Final Project Report

A Watershed-Based Approach for Waste Load Allocation in Iowa

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Executive Summary

It is recommended that Iowa adopt the watershed approach as the basis for water quality management in the State. The watershed approach should be implemented over a five year period, along the proposed watershed management cycle.

The Watershed-based approach is built around three central elements: organization of water quality management on the basis of geographic management units (usually river basins), coordination and cooperation between agencies and individuals involved in a watershed, and addressing water quality management issues within the framework of the basin management cycle. The basin management cycle consists of 6 phases: monitoring and data collection, assessment of water quality conditions and standards violations, determining priorities, developing management strategies (point and non-point source controls), establishing a basin management plan and watershed plans and, finally, implementation of the plans. The Watershed-based approach has advantages over a traditional, fragmentary way of dealing with water quality problems:

- provides a more integrated and effective management of both point and non-point pollution sources,
- increases involvement of a wider range of stakeholders in the water quality decisions,
- should result in increased efficiency in the conduct of water quality programs and NPDES permitting in Iowa.

The need to implement the Watershed-Based Approach in Iowa has emerged because a substantial part of Iowa's water quality problems is caused by non-point sources and because today's complex water quality issues are more efficiently addressed through a statewide system of prioritization.

The key components of the watershed-based approach for Iowa include the incorporation of non-point sources in water quality modeling, considering the entire watershed in future water quality analyses, and addressing water quality problems in river basins or watersheds in a Basin Management Cycle. For this purpose, Iowa needs to be subdivided into 5 groups of major river basins that have to be sequenced in a 5-year cycle, in order to cover the whole state, while balancing the workload at the same time. The 5 major river basins suggested in this report are Des Moines River, Skunk River and SW Iowa River Basins, Cedar and Iowa Rivers, Wapsipicicon and NE Iowa Rivers, and Western Iowa. It is recommended that a five year transition period be used to convert from the current water quality management programs and NPDES permits to a new watershed approach. During each year of the five year management cycle, one of the five river basins above will convert to the new cycle.

The collection of reliable and accurate data and the simulation of contaminant fate and transport processes in a watershed are essential for problem assessment and the subsequent design of effective pollution control strategies. Therefore, monitoring and modeling play key roles in the Watershed-Based Approach. Geographical Information Systems (GIS) is an important tool to help in monitoring and modeling. To develop and implement a watershed-based approach for waste load allocations in Iowa, both point and non-point sources of pollution over the entire watershed must be considered. Non-point source pollutants enter surface waters at intermittent intervals and they are generally related directly to meteorological events. Point sources are discharges to the surface water that come from a single pipe or discharge point. The total pollutant concentration is a combination of both point and non-point sources.

In order for Iowa to move to this new approach to water quality management, additional staff will be required. It is recommended that the following positions be added to the existing IDNR staff:

1. Statewide Watershed Coordinator/planner
2. Watershed Database manager
3. Monitoring Coordinator
4. 2 or 3 water quality monitoring technicians
5. Computer modelor

The additional cost of these staff and other associated cost for this approach is estimated at $348,000 per year plus a one time cost for additional computer workstations of $25,000. Iowa has been reported to have the lowest state expenditures for water quality management programs in the region. Additional resources are badly needed for water quality programs.

I. The Watershed-Based Approach

A. Introduction

1. Background

The Federal Water Pollution Control Act of 1972 (also called the Clean Water Act) established the national goal of restoring and maintaining the physical, chemical and biological integrity of the Nation's waters. Section 303 of this act laid a foundation for watershed protection with its provisions for intrastate water quality standards, comprehensive basin planning and establishment of Total Maximum Daily Loads (TMDLs).

However, the initial implementation of the Clean Water Act concentrated on the creation of a federal permitting program, the National Pollutant Discharge Elimination System (NPDES). The subsequent workload in handling NPDES permits overwhelmed many state water quality programs to the point where the primary focus became response to NPDES applications, establishment of point source wasteload allocations, issuance of NPDES permits and NPDES permit enforcement. Program resources were rarely allocated to the evaluation of non-point source loads, such as those from overland runoff or transport of pollutants through groundwater flow into surface waters.

The most recent National Water Quality Inventory [305(b)] Report states that the Nation has not yet achieved its goal of restoring and maintaining the physical, chemical and biological integrity of its aquatic ecosystems. Major limiting factors are non-point source pollution and habitat degradation. Currently, it is understood that different environmental issues are so much intertwined that they require a comprehensive approach, which incorporates ecological principles and collaboration among agencies. Many agencies and programs at all levels of government are now embracing the idea of using the geographic boundaries of a river basin or a watershed as the basis for coordinating and integrating environmental management efforts. This is known as the **watershed based approach**.

2. Statewide watershed management

Statewide watershed management involves the integration of various natural resource management programs into a comprehensive watershed protection approach and the coordination of watershed protection efforts throughout a state (EPA, 1995). This is not a new approach, but rather a logical extension of basin planning provisions in the Clean Water Act. This statewide approach provides numerous benefits to agencies responsible for implementing water-related legislative mandates, including:

- improved water quality management by including all sources of pollutant in the analysis,
- improving the efficiency of environmental program implementation,

- better involvement of all stakeholders involved with environmental management programs, and
- increased flexibility in implementing environmental programs that it can be adapted to the unique circumstances within each state.

The experience of various states with the watershed based approach to water quality management shows a variety of programs and approaches; however, several common elements from these programs can be identified:

Geographic Management Units

Under a watershed approach, a state is divided into geographic management units, drawn around large river basins (see Figure 1.1). These are used by the agencies involved as the geographic basis for coordination of their water resource management activities.

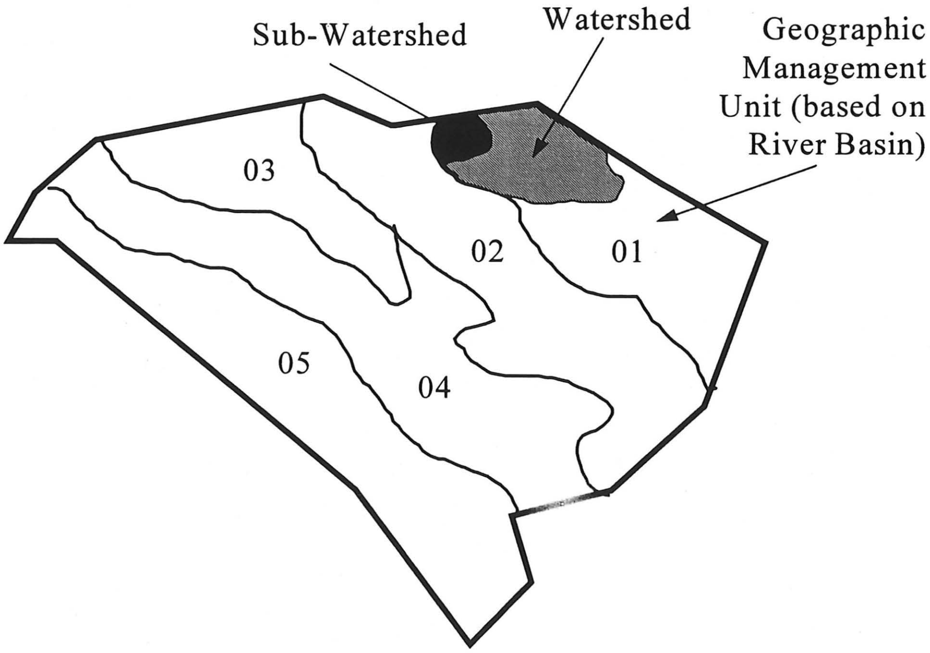


Figure 1.1. Example of Geographic Management Units : Division of a state based on 5 major River Basins, that can be subdivided into Watersheds and Sub-Watersheds

Participants

Under a watershed approach, participants are all agencies, organizations and individuals that are involved in or affected by water quality management decisions for a given basin are participants in the planning process. Participants can include, for example, regional offices of federal agencies, state natural resource management agencies, representatives of local (county or city) administrations, drinking water and wastewater utilities, industrial

(NPDES) dischargers, representatives of the agricultural sector, citizen volunteer monitoring groups and environmental organizations (see Figure 1.2.).

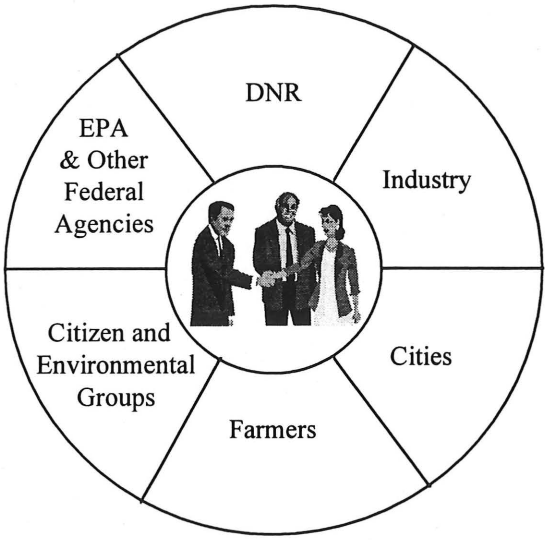


Figure 1.2. Example of Stakeholders in Basin Management

Basin Management Cycle

Under a statewide watershed based approach, the various water quality management activities for a given geographic management unit take place in an orderly cycle over a period of time. Many states that have used the watershed approach have selected a 5-year basin management cycle to coincide with the requirements for NPDES permit renewal. In these cases, the state would group and sequence the water quality management activities of all geographic management units such that, during any given year, one-fifth of the geographic management units in the State are in the first year of the cycle, one-fifth in the second year, one-fifth in the third year, etc. (see Fig. 1.3). In this way, any basin management activity, such as preparing a basin plan or issuing NPDES permits, is carried out in any year for approximately one-fifth of the state's GMU's. This should balance the planning and management workload for the responsible agencies.

3. The Basin Management Cycle

The management cycle for a given basin consists of five main groups of activities (see also Fig. 1.3):

- Strategic monitoring

Monitoring in the watershed based approach involves the collection of data that are necessary to support subsequent activities in the basin management cycle.

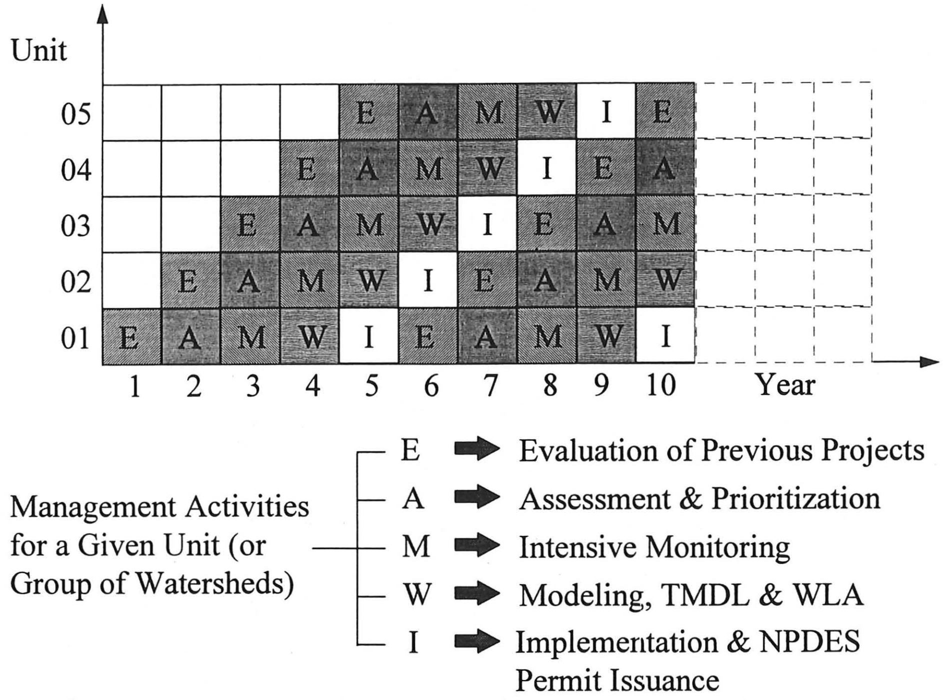


Figure 1.3. Example of 5-Year Management Cycle

Monitoring would include collecting data for assessing the general water quality of the GMU, development of a strategy for intensive monitoring for identified water quality limited reaches, intensive monitoring for modeling and NPDES permit allocation, and compliance monitoring.

- Assessment & Prioritization and targeting of critical watersheds

Different levels of water quality assessment are carried out during different stages of the basin management cycle. In the early stages (years 1 & 2), the purpose of the water quality assessment involves determining the severity of water quality impairment and identifying the sources of the impairment. In the middle stages of the basin management cycle(years 3 & 4), the assessment consists of analyses of the relationships between pollutant loading and water quality, and of predictive water quality modeling in order to establish TMDLs or waste load allocations. In the later phases of the basin management cycle(year 5), an assessment is used to evaluate the effectiveness of implemented water quality management strategies and to assess the achievement of water quality objectives.

Based on the water quality assessment, critical watersheds where water quality impairments are noted are identified. A priority system is developed that will ensure the resources of participating agencies are directed effectively and efficiently to priority concerns within a GMU and that efforts by all stakeholders are coordinated.

- Developing management strategies

  In this stage, the participants establish specific goals and objectives for targeted watersheds, and then design strategies to achieve these goals and objectives. These strategies include controls for point and non-point sources. For example, a targeted watershed might have an identified problem with high levels of sediment during heavy rainfall events. A management strategy to reduce sediment could be developed for this watershed.

- Establishing basin and watershed management plans

  Present water quality conditions, a list of priority concerns, strategies for improvement, a schedule for implementation and measures for evaluating effectiveness are all included in a basin management plan. Basin-wide goals are translated into local watershed management plans, that describe the selected management strategies for a given watershed and the role of various participating agencies.

- Implementation

  Implementation is the ultimate goal that results in improved water quality and it the major output of the basin management cycle. Implementation must include activities such as NPDES permit issuance, implementation of best management practices (BMPs), pollution prevention programs, outreach programs towards the general public, habitat restoration, monitoring activities to evaluate the effectiveness of various programs, etc.

B. The Need

Many States throughout the USA have already implemented the Watershed-Based Approach for solving their water quality problems, and many others are planning to do so in the near future. The use of this approach is being encourages by the regional offices of EPA as well. The interest in this approach for water quality management is not surprising, since it has many advantages over the traditional, fragmentary, point-source oriented way of dealing with water quality concerns. Two advantages of the Watershed-Based Approach deserve some special attention:

Non-Point Sources

Many water quality impairments are related to non-point sources of pollutants. Examples include runoff from agricultural and urban areas that contain pollutants like sediment, nutrients, and pesticides. This is especially important in Iowa due to the predominance of agricultural land-use that contributes to water quality impairments. Elevated levels of nitrate nitrogen, phosphorous, and sediment often result in uncontrolled algae populations, depressed dissolved oxygen concentrations and impacts on fisheries in many of Iowa's waters. For many waterbodies, the only way to achieve significant improvement in water quality is to development control programs that consider the combined effect of both point and non-point sources in the entire watershed. The watershed based approach forces consideration of both point and non-point source control programs explicitly.

Prioritization and Coordination

Most agencies responsible for water quality management must accomplish their mission with budgets that tend to be very restrictive. The State of Iowa was identified as ranking 50th among all state in expenditure for water quality programs. This fact could be interpreted as indicating Iowa is much more efficient in their implementation of water quality management programs or it could mean Iowa has not properly funded their water quality management programs. Regardless of how the past funding in Iowa is interpreted, it is essential to address water quality issues in the most efficient way by allocating the scarce resources (personnel, funding) to the watersheds where they are most needed, and by coordinating and cooperating with other stakeholders involved to combine forces and avoid overlaps to achieve common environmental goals. The Watershed-Based Approach provides a methodology for establishing priority ranking of watersheds within a GMU and provides a structure for cooperation with other stakeholders involved.

C. Key Elements of the Watershed Approach in Iowa

IDNR should move as quickly as possible toward using the Watershed Based Approach for water quality management programs in Iowa. Some of the key elements that need to be incorporated in this Watershed Approach to water quality management in Iowa are discussed below.

- Include Non-Point Sources

  As is obvious from the previous paragraph, non-point sources, like agricultural practices and urban developments, need to be included in water quality analyses. An important constraint to implementing the Watershed Approach are the limited possibilities to measure the impacts of non-point sources, and the lack of water quality standards specifically related to these sources. One way to approach this problem is the development of stream biocriteria, an activity that is currently being carried out by IDNR. The Clean Water Act provides for the development of in-state water quality standards. IDNR should consider developing instream water quality standards for non-point source pollutants. However, it will still be necessary to devote a significant amount of attention to monitoring and controlling non-point sources, in order to make the Watershed Approach a success. The focus of the non-point source control programs will continue to be education and voluntary compliance programs.

- Analyze the Entire Watershed

  In order to include non-point sources in a water quality analysis, and also to be sure that all point source discharges on a stream and its tributaries are taken into account, the entire watershed has to be considered.

- Adopt a 5-Year Basin Management Cycle

In order to improve water quality conditions in target watersheds in different basins over a multi-year period of time, planning will be needed. It needs to be decided how watershed management activities carried out by IDNR, like monitoring and permit issuance, will be scheduled in time and space. Two key decisions will have to be made:

Development of a Basin Management Cycle

A suitable planning framework, which is used by most other states implementing the watershed approach, is the basin management cycle. A workable cycle has to be developed, meeting the particular needs of IDNR.

Delineation of Geographic Management Units

IDNR needs to be decided how Iowa can be subdivided into a number of major river basins or groups of basins, that will be used as units for the basin management cycle.

The first two points mentioned above have important implications for the watershed modeling approach chosen by IDNR.

D. Development of a Basin Management Cycle

The purpose of a Basin Management Cycle is to effectively and efficiently organize watershed management activities in time and space. This has to be done in a way ensuring coordination between various activities for one watershed and balancing the workload over time while addressing different watersheds.

Following this approach, various water quality management activities for a given watershed will take place in a cycle of a specified duration. Because of the 5-year time frame on NPDES permits, a 5-year cycle seems to be most appropriate for this purpose.

In this case, IDNR would group and sequence all watersheds in Iowa such that, during any given year, one-fifth of the watersheds is in the first year of the cycle, one-fifth in the second year, etc. (see also Figure 1.3.). In this way, any watershed management activity, such as intensive monitoring or issuing NPDES permits, is carried out in any given year for approximately one-fifth of the state's watersheds, thus balancing the workload for the personnel involved.

The activities to be addressed in each year of the cycle are explained in more detail in the following:

Year 1

During the first year of the cycle for a given management unit, IDNR would assemble all previous studies and water quality data for the GMU and would evaluate the results of previous studies in the area (although this activity might be continuing over a more extended period of time). Also, IDNR would monitor the rotational stations located within the management unit, approximately one in each watershed. The stations being monitored each new cycle will generally be at the same locations, although it would be possible to adjust these locations or tailor the parameters to be monitored, dependent on the specific conditions of the watershed.

Year 2

Based on the results of the rotational station monitoring and the analysis of the previous studies in the GMU, IDNR would assess water quality conditions and designated use support in each of the watersheds within the management unit. Based on these assessments, water quality goals would be developed for the watersheds. These goals represent reasonable targets for water quality improvements in the respective watersheds. Therefore, goal setting is independent from the legislative process of designated use classification or setting water quality standards.

The activities of water quality assessment and goal setting would involve meetings with the stakeholders, i.e. the agencies, organizations, local governments, industries and groups that have interests in water quality issues in the watersheds within the management unit. To the discretion of IDNR, these meetings could be organized for the management unit as a whole, or in case there is little relationship between the individual watersheds within the unit, on a watershed basis.

Based on the water quality assessment and goals, IDNR would set priorities to devote its attention to the most critical watersheds within the management unit. For the critical areas, an intensive monitoring plan will be developed.

Year 3

During the third year, IDNR will carry out the intensive monitoring identified in the Monitoring Plan that was developed in year 2. The data obtained through the intensive monitoring studies will be processed, stored and analyzed.

Year 4

During the fourth year of the cycle, IDNR will use the data from the intensive monitoring studies for the calibration and verification of water quality models for the critical watersheds within the management unit. The calibrated models can then be used for development of Total Maximum Daily Loads (TMDLs) for the targeted watersheds, and for Waste Load Allocation (WLA) calculations. Also, in cooperation with the stakeholders, management strategies will be developed that are aimed at controlling both point and non-point sources. Non-point source control strategies could include, for example, incentive programs for farmers to adopt best management practices (BMPs).

Year 5

During the fifth and final year of the cycle, NPDES permits will be issued based on the Waste Load Allocations, and approved management strategies will be implemented. This will be done in close coordination with relevant stakeholders. Also, evaluation procedures will be developed and indicators will be defined to monitor if the selected management strategies actually lead to achievement of the desired water quality level. This information will be used in the first year of the next management cycle.

These activities carried out each year of the Basin Management Cycle are summarized in Table 1.1. During the first stages of IDNR implementation of a Watershed Based Approach, IDNR will need to add further detail to the activities in Table 1.1.

Table 1.1. Example of 5 Groups of Basin Management Activities

Year	Activity
1	Evaluation of results of previous projects in the basin Development of rotational station monitoring plan Rotational station monitoring
2	Water quality assessment* Setting water quality goals* Prioritization of intensive monitoring and modeling efforts Design of intensive monitoring plan
3	Intensive watershed monitoring Data processing and analysis
4	Water quality modeling Total Maximum Daily Load (TMDL) development Development of management strategies* Waste Load Allocation (WLA)
5	NPDES permit issuance Implementation of management strategies* Design of evaluation procedures / performance indicators*

(The activities marked with a * involve some form of stakeholder input or participation)

E. Delineation of Geographic Management Units

In order to effectively cover the entire State of Iowa in IDNR's water quality management program, it is recommended that Iowa be subdivided into river basins and watersheds. These will be used as units to efficiently organize water quality management efforts, like TMDL development and NPDES permitting, as described in the previous section.

