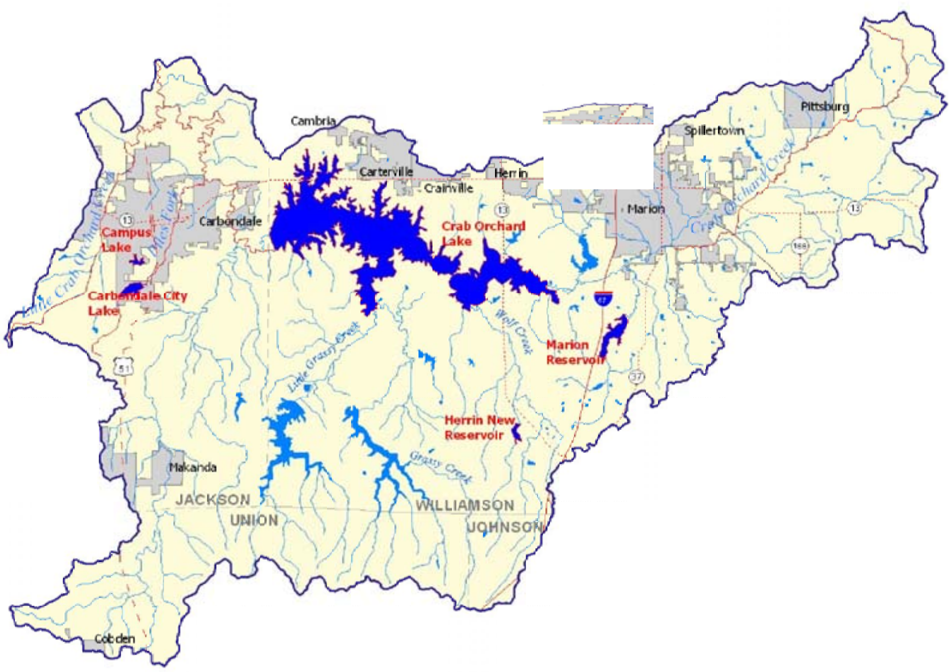
Illinois
Environmental
Protection Agency

Bureau of Water
P.O. Box 19276
Springfield, IL 62794-9276

June 2008

IEPA/BOW/08-005

Crab Orchard Watershed TMDL Report



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TMDL Development for the Crab Orchard Creek Watershed, Illinois

This file contains the following documents:

1) U.S. EPA Approval letter for Stage Three TMDL Report

2) Stage One Report: Third Quarter Draft Report

3) Stage Two Report: Data Report

4) Stage Three Report: TMDL Development

5) Implementation Plan

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

JUL 18 2008

REPLY TO THE ATTENTION OF:

WW-16J

Marcia Willhite, Chief
Bureau of Water
Illinois Environmental Protection Agency
P.O. Box 19276
Springfield, Illinois 62794-9276

Dear Ms. Willhite:

The U. S. Environmental Protection Agency has reviewed the final Total Maximum Daily Loads from the Illinois Environmental Protection Agency for the Crab Orchard Creek Watershed in Illinois. The TMDLs are for several pollutants in several waterbodies in the watershed as discussed in the enclosure, and addresses the recreational use and aquatic life impairments in these waterbodies.

Based on this review, EPA has determined that Illinois's TMDLs meet the requirements of Section 303(d) of the Clean Water Act and EPA's implementing regulations at 40 C.F.R. Part 130. Therefore, EPA hereby approves 22 TMDLs for 18 impairments in the Crab Orchard Creek Watershed in Illinois. The statutory and regulatory requirements, and EPA's review of Illinois's compliance with each requirement, are described in the enclosed decision document.

We wish to acknowledge Illinois's effort in submitting this TMDL and look forward to future TMDL submissions by the State of Illinois. If you have any questions, please contact Kevin Pierard, Chief of the Watersheds and Wetlands Branch, at 312-886-4448.

Sincerely yours,

Tinka G. Hyde

Tinka G. Hyde
Acting Director, Water Division

Enclosure

cc: Dean Studer, IEPA

Illinois Environmental
Protection Agency

Crab Orchard Creek Watershed TMDL
Stage One
Third Quarter Draft Report

June 2006

Draft Report

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Acronyms

°F	degrees Fahrenheit
BMP	best management practice
CWA	Clean Water Act
DMR	Discharge Monitoring Reports
DO	dissolved oxygen
ft	Foot or feet
GIS	geographic information system
HUC	Hydrologic Unit Code
IDA	Illinois Department of Agriculture
IDNR	Illinois Department of Natural Resources
IL-GAP	Illinois Gap Analysis Project
ILLCP	Illinois Interagency Landscape Classification Project
Illinois EPA	Illinois Environmental Protection Agency
INHS	Illinois Natural History Survey
IPCB	Illinois Pollution Control Board
LA	load allocation
LC	loading capacity
lb/d	pounds per day
mgd	Million gallons per day
mg/L	milligrams per liter
MOS	margin of safety
MUID	Map Unit Identification
NA	Not applicable
NASS	National Agricultural Statistics Service
NCDC	National Climatic Data Center
NED	National Elevation Dataset
NPDES	National Pollution Discharge Elimination System
NRCS	National Resource Conservation Service
PCS	Permit Compliance System
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic
STORET	Storage and Retrieval
STP	Sanitary Treatment Plant
TMDL	total maximum daily load

ug/L	Micrograms per liter
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WLA	waste load allocation
WTP	Water Treatment Plant

Section 1
Goals and Objectives for Crab Orchard Creek Watershed (0714010608)

1.1 Total Maximum Daily Load (TMDL) Overview

A Total Maximum Daily Load, or TMDL, is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. TMDLs are a requirement of Section 303(d) of the Clean Water Act (CWA). To meet this requirement, the Illinois Environmental Protection Agency (Illinois EPA) must identify water bodies not meeting water quality standards and then establish TMDLs for restoration of water quality. Illinois EPA lists water bodies not meeting water quality standards every two years. This list is called the 303(d) list and water bodies on the list are then targeted for TMDL development.

In general, a TMDL is a quantitative assessment of water quality problems, contributing sources, and pollution reductions needed to attain water quality standards. The TMDL specifies the amount of pollution or other stressor that needs to be reduced to meet water quality standards, allocates pollution control or management responsibilities among sources in a watershed, and provides a scientific and policy basis for taking actions needed to restore a water body.

Water quality standards are laws or regulations that states authorize to enhance water quality and protect public health and welfare. Water quality standards provide the foundation for accomplishing two of the principal goals of the CWA. These goals are:

- Restore and maintain the chemical, physical, and biological integrity of the nation's waters
- Where attainable, to achieve water quality that promotes protection and propagation of fish, shellfish, and wildlife, and provides for recreation in and on the water

Water quality standards consist of three elements:

- The designated beneficial use or uses of a water body or segment of a water body
- The water quality criteria necessary to protect the use or uses of that particular water body
- An antidegradation policy

Examples of designated uses are recreation and protection of aquatic life. Water quality criteria describe the quality of water that will support a designated use. Water quality criteria can be expressed as numeric limits or as a narrative statement. Antidegradation policies are adopted so that water quality improvements are conserved, maintained, and protected.

1.2 TMDL Goals and Objectives for Crab Orchard Creek Watershed

The Illinois EPA has a three-stage approach to TMDL development. The stages are:

- Stage 1 – Watershed Characterization, Data Analysis, Methodology Selection
- Stage 2 – Data Collection (optional)
- Stage 3 – Model Calibration, TMDL Scenarios, Implementation Plan

This report addresses Stage 1 TMDL development for the Crab Orchard Creek watershed. Stage 2 and 3 will be conducted upon completion of Stage 1. Stage 2 is optional as data collection may not be necessary if additional data are not required to establish the TMDL.

Following this process, the TMDL goals and objectives for the Crab Orchard Creek watershed will include developing TMDLs for all impaired water bodies within the watershed, describing all of the necessary elements of the TMDL, developing an implementation plan for each TMDL, and gaining public acceptance of the process. Following are the impaired water body segments in the Crab Orchard Creek watershed for which a TMDL will be developed:

- Crab Orchard Creek (ND 01)
- Crab Orchard Creek (ND 02)
- Crab Orchard Creek (ND 04)
- Crab Orchard Creek (ND 11)
- Crab Orchard Creek (ND 12)
- Crab Orchard Creek (ND 13)
- Little Crab Orchard Creek (NDA 01)
- Piles Fork (NDB 03)
- Crab Orchard Lake (RNA)
- Carbondale City Lake (RNI)
- Marion Reservoir (RNL)
- Herrin New Reservoir (RNZC)
- Campus Lake (RNZH)

These impaired water body segments are shown on Figure 1-1. There are 13 impaired segments within the Crab Orchard Creek watershed. Table 1-1 lists the water body segment, water body size, and potential causes of impairment for the water body.

Table 1-1 Impaired Water Bodies in Crab Orchard Creek Watershed

Water Body Segment ID	Water Body Name	Size	Causes of Impairment with Numeric Water Quality Standards	Causes of Impairment with Assessment Guidelines
ND 01	Crab Orchard Creek	9.61 miles	Total fecal coliform	
ND 02	Crab Orchard Creek	1.92 miles	Manganese, dissolved oxygen	Other flow alterations
ND 04	Crab Orchard Creek	13.93 miles	Manganese, sulfates, pH, dissolved oxygen, total dissolved solids (TDS)	TSS
ND 11	Crab Orchard Creek	0.95 miles	Manganese, pH, dissolved oxygen	Sedimentation/siltation
ND 12	Crab Orchard Creek	1.13 miles	Manganese, pH	Total phosphorus
ND 13	Crab Orchard Creek	1.5 miles	Manganese, dissolved oxygen	Total nitrogen, total phosphorus
NDA 01	Little Crab Orchard Creek	12.21 miles	Manganese, dissolved oxygen	Habitat alterations (streams), methoxychlor
NDB 03	Piles Fork	7 miles	Dissolved oxygen	Other flow alterations, habitat alterations (streams), methoxychlor
RNA	Crab Orchard Lake	6,965 acres	Total phosphorus	Excess algal growth, PCBs
RNI	Carbondale City Lake	135.6 acres	Manganese, total phosphorus	TSS, excess algal growth
RNL	Marion Reservoir	220 acres	Manganese, total phosphorus	Excess algal growth
RNZC	Herrin New Reservoir	46.1 acres	Manganese	Excess algal growth
RNZH	Campus Lake	40 acres	Total phosphorus	Excess algal growth, PCBs, mercury

Illinois EPA is currently only developing TMDLs for parameters that have numeric water quality standards, and therefore the remaining sections of this report will focus on the pH, dissolved oxygen, total fecal coliform, manganese, sulfates, TDS, and total phosphorus (numeric standard) impairments in the Crab Orchard Creek watershed. For potential causes that do not have numeric water quality standards as noted in Table 1-1, TMDLs will not be developed at this time. However, in the implementation plans completed during Stage 3 of the TMDL, many of these potential causes may be addressed by implementation of controls for the pollutants with water quality standards.

The TMDL for the segments listed above will specify the following elements:

- Loading Capacity (LC) or the maximum amount of pollutant loading a water body can receive without violating water quality standards

- Waste Load Allocation (WLA) or the portion of the TMDL allocated to existing or future point sources

- Load Allocation (LA) or the portion of the TMDL allocated to existing or future nonpoint sources and natural background

- Margin of Safety (MOS) or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality

These elements are combined into the following equation:

$$\mathbf{TMDL = LC = \Sigma WLA + \Sigma LA + MOS}$$

The TMDL developed must also take into account the seasonal variability of pollutant loads so that water quality standards are met during all seasons of the year. Also, reasonable assurance that the TMDL will be achieved will be described in the implementation plan. The implementation plan for the Crab Orchard Creek watershed will describe how water quality standards will be attained. This implementation plan will include recommendations for implementing best management practices (BMPs), cost estimates, institutional needs to implement BMPs and controls throughout the watershed, and timeframe for completion of implementation activities.

1.3 Report Overview

The remaining sections of this report contain:

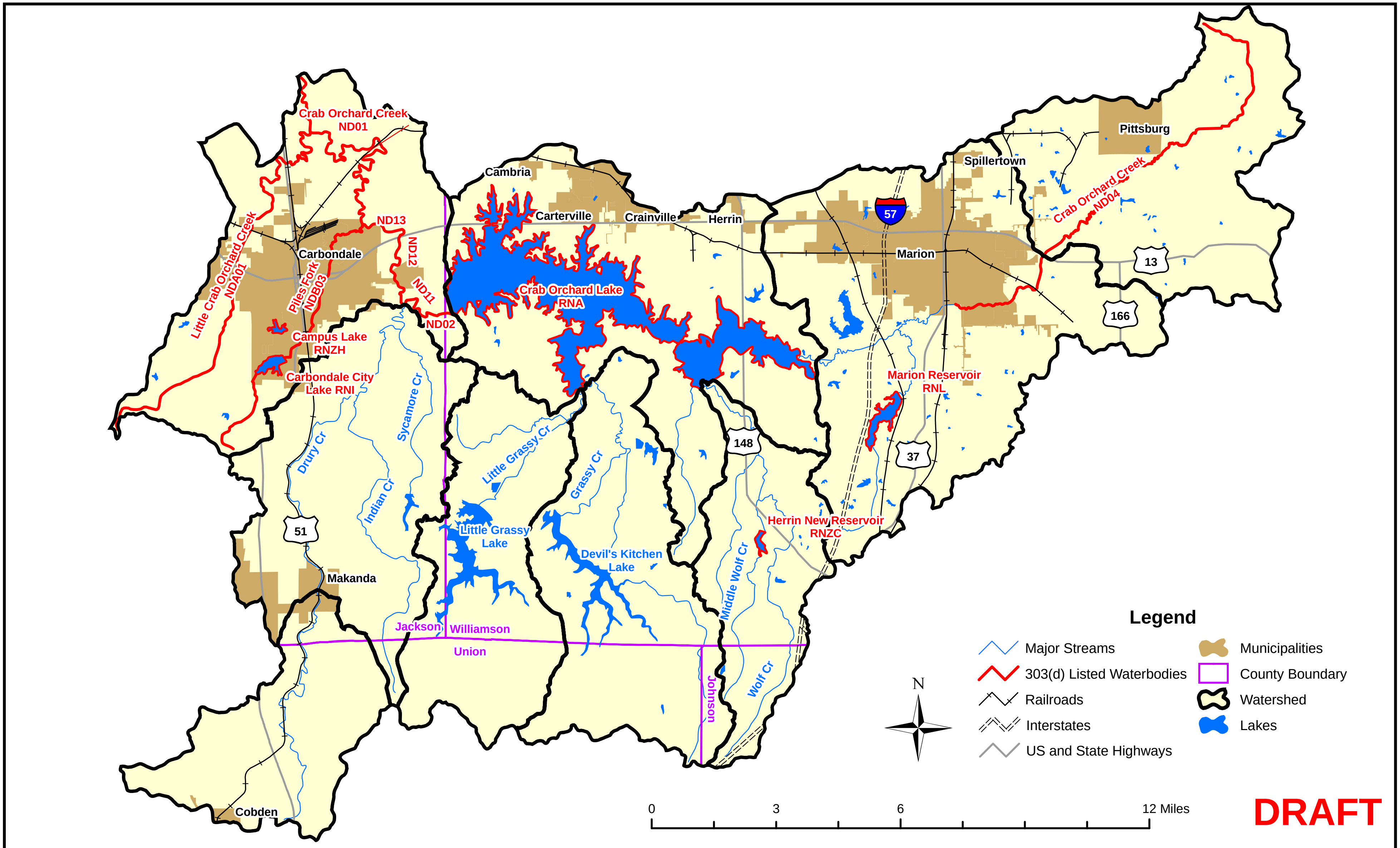
- **Section 2 Crab Orchard Creek Watershed Characteristics** provides a description of the watershed's location, topography, geology, land use, soils, population, and hydrology

- **Section 3 Public Participation and Involvement** discusses public participation activities that occurred throughout the TMDL development

- **Section 4 Crab Orchard Creek Watershed Water Quality Standards** defines the water quality standards for the impaired water body

- **Section 5 Crab Orchard Creek Watershed Characterization** presents the available water quality data needed to develop TMDLs, discusses the characteristics of the impaired reservoirs in the watershed, and also describes the point and non-point sources with potential to contribute to the watershed load.

- **Section 6 Approach to Developing TMDL and Identification of Data Needs** makes recommendations for the models and analysis that will be needed for TMDL development and also suggests segments for Stage 2 data collection.



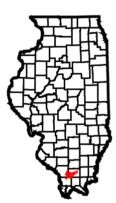


Figure 1-1
Crab Orchard Creek Watershed

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Section 2
Crab Orchard Creek Watershed Description

2.1 Crab Orchard Watershed Location

The Crab Orchard Creek watershed (Figure 1-1) is located in southern Illinois, flows in a westerly direction, and drains approximately 185,000 acres within the state of Illinois. The watershed covers land within Johnson, Williamson, Union, and Jackson counties.

2.2 Topography

Topography is an important factor in watershed management because stream types, precipitation, and soil types can vary dramatically by elevation. National Elevation Dataset (NED) coverages containing 30-meter grid resolution elevation data are available from the USGS for each 1:24,000-topographic quadrangle in the United States. Elevation data for the Crab Orchard Creek watershed was obtained by overlaying the NED grid onto the GIS-delineated watershed. Figure 2-1 shows the elevations found within the watershed.

Elevation in the Crab Orchard Creek watershed ranges from 886 feet above sea level in the headwaters of Crab Orchard Creek to 348 feet at its most downstream point in the northwest corner of the watershed. The absolute elevation change is 164 feet over the approximately 43-mile stream length of Crab Orchard Creek, which yields a stream gradient of approximately 3.8 feet per mile.

2.3 Land Use

Land use data for the Crab Orchard Creek watershed were extracted from the Illinois Gap Analysis Project (IL-GAP) Land Cover data layer. IL-GAP was started at the Illinois Natural History Survey (INHS) in 1996, and the land cover layer was the first component of the project. The IL-GAP Land Cover data layer is a product of the Illinois Interagency Landscape Classification Project (IILCP), an initiative to produce statewide land cover information on a recurring basis cooperatively managed by the United States Department of Agriculture National Agricultural Statistics Service (NASS), the Illinois Department of Agriculture (IDA), and the Illinois Department of Natural Resources (IDNR). The land cover data were generated using 30-meter grid resolution satellite imagery taken during 1999 and 2000. The IL-GAP Land Cover data layer contains 23 land cover categories, including detailed classification in the vegetated areas of Illinois. Appendix A contains a complete listing of land cover categories. (Source: IDNR, INHS, IDA, USDA NASS's 1:100,000 Scale Land Cover of Illinois 1999-2000, Raster Digital Data, Version 2.0, September 2003.)

The land use of the Crab Orchard Creek watershed was determined by overlaying the IL-GAP Land Cover data layer onto the GIS-delineated watershed. Table 2-1 contains the land uses contributing to the Crab Orchard Creek watershed, based on the IL-GAP land cover categories and also includes the area of each land cover category and percentage of the watershed area. Figure 2-2 illustrates the land uses of the watershed.

The land cover data reveal that approximately 83,464 acres, representing nearly 45 percent of the total watershed area, are devoted to agricultural activities. Corn and soybean farming account for about 6 percent and 9 percent of the watershed area, respectively, and rural grasslands occupy about 25 percent. About 22 percent of the total watershed area is covered with upland forests. Wetlands and surface water occupy approximately 12 and 7 percent, respectively. Other land cover categories represent 5 percent or less of the watershed area.

Table 2-1 Land Use in Crab Orchard Creek Watershed

Land Cover Category	Area (Acres)	Percentage
Corn	10,323	5.6%
Soybeans	17,402	9.4%
Winter Wheat	4,699	2.5%
Other Small Grains & Hay	1,626	0.9%
Winter Wheat/Soybeans	2,575	1.4%
Other Agriculture	109	0.1%
Rural Grassland	46,730	25.3%
Upland	40,526	21.9%
Forested Area	8,010	4.3%
High Density	3,266	1.8%
Low/Medium Density	3,760	2.1%
Urban Open Space	9,618	5.2%
Wetlands	22,876	12.4%
Surface Water	13,311	7.2%
Barren & Exposed Land	139	0.1%
Total	**184,976**	

1. Forested areas include partial canopy/savannah upland and coniferous.
2. Wetlands include shallow marsh/wet meadow, deep marsh, seasonally/temporally flooded, floodplain forest, swamp, and shallow water.

2.4 Soils

Two types of soil data are available for use within the state of Illinois through the National Resource Conservation Service (NRCS). General soils data and map unit delineations for the entire state are provided as part of the State Soil Geographic (STATSGO) database. Soil maps for the database are produced by generalizing detailed soil survey data. The mapping scale for STATSGO is 1:250,000. More detailed soils data and spatial coverages are available through the Soil Survey Geographic (SSURGO) database for a limited number of counties. For SSURGO data, field mapping methods using national standards are used to construct the soil maps. Mapping scales generally range from 1:12,000 to 1:63,360 making SSURGO the most detailed level of soil mapping done by the NRCS.

The Crab Orchard Creek watershed falls within Jackson, Williamson, Union, and Johnson Counties. At this time, SSURGO data are only available for Union County. STATSGO data have been used in lieu of SSURGO data for the portion of the watershed that lies within the other three counties. Figure 2-3 displays the STATSGO soil map units as well as the SSURGO soil series in the Crab Orchard Creek watershed. Attributes of the spatial coverage can be linked to the STATSGO and SSURGO databases, which provide information on various chemical and physical soil characteristics for each map unit and soil series. Of particular interest for TMDL development are the hydrologic soil groups as well as the K-factor of the Universal Soil Loss Equation. The following sections describe and summarize the specified soil characteristics for the Crab Orchard Creek watershed.

2.4.1 Crab Orchard Creek Watershed Soil Characteristics

Appendix B contains the STATSGO Map Unit IDs (MUIDs) for the Crab Orchard Creek watershed as well as the SSURGO soil series. The table also contains the area, dominant hydrologic soil group, and K-factor range. Each of these characteristics is described in more detail in the following paragraphs. The predominant soil type in the STATSGO portion of the watershed are soils categorized as a fine-grained and made up of silts and clays with a liquid limit of less than 50 percent that tend toward a lean clay and silt. The predominant soil type in the SSURGO portion of the watershed is Homer silt loam on varying slopes.

Hydrologic soil groups are used to estimate runoff from precipitation. Soils are assigned to one of four groups. They are grouped according to the infiltration of water when the soils are thoroughly wet and receive precipitation from long-duration storms. Hydrologic soil groups B, C, and D are found within the Crab Orchard Creek watershed with the majority of the watershed falling into category C. Category C soils are defined as "soils having a slow infiltration rate when thoroughly wet." C soils consist "chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture." These soils have a slow rate of water transmission (NRCS, 2005).

A commonly used soil attribute is the K-factor. The K-factor:

> *Indicates the susceptibility of a soil to sheet and rill erosion by water.* (The K-factor) *is one of six factors used in the Universal Soil Loss Equation (USLE) to predict the average annual rate of soil loss by sheet and rill erosion. Losses are expressed in tons per acre per year. These estimates are based primarily on percentage of silt, sand, and organic matter (up to 4 percent) and on soil structure and permeability. Values of K range from 0.02 to 0.69. The higher the value, the more susceptible the soil is to sheet and rill erosion by water (NRCS 2005).*

The distribution of K-factor values in the Crab Orchard Creek watershed range from 0.1 to 0.64.

