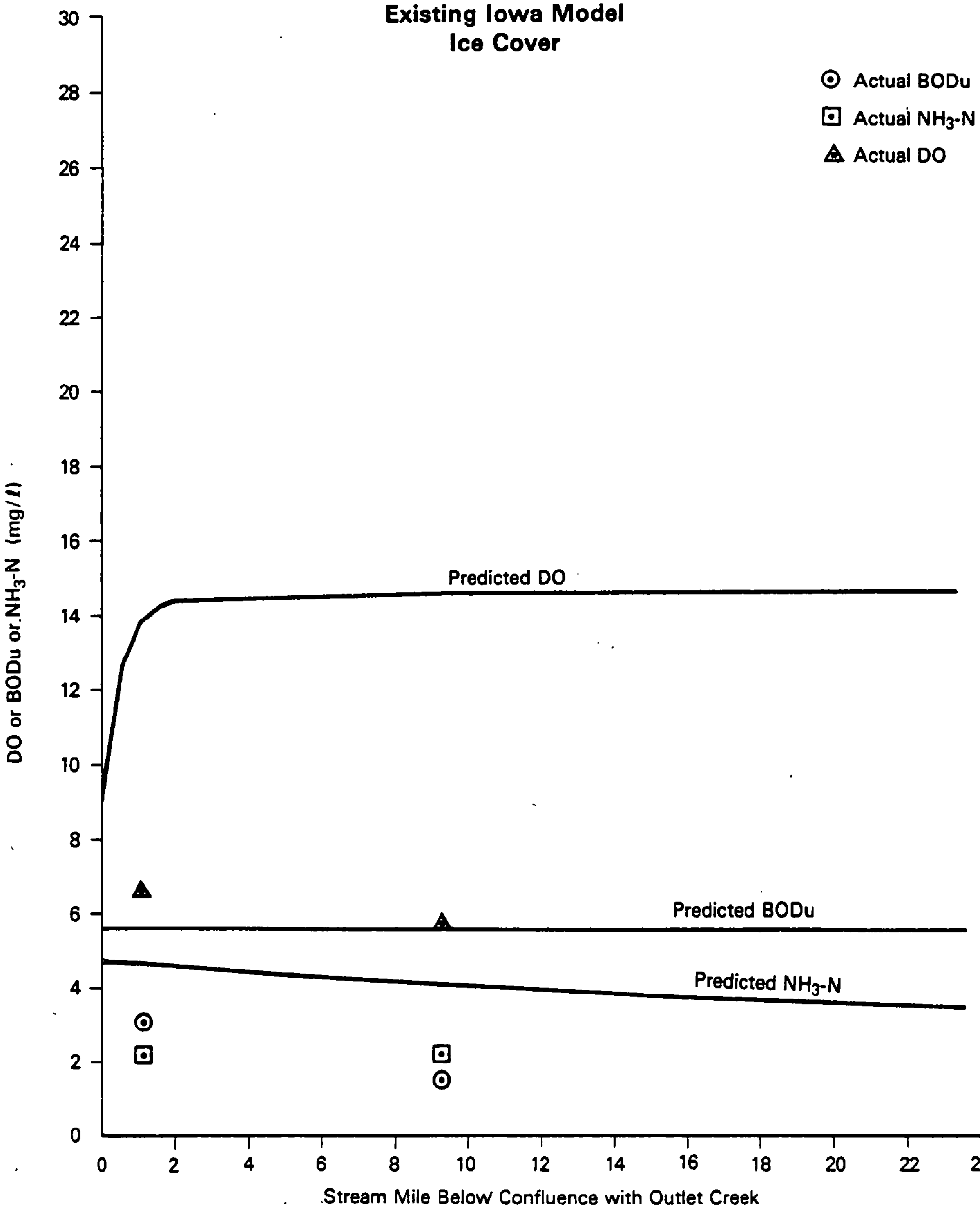


Figure 4.5.
North Raccoon River
Verification
January 1978 Data
Existing Iowa Model
Ice Cover



4.2.2 Modified Iowa Model Calibration/Verification

Table 4.7 shows the final calibration dataset of instream process parameters for the modified Iowa model. Figures 4.6 and 4.7 contain the plots of observed versus predicted concentrations of BOD_u, NH_3-N and DO for Outlet Creek and the North Raccoon River during the September 1981 sampling event. Tables 4.5 and 4.6 present the statistical measurements of goodness-of-fit. The same deoxygenation rates obtained through calibration with the existing model were also used in the modified Iowa model but slightly lower BOD concentrations were predicted because JRB added a term to the modified model which reduces nitrification rates when DO concentrations fall to low levels. In both models, values of BOD, NOD and DO deficit are calculated for each stream section. After these values are computed, the models check to see if the DO deficit exceeds the saturated DO level. If it does, they internally reduce the predicted removal of BOD and NOD to account for the insufficient oxygen levels, and set the DO deficit equal to the DO saturation value. In the existing model, calculations for both sections of the reach between the municipal plant and industrial lagoon discharges predicted an insufficient oxygen supply, and BOD and NOD removals were reduced proportionately in both sections. In the modified model, an insufficient oxygen supply was predicted only in the first section of the reach. Because the predicted oxygen concentration entering the second section was zero, the K_N value was greatly reduced by the newly added nitrification rate equation. The reduction in the nitrification rate caused so little oxygen demand that it did not result in a DO deficit less than the DO saturation value. Consequently, the deoxygenation rate for that section did not have to be reduced and the predicted BOD removal was greater than the removal in the existing model.

In comparison with the existing model results, the NH_3 calibration with the modified model was almost as good on Outlet Creek and much better on the North Raccoon River. This improved NH_3 calibration was achieved using more reasonable nitrification rates because of the preferential uptake of ammonia included in the modified model. The DO simulation on both Outlet Creek and the North Raccoon River was so much better than the existing model results that the reaeration coefficient did not have to be adjusted beyond the value

TABLE 4.7

INSTREAM PROCESS
PARAMETER VALUES
MODIFIED IOWA MODEL

MODEL PARAMETER	CALIBRATION OUTLET CREEK	CALIBRATION NORTH RACCOON RIVER	VERIFICATION OUTLET CREEK	VERIFICATION NORTH RACCOON RIVER
Algal Preference for NH_3	0.85	0.85	0.0	0.0
mg N/ug Chlorophyll-a	0.007	0.007	0.007	0.007
Nitrogen Half-saturation Constant (mg/l)	0.20	0.20	—	—
Phosphorus Half-saturation Constant (mg/l)	0.05	0.05	—	—
Light Half-saturation Constant (kcal/m^2 - s)	0.0035	0.0035	—	—
ug Chlorophyll-a/mg Algae	50.00	50.00	50.00	50.00
O_2 Production by Algae	1.63	1.63	1.63	1.63
Carbonaceous Deoxygenation Rate	0.60	0.05	0.60	0.05
Nitrogenous Deoxygenation Rate	2.50	1.00	2.50	1.00
Tsivoglou Coefficient	0.11	0.11	0.11	0.11
Maximum Algal Growth Rate	3.0	3.0	—	—
Algal Death Rate	0.24	0.24	—	—
Ice Factor	1.0	1.0	0.70	0.05
O_2 Uptake by Nitrification (mg O_2/mg NH_3)	4.33	4.33	4.33	4.33
Chlorophyll-a Concentration (ug/l)	400.0	259.0	5.0	5.00

Figure 4.6.
Outlet Creek
Calibration
September 1981 Data
Modified Iowa Model

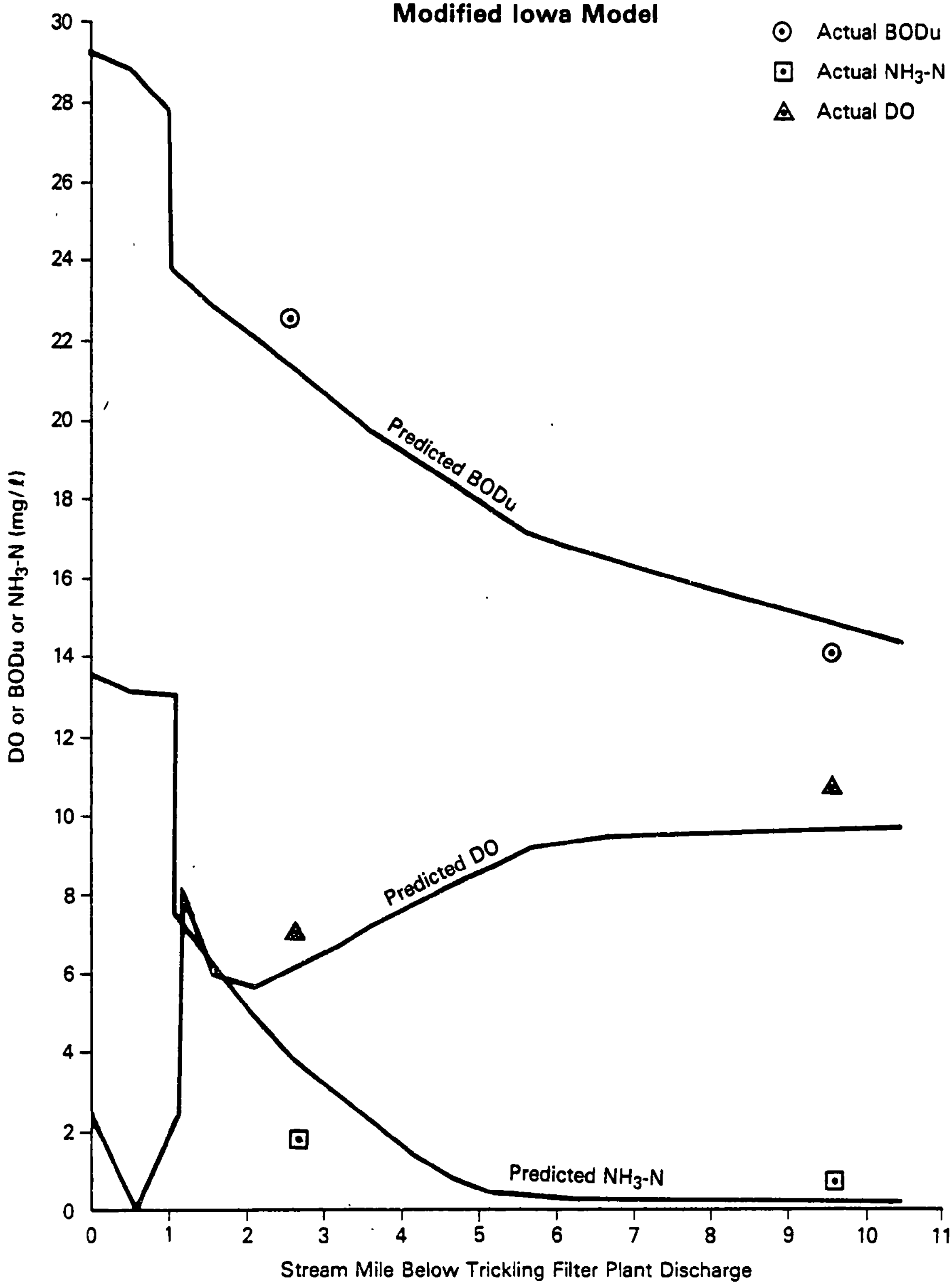
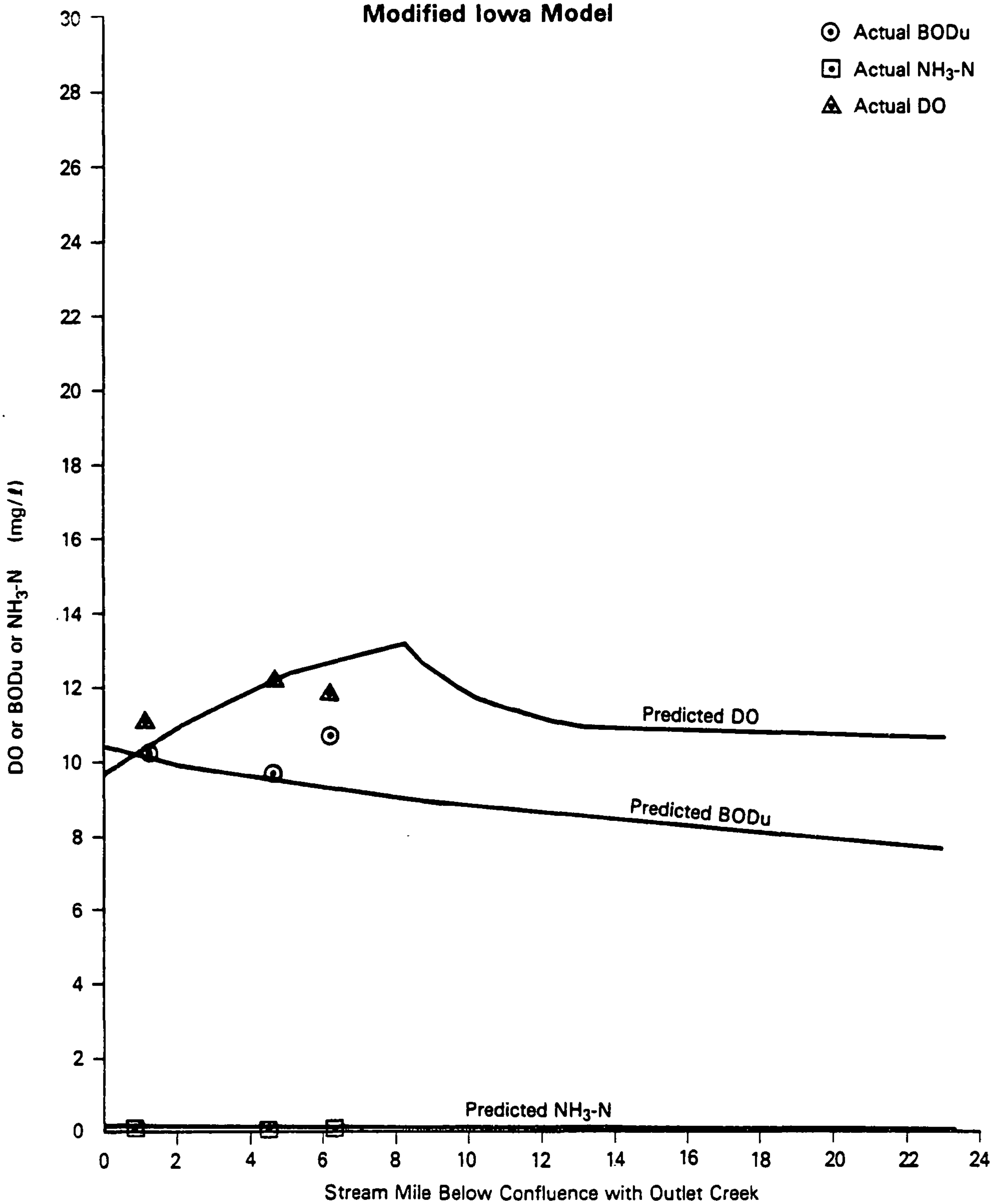


Figure 4.7.
North Raccoon River
Calibration
September 1981 Data
Modified Iowa Model



recommended for these low flow conditions. The improved DO calibration is attributable to the calibration of more realistic nitrification rates and the inclusion of algal effects on DO.

The January 1978 model results shown in Figures 4.8 and 4.9 and analyzed in Tables 4.5 and 4.6 confirm the calibration evidence that the modified model's rate coefficients are more realistic and, therefore, more verifiable than the existing model's values. The BOD_u simulation is, of course, equally as poor as the existing model predictions, but this can be explained in large part by the lack of appropriate BOD effluent data. The DO and NH_3 predictions are significantly improved over the existing model results for the winter period. The improvement in NH_3 is due to the new temperature correction function for nitrification, and the improvement in DO is attributable to the more reasonable reaeration values (Tsivoglou's Coefficient).

4.2.3 Vermont QUAL-II Model Calibration/Verification

Table 4.8 shows the final calibration dataset of instream process parameters for the Vermont QUAL-II model. Figures 4.10 through 4.15 contain the plots of observed versus predicted concentrations of BOD_u, NH_3-N, DO, NO_3, Organic N, Dissolved P, and Organic P for Outlet Creek and the North Raccoon River during the September 1981 sampling event. Tables 4.5 and 4.6 present the statistical measurements of goodness-of-fit for BOD_u, DO and NH_3. It is difficult to evaluate the calibration results of the QUAL-II model since the effluent data needed for proper operation of the model was completely missing and had to be estimated from literature values and historical data (see Section 4.1.2). The modified Iowa model is designed to simulate the impact of algae on DO and NH_3 without having inorganic N and P effluent data since algal growth is calculated outside the model using observed instream concentrations of these constituents. The Vermont QUAL-II model, however, calculates local algal growth rates within the program by routing point source discharges of N and P through the system. The lack of accurate effluent data for the two treatment facilities means that the QUAL-II calculations of photosynthetic DO production and algal uptake of ammonia will be hindered. The lack of effluent data also prevents any calibration of organic N, NO_3, dissolved P or organic P. Despite these problems, JRB attempted calibration of the Vermont QUAL-II model in order to demonstrate its capabilities.