Because of the 5-year duration of the water quality management cycle (which is based on the 5-year period for which NPDES permits are issued), Iowa should be divided into 5 basins or groups of basins, which will be called units. Every year activities like monitoring or permitting will be carried out in one of the 5 units, so that after 5 years all units, covering the whole state, have been addressed. Therefore, the workload should be more or less evenly balanced among the 5 units.

An important factor in determining the workload for a given unit is the number of NPDES permits to be issued in that area. Since this information cannot be easily obtained, a division will be proposed that defines five units with more or less equal land areas. It is assumed that the number of permits to be issued in these large areas is approximately of the same order of magnitude. As a basis for the division of Iowa into units, the USGS Hydrologic Unit Map has been used. However, the USGS hierarchy of regions and subregions has to be adapted in order to enable the designation of 5 units having an approximately equal area.

The following management units are proposed (see Table 1.2.) for implementation of the Watershed Based Approach in Iowa. We have attempted to balance the number of NPDES permits within each river basin combination.

Table 1.2. Example of Delineation of Geographic Management Units in Iowa

Unit	River Basin(s)	USGS Number(s)
I	Des Moines River	0710####
II	Skunk River South-Central Iowa North-Central Iowa	07080104 through 07080107 0711####, 102801## and 102802## 07020009
III	Iowa and Cedar Rivers	070802##
IV	Wapsipinicon River North-East Iowa	07080101 through 07080103 0706####
V	West Iowa	1017####, 1023#### and 1024####

II. Modeling Strategy

Modeling is used in different phases of the basin management cycle. First, modeling is used in the assessment phase, to analyze water quality impairments and determine the source of violation of water quality standards. Also, modeling plays a key role in the development of strategies for water quality improvement, like waste load allocations (WLA) and Total Maximum Daily Loads (TMDLs). The watershed approach implies that any modeling activity needs to combine both non-point source and point source modeling and take into account the entire watershed.

The watershed based approach for water quality management and WLA in Iowa will be used to evaluate the effects of both point and nonpoint sources pollution loads on water quality for all river watersheds in Iowa. A key component of this approach is utilizing simple Total Maximum Daily Loads (TMDLs) to prioritize watersheds based on the magnitude of pollutant loads in the watershed. This prioritization allows IDNR to focus its monitoring and modeling efforts on watersheds where water quality goals are not being obtained. This will provide a more comprehensive approach to water quality management and should prove more efficient than the approach currently used.

A. Considerations

A hydrological/nonpoint source pollution model and in-stream water quality model are essential tools for the development and implementation of a watershed-based approach to waste load allocations in Iowa. These models will be utilized to assess the impacts of point and nonpoint pollution sources on water quality and aid in the waste load allocation calculations necessary for IDNR's NPDES Program. The hydrological component is needed to provide streamflow data for engaged segments of a waterbody. Streamflow data for multiple segments of a river are necessary for input into the water quality model. A nonpoint source pollution model will be used to calculate sediment, nutrient, and BOD loadings from agricultural and urban land uses. These data are necessary to determine the distributed pollutant or "background" concentrations for input into the surface water quality model. The water quality model will simulate the effects of point and nonpoint source pollution loads on a waterbody under a specified set of hydrological conditions. This will enable IDNR staff to evaluate water quality conditions and implement the appropriate pollution control measures to obtain the desired water quality standards.

The hydrological/nonpoint source and water quality models should be applied to entire GMUs (watersheds or river basins) to facilitate a comprehensive approach for waste load allocations. The GMU scale is important because it provides a complete picture of the cumulative effects of point and nonpoint source pollution on water quality. This is different from the current mixing zone scale approach that the IDNR uses to calculate waste load allocations. The mixing zone approach involves modeling the point source pollutant loading along a 2,000 foot stretch of river immediately downstream of the point source discharge. The watershed-based approach involves modeling the water quality along the entire river in the drainage basin. The IDNR would continue using the mixing zone approach for waste load allocations in locations where water quality problems exists in the mixing zone.

The inclusion of nonpoint source pollution loadings into the waste load allocation calculations is an important element of the watershed-based approach. A review of Iowa's 1992-1993 Water Quality Report reveals that point source pollution has less overall impact on Iowa's waterbodies than nonpoint source pollution. Nonpoint source pollution is responsible for the majority of Iowa's waterbodies classified as water quality limited. Agricultural activities accounted for an estimated 93% of the stream miles assessed as being impacted by nonpoint source pollution. Soil erosion, with the associated sediment loadings, fecal coliforms from field runoff, nutrients, and pesticides were all cited as water quality problems attributable to agricultural nonpoint sources.

The river basin drainage area will be divided into watersheds that correspond to the river segmentation developed for the water quality model. Nonpoint pollution loadings will be calculated for ammonia (NH_3), nitrate (NO_2), phosphate (PO_4), sediment, and BOD for each of the watersheds. These data will then be input into the water quality model. The inclusion of nonpoint pollution modeling in the waste load allocations is expected to be an improvement in the level of accuracy over the present method of using state-wide "background" concentrations.

In the watershed-based approach, IDNR will evaluate point and nonpoint source loadings under a number of different historical and statistical flow conditions to determine where and when a peak pollutant concentration occurs. For this report, we have chosen flows for our example analysis that represents both high and low flow extremes. These flows we have used include the Flood of 1993 (April-July), the Spring of 1994 (April-July), $7Q_{10}$, and the low flow condition that occurred from June to August in 1988.

The IDNR presently uses the $7Q_{10}$ to calculate waste load allocations. This flow condition results in the highest concentration for many water quality parameters but may not represent the highest concentration of water quality parameters effected by nonpoint sources (sediment, nutrient, and BOD loadings). The nonpoint source pollutant concentrations resulting from agricultural activities is greatest for storms that produce surface runoff. The total pollutant concentration in a stream or river is the sum of nonpoint and point source concentrations so that the maximum pollutant concentration may not occur when the point source pollutant concentration is at maximum. The hydrological/nonpoint source pollution and river water quality models are used to aid the IDNR in determining when the maximum concentration of a particular pollutant will occur (the worst case scenario) at the specified statistical and historical flows.

Iowa can be divided into the five river basins combinations shown in Table 2, based on the 8 digit U.S. Geological Survey watersheds. During the fourth year of the basin management cycle, each river basin will be modeled to determine the waste load allocation and to assess the effectiveness of proposed non-point control programs. For modeling, the main branch of the river channel is divided into segments for the water quality model. The nonpoint source pollution loading models are applied to each watershed (8 digit watershed) to determine the loadings to be included in the river water quality model. The hydrological conditions for the analysis must be specified and point source loadings for each segment must be calculated. Then the water quality for each river segment is simulated with the water quality model to determine the permit conditions for the discharger in that segment of the river.

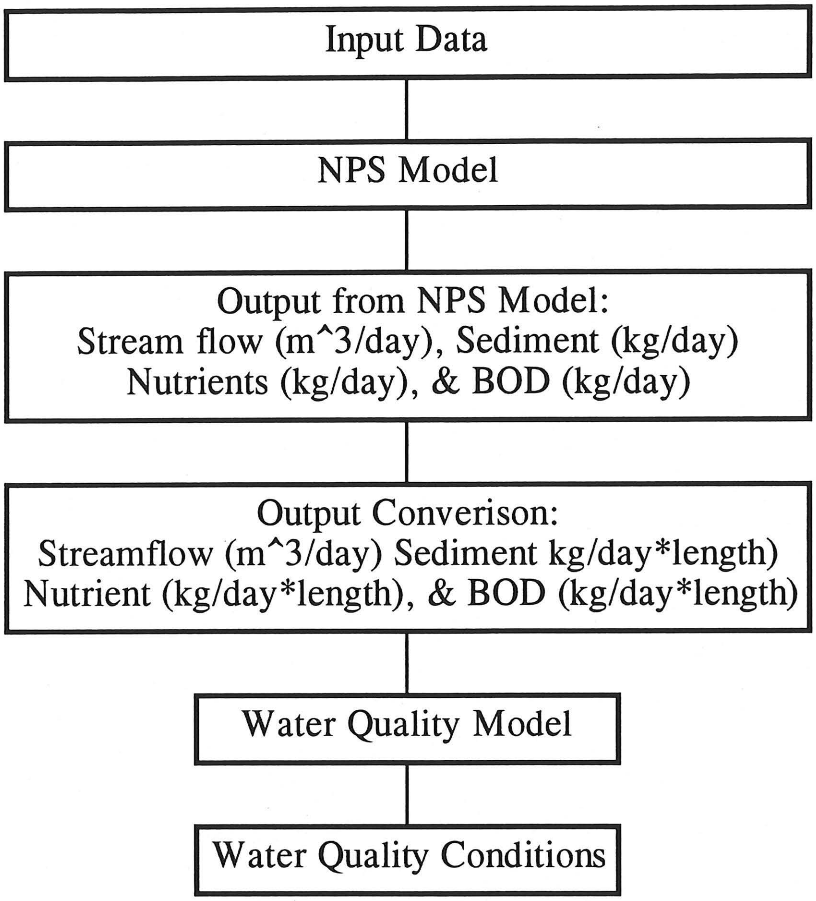
B. Linking Hydrological/Nonpoint Source Model to Water Quality Model

The sources of water pollution generally consist of two components: point and nonpoint. The sources differ significantly from each other in critical time of occurrence, control methods, and the type of pollutant involved. Parameters of concern in point sources include biochemical oxygen demand (BOD), ammonia nitrogen (NH_3 - N), suspended solids, and toxic organic/inorganic chemicals from wastewater treatment or industrial dischargers. Typically the critical condition for point source pollution is low flow conditions and the pollution discharges are controlled through the NPDES permit program.

Nonpoint source pollution is pollutant that enter the stream system diffused rather than through a discharge from a pipe. Non-point source pollution loads are larger in the agricultural areas of Iowa. The nonpoint source pollution parameters of concern are suspended solids, nitrate nitrogen (NO_3- N), phosphate (PO_4), and ammonia nitrogen (NH_3 - N). Nonpoint pollution occurs largely when precipitation is enough for surface runoff to occur, but non-point source pollution can also occur from baseflow (groundwater) entering the river during low flow periods. The largest nonpoint source pollution loads typically occur in the early spring after the soil has been plowed. Nonpoint source pollution is controlled through legislation (e.g. Iowa's Soil Loss Limit of 5 ton/acre) or through the voluntary implementation of best management practices (BMPs) (e.g. subsidizing farmers to use no till farming).

The goal of the watershed-based approach developed for Iowa is to incorporate both of these distinct pollution sources into a water quality management plan that will protect Iowa's waterbodies from both types of pollution. Figure 2.1 is a flow diagram showing how the non-point source model (NPS) and the River Water Quality Model is linked together in a modeling system.

The output data file from the hydrological/nonpoint source model contains daily estimated surface water runoff in cm, streamflow rates in m^3/day, sediment yield (kg/day), dissolved and particulate nitrogen load (kg/day), and dissolved and particulate phosphorus load (kg/day) for the given hydrologic conditions. The nutrient and sediment yields can be divided by the total channel length multiplied by two to calculate the distributed nonpoint source loadings in units of mass/day/length of channel.



Linking Flow Chart

Figure 2.1. Linking of Non-Point Source and River Water Quality Models

C. Total Maximum Daily Loads (TMDLs)

A TMDL represents the maximum daily amount of a pollutant that occurs at a point on the river or stream. TMDL is the sum of the individual pollutant loads from all sources -- point sources, nonpoint sources, and natural background sources, plus a margin of safety. A TMDL at the watershed outlet is determined by doing a simple mass balance of total pollutant loads for the watershed. The mass of pollutant entering the river or stream from all sources are summed over the watershed. The concentration of a particular pollutant is the total mass of pollutant divided by the total flow. For example, the TMDL BOD concentration could be estimated by summing all the mass of BOD discharged in the watershed and divided by the critical flow, i.e. the $Q_{7\ \mathrm{day},\ 10\ \mathrm{year}}$ at the watershed outlet. The TMDLs are intended to be a simple and quick way to evaluate the pollutant loads for a watershed.

TMDLs should be developed as part of the watershed management cycle for all GMUs in Iowa as part of the initial screening process to evaluate the magnitude and type of pollution loads in each GMU. Two TMDLs need to be developed for each watershed. The first will be a low flow TMDL that evaluates the cumulative effects of point source pollutant loads for the $Q_{7\ \mathrm{day},\ 10\ \mathrm{year}}$ low flow. Nonpoint source pollution may not be a significant component of the low flow TMDL because there would be no surface runoff occurring during the low flow condition. TMDLs for the parameters of BOD, SS, and NH_3 are needed as a minimum because these are the parameters regulated by the NPDES permit program. Pollutant loads for from NPDES permitted dischargers can be determined from the IDNR data base. If toxic organic or inorganic chemicals from a discharger are present in a waterbody in a watershed, these chemicals should also have a TMDL established.

The second TMDL would be for a high flow condition (10 year flood or actual high flow) to evaluate the cumulative effects of point and nonpoint source pollution in the watershed. The water quality parameters evaluated for the high flow TMDL include SS, NO_3, PO_4, and NH_3. Nonpoint pollution loads could be determined from an nonpoint pollution model (e.g. AGNPS), a simple nonpoint equation (e.g. USLE), or computed from water quality data (NPS load = Total Load -PS Load). Point source pollutant loads used for the low flow TMDL can also be used for the high flow TMDL.

D. Prioritization and Control Measures

After the TMDLs are completed, the watersheds can be prioritized based on those watershed with the highest TMDLs. If the low flow TMDL concentration does not exceed the IDNR water quality standard for the classification of waterbody (A, B, or C) then the NPDES permits for all dischargers in the watershed can be issued using a simple mass balance procedure after the mixing zone requirements have been satisfied. If the low flow TMDL concentration exceeds that water quality standard, then an in-stream water quality model (e.g. QUAL2E and WASP5) must be used to issue the NPDES permits after the mixing zone requirements have been met.

In watersheds where the high flow TMDL concentration exceeds the ambient water quality standards, various type BMPs could be evaluated to attempt to achieve the desired water quality. The IDNR should work cooperatively with the Department of Agriculture and local soil and water conservation districts to develop conservation plans for the priority watershed. Watersheds that have a high flow TMDL concentration below the ambient water quality standard would require no additional action.

E. Steps in TMDLs procedure for the watershed-based approach

1. Conduct a simple mass balance and preliminary assessment to determine if there is a water quality problem in a watershed.

2. Perform low flow TMDL analysis for instream BOD, NH_3, and SS concentrations responding to all loads under a flow of $Q_{7\ day,\ 10\ year}$.

3. Perform high flow TMDL analysis for NO_3, PO_4, NH_3, and SS concentrations responding to all loads using a 10-year peak flow.

4. a. If low flow concentrations meet water quality standards, IDNR should issue permits based on the mass balance or the mixing-zone modeling currently used.

   b. If low flow concentrations do not meet water quality standards, conduct more detailed water quality modeling and issue permits based on model results.

5. a. If high flow concentrations meet ambient water quality standards, no work is needed.

   b. If high flow concentrations do not meet water quality standards, conduct nonpoint source modeling and use BMPs or conservation measures to achieve desired water quality.

F. Summary

In the watershed-based approach for Iowa, two types of TMDLs can be used to evaluate both nonpoint and point pollutants. The low flow TMDL will address only point source loads for BOD, SS, NH_3, and toxic organic/inorganic chemicals for the $Q_{7\ day,\ 10\ year}$ low flow. If the low flow TMDL indicates a water quality problem, an in-stream water quality model is necessary. NPDES permits can be issued using a simple mass balance and mixing zone model if the low flow TMDL indicates that there is not a water quality problem. The high flow TMDL will address point and nonpoint source loads for 55, NO_3, PO_4, and NH_3. If the high flow TMDL indicates a water quality problem, IDNR can explore BMPs to lower the nonpoint source pollutant load.

III. Surface Water Quality Modeling

A. Introduction

1. Model selection

To develop and implement a watershed-based approach for waste load allocations in Iowa, both point sources and non-point sources in the entire watershed must be considered when surface water model is chosen. Non-point source pollutants enter surface waters at intermittent intervals that is related to meteorological events. The total pollutant concentration is contributed by both point and non-point sources. Therefore, the maximum pollutant concentration may not occur at the lowest flow. A dynamic model is needed to determine the highest concentration of pollutants in a river basin resulting from non-point source loading as well as point source loading.

After reviewing several surface water quality models, WASP5 was chosen as the surface water quality model to be used for the watershed-based approach for waste load allocations. WASP5 was chosen as surface water quality model for this project based on its ability to simulate flow, point source loading and non-point source loading dynamically and its ability to simulate sediment and toxic pollutants. WASP5 is a dynamic compartment modeling program for conventional pollutants (including DO, BOD, nutrients and eutrophication) and toxic pollutants (including organic chemicals, metals, and sediments). WASP5 can simulate and predict pollutant concentrations and their variations with time and over space, resulting from point source loading and non-point source loading and spatial and temporal variations in the entire watershed. WASP5 permits the user to structure one, two or three dimensional model. It allows the specification of time-variable exchange coefficients, flows, point source loading and non-point source loading, and water quality boundary conditions (Ambrose, et al. 1987; 1993).

WASP5 is found to have some advantages. WASP5 is an unsteady state model for conventional pollutants and toxic pollutants. Hydraulically, it is not limited to simulations for periods during which both the stream flow and waste loading are essentially constant. WASP5 can be used to determine the highest concentration of pollutant in a river basin resulting from non-point loading as well as point source loading. WASP5 can simulate sediment and toxic pollutants. On the other side, WASP5 is more sophisticated in eutrophication simulation. For the development and implementation of a watershed-based approach to waste load allocations in Iowa, WASP5 is selected.

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

2. Description of the selected model (WASP5)

a. General description

WASP is generalized modeling framework for modeling contaminant fate and transport in surface waters and is supported by the Environment Protection Agency's (EPA) environment research laboratory in Athens, Georgia. WASP5 is the latest version of a series of developments. The Water Quality Analysis Simulation Program--5 (WASP5) helps users interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decision's conditions (Ambrose, et al. 1987; 1993). WASP5 is a dynamic compartment modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program.

The flexibility afforded by the Water Quality Analysis Simulation program is unique. WASP5 allows the specification of time-variable exchange coefficients, advective flows, waste loads and water quality boundary conditions. WASP5 allows users to specify point source and non-point source loading to water bodies. It is a dynamic compartment model that can be used to analyze a variety of water quality problems in such diverse water bodies as ponds, streams, lades, reservoirs, rivers, estuaries, and coastal waters.

The equations solved by WASP5 are based on the conservation of mass. WASP5 traces each water quality constituent from the point of spatial and temporal input to its final point of export, conserving mass in space and time.

b. Overview of the model system

The WASP5 system of two stand-alone computer programs, DYNHYD5 and WASP5, that can be run in conjunction or separately conditions (Ambrose, et al. 1987; 1993). The hydrodynamics program, DYNHYD, simulates the movement and interaction of pollutants within the water. WASP5 is supplied with two kinetic sub-models to simulate two of the major classes of water quality problems: conventional pollutants(including dissolved oxygen, biochemical oxygen demand, nutrients and eutrophication) and toxic pollutants (including organic chemicals, metals, and sediments).

EUTRO5 can simulate 8 systems, Table 3.1 summarizes these systems and their use in six discrete levels of complexity. These discrete levels of complexity are suggestive. The user may choose to simulate any combination of these variables using any combination of parameter functions and values described in manual, the user may choose to simulate only one variable, such as CBOD, while bypassing (and thus holding constant) all other variables.

TOXI5 can simulate 6 systems. Table 3.2 summarizes these systems and their use in several discrete levels of complexity. These levels of complexity describe possible approaches to simulating solids, equilibrium reactions, and kinetic reactions. They are suggestive. The user may choose to simulate any combination of these variables using any combination of the parameter functions and values described in manual.

Table 3.1 EUTRO5 Systems and Levels of Complexity

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

Table 3.1 EUTRO5 Systems and Levels of Complexity (Continued)

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

Table 3.2 TOXI5 Systems and Levels of Complexity

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

Table 3.2 TOXI5 Systems and Levels of Complexity (Continued)

Complexity Level	Explanation
Solids1	Descriptive solids concentration field
Solids2	Descriptive solids concentration field with specific solids transport rates
Solids3	Simulated total solids
Solids4	Three simulated solids types
Equil1	Constant partition coefficient
Equil2	Spatially-variable partition coefficients
Equil3	Hydrophobic sorption
Equil4	Solids-dependent partitioning
Equil5	Sorption plus ionic speciation
Kinetic1	Constant half lives or rate constants
Kinetic2	Spatially-variable rate constants
Kinetic3	Second order rates
Kinetic4	Transformation products

c. Summary

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

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

B. Modeling procedure

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

C. Application to the Cedar Creek

1. Considerations

The Cedar Creek watershed is located in southeast of Iowa. The river merges with South Skunk River. In the Iowa Administrative Code, Cedar Creek River is identified as class B(WW) from mouth to confluence with Little Cedar Creek and B(LR) from confluence with Little Cedar Creek to confluence with an unnamed tributary by Environmental Protection Commission of Iowa. The class B(WW) water is to be protected as significant resource warm water. "Water in which temperature, flow and other habitat characteristics are suitable for maintenance of a wide variety of reproducing populations of warm water fish and associated aquatic communities, including sensitive species" (Iowa Administrative Code, Sec 61.3(1)). The class B(LR) water is to be protected as limited resource water. Water that only supports species able to survive in a wide range of condition, which are generally not used for human consumption. Criteria for Dissolved Oxygen for class B(WW) and B(LW) is 5.0 mg/L or higher (Iowa Administrative Code, Sec 61.3(3)). Criteria for Ammonia Nitrogen for class B(WW) are listed in Table 3.3 (Iowa Administrative Code, Sec 61.3(3)).

Table 3.3 Criteria For Ammonia Nitrogen -- Warm Water Stream and Lake (all values expressed in milligrams per liter as Nitrogen)

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

Based on the water quality data monitored between 1988 and 1995, the highest water temperature is 30°C in Cedar Creek low flow period (June - September) and PH range is 7.5-9.3. The criteria of total ammonia as nitrogen in Iowa State Standard depends on the temperature and PH. The criteria of total ammonia as nitrogen from Iowa State Standard is less than 0.8 mg/L for PH = 9.0 and T = 30°C.