2.5 Population

Population data were retrieved from Census 2000 TIGER/Line Data from the U.S. Bureau of the Census. Geographic shape files of census blocks were downloaded for every county containing any portion of the watersheds. The block files were clipped to each watershed so that only block populations associated with the watershed would be counted. The census block demographic text file (PL94) containing population data were downloaded and linked to each watershed and summed. City populations were taken from the U.S. Bureau of the Census. For municipalities that are located across watershed borders, the population was estimated based on the percentage of area of municipality within the watershed boundary.

Approximately 94,700 people reside in the watershed. The municipalities in the Crab Orchard Creek watershed are shown in Figure 1-1. The city of Carbondale is the largest population center in the watershed followed by the city of Marion. Each contributes an estimated 19,600 and 16,000 people to total watershed population, respectively.

2.6 Climate and Streamflow

2.6.1 Climate

Southern Illinois has a temperate climate with hot summers and cold, snowy winters. Monthly precipitation and temperature data from the Carbondale Sewage Plant (station id. 1265) in Johnson County were extracted from the NCDC database for the years of 1910 through 2004. The data station in Carbondale, Illinois was chosen to be representative of meteorological conditions throughout the Crab Orchard Creek watershed.

Table 2-2 contains the average monthly precipitation along with average high and low temperatures for the period of record. The average annual precipitation is approximately 44 inches.

Table 2-2 Average Monthly Climate Data in Carbondale, Illinois

Month	Total Precipitation (inches)	Maximum Temperature (degrees F)	Minimum Temperature (degrees F)
January	3.0	42	24
February	1.2	47	27
March	5.5	57	35
April	3.4	69	45
May	6.6	78	54
June	3.1	86	63
July	4.3	90	67
August	1.8	89	64
September	0.1	83	57
October	6.3	72	45
November	6.0	57	35
December	3.0	46	27
Total	**44.3**		

2.6.2 Streamflow

Analysis of the Crab Orchard Creek watershed requires an understanding of flow throughout the drainage area. USGS gage 05597500 (Crab Orchard Creek near Marion, Illinois) is the only available data gage within the watershed with current data (Figure 2-4). The gage is located just upstream of the town of Marion, Illinois on the ND04 segment of Crab Orchard Creek. The station is approximately seven miles upstream of Crab Orchard Lake.

Data was available for the gage from the USGS for the years 1951 through 2004. The average monthly flows recorded at the gage range from 3.8 cubic feet per second (cfs) in September to 64 cfs in March with a mean annual monthly flow of 29 cfs (Figure 2-5).

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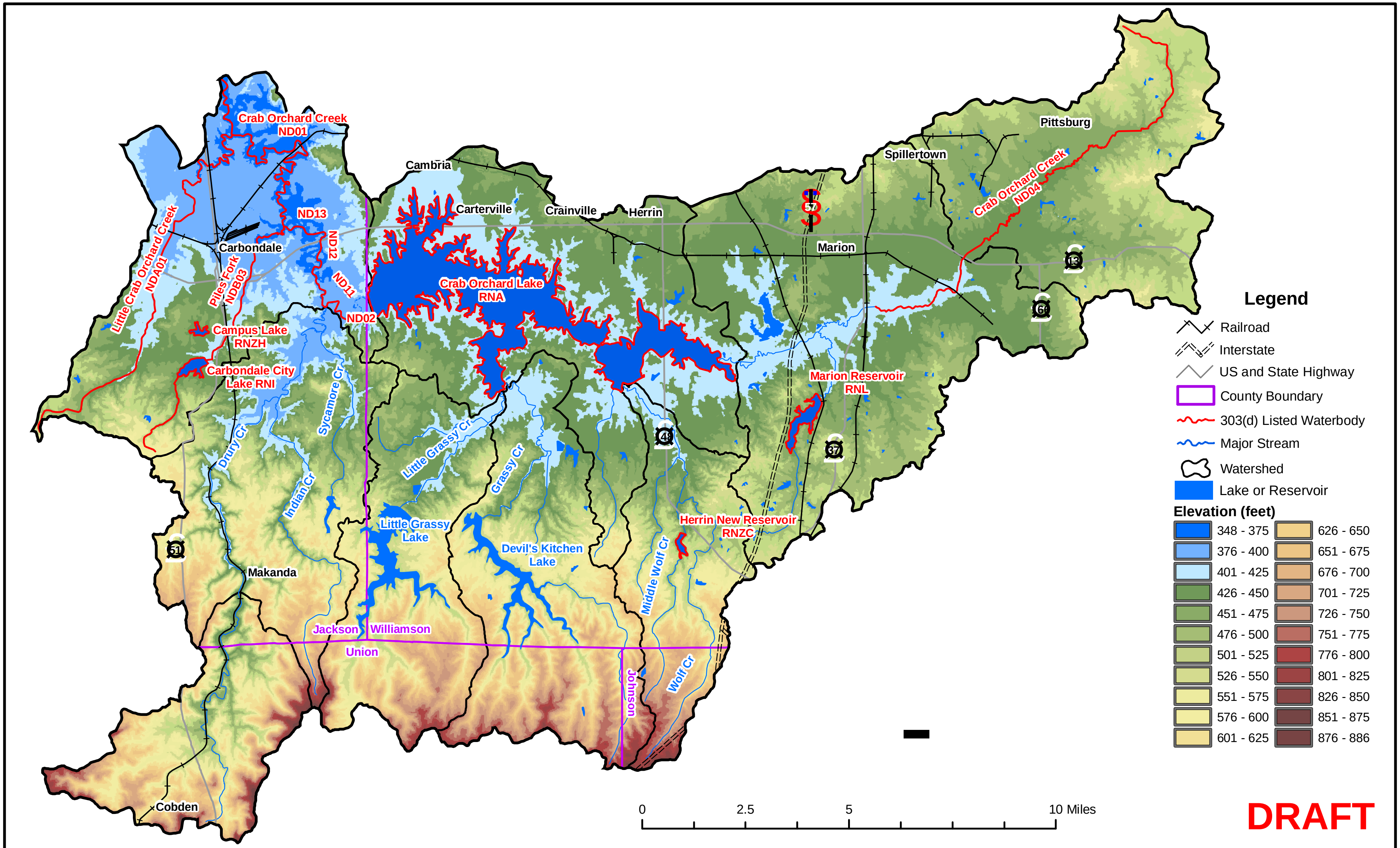

Figure 2-1
Crab Orchard Creek Watershed
Elevation

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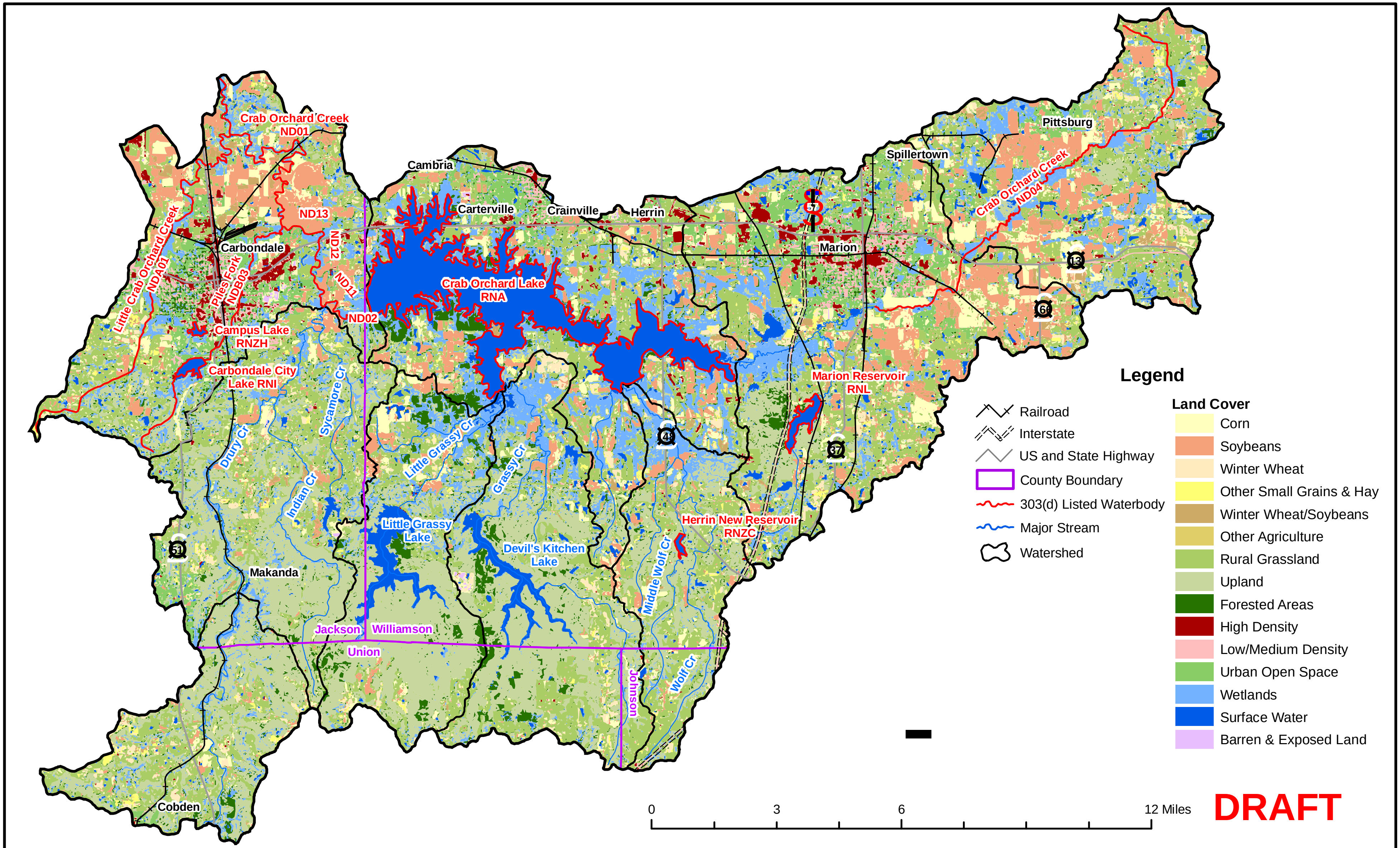

Figure 2-2
Crab Orchard Creek Watershed
Land Use

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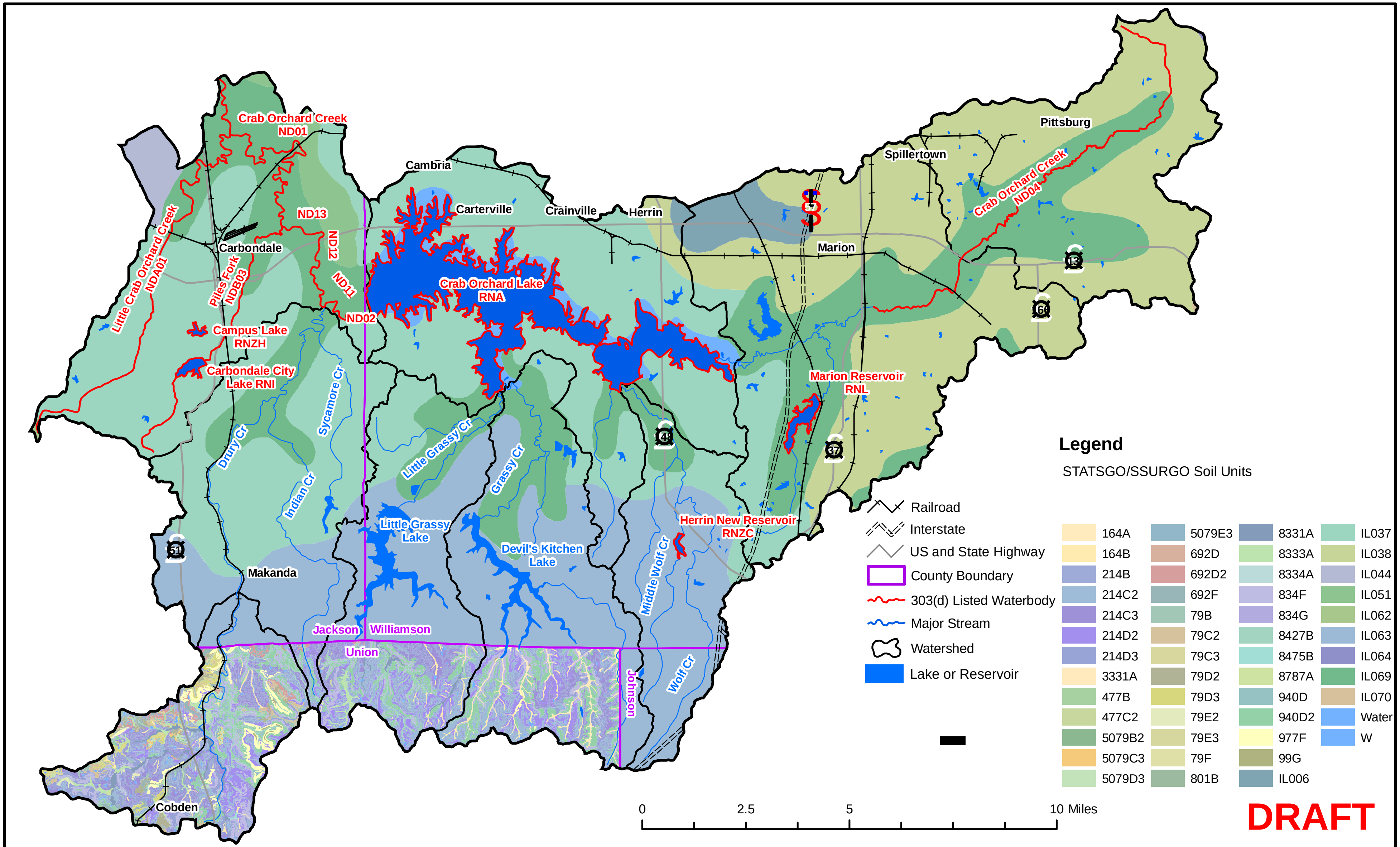

Figure 2-3
Crab Orchard Creek Watershed
Soils

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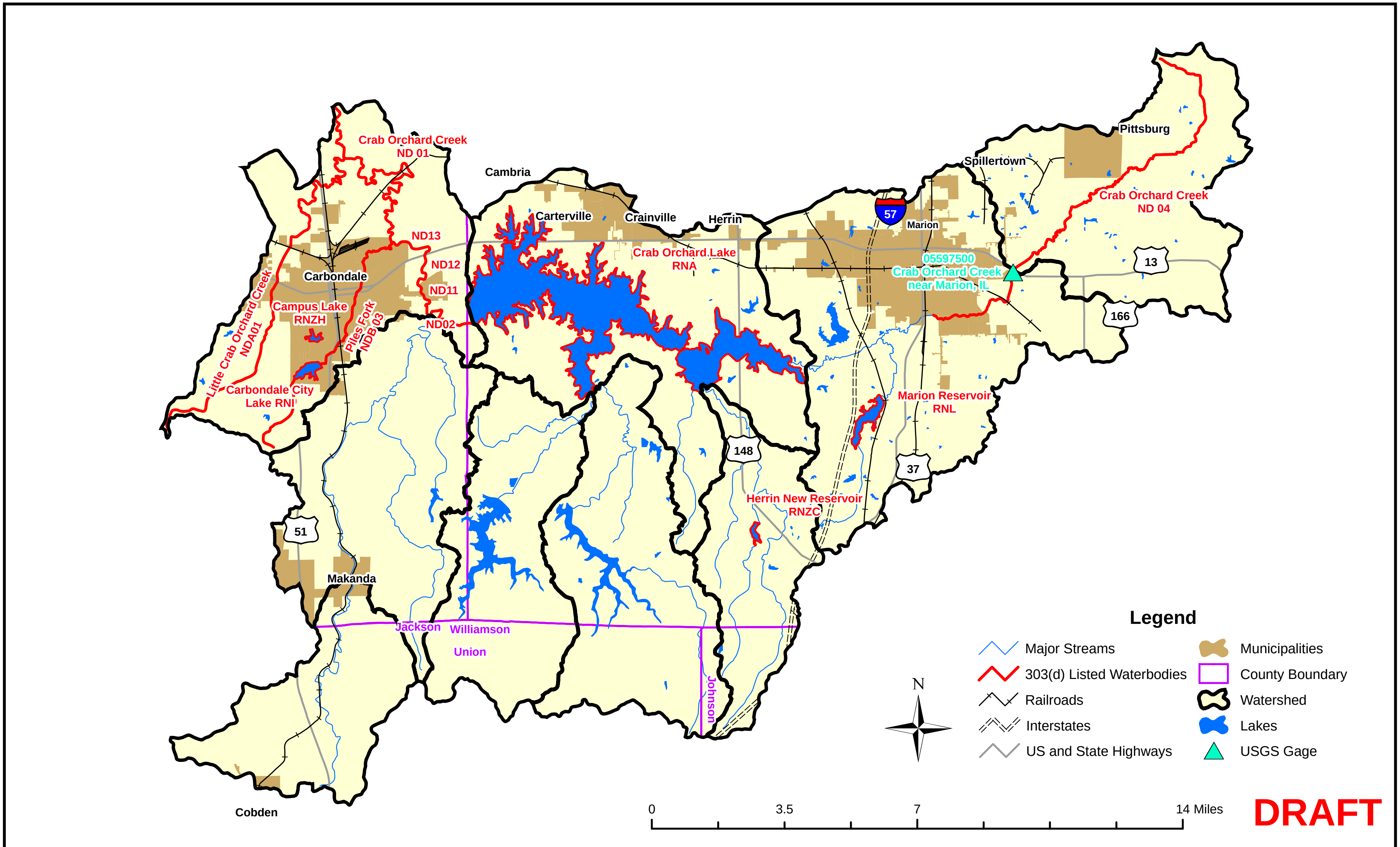

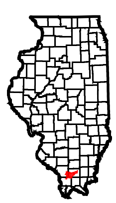

Figure 2-4
Flow Gage
Crab Orchard Creek Watershed

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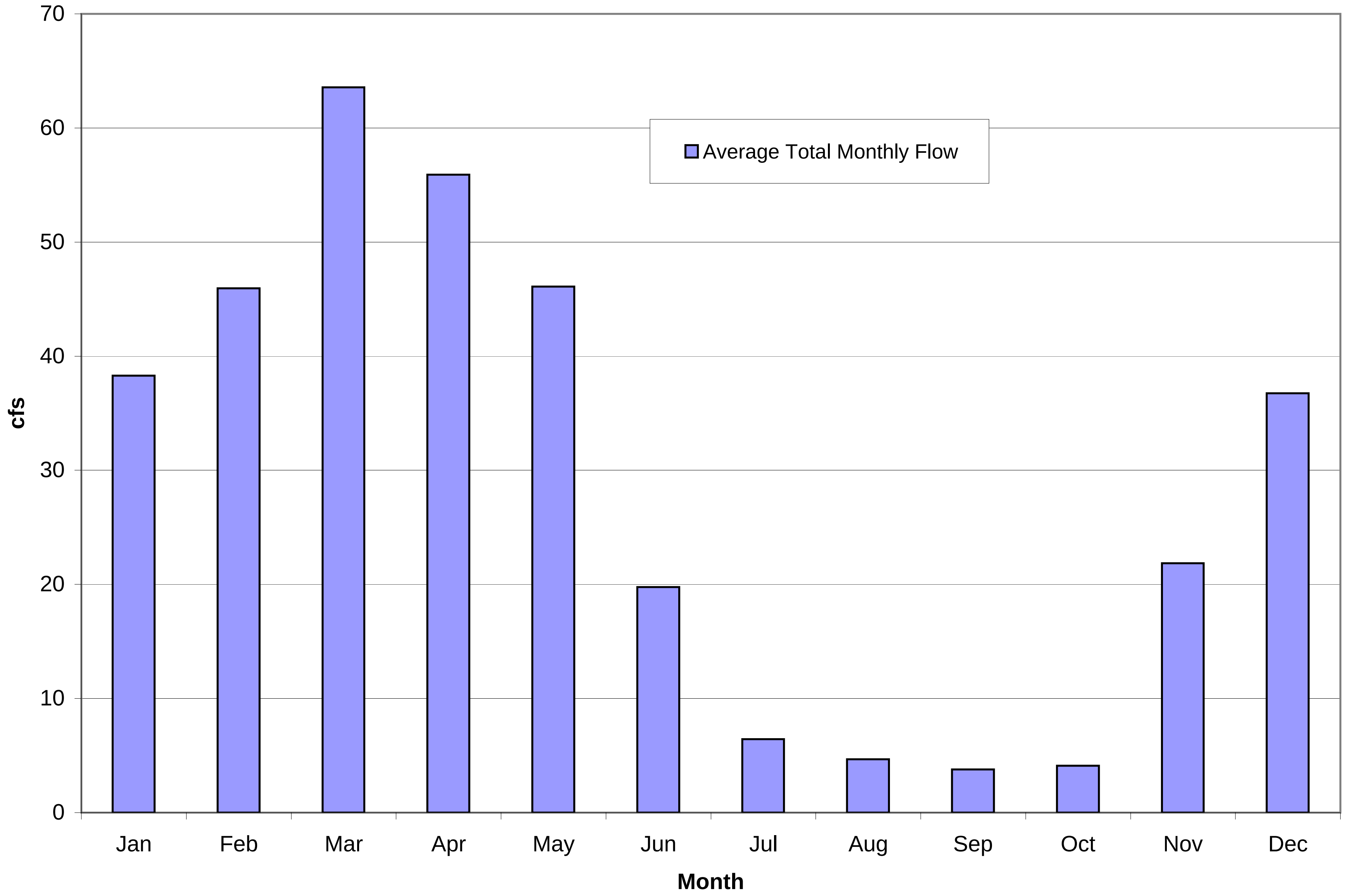

CDM

T:\GIS\WRITEUP\1 Crab Orchard\Data\Crab Orchard Flow-Precip-temp.xlscrab orchard flow

Figure 2-5
Streamflow at USGS Gage 05597500
Crab Orchard Creek near Marion, IL

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Section 3
Public Participation and Involvement

3.1 Crab Orchard Creek Watershed Public Participation and Involvement

Public knowledge, acceptance, and follow through are necessary to implement a plan to meet recommended TMDLs. It is important to involve the public as early in the process as possible to achieve maximum cooperation and counter concerns as to the purpose of the process and the regulatory authority to implement any recommendations.

Illinois EPA, along with CDM, will hold up to four public meetings within the watershed throughout the course of the TMDL development. This section will be updated once public meetings have occurred.

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Section 4
Crab Orchard Creek Watershed Water Quality Standards

4.1 Illinois Water Quality Standards

Water quality standards are developed and enforced by the state to protect the "designated uses" of the state's waterways. In the state of Illinois, setting the water quality standards is the responsibility of the Illinois Pollution Control Board (IPCB). Illinois is required to update water quality standards every three years in accordance with the CWA. The standards requiring modifications are identified and prioritized by Illinois EPA, in conjunction with USEPA. New standards are then developed or revised during the three-year period.