Figure 4.8.
Outlet Creek
Verification
January 1978 Data
Modified Iowa Model
Ice Cover

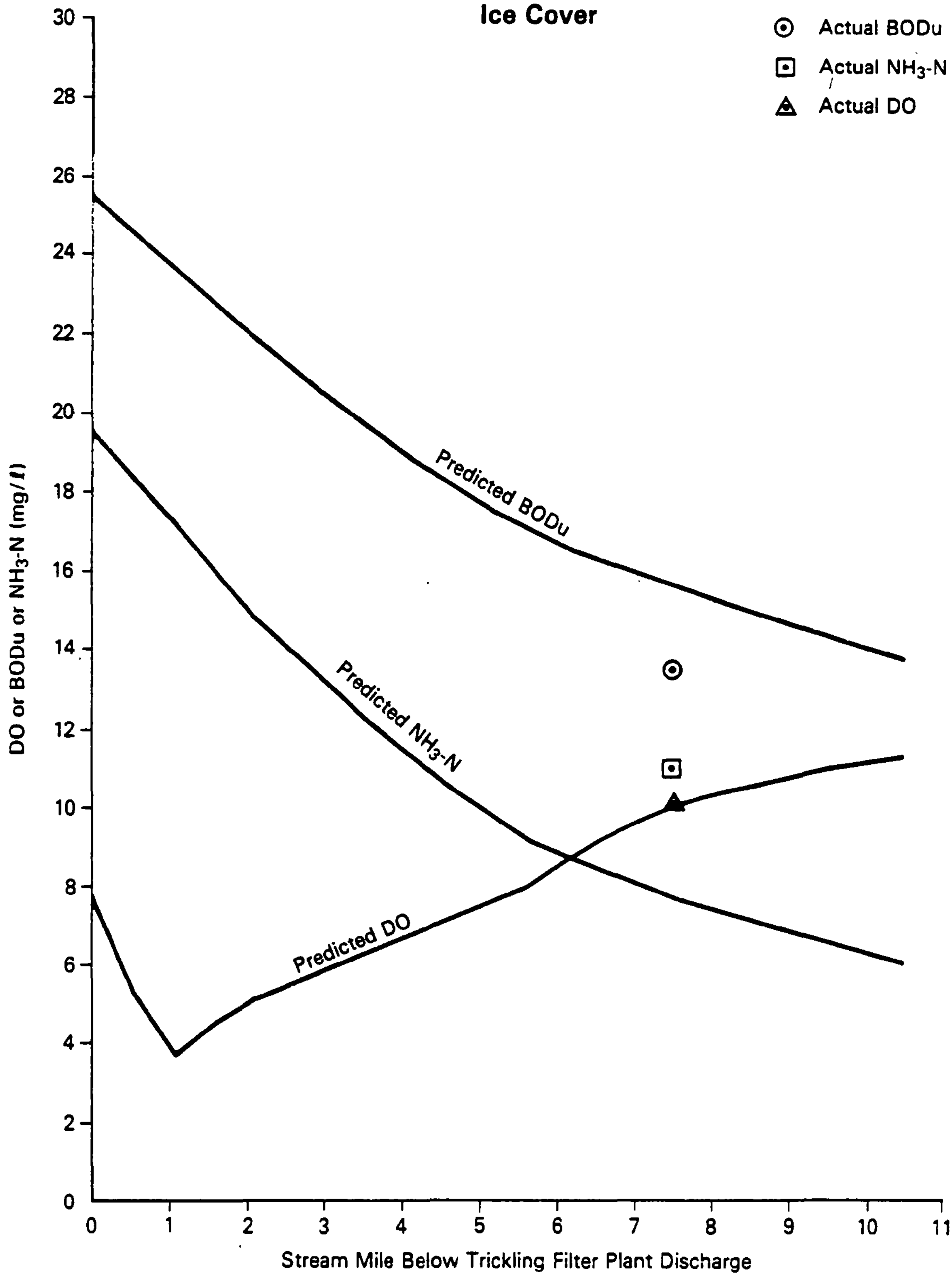


Figure 4.9.
North Raccoon River
Verification
January 1978 Data
Modified Iowa Model
Ice Cover

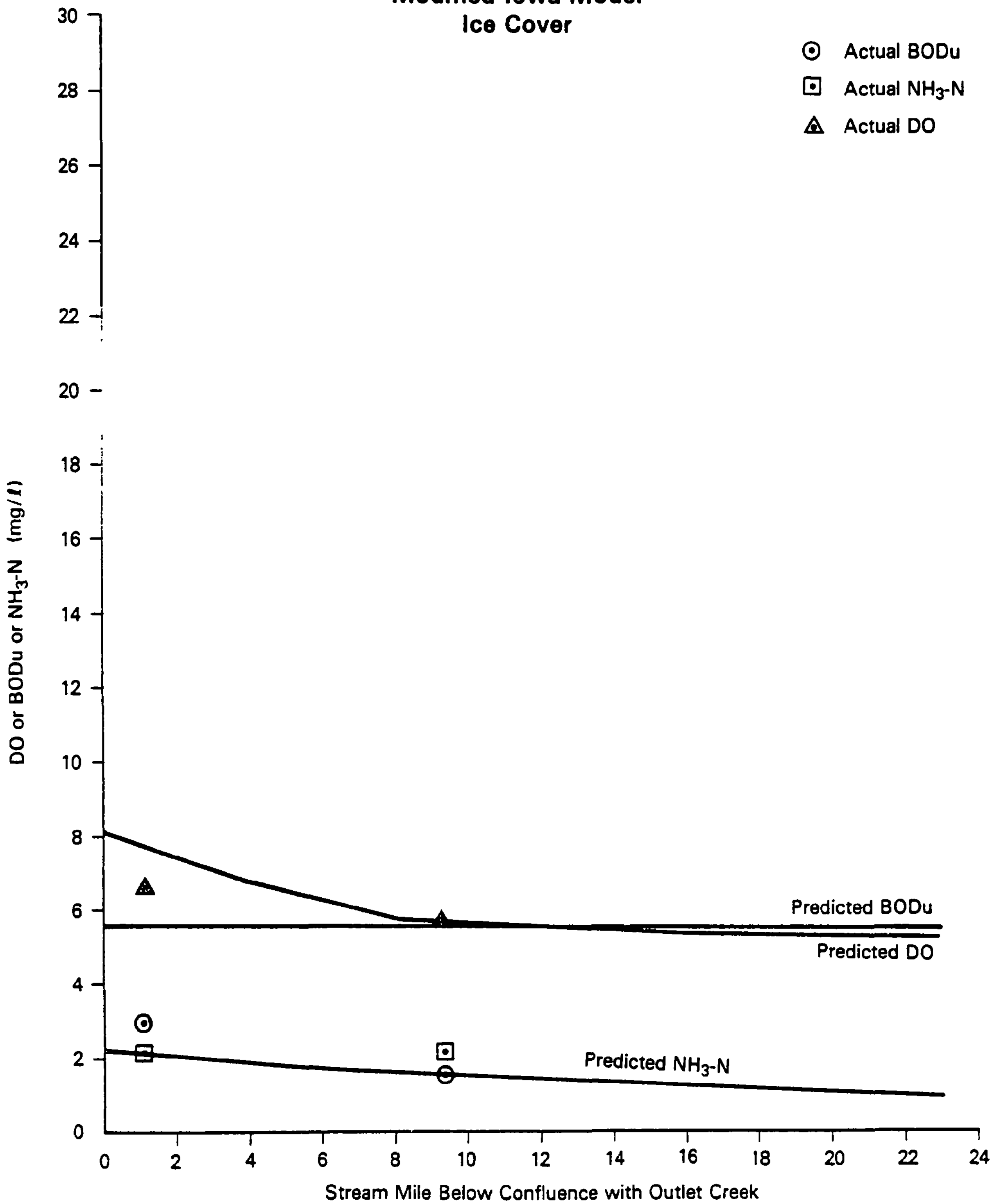


TABLE 4.8

INSTREAM PROCESS
PARAMETER VALUES
VERMONT QUAL II MODEL

MODEL PARAMETER	CALIBRATION		VERIFICATION	
	OUTLET CREEK	NORTH RACCOON RIVER	OUTLET CREEK	NORTH RACCOON RIVER
Algal Preference for NH_3	0.89	0.89	0.89	0.89
mgN/mg Algae	0.09	0.09	0.09	0.09
Nitrogen Half-saturation Constant (mg/l)	0.01	0.01	0.01	0.01
Phosphorus Half-saturation Constant (mg/l)	0.01	0.01	0.01	0.01
Light Half Saturation Constant (Langleys/min)	0.03	0.03	0.03	0.03
ug Chlorophyll-a/mg Algae	50.0	50.0	50.0	50.0
O_2 Production by Algae	1.63	1.63	1.63	1.63
Carbonaceous Deoxygenation Rate	0.553 0.869	0.061 0.191	0.553 0.869	0.061 0.191
Nitrogenous Deoxygenation Rate	4.00	2.50	4.00	2.50
Tsivoglou Coefficient	0.11	0.11	0.11	0.11
Maximum Algal Growth	4.00	4.00	2.00	2.00
Algal Death Rate	0.24	0.24	0.24	0.24
Ice Factor	--	--	0.70	0.05
Manning's n	0.035	0.035	0.035	0.035
O_2 Uptake by NO_3 (Oxidation to NO_2)	3.33	3.33	3.33	3.33
O_2 Uptake by NO_2 (Oxidation to NO_3)	1.00	1.00	1.00	1.00
O_2 Uptake by Algae	2.00	2.00	2.00	2.00
Algal Respiration Rate	0.275	0.275	0.275	0.275
Organic P Decay Rate	0.35	0.35	0.35	0.35
Organic P Settling Rate	0.00	0.00	0.00	0.00
Dissolved P Decay Rate	0.35	0.35	0.35	0.35
Organic N Decay Rate	0.01	0.01	0.01	0.01
BOD Settling Rate	0.00	0.00	0.00	0.00
Algal Settling Rate	0.50	0.50	0.50	0.50
Light Extinction Coefficient	0.01	0.01	0.01	0.01