In Cedar Creek watershed, there are seventeen point sources discharges into the river. Most of point sources are very little except Fairfield city Sewage Treatment Plant discharge much more than others. Because there is only one USGS gauging station on Cedar Creek river, we do not have any low flow information for other points in Cedar Creek River. At the outlet of Fairfield city Sewage Treatment Plant discharging to Cedar Creek River, we assume the streamflow is directly proportional to drainage area. From "Annual and Season low flow characteristic of Iowa Stream" (USGS, 1979) for USGS gauging station 05-473400, the 7-day 10-year low streamflow was 0.3 cfs. At the point of Fairfield city Sewage Treatment Plant discharging to Cedar Creek River, the drainage area is 2/3 drainage area of gauging station

05-473400. Therefore, At the outlet of Fairfield city Sewage Treatment Plant, the 7-day 10-year low streamflow was assumed as 0.2 cfs.

From 1987 to 1994, the range of effluent from Fairfield city Sewage Treatment Plant was 0.7-2.2 MGD. During low flow period, the effluent is less than 1.2 MGD. 1.2 MGD (1.85 cfs) is used as the flow from Fairfield city Sewage Treatment Plant. For this model application, the limit of total ammonia concentration for Fairfield city Sewage Treatment Plant is 0.9 mg/L.

2. Input data

In Cedar Creek River, there is only one water quality monitoring station installed and maintained by the Iowa Department of natural Resources. No special studies for this river have been done before. The constants and coefficients in the model can't be calibrated and verified because of insufficient field data. Literature values of constants and coefficients are used to calculate waste load allocation. In Hydroscience (1971), the equation for the relationship between deoxygenation rate K_d at 20°C and depth is suggested as

$$\begin{aligned} K_d &= 0.3\left(\frac{H}{8}\right)^{-0.434} && \text{for } 0 \leq H \leq 8 \\ &= 0.3 && \text{for } H > 8 \end{aligned}$$

where H is the depth in ft and K_d is in day^{-1}. In "Principles of Surface Water Quality Modeling and Control" (Thomann, 1987), "The range of values for K_N (denitrification rate) is approximately the same as for deoxygenation coefficient of the CBOD. Therefore, for the deeper larger bodies of water, K_N value of 0.1-0.5 day^{-1} at 20°C are typical. For smaller streams, values greater than 1/day are not uncommon." A value of 0.5 day^{-1} is assumed for K_N in this application.

3. Results

Using $K_d = K_N = 0.5\ \text{day}^{-1}$, an input file for EUTRO5 submodel was made. Results for DO, CBOD5, and NH3 had been obtained for various loading rates from the output files of the model. Figures 3.1-3.5 show the results for different point source loading. From the model results, the acceptable CBOD5 concentration is 6.5 mg/L at the discharge point in the river and the allowable CBOD5 concentration in the effluent of Fairfield City Sewage Treatment Plant is calculated as 7.2 mg/L.

4. Waste load allocation

In waste load allocation considering the 7-day 10-year low streamflow (0.2 cfs), the allowable concentrations in discharges from the Fairfield City Sewage Treatment Plant are calculated from the above model results as: CBOD5 < 7.2 mg/L and NH3 < 0.9 mg/L.

D. Application to the Des Moines River

1. Introduction

The 24 mile reach of the Des Moines River below Des Moines City receives wastewater from the Des Moines Sewage Treatment Plant (point source) and from non-point sources that mainly come from agricultural cropland. Both point source and non-point source discharges affect the water quality of the river. Discharging of point source and non-point sources into the reach of river causes biochemical processes. For the watershed-based approach, the effects of wastewater from the Des Moines Sewage Treatment Plant and non-point source discharges are needed to determine. WASP5 Model was calibrated and verified for study reach. The verified WASP5 Model was applied to simulate some of the biochemical processes and calculate the waste load allocation. The study reach is from the outfall of the treatment plant(river mile 198.5) to downstream distance of about 24 miles.

The water quality model was applied to simulate the instream concentration of dissolved oxygen, carbonaceous biochemical oxygen demand, and total ammonia as nitrogen. For these three parameters, WASP5 Model was calibrated and verified. The verified model was applied to various combinations of different discharges from point sources and non-point sources, and different flow conditions. The potential of failing to meet water quality standard is greatest during lower streamflows, higher stream temperatures or both, or during highest concentration of pollutants from runoff. The water quality model was used as a tool to evaluate the effects of discharging from treated wastewater from Des Moines Sewage Treatment Plant and discharging from non-point sources mainly coming from cropland and the water quality model was used as a tool to identify the waste assimilation capacities of the river.

The Environmental Engineering Division of the Department of Civil and Construction Engineering at Iowa State University has conducted water quality monitoring along the Des Moines River under an ongoing contract with the United States Army Corps of Engineers, Rock island District since 1968. Fig. 3.6a shows a vicinity map and the locations of regular sampling stations (Lutz, 1994). The simulation domain is shown in Fig. 3.6b. In order to investigate the effects of the Des Moines Sewage Treatment Plant discharge on the water quality of the Des Moines River, three special profile studies were conducted on 24 September 1975, 15 October 1975, and 13 July 1977. In special profile studies, more sampling sites were set from above the of the treatment plant to distance of about 22 miles below the treatment plant. The data obtained on 13 July 1977 was used to calibrate the WASP5 Model. The data obtained on 24 September 1975, and on 15 October 1975 were used to verify WASP5 Model.

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

2. Water Quality Standards

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

3. Hydrological characteristics

The watershed drainage area of the 24 mile reach is about 1776 mi.^{2}, The U. S. Geological Survey gauging station (05485500) is located at river mile 200.7, which is 2.2 mile upstream of the study reach. The streamflow in the Des Moines River is quite variable from year to year and season to season. The variability and duration of streamflow in the Des Moines River are an important water quality consideration.

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

4. Data Collection

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

The Environmental Engineering Division of the Department of Civil and Construction Engineering at Iowa State University has conducted water quality monitoring along the Des Moines River under an ongoing contract with the United States Army Corps of Engineers, Rock island District since 1968. To evaluate the effects of the Des Moines Sewage Treatment Plant discharge on the river water quality, some special profile studies were conducted by The Environmental Engineering Division of the Department of Civil and Construction Engineering at Iowa State University. Two special profile studies were conducted from the outfall of the treatment plant to distance of about 11 miles to 22 miles below the treatment plant on 24 September 1975 and 15 October 1975. Among the data of 24 September 1975, the data of five sampling station was used to verify the model. Among the data of 15 October 1975, the data of five sampling station was used to verify the model. Severe drought conditions experienced in central Iowa during the summer of 1977. The low flow condition in 1977 offers an excellent opportunity to calibrate the water quality model as water column kinetics becomes more pronounced during low flow periods. A special profile study was conducted on 13 July 1977. Sampling was conducted at eight river locations from above the outfall of the treatment plant to distance of about 27 miles below the treatment plant. Because the very low flow condition, the oxygen sag is much greater with the minimum in the sag occurring farther upstream than two profile studies on 24 September 1975 and 15 October 1975. Among the data of 13 July 1977, the data of six sampling stations were used to calibrated the model because no other point source information except the Des Moines Sewage Treatment Plant. The water quality data used in this study were from a report entitled "Water Quality Studies --Red Rock and Saylorville Reservoirs, Des Moines River, Iowa" (Baumann, et al. 1977a, 1977b) are listed in Tables 3.4- 3.6.

Table 3.4 Data from the July 13,1977 profile study

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

Table 3.5 Data from the September 24,1975 profile study

Station	River Miles	DO (mg/L)	BOD_5 (mg/L)	Ammonia (mg/L)
1	197.5	11.16	9.1	0.99
2	195.8	10.49	9.4	0.73
3	193.4	9.65	9.1	0.78

4	190.8	9.77	8.6	0.71
5	187.8	9.92	9.9	0.77

Table 3.6 Data from the October 15,1975 profile study

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

5. Model Calibration and Verification

The one dimensional steady state model was calibrated and verified. The first upstream station data was used as Boundary condition. The loading rate from the Des Moines Sewage Treatment Plant is major input to the model, it is incorporated into the EUTRO5 input files via the boundary condition group. The water temperature data at monitoring stations were used for input. The calibration parameters were denitrification rate, the half-saturation constant for nitrification-oxygen limitation and the CBOD deoxygenation rate. In the model calibration, adjustments were made to various reaction coefficients within appropriate range until simulation output match the field observations on 13 July 1977. Appropriate ranges for each parameter were defined by literature value. In the model verification, same various reaction coefficients were used for input, and different sets of field data were used to verify the model. As the results of the calibration and verification of the model, the each coefficient identified for this reach of the Des Moines River are presented in Table 3.7. The literature value is come from "Principles of Surface Water Quality Modeling and Control" (Thomann, 1987).

Table 3.7 Summary of calibrated model parameters

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

Figure 3.7 shows the result of calibration with data on 13 July 1977. The predicted DO, BOD, and ammonia nitrogen concentration profiles in the reach of the Des Moines River below Des Moines City were examined and compare favorably with field data by visual inspection in first four sample point but last two sample point. The predicted BOD of the last two sample points is lower than the filed data and The predicted DO of the last two sample points is higher than the filed data. There is a tributary before the last two sample point. The

water quality data in this tributary is not available. From historical water quality data of the Des Moines River, there is pollutant in this tributary. The predicted results for the last two sample points were reasonable. Figure 3.8 shows the result of verification with data on 24 September 1975, Figure 3.9 shows the result of verification with data on 15 October 1975. The predicted DO, BOD and ammonia nitrogen concentrations in two verifications closely agree with the field data.

6. Application

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

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

Figure 3.10-3.14 show the application results for the different streamflow and point source loading condition. A summary is given in Table 3.8. These results show how much waste can be discharged into the study reach that do not cause exceed to the water quality standards for only considering point source (the Des Moines Sewage Treatment Plant) in low streamflow condition.

Table 3.8 Summary of model application results: point source only

	Streamflow	Point source loading (from Des Moines Sewage Treatment Plant)
Fig 3.10	Q7, 10 (98 cfs)	BOD_5 = 30.0 mg/L, NH_3 = 3.2 mg/L
Fig 3.11	Q7, 10 (98 cfs)	A: BOD_5 = 21.1 mg/L, NH_3 = 3.2 mg/L. B: BOD_5 = 30.0 mg/L, NH_3 = 3.2 mg/L. C: BOD_5 = 35.6 mg/L,

		NH_3 = 3.2 mg/L.
Fig 3.12	Q7, 5 (135 cfs)	BOD_5 = 34.2 mg/L, NH_3 = 3.6 mg/L
Fig 3.13	Q7, 2 (264 cfs)	BOD_5 = 49.7 mg/L, NH_3 = 5.2 mg/L
Fig 3.14	Q84% (399 cfs)	BOD_5 = 66.0 mg/L, NH_3 = 7.0 mg/L

Girton (1994) reported results from his non-point source research on upper Des Moines River and Raccoon River. The regression equation for annual unit load as a function of annual discharge was: $BOD_5 = 0.46q+1.41$ (lbs/ac/yr); $NH_3 = 0.035q+0.052$ (lbs/ac/yr). Because median value of annual mean discharges was 3580 cfs (4.9 in/yr) (Water Resources Data, Iowa, Water Year 1989), therefore average BOD_5 discharge from non-point source is computed as 3.7 (lbs/ac/yr); average NH_3 discharge from non-point source is computed as 0.22 (lbs/ac/yr).

Figure 3.15-3.16 show the application results for the different streamflow and point source loading and non-point source loading conditions. Assume the point source discharge from the Des Moines Sewage Treatment is same as the limited discharge from Q7, 10 streamflow condition. Plant Summary is list in Table 3.9. These results show how much waste can be discharged into the study reach that do not cause exceed to the water quality standards for considering point source (the Des Moines Sewage Treatment Plant) and non-point source in higher streamflow conditions.

Table 3.9 Summary of model application results: point and nonpoint sources

	Streamflow	Point source loading from Des Moines Sewage Treatment Plant	Non-point source loading
Figure 3.15	Q84% (399 cfs)	BOD_5 = 30.0 mg/L, NH_3 = 3.2 mg/L	Scenario: A: BOD_5 = 0 lbs/ac/yr; NH_3 = 0 lbs/ac/yr B: BOD_5 = 3.7 lbs/ac/yr; NH_3 = 0.22 lbs/ac/yr C: BOD_5 = 18.5 lbs/ac/yr; NH_3 = 1.1 lbs/ac/yr
Figure 3.16	Qmean (3580 cfs)	BOD_5 = 30.0 mg/L, NH_3 = 3.2 mg/L	Scenario: A: BOD_5 = 0 lbs/ac/yr; NH_3 = 0 lbs/ac/yr B: BOD_5 = 18.5 lbs/ac/yr; NH_3 = 1.1 lbs/ac/yr C: BOD_5 = 37 lbs/ac/yr; NH_3 = 2.2 lbs/ac/yr

7. Summary

For watershed based approach, the verified model of WASP5 for Des Moines River can be used as a tool to evaluate various water quality management strategies in a subwatershed that involves point source and non-point source discharge and water quality in the Des Moines River. The model of WASP5 for Des Moines River has been demonstrated to offer highly accurate predictions of water quality (DO, BOD and ammonia). Given appropriate field data, this approach may be expected to provide accurate results for other system.

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

E. Conclusions

Surface water quality modeling provides a means to predict the impacts of natural processes and human activities on physical, chemical, and biological characteristics of a water body. Models are used widely to evaluate the impacts of waste loads from wastewater treatment plants or pollutant loads from various other point sources and nonpoint sources. For the watershed-based approach, selected surface water quality models should be applicable to a watershed scale and various sources of pollution. For choosing a model, site-specific characteristics, required accuracy and project resources (data, staff, time) need to be considered. QUAL-2E, WASP and MULTI-SMP/SMPTOX3 are recommended by EPA for the watershed-based approach. WASP5 is a detailed receiving water quality model. It allows users to interpret and predict water quality responses to natural phenomena and manmade stressed for various pollution management decisions. WASP5 is a dynamic compartment modeling program for aquatic systems, including both the water column and the underlying benthos. The model includes the time-varying processes of advection, dispersion, point and nonpoint mass loading, and boundary exchanges. WASP5 may be applied in two modes: (1) EUTRO for nutrient and eutrophication analyses and (2) TOXI for analysis of toxic pollutants and metals. The flexibility of WASP5 is unique in that it permits the modular to structure one two, or three dimensional model applications to rivers, lakes, estuaries or open coastal areas. Based on the application of WASP5 to Cedar Creek River and to the Des Moines River demonstrated above, WASP5 is recommended to be used for watershed-based approach in Iowa, although other models(such as QUAL-2E) may be selected.

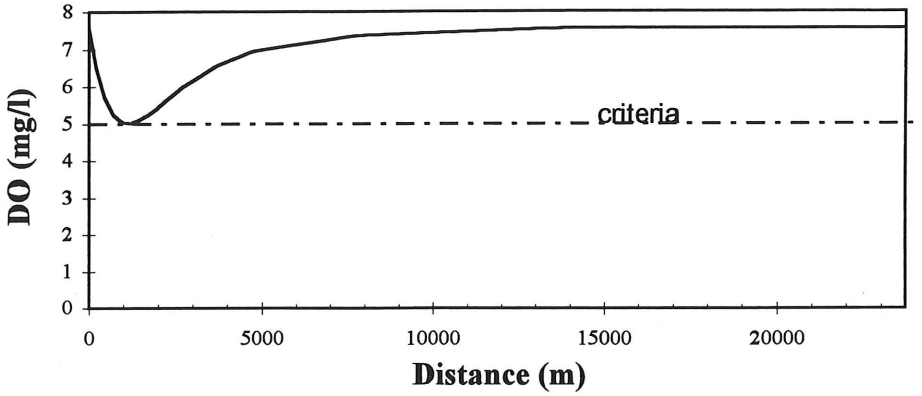


Figure 3.1 Calculated DO in Cedar Creek: STP CBOD5 = 7.2 mg/L, NH3 = 0.9 m

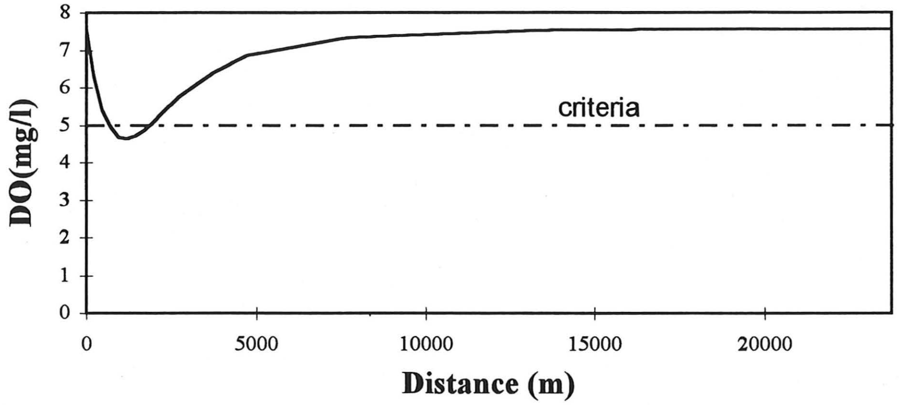


Figure 3.2 Calculated DO in Cedar Creek: STP CBOD5 = 8.9 mg/L, NH3 = 0.9 m

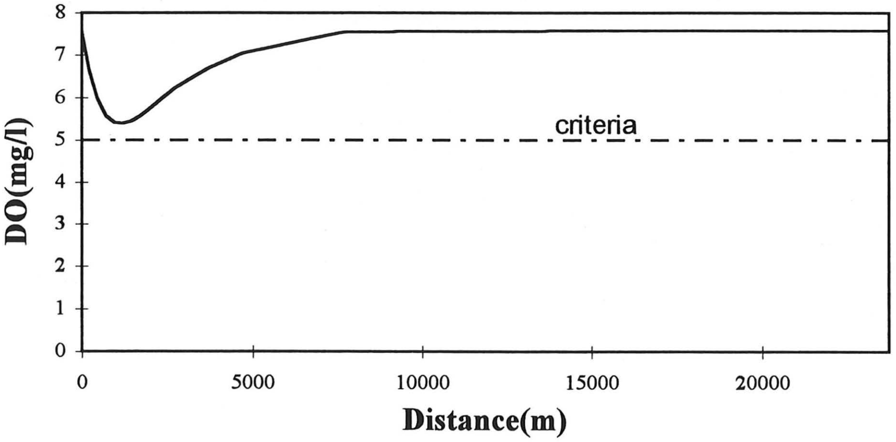


Figure 3.3 Calculated DO in Cedar Creek: STP CBOD5 = 5.5 mg/L, NH3 = 0.9 m

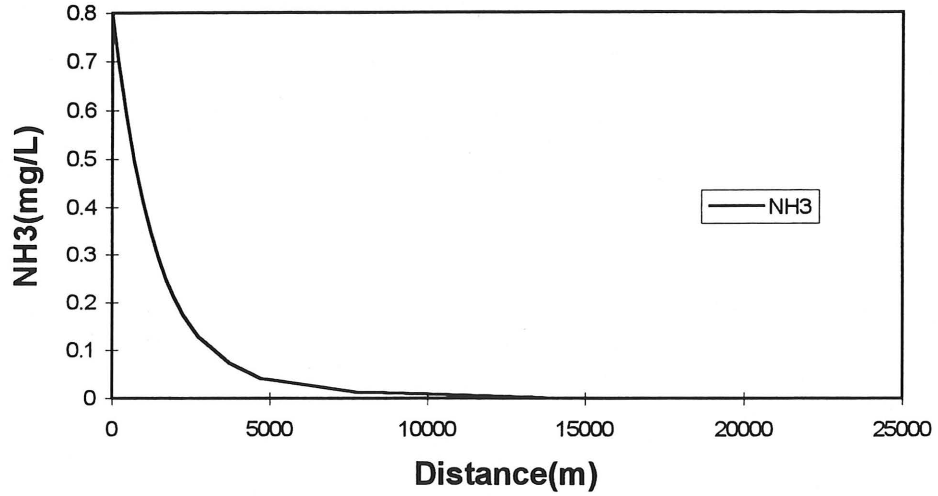


Figure 3.4 Simulated NH4 in Cedar Creek: STP CBOD5 = 7.2 mg/L, NH3 = 0.9 m

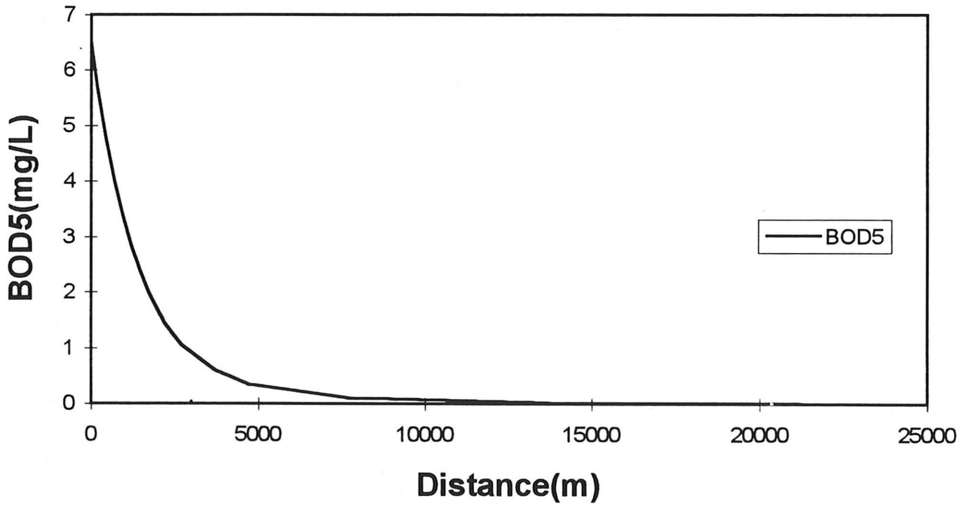


Figure 3.5 Simulated CBOD5 in Cedar Creek: STP CBOD5 = 7.2 mg/L, NH3 = 0.