Illinois EPA is also responsible for developing scientifically based water quality criteria and proposing them to the IPCB for adoption into state rules and regulations. The Illinois water quality standards are established in the Illinois Administrative Rules Title 35, Environmental Protection; Subtitle C, Water Pollution; Chapter I, Pollution Control Board; Part 302, Water Quality Standards.

4.2 Designated Uses

The waters of Illinois are classified by designated uses, which include: General Use, Public and Food Processing Water Supplies, Lake Michigan, and Secondary Contact and Indigenous Aquatic Life Use (Illinois EPA 2005). The designated uses applicable to the Crab Orchard Creek watershed are the General Use and Public and Food Processing Water Supplies Use.

4.2.1 General Use

The General Use classification is defined by IPCB as standards that "will protect the State's water for aquatic life, wildlife, agricultural use, secondary contact use and most industrial uses and ensure the aesthetic quality of the state's aquatic environment." Primary contact uses are protected for all General Use waters whose physical configuration permits such use.

4.2.2 Public and Food Processing Water Supplies

The Public and Food Processing Water Supplies Use is defined by IPCB as standards that are "cumulative with the general use standards of Subpart B and must be met in all waters designated in Part 303 at any point at which water is withdrawn for treatment and distribution as a potable supply or for food processing."

4.3 Illinois Water Quality Standards

To make 303(d) listing determinations for aquatic life uses, Illinois EPA first collects biological data and if this data suggests that an impairment to aquatic life exists, a comparison of available water quality data with water quality standards will then occur. For public and food processing water supply waters, Illinois EPA compares available data with water quality standards to make impairment determinations. Tables 4-1 and 4-2 present the water quality standards of the potential causes of impairment for both lakes and streams in the Crab Orchard Creek watershed. Only constituents with numeric water quality standards will have TMDLs developed at this time.

Table 4-1 Summary of Water Quality Standards for Potential Crab Orchard Creek Watershed Lake Impairments

Parameter	Units	General Use Water Quality Standard	Public and Food Processing Water Supplies
Excess Algal Growth	NA	No numeric standard	No numeric standard
Manganese (total)	µg/L	1000	150
Mercury - Statistical Guideline	NA		No numeric standard
PCBs - Statistical Guideline	NA	No numeric standard	No numeric standard
Total Phosphorus	mg/L	0.05[1]	No numeric standard
Total Suspended Solids	NA	No numeric standard	No numeric standard

µg/L = micrograms per liter mg/L = milligrams per liter NA = Not Applicable

[1] Standard applies in particular to inland lakes and reservoirs (greater than 20 acres) and in any stream at the point where it enters any such lake or reservoir.

Table 4-2 Summary of Water Quality Standards for Potential Crab Orchard Creek Watershed Stream Impairments

Parameter	Units	General Use Water Quality Standard	Public and Food Processing Water Supplies
Habitat Alterations (Streams)	NA	No numeric standard	No numeric standard
Manganese (total)	µg/L	1000	150
Methoxychlor - Statistical Guideline	NA	No numeric standard	No numeric standard
Other flow alterations	NA	No numeric standard	No numeric standard
Oxygen, Dissolved	mg/L	5.0 instantaneous minimum;	No numeric standard
		6.0 minimum during at least 16 hours of any 24 hour period	
pH		6.5 minimum	No numeric standard
		9.0 maximum	
Sedimentation/Siltation	NA	No numeric standard	No numeric standard
Sulfates	mg/L	500	250
Total Dissolved Solids	mg/L	1000	500
Total Fecal Coliform	Count/ 100 mL	May through Oct – 200(1), 400(2)	2000(1)
		Nov though Apr – no numeric standard	
Total Nitrogen as N	NA	No numeric standard	No numeric standard
Total Phosphorus - Statistical Guideline	NA	No numeric standard	No numeric standard
Total Suspended Solids	NA	No numeric standard	No numeric standard

µg/L = micrograms per liter mg/L = milligrams per liter NA = Not Applicable

(1) Geometric mean based on a minimum of five samples taken over not more than a 30-day period.
(2) Standard shall not be exceeded by more than 10 percent of the samples collected during any 30-day period.

4.4 Potential Pollutant Sources

In order to properly address the conditions within the Crab Orchard Creek watershed, potential pollution sources must be investigated for the pollutants where TMDLs will be developed. The following is a summary of the potential sources associated with the listed causes for the 303(d) listed segments in this watershed. They are summarized in Table 4-3.

Table 4-3 Summary of Potential Sources for Crab Orchard Creek Watershed

Segment ID	Segment Name	Potential Causes	Potential Sources
ND 01	Crab Orchard Creek	Total fecal coliform	Municipal point sources, agriculture, crop-related sources, nonirrigated crop production, urban runoff/storm sewers, source unknown
ND 02	Crab Orchard Creek	Manganese, dissolved oxygen, other flow alterations	Hydromodification, upstream impoundment, flow regulation/ modification, source unknown
ND 04	Crab Orchard Creek	Manganese, sulfates, pH, dissolved oxygen, TSS, TDS	Agriculture, crop-related sources, nonirrigated crop production, grazing-related sources, pasture grazing – riparian and/or upland, intensive animal feeding operations, resource extraction, surface mining, source unknown
ND 11	Crab Orchard Creek	Manganese, pH, dissolved oxygen, sedimentation/ siltation	Agriculture, crop-related sources, nonirrigated crop production, resource extraction, surface mining, source unknown
ND 12	Crab Orchard Creek	Manganese, pH. total phosphorus	Agriculture, crop-related sources, nonirrigated crop production, resource extraction, surface mining
ND 13	Crab Orchard Creek	Manganese, dissolved oxygen, total nitrogen as N, total phosphorus	Agriculture, crop-related sources, nonirrigated crop production, resource extraction, surface mining
NDA 01	Little Crab Orchard Creek	Manganese, dissolved oxygen, habitat alterations (streams), methoxychlor	Agriculture, crop-related source, nonirrigated crop production, grazing-related sources, pasture grazing – riparian and/or upland, urban runoff/storm sewers, habitat modification (other than hydromodification), removal of riparian vegetation, bank or shoreline modification/destabilization
NDB 03	Piles Fork	Dissolved oxygen, other flow alterations, habitat alterations (streams), methoxychlor	Urban runoff/storm sewers, hydromodification, upstream impoundment, habitat modification (other than hydromodification), bank or shoreline modification/destabilization

Table 4-3 Summary of Potential Sources for Crab Orchard Creek Watershed (continued)

Segment ID	Segment Name	Potential Causes	Potential Sources
RNA	Crab Orchard Lake	Total phosphorus, excess algal growth, PCBs	Municipal point sources, agriculture, crop-related sources, nonirrigated crop production, land disposal, hazardous waste, habitat modification (other than hydromodification), bank or shoreline modification/destabilization, contaminated sediments, source unknown
RNI	Carbondale City Lake	Manganese, total phosphorus, total suspended solids, excess algal growth	Urban runoff/storm sewers, forest/grassland/parkland, source unknown
RNL	Marion Reservoir	Manganese, total phosphorus, excess algal growth	Agriculture, crop-related sources, nonirrigated crop production, hydromodification, flow regulation/modification, herbicide/algicide application, source unknown
RNZC	Herrin New Reservoir	Manganese, excess algal growth	Habitat modification (other than hydromodification), bank or shoreline modification/destabilization, forest/grassland/parkland, source unknown
RNZH	Campus Lake	Total phosphorus, excess algal growth, PCBs, Mercury	Urban runoff/storm sewers, spills, waterfowl, forest/grassland/parkland, source unknown

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Section 5
Crab Orchard Creek Watershed Characterization

Data was collected and reviewed from many sources in order to further characterize the Crab Orchard Creek watershed. Data has been collected in regards to water quality, reservoirs, and both point and nonpoint sources. This information is presented and discussed in further detail in the remainder of this section.

5.1 Water Quality Data

There are 40 historic water quality stations within the Crab Orchard Creek watershed that were used for this report. Figure 5-1 shows the water quality data stations within the watershed that contain data relevant to the impaired segments.

The impaired water body segments in the Crab Orchard Creek watershed were presented in Section 1. Refer to Table 1-1 for impairment information specific to each segment. The following sections address both stream and lake impairments. Data are summarized by impairment and discussed in relation to the relevant Illinois numeric water quality standard. Data analysis is focused on all available data collected since 1990. The information presented in this section is a combination of USEPA Storage and Retrieval (STORET) database and Illinois EPA database data. STORET data are available for stations sampled prior to January 1, 1999 while Illinois EPA data (electronic and hard copy) are available for stations sampled after that date. The following sections will first discuss Crab Orchard Creek watershed stream data followed by Crab Orchard Creek watershed lake/reservoir data.

5.1.1 Stream Water Quality Data

The Crab Orchard Creek watershed has eight impaired streams within its drainage area that are addressed in this report. There are 12 active water quality stations on impaired segments (see Figure 5-1). The data summarized in this section include water quality data for impaired constituents as well as parameters that could be useful in future modeling and analysis efforts. All historic data are available in Appendix B.

5.1.1.1 Fecal Coliform

Segment ND01 Crab Orchard Creek is listed as impaired for total fecal coliform. Table 5-1 summarizes available historic fecal coliform data on the segment. The general use water quality standard for fecal coliform states that the standard of 200 per 100 mL not be exceeded by the geometric mean of at least five samples, nor can 10 percent of the samples collected exceed 400 per 100 mL in protected waters, except as provided in 35 Ill. Adm. Code 302.209(b). Samples must be collected over a 30 day period and the standard applies during the months of May through October. There are no instances since 1990 where at least five samples have been collected during a 30-day period. The summary of data presented in Table 5-1 reflects single samples compared to the standards during the appropriate months. Figure 5-2 shows the total fecal coliform samples collected over time at ND01..

Table 5-1 Existing Fecal Coliform Data

Sample Location and Parameter	Period of Record and Number of Data Points	Geometric mean of all samples	Maximum	Minimum	Number of samples > 200 [(1)]	Number of samples > 400 [(1)]
Crab Orchard Creek Segment ND01; Sample Location ND01						
Total Fecal Coliform (cfu/100 mL)	1990-2004; 66	240	7,900	10	37	29

(1) Samples collected during the months of May through October

5.1.1.2 Dissolved Oxygen

Segments ND02, ND04, ND11, and ND13 of Crab Orchard Creek, segment NDA01 or Little Crab Orchard Creek, and segment NDB03 of Piles Fork are listed impairment potentially caused by DO. Table 5-2 summarizes the available historic DO data since 1990 for the impaired stream segments (raw data contained in Appendix C). The table also shows the number of violations for each segment. A sample was considered a violation if it was below 5.0 mg/L. The average DO concentration is below the standard (5.0 mg/L instantaneous minimum) on two of the six impaired segments. Minimum values for all segments are below the DO standard. Figure 5-3 shows the instantaneous DO concentrations over time on Crab Orchard Creek segments ND02 and ND04. There was not enough data available on the remaining segments for time series plots.

Table 5-2 Existing Dissolved Oxygen Data for Crab Orchard Creek Watershed Impaired Stream Segments

Sample Location and Parameter	Illinois WQ Standard (mg/L)	Period of Record and Number of Data Points	Mean	Maximum	Minimum	Number of Violations
Crab Orchard Creek Segment ND02; Sample Location ND02						
DO	5.0[(1)]	1990-1997; 65	8.9	14.1	1.5	9
Crab Orchard Creek Segment ND04; Sample Location ND04						
DO	5.0[(1)]	1990-2003; 136	7.2	13.5	0.9	23
Crab Orchard Creek Segment ND11; Sample Location ND-CD-A1						
DO	5.0[(1)]	1995-2000; 2	4.4	5.2	3.6	1
Crab Orchard Creek Segment ND13; Sample Locations ND-CD-C2 and ND-CD-C3						
DO	5.0[(1)]	2000; 4	4.4	4.8	4	4
Little Crab Orchard Creek Segment NDA01; Sample Location NDA01						
DO	5.0[(1)]	1995-1996; 2	5.8	8.9	2.7	1
Piles Fork Segment NDB03; Sample Location NDB03						
DO	5.0[(1)]	1995-1996; 2	6.7	9.1	4.2	1

(1) Instantaneous Minimum

Table 5-3 contains information on data availability for other parameters that may be useful in data needs analysis and future modeling efforts for DO. Where available, all nutrient, biological oxygen demand (BOD), and total organic carbon data has been collected for possible use in future analysis.

Table 5-3 Data Availability for DO Data Needs Analysis and Future Modeling Efforts

Sample Location and Parameter	Available Period of Record Post 1990	Number of Samples
Crab Orchard Creek Segment ND02; Sample Location ND02		
Ammonia, Unionized (Calc Fr Temp-pH-NH4) (mg/L)	1990-1997	67
Ammonia, Unionized (mg/L as N)	1990-1998	67
Carbon, Total Organic (mg/L as C)	1990-1997	66
Nitrite plus Nitrate, Total 1 Det. (mg/L as N)	1990-1997	67
Nitrogen, Ammonia, Total (mg/L as N)	1990-1997	67
Nitrogen, Kjeldahl, Total (mg/L as N)	1990-1997	66
Phosphorus, Dissolved (mg/L as P)	1990-1997	67
Phosphorus, Total (mg/L as P)	1990-1997	67
Crab Orchard Creek Segment ND04; Sample Locations ND04 and ND-MA-D3		
Ammonia, Unionized (Calc Fr Temp-pH-NH4) (mg/L)	1990-1998	82
Ammonia, Unionized (mg/L as N)	1990-1998	82
BOD, 5-Day, 20 Deg C (mg/L)	2000	1
BOD, Carbonaceous, 5-Day, 20 Deg C (mg/L)	2000	1
Carbon, Total Organic (mg/L as C)	1990-2001	102
Chlorophyll (A+B+C) Filterable	2000	2
Chlorophyll-a, Uncorrected for Pheophytin, Fixed	2000	2
Chlorophyll-a, Uncorrected for Pheophytin, Total	2000	1
COD, .025N K2CR2O7 (mg/L)	1990-1993	33
Nitrite plus Nitrate, Total 1 Det. (mg/L as N)	1990-2002	114
Nitrogen, Ammonia, Total (mg/L as N)	1990-2002	114
Nitrogen, Kjeldahl, Total (mg/L as N)	1995-2000	10
Nitrogen, Kjeldahl, Total Bottom Dep Dry Wt (mg/kg)	1995	1
Phosphorus, Dissolved (mg/L as P)	1990-2002	114
Phosphorus, Total (mg/L as P)	1990-2002	114
Phosphorus, Total, Bottom Deposit (mg/kg-P Dry Wgt)	1995	1
Crab Orchard Creek Segment ND11; Sample Location ND-CD-A1		
BOD, 5-Day, 20 Deg C (mg/L)	2000	2
BOD, Carbonaceous, 5-Day, 20 Deg C (mg/L)	2000	2
Carbon, Total Organic (mg/L as C)	2000	2
Nitrogen, Nitrite (NO2) + Nitrate (NO3) (mg/L)	2000	2
Nitrogen, Ammonia, Total (mg/L as N)	2000	2
Phosphorus, Total (mg/L as P)	2000	2
Crab Orchard Creek Segment ND13; Sample Locations ND-CD-C2 and ND-CD-C3		
BOD, 5-Day, 20 Deg C (mg/L)	2000	4
BOD, Carbonaceous, 5-Day, 20 Deg C (mg/L)	2000	4
Carbon, Total Organic (mg/L as C)	2000	4
Nitrogen, Nitrite (NO2) + Nitrate (NO3) (mg/L)	2000	4
Nitrogen, Ammonia, Total (mg/L as N)	2000	4
Phosphorus, Total (mg/L as P)	2000	4
Little Crab Orchard Creek Segment NDA01; Sample Location NDA01		
Ammonia, Unionized (Calc Fr Temp-pH-NH4) (mg/L)	1995-1996	2
Ammonia, Unionized (mg/L as N)	1995-1996	2
Carbon, Total Organic (mg/L as C)	1995-1996	2
Nitrogen, Nitrite (NO2) + Nitrate (NO3) (mg/L)	1995-1996	2
Nitrogen, Ammonia, Total (mg/L as N)	1995-1996	2
Nitrogen, Kjeldahl, Total (mg/L as N)	1995	1
Nitrogen, Kjeldahl, Total Bottom Dep Dry Wt (mg/kg)	1995-1996	2
Phosphorus, Dissolved (mg/L as P)	1995-1996	2
Phosphorus, Total (mg/L as P)	1995-1996	2
Phosphorus, Total, Bottom Deposit (mg/kg-P Dry Wgt)	1995	1

Table 5-3 Data Availability for DO Data Needs Analysis and Future Modeling Efforts continued

Sample Location and Parameter	Available Period of Record Post 1990	Number of Samples
Piles Fork Segment NDB03; Sample Location NDB03		
Ammonia, Unionized (Calc Fr Temp-pH-NH4) (mg/L)	1995-1996	2
Ammonia, Unionized (mg/L as N)	1995-1996	2
Carbon, Total Organic (mg/L as C)	1995-1996	2
Nitrogen, Nitrite (NO2) + Nitrate (NO3) (mg/L)	1995-1996	2
Nitrogen, Ammonia, Total (mg/L as N)	1995-1996	2
Nitrogen, Kjeldahl, Total (mg/L as N)	1995-1996	2
Nitrogen, Kjeldahl, Total Bottom Dep Dry Wt (mg/kg)	1995	1
Phosphorus, Dissolved (mg/L as P)	1995-1996	2
Phosphorus, Total (mg/L as P)	1995-1996	2
Phosphorus, Total, Bottom Deposit (mg/kg-P Dry Wgt)	1995	1

5.1.1.3 pH

All impaired Crab Orchard Creek segments except ND01, ND02 and ND13 are listed for pH impairment. Table 5-4 summarizes the available historic pH data since 1990 for the impaired stream segments (raw data contained in Appendix C). The table also shows the number of violations for each segment. Some of the pH data for this watershed have come from Facility Related Stream Surveys. Facility Related Stream Surveys were conducted for the Marion Municipal WWTP in 2000 and 2004 and for the Carbondale SE WWTP in August 2004. A sample was considered a violation if the value was not within the 6.5-9.0 pH range. The average pH value was within the standard range for all segments, and only segments ND01 and ND04 had violations. There was only one violation above 9.0. The other two violations occurred when pH levels dropped below 6.5. Figure 5-4 shows pH values recorded over time. The graphic shows that all violations have occurred since 1995.

Table 5-4 Existing pH Data for Crab Orchard Creek Watershed Impaired Stream Segments

Sample Location and Parameter	Illinois WQ Standard (s.u.)	Period of Record and Number of Data Points	Mean	Maximum	Minimum	Number of Violations
Crab Orchard Creek Segment ND04; Sample Location ND04						
pH	6.5-9.0	1990-1998; 81	7.3	8.4	6.3	2
Crab Orchard Creek Segment ND11; Sample Location ND-CD-A1						
pH[1]	6.5-9.0	2004; 3	6.7	7.3	6.1	1
Crab Orchard Creek Segment ND12; Sample Locations ND-CD-C1						
pH[1]	6.5-9.0	2004; 3	6.6	7.3	5.7	1

(1) Data point was obtained from 2004 Facility Related Stream Survey

5.1.1.4 Chemical Constituents: Manganese, Sulfates, Total Dissolved Solids

All of the impaired Crab Orchard Creek segments except ND01 and Piles Fork segment NDB03 are impaired for manganese. The applicable water quality standard is a maximum total manganese concentration of 1,000 µg/L. Crab Orchard Creek segment ND04 is also impaired for sulfates. The applicable water quality standard for sulfates is a maximum total sulfate concentration of 500 mg/L. Crab Orchard Creek segment ND04 is impaired for total dissolved solids as well. The applicable water quality standard for total dissolved solids is a maximum total dissolved solids concentration of 1,000 mg/L. Standards for general use waters cannot be exceeded except where mixing is allowed as provided in 35 Ill. Adm. Code 302.102. Table 5-5 summarizes the available historic manganese, sulfates, and TDS data since 1990 for the impaired stream segments. This includes dissolved and bottom deposit manganese samples where available. The table also shows the number of violations for each segment. Figure 5-5 shows total manganese values recorded over time for ND02 and ND04. There is limited manganese data for the following impaired segments: Crab Orchard Creek segments ND11, ND13, and ND02. There is also limited data for the Little Crab Orchard Creek segment. These impaired segments have only two total manganese data points each. Figure 5-6 shows sulfate values recorded over time for ND04.

Table 5-5 Existing Chemical Constituents Data (Manganese, Sulfates, and Total Dissolved Solids)

Sample Location and Parameter	Illinois WQ Standard (µg/L)	Period of Record and Number of Data Points	Mean	Maximum	Minimum	Number of Violations
Crab Orchard Creek Segment ND02; Sample Location ND02						
Total Manganese (µg/L)	1000	1990-1997; 67	610	18,000	25	4
Dissolved Manganese (µg/L)	NA	1990-1997; 67	458	16,000	15	NA
Crab Orchard Creek Segment ND13; Sample Location ND-CD-02						
Total Manganese (µg/L)	1000	1990-1997; 67	610	18,000	25	4
Crab Orchard Creek Segment ND04; Sample Location ND04						
Total Manganese (µg/L)	1000	1990-2003; 126	879	15,000	150	23
Dissolved Manganese (µg/L)	NA	1990-2003; 124	780	13,000	69	NA
Manganese Sediments (mg/kg)	NA	1995; 1	442	442	442	NA
Sulfates (mg/L)	500	1990-2002; 112	421	1,780	421	33
TDS (mg/L)	1000	1995-2000; 4	732	852	685	0
Crab Orchard Creek Segment ND11; Sample Location ND-CD-A1						
Total Manganese (µg/L)	1000	2000; 2	3,600	4,900	2,300	2

Table 5-5 Existing Chemical Constituents Data (Manganese, Sulfates, and Total Dissolved Solids) continued

Sample Location and Parameter	Illinois WQ Standard (µg/L)	Period of Record and Number of Data Points	Mean	Maximum	Minimum	Number of Violations
Crab Orchard Creek Segment ND12; Sample Locations ND-CD-C1						
Total Manganese (µg/L)	1000	2000; 2	2,610	4,900	320	1
Little Crab Orchard Creek Segment NDA01; Sample Location NDA01						
Total Manganese (µg/L)	1000	1995-1996; 2	1,145	1,800	490	1
Dissolved Manganese (µg/L)	NA	1995-1996; 2	825	1,200	450	NA
Manganese Sediments (mg/kg)	NA	1995; 1	357	357	357	NA

5.1.2 Lake and Reservoir Water Quality Data

The Crab Orchard Creek watershed has five impaired lakes within its drainage area that are addressed in this report. There are 22 active water quality stations on or tributary to the impaired water bodies (see Figure 5-1). The data summarized in this section include water quality data for impaired constituents as well as parameters that could be useful in future modeling and analysis efforts. All historic data are available in Appendix C.

5.1.2.1 Crab Orchard Lake

There are four active stations in Crab Orchard Lake and eight tributary stations. The reservoir is impaired for total phosphorus. An inventory of all available phosphorus data at all depths is presented in Table 5-6.