Figure 4.10.
Outlet Creek
Calibration
September 1981 Data
Qual-II Model

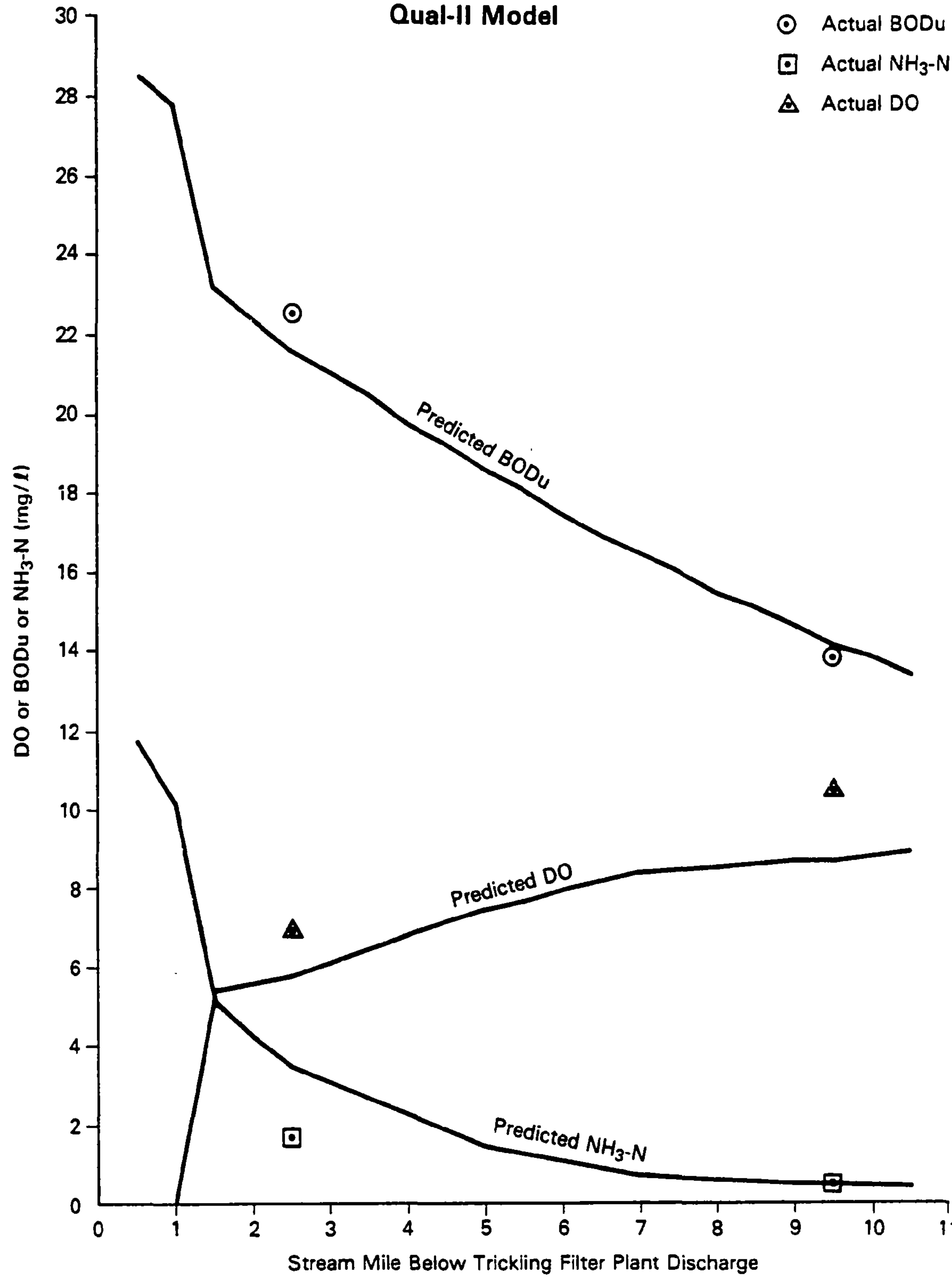


Figure 4.11.
Outlet Creek
Calibration
September 1981 Data
Qual-II Model

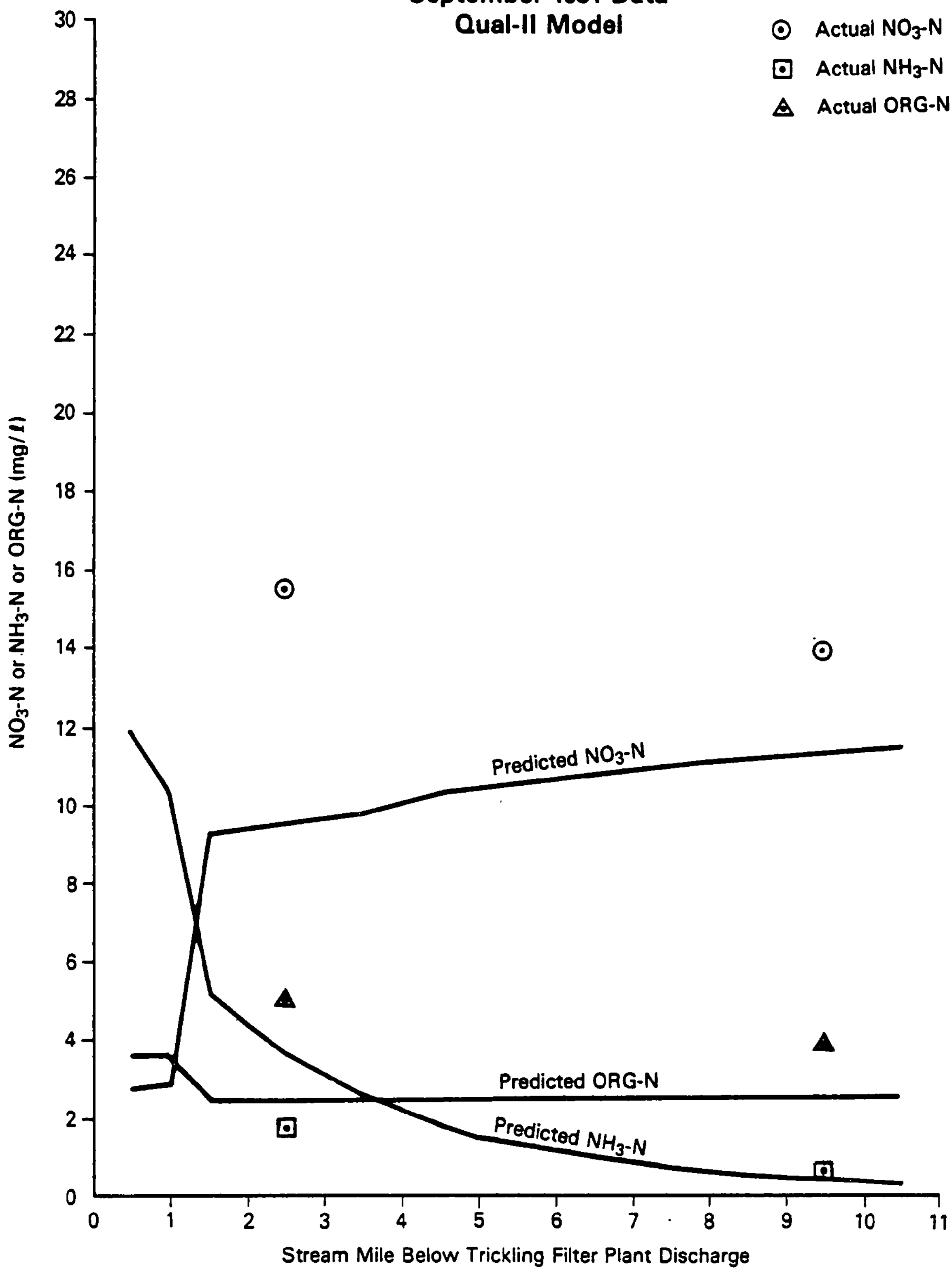


Figure 4.12.
Outlet Creek
Calibration
September 1981 Data
Qual-II Model

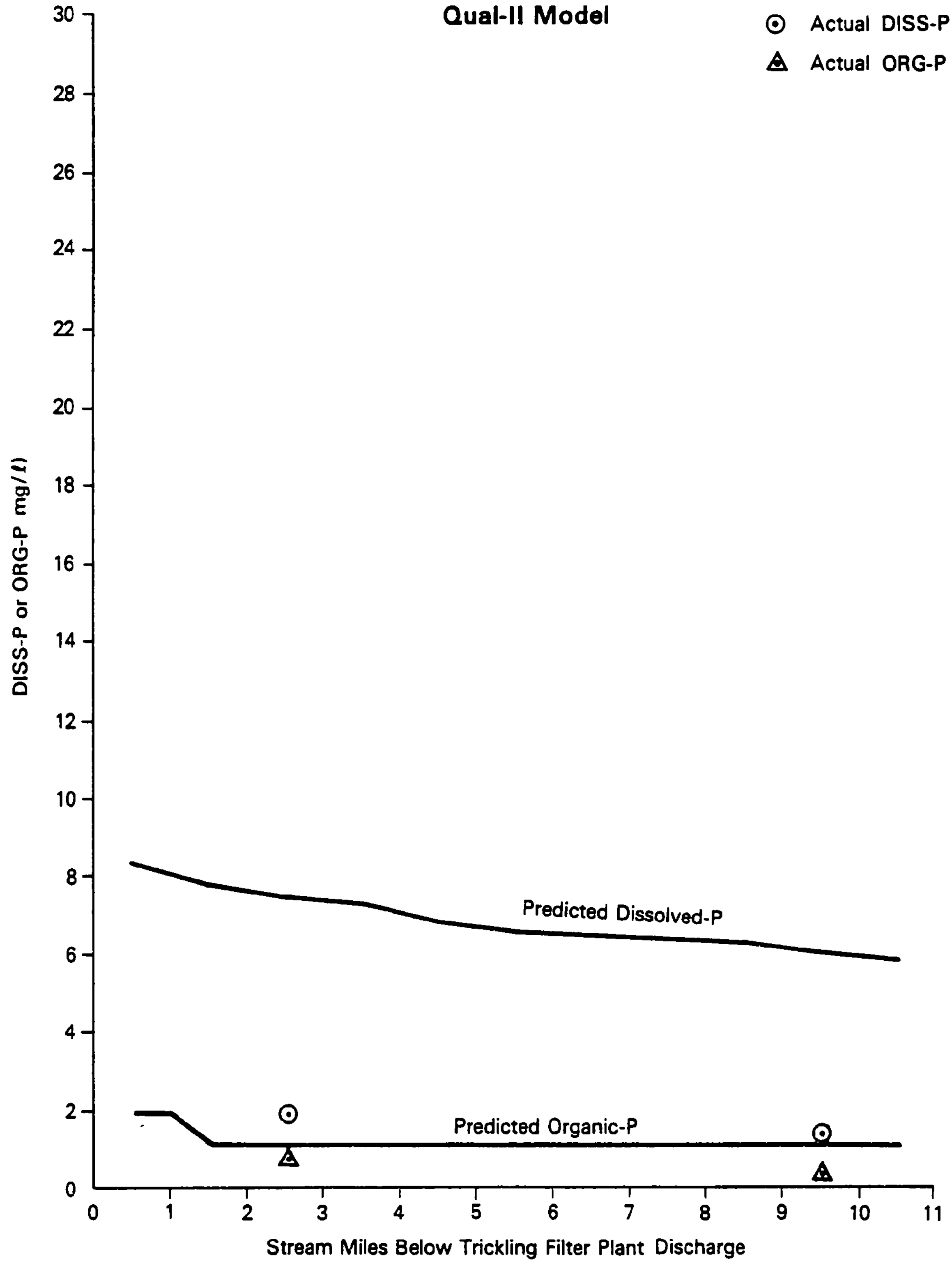


Figure 4.13.
North Raccoon River
Calibration
September 1981 Data
Qual-II Model

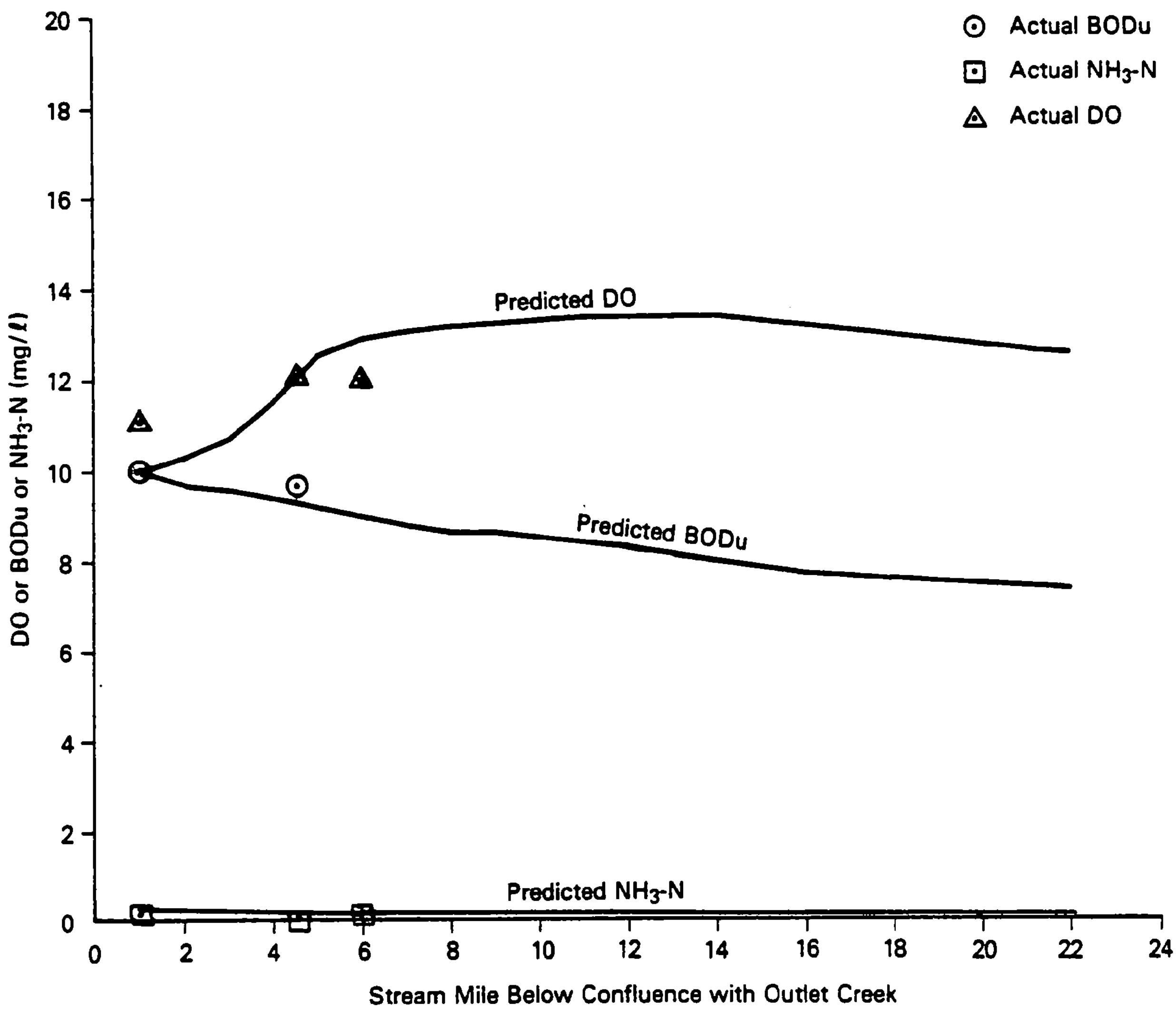


Figure 4.14.
North Raccoon River
Calibration
September 1981 Data
Qual-II Model

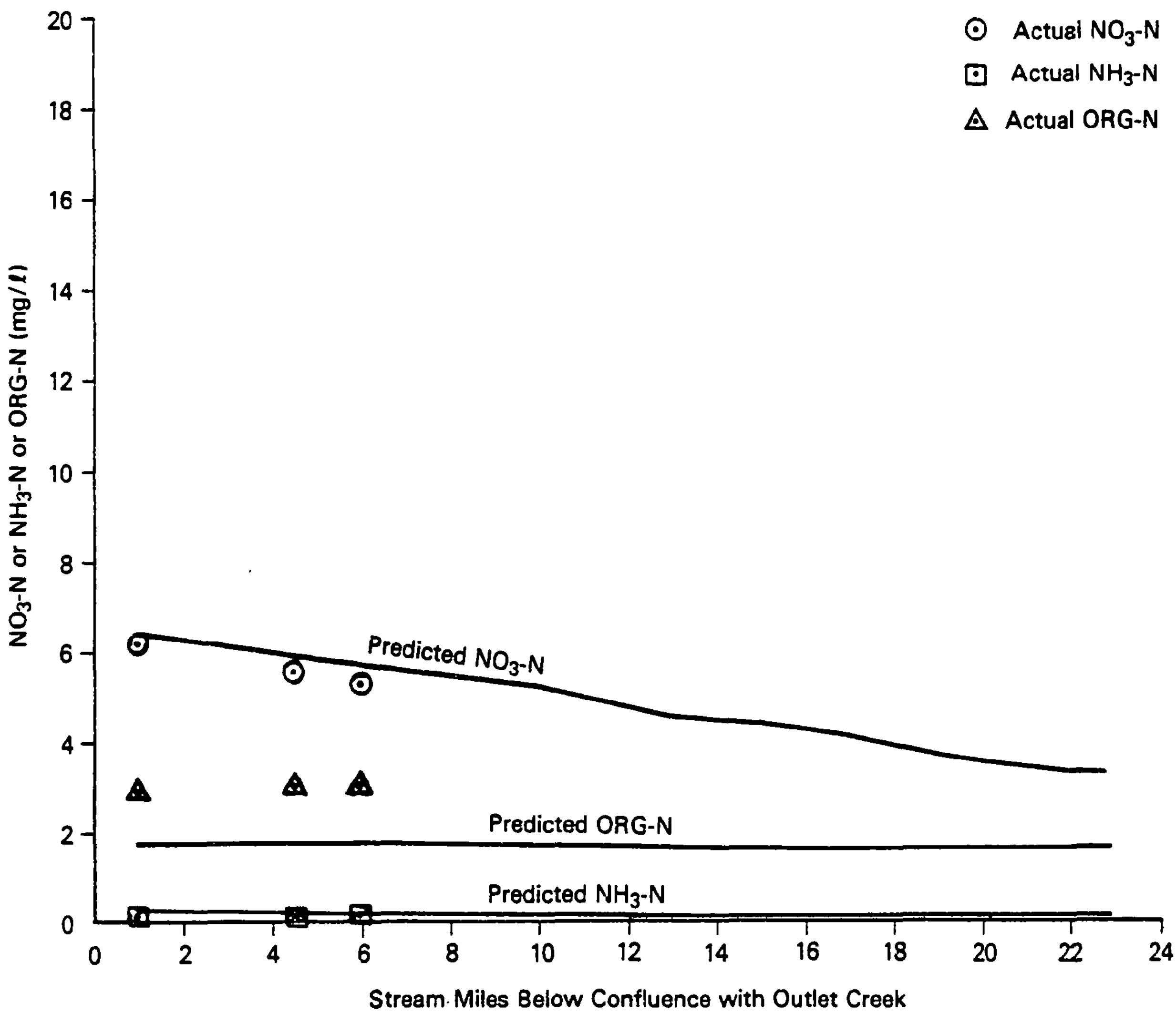
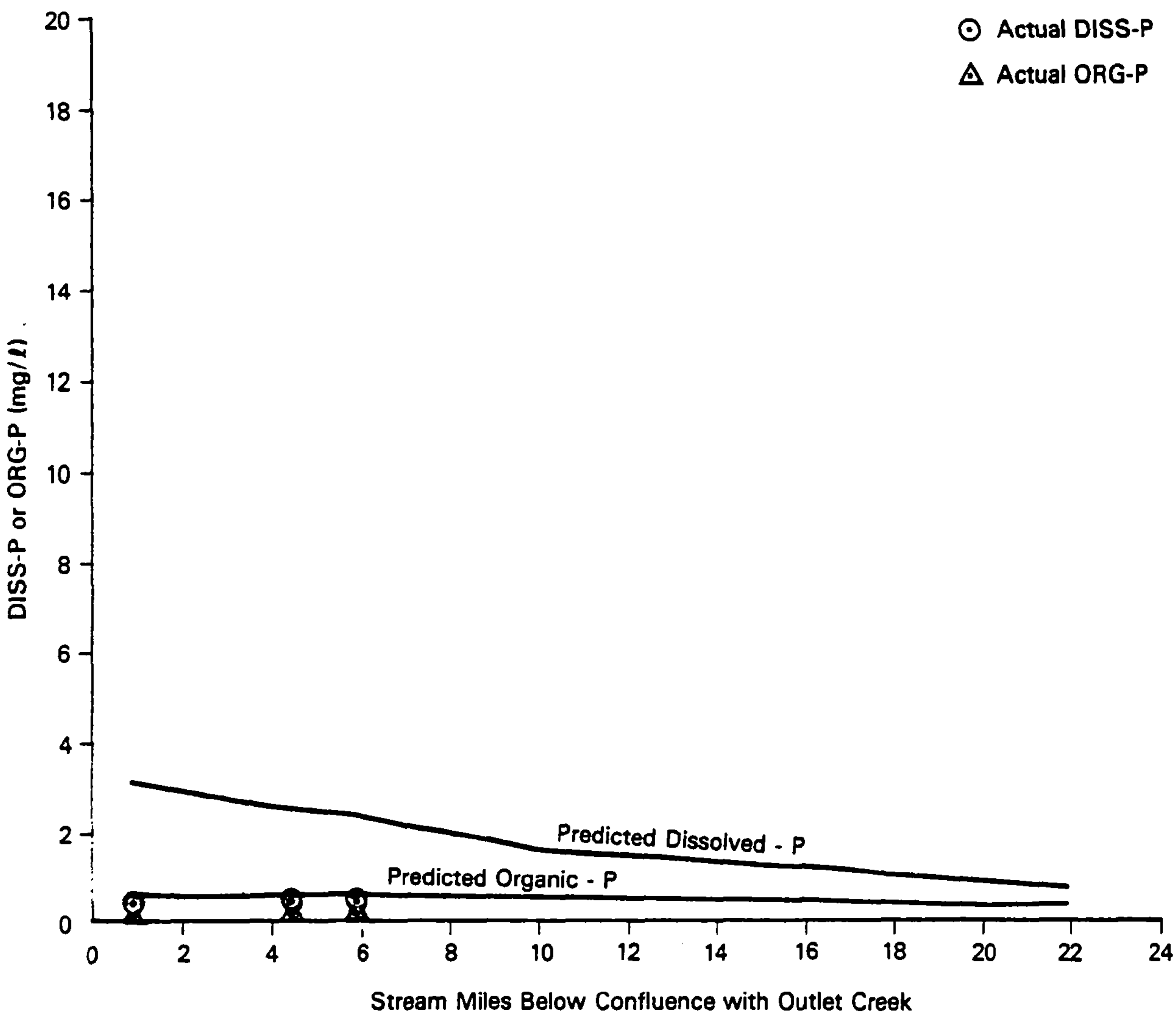


Figure 4.15.
North Raccoon River
Calibration
September 1981 Data
Qual-II Model



Deoxygenation rates which are slightly higher than those used in the existing and modified Iowa models were calibrated for QUAL-II. This resulted in slightly better BOD_u simulations.

The same high nitrification rates that were used in the existing model also had to be included in the QUAL II model in order to simulate the rapid decline in NH_3 concentrations which was observed during the summer sampling event. Unlike the modified Iowa model, the simulated uptake of NH_3 by algae was not adequate in QUAL-II to account for this decline. Since algal uptake of NH_3 is a function of algal growth, the differences in uptake simulation can be explained by the growth rates. The Vermont QUAL-II model uses a more sophisticated algal growth rate equation than the modified Iowa model. The primary difference in the computed values lies in the light term used in the two models. The modified Iowa model uses a simple Michaelis-Menton relationship that divides measured light intensity by the sum of the half-saturation constant and the light intensity. The QUAL-II model modifies the Michaelis-Menton light expression by the fraction of daylight hours in the day, the light extinction coefficient in the stream, and the mean stream depth. These values reduce the Michaelis-Menton expression by approximately one-half. This difference in algal growth calculations also explains the difference between the Michaelis-Menton half-saturation constants calibrated for the modified Iowa model and the QUAL-II model. Each constant represents the concentration at which that particular factor limits algal growth to half the maximal or "saturated" value. The nitrogen and phosphorus half-saturation constants in QUAL-II had to be set as low as possible in order to counterbalance the reduced light term and simulate as much algal growth as possible. The QUAL-II growth rate equation is more representative of actual conditions and could be substituted for the simple modified Iowa term, but it would require the additional calculation of a light extinction coefficient from empirical estimates of algal and non-algal extinction effects. It was JRB's opinion that the extra effort was not worthwhile, given the limitations of the modified model which does not even route nitrate, phosphorus, or chlorophyll-a concentrations.