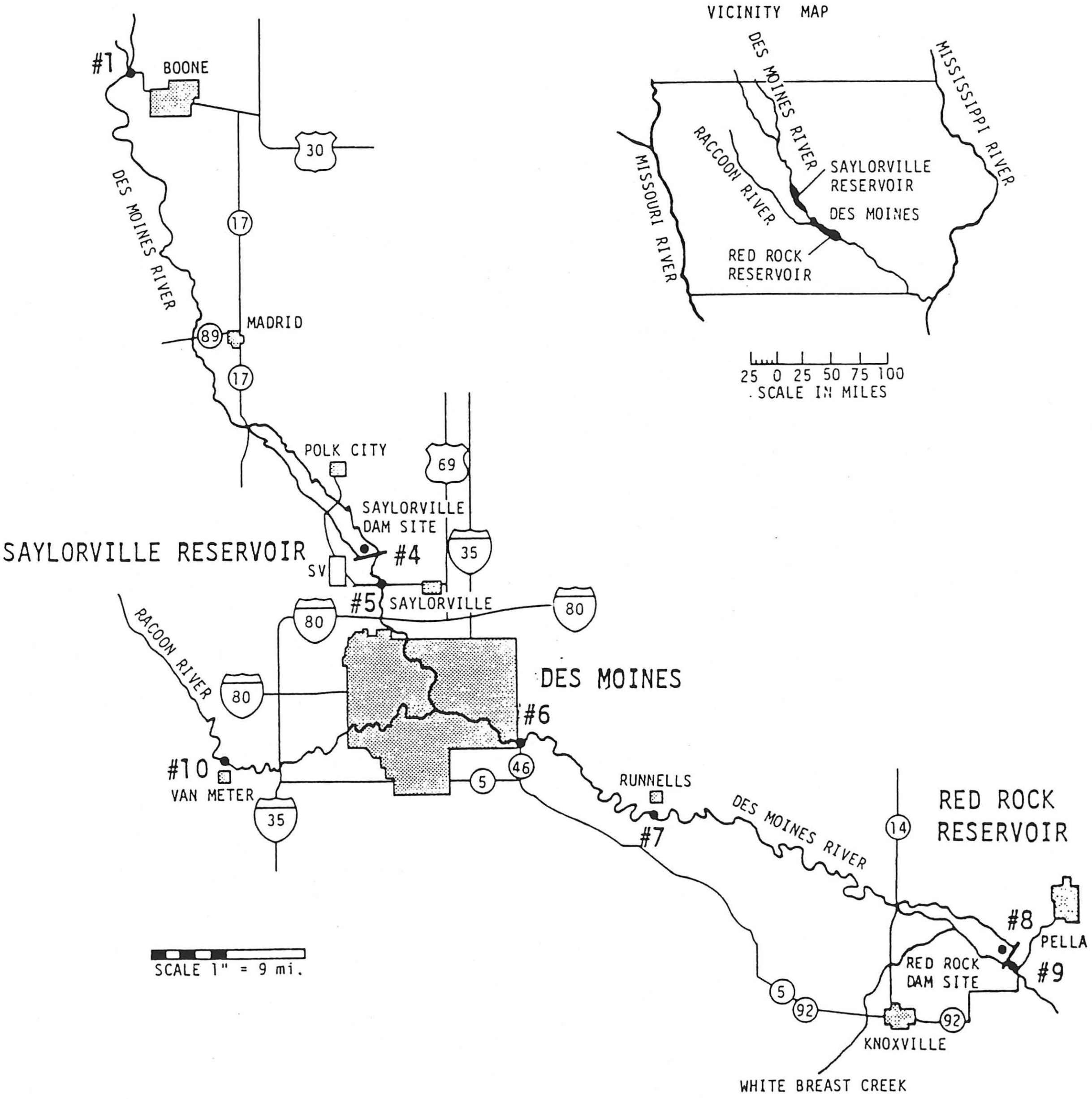


Fig. 3.6a Location map for sampling stations on Des Moines River, the Raccoon River, Saylorville Reservoir and Red Rock Reservoir

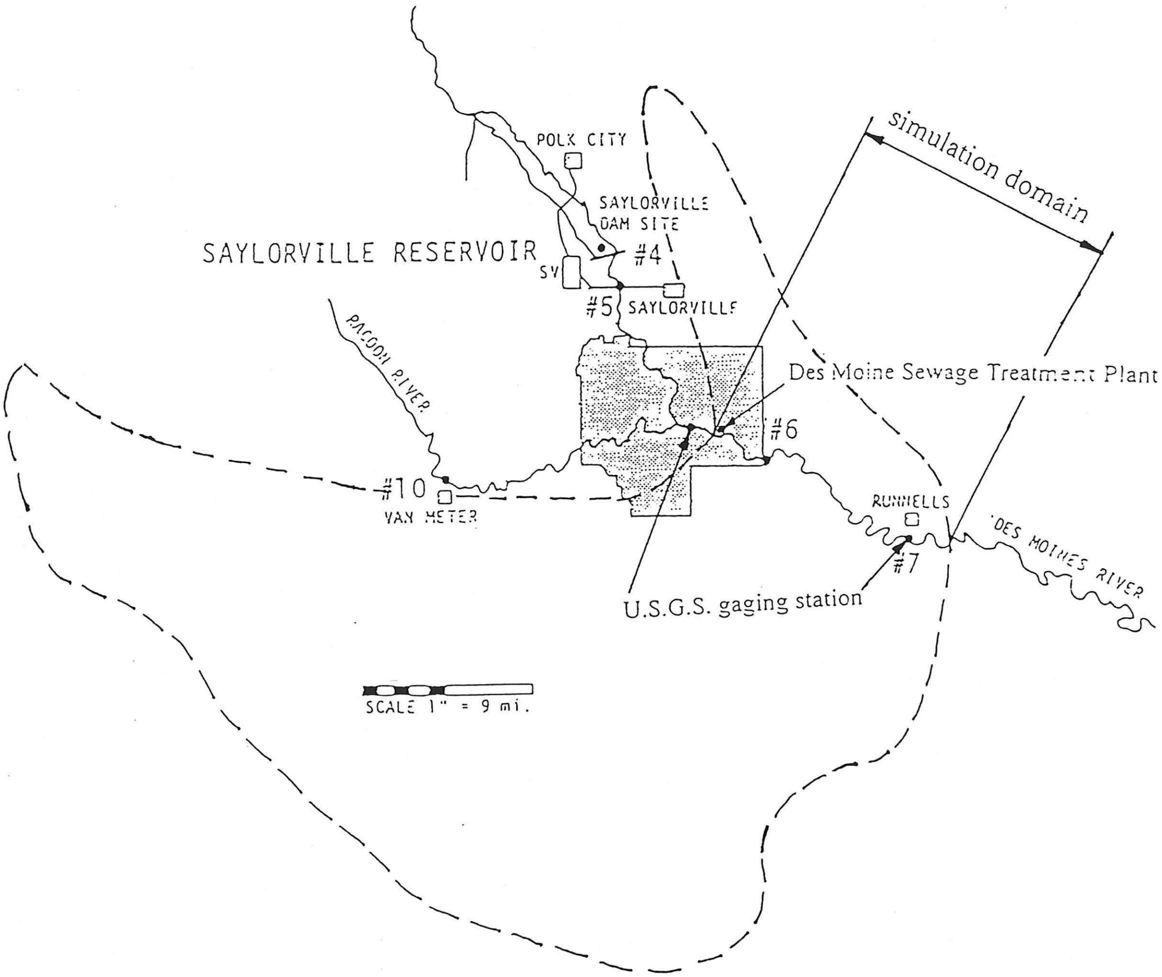


Fig. 3.6b Simulation domain for model application to the Des Moines River

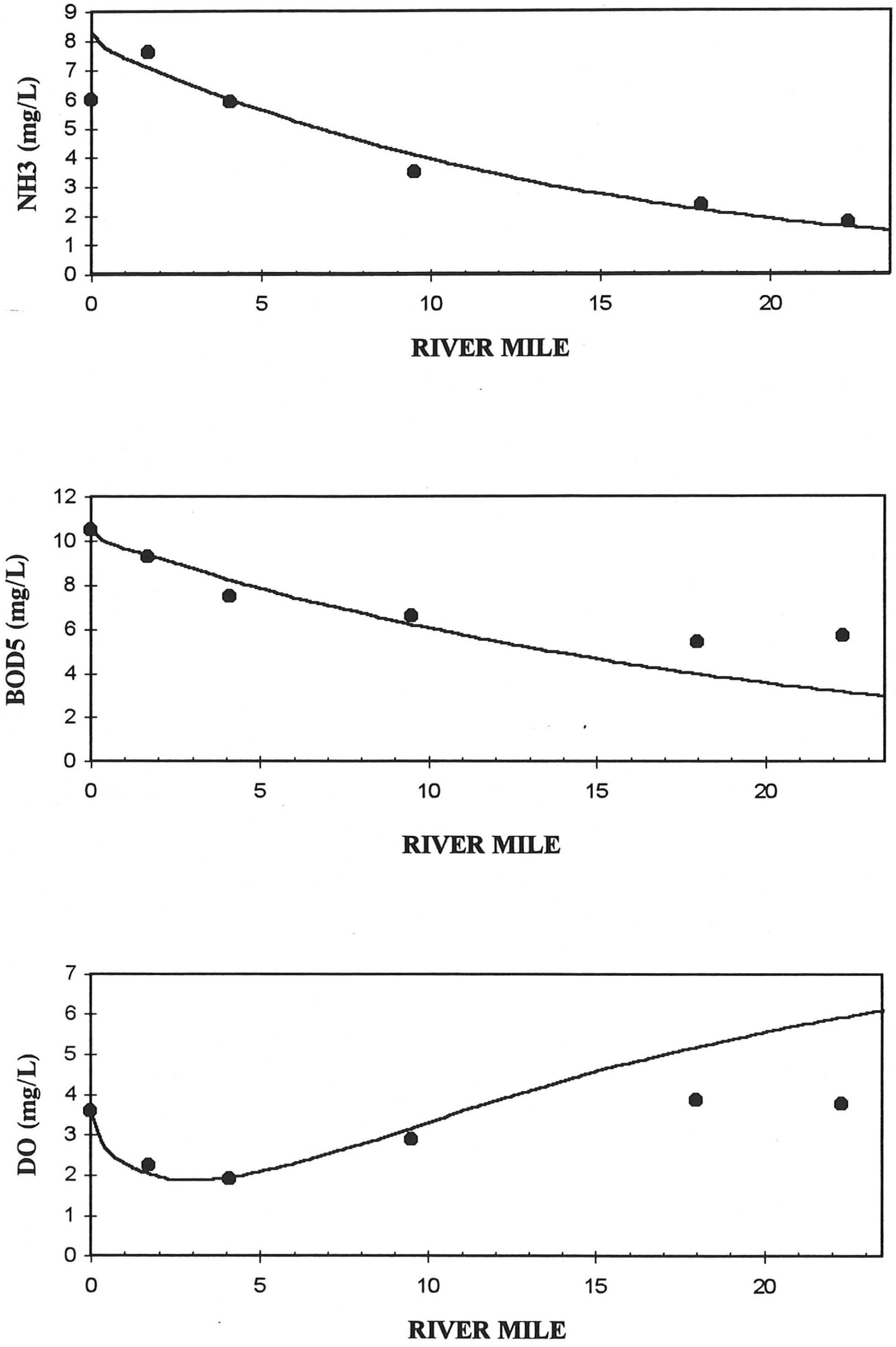


Figure 3.7 Measured (dots) and simulated (lines) ammonia, BOD and DO (July 13, 1977)

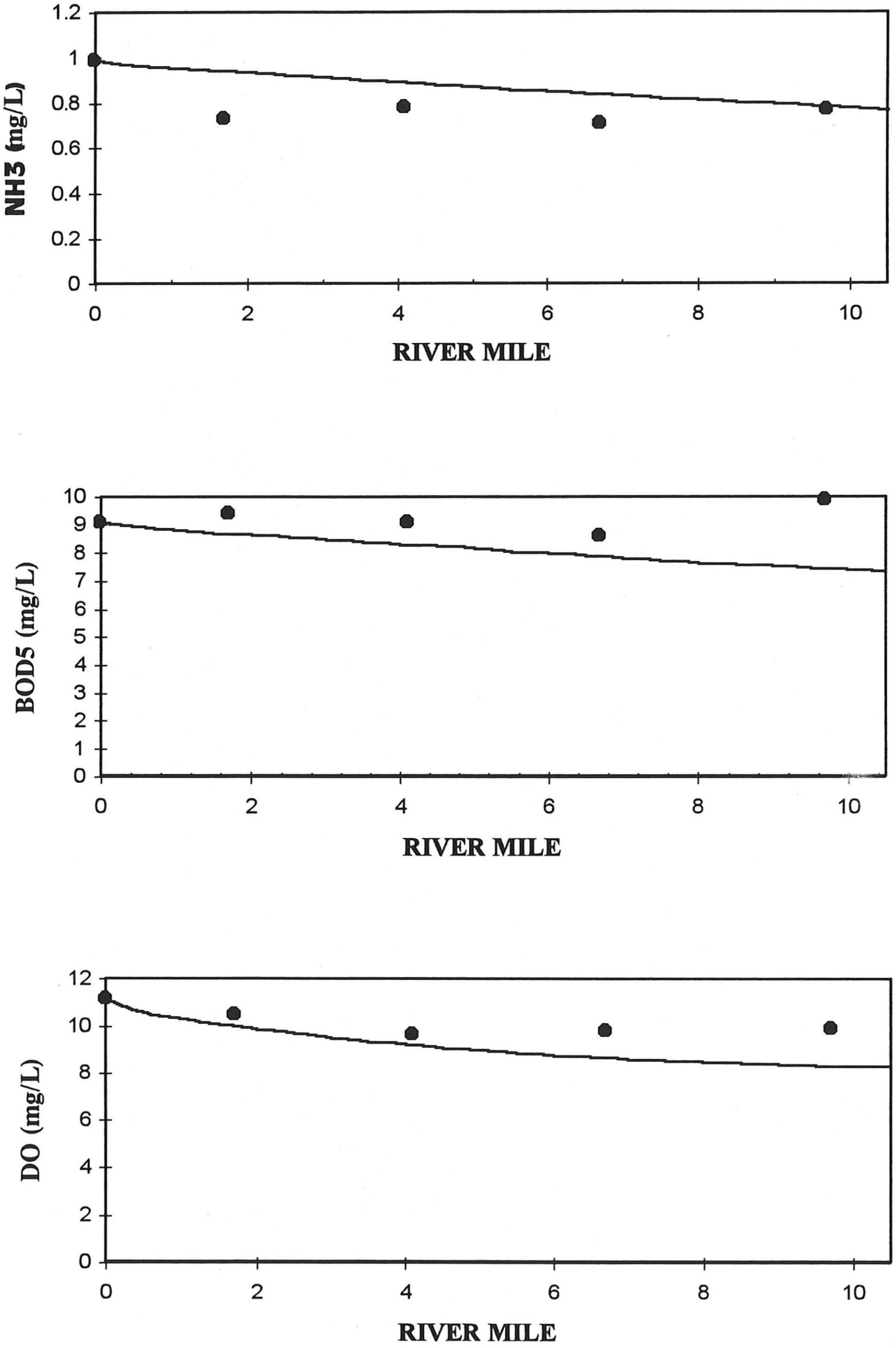


Figure 3.8 Measured (dots) and simulated (lines) ammonia, BOD and DO (Sept. 24, 1975)

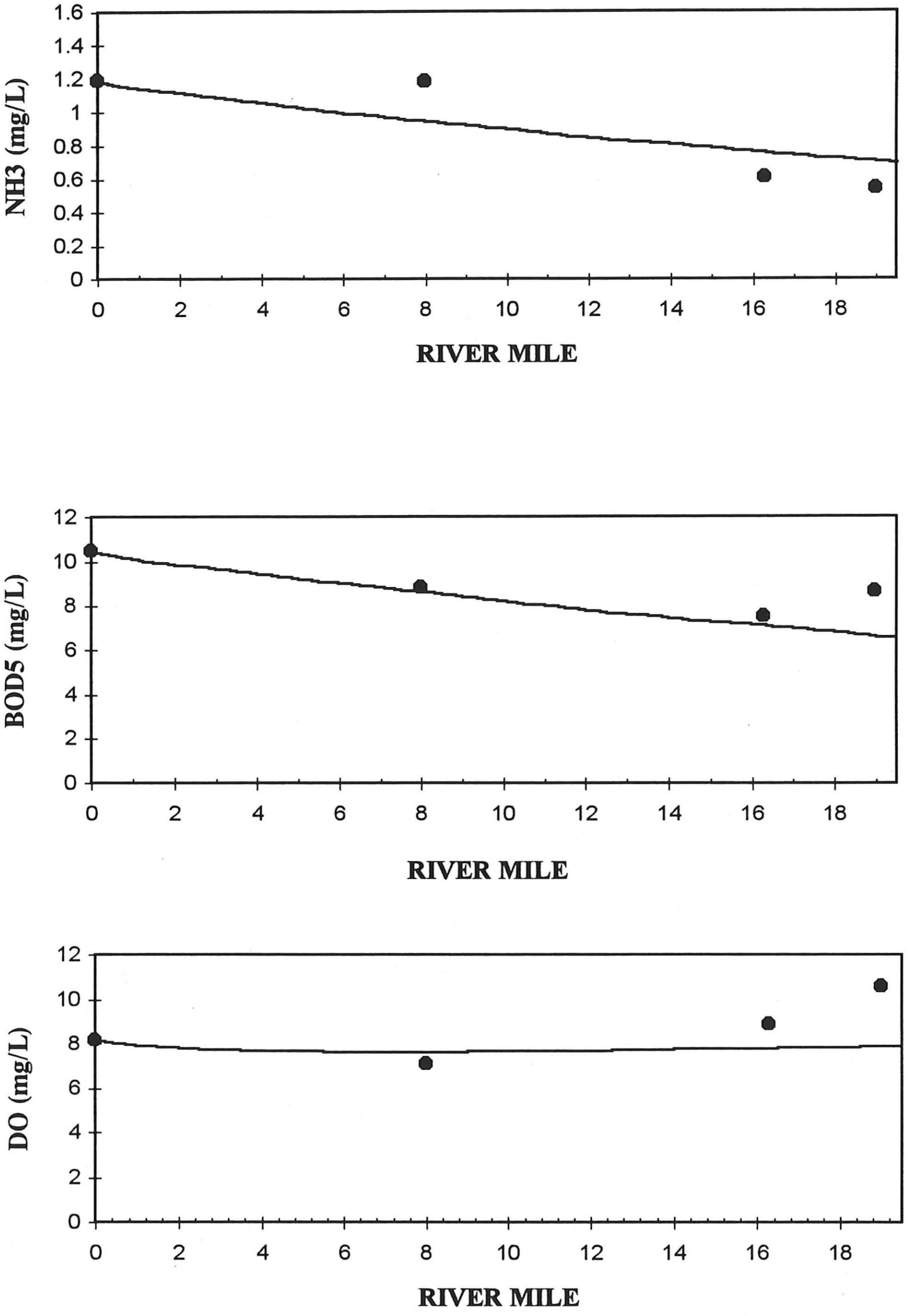


Figure 3.9 Measured (dots) and simulated (lines) ammonia, BOD and DO (Oct. 15, 1975)

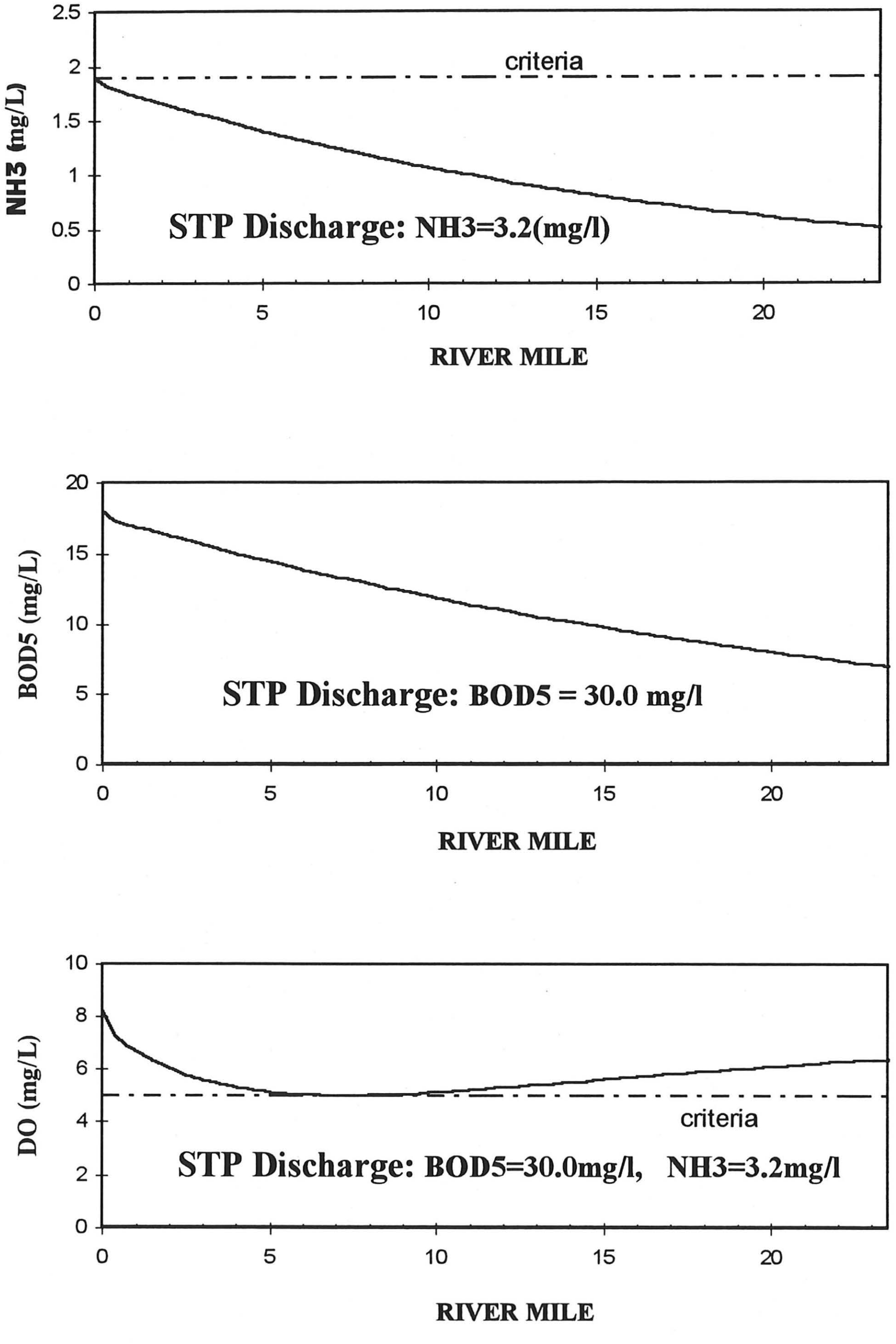
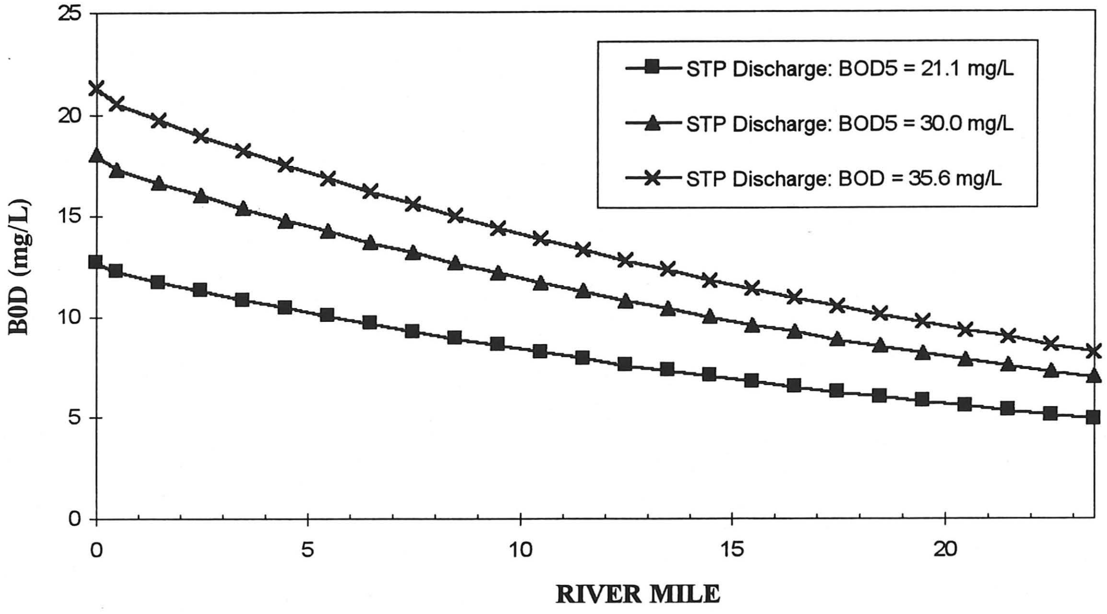