Table 5-6 Crab Orchard Lake Data Inventory for Impairments

Crab Orchard Lake Segment RNA; Sample Locations RNA-1, RNA-2, RNA-3 and RNA-4		
RNA-1	**Period of Record**	**Number of Samples**
Total Phosphorus	1991-2000	48
Dissolved Phosphorus	1991-1997	31
Total Phosphorus in Bottom Deposits	1991-1997	4
RNA-2		
Total Phosphorus	1991-2000	19
Dissolved Phosphorus	1991-1997	14
RNA-3		
Total Phosphorus	1991-2000	20
Dissolved Phosphorus	1991-1997	15
Total Phosphorus in Bottom Deposits	1994	2
RNA-4		
Total Phosphorus	2000	5

Table 5-7 contains information on data availability for other parameters that may be useful in data needs analysis and future modeling efforts for total phosphorus. DO at varying depths as well as chlorophyll-a data has been collected where available.

Table 5-7 Crab Orchard Lake Data Availability for Data Needs Analysis and Future Modeling Efforts

Crab Orchard Lake Segment RNA; Sample Locations RNA-1, RNA-2, RNA-3 and RNA-4		
RNA-1	**Period of Record**	**Number of Samples**
Chlorophyll-a Corrected	2000	5
Chlorophyll-a Uncorrected	1991-2000	20
Total Depth	1990-1998	97
Dissolved Oxygen	1991-2000	277
Temperature	1991-2000	277
RNA-2		
Chlorophyll-a Corrected	2000	5
Chlorophyll-a Uncorrected	1991-2000	19
Total Depth	1990-1998	80
Dissolved Oxygen	1991-2000	142
Temperature	1991-2000	142
RNA-3		
Chlorophyll-a Corrected	2000	5
Chlorophyll-a Uncorrected	1991-2000	19
Total Depth	1990-1998	80
Dissolved Oxygen	1991-2000	58
Temperature	1991-2000	58
RNA-4		
Chlorophyll-a Corrected	2000	5
Chlorophyll-a Uncorrected	2000	5
Total Depth	1990-1998	46
Dissolved Oxygen	2000	12
Temperature	2000	12

5.1.2.1.1 Total Phosphorus

Compliance with the total phosphorus standard is based on samples collected at a one-foot depth from the lake surface. The average total phosphorus concentrations at a one-foot depth for each year of available data at each monitoring site in Crab Orchard Lake are presented in Table 5-8. The general use numeric water quality standard for total phosphorus in the lake is a maximum concentration of 0.05 mg/L.

Table 5-8 Average Total Phosphorus Concentrations (mg/L) in Crab Orchard Lake at One-Foot Depth

	RNA-1		RNA-2		RNA-3		RNA-4		Lake Average	
Year	**Data Count; Number of Violations**	**Average**	**Data Count; Number of Violations**	**Average**	**Data Count; Number of Violations**	**Average**	**Data Count; Number of Violations**	**Average**	**Data Count; Number of Violations**	**Average**
1991	5; 3	0.064	5; 5	0.108	5; 5	0.488	NA	NA	15; 13	0.220
1994	6; 4	0.063	4; 3	0.119	5; 5	0.355	NA	NA	15; 13	0.179
1996	2; 2	0.08	NA	NA	NA	NA	NA	NA	2; 2	0.080
1997	5; 5	0.074	5; 5	0.126	5; 5	0.324	NA	NA	15; 15	0.175
2000	5; 1	0.07	5; 4	0.08	NA	NA	5; 5	0.09	15; 8	0.080

The annual averages for total phosphorus at all four sites where data were available as well as the lake average have been greater than the 0.05 mg/L standard. The majority of the samples taken at all three sites have been above the standard. Figure 5-7 shows the average values by year.

Tributary data were collected in 2000. There is no numeric standard for total phosphorus in streams; however, the lake standard does apply to streams at the point at which it enters the lake or reservoir. The majority of samples collected on Crab

Orchard Lake tributaries have total phosphorus concentrations that exceed the lake standard of 0.05 mg/L (Table 5-9).

Table 5-9 Crab Orchard Lake Tributary Total Phosphorous

Sample Location	NDDA01	NDJ 01	NDK-MA-E1	ND-MA-C2	ND-MA-C4	ND-MA-C5	ND-MA-D2
Period of Record	1995-1996	1995-1996	2000	2000	2000	2000	2000
Number of Samples	2	2	1	1	1	1	1
Average	0.06	0.05	0.64	0.5	0.13	0.09	0.5
Maximum	0.12	0.06	0.64	0.5	0.13	0.09	0.5
Minimum	0.01	0.03	0.64	0.5	0.13	0.09	0.5

5.1.2.2 Carbondale City Lake

There are three active stations on Carbondale City Lake. The lake is impaired for manganese and total phosphorus. An inventory of all available manganese and phosphorus data at all depths is presented in Table 5-10.

Table 5-10 Carbondale City Lake Data Inventory for Impairments

Carbondale City Lake Segment RNI; Sample Locations RNI-1, RNI-2 and RNI-3		
RNI-1	**Period of Record**	**Number of Samples**
Total Phosphorus	1991-2000	20
Dissolved Phosphorus	1991-1997	20
Total Phosphorus in Bottom Deposits	1991-1997	2
Total Manganese	2000	5
Manganese Bottom Deposits	1991-2000	3
RNI-2		
Total Phosphorus	1991-2000	15
Dissolved Phosphorus	1991-1997	10
RNI-3		
Total Phosphorus	1991-2000	15
Dissolved Phosphorus	1991-1997	10
Total Phosphorus in Bottom Deposits	1991-1997	2
Manganese Bottom Deposits	1991-2001	3

Table 5-11 contains information on data availability for other parameters that may be useful in data needs analysis and future modeling efforts for total phosphorus and manganese. DO and chlorophyll-a data has been collected where available.

Table 5-11 Carbondale City Lake Data Availability for Data Needs Analysis and Future Modeling Efforts

Carbondale City Lake Segment RNI; Sample Locations RNI-1, RNI-2, and RNI-3		
RNI-1	**Period of Record**	**Number of Samples**
Chlorophyll-a Corrected	2000	5
Chlorophyll-a Uncorrected	1991-2000	15
Total Depth	1991-1997	30
Dissolved Oxygen	1991-2000	101
Temperature	1991-2000	101
RNI-2		
Chlorophyll-a Corrected	2000	5
Chlorophyll-a Uncorrected	1991-2000	15
Depth of Pond or Reservoir in Feet	1991-1997	20
Oxygen, Dissolved, Analysis by Probe (mg/L)	1991-2000	71
Temperature	1991-2000	71

Table 5-11 Carbondale City Lake Data Availability for Data Needs Analysis and Future Modeling Efforts continued		
Carbondale City Lake Segment RNI; Sample Locations RNI-1, RNI-2, and RNI-3 continued		
RNI-3	**Period of Record**	**Number of Samples**
Chlorophyll-a Corrected	2000	5
Chlorophyll-a Uncorrected	1991-2000	15
Depth of Pond or Reservoir in Feet	1991-1997	20
Oxygen, Dissolved, Analysis by Probe (mg/L)	1991-2000	35
Temperature	1991-2000	35

5.1.2.2.1 Total Phosphorus

The average total phosphorus concentrations at a one-foot depth for each year of available data at each monitoring site in Carbondale City Lake are presented in Table 5-12. The general use numeric water quality standard for total phosphorus in a lake is a maximum concentration of 0.05 mg/L. Compliance is assessed at a one-foot depth from the lake surface.

Table 5-12 Average Total Phosphorus Concentrations (mg/L) in Carbondale City Lake at one-foot depth

	RNI-1		RNI-2		RNI-3		Lake Average	
Year	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average
1991	5; 5	0.194	5; 5	0.206	5; 5	0.234	15; 15	0.211
1997	5; 4	0.091	5; 5	0.095	5; 5	0.098	15; 14	0.095
2000	5; 1	0.05	5; 1	0.047	5; 2	0.05	15; 4	0.049

All samples collected in 1991 and 1997 violated the standard except one collected at RNI-1 in 1997. Four violating samples were collected in 2000. Each site violated the standard in July 2000. The final violating sample was collected in October at RNI-3. Figure 5-8 shows the annual average total phosphorus concentrations for each sampling location as well as for the entire lake.

5.1.2.2.2 Manganese

The applicable water quality standard for manganese is 1,000 µg/L for general use and 150 µg/L for public water supplies. Table 5-13 shows available manganese data for Carbondale City Lake. All of the samples taken in 2000 violated the public water supply standard.

Table 5-13: Total Manganese Concentrations in Carbondale City Lake

Sample Location	Date	Result (ug/L)	Sample Depth (ft)
RNI-1	5/8/2000	340	7
RNI-1	6/13/2000	250	7
RNI-1	7/7/2000	380	7
RNI-1	8/8/2000	320	7
RNI-1	10/12/2000	260	6

5.1.2.3 Marion Reservoir

There are three active stations on Marion Reservoir. The reservoir is impaired for manganese and total phosphorus. An inventory of all available manganese and phosphorus data at all depths is presented in Table 5-14.

Table 5-14 Marion Reservoir Data Inventory for Impairments

Marion Reservoir Segment RNL; Sample Locations RNL-1, RNL-2, and RNL-3		
RNL-1	**Period of Record**	**Number of Samples**
Total Phosphorus	1997-2000	23
Dissolved Phosphorus	1997	2
Total Phosphorus in Bottom Deposits	1997	1
Total Manganese	2000	5
Manganese Bottom Deposits	2000	1
RNL-2		
Total Phosphorus	1997-2000	10
Dissolved Phosphorus	1997	5
Total Phosphorus in Bottom Deposits	1997	1
Total Manganese	2000	5
Manganese Bottom Deposits	2000	1
RNL-3		
Total Phosphorus	1997-2000	11
Dissolved Phosphorus	1997	5
Total Phosphorus in Bottom Deposits	1997	1
Total Manganese	2000	5
Manganese Bottom Deposits	2000	1

Table 5-15 contains information on data availability for other parameters that may be useful in data needs analysis and future modeling efforts for total phosphorus and manganese. Chlorophyll-a data has been collected where available.

Table 5-15 Marion Reservoir Data Availability for Data Needs Analysis and Future Modeling Efforts

Marion Reservoir Segment RNL; Sample Locations RNL-1, RNL-2, and RNL-3		
RNL-1	**Period of Record**	**Number of Samples**
Chlorophyll-a Corrected	2000	10
Chlorophyll-a Uncorrected	1997-2000	10
Oxygen, Dissolved, Analysis by Probe (mg/L)	1997-2000	88
Temperature	1997-2000	88
RNL-2		
Chlorophyll-a Corrected	2000	10
Chlorophyll-a Uncorrected	1997-2000	10
Oxygen, Dissolved, Analysis by Probe (mg/L)	1997-2000	65
Temperature	1997-2000	65
RNL-3		
Chlorophyll-a Corrected	2000	10
Chlorophyll-a Uncorrected	1997-2000	10
Oxygen, Dissolved, Analysis by Probe (mg/L)	1997-2000	25
Temperature	1997-2000	25

5.1.2.3.1 Total Phosphorus

The general use numeric water quality standard for total phosphorus in a lake is a maximum concentration of 0.05 mg/L. Compliance is assessed at a one-foot depth from the reservoir surface. The average total phosphorus concentrations at a one-foot depth for each year of available data at each monitoring site in Marion Reservoir are presented in Table 5-16.

Table 5-16 Average Total Phosphorus Concentrations (mg/L) in Marion Reservoir at one-foot depth

	RNL-1		RNL-2		RNL-3		Lake Average	
Year	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average
1997	5; 4	0.066	5; 4	0.064	5; 5	0.126	15; 13	0.085
2000	4; 0	0.042	5; 3	0.052	5; 4	0.066	14; 7	0.053

With the exception of samples taken at RNL-1 in 2000, the majority of samples have exceeded the 0.05 mg/L total phosphorus standard. Figure 5-9 shows the annual average total phosphorus concentration at each sampling location as well as the concentration for the reservoir.

5.1.2.3.2 Manganese

The applicable water quality standard for manganese is 1,000 µg/L for general use and 150 µg/L for public water supplies. Table 5-17 summarizes available manganese data for Marion Reservoir. Four out of five samples taken in 2000 violated the public water supply standard.

Table 5-17: Total Manganese Concentrations in Marion Reservoir

Sample Location	Date	Result (ug/L)	Sample Depth (ft)
RNL-1	4/13/2000	620	8
RNL-1	6/20/2000	170	9
RNL-1	7/14/2000	530	9
RNL-1	8/17/2000	100	8
RNL-1	10/6/2000	560	8

5.1.2.4 Herrin New Reservoir

The Herrin New Reservoir is impaired for manganese. There are three active stations on the reservoir. However, manganese data were only collected at two of the stations and total manganese data were only collected as sample location RNZC-1. An inventory of all available manganese data are presented in Table 5-18. Manganese data were not available for sampling location RNZC-2.

Table 5-18 Herrin New Reservoir Data Inventory for Impairments

Herrin New Reservoir Segment RNA; Sample Locations RNZC-1 and RNZC-3		
RNZC-1	**Period of Record**	**Number of Samples**
Total Manganese	2000-2004	10
Manganese Bottom Deposits	2000	1
RNZC-3		
Manganese Bottom Deposits	2000	1

The applicable water quality standard for manganese is 1,000 µg/L for general use and 150 µg/L for public water supplies. Table 5-19 summarizes manganese data for Herrin New Reservoir. Eight of the ten samples collected violated the public water supply standard while four of the ten also violated the general use standard. Samples depths ranged from 11 to 13 feet.

Table 5-19: Total Manganese Concentrations (ug/L) in Herrin New Reservoir

Sample Location	Data Count	Minimum	Maximum	Average
RNZC-1	10	90	2200	913

5.1.2.5 Campus Lake

There are three active stations on Campus Lake. An inventory of all available phosphorus data are presented in Table 5-20.

Table 5-20 Campus Lake Data Inventory for Impairments

Campus Lake Segment RNA; Sample Locations RNZH-1, RNZH-2, and RNZH-3		
RNZH-1	**Period of Record**	**Number of Samples**
Total Phosphorus	1990-1998	55
Dissolved Phosphorus	1997-1998	18
Total Phosphorus in Bottom Deposits	1997	1
RNZH-2		
Total Phosphorus	1997-1998	24
Dissolved Phosphorus	1997-1998	9
Total Phosphorus in Bottom Deposits	1997	1
RNZH-3		
Total Phosphorus	1997-1998	24
Dissolved Phosphorus	1997-1998	9
Total Phosphorus in Bottom Deposits	1997	1

Table 5-21 contains information on data availability for other parameters that may be useful in data needs analysis and future modeling efforts. Chlorophyll-a and DO data have been collected where available.

Table 5-21 Campus Lake Data Availability for Data Needs Analysis and Future Modeling Efforts

Campus Lake Segment RNA; Sample Locations RNZH-1, RNZH-2, and RNZH-3		
RNZH-1	**Period of Record**	**Number of Samples**
Chlorophyll-a µg/L Uncorrected	1996-1998	34
Depth of Pond or Reservoir in Feet	1990-1998	151
Oxygen, Dissolved, Analysis by Probe (mg/L)	1997-1998	194
Temperature	1997-1998	197
RNZH-2		
Chlorophyll-a µg/L Uncorrected	1997-1998	22
Depth of Pond or Reservoir in Feet	1990-1998	132
Oxygen, Dissolved, Analysis by Probe (mg/L)	1997-1998	187
Oxygen, Dissolved, Percent of Saturation (%)	1997-1998	187
Temperature	1997-1998	187
RNZH-3		
Chlorophyll-a µg/L Uncorrected	1996-1998	34
Depth of Pond or Reservoir in Feet	1990-1998	131
Oxygen, Dissolved, Analysis by Probe (mg/L)	1997-1998	161
Temperature	1997-1998	161

The general use numeric water quality standard for total phosphorus concentrations in a lake is a maximum concentration of 0.05 mg/L. Compliance is assessed at a one-foot depth from the lake's surface. The average total phosphorus concentrations at a one-foot depth for each year of available data at each monitoring site in Campus Lake are presented in Table 5-22.

Table 5-22 Average Total Phosphorus Concentrations (mg/L) in Campus Lake at one-foot depth

Year	RNZH-1		RNZH-2		RNZH-3		Lake Average	
	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average	Data Count; Number of Violations	Average
1990	1; 0	0.01	NA	NA	NA	NA	1; 0	0.010
1996	6; 2	0.045	NA	NA	NA	NA	6; 2	0.045
1997	16; 4	0.037	16; 4	0.039	16; 4	0.038	48; 12	0.038
1998	10; 2	0.042	8; 1	0.037	8; 2	0.037	26; 4	0.039

Although the annual average phosphorus concentrations for each year have been below the 0.05 mg/L total phosphorus standard, numerous violations have been collected at each individual sampling location. The most violations were recorded in 1997 when one-quarter of all samples collected at one-foot depth violated the standard. Figure 5-10 shows the yearly average total phosphorus concentration at each sampling location as well as the average lake value.

5.2 Reservoir Characteristic

There are five impaired reservoirs in the Crab Orchard Creek watershed. Reservoir information that can be used for future modeling efforts was collected from GIS analysis, the US Army Corps of Engineers, the Illinois EPA, and USEPA water quality data. The following sections will discuss the available data for each reservoir.

5.2.1 Crab Orchard Lake

Crab Orchard Lake is located east of Carbondale and west of Marion. The lake was created by damming Crab Orchard Creek. The lake has a surface area of 6,965 acres. The lake is part of the Crab Orchard National Wildlife Refuge. Table 5-23 contains U.S. Army Corp of Engineers dam data.

Table 5-23 Crab Orchard Lake Dam Information (U.S. Army Corps of Engineers

Dam Length	2,960 feet
Dam Height	45 feet
Maximum Discharge	240,000 cfs
Maximum Storage	166,000 acre-feet
Normal Storage	70,746 acre-feet
Spillway Width	1,361 feet
Outlet Gate Type	U

Table 5-24 contains depth information for each sampling location on the lake. The average maximum depth in Crab Orchard Lake is 24.0 feet.

Table 5-24 Average Depths (ft) for Crab Orchard Lake Segment RNA (Illinois EPA 2002 and USEPA 2002a)

Year	RNA-1	RNA-2	RNA-3	RNA-4
1990	22.0	12.2	5.8	5.3
1991	24.7	12.9	4.5	4.4
1992	21.7	12.0	5.9	6.7
1993	23.8	12.1	6.4	6.1
1994	23.3	12.6	5.2	3.0
1995	24.3	2.0	7.3	6.9
1996	23.8	11.8	7.0	6.0
1997	27.5	12.4	5.4	–
1998	22.3	12.3	7.0	8.0
2000	27.0	12.2	4.8	3.5
Average	**24.0**	**12.3**	**5.9**	**5.5**

5.2.2 Marion Reservoir and Herrin New Reservoir

Marion Reservoir is located south of Marion, and has a surface area of 220 acres. Herrin New Reservoir is located southeast of Crab Orchard Lake and has a surface area of approximately 40 acres. Marion City Lake was constructed by damming Limb Branch in 1970. Both Marion City Lake and Herrin New Reservoir are upstream of Crab Orchard Lake and serve as sources of drinking water for the Marion community water supply. Table 5-25 contains U.S. Army Corp of Engineers Dam data.

Table 5-25 Herrin New and Marion Reservoir Dam Information (U.S. Army Corps of Engineers

	Herrin New	**Marion**
Dam Length	630 feet	895 feet
Dam Height	27 feet	25 feet
Maximum Discharge	NA	NA
Maximum Storage	659 acre-feet	1,931 acre-feet
Normal Storage	411 acre-feet	966 acre-feet
Spillway Width	95 feet	NA
Outlet Gate Type	U	U

Tables 5-26 and 5-27 contain depth information for each sampling location on the water bodies. The average maximum depth in Marion Lake is 16.1 feet while the maximum depth in Herrin New Reservoir is 24.5 feet.

Table 5-26 Average Depths (ft) for Marion Reservoir (Illinois EPA 2002 and USEPA 2002a)

Year	**RNL-1**	**RNL-2**	**RNL-3**
1997	16.0	12.4	3.8
2000	16.2	11.9	3.9
Average	**16.1**	**12.2**	**3.9**

Table 5-27 Average Depths (ft) for Herrin New Reservoir (Illinois EPA 2002 and USEPA 2002a)

Year	**RNZC-1**	**RNZC-2**	**RNZC-3**
1996	24.4	20.2	11.2
2000	24.5	21.6	12.0
Average	**24.5**	**20.9**	**11.6**

5.2.3 Campus and Carbondale City Lakes

Campus and Carbondale City Lakes are located within the boundaries of the City of Carbondale. Campus Lake is located at Southern Illinois University. Campus Lake has a surface area of 40 acres, and Carbondale City Lake has a surface area of approximately 136 acres. Carbondale City Lake was constructed in 1926. In conjunction with Cedar Lake located in the Cedar Creek/Cedar Lake watershed, Carbondale City Lake supplies drinking water to the to the City of Carbondale. Table 5-28 contains U.S. Army Corp of Engineers Dam data.

Table 5-28 Carbondale City and Campus Lake Dam Information (U.S. Army Corps of Engineers)

	Carbondale	**Campus**
Dam Length	2,400 feet	500 feet
Dam Height	33 feet	20 feet
Maximum Discharge	10,000 cfs	365 cfs
Maximum Storage	1,940 acre-feet	290 acre-feet
Normal Storage	480 acre-feet	158 acre-feet
Spillway Width	175 feet	13 feet
Outlet Gate Type	U	U

Tables 5-29 and 5-30 contain depth information for each sampling location on the lakes. The average maximum depth in Campus Lake is 11.1 feet while the average maximum depth in Carbondale City Lake is 11.6 feet.

Table 5-29 Average Depths (ft) for Campus Lake Segment RNZH (Illinois EPA 2002 and USEPA 2002a)

Year	RNZH-1	RNZH-2	RNZH-3
1990	11.9	10.5	9.8
1991	12.1	10.3	9.5
1992	10.4	10.2	9.9
1993	11.1	10.4	9.2
1994	11.2	10.0	9.7
1995	8.9	10.7	9.6
1996	9.3	10.4	9.4
1997	11.7	11.8	10.5
1998	13.1	10.8	10.0
Average	**11.1**	**10.6**	**9.7**

Table 5-30 Average Depths (ft) for Carbondale City Lake Segment RNI (Illinois EPA 2002 and USEPA 2002a)

Year	RNI-1	RNI-2	RNI-3
1991	11.5	6.8	1.9
1993	9.0	5.3	1.7
1997	13.0	8.0	3.2
2000	12.8	8.4	3.7
Average	**11.6**	**7.1**	**2.6**

5.3 Point Sources

Point sources for the Crab Orchard Creek watershed have been separated into municipal/industrial sources and mining discharges. Available data have been summarized and are presented in the following sections.