The Vermont QUAL-II DO calibration was significantly better than the existing model but not quite as good as the modified Iowa model results. The improvement over the existing model is attributable to the inclusion of photosynthetic production of DO. Even though QUAL-II and the existing model used the same high nitrification rates, photosynthesis maintained observed DO levels without requiring the unreasonably high reaeration rates used in the existing model. The modified Iowa model had a slightly better DO simulation than QUAL-II primarily because of the lower nitrification rates calibrated for that model.

QUAL-II has a distinct advantage over the other two models in that it predicts daily minimum and maximum values of DO, as well as mean DO concentrations. This is valuable information because minimum DO concentrations have greater implications for receiving water quality than calculated mean values. Table 4.9 compares the simulated and observed diurnal DO fluctuations for the September 1981 sampling event. QUAL-II reproduced the range of daily values reasonably well, even though model input data were so faulty.

The January 1978 model results shown in Figures 4.16 and 4.17 and analyzed in Tables 4.5 and 4.6 confirm the calibration evidence that the QUAL-II model performed much better than the existing model but not quite as well as the modified Iowa model because of the lack of appropriate input data for the calibration of rate coefficients. The BOD_u simulation during the verification period was slightly better than the other models because of the higher rate coefficients calibrated for QUAL-II. The QUAL-II NH_3 verification was much better than the existing model even though the same nitrification rates were used. This result can be attributed to the use of the improved temperature correction function. The QUAL-II DO simulation in January was also much better than the existing model because of the more realistic reaeration rates calibrated for this model.

4.3 COST COMPARISONS

The selection of a model cannot be based solely upon the model's predictive accuracy but must also consider the cost of using the model. In this study, the additional simulation capabilities of the QUAL II model must be weighed against the additional costs of using the model. Incremental costs will be required for the laboratory analysis of more parameters and the increased personnel time needed to set up the run stream and calibrate the more complex model.

TABLE 4.9

CALIBRATED DIURNAL DO FLUCTUATIONS
VERMONT QUAL II MODEL

SAMPLING STATION		DO MIN	DO MAX	DO AVG
1	Observed	7.0	13.0	10.2
	Simulated	9.6	10.7	10.2
2	Observed	3.5	10.8	7.0
	Simulated	4.9	8.1	6.0
4	Observed	6.9	13.7	10.6
	Simulated	7.6	11.4	8.9
5	Observed	6.9	15.3	11.0
	Simulated	5.5	15.0	9.9
6	Observed	8.8	15.7	12.0
	Simulated	7.1	17.2	12.0
7	Observed	7.6	16.4	11.8
	Simulated	8.9	17.0	12.8

Figure 4.16.
Outlet Creek
Verification
January 1978 Data
Qual-II Model
Ice Cover

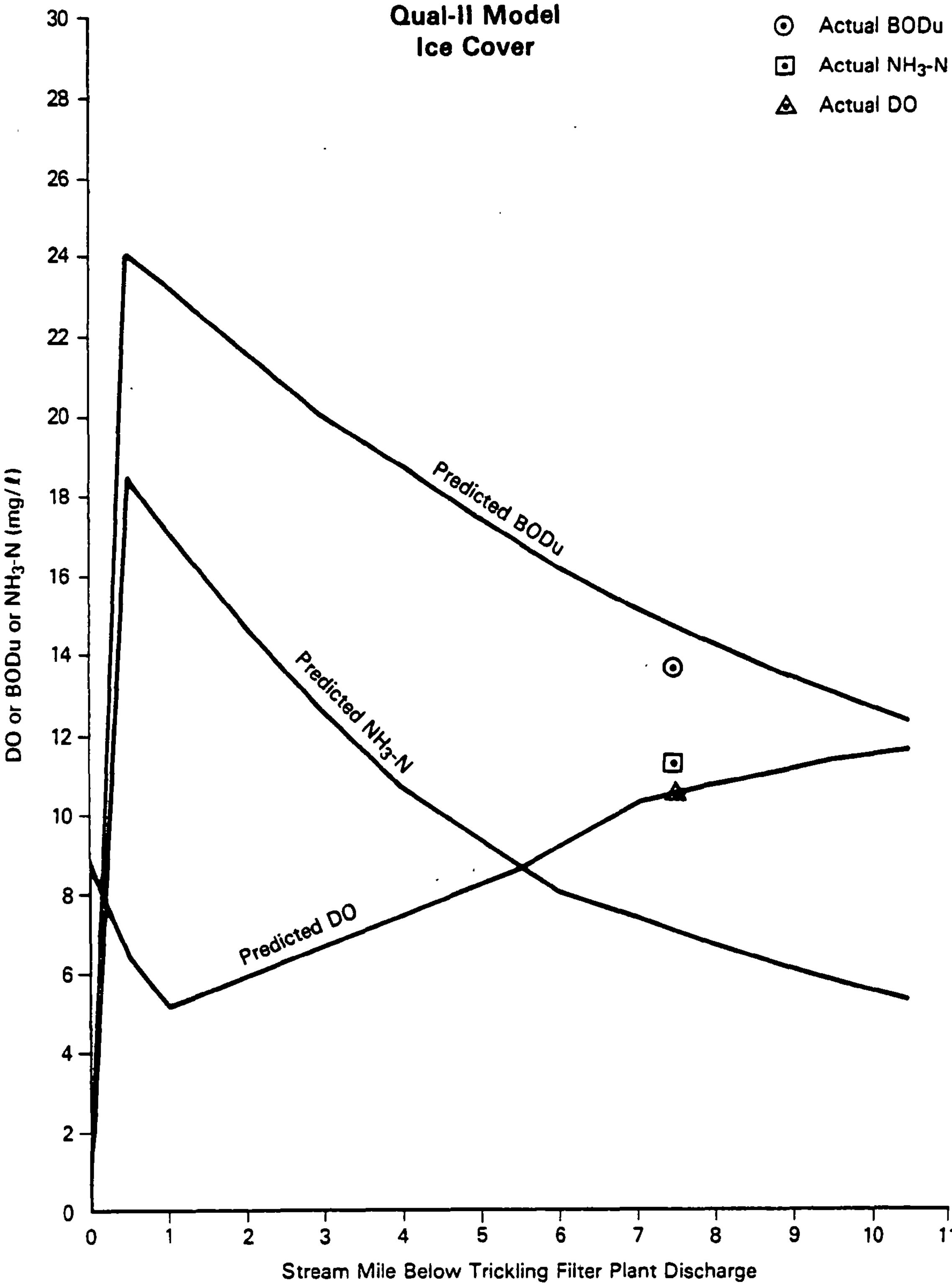
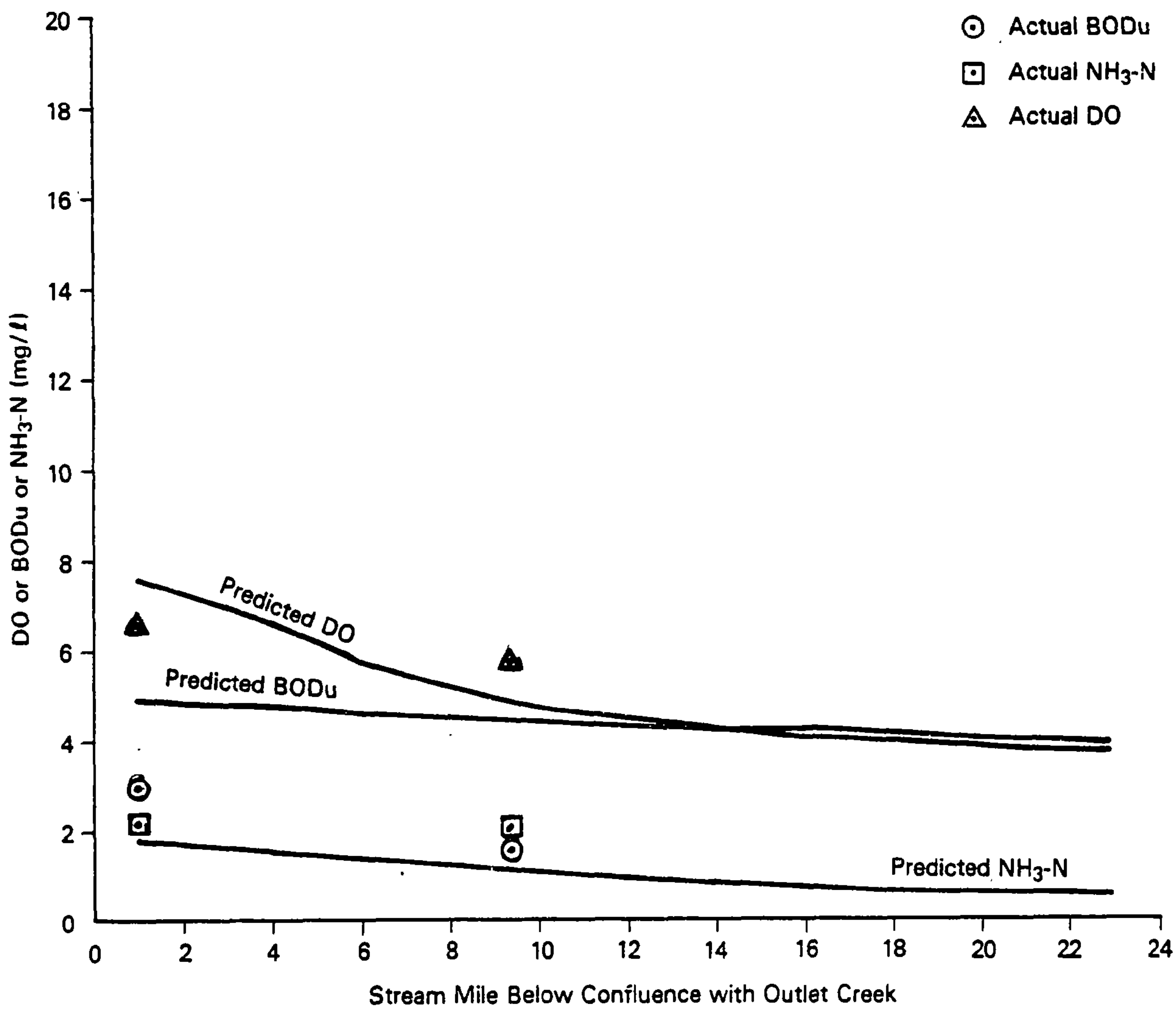


Figure 4.17.
North Raccoon River
Verification
January 1978 Data
Qual-II Model
Ice Cover



4.3.1 Sampling Costs

It is evident from Table 4.1 that the QUAL-II model requires more sampling data than the modified Iowa DEQ model. To properly calibrate the QUAL-II model, organic and inorganic nitrogen and phosphorus data are required for both the point source discharges and the stream samples. By contrast, the modified Iowa model does not require such data for point source discharges and uses only inorganic nutrient concentrations in the stream to calculate the local algal growth rates. Both models require chlorophyll-a measurements, but the modified Iowa model only needs stream samples.

The Hygienic Laboratory at the University of Iowa estimates laboratory costs at \$24, \$16, and \$10 per sample for the analysis of organic N, NO_3, and NH_3; dissolved P and organic P; and chlorophyll-a, respectively. The existing Iowa DEQ model requires only the NH_3-N measurements which cost approximately \$8 per effluent or stream sample. The modified Iowa model requires NO_3, NH_3, dissolved P, and chlorophyll-a instream measurements at a total cost of about \$34 per stream sample, and only \$8 per effluent sample for NH_3 analysis. The QUAL II model requires all analyses for both stream and point source samples at a total cost of \$50 per effluent or stream sample.

4.3.2 Personnel Time

Because of the additional data cards and input formats used in the QUAL II model, more personnel time is needed to establish the input data set. Table 4.10 lists the number of data cards used by both models.

TABLE 4.10
REQUIRED INPUT DATA CARDS

	QUAL II	MODIFIED IOWA	EXISTING IOWA
Cards per Reach	10	2	2
Cards per Headwater	2	1	1
Cards per Junction	1	1	1
Cards per Point Source	2	0	0
Other Required Cards	51	1	1

The "Other Required Cards" in the QUAL II model include cards which identify the parameters to be simulated, define the overall reach system, separate one type of data from another, and establish factors relating to algae, nitrogen and phosphorus. Clearly, the QUAL II model requires many more input statements than the other models. The existing and modified Iowa models also maintain a consistent card format while the QUAL II model employs card formats which vary throughout the data set. This increases the time required to code the input data and increases the chance of making a mistake while entering the data.

If the QUAL-II model is used to simulate algae and all forms of N and P, calibration of this model will also require more personnel time than the calibration of the modified Iowa model which predicts only DO, BOD_u, and NH_3. More rate constants must be calibrated for the more complex model including settling rates, bed activity, and benthic inputs which are not considered in the modified Iowa model.

4.3.3 Computer Costs

The difference in computer costs will be small in comparison to the difference in personnel time costs, but the QUAL II model will be the more expensive model. Computer costs can be broken down into connect costs, job costs, and storage costs. Connect costs are the charges for accessing the computer and are directly proportional to the time spent interacting with the computer. Connect time is highly variable and difficult to estimate, depending on the editing required for each job. Consequently, these costs will not be estimated here. It can be assumed, however, that connect charges will be higher for QUAL-II since it has a longer, more complicated run stream and requires more calibration runs. Storage costs include the expense of storing the model, input data files, and output data files on a disk or tape. These costs are virtually the same for each model. Job costs include the expense of CPU time and EXCP's used by the model (one EXCP = one block of data transferred into or out of the system). Table 4.11 shows job costs for a calibration run of each model at rates charged by the USEPA National Computer Center.

TABLE 4.11
JOB COSTS FOR MODEL CALIBRATION

MODEL	CPU TIME (SEC)	EXCPS	CPU COST (@ $425/hr)	EXCPS COST (@ $.74/1000)	JOB COST
Existing Iowa	0.40	3	$0.05	$0.00	$0.05
Modified Iowa	0.53	16	$0.06	$0.01	$0.07
QUAL II	1.86	63	$0.22	$0.05	$0.27

Despite the differences in cost, the total cost is so low that the QUAL II model will not be prohibitively expensive when compared to the modified Iowa model.

4.4 RECOMMENDATIONS FOR MODEL USE

After reviewing the above comparisons of the predictive accuracy and costs of each model, JRB recommends that use of the existing Iowa model be discontinued. This model has serious deficiencies which prevent the representation of instream processes and the prediction of receiving water quality. In its place, DEQ should consider using the modified Iowa model to identify those stream segments which appear to require advanced treatment facilities in order to meet State water quality standards. JRB recommends that the Vermont QUAL-II model be used for the final determination of NPDES permit limits for point source dischargers in these potential AWT streams. In comparing the expenses of the modified Iowa model to the Vermont QUAL-II, the differences in monitoring costs of $34 versus $50/sample and in computer costs of $0.07 versus $0.27/model run are not significant enough to merit any use of the modified Iowa model. The differences in personnel time are, however, quite substantial. Until DEQ staff become more familiar with QUAL-II, it will probably be more efficient to use the modified Iowa model for most waste load allocations and save QUAL-II for AWT determinations.

5. WASTE LOAD ALLOCATION ANALYSES

Waste load allocations are used to establish a quantitative relationship between a particular discharge and its impact on water quality. Knowledge of such a relationship makes it possible to compare incremental changes in the concentration of specific constituents in the receiving water. This capability allows identification of the maximum effluent concentration that can be discharged without violating a water quality standard. A determination can then be made of a cost effective level of treatment in order to meet this water quality standard (9).

The Iowa DEQ has developed future permit limits for the Storm Lake POTW based on waste load allocations developed with the existing Iowa model. These future permit limits assume a flow increase at the Storm Lake POTW from the current level of 2.74 cfs to 6.67 cfs. In order to meet Iowa water quality standards for DO and NH_3, the current NH_3 concentration must be reduced from 14 mg/l to 3 mg/l in the summer, and from 21 mg/l to 5 mg/l in the winter. Year around operation of nitrification facilities will be needed to meet these new NH_3 limits.

Using both the modified Iowa and Qual-II models, JRB conducted additional waste load allocation analyses for the Storm Lake POTW. Because inadequate monitoring data prevented calibration and verification of these models, new permit limits cannot be derived from these analyses. JRB conducted the study only to illustrate the various permit limits that can be developed based on different assumptions regarding the waste load allocation model, the critical flow conditions, ice cover, and water quality standards. The study was done with both seasonal and annual low flows to determine if appreciable cost savings could be achieved through the use of seasonal flows with the State of Iowa's seasonal NH_3 standards. The winter allocations were modeled with and without ice cover to illustrate the impact of the reduced reaeration capacity caused by ice cover. As a matter of interest, the summer and winter waste load allocations were also performed with proposed new EPA ammonia toxicity criteria.