Figure 3.10 Predicted ammonia, BOD and DO for Q7,10



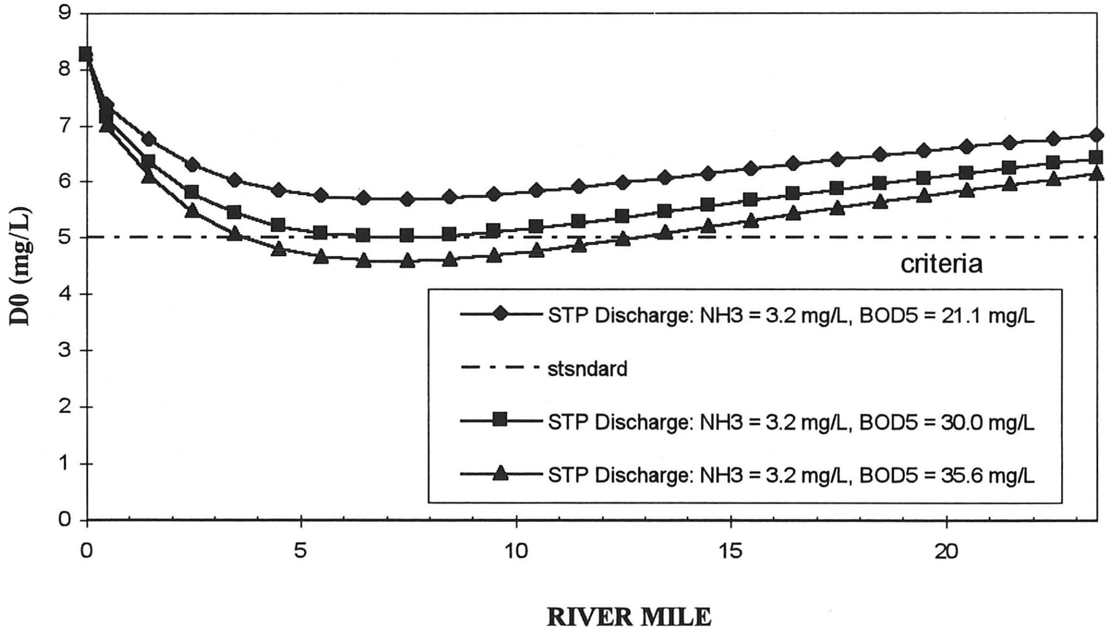


Figure 3.11 Predicted BOD and DO for Q7,10 and different point loadings

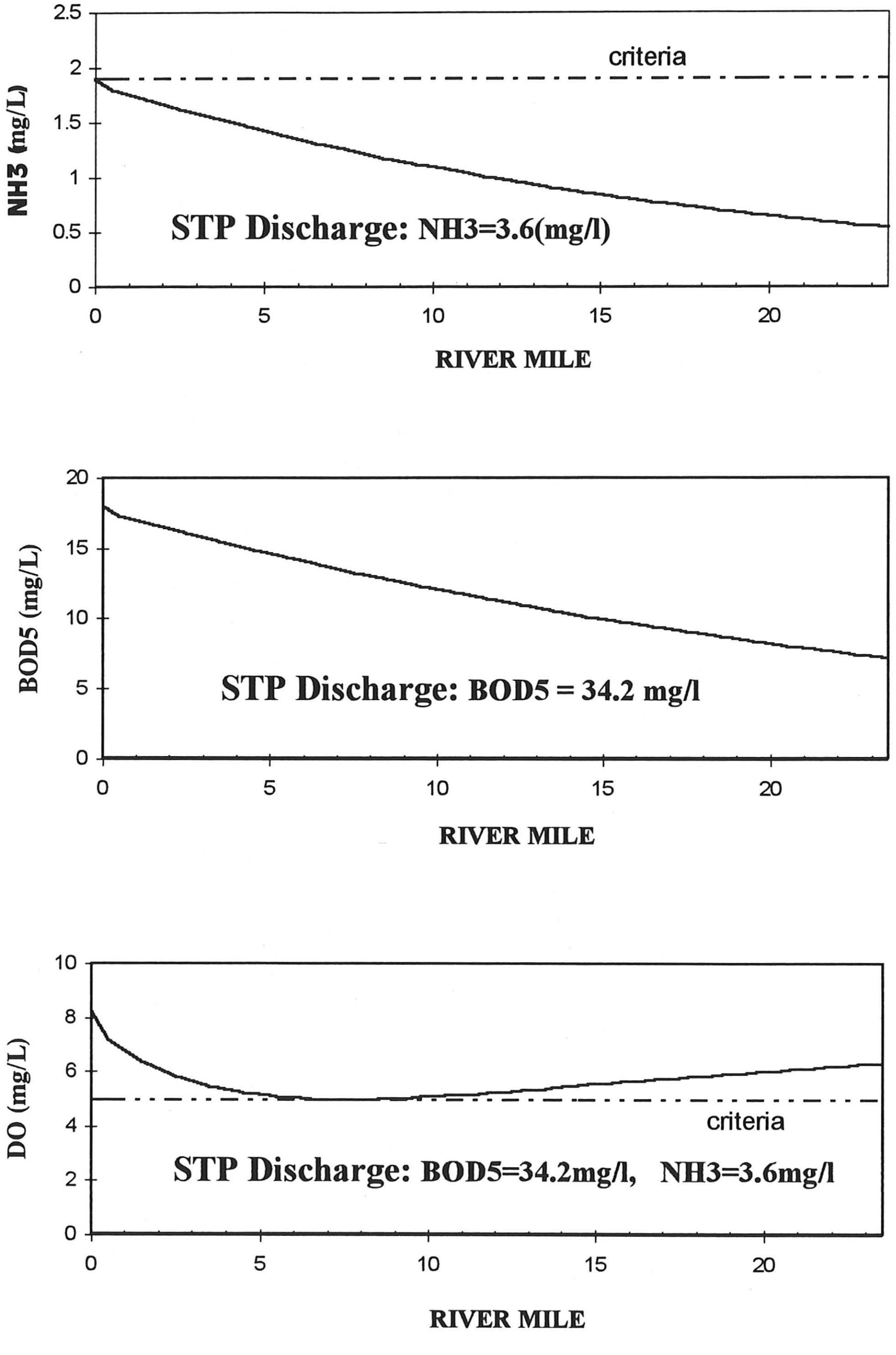


Figure 3.12 Predicted ammonia, BOD and DO for Q7, 5

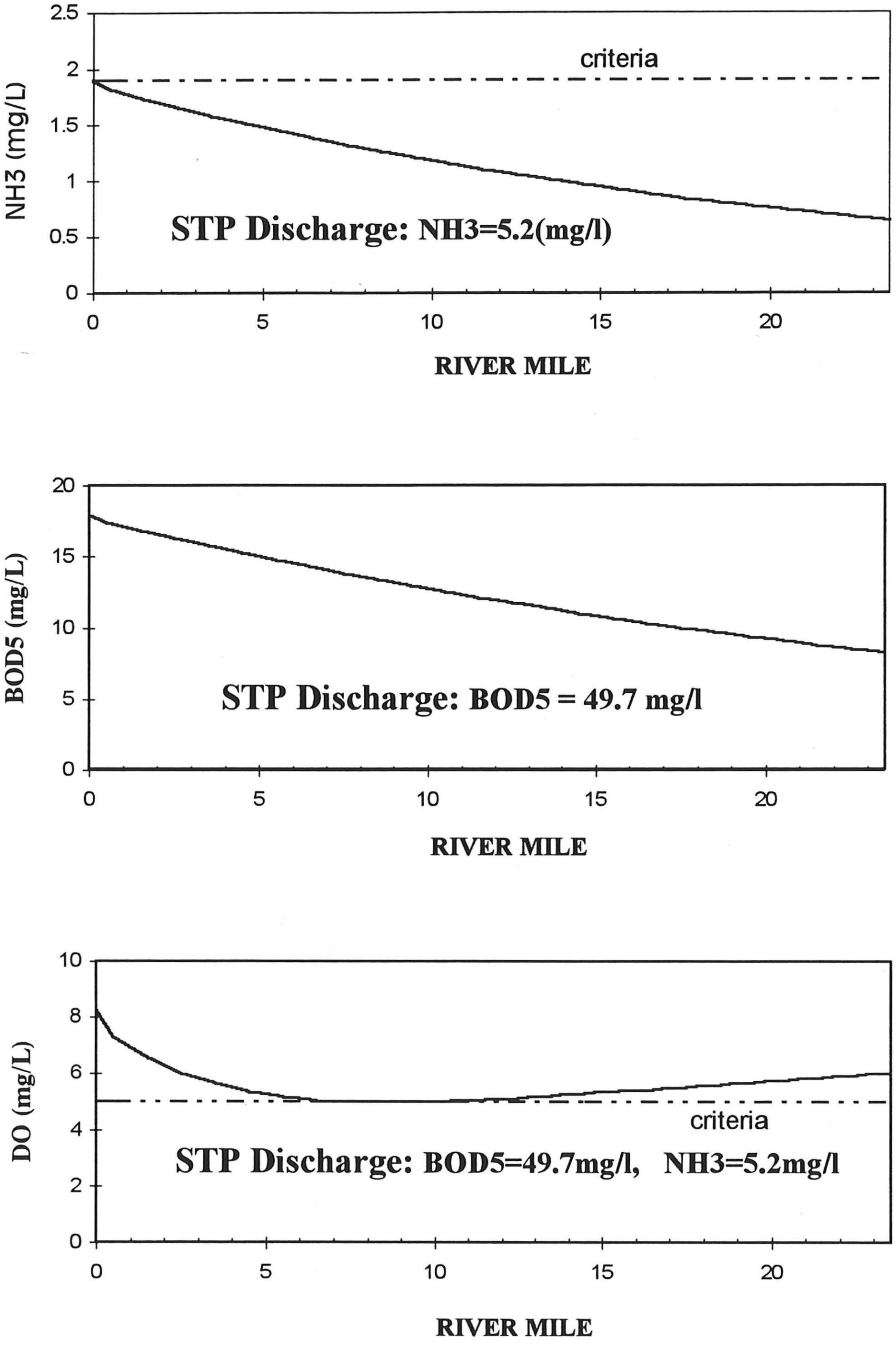


Figure 3.13 Predicted ammonia, BOD and DO for Q7, 2

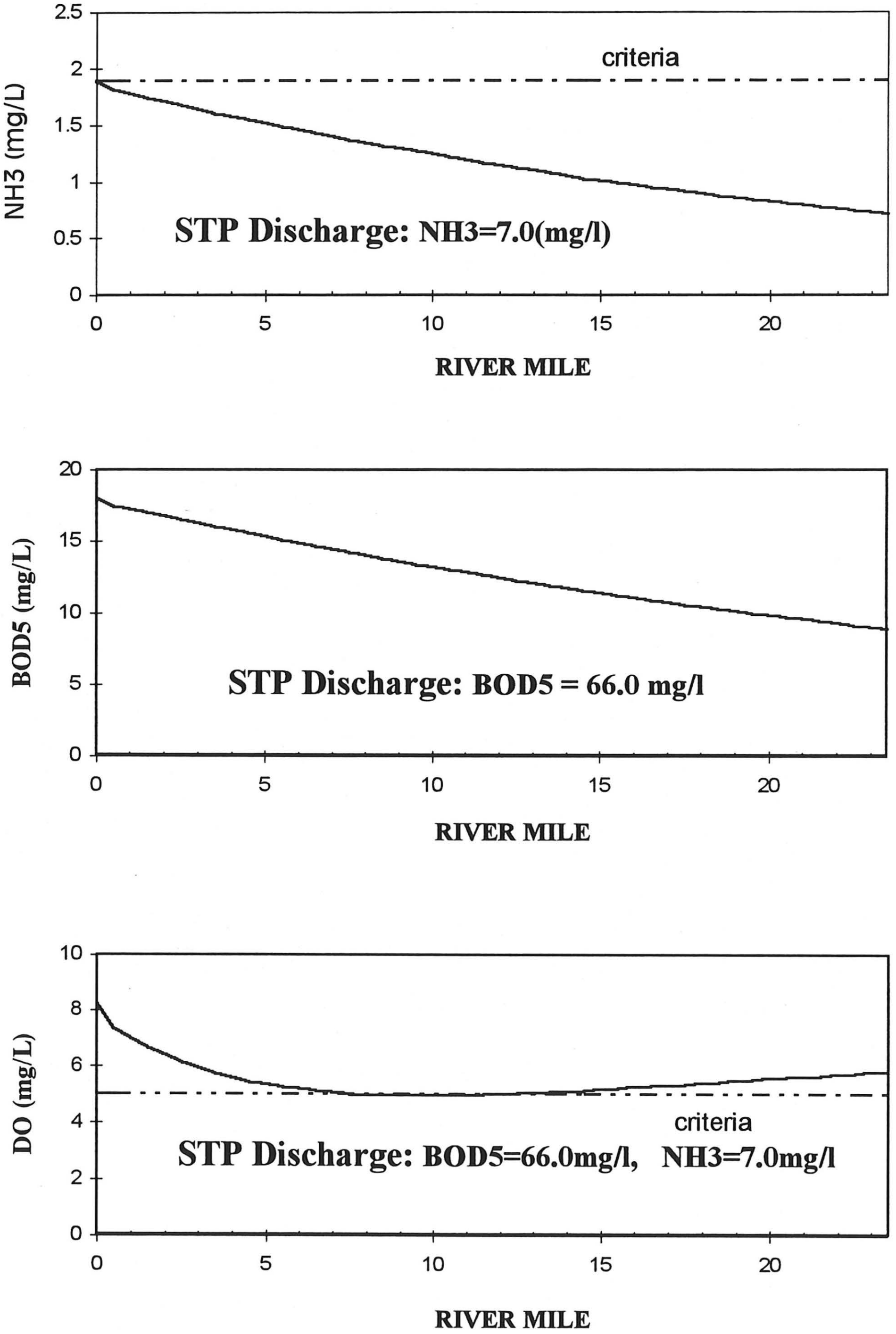


Figure 3.14 Predicted ammonia, BOD and DO for Q84%

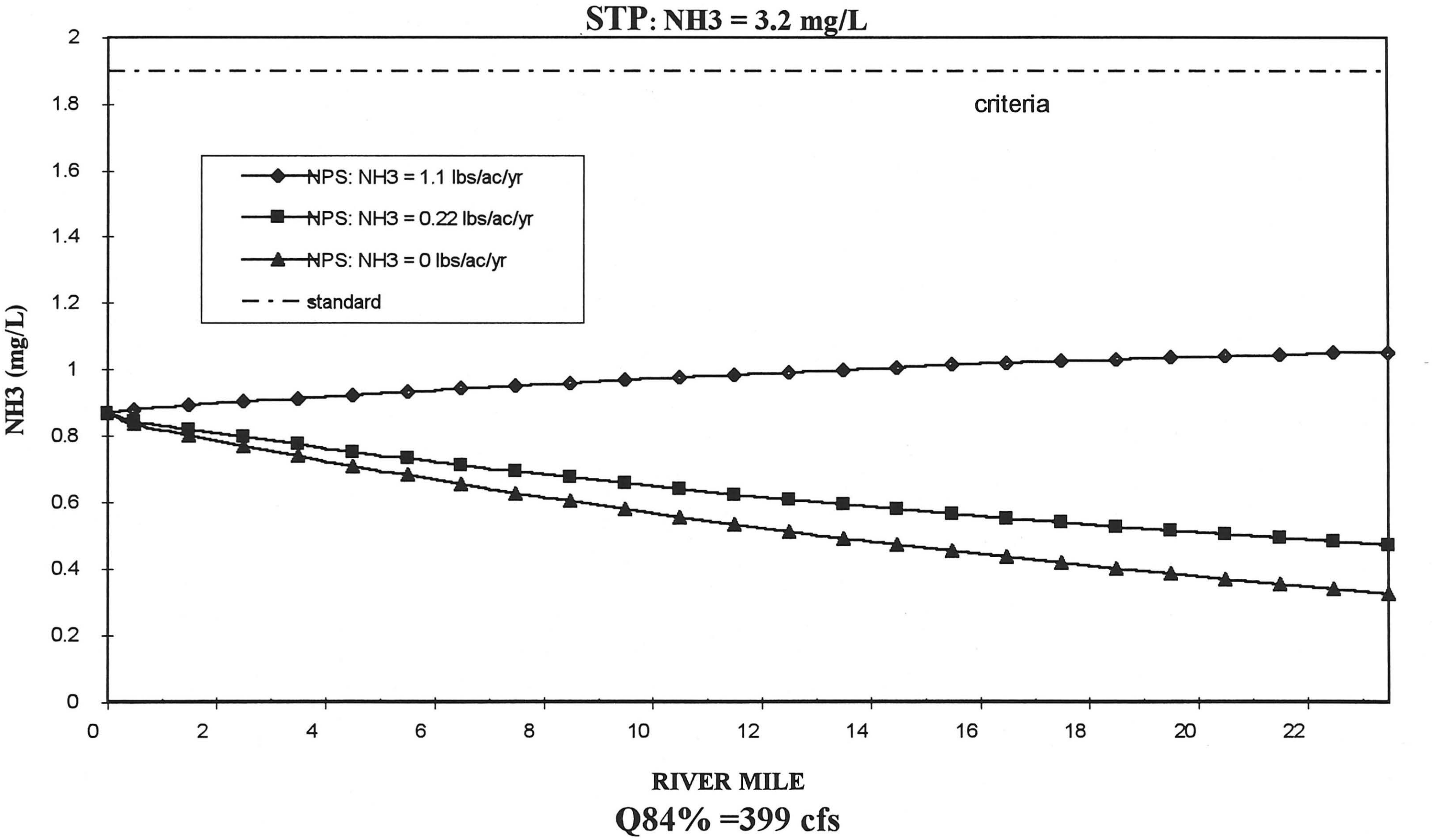


Figure 3.15a Predicted ammonia for Q84% and under different nonpoint source loading rates