5.3.1 Municipal and Industrial Point Sources

Permitted facilities must provide Discharge Monitoring Reports (DMRs) to Illinois EPA as part of their NPDES permit compliance. DMRs contain effluent discharge sampling results, which are then maintained in a database by the state. There are 36 point sources located within the Crab Orchard Creek watershed. Figure 5-11 shows all facilities with available DMR data. In order to assess point source contributions to the watershed, the data has been examined by receiving water and then by the downstream impaired segment that has the potential to receive the discharge. Receiving waters were determined through information contained in the USEPA Permit Compliance System (PCS) database. Maps were used to determine downstream impaired receiving water information when PCS data were not available. The impairments for each segment or downstream segment were considered when reviewing DMR data. Data has been summarized for any sampled parameter that is associated with a downstream impairment (i.e., all available nutrient and BOD data were reviewed for segments that are impaired for DO). This will help in future model selection as well as source assessment and load allocation.

5.3.1.1 Crab Orchard Creek Segment ND04

There is only one point source with the potential to contribute discharge to Crab Orchard Creek Segment ND04. Segment ND04 is listed as impaired for manganese, sulfates, pH, DO, and total dissolved solids. The Crab Orchard Grade and High School is permitted to discharge to an unnamed tributary to Segment ND04. Table 5-31 contains a summary of available and pertinent DMR data for this point source. Data from the school does not contain any information on sulfates, manganese, or TDS because sampling for these parameters is not required by the permit.

Table 5-31 Effluent Data from Point Sources Discharging Upstream of Crab Orchard Creek Segment ND04 (Illinois EPA 2005)

Facility Name Period of Record Permit Number	Receiving Water/ Downstream Impaired Waterbody	Constituent	Average Value	Average Loading (lb/d)
Crab Orchard Community Unit School District #3-STP 1994 - 2004 IL0037311	NA/Crab Orchard Creek Segment ND 04	Average Daily Flow	0.003 mgd	NA
		CBOD, 5-day	18 mg/L	2.01
		Nitrogen, Ammonia	3.85 mg/L	0.18
		pH	7.57 su	

5.3.1.2 Marion Reservoir

There is one permitted facility that discharges to Marion Reservoir. Marion Reservoir is listed for manganese and total phosphorus impairments. The U.S. Federal Penitentiary currently discharges directly into the reservoir, and has previously discharged into an unnamed tributary to Marion Reservoir. Table 5-32 contains a summary of available DMR data for this point source. No phosphorus or manganese data were available.

Table 5-32 Effluent Data from Point Sources Discharging to Marion Reservoir (RNL) (Illinois EPA 2005)

Facility Name Period of Record Permit Number	Receiving Water/ Downstream Impaired Waterbody	Constituent	Average Value	Average Loading (lb/d)
U.S. Federal Penitentiary WTP 2002 - 2005 IL0074829	NA/Marion Reservoir Segment RNL	Average Daily Flow	0.003 mgd	NA

5.3.1.3 Crab Orchard Lake and Tributaries

There are 8 point sources with the potential to contribute discharge to Crab Orchard Lake (Segment RNA) directly or through tributaries. Crab Orchard Lake is listed as impaired for total phosphorus. Table 5-33 contains a summary of available DMR data for these point sources. Total phosphorus records were only available for the Crab Orchard Refuge treatment facility and the Marion Southeast plant.

Table 5-33 Effluent Data from Point Sources Discharging to Crab Orchard Lake RNA and Crab Orchard Lake Tributaries (Illinois EPA 2005)

Facility Name Period of Record Permit Number	Receiving Water/ Downstream Impaired Waterbody	Constituent	Average Value	Average Loading (lb/d)
IL DNR-Giant City State Park 1993 - 2005 IL0049531	Little Grassy Creek/ Crab Orchard Lake Segment RNA	Average Daily Flow	0.0126 mgd	NA
IL DNR-Ltl Grassy Fish Hatchry 1992 - 2005 IL0059838	Little Grassy Lake/Crab Orchard Lake Segment RNA	Average Daily Flow	0.080 mgd	NA
DOI-Little Grassy Campgrnd STP 1995 - 2005 IL0033073	Little Grassy Lake/Crab Orchard Lake Segment RNA	Average Daily Flow	0.0024 mgd	NA
SI Bowling & Recreation Center 1996 - 2005 IL0054101	Unnamed Tributary to Pigeon Creek/Crab Orchard Lake Segment RNA	Average Daily Flow	0.008 mgd	NA
Marion WTP 1992 - 2005 IL0001091, ILG640158	Mule Creek/Crab Orchard Lake Segment RNA	Average Daily Flow	0.25 mgd	NA
Crab Orchard Estates-Hughes 1994 - 2005 IL0053830	Unnamed Tributary to Crab Orchard Lake/Crab Orchard Lake Segment RNA	Average Daily Flow	0.002 mgd	
Verizon Communications-Marion 1994 - 2004 IL0059625	Unnamed Ditch to Crab Orchard/Crab Orchard Lake Segment RNA	Average Daily Flow	0.0036 mgd	NA
Marion Southeast STP 1989 - 2005 IL0029734	West End Creek to Crab Orchard Creek/Crab Orchard Lake Segment RNA	Average Daily Flow	4.95 mgd	NA
		Phosphorus, Total	0.449 mg/L	13.6

5.3.1.4 Crab Orchard Creek Segments ND11, ND12, and ND13

There are 21 point source with the potential to contribute discharge to Crab Orchard Creek Segments ND11, ND12, and ND13. Segments ND11, ND12, and ND13 are impaired for manganese and pH. Segments ND11 and ND13 are also impaired for DO. Table 5-34 contains a summary of available DMR data for these point sources.

Table 5-34 Effluent Data from Point Sources Discharging Upstream of or Directly to Crab Orchard Creek Segments ND11, ND12, and ND13 (Illinois EPA 2005)

Facility Name Period of Record Permit Number	Receiving Water/ Downstream Impaired Waterbody	Constituent	Average Value	Average Loading (lb/d)
Southern IL Univ-C Lit Grassy 1994 - 2004 IL0047899	Indian Creek/Crab Orchard Creek Segment ND 11	Average Daily Flow	0.0375 mgd	NA
		CBOD, 5-day	2.23 mg/L	0.077
		Nitrogen, Ammonia	1.98 mg/L	0.072
		pH	6.93 su	
Bush MHP STP #2-Carbondale 1997 - 2004 IL0046060	Unnamed Tributary to Drury Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.0063 mgd	NA
		CBOD, 5-day	7.97 mg/L	0.44
		Nitrogen, Ammonia	1.35 mg/L	0.10
		pH	6.95 su	
Carbondale Southeast STP 1989 - 2005 IL0027898	Unnamed Tributary to Crab Orchard Creek/Crab Orchard Creek Segment ND12	Average Daily Flow	6.0 mgd	NA
		CBOD, 5-day	39.3 mg/L	570.8
		Nitrogen, Ammonia	0.338 mg/L	33.7
		Manganese	0.0625 mg/L	—
Chateau Apartments 1994 - 2004 ILG551058	NA/Crab Orchard Creek Segment ND11	Average Daily Flow	0.017 mgd	NA
		CBOD. 5-day	3.83 mg/L	1.12
		pH	6.95 su	
Corner One Stop - Carbondale 1994 - 2004 ILG551016	Unnamed Tributary to Sycamore Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.006 mgd	NA
		CBOD, 5-day	8.88 mg/L	0.50
		Nitrogen, Ammonia	1.35 mg/L	0.10
		pH	7.04 su	
Country Village Apartments 1993 - 2005 IL0051918	Unnamed Tributary to Crab Orchard Creek/ Crab Orchard Creek Segment ND12	Average Daily Flow	0.007 mgd	NA
		CBOD, 5-day	3.44 mg/L	0.194
		Nitrogen, Ammonia	2.57 mg/L	0.498
		pH	6.87 su	
Crab Orchard Park MHP 1995 - 2004 ILG551019	Crab Orchard Creek/ Crab Orchard Creek Segment ND12	Average Daily Flow	0.038 mgd	NA
		CBOD, 5-day	48.8 mg/L	1.79
		pH	7.19 su	
Frost Mobile Home Park 1997 - 2005 IL0047635	Unnamed Ditch to Drury Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.0082 mgd	NA
		CBOD, 5-day	7.26 mg/L	0.69
		pH	6.94 su	
Giant City School 1994 - 2005 IL0025844	Unnamed Tributary to Sycamore Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.035 mgd	NA
		CBOD, 5-day	3.49 mg/L	0.063
		Nitrogen, Ammonia	2.03 mg/L	0.013
		pH	6.93 su	
IL DOC-Giant City State Park 1993 - 2005 IL0049794	Unnamed Tributary to Indian Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.0132 mgd	NA
		CBOD, 5-day	14.8 mg/L	2.63
		Nitrogen, Ammonia	3.00 mg/L	—
		pH	7.70 su	
M&M Rentals MHP 1995 - 2005 ILG551017	Ditch to Crab Orchard Creek/Crab Orchard Creek Segment ND12	Average Daily Flow	0.003 mgd	NA
		CBOD, 5-day	72.0 mg/L	0.061
		pH	7.37 su	—
Meadowbrook Estates MHP 1995 - 2005 IL0038423	Unnamed Tributary to Drury Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.00750 mgd	NA
		CBOD, 5-day	7.44 mg/L	0.48
		Nitrogen, Ammonia	2.36 mg/L	0.14
		pH	6.87 su	
Pleasant Hill MHP 2000 - 2004 ILG551059	Drury Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.02 mgd	NA
		CBOD, 5-day	6.38 mg/L	0.42
		pH	6.96 su	
Pleasant Valley MHP 1997 - 2004 IL0047601	Unnamed Tributary to Drury Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.035 mgd	NA
		CBOD, 5-day	1.33 mg/L	0.13
		pH	7.00 su	

Table 5-34 Effluent Data from Point Sources Discharging Upstream of or Directly to Crab Orchard Creek Segments ND11, ND12, and ND13 (Illinois EPA 2005)

Facility Name Period of Record Permit Number	Receiving Water/ Downstream Impaired Waterbody	Constituent	Average Value	Average Loading (lb/d)
Reed Station MHP 1994 - 2004 ILG551008	Crab Orchard Creek/Crab Orchard Creek Segment ND13	Average Daily Flow	0.021 mgd	NA
		CBOD, 5-day	49.4 mg/L	0.82
S.I. Properties LLC 2001 - 2004 ILG551066	Unnamed Tributary of Crab Orchard Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.0168 mgd	NA
		CBOD, 5-day	6.68 mg/L	0.92
		pH	7.01 su	
Southern Mobile Home Park 1996 - 2004 ILG551077	NA/Crab Orchard Creek Segment ND11	Average Daily Flow	0.019 mgd	NA
		CBOD, 5-day	16.2 mg/L	2.47
		pH	7.38 su	
United Methodist Camp 1997 - 2004 IL0045632	Unnamed Tributary to Sycamore Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.006 mgd	NA
		CBOD, 5-day	6.56 mg/L	0.081
		pH	7.20 su	
Unity Point Elm Sch Dist 140 1998 - 2004 IL0045748	Unnamed Tributary to Drury Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.019 mgd	NA
		CBOD, 5-day	13.4 mg/L	0.48
		Nitrogen, Ammonia	1.59 mg/L	0.04
		pH	7.38 su	
University Heights MHP 1992 - 2004 IL0038415	Unnamed Tributary to Drury Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.025 mgd	NA
		CBOD, 5-day	5.94 mg/L	1.28
		Nitrogen, Ammonia	2.20 mg/L	0.42
		Oxygen, Dissolved	5.43 mg/L	
		pH	6.97 su	
Wildwood Mobile Home Park 1995 - 2004 ILG551093	Unnamed Tributary to Drury Creek/Crab Orchard Creek Segment ND11	Average Daily Flow	0.013 mgd	NA
		CBOD, 5-day	19.0 mg/L	0.038
		pH	7.37 su	

5.3.1.5 Crab Orchard Creek Segment ND01

There are two point sources with the potential to contribute discharge to Crab Orchard Creek segment ND01. Segment ND01 is impaired for total fecal coliform. Table 5-35 contains a summary of available DMR data for these point sources. No fecal coliform data were available from either source.

Table 5-35 Effluent Data from Point Sources Discharging Upstream of Crab Orchard Creek Segment ND01 (Illinois EPA 2005)

Facility Name Period of Record Permit Number	Receiving Water/ Downstream Impaired Waterbody	Constituent	Average Value	Average Loading (lb/d)
Beazer East Inc.-Carbondale 1996 - 2004 IL0000400	Glade Creek/Crab Orchard Creek ND01	Average Daily Flow	0.1 mgd	NA
Lenore Basin Corp-Union Hills 1992 - 2004 ILG551037	Crab Orchard Creek/Crab Orchard Creek Segment ND01	Average Daily Flow	0.0038 mgd	NA

5.3.1.6 Piles Fork

There are two point sources with the potential to contribute discharge to Piles Fork Segment NDB03. Segment NDB03 has a DO impairment. Table 5-36 contains a summary of available DMR data for these point sources.

Table 5-36 Effluent Data from Point Sources Discharging Upstream of Piles Fork (Illinois EPA 2005)

Facility Name Period of Record Permit Number	Receiving Water/ Downstream Impaired Waterbody	Constituent	Average Value	Average Loading (lb/d)
Lilac Basin Corp.-Union Hill 1994 - 2005 IL0046221	NA/Piles Fork Segment NDB03	Average Daily Flow	0.0058 mgd	NA
		CBOD, 5-day	3.21 mg/L	0.15
		Nitrogen, Ammonia	1.94 mg/L	0.084
SIU-Carbondale 1998 - 2005 IL0072320	Tributary to Piles Fork/ Piles Fork Segment NDB03	Average Daily Flow	0.0173 mgd	NA
		TOC	5.45 mg/L	—

5.3.1.7 Little Crab Orchard Creek

There is one point source with the potential to contribute discharge to Little Crab Orchard Creek Segment NDA01. Segment NDA01 is on the 303(d) list for manganese and DO. Table 5-37 contains a summary of available DMR data.

Table 5-37 Effluent Data from Point Sources Discharging Upstream of Little Crab Orchard Creek Segment NDA01 (Illinois EPA 2005)

Facility Name Period of Record Permit Number	Receiving Water/ Downstream Impaired Waterbody	Constituent	Average Value	Average Loading (lb/d)
Tan Tara 2 Mobile Home Park 1992 - 2005 IL0049077	NA/Little Crab Orchard Creek Segment NDA01	Average Daily Flow	0.0227 mgd	NA
		CBOD, 5-day	12.4 mg/L	0.80
		Nitrogen, Ammonia	11.0 mg/L	0.12

5.3.1.8 Other Impaired Waterbodies

There are no permitted facilities that discharge directly to Crab Orchard Creek ND 02, Campus Lake, Carbondale City Lake, or Herrin New Reservoir.

5.3.2 Mining Discharges

There are two NPDES permits for mining within the Crab Orchard Creek watershed. The permits are held by LLC Illinois, Classic Mine, and Delta Mine. Both the Classic Mine and Delta Mine are in reclamation with no active mining taking place at these facilities. Figure 5-12 shows the locations of permitted outfalls within the watershed as well as historic coal mine areas.

Data provided from the state of Illinois includes DMRs for permit IL0060372. DMRs for the last three years were provided for Outfalls 001, 002, 003, and 004. The single outfall from the Delta Mine facility receives runoff from a very limited watershed and seldom, if ever, has discharged. To date, the permittee has been unable to obtain a discharge sample from this basin, and therefore, there are no available DMR data for this outfall. Table 5-38 contains a summary of available relevant data from each outfall with DMRs.

Table 5-38 Sulfate, Iron, and pH Pipe Outfall Concentrations

Permit ID and Sample Dates	Pipe Outfall	Flow (cfs)				pH				Manganese (mg/L)				Sulfate (mg/L)			
		# of Samples	Minimum	Maximum	Average	# of Samples	Minimum	Maximum	Average	# of Samples	Minimum	Maximum	Average	# of Samples	Minimum	Maximum	Average
IL0060372	001	18	0.00	0.08	0.02	18	6.35	7.61	7.0	0				18	113	440	284
1/02 - 3/05	002	15	0.00	0.07	0.02	15	6.77	7.81	7.	0				15	167	680	384
	003	17	0.00	0.07	0.02	16	6.97	8.06	7.5	17	0.01	0.44	0.10	17	263	508	393
	004	3	0.00	0.11	0.09	3	7.65	8.22	7.9	3	0.13	0.18	0.15	3	700	764	734

5.4 Nonpoint Sources

There are many potential nonpoint sources of pollutant loading to the impaired segments in the Crab Orchard Creek watershed. This section will discuss site-specific cropping practices, animal operations, and area septic systems. Data was collected through communication with local NRCS, Soil and Water Conservation District (SWCD), Public Health Department, and County Tax Department officials.

5.4.1 Crop Information

Nearly 37,000 acres of the land found within the Crab Orchard Creek watershed are devoted to crops. This represents 20 percent of the total watershed area. Soybeans and corn are the most abundant crops, accounting for approximately 9 percent and 6 percent respectively. Tillage practices can be categorized as conventional till, reduced till, mulch-till, and no-till. The percentage of each tillage practice for corn, soybeans, and small grains by county are generated by the Illinois Department of Agriculture from County Transect Surveys. The most recent survey was conducted in 2004. Data specific to the Crab Orchard Creek watershed was not available; however, the Johnson, Williamson, Union, and Jackson Counties practices were available and are as shown. Communications with Union County have indicated that very little small grains and row crop agriculture takes place in the Union County portion of the watershed. The land in that part of Union County is mostly pasture and some orchards.

Table 5-39 Tillage Practices in Johnson County

Tillage System	Corn	Soybean	Small Grain
Conventional	61%	36%	0%
Reduced - Till	4%	0%	0%
Mulch - Till	0%	0%	0%
No - Till	36%	64%	0%

Table 5-40 Tillage Practices in Williamson County

Tillage System	Corn	Soybean	Small Grain
Conventional	28%	21%	38%
Reduced - Till	17%	21%	0%
Mulch - Till	0%	15%	0%
No - Till	55%	42%	63%

Table 5-41 Tillage Practices in Union County

Tillage System	Corn	Soybean	Small Grain
Conventional	15%	11%	0%
Reduced - Till	4%	4%	0%
Mulch - Till	4%	5%	40%
No - Till	77%	80%	60%

Table 5-42 Tillage Practices in Jackson County

Tillage System	Corn	Soybean	Small Grain
Conventional	57%	54%	59%
Reduced - Till	0%	0%	0%
Mulch - Till	17%	18%	41%
No - Till	26%	27%	0%

Site-specific data on tile drainage has not been available. Should this information become available, it will be reviewed and incorporated where appropriate during Stage 3 TMDL development.

5.4.2 Animal Operations

Watershed specific animal numbers were not available for the Crab Orchard Creek watershed. Data from the National Agricultural Statistics Service was reviewed and is presented below to show countywide livestock numbers.

Table 5-43 Williamson County Animal Population (2002 Census of Agriculture)

	1997	2002	Percent Change
Cattle and Calves	9,362	9,774	0%
Beef	4,836	5,104	4%
Dairy	58	14	-76%
Hogs and Pigs	6,475	8,221	27%
Poultry	567	298	-47%
Sheep and Lambs	103	111	8%
Horses and Ponies	NA	814	NA

Table 5-44 Jackson County Animal Population (2002 Census of Agriculture)

	1997	2002	Percent Change
Cattle and Calves	16,066	16,566	3%
Beef	7,833	7,416	-5%
Dairy	542	1,183	118%
Hogs and Pigs	9,975	6,335	-36%
Poultry	510	715	40%
Sheep and Lambs	202	379	88%
Horses and Ponies	NA	864	NA

Table 5-45 Union County Animal Population (2002 Census of Agriculture)

	1997	2002	Percent Change
Cattle and Calves	17,453	14,002	-20%
Beef	8,340	7,162	-14%
Dairy	687	431	-37%
Hogs and Pigs	3,030	710	-77%
Poultry	319	331	4%
Sheep and Lambs	202	379	88%
Horses and Ponies	NA	741	NA

Table 5-46 Johnson County Animal Population (2002 Census of Agriculture)

	1997	2002	Percent Change
Cattle and Calves	18,093	17,190	-5%
Beef	8,441	9,187	9%
Dairy	56	175	213%
Hogs and Pigs	6,241	8,421	35%
Poultry	550	337	-39%
Sheep and Lambs	92	94	2%
Horses and Ponies	NA	969	NA

The Illinois EPA provided a GIS shapefile illustrating the location of livestock facilities in the Big Muddy River Basin, which contains the Crab Orchard Creek watershed. In 2001, Illinois EPA assessed the potential impact of each facility on water quality with regard to the size of the facility, the site condition and management, pollutant transport efficiency, and water resources vulnerability. The GIS data have been used as reference since the surveys were conducted four years ago. Thirteen animal facilities existed at the time of the survey. Five of the facilities were assessed to have a slight impact. One of the facilities assessed to have slight impact was a hog operation located in the upper portion of Crab Orchard Creek segment ND04. Three other slight impact facilities were located near segment NDA01 of Little Crab Orchard Creek. These facilities were two dairies and one horse farm which were all associated with Southern Illinois University. The remaining facility assessed to have slight impact was not located near any impaired segments.

5.4.3 Septic Systems

Many households in rural areas of Illinois, which are not connected to municipal sewers, make use of onsite sewage disposal systems, or septic systems. There are a variety of types of septic systems, but the most common septic system is composed of a septic tank draining to a septic field, where nutrient removal occurs. However, the degree of nutrient removal is limited by soils and system upkeep and maintenance.

Information on sewered and septic municipalities was obtained from Jackson, Williamson, Union, and Johnson County health departments. Because the county health departments were unable to provide estimates of the number of septic systems, estimates of the number of existing residences within the watershed were obtained in the areas known to be served by septic systems. Data provided from county tax assessors and the U.S. Census Bureau were used to estimate the number of septic systems in Jackson and Johnson counties. Neither estimates of the number of residences nor septic systems were available for Williamson and Union counties. Table 5-47 is a summary of the available septic system data in the Crab Orchard Creek watershed.

Table 5-47 Estimated Septic Systems in the Crab Orchard Creek Watershed

County	Estimated No. of Septic Systems	Source of Septic Areas/ No. of Septic Systems
Jackson	4,930	Health Department/Tax Assessor
Williamson	NA	Health Department
Union	NA	Health Department
Johnson	400	Health Department/Tax Assessor, U.S. Census Bureau
Total	**5,330**	

There are at least 5,300 septic systems in the watershed. The impaired Campus and Carbondale City lakes are located in Carbondale (in Jackson County), which is served by a municipal sewer system. In Williamson County, where the impaired Crab Orchard Lake, Marion Reservoir, and Herrin New Reservoir are located, the municipalities are served by sewers. However, the residences around Carterville are not sewered, and the Franklin-Williamson Bi-County Health Department has reported that pollutants from failing septic systems are draining to Crab Orchard Lake. Areas outside of Marion, along Crab Orchard Lake, are also served by septic systems. It is estimated that 90 percent of the septic systems in Williamson County produce surface discharges and 60 to 70 percent of them are not kept up. From the land use data (Section 2.3), it appears that there are very few residences located around Marion and Herrin New reservoirs.