With a few exceptions, the waste load allocations were generated using the same rate coefficients which were derived for each model through the calibration process. The exceptions refer to the algal growth and death rates, and the instream concentration of chlorophyll-a. These parameters were reduced for the waste load allocations because the industrial lagoon is not permitted to discharge during low flow (7Q10) conditions, and thus was not simulated in the waste load allocation.

Both models were calibrated for a summer situation when the lagoon was discharging, seeding the stream with algae and influencing all rate constants. With this significant discharge missing for waste load allocation purposes, it was necessary to reduce the algal growth and death rates, as well as the estimated instream concentration of chlorophyll-a.

Inflow values for the waste load allocations were changed to reflect the assumed seasonal or annual natural inflow, and point source water quality parameters were iteratively adjusted to determine the maximum allowable concentrations.

It should be noted that at the direction of the Iowa DEQ, the waste load allocations were based only on the water quality of the North Raccoon River and not on Outlet Creek, which is comprised of almost 100% effluent flow.

5.1 STATE NH_3 STANDARDS

The current seasonal Total NH_3 standards for the State of Iowa are 2 mg/l in summer (April 1 - November 1) and 5 mg/l in winter. These figures were derived from the USEPA "Red Book" criterion of 0.020 mg/l un-ionized ammonia (10). The fraction of instream total ammonia which is un-ionized and, therefore, toxic to fish and aquatic invertebrates, is related to the stream pH and temperature. As pH and temperature increase, the fraction of total ammonia which is un-ionized increases; hence, total ammonia is more toxic in summer than in winter. This is reflected in the Iowa standards, which were calculated by assuming typical seasonal values of pH and temperature.

5.2 PROPOSED EPA AMMONIA TOXICITY CRITERIA

The USEPA has recently issued a draft document providing ammonia criteria based on the toxicity of NH_3 to fish and invertebrates (11). This document proposes the use of an equation to calculate allowable ammonia concentrations as a function of pH and temperature. Assuming typical Iowa conditions of 1°C stream temperatures in winter and 26°C in summer with pH estimated at 7.5 for both seasons, the new EPA function results in a winter ammonia criterion of 12.8 mg/l total NH_3 and a summer criterion of 3.91 mg/l total NH_3. Both values are about double the numerical limits adopted by the State of Iowa. The EPA draft criteria must go through a complete agency review and public comment in the Federal Register before it is approved.

5.3 CRITICAL FLOW CONDITIONS

The streamflow used in a waste load allocation study is usually a low flow because it provides protection during "worst case" conditions. The Iowa DEQ uses the 7Q10 (one-in-ten-year, seven-consecutive-day) low flow as the basis for its modeling. Calculation of low flows is based on daily streamflow records collected by the U.S. Geological Survey at gaging stations throughout the State.

Both the annual and seasonal low flows at the Sac City gaging station on the North Raccoon River were calculated using the STORET computer package and flow data for the years 1959 through 1976. The STORET program uses the log Pearson type III distribution to calculate the 7Q10 values. The annual low flow was determined using every month's gaging data; the summer low flow was determined using data from April through October; and the winter low flow was determined using data from November through March.

Table 5.1 lists the annual and seasonal low flows generated by the STORET program and shows the calculated proportion of point source discharge and natural inflow.

TABLE 5.1 LOW FLOWS FOR WASTE LOAD ALLOCATION ANALYSES

LOW FLOW	STREAM FLOW (cfs)	POINT SOURCE DISCHARGE (cfs)	NATURAL INFLOW (cfs)
Annual 7Q10	4.45	3.40	1.05
Summer 7Q10	7.77	3.40	4.37
Winter 7Q10	2.94	3.40	0

The point source discharge value is the sum of the average flows from the treatment plants above the Sac City gaging station which discharge to the North Raccoon River and its tributaries. The discharge of the lagoon system on Outlet Creek was omitted because its operation is not permitted when stream flows are at or below the 7Q10 level. The difference between the total stream flow and the point source discharge was attributed to natural inflow, and was proportioned to the river and its tributaries by drainage area.

The results of the seasonal low flow calculations were unexpected, with the summer low flow exceeding the winter low flow. In most stream systems, the lowest flows occur during dry summer conditions. In the case of the North Raccoon River, however, the lowest flows are in winter, apparently due to extensive freezing of the shallow river. By using seasonal low flows, the predicted dilution capability of the river will be greater in summer and smaller in winter than that predicted using the annual low flow.

5.4 RESULTS OF MODIFIED IOWA WASTE LOAD ALLOCATION

The results of the waste load allocations using the modified Iowa DEQ model are provided in Tables 5.2 and 5.3, along with the future permit limits based on the results of the existing Iowa DEQ waste load allocation model.

As can be seen in Tables 5.2 and 5.3, the waste load allocations based on seasonal flows are virtually identical to those based on annual flows. This is due to the low natural inflows relative to the assumed discharge flow from the Storm Lake POTW. Larger stream systems with much higher flows usually

TABLE 5.2

RESULTS OF WASTE LOAD ALLOCATION ANALYSES
STATE NH_3 STANDARDS
MODIFIED IOWA MODEL

			EFFLUENT CONC. LIMITS			
			MODIFIED IOWA MODEL		EXISTING IOWA MODEL	
SEASON	7Q10	ICE COVER	BOD_5 (mg/l)	NH_3-N (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)
Summer	Annual	No	30	13	30	3
Summer	Seasonal	No	30	13	30	3
Winter	Annual	Yes	25	5	25	5
Winter	Annual	No	25	8	25	5
Winter	Seasonal	Yes	25	5	25	5
Winter	Seasonal	No	25	8	25	5

TABLE 5.3

RESULTS OF WASTE LOAD ALLOCATION ANALYSES
PROPOSED EPA TOXICITY CRITERIA
MODIFIED IOWA MODEL

			EFFLUENT CONC. LIMITS			
			MODIFIED IOWA MODEL		EXISTING IOWA MODEL	
SEASON	7Q10	ICE COVER	BOD_5 (mg/l)	NH_3-N (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)
Summer	Annual	No	30	13	30	3
Summer	Seasonal	No	30	13	30	3
Winter	Annual	Yes	25	5	25	5
Winter	Annual	No	25	21	25	5
Winter	Seasonal	Yes	25	5	25	5
Winter	Seasonal	No	25	20	25	5

exhibit a wider variation in seasonal flows. Because of this wider variation, significant differences in waste load allocations can result from using seasonal flows.

5.4.1 Summer Waste Load Allocation

The summer waste load allocation results based on the State of Iowa's water quality standards are shown in Table 5.2 and illustrated by Figures 5.1 and 5.2. These results indicate that the proposed NH_3 discharge limits may be too conservative and could be raised considerably without violating stream water quality standards. Future permit limits developed by DEQ using the existing model require that the Storm Lake POTW only discharge 3 mg/l NH_3 in the summer. In contrast to this result, the modified model shows that the discharge could be as high as 13 mg/l before the nitrogenous oxygen demand would result in a violation of the State Water Quality Standards for DO of 5 mg/l. The modified Iowa Model predicts that the allowable NH_3 effluent concentration in the summer is limited by the State of Iowa's water quality standard for DO rather than the NH_3 standard for toxicity.

The Storm Lake POTW is currently discharging an average NH_3 concentration of 14 mg/l in the summer and an average BOD concentration of 30 mg/l. These data are based on studies conducted by the University of Iowa's Hygienic Laboratory for the Iowa DEQ. Using the results of the modified Iowa waste load allocation model, the allowable effluent concentration of 13 mg/l is almost as high as the current level.

5.4.2 Winter Waste Load Allocation

In winter, the waste load allocations are dominated by the ice cover, as is shown in Table 5.2. Ice cover on streams during winter low flow conditions reduces the surface area of the air-water interface through which reaeration occurs. In order to represent this effect in the models, reaeration rates must be multiplied by an ice cover factor. The waste load allocation analyses presented here illustrate the importance of correctly estimating the extent of

Figure 5.1.
North Raccoon River
Waste Load Allocation
Annual 7Q10 - Summer
Modified Iowa Model

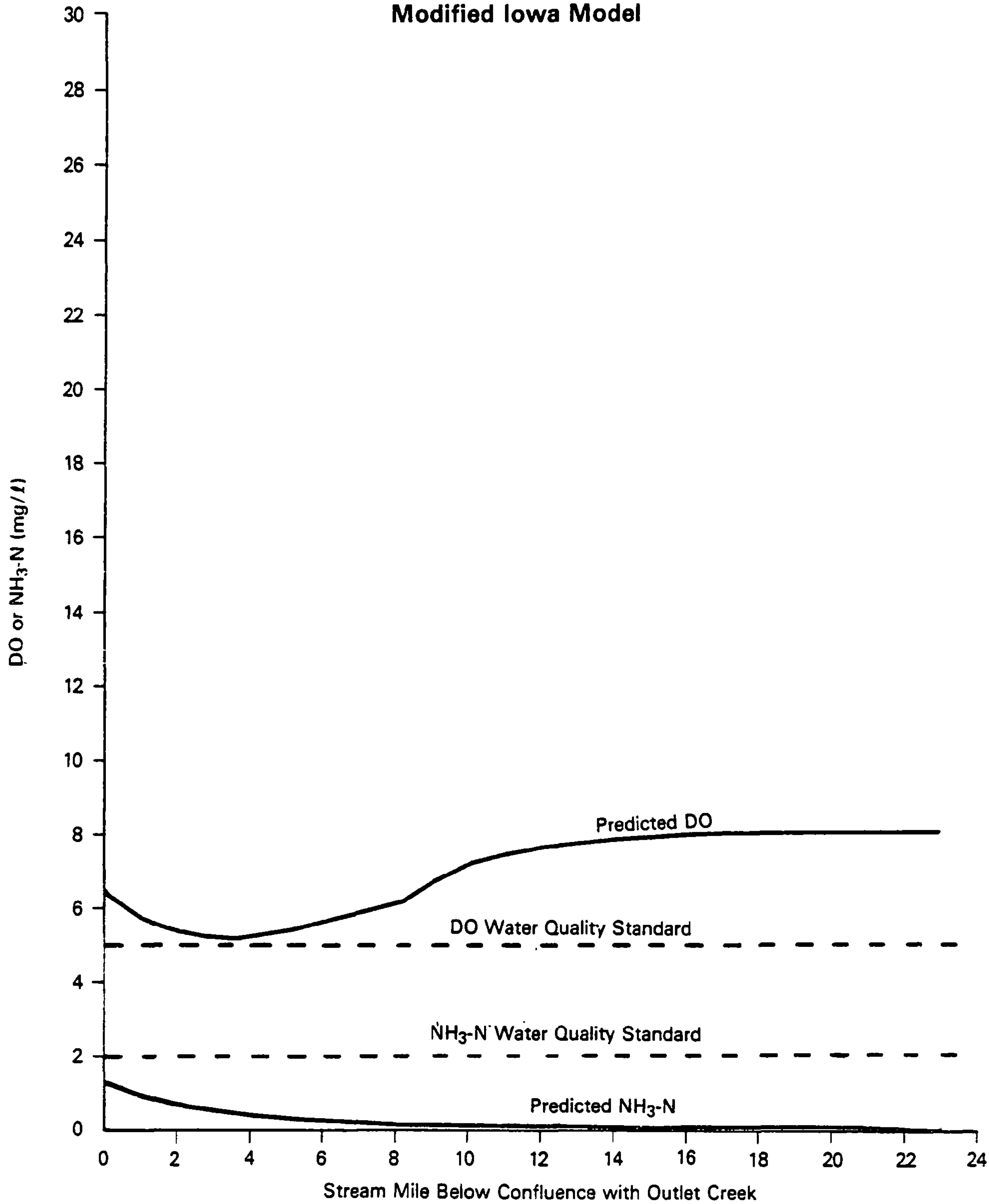
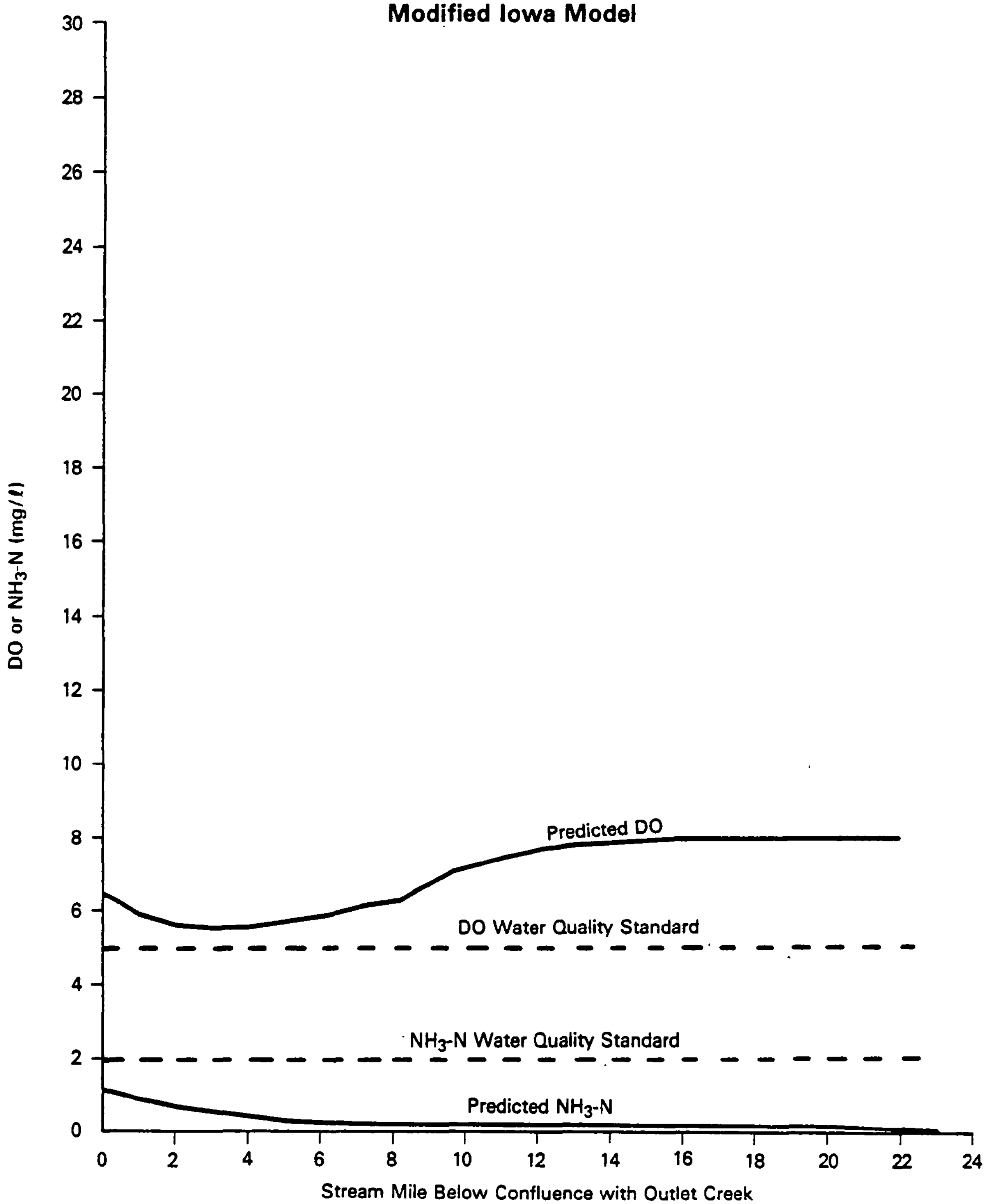


Figure 5.2.
North Raccoon River
Waste Load Allocation
Seasonal 7Q10 - Summer
Modified Iowa Model



ice cover. The most reliable estimates are based on extensive field observations. On Iowa streams, TenEch calibrated a range of values from 0.01 to 0.40 for the ice cover factor representative of complete ice cover but recommended the use of 0.05 (2). In order to test the effect of this recommended value on waste load allocations, JRB performed the analyses once with an ICE factor of 0.05 (assuming complete ice cover) and again for 1.0 (assuming zero ice cover).

The difference ice cover can make in the winter waste load allocations can be seen by comparing winter conditions with 100 percent ice cover, illustrated by Figures 5.3 and 5.4, with winter conditions and no ice cover, illustrated by Figures 5.5 and 5.6. Under 100 percent ice cover conditions, the DO in the North Raccoon River exhibited a continual decrease as the stream flowed toward Sac City. JRB had to lower the NH_3 discharge concentration until the DO concentrations in the stream remained above the Iowa water quality standard of 5 mg/l. The instream concentration of DO limited the POTW's effluent NH_3 concentration when ice was present on the stream.

The modified Iowa model's waste load allocation with complete ice cover predicts that, for both seasonal and annual low flows, the discharge levels of NH_3 would not differ from the current future permit limits determined using the existing Iowa model. Both models estimated that a discharge of 5 mg/l would be required to meet Iowa water quality standards.

Without the reduced reaeration imposed by ice cover, the modified model indicates that NH_3 discharge concentrations could be increased somewhat, as illustrated in Figures 5.5 and 5.6. Under no ice conditions, Table 5.2 shows that the Storm Lake POTW could discharge up to 8 mg/l NH_3. JRB's study suggests that the State NH_3 standard for toxicity limits the effluent NH_3 concentrations in winter when no ice cover is present, in contrast to the ice cover situation when the State DO standard limits the concentrations.