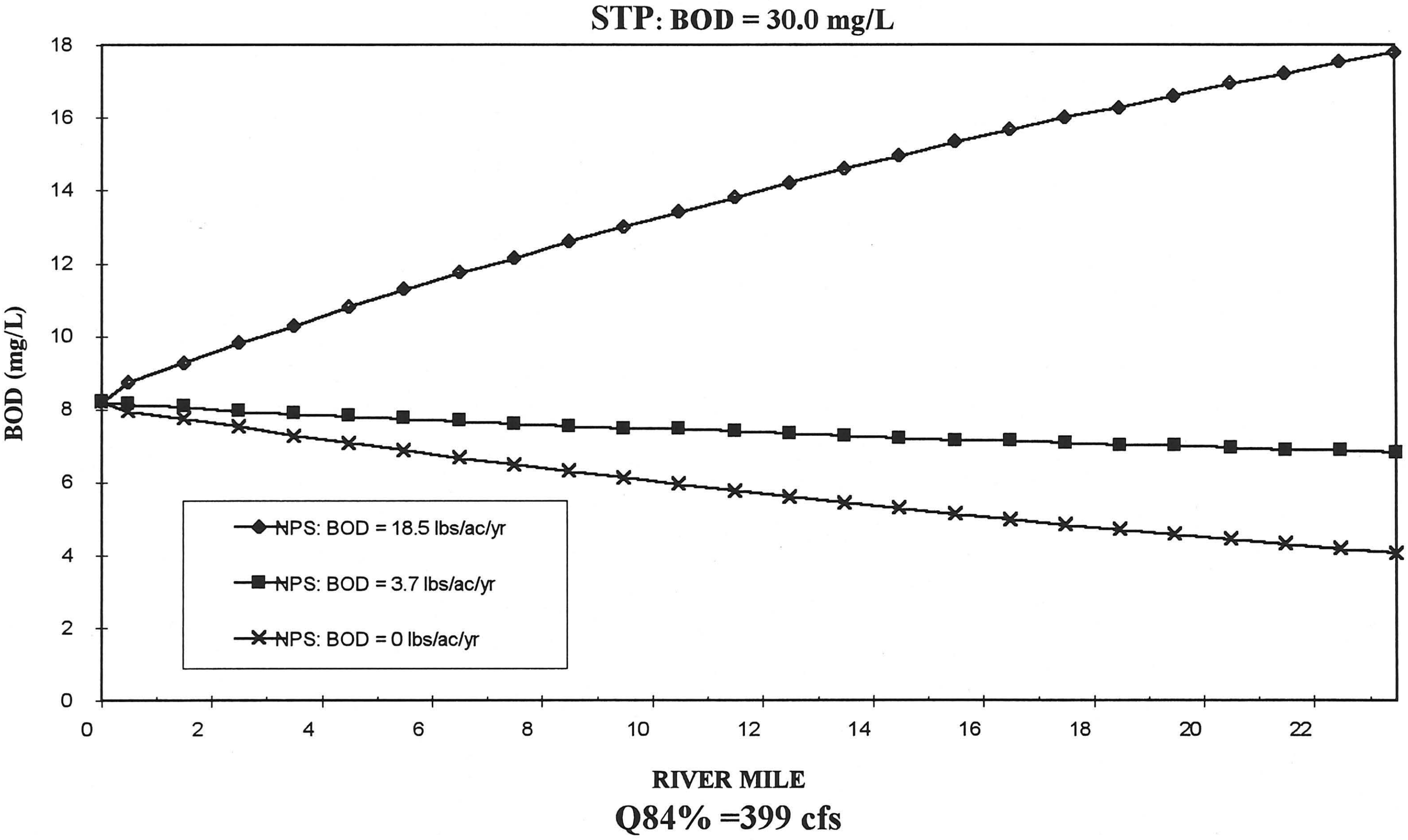


Figure 3.15b Predicted BOD for Q84% and under different nonpoint source loading rates

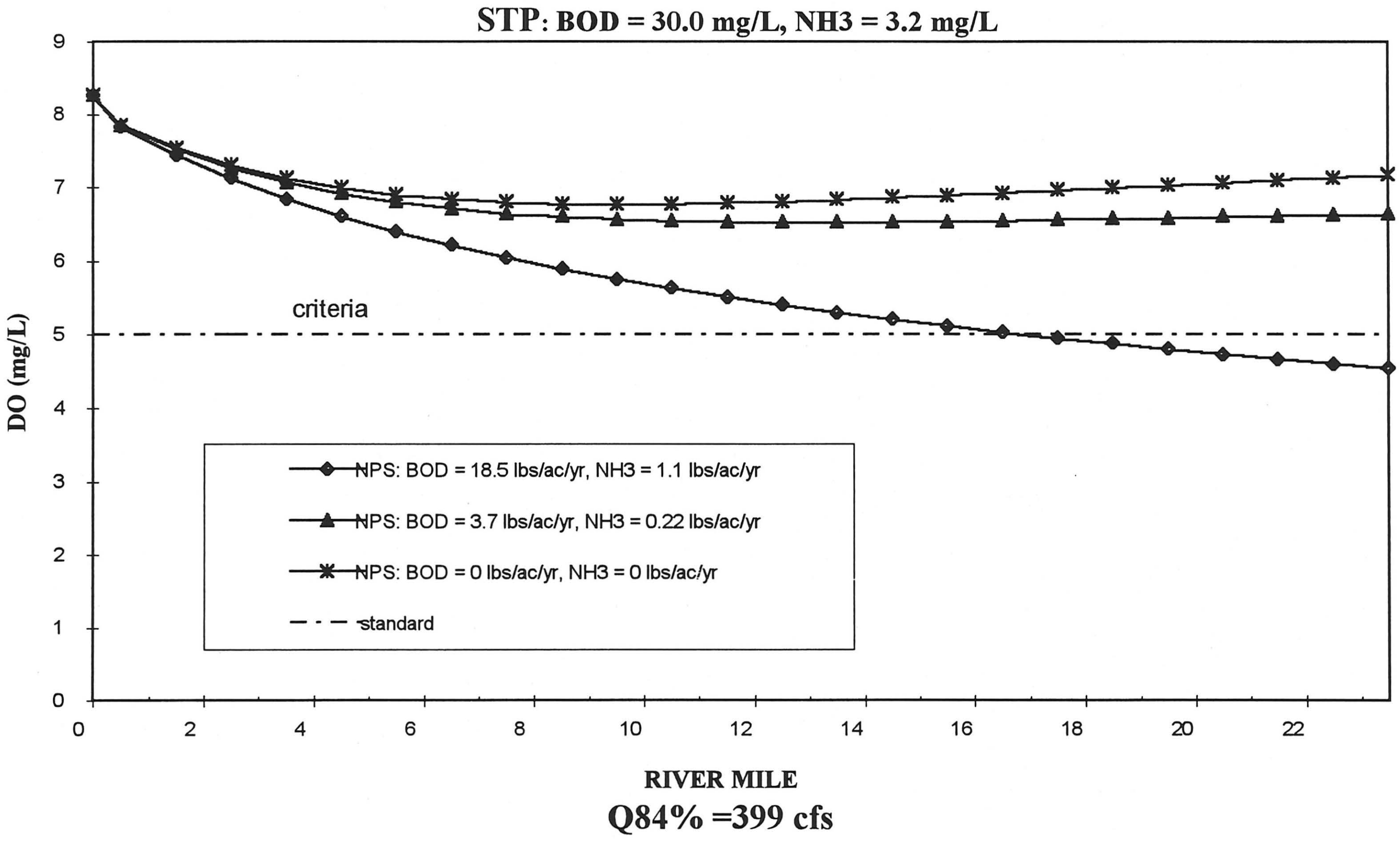


Figure 3.15c Predicted DO for Q84% and under different nonpoint source loading rates

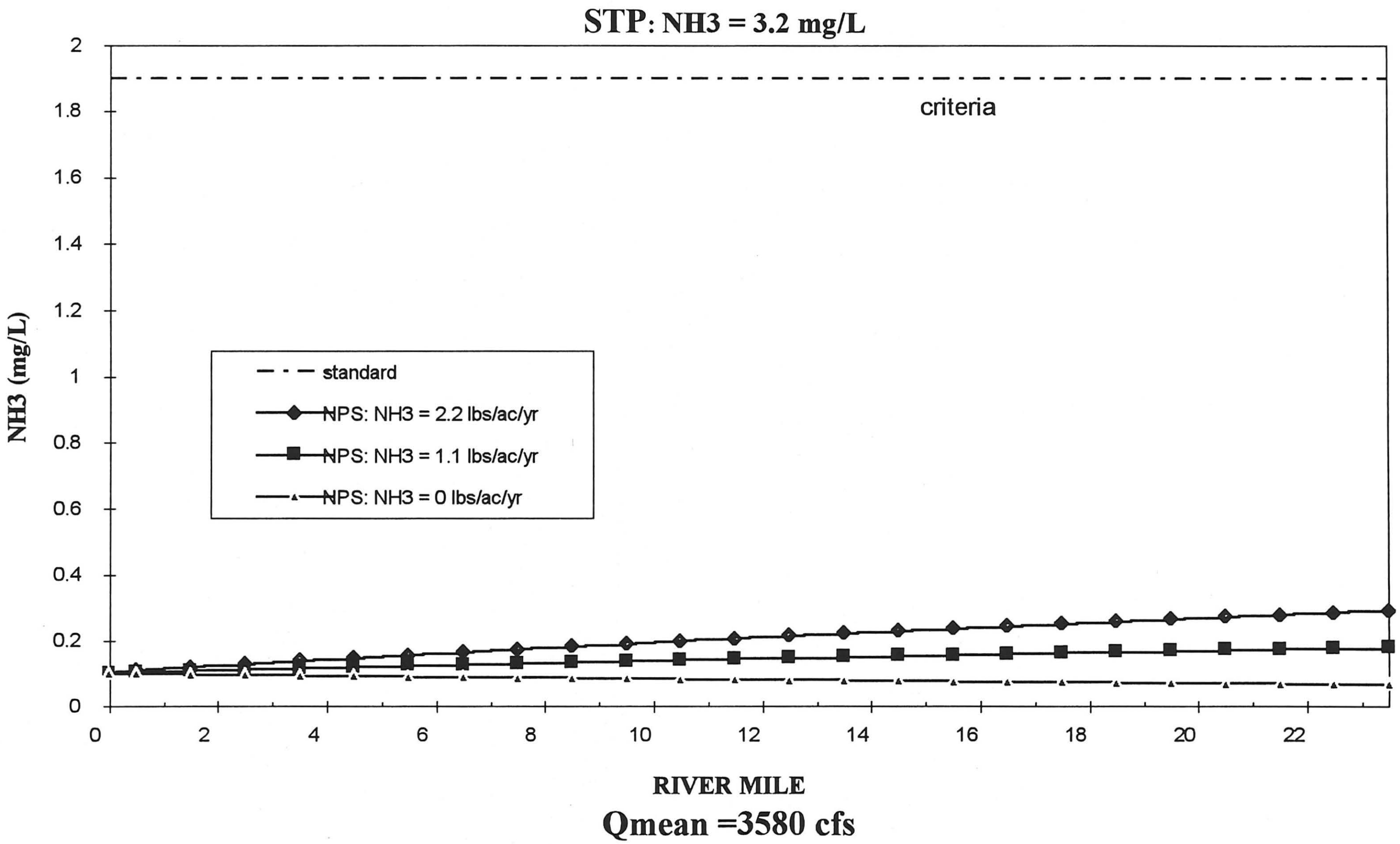


Figure 3.16a Predicted ammonia under Qmean and different nonpoint source loading rates

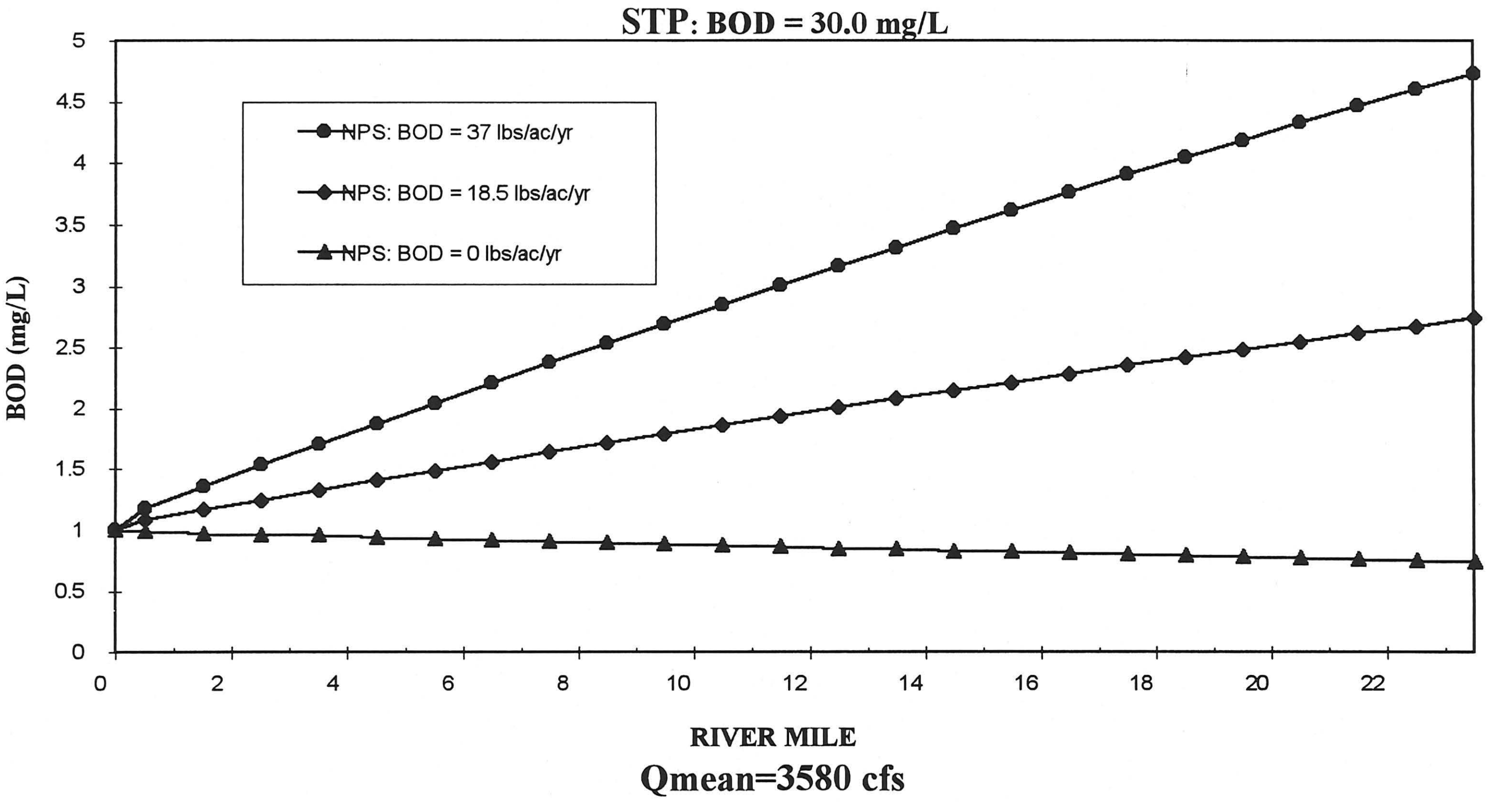


Figure 3.16b Predicted BOD under Qmean and different nonpoint source loading rates

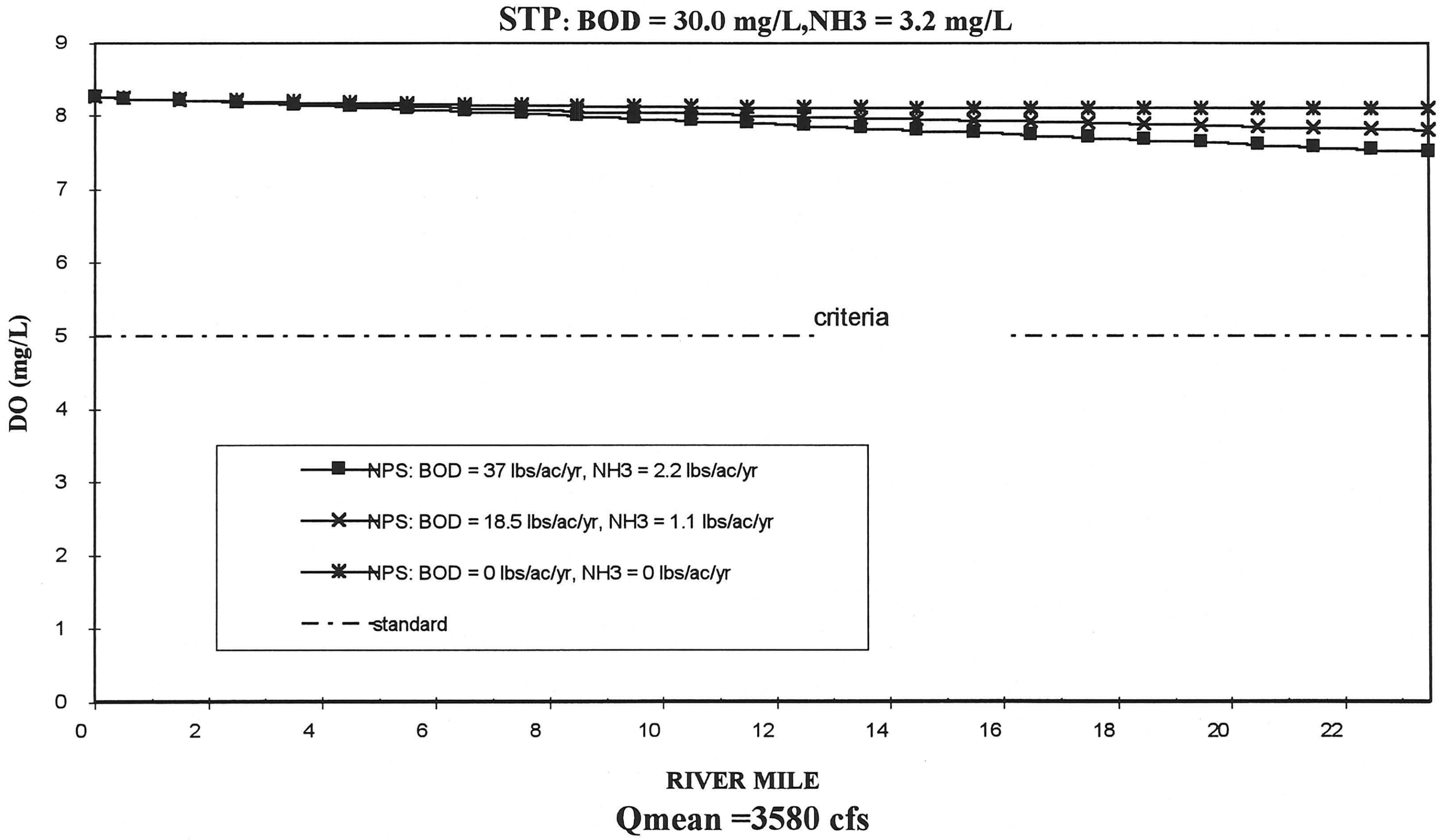


Figure 3.16c Predicted DO under Qmean and different nonpoint source loading rates

IV. Nonpoint Source Pollution Modeling

A. Introduction

Agricultural cropland is the largest and most significant source of nonpoint pollution in Iowa and across the United States. An Environmental Protection Agency (EPA) report on nonpoint pollution submitted to Congress in 1984 stated that, "the principal sources of nonpoint pollution were identified as agricultural activities - including those resulting from tillage practices and animal waste management - which were the most pervasive polluting activities reported in the United States" (Novontony and Olson 1994). Agricultural pollutants include sediments from soil erosion, nutrients from fertilizers, and agrochemical pesticides. These pollutants reduce agricultural productivity, damage aquatic ecosystems, and threaten the public's drinking water supply. Agricultural activities accounted for 93% of the stream miles in Iowa assessed as being impacted by nonpoint source pollution (IDNR 1994). Agricultural nonpoint pollution negatively impacts Iowa's economy and environment.

Waste load allocations for the National Pollution Discharge Elimination System (NPDES) have traditionally focused on point source pollution. Nonpoint source pollution over the last two decades has been recognized as a significant source of pollution that negatively impacts water quality. The EPA and state environmental regulatory agencies are making an effort to incorporate nonpoint source pollution loads into the waste load allocation process. A watershed-based approach for waste load allocations involves evaluating the water quality for an entire drainage basin rather then the river below the point of pollution discharge. Point and nonpoint source pollution loads are both included in a watershed-based approach.

1. Magnitude of NPS Problem

The state of Iowa was required by Section 319 of the Clean Water Act to prepare an assessment report describing the impact of nonpoint source pollution on the state's waterbodies. The IDNR assessed 8,235 (99%) of the 8,320 miles of designated use rivers, 46,336 (99%) of the 48,549 acres of designated use lakes, all 26,192 acres of designated wetlands, and all four flood control reservoirs for the impacts of nonpoint source pollution (IDNR, 1994). Waterbodies were classified as either fully supporting, partially supporting, or not supporting a designated use. The results of the nonpoint source assessment report show that many of Iowa's waterbodies are not supporting their designated uses due to nonpoint source pollution. Agricultural nonpoint source pollution is the largest cause of water quality impairment in Iowa.

Agricultural nonpoint source pollution in Iowa consists primarily of siltation and nutrients. "Siltation, primarily from agricultural nonpoint sources, was identified as a major impact on only 1.7 percent of the stream/river miles assessed as not fully supporting designated uses but was identified as a moderate/minor impact on nearly 40 percent of the miles assessed for support of Class B uses" (IDNR 1988). Siltation was assessed as a major impact at 19 lakes and a moderate minor/impact at 6 lakes. Siltation was the major impairment on 39 percent of wetland acres and a moderate/minor impairment on 20 percent of the wetland acres not fully supporting designated uses.

Plant nutrients, nitrogen and phosphorus, are identified as having moderate/minor impacts on Iowa's surface water quality. Only 35 of the 5,700 river miles monitored had moderate/minor impairment. (IDNR 1994) The primary source of plant nutrients is agricultural chemicals. Plant nutrients were identified as major impacts at three lakes and as moderate/minor impacts at 16 lakes. Noxious aquatic plant growth (algae blooms) were identified as a major water quality impact at 17 Iowa lakes and a moderate impact at four lakes. Noxious aquatic plant growth is directly related to the availability of plant nutrients but IDNR classifies it as a separate impairment. "Plant nutrients were identified as major impacts on 22 percent, and as moderate/minor impacts on 27 percent, of the wetland acres assessed as not fully supporting designated uses" (IDNR 1994). Nitrate was identified as a major impact on 15 of the 151 Class C river miles monitored. "High levels of nitrate in the Iowa River in December 1991 led to issuance of a drinking water advisory in Iowa City" (IDNR 1994). Agricultural runoff and natural phenomena are the two primary sources of nitrate in Iowa's waterbodies.

2. Existing Technology for modeling and controlling NPS

Mathematical models have been used by mankind to better understand and control his environment since the days of Newton. Models provide man with the ability to replicate phenomena for further study and the ability to made predictions relating to the real system utilizing the model. A model is defined as a simplified version of the reactions taking place in a real system. Input parameters are entered into the model where the desired processes are simulated and output data is produced. In nonpoint source pollution modeling mathematical equations are used to express hydrological, soil loss, and chemical phenomena. Theses equations are derived based on scientific laws or with empirical equations based upon observed watershed data. "In order to be sufficiently accurate and realistic, a model must be able to capture mathematically the key systems being studied" (Hipel and McLeod 1994).