5.5 Watershed Studies and Other Watershed Information

Previous planning efforts have been conducted within the Crab Orchard Creek watershed. An Intensive Survey of the Big Muddy River Basin was conducted in 2000. Facility related stream surveys were conducted in October 2000 for the Marion WWTP and in August 2004 for the Carbondale SE WWTP. Phase I of a diagnostice/feasibility study has been performed on Campus Lake as part of the Clean Lakes Program. The study was completed in March 2004 and Phase II of the study has commenced. Also a Clean Lakes Study has for Carbondale City Lake began in October 2004. Data from these reports will be used as reference during Stage 3 TMDL development and further investigation into watershed-specific groups and associated activities will be conducted.

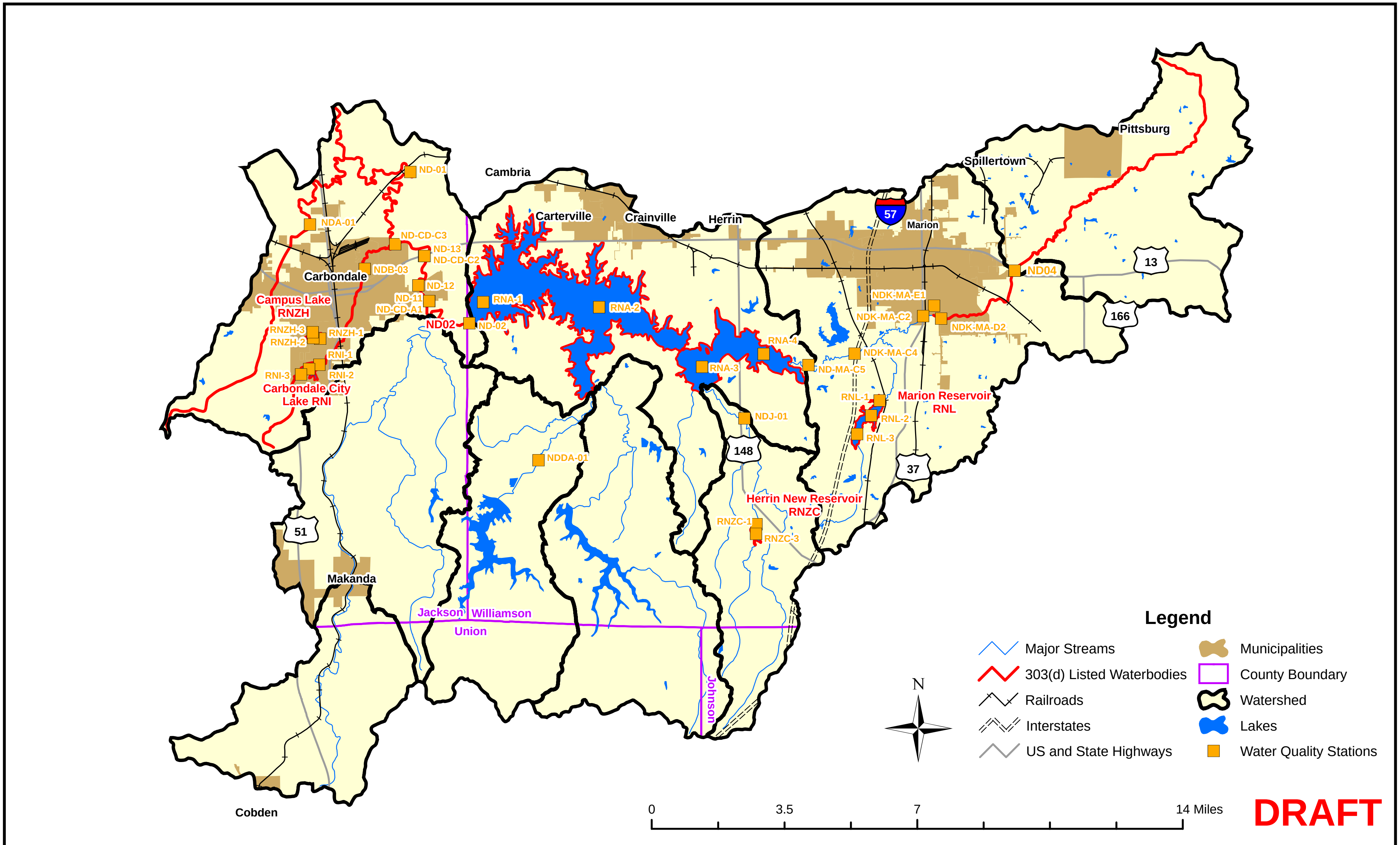

Figure 5-1:
Water Quality Stations
Crab Orchard Creek Watershed

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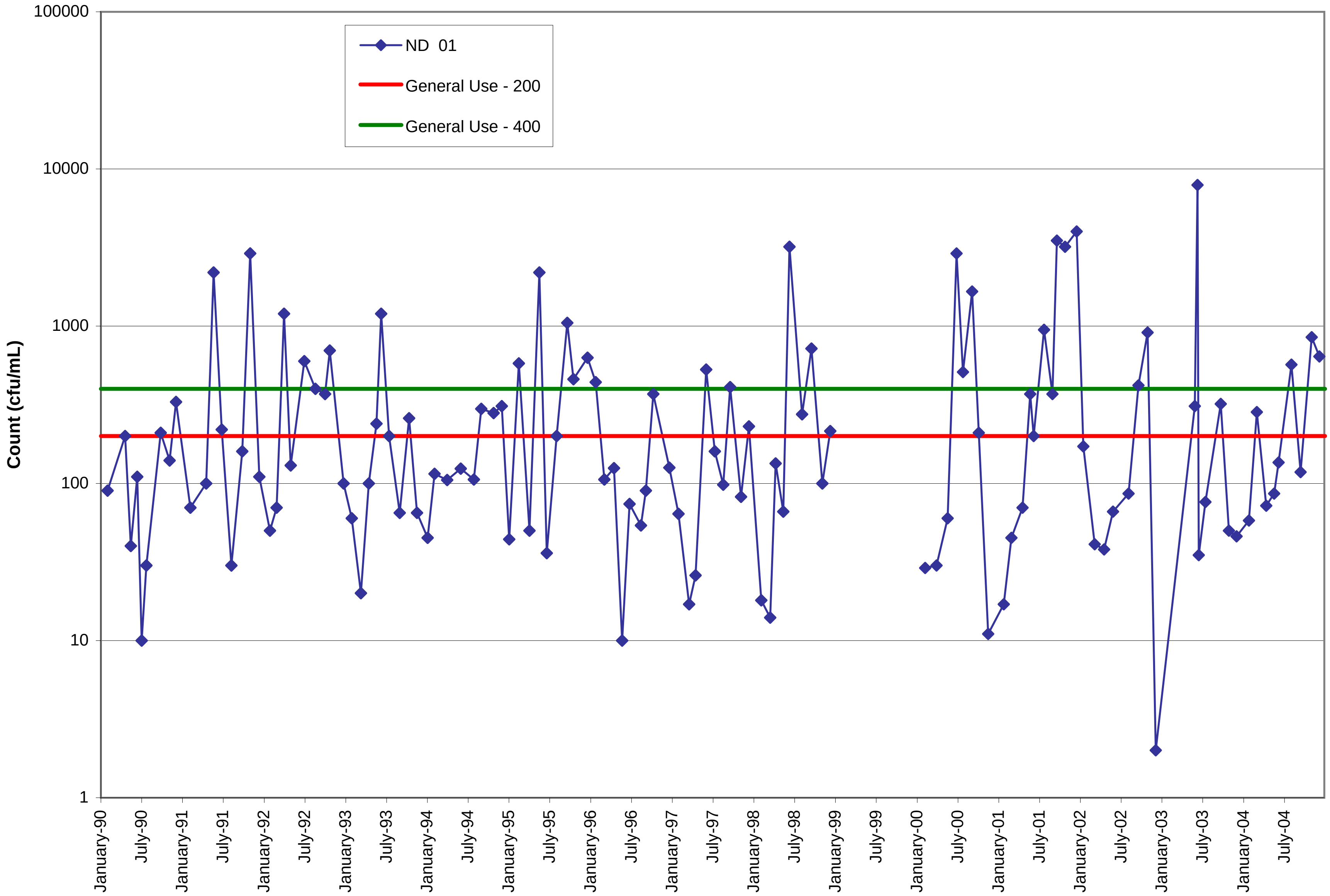

Figure 5-2:
Crab Orchard Creek
Segment ND01
Fecal Coliform Samples

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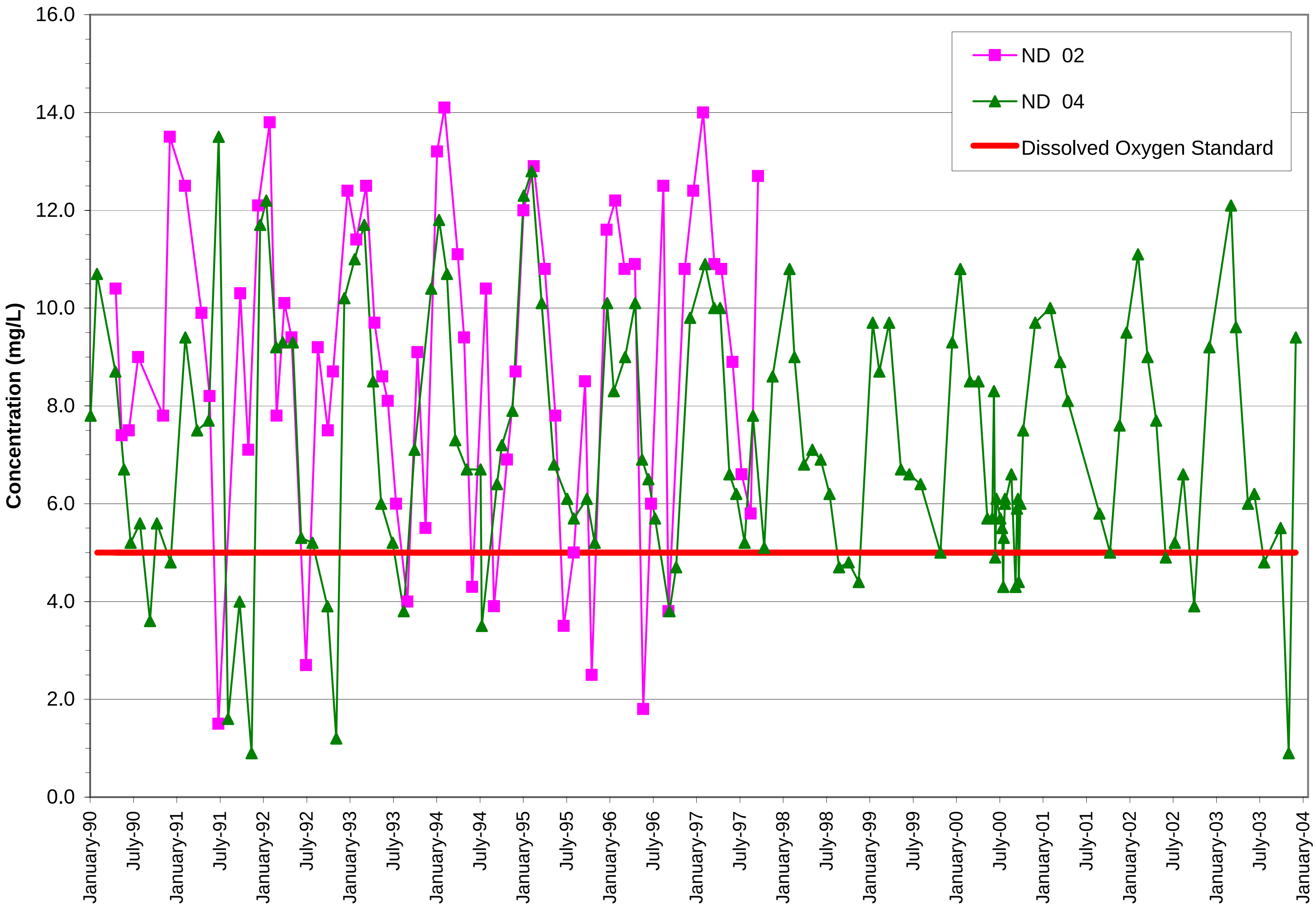

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Figure 5-3:
Crab Orchard Creek Segments ND02 and ND04
DO Samples

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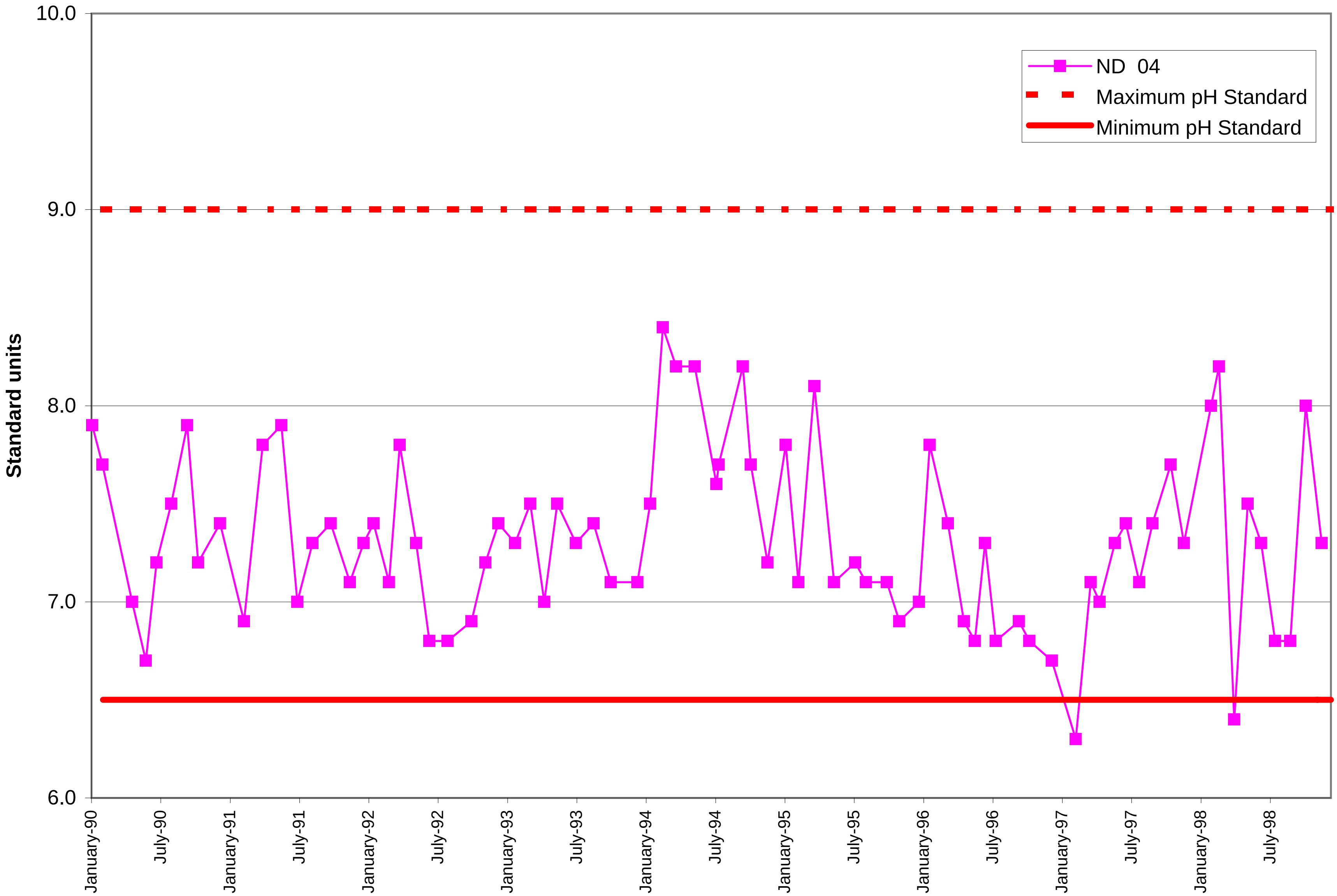

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Figure 5-4:
Crab Orchard Creek Segment ND04
pH Samples

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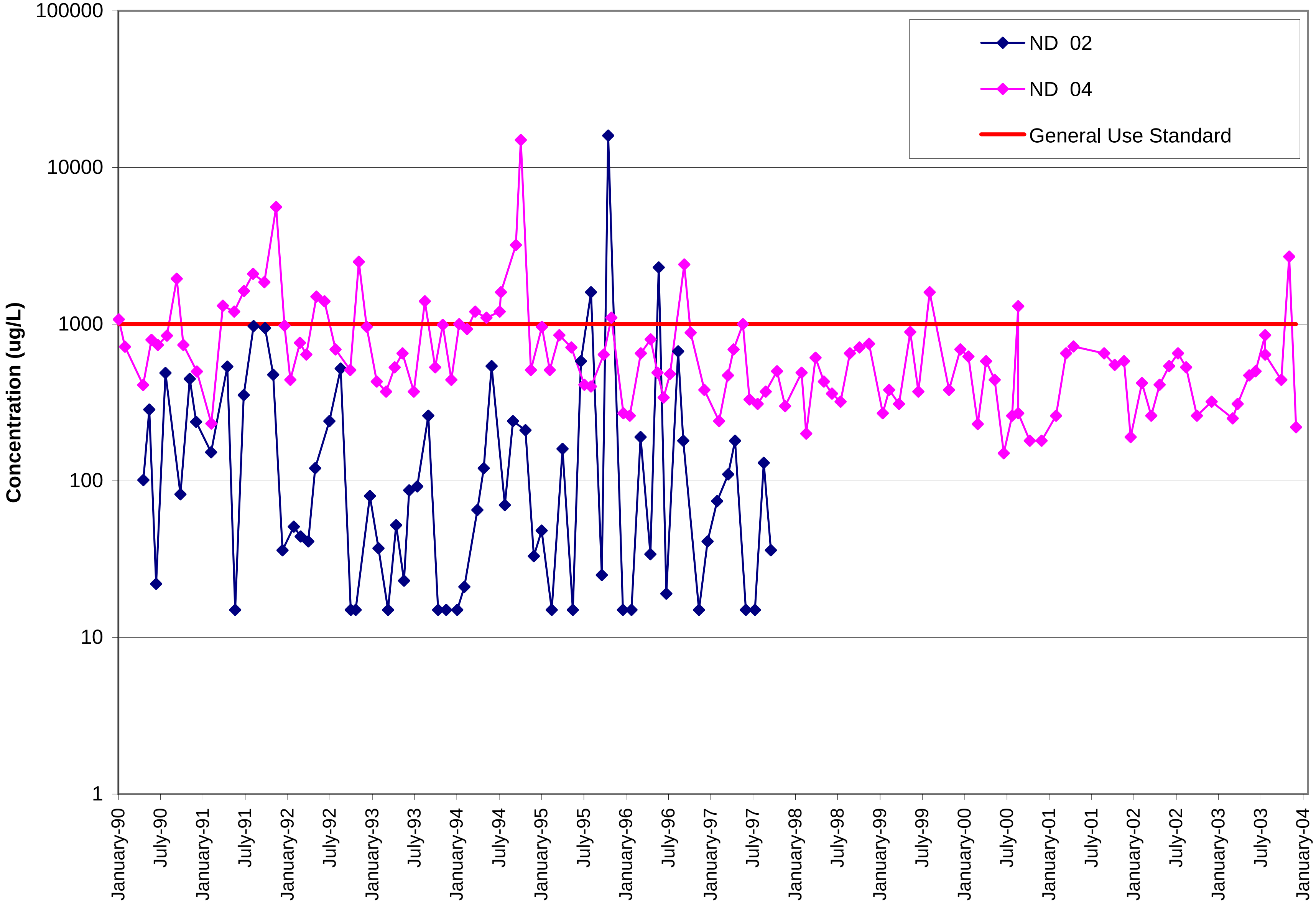

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Figure 5-5:
Crab Orchard Creek Segments ND02 and ND04
Total Manganese Samples

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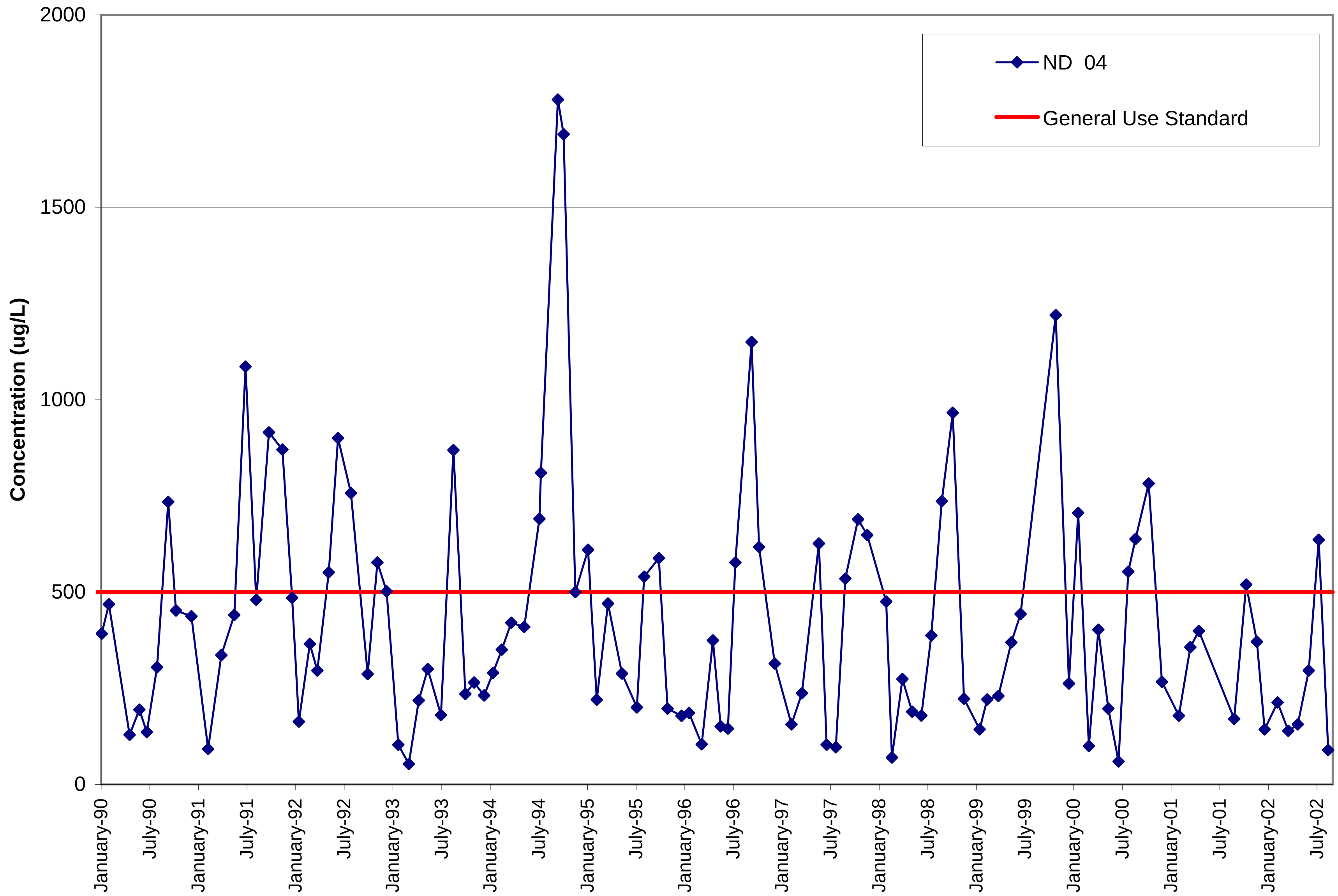