According to Iowa DEQ staff, the Storm Lake POTW currently discharges an average of 21 mg/l of NH_3 during the winter. Waste load allocation results from both the existing and modified Iowa models, with and without ice cover

Figure 5.3.
North Raccoon River
Waste Load Allocation
Annual 7Q10 - Winter
Modified Iowa Model
Ice Cover

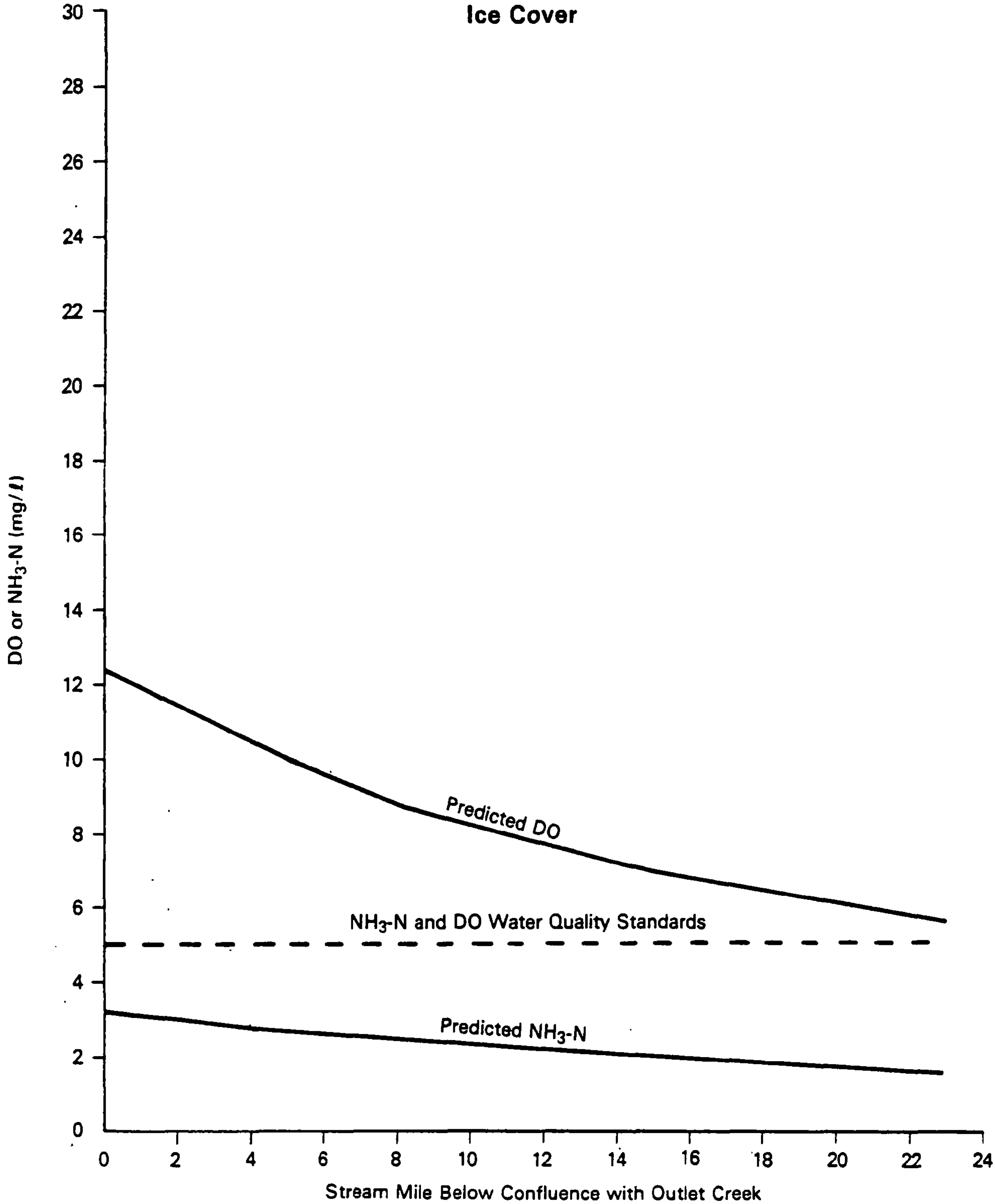


Figure 5.4.
North Raccoon River
Waste Load Allocation
Seasonal 7Q10 - Winter
Modified Iowa Model
Ice Cover

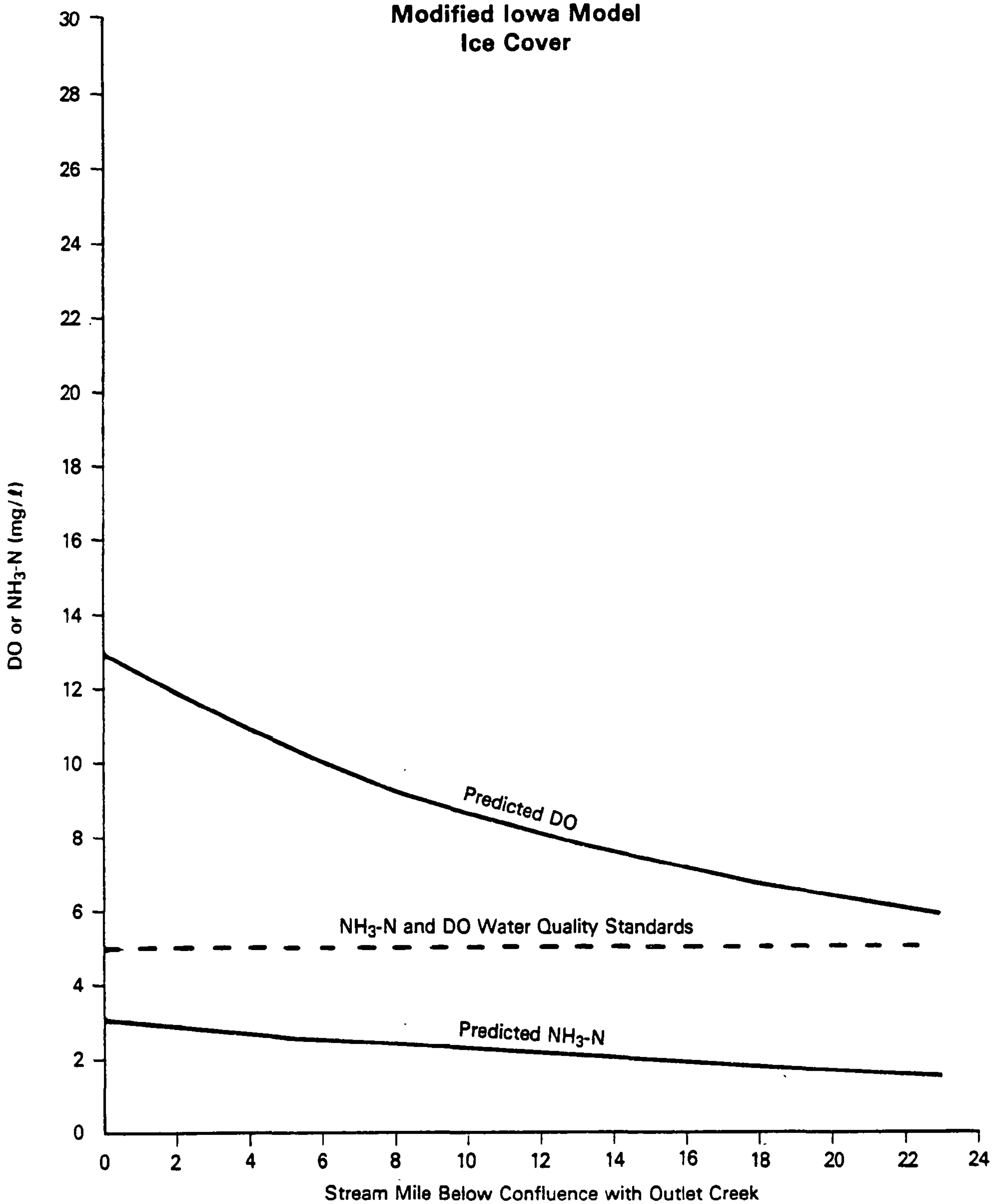


Figure 5.5.
North Raccoon River
Waste Load Allocation
Annual 7Q10 - Winter
Modified Iowa Model
No Ice Cover

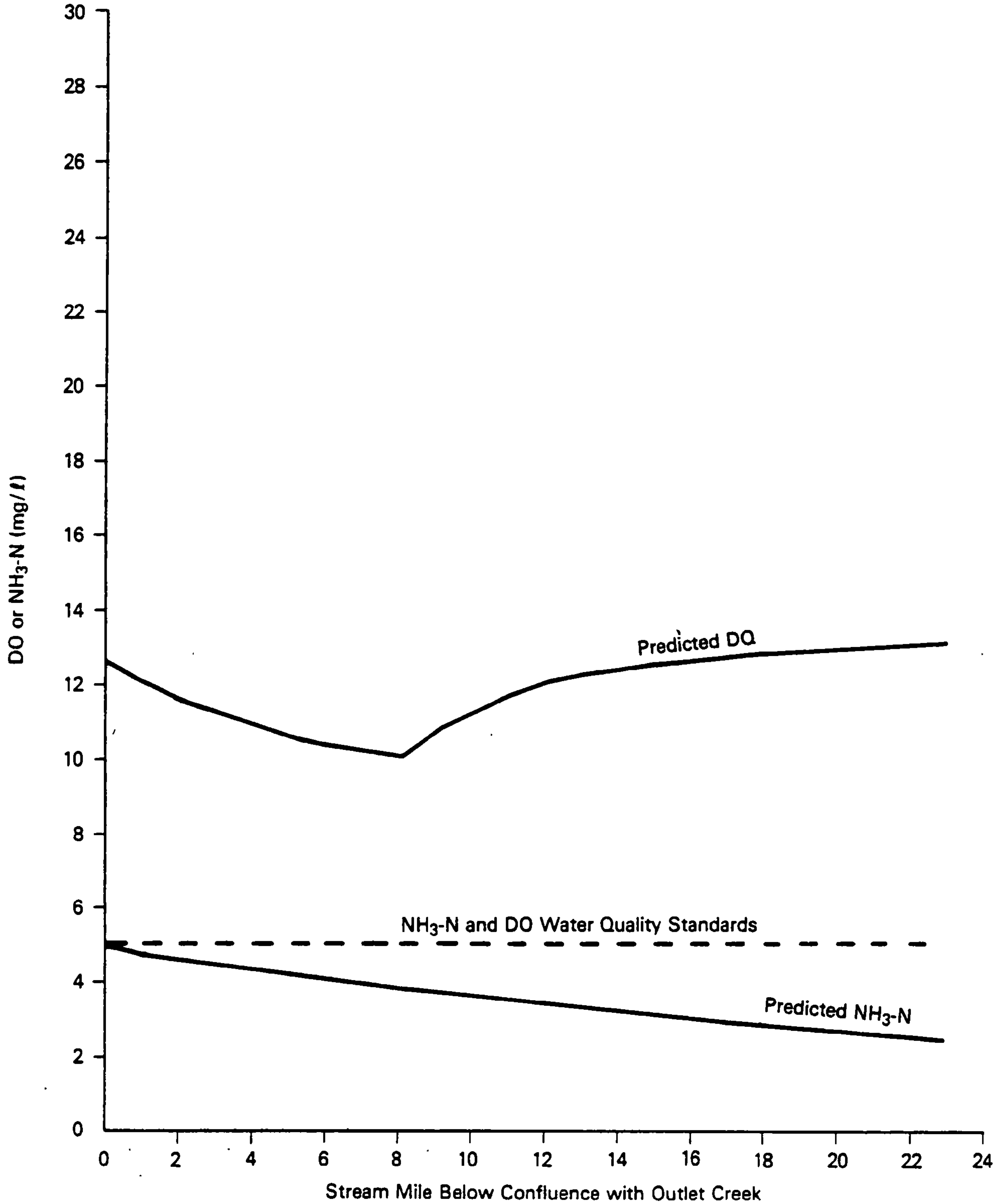
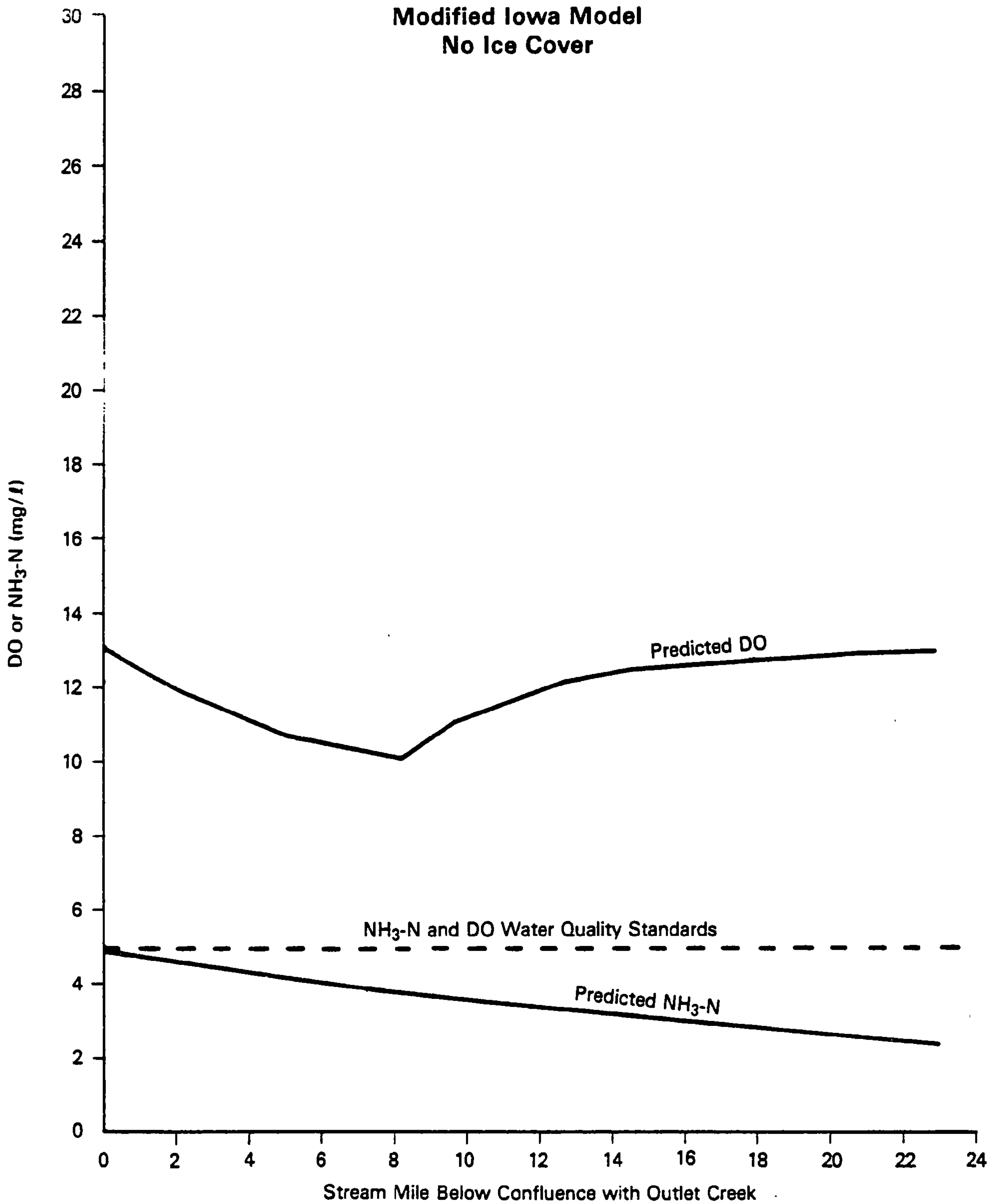


Figure 5.6.
North Raccoon River
Waste Load Allocation
Seasonal 7Q10 - Winter
Modified Iowa Model
No Ice Cover



assumptions, require increased nitrification at the plant in winter to produce NH_3 concentrations considerably lower than existing levels.

5.4.3 Proposed EPA NH_3 Toxicity Criteria

As shown on Table 5.3, the use of the calculated EPA summer criterion of 3.91 mg/l total NH_3 in place of the State standard of 2 mg/l did not change the permit limits developed from the modified Iowa model's waste load allocation. This is because summer NH_3 discharges are limited by the DO standard, not by NH_3 toxicity concerns.

The use of the calculated EPA winter criterion of 12.8 mg/l total NH_3 in place of the State standard of 5 mg/l also had no effect on the modified model's winter waste load allocations when 100% ice cover was assumed. Again this is due to the fact that the reduced reaeration caused by ice cover makes the DO standard the limiting parameter for effluent limits. This is not the case, however, when zero ice cover is assumed. Under the no ice cover condition, the NH_3 standard limits the permissible level of effluent NH_3 concentration. Consequently, the higher EPA criterion results in a permit limit of 21 mg/l Total NH_3 instead of the 8 mg/l predicted with the modified model using the State NH_3 standard. The current winter discharge level of NH_3 measured at the Storm Lake treatment plant is 21 mg/l, so that adoption of EPA's proposed ammonia toxicity standards could result in little change in the level of treatment under winter conditions.