Non-urban nonpoint pollution source models focus on the hydrological processes, pollution generation, and pollution transport off pervious land surfaces. The key parameters for non-urban NPS models are land use, precipitation, temperature, slope, and soil data (type, erosion factors, and moisture). "The key issue in estimating nonpoint pollution loads from a watershed, or parcel of land, is the type and extent of human activities occurring (or not occurring) on the land." (Novotny & Olem 1994) Surface water runoff, sediment, nutrient, and pesticide loadings are the simulated by non-urban NPS models. Agricultural cropland is the focus of the majority of the non-urban NPS models. The focus on agricultural cropland is because agricultural NPS pollution has been identified by the EPA as the most pervasive polluting activity reported from every part of the United States. Non-urban nonpoint pollution source models most often contain computerized procedures that perform hydrological, sediment erosion, and pollutant calculations on short time intervals , usually ranging from one hour to one day, for several years. The following is a summary of watershed scale non-urban watershed models that are presently available for application.

AGNPS

The Agricultural Nonpoint Pollution Source (AGNPS) model was developed to address concerns related to the potential impact of point and nonpoint source pollution on surface and ground waters. AGNPS is a distributed parameter model with a structure that consists of a square grid square cell system to represent the spatial distribution of watershed properties. The grid cell system allows the model to be connected to a Geographic Information System obtaining input data required for model simulation. AGNPS is a storm event orientated model but a continuous model is being developed and is anticipated to be available for release in the late fall of 1995. "The model simulates surface water runoff along with nutrient and sediment constituents associated with agricultural nonpoint sources, and point sources such as feedlots, wastewater treatment plants, and stream bank or gully erosion." (EPA, 1992) AGNPS quantitatively estimates pollution loads and assesses the relative effects of alternative management programs. AGNPS is not appropriate for the IDNR modeling program because it is a storm event orientated model as opposed to continuous time model. The vast information requirements for AGNPS's grid cell system input file also make it undesirable to the IDNR.

ANSWERS

The Areal Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS) is a distributed parameter that is storm event orientated. ANSWERS was developed by the University of Georgia to evaluate the effects of land use, management schemes, and conservation practices or structures on the quantity and quality from both agricultural and nonagricultural watersheds. The model uses a cell grid system similar to the system used by AGNPS to represent the spatial distribution of watershed parameters. ANSWERS simulates surface and subsurface flow, erosion, sediment yield, and nutrient loadings. ANSWERS is not appropriate for the IDNR modeling program because it is a storm event orientated model as opposed to continuous time model. The vast information requirements for ANSWERS's grid cell system input file also make it undesirable to the IDNR.

CREAMS

The Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) is a field scale agricultural runoff model developed by the U.S. Department of Agriculture. The model is designed to provide detailed information for designing agricultural management systems. "CREAMS is a physically based, daily simulation model that estimates runoff, erosion/sediment transport, plant nutrients, and pesticide yield from field size areas."(EPA, 1992) effects of different Best Management Practices (BMPs) can be compared with CREAMS. CREAMS is not an appropriate model for the IDNR because it is a agricultural field scale model rather than the watershed basin model.

EPA Screening Procedures

The EPA Screening Procedures were developed by the EPA Environmental Research Laboratory in Athens Georgia as a simplified method model that calculates pollutant loads from point and nonpoint sources. "The procedures consist of loading functions and simple empirical expressions relating nonpoint source loads to other readily available parameters". (EPA, 1992) Land use, management practices, soils, and topography are the data required to run the model. The procedures are not coded into a computer program but can easily be used in a spreadsheet or used with a hand calculator to estimate pollutant loadings. The EPA Screening Procedures are not desirable for adoption by the IDNR because the accuracy of the pollutant loadings is questionable.

EUTROMOD

Eutromod is a spreadsheet based modeling procedure for eutrophication management developed by Duke University. "It is a watershed and lake model designed to estimate nutrient loadings, various trophic state parameters, and trihalomethane concentrations in lake water." (EPA, 1992) The computation algorithms are based on statistical relationships and a continuously stirred reactor model. Eutromod can model watersheds with multiple land uses including rural and urban areas, feedlots, septic tanks, and discharges from wastewater treatment plants. The model is specific to watersheds in the southeastern United States and would have little applicability in Iowa. Output from the model includes the most likely predicted phosphorus and nitrogen loading for the watershed and each land use category. The Eutromod model is not appropriate to IDNR's modeling needs because it does not simulate runoff, and sediment yields. Eutomod is also undesirable because it is site specific to the southeast U.S. and not to Iowa's watersheds.

GWLF

The Generalized Watershed Loading Functions (GWLF) model is a mathematical model for estimating nonpoint sources of nitrogen and phosphorus in streamflow. It was developed at Cornell University to assess the point and nonpoint loadings of nitrogen and phosphorus from a relatively large agricultural watershed and to evaluate the effectiveness of certain land use management practices. The GWLF model is capable of predicting stream flows, sediment yields, and nutrient loadings; however, it is not capable of modeling pesticide transport. GWLF analyzes nutrients in both the solid and dissolved phases. Dissolved phase nutrient loads are received from point sources, groundwater, and rural runoff. Solid phase nutrients loads are received from rural runoff and urban runoff sources. The model uses daily time steps and allows analysis of annual and seasonal time series.

HSPF

The Hydrological Simulation Program - FORTRAN (HSPF) was developed by the EPA for simulating water quality and quantity for organic and inorganic pollutants from agricultural and urban watersheds. HSPF is a continuous, lumped parameter model known for its complexity and extensive data requirements. "The model uses continuous simulations of water balance and pollutant generation, transformation, and transport." (EPA, 1992) A time series of runoff flow rate, sediment yield, and user-specified pollutants can be generated at any point in the watershed. In-stream quality components for nutrient fate and transport, BOD, DO, and pH, phytoplankton, zooplankton, and benthic algae are included in the model. HSPF consists of a central program that calls subroutine modules for pervious land runoff, impervious land runoff, hydraulic components of the watershed, and in-stream water quality. The subroutine modules can be turned on or off by the user. HSPF is too complex, the data requirements to extensive, and the program execution to time consuming for the IDNR to use for its nonpoint source modeling efforts.

NPSMAP

Nonpoint Pollution Source Model for Analysis and Planning (NPSMAP) is a LOTUS 123 spreadsheet program developed to simulate nonpoint source runoff and nutrient loadings. The model can be run for a single event or on a continuous time series. The current version of the model does not simulate sediment and pesticide loadings . Irrigation, evaportranspiration, and drainage to groundwater are incorporated into the nonpoint source runoff simulations. NPSMAP has the capability to simulate point source discharges which include the simulation of infiltration, overflows and bypasses, and changes in treatment plant changes. "The model can be used to evaluate user-specified alternative control strategies, and it simulates stream segment load capacities in an attempt to develop point source waste load allocations and nonpoint source load allocations." (EPA, 1992) NPSMAP is undesirable to the IDNR for nonpoint pollution modeling because it doesn't simulate sediment and pesticide loadings, is only calibrated for the Northeast U.S., and is the property of FETROW Engineers which refused to release a copy of the spreadsheet to the author of this report.

PRMS

The Precipitation-Runoff Modeling System is a deterministic physical process model developed by the US Geological Service (USGS). PRMS evaluates "the impacts of various combinations of precipitation, climate, and land use on surface water runoff, sediment yield, and general watershed hydrology" (EPA, 1992). The model determines changes in the water balance, flood peaks, and groundwater recharge for normal and extreme rainfall and snowmelt. PRMS is a distributed parameter model that divides the watershed into homogenous hydrological response units. The model is designed to run with data directly retrieved from the USGS's National Water Data Storage and Retrieval (WATSTORE) system and can only be run on a mainframe computer. PRMS is undesirable to the IDNR because it can only be run in watersheds that are part of the WATSTORE network and the program must be executed on a mainframe computer for which IDNR personnel may not have access to.

SLOSS-PHOSPH

SLOSS and PHOSPH are two simplified loading algorithms to evaluate soil erosion, sedimentation, and phosphorus transport from distributed watershed areas. "The SLOSS algorithm provides estimates of sediment yield, while the PHOSPH algorithm uses a loading function to evaluate the amount of sediment bound phosphorus." (EPA, 1992) SLOSS and team's modeling efforts but could be a useful tool for the Iowa Department of Natural Resources to manage nonpoint source load controls after a more complex nonpoint source pollution model has been run.

<u>WMM</u>

The Watershed Management Model (WMM) was developed by Camp Dressler and McKee for the Florida Department of Environmental Protection for watershed management and estimation of watershed pollutant loads. The model simulates nitrogen, phosphorus, lead, and zinc loadings from point and nonpoint sources. WMM is a Lotus 123 spreadsheet that uses a series of macro commands to prompt the user to enter data and then display the desired output. Pollutant loads are predicted on an annual or seasonal basis. The model requires site specific information on annual or seasonal mean event concentration data for different types of land uses. "In the absence of site-specific information, the event concentration derived from the National Urban Runoff Program (NURP) surveys may be used as default values." (EPA, 1992) WMM includes computational components for stream and lake water quality analysis using simple transport and transformation formulations based on travel times. This model is not appropriate if for IDNR's modeling needs because the annual/seasonal mean event concentrations in Iowa are unknown and no rural Iowa sites were included in the NURP study.

Slope modification measures and soil-conserving tillage practices such as conservation tillage, no-till farming, contoured planting and terracing can reduce soil erosion from agricultural fields. "Conservation tillage, reducing the number of times the field is plowed and leaving the pervious year's crop residue in place, could reduce the amount of contaminated sediment running into nations rivers and streams by 90% , according to the Soil and Water Conservation Service." (WEF 1995) Farmers are attempting to reduce the amount of chemical fertilizers they apply by testing their soil for nutrient content to prevent over application and applying fertilizer only at the critical stages of crop development. "The sharp upward trend in fertilizer consumption throughout the 1960s and 1970s peaked in 1981 and then reversed." New approaches to pest control such as biological predators, pathogenic microorganisms, and pest growth regulators hold promise as alternatives to chemical pesticides. The future of agricultural pollution promises to see further reductions in agricultural nonpoint source pollution with the development of new technologies and better land management practices.

3. Benefits of modeling and controlling NPS

Nonpoint source pollution impacts both the environment and economy of Iowa. Soil erosion is the largest source of nonpoint source pollution and carries the highest economic impact. The economic costs and environmental impacts of soil erosion are classified as on-site or off-site damages. The major on-site damage of erosion is reduced agricultural productivity. "Preliminary results from an erosion productivity study shows that corn yields may drop by 20 bushels on Iowa's severely eroded glacial tills." (USDA, 1986) Off-site impacts include: stream pollution, reduced reservoir capacity, sediment deposition on lowlands, reduced stream/channel capacity, harbor fill up, reduced navigability of rivers, clogged drains, scarring the landscape, and roadway damage. "The study called, 'Off-Site Costs of Erosion', estimates sediment damages at more than $32 million dollars a year in Iowa." (USDA, 1986) Sediment reduces fish populations, damages aquatic habitats, decreases the recreational value of waterbodies, and increases the cost of surface water treatment for the public drinking water supply. "Siltation, primarily from agricultural nonpoint sources, was identified as a moderate minor impact on nearly 40 percent of the stream miles assessed." (IDNR, 1994) Nutrient losses also impact Iowa's economy and environment negatively. Nutrients dissolved in runoff promote eutrophication of lakes decreasing the recreational value of waterbodies. Ammonia is toxic to fish which impacts the sport fishery sector of the economy. High nitrate levels can raise the treatment cost of water. There are many economical and environment benefits to be gained by controlling nonpoint source pollution in Iowa.

B. Modeling Procedure

Nonpoint pollutants that negatively impact water quality and aquatic ecosystems include: ammonia (NH_3), nitrate (NO_2), phosphate (PO_4), and sediment. These pollutants differ from the point source pollutants typically addressed under the NPDES program. Nonpoint source pollutant concentrations resulting from agricultural activities are greatest for storms that produce just enough rain to initiate runoff. The total pollutant concentration is the sum of nonpoint and point source concentrations so that the maximum pollutant concentration may not occur when the point source pollutant concentration is at maximum. Thus, it is important for the state regulatory agency to evaluate the nonpoint source pollutant loadings to a watershed for a historical or statistical rain event. It is recommended that a Total Maximum Daily Load (TMDL) procedure is developed for Iowa's watersheds to assess and address the impacts of nonpoint source pollution on waterbodies.

A TMDL is the sum of the individual wasteload allocations for point sources, load allocations for nonpoint sources, natural background sources, and a margin of safety. $TMDL = WLA + LA + MOS$ Where WLA is the portion attributed to point sources, LA is the portion attributed to nonpoint sources or background sources, and MOS is the portion of loading attributed to uncertainty. The MOS may be explicit or implicit via conservative assumptions. Generally, a ninety-five percent confidence interval is required for the data to be considered accurate. The five stages of TMDL development activity are: (1) define a quantitative objective, (2) relate load to water quality, (3) estimate pollution sources, (4) select/evaluate control alternatives, and (5) allocate among sources.

Example from TMDL Regional Exchange Workshop Manual

Define Objective

$$WQS=0.05 \text{ mg/l} - 0.05 \text{gm/m}^3$$

Relate Load to Water Quality - water quality model applicable here

Concentration = Load/Flow
Allowable Load = Target Concentration * Flow
$W=0.05 \text{ gm/m}^3 * 10 \text{ m}^3\text{/sec} = 0.5 \text{ g/sec}$

a total pollutant load for the watershed. Then the estimated total pollutant loading from ammonia, nitrate, phosphate, and sediment is compared to the TMDLs established for the watershed. If the estimated loadings are less than or equal to the TMDLs these pollutants do not threaten the water quality of the watershed. However, if the estimated loading is greater than the TMDLs, corrective actions must be taken to prevent these pollutants from harming the watershed's water quality.

An important step in the high flow TMDL process is selecting a historical or statistical storm and estimating the runoff resulting from that storm. The state regulatory agency would select the design storm or historical storm based on criteria established by them. Flow data from a gauged site should be used if available. If no flow data is available for the watershed or a design storm is desired the Soil Conservation Service (SCS) equation should be utilized. Soil erosion loss rates are to be estimated using the Universal Soil Loss Equation (USLE). Sediment yield is calculated by multiplying the soil loss rate by a sediment delivery ratio. A sediment delivery ratio is the ratio of actual soil losses to the sediment that reaches a waterbody. The sediment delivery ratio should be obtained from literature based on the watershed's size and land characteristics. Nutrient losses are computed by multiplying the volume of surface runoff by a dissolved nutrient concentration in the runoff. The dissolved nutrient concentration in agricultural runoff should be obtained from literature based on the agricultural practices of the watershed. A detailed description of the SCS Runoff curve method and USLE are as follows.

Soil Conservation Service Runoff Curve Number (CN) Equation

The Soil Conservation Service (SCS) has developed an empirical equation for estimating rainfall excess that does not require infiltration and surface storage to be calculated separately (Novotony and Olson 1994). This equation is known as the SCS Runoff Curve Number Equation and computes the surface runoff resulting from a twenty-four hour storm based upon land use characteristics.

Four hydrological soil classes exist for the runoff curve number parameter. Class A soils have low runoff potentials and high infiltration rates even when thoroughly wetted. Sand, loamy sand, and sandy loam are examples of Class A soils. Class B soils have moderate infiltration rates. Silt loams and loams are classified as Class B soils. Class C soils are characterized by low infiltration rates and are typically sandy clay loams. Class D soils have very low infiltration rates and high potential runoff rates. Clay loam, silty clay loams, sandy clay, silty clay, and clay soils are classified as Class D soils.

Arif (1991) evaluated the accuracy of the SCS Runoff Curve Number on the Four Mile Creek Watershed. Arif used a soil moisture procedure to determination the maximum basin retention parameter for the SCS CN equation. This procedure is different from the method used to determine the maximum basin retention parameter reach in this study. The maximum basin retention parameter for this study was determined using the five day antecedent rainfall amount. Simulated runoff was compared to observed data for a five year period from 1976 to 1980. Arif reported that validation runs with this coefficient for the 5 year period gave a correlation coefficient of $r^2 = 0.054$ for corn cover and $r^2 = 0.57$ for soybean cover (Arif 1991).

Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) is the most widely applied soil loss equation in practice today. Nonpoint source pollution models such as the Generalized Watershed Loading Function (GWLF), Simulator of Rural Watershed Basins (SWRRB), Agricultural Nonpoint Pollution Source (AGNPS), and the Aerial Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS) have adopted the USLE to simulate soil erosion from agricultural activities. Applications of the USLE cover a broad range of activities including soil conservation planning, the estimation of nonpoint source pollution loading, evaluation of best management practices, and predicting soil losses associated with silviculture and construction activities. The USLE is an empirical equation that is based on soil loss data collected throughout the U.S. "The equation enables the planner to predict the average rate of soil erosion for each of various crop system, management techniques, and control practices on any particular site" (Wischmeir and Smith 1978). The USLE calculates the average annual soil loss for a specified agricultural field, and does not calculate sediment loading.

Research on soil erosion began in the U.S. during the 1930's with the establishment of ten soil erosion research stations across the country. These research stations were funded and operated by the U.S. Department of Agriculture (USDA). In the 1940's Browing, Smith, and Musgrave used the data collected from these research stations to develop soil loss equations that addressed the pertinent causes of erosion. (Smith and Willrich) These equations proved unsatisfactory, but laid a foundation for the development of the USLE. In 1954, a Runoff and Soil Erosion Center was established at Purdue University by the USDA to further research soil erosion resulting from agricultural practices. "All available data from soil and water loss experiments from across the United States were assembled for summarization and analysis" (Smith and Willrich 1970. The result of this data collection and analysis effort was the development of the Universal Soil Loss Equation. The equation is:

$$A = R*K*LS*C*P$$

where A is the predicted average annual soil lose in tons/acre, R is the rainfall energy factor, K is the soil erodibility factor, LS is the length-slope factor, C is the cropping management factor, and P is the erosion control parameter. The K, LS, C, and P parameters are all dimensionless. The rainfall energy factor, R, is the number of erosion unit index units in a normal year's rain and accounts for the kinetic energy of the raindrops and is in units of foot-tons/acre. K , the soil erodibility factor, is the erosion rate per unit of R for a specific soil continuously cultivated on a fallow test plot. The length-slope factor, LS, adjusts for the difference between the slope length and slope gradient of an agricultural field to the 72 foot long test plot with a nine percent slope. C, the crop management factor, is the ratio of soil loss from a field with a specified cropping and management technique to that fallow test plot which K was evaluated on. The erosion control parameter, P, is the ratio of the soil loss from strip cropping, contouring, and terracing to the soil loss associated with straight row cropping.

Typically the units of the USLE are in the English dimensional system but the equation can be converted to metric units. The C and P factors are dimensionless and no conversion is necessary. The LS, K, and R factors must be converted to metric units so that A will be in units of metric tons per hectare.

All the parameters of the USLE are easily obtainable from tables and graphs published by the USDA. The rainfall factor can be read from annual charts or can be calculated for individual storm events, if meteorological data are available. K values are available in County Soil Survey Reports published by the Soil Conservation Service. The cropping management and conservation practice parameters can be determined using tables prepared by the USDA, crop dates and tillage practices are known. The slope factor is calculated using topographic maps and an equation or graph provided by the USDA . The slope-length parameter is the only difficult parameter to determine. "Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition occurs or the runoff enters a well defined channel that may be part of a drainage network" (Wischmeir and Smith 1978). In practice slope length is very difficult to determine.

The USLE has been tested on numerous agricultural fields across the U.S. When USLE soil erosion predictions were compared to actual soil loss data Wischmeir reported that, "about 53 percent of the differences were less than 1 tons/acre, 84 percent were less than 2 tons/acre, and 5 percent were as much as 4.6 tons/acre" (Wischmeir and Smith 1978). These results indicate that for annual soil loss erosion rates the USLE is a fairly accurate equation. However as Novotony points out, "larger errors should be expected if the equation is used for predicting the soil loss of individual storms" (Novotony and Olson 1994).

The High Flow TMDL procedure provides a comprehensive evaluation of the impacts of point and nonpoint source pollution on the water quality of a waterbody. A maximum pollutant loading is developed for a waterbody based on the desired water quality criteria. Then nonpoint source pollutant loads are estimated using simple mathematical equations rather than complex time consuming computer models. Point and estimated nonpoint source pollutant loads are added together to obtain a total load. If the total pollutant load exceeds the TMDL for the watershed than corrective actions must be initiated. Water quality standards for sediment, nitrate, and phosphate must be developed by the state in order to implement this approach.