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Figure 5-6:
Crab Orchard Creek Segment ND04
Sulfate Samples

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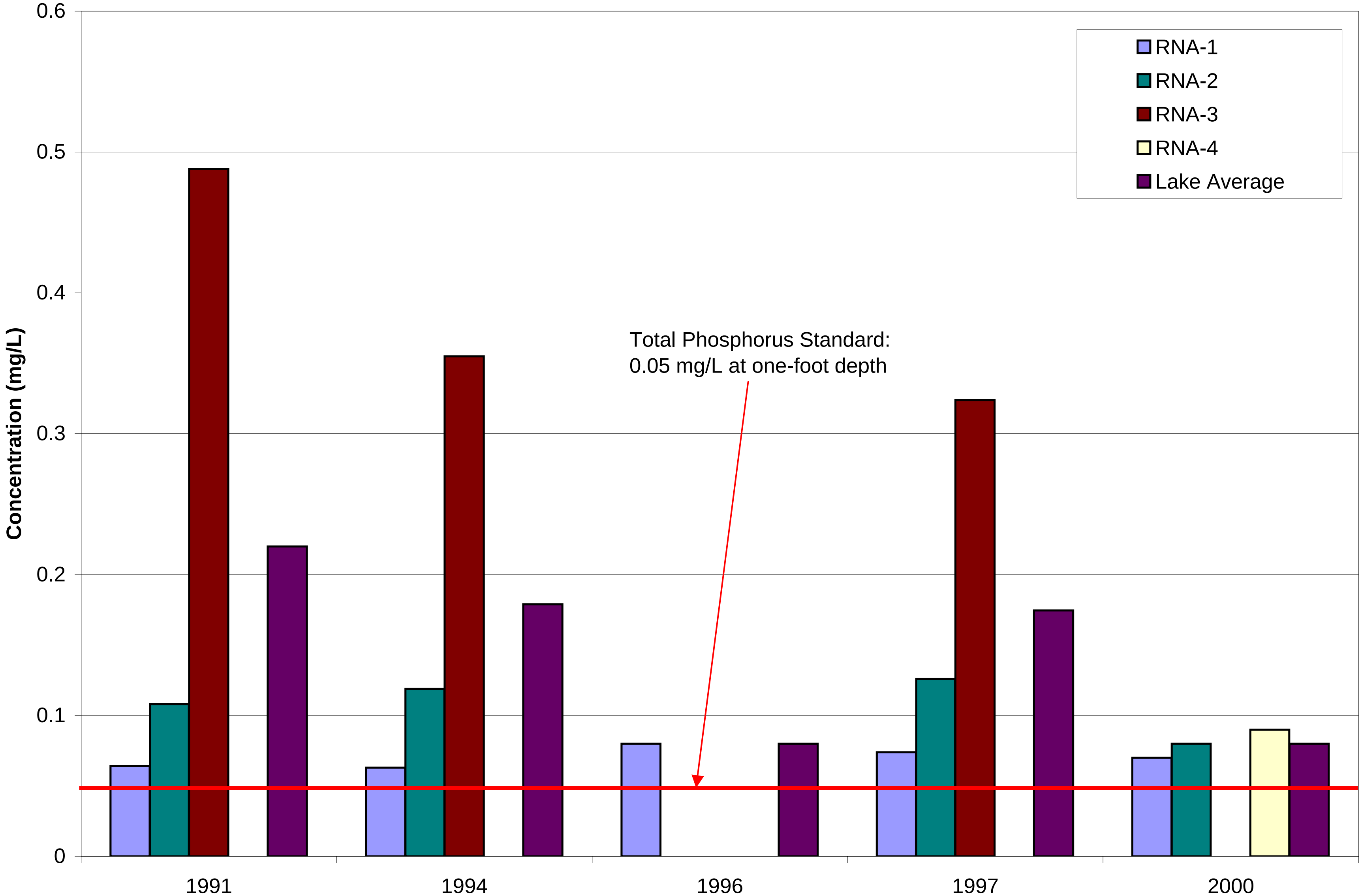

Figure 5-7:
Crab Orchard Lake
Average Annual Total Phosphorus Concentrations
at One-Foot Depth

CDM

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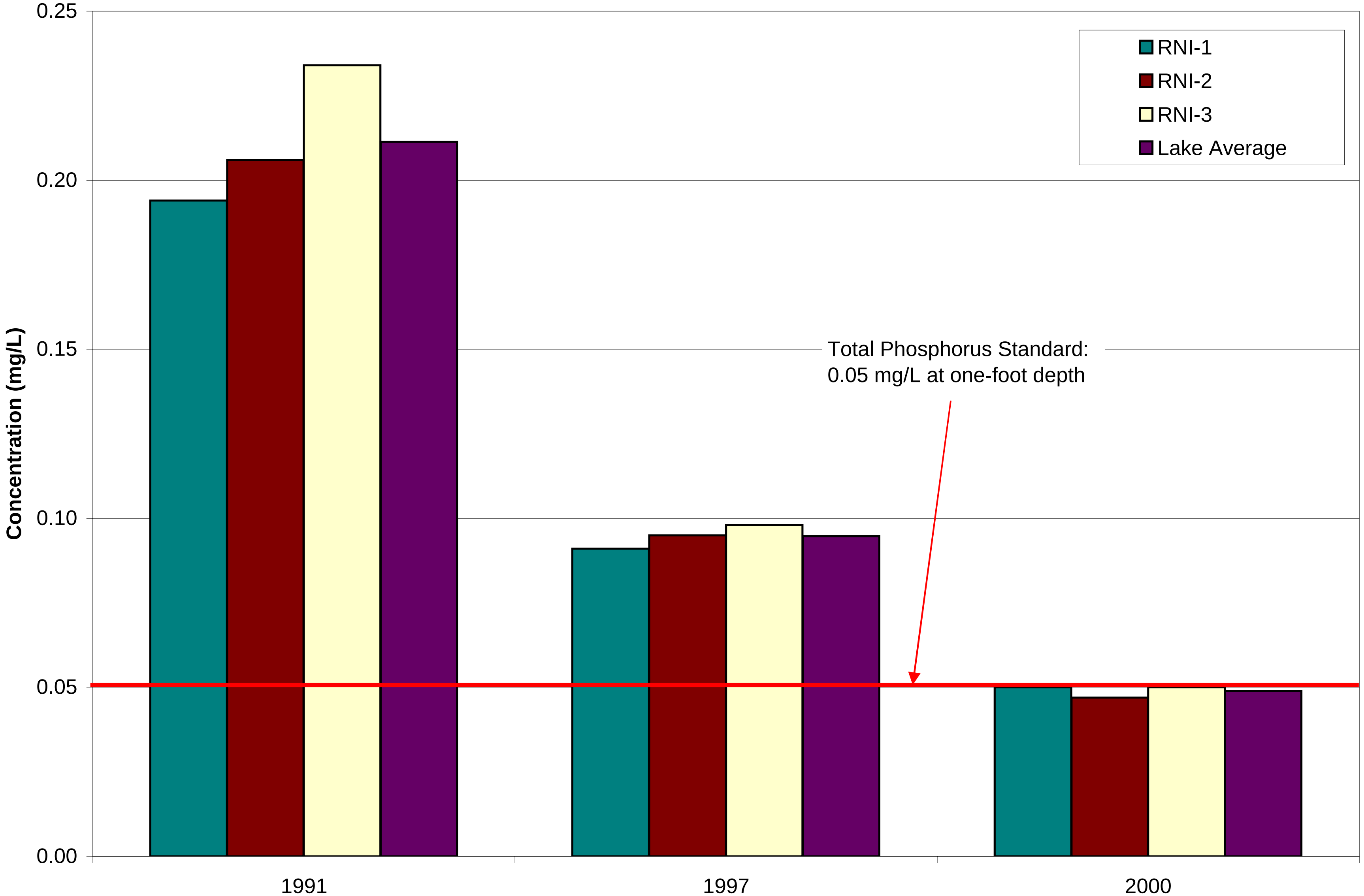

Figure 5-8:
Carbondale City Lake
Average Annual Total Phosphorus Concentrations
at One-Foot Depth

CDM

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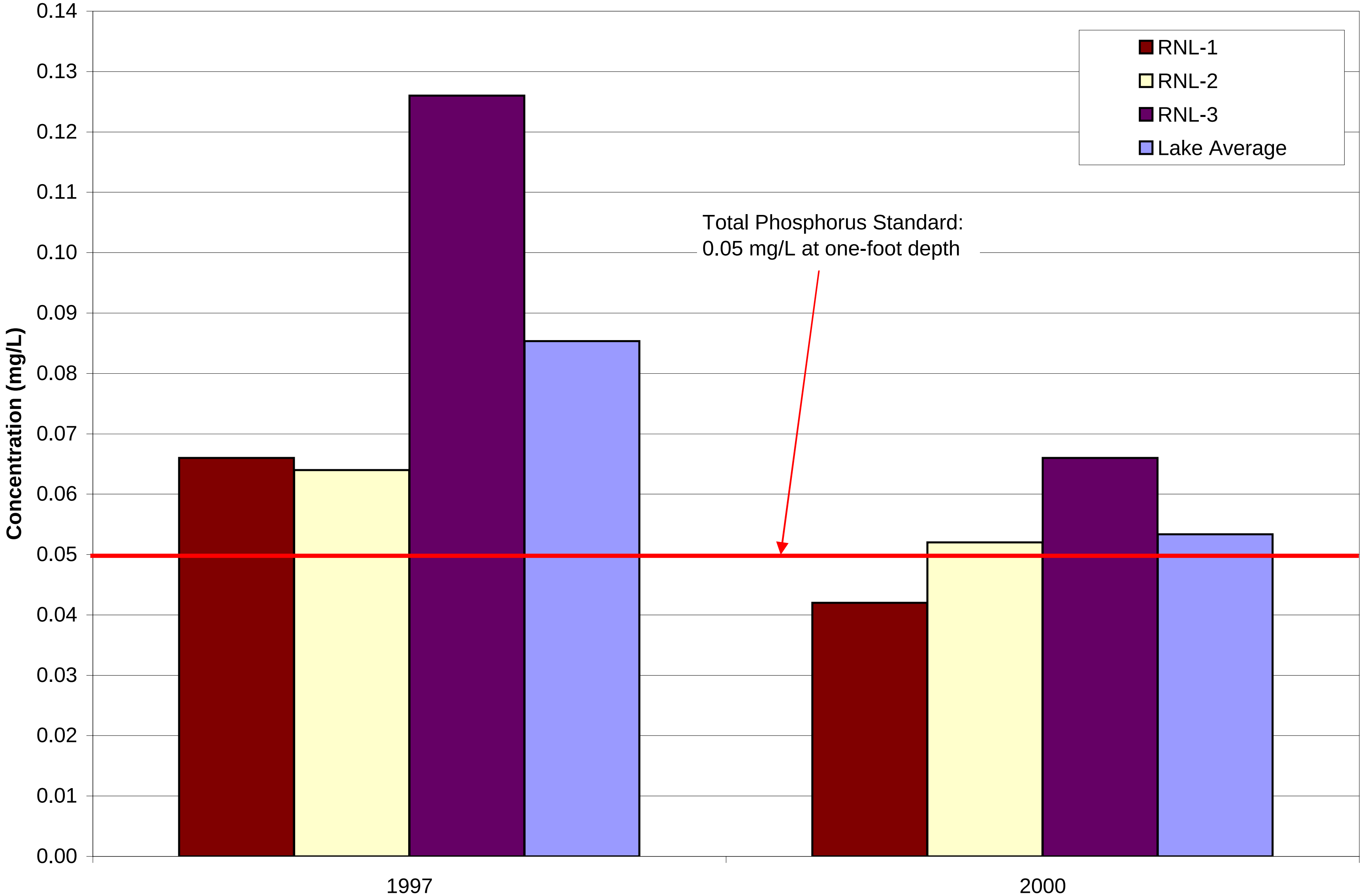

Figure 5-9:
Marion Reservoir
Average Annual Total Phosphorus Concentrations
at One-Foot Depth

CDM

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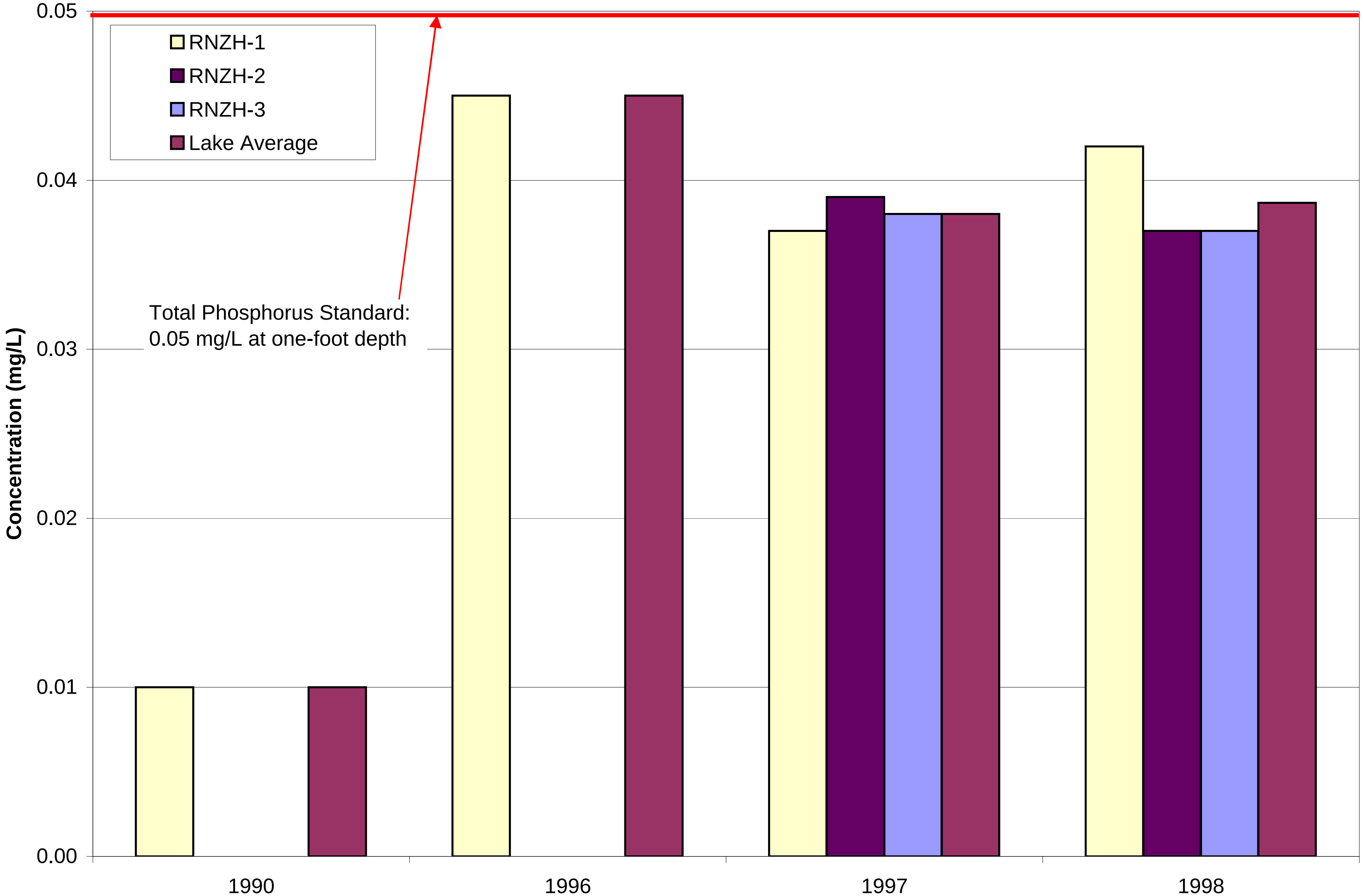

Figure 5-10:
Campus Reservoir
Average Annual Total Phosphorus Concentrations
at One-Foot Depth

CDM

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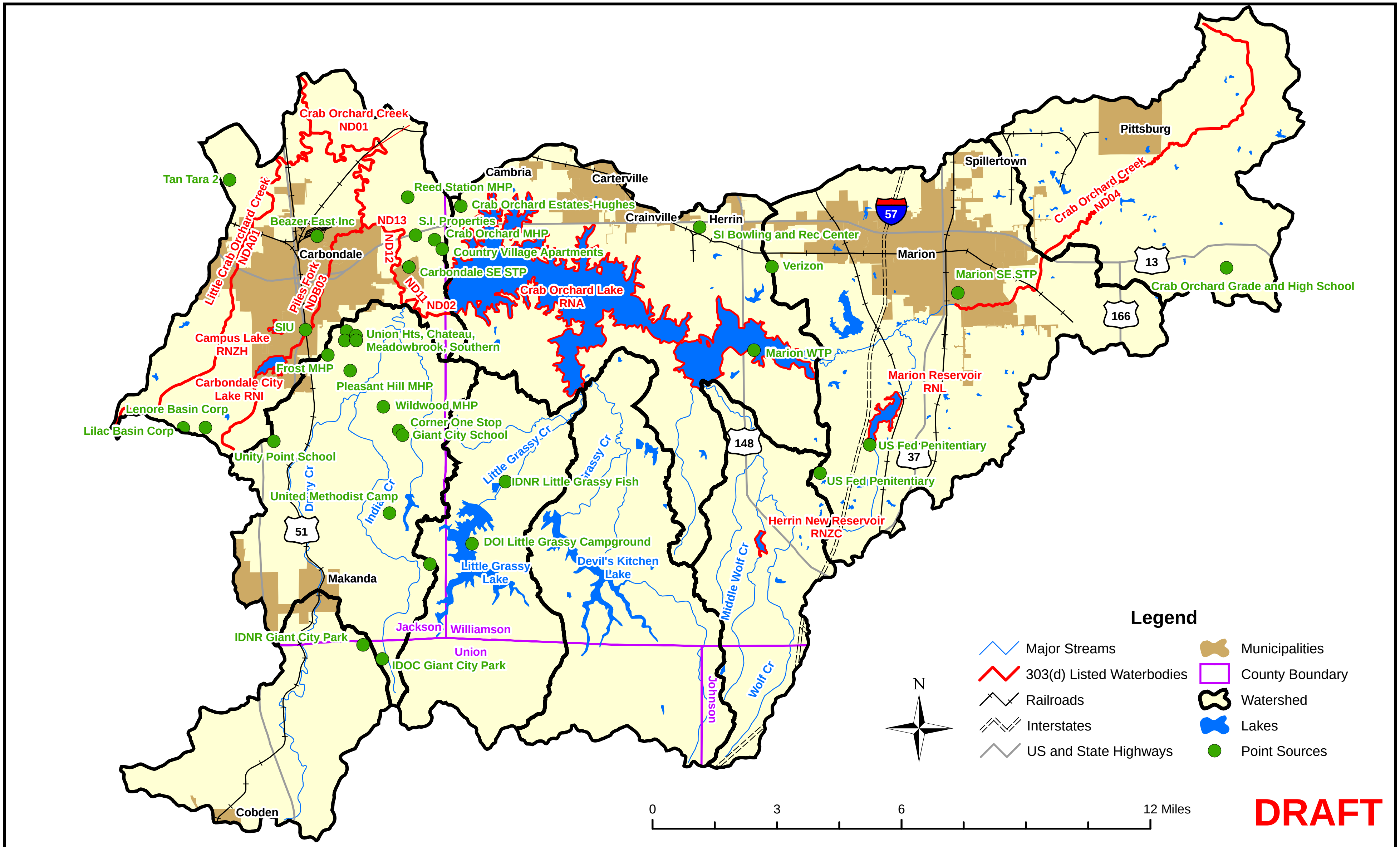

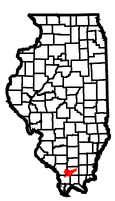

Figure 5-11
NPDES Permits
Crab Orchard Creek Watershed

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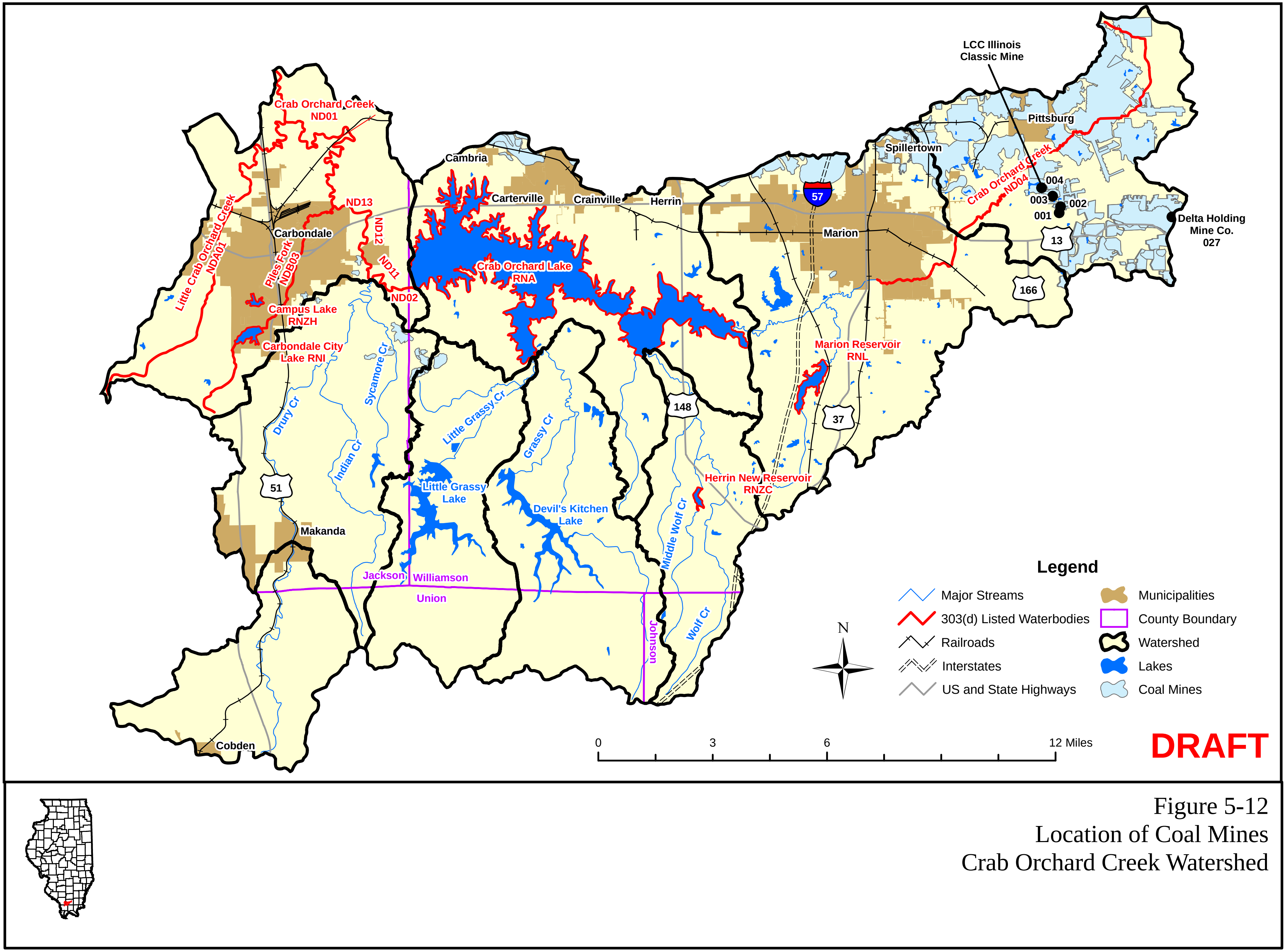

Figure 5-12
Location of Coal Mines
Crab Orchard Creek Watershed

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Section 6
Approach to Developing TMDL and Identification of Data Needs

Illinois EPA is currently developing TMDLs for pollutants that have numeric water quality standards. Of the pollutants causing impairment to stream segments in the Crab Orchard Creek/Crab Orchard Lake watershed, manganese, pH, DO, total fecal coliform, sulfates, and TDS are all of the parameters with numeric water quality standards. For the lakes in the watershed, manganese and total phosphorus are the only parameters with numeric water quality standards. Refer to Table 1-1 for a full list of potential causes of impairment. Illinois EPA believes that addressing the parameters with numeric standards should lead to an overall improvement in water quality due to the interrelated nature of the other listed pollutants. Recommended technical approaches for developing TMDLs for streams and lakes are presented in this section. Additional data needs are also discussed.