5.5 RESULTS OF VERMONT QUAL-II WASTE LOAD ALLOCATION

Results of the waste load allocations for the North Raccoon River using the Vermont QUAL-II Model are provided in Tables 5.4 and 5.5. These permit limits are more stringent than those generated using the modified Iowa model. This is due to the differing rate constants each derived from the calibration process, including different carbonaceous deoxygenation rates and nitrification rates.

The waste load allocation results from the QUAL-II model, as from the modified Iowa DEQ model, indicate that allocations based on annual and seasonal low flows are almost identical. The one difference results from using

TABLE 5.4

RESULTS OF WASTE LOAD ALLOCATION ANALYSES
STATE NH_3 STANDARDS
VERMONT QUAL II

			EFFLUENT CONC. LIMITS			
			QUAL II MODEL		EXISTING IOWA MODEL	
SEASON	7Q10	ICE COVER	BOD_5 (mg/l)	NH_3-N (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)
Summer	Annual	No	30	8.5	30	3
Summer	Seasonal	No	30	9.5	30	3
Winter	Annual	Yes	25	3.0	25	5
Winter	Annual	No	25	8.0	25	5
Winter	Seasonal	Yes	25	3.0	25	5
Winter	Seasonal	No	25	8.0	25	5

TABLE 5.5

RESULTS OF WASTE LOAD ALLOCATION ANALYSES
PROPOSED EPA NH_3 TOXICITY CRITERIA
VERMONT QUAL II MODEL

			EFFLUENT CONC. LIMITS			
			QUAL II MODEL		EXISTING IOWA MODEL	
SEASON	7Q10	ICE COVER	BOD_5 (mg/l)	NH_3-N (mg/l)	BOD_5 (mg/l)	NH_3-N (mg/l)
Summer	Annual	No	30	8.5	30	3
Summer	Seasonal	No	30	9.5	30	3
Winter	Annual	Yes	25	3.0	25	5
Winter	Annual	No	25	16.0	25	5
Winter	Seasonal	Yes	25	3.0	25	5
Winter	Seasonal	No	25	15.0	25	5

the summer seasonal low flow (Figure 5.8) which is slightly higher than the summer annual low flow (Figure 5.7) and, thus, allows the POTW to discharge 1 mg/l more NH_3 and still meet Iowa water quality standards.

5.5.1 Summer Waste Load Allocation

Summer annual and seasonal NH_3 effluent concentrations of 8.5 and 9.5 mg/l respectively, derived from the QUAL-II waste load allocations (Figures 5.7 and 5.8), and based on Iowa water quality standards, are higher than those proposed by the existing Iowa DEQ model of 3 mg/l. They are, however, lower than the modified Iowa model's predicted NH_3 concentrations of 13 mg/l. This is because the calibrated QUAL-II model had higher deoxygenation and nitrification rate constants than the modified model. As a result, NH_3 discharges exert a greater oxygen demand in this model and permit limits must be more stringent to meet the State DO standard.

5.5.2 Winter Waste Load Allocation

The QUAL-II winter waste load allocations which assume 100 percent ice cover require even lower permit limits than the existing or modified Iowa models. Again this is because the higher nitrification and deoxygenation rate constants in QUAL-II exert a greater oxygen demand. A comparison of Figures 5.9 and 5.10, with ice cover, to Figures 5.11 and 5.12, without ice cover, graphically illustrates the profound effect ice cover exerts on the stream's capacity to assimilate wastes. The simulated DO concentrations in Figures 5.9 and 5.10 exhibit a steady decline throughout the North Raccoon River to Sac City. In contrast, Figures 5.11 and 5.12 indicate that DO concentrations remain high and that the NH_3 standard is the limiting factor for point source discharges. For winter conditions with no ice cover, the Vermont QUAL-II results parallel those of the modified Iowa model. Both models suggest that, with no ice cover, a higher concentration of NH_3 (8 mg/l) can be discharged from the POTW than with ice cover (3 mg/l). QUAL-II indicates, as do the other two models, that increased nitrification is required at the Storm Lake facility in order to reduce effluent concentrations from the current level of 21 mg/l Total NH_3.

Figure 5.7.
North Raccoon River
Waste Load Allocation
Annual 7Q10 - Summer
Qual-II Model

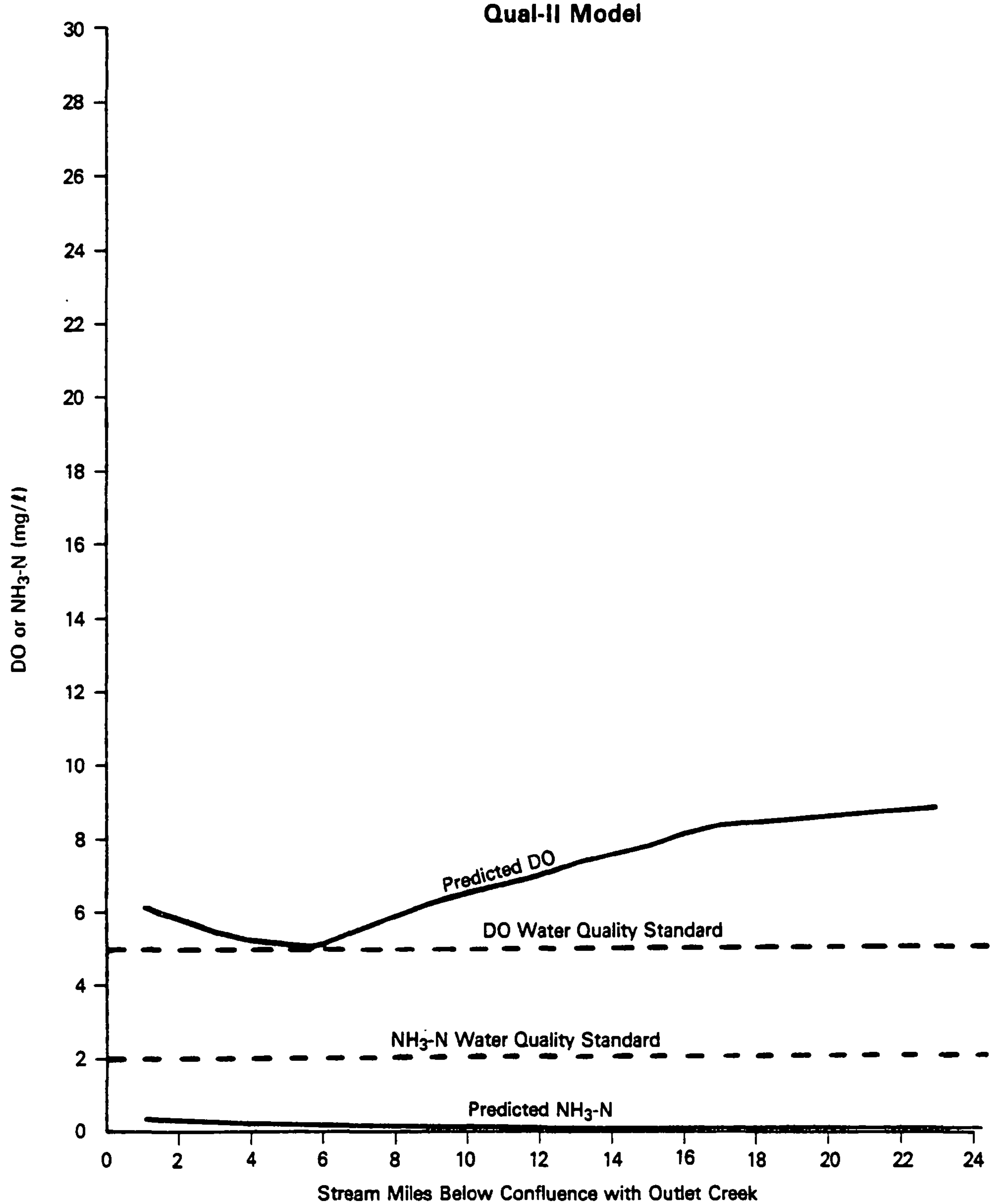


Figure 5.8.
North Raccoon River
Waste Load Allocation
Seasonal 7Q10 - Summer
Qual-II Model

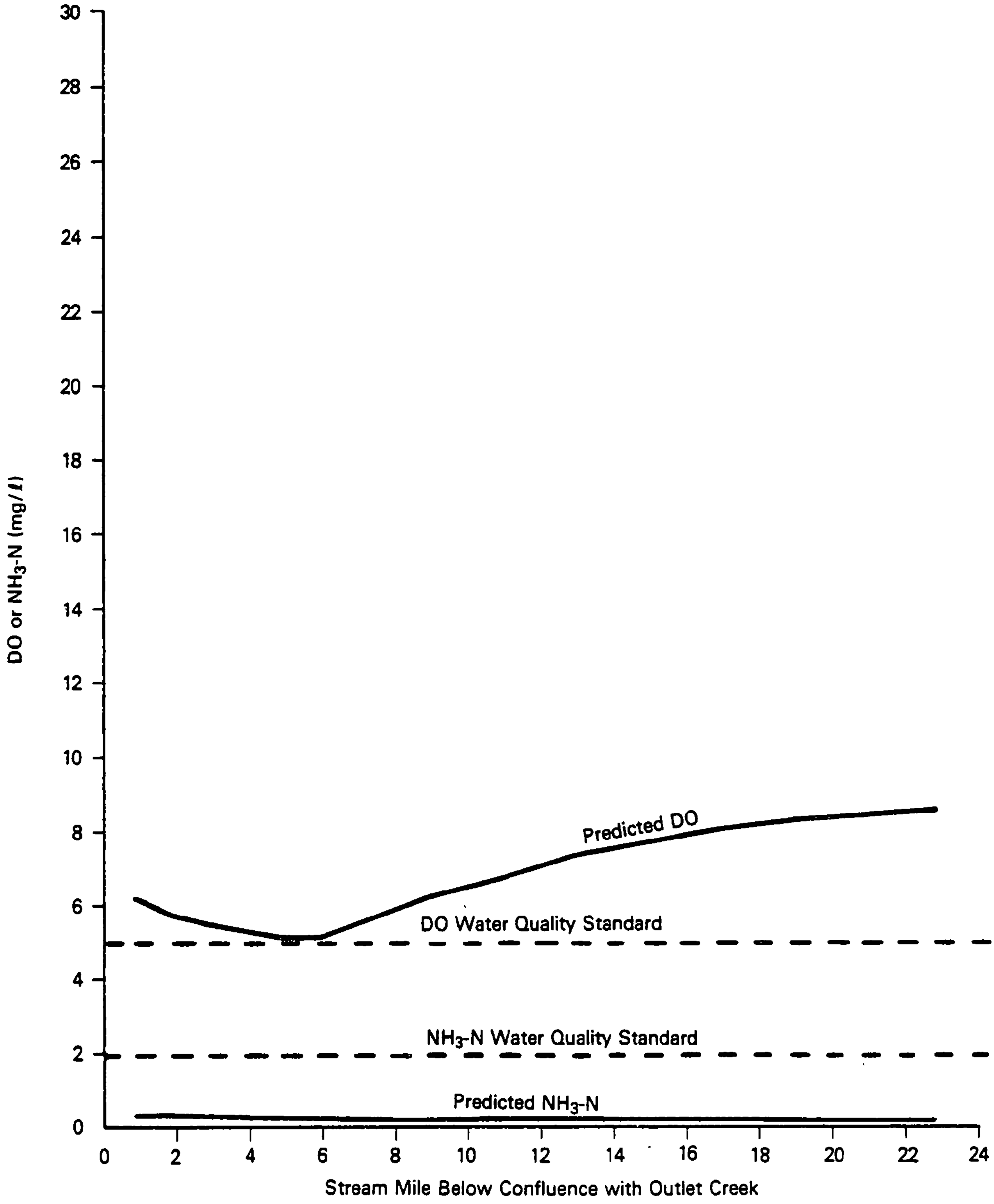


Figure 5.9.
North Raccoon River
Waste Load Allocation
Annual 7Q10 - Winter
Qual-II Model
Ice Cover

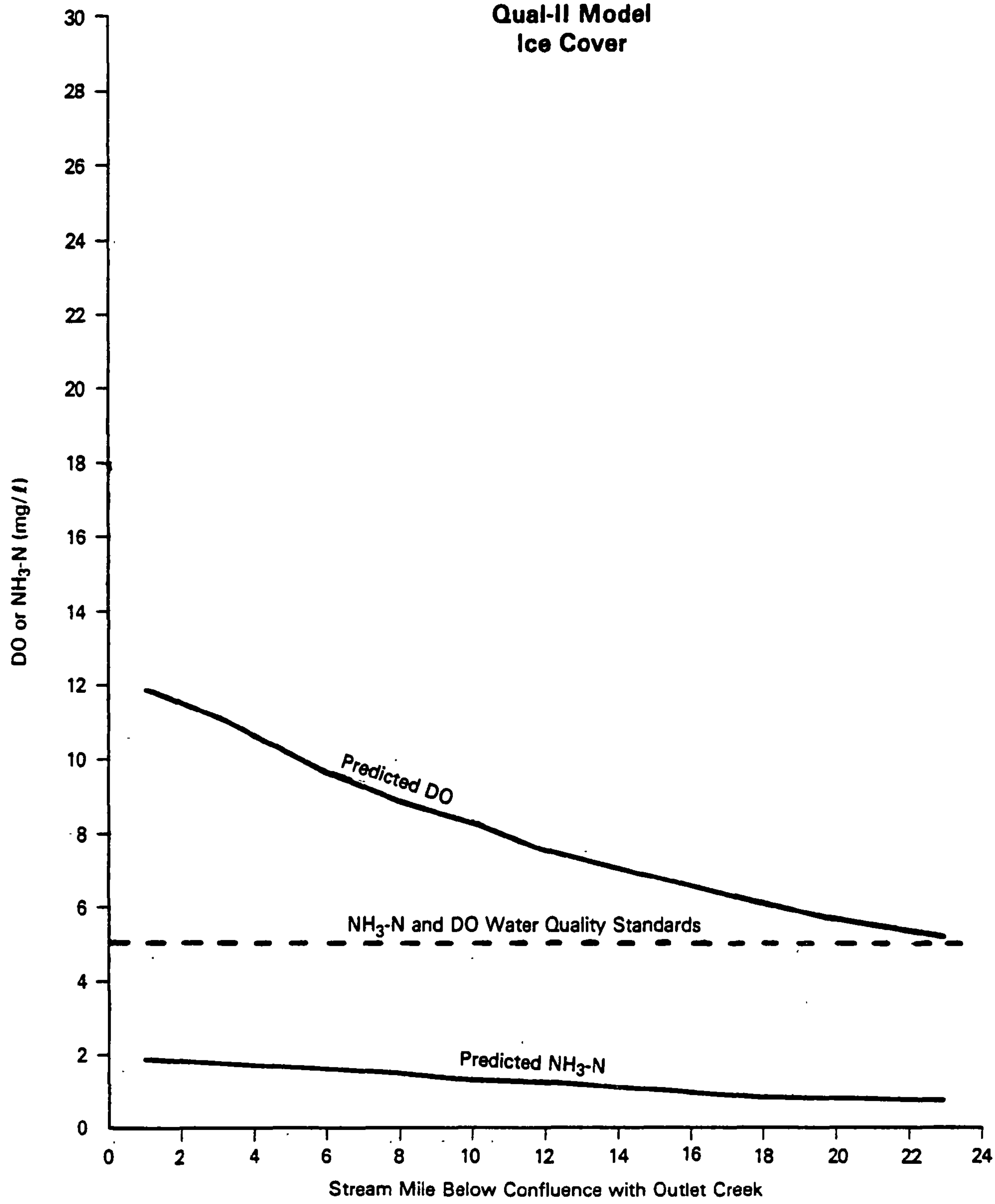


Figure 5.10.
North Raccoon River
Waste Load Allocation
Seasonal 7Q10 - Winter
Qual-II Model
Ice Cover