C. Demonstration

The following is a demonstration of the High Flow TMDL procedure implemented on the Cedar Creek watershed in south-central Iowa. Ammonia is the only nonpoint source pollutant that has a water quality standard so it was the only pollutant where a TMDL was computed. The acute and chronic water quality standards for the Cedar Creek watershed are 1.9 mg/l and 9.7 mg/l. A two year 24 hour design storm was selected as the statistical storm for this demonstration. A rainfall depth of 8.13 cm was obtained from the isohyetal map of design rainfall depth in Iowa for the approximate location of the Cedar Creek Watershed. The land use for the watershed was approximated as straight row crops with crop residues. Soil type for the watershed was approximated as hydrological group B, which is typical of Iowa soils. A curve number of 77.5 was obtained for row crops with crop residue. The potential maximum loss SN was computed with the following equation and yielded a loss of 7.37 cm.

$$SN = 2540/77.5 - 25.4 = 7.37 \text{ cm}$$

Surface runoff was computed using the SCS equation and resulted in 3.15 cm of surface runoff. The watershed has an area of 530 square miles which gives a runoff volume of 43,239,851.5 cubic meters of water.

$$Q = (8.13 \text{ cm} - 0.2*7.37 \text{ cm})^2/(8.13 \text{ cm} + 0.8*7.37 \text{ cm})$$

The TMDLs for ammonia are than computed by multiplying the water quality standards for ammonia by the volume of surface runoff. The TMDLs for ammonia are 82 MG for acute exposure and 419 MG for chronic exposure, where MG denotes million grams (10^6 g).

$$\text{Acute\_TMDL} = 1.9 \text{ (mg/l)}*43239851 \text{ (m}^3)*1000 \text{ (l/m}^3)*1 \text{ (MG)}/10^9\text{(mg)} = 82 \text{ MG}$$

$$\text{Chronic\_TMDL} = 9.7\text{(mg/l)}*43239851 \text{ (m}^3)*1000 \text{ (l/m}^3)*1\text{(MG)}/10^9\text{(mg)} = 419 \text{ MG}$$

The following agricultural cultural practices were approximated for the entire watershed. A corn-soybean crop rotation was used with the cropping management factors for corn and soybeans averaged together. The corn and soybeans were planted no till with 50 to 70 % of the plant left as residue in the fall. Crop management factors were obtained. The average C factor was 0.145. It was assumed that no conservation management practices for the watershed were used resulting in a P factor of 1.0.

$$C_{avg} = (0.11+0.18)\ /2 = 0.145$$

The predominant soils in the Cedar Creek Watershed are the Grundy, Hindly, Belinda, and Haig silt loams. The soil erodibility factor for these soils is 0.37. An average slope of 5.37 % was obtained from a GIS database for the watershed. The average slope length was assumed to be 130 meters. This estimate of slope length is based on data from the Four Mile Creek Watershed Study. A length slope factor of 0.98 results from using a slope and slope length. Rainfall erositivity was computed using an equation developed by Haith and Merrill (1987) where a is a seasonal and geographical constant and R is the daily precipitation. A seasonal and geographical constant of 0.25 was selected (Haith et al. 1992). Rainfall erositivity is then computed as 716.86 tons/ha.

$$RE_t = 64.6*a*R^{1.81} = 64.6*0.25*8.13^{1.81} = 716.86 \text{ tons/ha}$$

The soil loss rate can then be computed using the USLE as follows:

$$R = 0.132 * \text{Re} * C * P * Ls * K = 0.132 * 716.86 * 0.145 * 1 * 0.98 * 0.37 = 6.47\, MG\,/\,ha$$

The next step is to determine the sediment delivery ratio for the watershed. Using a watershed area of 1372 km^2 the sediment delivery ratio becomes 0.028. The sediment loading to the watershed is then calculated by multiplying the soil erosion loss rate by the watershed area and the sediment delivery ratio.

$$Sed\_Load = 6.47\frac{MG}{ha} * 530mi^2 * \frac{259ha}{1mi^2} * 0.18 = 24{,}708\,MG$$

A total sediment load of 24,708 MG from nonpoint source pollution was estimated for the Cedar Creek Watershed.

Dissolved nutrient concentrations were used from Dr. James Baker's article "Nitrogen and Phosphorus Dynamics and the Fate of Agricultural Runoff". Nitrate concentrations for corn and soybeans were reported as 4.5 and 3.5 mg/l. Ammonia concentrations for corn and soybeans were 0.8 and 0.1 mg/l. The phosphorus concentration in surface runoff for corn and soybeans were 0.16 and 0.03 mg/l. The corn and soybean dissolved nutrient concentrations were averaged together to obtain a composite dissolved nutrient concentration for the watershed. The average dissolved nutrient concentrations for the Cedar Creek watershed are 4 mg/l NO_3, 0.45 mg/l NH_4, and 0.095 mg/l PO_4. Dissolved nutrient loads were computed by multiplying the nutrient concentration by the volume of surface runoff. Nonpoint source nutrient loads are 173 MG of nitrate, 19.5 MG of ammonia, and 4.1 MG of phosphate.

$$NO_3\_load = 4mg/l * 43{,}239{,}851m^3 * \frac{1000L}{m^3} * \frac{1MG}{1*10^9 mg} = 173\,MG$$

$$NH_3\_load = 0.45mg/l * 43{,}239{,}851m^3 * \frac{1000L}{m^3} * \frac{1MG}{1*10^9 mg} = 19.5\,MG$$

$$PO_4\_load = 0.095mg/l * 43{,}239{,}851m^3 * \frac{1000L}{m^3} * \frac{1MG}{1*10^9 mg} = 4.1\,MG$$

Cedar Creek contained a total of thirteen point source dischargers. Nitrate and phosphate concentrations were not required to reported by IDNR so the concentrations had to be assumed at 15 mg/l and 4 mg/l. This concentrations are typical of values reported by treatment plants for their effluent. When ammonia concentrations were not reported an average of the reported concentrations was used. Point source loads were computed by multiplying the nutrient and suspended solids concentrations by the volume of flow to obtain the loading in kg. Point source loading information is presented in the Table 4.1. The nonpoint and point source loads were added together to obtain total pollutant loads for the watershed.

Nonpoint and point source loads to the Cedar Creek Watershed

Pollutant	Nonpoint Load	Point Source Load	Total Load
NO3	173 MG	0.015 MG	173 MG
NH3	19.5 MG	0.0006 MG	19.5 MG
PO4	4.1 MG	0.0039 MG	4.1 MG
Sediment (SS)	24,708 MG	0.0061 MG	24,708 MG

The only pollutant with an established TMDL is ammonia at 82 MG so with the estimated high flow loading of 19.5 MG the total pollution loading does not threaten water quality within the watershed.

Table 4.1 Cedar Creek Watershed Point Source Loads

Name	Flow MGD	PO4 conc mg/l	NO3 conc mg/l	NH3 conc mg/l	SS conc mg/l	PO4 load kg	NO3 load kg	NH3 load kg	SS load kg
Strawberry Point	0.051	4	15	0.55	0	0.77	2.90	0.11	0.00
Prarie View	0.0081	4	15	0.55	0	0.12	0.46	0.02	0.00
Manyard	0.045	4	15	0.55	0	0.68	2.56	0.09	0.00
Hillbourgh	0.054	4	15	0.55	75	0.82	3.07	0.11	15.35
Maharishi Resort	0.004	4	15	0.55	12	0.06	0.23	0.01	0.18
Cedar Creek	0.004	4	15	0.55	0	0.06	0.23	0.01	0.00
Fairfield	1.948	4	15	0.6	3.6	29.54	110.77	4.43	26.58
Packwood	0.0012	4	15	0.55	0	0.02	0.07	0.00	0.00
Fremount	0.0366	4	15	0.55	0	0.55	2.08	0.08	0.00
Birmingham	0.29	4	15	0.56	0	4.40	16.49	0.62	0.00
Stockport	0.061	4	15	0.55	3	0.92	3.47	0.13	0.69
Cardinal School	0.004	4	15	0.55	67	0.06	0.23	0.01	1.02
Agency City	0.092	4	15	0.55	51	1.40	5.23	0.19	17.79
Totals						**39.41**	**147.78**	**5.80**	**61.62**

V. Costs and Benefits

A. Background

The Iowa State University Surface Water Quality Team (ISU SWQT) conducted a survey of the costs and benefits associated with implementing a watershed-based approach to waste load allocations (WBA WLA). Surveys were mailed to all fifty state's environmental regulatory agencies. The survey contained the following questions: when the state started a watershed-based approach to waste load allocations, if any additional staff were needed to implement a WBA WLA, if any additional equipment were needed to implement a WBA WLA, if there was an increase in the budget expenditures for the water quality section after a WBA WLA was implemented, if additional funding was received to offset costs associated with a WBA WLA, where the additional funding sources came from, and what benefits had they observed from implementing a WBA WLA. Fifteen states responded to the survey. Typically, the states that responded to the survey were leaders in implementing a WBA WLA, for example Washington, Nebraska, and Illinois (Table 5.1).

B. Results

Twelve of the sixteen states replied that they were implementing or already using a watershed-based approach to waste load allocations. Several states indicated that they had been using a WBA WLA for quite some time. New York wrote that they had been using a WBA WLA since the 1960's. Another example is the state of Michigan which replied that it had been using a WBA WLA since 1983. The WBA WLA that these states refer is not the same approach that the Environmental Protection Agency (EPA) has been encouraging states to adopt so caution must be used when using the survey results from these states. EPA's favored approach did not begin to be implemented into the 1990's. Washington and Illinois began their WBA WLA programs in 1993. Nebraska began its WBA WLA program in 1994.

Six states responded that no additional staff were necessary to implement a watershed-based approach to waste load allocations. Illinois replied that they hired one contractual employee to aid them in switching the individual NPDES permitting to a river basin permitting approach. Kentucky and New Hampshire each hired one additional staff person to implement a WBA WLA. West Virginia hired two additional staff persons to help implement their WBA WLA program. Wisconsin hired one additional staff person to assist with integration of a Geographical Information System (GIS) into their WBA WLA program. Five states did not respond to this question.

Six states responded that no additional equipment was necessary to implement a watershed-based approach to waste load allocations. Illinois needed to purchase an additional Pentium computer to implement their WBA WLA. Kentucky upgraded their 386 computers to facilitate a WBA WLA. West Virginia had to add GIS work stations and monitoring equipment for their WBA WLA. Nevada had to add reading and recording data loggers to their water quality department to implement their WBA WLA program. Five states did not respond to this question.

Five states responded that they needed no additional funding to implement a watershed-based approach to waste load allocations. Illinois received a $275,000 grant from section 104 b (3) for the Clean Water Act (CWA) to help implement a WBA WLA. Nebraska received a $20,000 grant from the CWA for its WBA WLA program. Washington also received a $20,000 grant from the CWA for its WBA WLA program. Wisconsin received $24,000 from EPA funds to establish a GIS system for their WBA WLA program. West Virginia did not specify the amount of additional funding they received but did report that they received money from federal grants and state funds. Five states did not respond to this question.

Ten states responded to the question of the benefits the had observed after implementing a watershed-based approach to waste load allocations. Nebraska replied that, "improved coordination between sections, better understanding of issues, and reduced public notice costs" were the benefits they had witnessed. Washington wrote that, "more TMDLs completed, NPDES permit backlog is being reduced, and better interaction with local communities on their priorities" were the benefits they had observed. Illinois responded, "a watershed approach to waste load allocations has provided a more comprehensive process for the determination of appropriate water quality-based effluent limits". Wisconsin and West Virginia responded that it was too early in their implementation process to know the benefits of a WBA WLA.

New York replied that, "it is not a question of benefits but rather a question of doing the job properly". Michigan wrote, "the major benefit is that it allows us to focus our studies and work on 20 % of the state each year". New Hampshire responded that they had not observed any benefits of the watershed-based approach. Nevada replied, "evaluating a watershed as a whole provides more opportunity for achieving goals because all pollution sources are evaluated".

C. Summary

The EPA proposed watershed-based approach to waste load allocations concept is relatively new with the earliest state implementation of it occurring in 1993. There is very little data available on the costs and benefits associated with a WBA WLA because only a few states have implemented it. Nebraska, Washington, Illinois, West Virginia, Wisconsin, and New Hampshire are implementing or have implemented the EPA's WBA WLA. The survey results from these states provides valuable information on the costs and benefits of implementing a WBA WLA program. Survey results from the other states that responded to the survey is misleading because they have not implemented the EPA's proposed WBA WLA program.

Nebraska, Washington, West Virginia, Illinois, Wisconsin, and New Hampshire reported costs associated with the implementing a watershed-based approach to waste load allocations. These costs ranged from $20,000 to $275,000 with accounted for additional staff people or equipment necessary to implement a WBA WLA program. West Virginia, Wisconsin, and New Hampshire reported hiring additional staff but this may be because of the large staffs the other states already had. Nebraska has 24 full time employees (FTEs) and Washington 160 FTEs in their waste load allocation staffs. Nebraska, Washington, and Illinois were able to reassign FTEs to their WBA WLA programs without hiring additional staff because of their large staff sizes they had to begin with. Iowa may need to add additional staff to implement a WBA WLA program. Wisconsin and West Virginia spent additional funds on acquiring GIS workstations for their WBA WLA programs while Illinois purchased an extra Pentium computer. Iowa may not need additional equipment to implement a WBA WLA because it has a GIS system and its computer hardware and software should be adequate for a WBA WLA.

The ISU SWQT concludes that implementing a watershed-based approach to waste load allocations will cost the Iowa Department of Natural Resources (IDNR) between $20,000 to $275,000, with $20,000 being the lowest reported implementation cost from the survey. Iowa's staff size is considerably smaller than the five survey states so the implementation cost is expected to be quite higher than $20,000 figure. Expected benefits could include better coordination between departments, a reduced backlog of NPDES permits, and improved interaction with the public on water quality issues. The IDNR needs to carefully weight the costs of a watershed-based approach to waste load allocations against benefits. If the benefits justify the costs then the IDNR may seek funding through federal grants from the CWA, state funds, or perhaps by increasing the NPDEs permit fee. All six states reported that they had received federal grants to implement a WBA WLA program.

Table 5.1 Costs and Benefits Survey of Watershed-Based Approach

State	Using or implementing WBA to WLA?	Date Initiated?	Increase in staff?	# of added staff?	Additional equipment?	Equipment?	Budget Increase?	Additional funding?	Source ?
Hawaii	No	NA	NA	NA	NA		NA	NA	NA
Illinois	Yes	1993	No*	0	Yes	Pentium computer	No	$275,000	CWA
Kentucky	Yes	1986	Yes	1	Yes	Upgrade PC's	No	0	
Louisiana	Yes	Since origin of program	NA	NA	NA	NA	NA	NA	NA
Maine	No	NA	NA	NA	NA	NA	NA	NA	NA
Michigan	Yes	1983	No	0	No		No	0	
Mississippi	No	NA	NA	NA	NA	NA	NA	NA	NA
Nebraska	Yes	1994	No*	0	No	No	Yes	$20,000	CWA
Nevada	Yes	Late 80's	No	0	Yes	Data loggers	No	0	
New Hampshire	Yes	1996	Yes	1	No		Unsure	0	
New York	Yes	Late 60's	No	0	No		No	0	
Texas	No	NA	NA	NA	NA	NA	NA	NA	NA
Washington	Yes	1993	No	0	No		Yes	$20,000	CWA
West Virginia	Yes	1995	Yes	2	Yes	GIS & field monitoring equipment	Yes	NA	Federal grants & state funds
Wisconsin	Yes	1996	Yes	1	No		Yes	24,000	CWA

Key
NA = This survey question was not answered
* = Contractual employees were used for Illinois and Nebraska to switch NPDES permits to a river basin schedule

VI. Implementation and Feasibility

A. Implementation of the Watershed Approach

It is recommended that IDNR adopt the watershed-based approach as a basis for water quality management programs in the State of Iowa. This approach will offer:

- a more integrated and effective management of both point and non-point pollution sources,
- the increased involvement of a wider range of stakeholders should improved relationships between IDNR and the stakeholders, and
- the potential efficiency gains in conduct of the water quality programs for the State of Iowa should be significant.

Iowa does not have sufficient personnel allocated for water quality management programs including the NPDES, NPS and monitoring activities. Additional staff is necessary in order to move ahead with implementation of the watershed approach. It is recommended that additional staff be hired including:

1. Statewide watershed coordinator and planner
2. Watershed database manager
3. Monitoring Coordinator
4. 2 to 3 monitoring technicians
5. Computer modelor

Funding for these additional personnel should be developed from U.S. EPA funding, State Legislature of Iowa, and/or increased fees for NPDES permits. It is expected that an additional annual budget of $328,000 will be needed ($280,000 for additional staff plus $68,000 for the additional laboratory cost for monitoring). In addition, there will need to be updated computer facilities that represents a one time cost of $25,000.

One limit to the effectiveness of the watershed approach is the lack of water quality standards for non-point source pollutants. The Clean Water Act provides a mechanism for establishment of in-stream water quality standards for pollutants such as nitrate-nitrogen, phosphorus, total dissolved solids and total suspended solids. It is recommended that IDNR evaluate setting standards for non-point pollutants. A process for developing these standards must be developed. A careful evaluation of the in-stream standards currently being used by the World Health Organization, Environment Canada, European Community, Russia and other states in the US, such as, Indiana, Michigan, and Illinois.

B. Implementation of the Monitoring Strategy

It is recommended that IDNR adopts a watershed-based monitoring strategy, in order to support the implementation of the watershed approach. Recommendations for the design of this watershed-based monitoring strategy have been proposed in "A Statewide Monitoring Strategy for Iowa", a separate report prepared for IDNR.

It is recommended that the proposed monitoring strategy be implemented in stages, that should coincide with the five-year period of the basin management cycle:

1. In the first stage, the focus should be on implementing rotational monitoring for the GMU's in year 1 and intensive surveys on priority watersheds in GMU's in year 3, as well as improving stakeholder interest in and involvement with water quality management in general and the monitoring program in particular.
2. In the second stage, when more data should be available from the first year monitoring, more emphasis can be placed on non-point sources and TMDL development, and also on expanding volunteer monitoring programs in the GMU's.
3. These trends will continue in the following cycles. Priorities will have to be re-evaluated for each new cycle.

C. Computer Support

It is recommended that IDNR re-evaluates its hardware and software needs, in order to support management of the increased amounts of data being collected under the proposed monitoring strategy. Specifically, an additional workstations might be needed to serve as a platform for increased use of GIS in the watershed approach.

References

Ambrose, R. B., Wool, T. A., Martin, J. L., Connolly, J. P., and Schanz, R. W. 1993. The water quality analysis simulation program, WASP5, Part A: Model documentation. US EPA, Athens, Georgia.

Ambrose, R. B., Wool, T. A., Martin, J. L., Connolly, J. P., and Schanz, R. W. 1987. A general water quality model for toxic and conventional pollutants, WASP4. EPA-600/3-87-093, US EPA, Athens, Georgia.

Ambrose, R. B., Wool, T. A., Connolly, J. P., and Schanz, R. W. (1988). "WASP4, a Hydrodynamic and water quality model--model theory, user's manual, and programmer's guide." EPA/600/3-87/039, Envir. Res. Lab., Envir. Protection Agency, Athens, Ga.

Ambrose, R. B., Wool, T. A., Martin, J. L. (1993). "The Water Quality Analysis Simulation Program, WASP5." Envir. Res. Lab., Envir. Protection Agency, Athens, Ga.

Ambrose, R. B., Wool, T. A., Martin, J. L. (1993). "The Dynamic Estuary Model Hydrodynamics Program, DYNHYD5." Envir. Res. Lab., Envir. Protection Agency, Athens, Ga.

Arif, Zouhrawoty (1991). "Runoff curve number evaluation for a small Iowa watershed," M.S. thesis, Iowa State University at Ames, IA.

Baumann, E. R., Speiran, G. K., Peterson, M. A., Burnett, J. M. (February, 1977) "Water Quality Studies -- Red Rock and Saylorville Reservoirs, Des Moines River, Iowa." Engineering Research Institute Annual Report, Iowa State University, Ames, Iowa.

Baumann, E. R., Speiran, G. K., Beckert, C. A., Olson, J. A. (November, 1977) "Water Quality Studies -- Red Rock and Saylorville Reservoirs, Des Moines River, Iowa." Engineering Research Institute Annual Report, Iowa State University, Ames, Iowa.

EPA. Compendium of Watershed-Scale Models for TMDL Development. Environmental Protection Agency: Washington D.C., 1992.

EPA. The Statewide Watershed Management Course, Environmental Protection Agency, Washington DC, 1995

Environmental Protection Agency (1992). *Compendium of watershed-scale models for TMDL development*, EPA: Washington, D.C.

Girton, R. D. (1994). "Trends in annual water quality loadings of nutrients and suspended solids in the Upper Des Moines and Raccoon Rivers." M.S. Thesis, Iowa State University, Ames, Iowa.

Hydroscience, Inc., (1971). “Simplified Mathematical Modeling of Water Quality.” prepared for the Mitre Corporation and the USEPA, Water Programs, Washington, D.C.

Haith, D.A., Ross Mandel, and Ray Shyan Wu (1992). *GWLF User's Manual, Version 2.0.* Cornnel University: Ithaca, NY.

Haith, D.A. and Merrill, D.E. (1987). “Evaluation of a Daily Rainfall Erositivity Model”. *Transactions of the American Society of Civil Engineers* (ASAE). ASAE: St. Joseph, MI.

Hipel, Keith W am A. Ian McLeod (1994).*Time Series Modeling of Water Resources and Environmental Systems*. Elsevier: New York, NY.

IDNR. State Nonpoint Source Assessment Report - Iowa 1988. Iowa Department of Natural Resources, Des Moines, 1988.

Iowa Department of Natural Resources (1994). *Water Quality in Iowa During 1992 and 1993.* IDNR: Des Moines, IA.

Iowa Department of Natural Resources (1988). *State Nonpoint Source Assessment Report-Iowa 1988.* IDNR: Des Moines, IA.

IAC: State of Iowa. November 1990. Water Quality Standards. Environmental Protection [567] Chapter 61, *Iowa Administrative Code*. Des Moines, Iowa.

Lutz, D. S. (1995). “Water Quality Studies -- Red Rock and Saylorville Reservoirs, Des Moines River, Iowa.” Engineering Research Institute Annual Report, Iowa State University, Ames, Iowa.

Novotony, Vladimir and Harvey Olson (1994). *Water Quality: Prevention, Identification, and Management of Diffuse Pollution*. Van Nostrand Reinhold: New York, NY.

Smith, George and Ted L. Willrich (1970). *Agricultural Practices and Water Quality*, Iowa State University Press: Ames, IA.

Thomann, R. V., and Mueller, J. A. (1987). *Principles of Surface Water Quality Modeling and Control*. HarperCollins, Publishers, Inc., New York, N.Y.

United States Geological Survey. (1989) “Water Resources Data, Iowa, Water Year 1989.” Iowa city, Iowa, Report No. IA-89-1.

USDA. *Losing Ground: Iowa's Soil Erosion Menace and Efforts to Combat It.* U.S. Department of Agriculture: Washington D.C., 1986.

United States Geological Survey, Iowa Natural Resources Council and Iowa Department of Environmental Quality. (1979) "Annual and Season low flow characteristic of Iowa Stream." Iowa city, Iowa.

USDA. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. U.S. Department of Agriculture: Washington D.C., 1978.

Wischmeir, W.H., and D.D. Smith (1978). *Predicting Rainfall Erosion Losses*, U.S. Department of Agriculture: Washington, D.C.