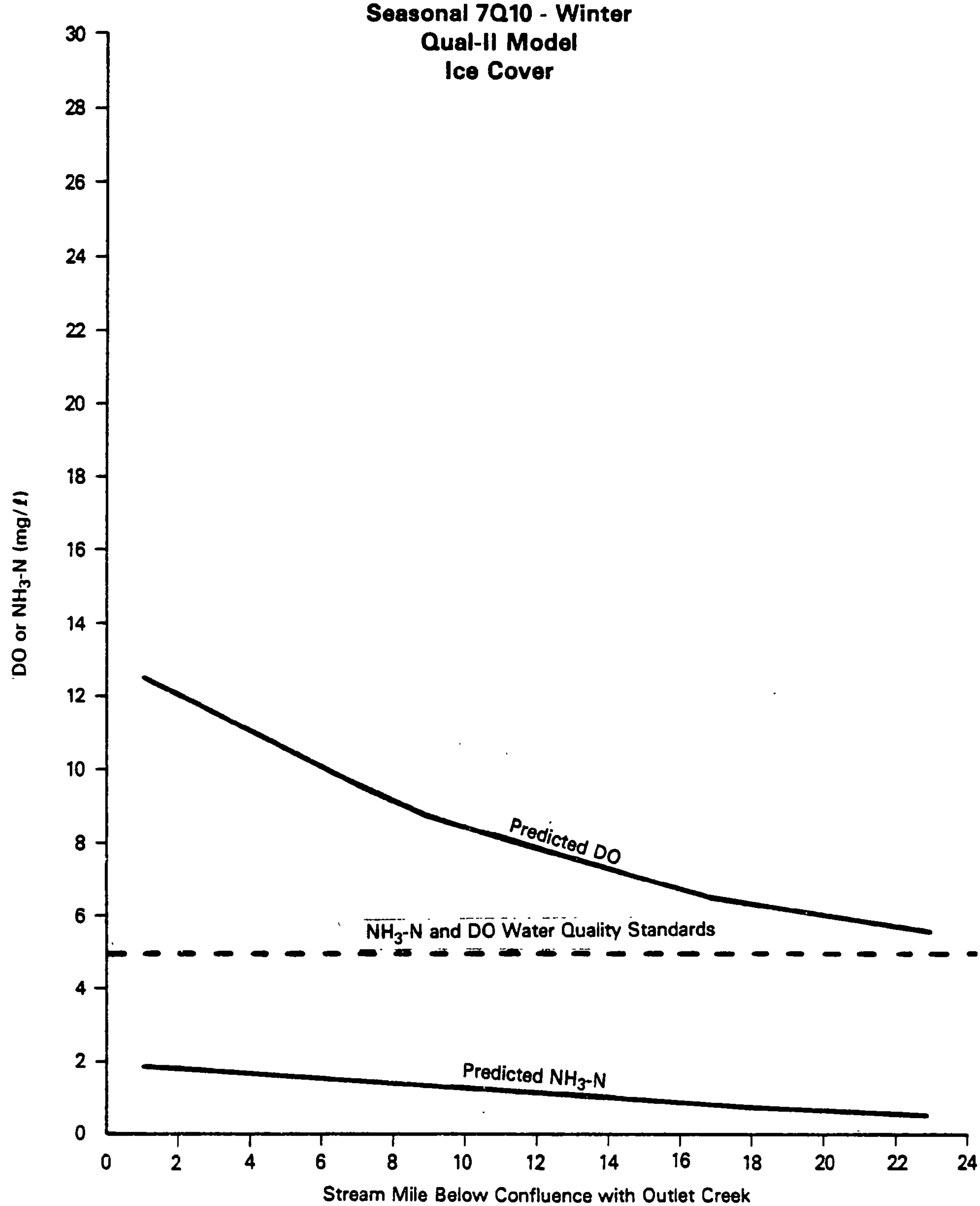


Figure 5.11.
North Raccoon River
Waste Load Allocation
Annual 7Q10 - Winter
Qual-II Model
No Ice Cover

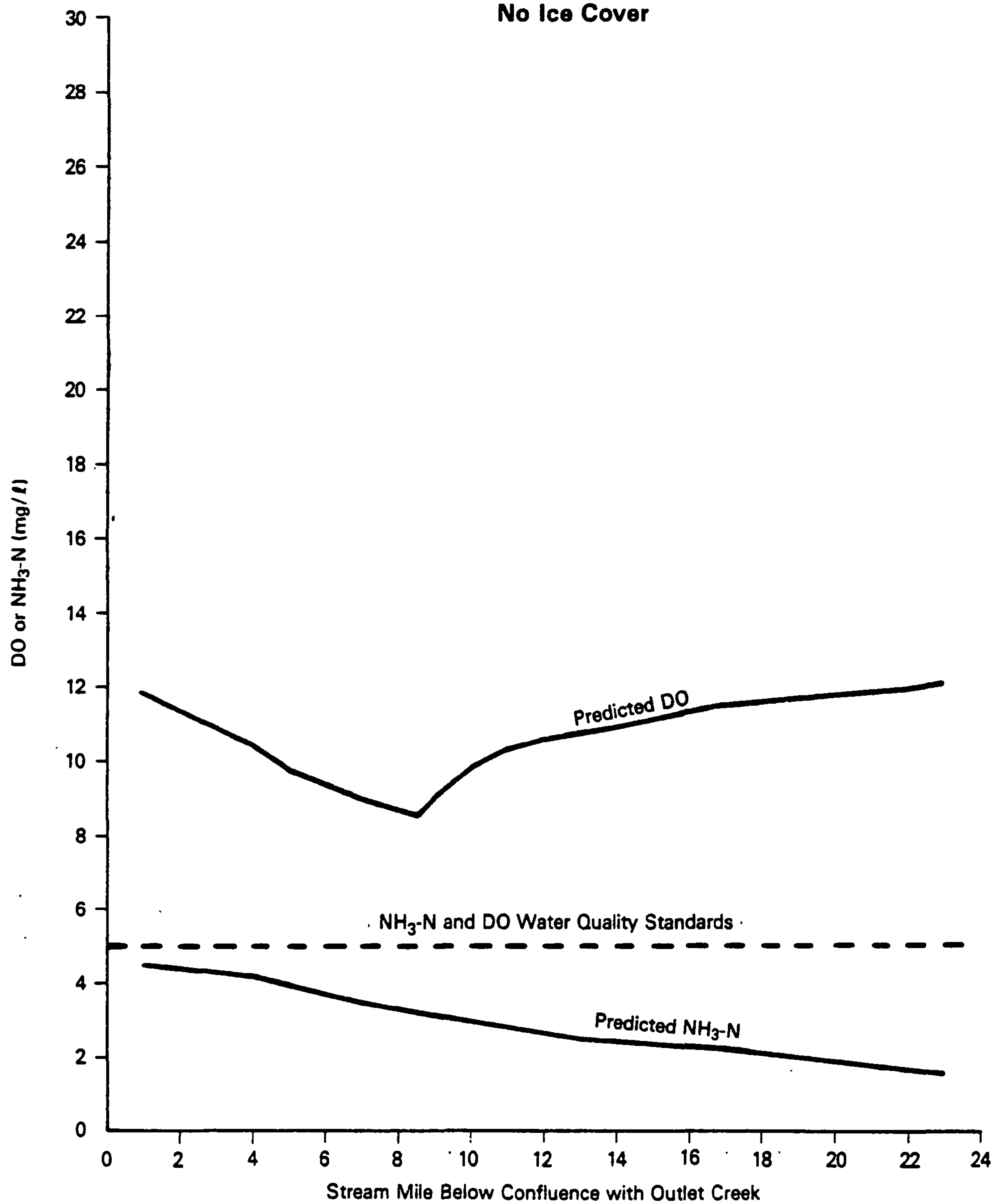
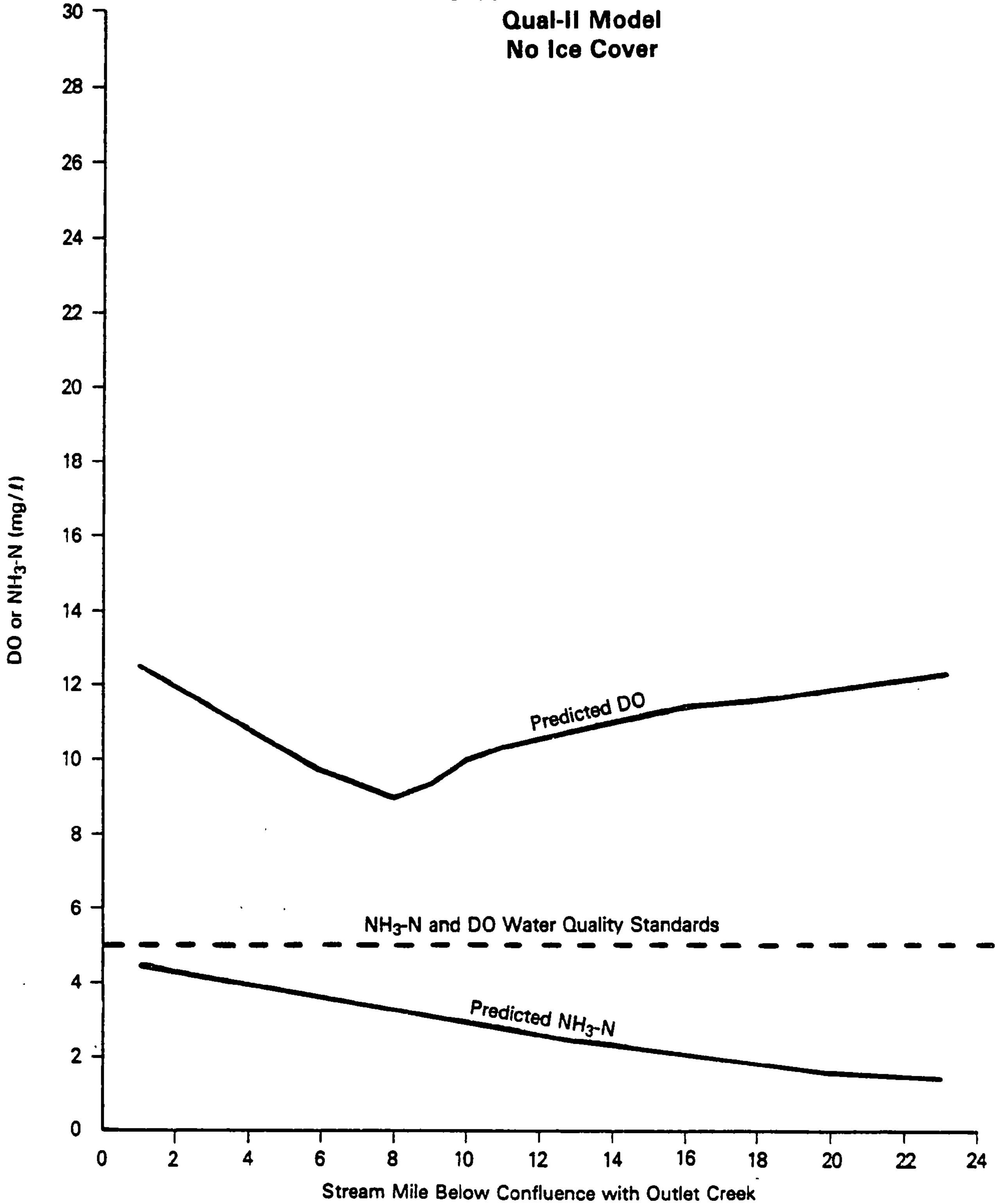


Figure 5.12.
North Raccoon River
Waste Load Allocation
Seasonal 7Q10 - Winter
Qual-II Model
No Ice Cover



5.5.3 Proposed EPA NH_3 Toxicity Criteria

The Vermont QUAL-II waste load allocations were also conducted using the proposed EPA NH_3 toxicity criteria. Results of the waste load allocation using this assumption are provided in Table 5.5. The outcome of this exercise is comparable to that using the modified Iowa model.

Wasteload allocations for the summer low flows (annual and seasonal) did not differ from those using the Iowa water quality standards. This is due to the fact that, as mentioned above, the effluent concentration is controlled by the Iowa DO standard and not the NH_3 toxicity standard.

Winter wasteload allocation results for complete ice cover conditions are also controlled by the DO level, and raising the NH_3 standard does not affect these results. Thus, using the Vermont QUAL-II Model with winter ice cover and the proposed EPA NH_3 criteria does not alter the allowable effluent concentrations at the Storm Lake Plant from what they were using the Iowa NH_3 standards.

When there is no ice cover, however, the winter waste load allocations show that the NH_3 effluent levels can increase to 16 and 15 mg/l for annual and seasonal low flows respectively, and still not exceed the proposed EPA NH_3 toxicity criterion and the Iowa standard for DO. The limiting factor, in this case, is the instream NH_3 criterion. As explained earlier, the QUAL-II model predicts lower permissible effluent concentrations of ammonia than the modified model because the nitrification and deoxygenation rates calibrated for this model are higher. While the modified model predicts that no decrease in existing NH_3 discharges are required for winter no ice conditions using the EPA NH_3 criterion, the QUAL II model indicates that current POTW effluent must be decreased from 21 mg/l to 16 mg/l Total NH_3.

5.6 POTENTIAL COST SAVINGS

The existing Iowa model for the North Raccoon River and its tributaries indicates the need for advanced wastewater treatment at the Storm Lake Treatment Plant. Both the QUAL-II and modified Iowa model results suggest that advanced treatment may not be required during the summer months. If this is confirmed through improved calibration/verification of the models, then operation and maintenance cost savings could be realized.

The magnitude of the cost savings depends upon the nitrification method. Table 5.6 lists operation and maintenance cost estimates taken from Culp, based on an influent flow of 6.98 cfs and an influent NH_3 concentration of 20 mg/l. These flow and NH_3 assumptions approximate the future Storm Lake POTW characteristics.

TABLE 5.6
OPERATION AND MAINTENANCE COSTS
FOR NITRIFICATION FACILITIES

Nitrification Method	Estimated O&M Cost ($/yr)
Breakpoint Chlorination	$190,000
Selective Ion Exchange	$130,000
Ammonia Stripping	$ 60,000

These figures are Fourth Quarter 1975 costs, and should be increased to reflect 1983 costs. In addition, the estimates do not include the costs of pH adjustment, which is necessary for ammonia stripping, and may be used in breakpoint chlorination. Obviously, significant savings would occur if the nitrification facility could be shut down for part of the year.

Instead of updating the existing municipal plant, the City of Storm Lake plans to abandon the trickling filter plant and build an oxidation ditch to achieve the future permit limits established by the existing waste load allocation model. Because winter conditions control the capacity of the oxidation ditch, the less stringent summer NH_3 limits predicted in this study would not result in capital cost savings. Significant cost savings under less stringent summer NH_3 limits could, however, result from reduced operation of aeration equipment during the summer months.

6. STREAM MONITORING REQUIREMENTS

This case study of Outlet Creek and the North Raccoon River illustrates the importance of proper stream monitoring. For both calibration and verification periods, essential data regarding the quality of point source discharges and the receiving water were missing and had to be estimated based on engineering judgement. Consequently, the models were not convincingly calibrated or verified, and the resulting waste load allocation is open to question. Model calibration and verification cannot be proven without sufficient and accurate data.

The key questions in sampling are when to sample, where to sample, and what data to acquire through sampling. Sampling stations must be located so that the instream water quality processes are adequately represented. The scheduling of sampling times at each station is also important. Finally, the sampling must be complete enough to provide all required data. Most of the water quality data can be analyzed in the laboratory, but onsite flow and velocity measurements must be made at the time of sampling.

6.1 SAMPLING LOCATIONS AND TIMING

Sampling stations should bracket point source discharges and major tributaries to the receiving stream. Samples should be taken upstream and downstream of the discharge, and the discharge must also be sampled. Enough samples must be taken between discharges so that the reaction rates of water quality parameters can be determined. For example, in the likely event that a DO sag occurs downstream of a discharge, enough sampling stations should be established so that the location of the DO sag can be identified.

The most efficient sampling for calibration and verification data is that performed during flows similar to the critical design flow for the waste load allocation analysis. If flow variable permitting is being considered, sampling should be done when actual flows approximate the various seasons or permitting periods. Before sampling is initiated, these flows should be computed using the low flow statistics package and USGS streamflow database which are available on STORET. A plug flow sampling method should be used in which samples at each station are taken in accordance with the travel time between stations, so that the same slug of water is sampled as it flows downstream. Any tributaries or point sources contributing to the slug of water being sampled should be monitored as the slug passes these points. Point source discharges in the headwaters of a stream should be monitored one travel time before the receiving water is sampled. The sampling should be arranged so that the calibration and verification periods have differing point source loads, water temperature, and/or flows.

6.2 CONSTITUENTS MONITORED

Since travel time is a factor in many of the predictive equations in each model, its accurate simulation is essential. The determination of travel time is best accomplished through dye tracer studies, particularly under the low flow conditions on many Iowa streams. At low velocities and shallow depths, parts of the receiving stream can exhibit highly forked and meandering flow regimes, with velocities much slower than the corresponding mean main-stem velocity. Under low flow conditions, many Iowa streams are less than or equal to one foot deep, with velocities less than 1 foot per second.

If dye tracer studies are not used, flow and velocity measurements should be made at enough locations to represent the hydraulics properly. Using the U.S.G.S. method, the stream should be divided into sections and the average velocity in each section determined with a current meter. Ideally, these measurements would be made over the entire range of flows considered for flow variable permitting. Waste load allocations using differing flows could then be developed with the appropriate velocities.

Table 4.1 lists the water quality parameters which must be monitored in both the stream and point source effluent in order to calibrate and verify the modified Iowa and Vermont QUAL-II models. The data limitations encountered in the calibration and verification of the QUAL-II model illustrate the importance of analyzing all parameters in the effluent as well as the receiving stream. The water quality parameters that should be monitored for QUAL-II include organic N, NH_3, NO_3, dissolved P, organic P, BOD, DO, temperature and chlorophyll-a. Organic N and P are the only instream parameters that do not have to be monitored for the modified Iowa model. In the receiving stream, sampling for DO should be conducted every 4 to 6 hours of the day in order to monitor diurnal fluctuations. In both stream and point source analyses, the BOD samples should be inhibited for nitrification so appropriate values of carbonaceous BOD are available for the models. Sediment oxygen demand (SOD) should also be measured if benthic deposits exert a significant influence on stream water quality. The modified Iowa model does not include benthic effects, but the QUAL-II model includes sediment oxygen demand as well as benthic releases of NH_3 and dissolved P.

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