6.1 Simple and Detailed Approaches for Developing TMDLs

The range of analyses used for developing TMDLs varies from simple to complex. Examples of a simple approach include mass-balance, load-duration, and simple watershed and receiving water models. Detailed approaches incorporate the use of complex watershed and receiving water models. Simple approaches typically require less data than detailed approaches and therefore these are the analyses recommended for the Crab Orchard Creek/Crab Orchard Lake watershed except for stream segments where there are major point sources whose NDPES permit may be affected by the TMDL's WLA. Establishing a link between pollutant loads and resulting water quality is one of the most important steps in developing a TMDL. As discussed above, this link can be established through a variety of techniques. The objective of the remainder of this section is to recommend approaches for establishing these links for the constituents of concern in the Crab Orchard Creek/Crab Orchard Lake watershed.

6.2 Approaches for Developing TMDLs for Stream Segments in Crab Orchard Creek/Crab Orchard Lake Watershed

Stream segments with a major point source discharging upstream in the Crab Orchard Creek/Crab Orchard Lake watershed are segments ND12, ND13, and ND01 of Crab Orchard Creek. The remaining impaired stream segments do not have major point sources discharging to them. Approaches for developing TMDLs for areas with and without major point sources are described below.

6.2.1 Recommended Approach for DO TMDLs for Stream Segments without Major Point Sources

Segments ND04, ND02, and ND11 of Crab Orchard Creek, NDA01 of Little Crab Orchard Creek, and NDB03 of Piles Fork do not have major point sources discharging to them. Minimum dissolved oxygen values collected on each stream suggest that impairment is occurring. However, data are very limited on segment ND11 of Crab Orchard Creek, NDA01 of Little Crab Orchard Creek, and NDB03 of Piles Fork. It is first recommended that more data be collected on these segments. Once each segment has adequate supporting data, a simplified approach that involves simulating pollutant oxidation and stream reaeration only within a spreadsheet model is recommended for DO TMDL development. This model simulates steady-state stream DO as a function of carbonaceous and nitrogenous pollutant oxidation and atmospheric reaeration. The model allows for non-uniform stream hydraulics, hydrology, and pollutant loadings at any level of segmentation. It is also free of numerical dispersion as it relies on well-known analytical solutions rather than numerical approximations of the fundamental equations. The model assumes plug flow (no hydrodynamic dispersion), which is likely an acceptable assumption for most small to medium sized streams. The model also does not incorporate the impacts of stream plant life, which generally require site-specific data for meaningful parameterization. A watershed model will not be used for these segments. Using the spreadsheet model iteratively, the estimated BOD loads causing the DO impairments and reductions needed to maintain a DO concentration of 5.0 mg/L will be calculated. These calculated loads will become the basis for recommending TMDL reductions if necessary.

6.2.2 Recommended Approach for DO TMDLs for Segments with Major Point Sources

The Carbondale SE STP discharges to Crab Orchard Creek ND12. Segment ND12 flows into segments ND13 and then ND01 of Crab Orchard Creek. Segment ND13 is impaired for DO. For this segment a more complicated approach that would also incorporate the impacts of stream plant activity, and possibly sediment oxygen demand (SOD), and would require a more sophisticated numerical model and an adequate level of measured data to aide in model parameterization is recommended.

The data for this segment does suggest impairment of the DO standard. However, spatial data are limited and therefore, additional data collection is recommended to support model development. Specific data requirements include a synoptic (snapshot in time) water quality survey of this reach with careful attention to the location of the point source dischargers. This survey should include measurements of flow, hydraulics, DO, temperature, nutrients, and CBOD. The collected data will be used to support the model development and parameterization and will lend significant confidence to the TMDL conclusions.

This newly collected data could then be used to support the development and parameterization of a more sophisticated DO model for this stream and therefore, the use of the QUAL2E model (Brown and Barnwell 1985) could be utilized to accomplish the TMDL analysis for Crab Orchard Creek. QUAL2E is well-known and USEPA-supported. It simulates DO dynamics as a function of nitrogenous and carbonaceous oxygen demand, atmospheric reaeration, SOD, and phytoplankton photosynthesis and respiration. The model also simulates the fate and transport of nutrients and BOD and the presence and abundance of phytoplankton (as chlorophyll-a). Stream hydrodynamics and temperature are important controlling parameters in the model. The model is essentially only suited to steady-state simulations.

In addition to the QUAL2E model, a simple watershed model such as PLOAD, Unit Area Loads or the Watershed Management Model is recommended to estimate BOD and nutrient loads from non-point sources in the watershed. This model will allow for allocation between point and nonpoint source loads and provide an understanding of percentage of loadings from point sources and nonpoint sources in the watershed.

6.2.3 Recommended Approach for pH TMDLs in Non-Mining Impacted Areas

Segment ND11 and ND12 of Crab Orchard Creek are listed for pH impairments. Data on each segment are limited to three samples. It is first recommended that additional data be collected. When more data are available, a spreadsheet approach will be utilized, which takes into account natural conditions in the watershed such as soil buffering capacity.

6.2.4 Recommended Approach for pH TMDLs in Mining Impacted Areas

Segment ND04 of Crab Orchard Creek is listed for pH impairments. Segment ND04 had only two violations of the pH standard out of 81 samples. The recommended procedure to develop the pH TMDL for a mining area based on an analytical procedure developed by the Kentucky Department of Environmental Protection (2001). The procedure calculates a maximum allowable hydrogen ion loading in the water column to maintain pH standards.

6.2.5 Recommended Approach for Fecal Coliform TMDLs

Segment ND01 is listed as impaired for total fecal coliform. The standard is based on a geometric mean of at least 5 samples collected in a 30 day period during the months of May through October. There have been no instances when this has been the case, however, the amount of data available is adequate for TMDL development. The recommended approach for developing TMDLs for this segment is use of the load-duration curve method. The load-duration methodology uses the cumulative frequency distribution of streamflow and pollutant concentration data to estimate the allowable loads for a waterbody.

6.2.6 Recommended Approach for Manganese TMDLs in Non-Mining Impacted Areas

Segments ND02, ND11, ND12, and ND13 of Crab Orchard Creek and NDA01 of Little Crab Orchard Creek are impaired for manganese. No apparent sources of manganese have been identified to date and therefore, an empirical loading and spreadsheet analysis is recommended for calculation of this TMDL. In order to use this method to calculate a manganese TMDL for these segments, further data collection will be required for segments ND11, ND12 and ND13 of Crab Orchard Creek and NDA01 of Little Crab Orchard Creek.

6.2.7 Recommended Approach for Manganese, Sulfates, and TDS TMDLs in Mining Impacted Areas

Segment ND04 of Crab Orchard Creek is impaired for manganese, TDS and sulfates. Because it is located in an area where mining or abandoned mines exist, a Monte Carlo simulation will be utilized to estimate a long-term average instream concentration needed to meet water quality standards. To complete these analyses, a distribution based on existing data is inputted in the Monte Carlo simulation program. This distribution is based on the amount of existing data available. Using this defined distribution, the computer simulation program randomly generates values to determine what long-term average (LTA) would be needed so that water quality criteria are met 99.9 percent of the time or so that water quality criteria are exceeded less than once every three years. The TMDL for manganese, TDS, and sulfates will be based on this LTA.

6.3 Approaches for Developing TMDLs for Lake Segments in the Crab Orchard Creek/Crab Orchard Lake Watershed

Recommended TMDL approaches for lakes within the Crab Orchard Creek/Crab Orchard Lake watershed will not be separated into those lakes with or without major point source discharges. It is assumed that for the lakes in the watershed, adequate data exist to develop a simple model for use in TMDL development.

6.3.1 Recommended Approach for Total Phosphorus TMDLs

Crab Orchard Lake, Carbondale City Lake, Marion Reservoir, and Campus Lake are all impaired for phosphorus. The BATHTUB model is recommended for all lake phosphorus assessments in this watershed. The BATHTUB model performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network that account for advective and diffusive transport, and nutrient sedimentation. The model relies on empirical relationships to predict lake trophic conditions and subsequent DO conditions as functions of total phosphorus and nitrogen loads, residence time, and mean depth. (USEPA 1997). Oxygen conditions in the model are simulated as meta and hypolimnetic depletion rates, rather than explicit concentrations. Watershed loadings to the lakes will be based on empirical data or tributary data available in the lake watersheds.

6.3.2 Recommended Approach for Manganese TMDLs

Carbondale City Lake, Marion Reservoir, and Herrin New Reservoir have manganese impairments. The applicable water quality standard for manganese is 150 µg/L. For Carbondale City Lake and Marion Reservoir, manganese will not be analyzed because it is assumed that development of the phosphorus TMDL (described above) will control the manganese concentrations. The manganese target is maintenance of hypolimnetic DO concentrations above zero, because the only controllable source of manganese to the lake is the release of manganese from lake sediments during periods when there is no DO in lake bottom waters. The lack of DO in lake bottom waters is presumed to be due to the effects of nutrient enrichment, as there are no significant sources of oxygen demanding materials to the lake. For this reason, attainment of the total phosphorus standard is expected to result in oxygen concentrations that will reduce sediment manganese flux to natural background levels. The TMDL target for manganese is therefore set as a total phosphorus concentration of 0.050 mg-P/l. The recommended approach for lake phosphorus TMDLs was discussed above.

A similar but varied approach is recommended for Herrin New Reservoir because it is not also impaired for phosphorus as is the case for Carbondale City Lake and Marion Reservoir. For this TMDL, manganese again will not be analyzed because it is assumed that development of a DO TMDL will control the manganese concentrations. The TMDL will first investigate dissolved oxygen levels throughout the water column. The lake is not impaired for DO, however DO compliance is assessed at one-foot depth from the surface. A preliminary review of DO concentrations at greater depths shows that DO levels in the summer have been recorded as low as 0.0 mg/L (sampled at 21 feet in October 2000). The manganese target will then be maintenance of hypolimnetic DO concentrations above zero. The cause of the lack of DO in lake bottom waters is unknown and it is recommended that a spreadsheet analysis be utilized to calculate this TMDL.

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CDM

Illinois Environmental Protection Agency

Stage 2 Data Report

March 2007

Final Report

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Contents

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Figures

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Tables

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Section 1
Introduction

The Illinois Environmental Protection Agency (Illinois EPA) has a three-stage approach to total maximum daily load (TMDL) development. The stages are:

Stage 1 – Watershed Characterization, Data Analysis, Methodology Selection

Stage 2 – Data Collection (optional)

Stage 3 – Model Calibration, TMDL Scenarios, Implementation Plan

This report addresses data collection associated with Stage 2 TMDL development for the following watersheds:

- Bay Creek
- Cahokia Creek/Holiday Shores Lake
- Cedar Creek/Cedar Lake
- Crab Orchard Creek/Crab Orchard Lake
- Crooked Creek
- Little Wabash River
- Mary's River/North Fork Cox Creek
- Sangamon River/Lake Decatur
- Shoal Creek
- South Fork Saline River/Lake of Egypt
- South Fork Sangamon River/Lake Taylorville

Sampling has been completed based on the recommendations presented in Section 6 of each watershed's Stage 1 TMDL report and the sampling plan described within the quality assurance project plan (QAPP). The Stage 2 data will supplement existing data collected and assessed as part of Stage 1 of TMDL development and will support the development of TMDLs under Stage 3 of the process. Where adequate supporting data exist, data collected during Stage 2 activities may also be used to support the delisting of certain parameters from the state 303(d) list.

The remaining sections of this report contain:

- **Section 2 Field Activities** includes information on sampling locations as well as field parameter, grab sample and continuous monitoring data
- **Section 3 Quality Assurance Review** discusses changes in the sampling plan from the original QAPP, data verification and validity, and conformance to the data quality objectives
- **Section 4 Conclusions** summarizes the Stage 2 work and makes recommendations for moving forward

Section 2
Field Activities

TMDL streams were sampled by CDM twice during the fall of 2006 to collect data needed to support water quality modeling and TMDL development. The first round of Stage 2 data collection took place between August 28 and September 29, 2006. The second round of Stage 2 data collection took place between October 16 and November 17, 2006. In addition, three segments within the Little Wabash River watershed were sampled by Illinois EPA between April and August of 2006. Over the course the sampling project, 32 streams (out of a possible 33) and one lake were sampled within the eleven Stage 2 watersheds. Table 2-1 contains data collection dates for each watershed.

Table 2-1: Stage 2 Data Collection Field Dates

Watershed	First Round Dates (2006)	Second Round Dates (2006)
Bay Creek	9/25-9/29	10/30-11/6
Cahokia Creek/Holiday Shores Lake	8/28-9/6	10/16-10/20
Cedar Lake	9/5-9/14	10/30-11/6
Crab Orchard Lake	9/5-9/14	10/30-11/6
Crooked Creek	9/5-9/14	10/16-10/20
South Fork Saline River/Lake of Egypt	9/25-9/29	10/30-11/6
Little Wabash River - CDM	9/5-9/14	10/30-11/16
Little Wabash River – Illinois EPA	4/18-8/8	
Mary's River	9/5-9/14	10/16-10/20
Sangamon River/Lake Decatur	8/28-9/6	10/30-11/3
Shoal	8/28-9/6	10/16-10/20
South Fork Sangamon River/Lake Taylorville	8/28-9/6	10/30-11/3

Sampling was conducted in accordance with the QAPP by CDM personnel at stream and lake locations with sufficient water and access. When time permitted, alternate locations were investigated if water and/or access were limited at original locations. Figures 2-1 through 2-11 show sampling locations used for Stage 2 data collection for each watershed. Refer to section 3.1 for further information related to sampling location changes from the original QAPP. Appendix A contains pictures of each sampling location. The sampling and analysis activities conducted at each sampling location included:

- In-stream field parameterization
- Grab samples for laboratory analysis
- Continuous monitoring
- Stream gaging

2.1 Instream field parameters

Water quality measurements for pH, temperature, dissolved oxygen (DO), conductivity, and turbidity were taken at each accessible sampling location where water was present using an In-Situ 9500 Profiler water quality meter. In-Situ 9500 Profilers were calibrated each morning of field activity. Water quality readings were taken at each accessible site with adequate water at the center of flow and values were recorded in field books. These values are presented in Table 2-2. Table 2-2 also contains sample location latitude and longitude as well as explanatory information as to why a limited number of sites were not sampled.

At each site with adequate and safely wadeable streamflow, flow measurements were recorded using a Marsh McBirney 2000 flow meter. Appendix B contains flow meter data and stream discharge analysis for these sites.

2.2 Grab Samples

Grab samples were collected based on the causes of impairment identified in the 303(d) list as well as data needed to support TMDL development under Stage 3. Samples collected on Owl Creek and South Fork Sangamon River were analyzed by Prairie Analytical Laboratories in Springfield, IL and all other samples collected by CDM were analyzed by ARDL, Inc in Mt. Vernon, IL. Samples were delivered in person to the laboratory or exchanged with laboratory personnel in the field. Select segments in the Little Wabash watershed (Elm River segment CD01, and Little Wabash River segments C09 and C33) were sampled by Illinois EPA and analyzed by the Illinois EPA Laboratory in Champaign, IL.

Table 2-3 contains data collected at each location associated with impairment status. Values shown in bold face with gray background violated the applicable water quality standard. All data analyzed by the laboratories are contained in Appendix C. This appendix includes the data shown in Table 2-3 as well as all other parameters that were sampled in order to support Stage 3 TMDL development. In addition, Appendix C shows data qualifiers as well as detection limits for all samples.

2.3 Continuous Monitoring

In-Situ 9500 Professional XP multi-parameter data-logging sondes were used for continuous data measurements on streams impaired by low DO and/or pH. The sondes were calibrated prior to deployment then deployed for at least 3 days at select locations with adequate water and access. DO, pH, conductivity and temperature data were recorded at 15 minute intervals during sonde deployment, after which the sonde was removed and data were downloaded to a laptop computer. The continuous data associated with impairment causes are presented in Appendix D. Because sondes were not field checked at the time of retrieval, there is a possibility that some experienced times of drying or build-up of sedimentation during deployment. A column was added to the data presented in Appendix D to estimate acceptable or “suspect” data. Data were deemed suspect when low conductivity or high temperature values indicate that the meter was likely out of the water or also at times when field log books indicated that the sonde had not yet been deployed or had been pulled from the stream. The data that were deemed acceptable were plotted on Figures D-1 through D-26. The charts are grouped by watershed and show data collected during the first and second round of sampling at each location.

Violations of the instantaneous DO standard (5.0 mg/L minimum) were not recorded during either monitoring period on the following segments that are currently listed for impairment caused by low DO:

- Cedar Creek AJF16 (Figure D-1)
- Big Muddy River N99 (Figure D-4)
- Shoal Creek OI05 (Figures D-22 and D-23)
- South Fork Saline River ATH08 (Figure D-24)

According to Table B-2 of the Illinois Integrated Water Quality Report (2006), the aquatic life use may also be impaired if DO concentrations are below 6.0 mg/L for more than 16 hours of any 24 hour period. Appendix D also contains this analysis for the segments that did not violate the instantaneous minimum standard. The number of values recorded below 6.0 mg/L during any 24 hour period were counted and if any count was above 64 (64 values equates to 16 hours worth of data), the stream was considered to be potentially impaired by low DO. The following segments did not experience a violation of either the 5.0 mg/L instantaneous standard or the 6.0 mg/L standard as described above:

- Cedar Creek AJF16 (Figure D-1)
- Shoal Creek OI05 (Figures D-22 and D-23)
- South Fork Saline River ATH08 (Figure D-24)

Violations of the pH standard (6.5 minimum, 9.0 maximum) were not recorded during either monitoring period on the following segments that are currently listed for impairment caused by pH:

- Crab Orchard Creek ND12 (Figure D-5)
- Briers Creek ATHS01 (Figure D-25)

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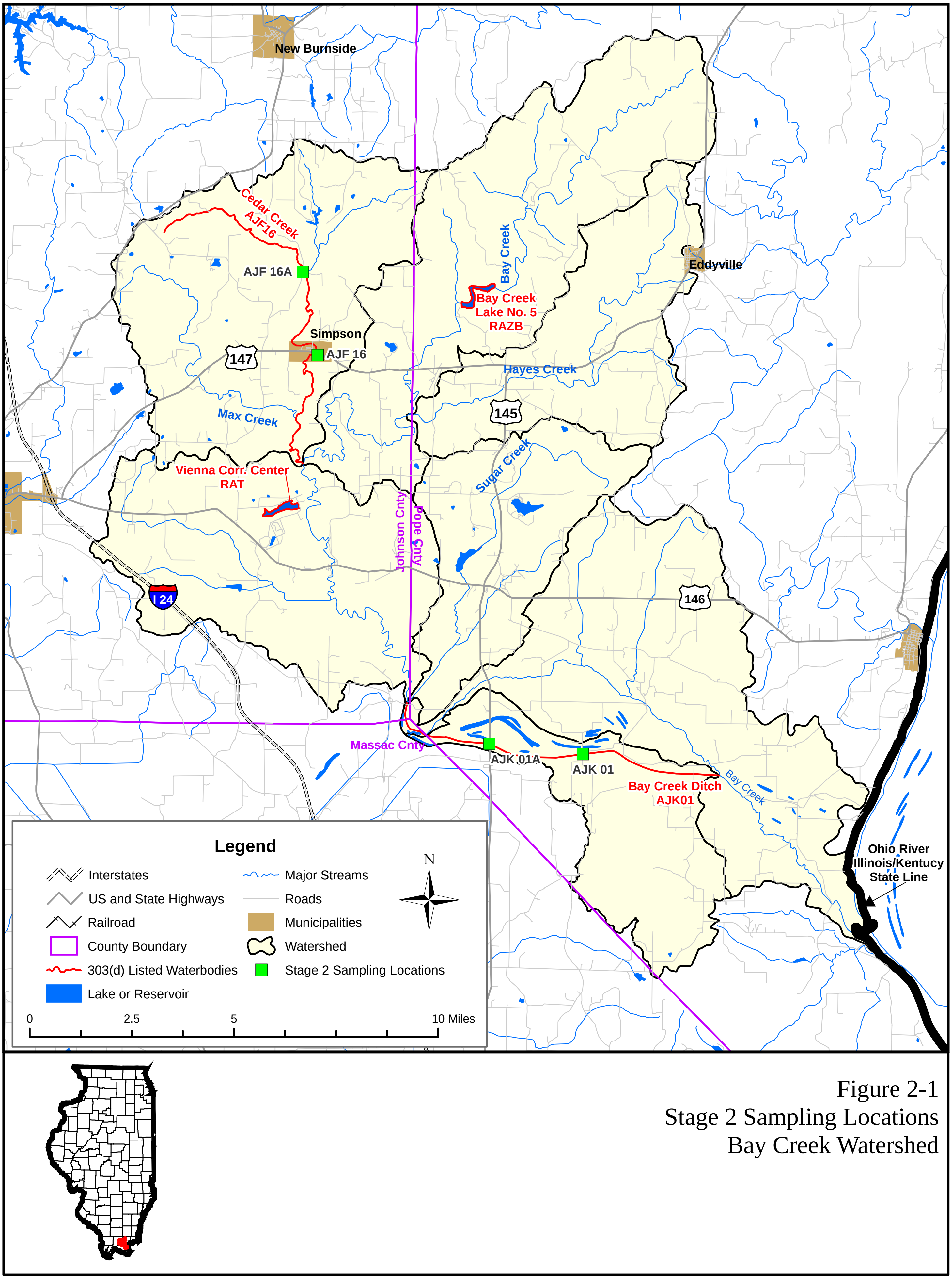

Figure 2-1
Stage 2 Sampling Locations
Bay Creek Watershed

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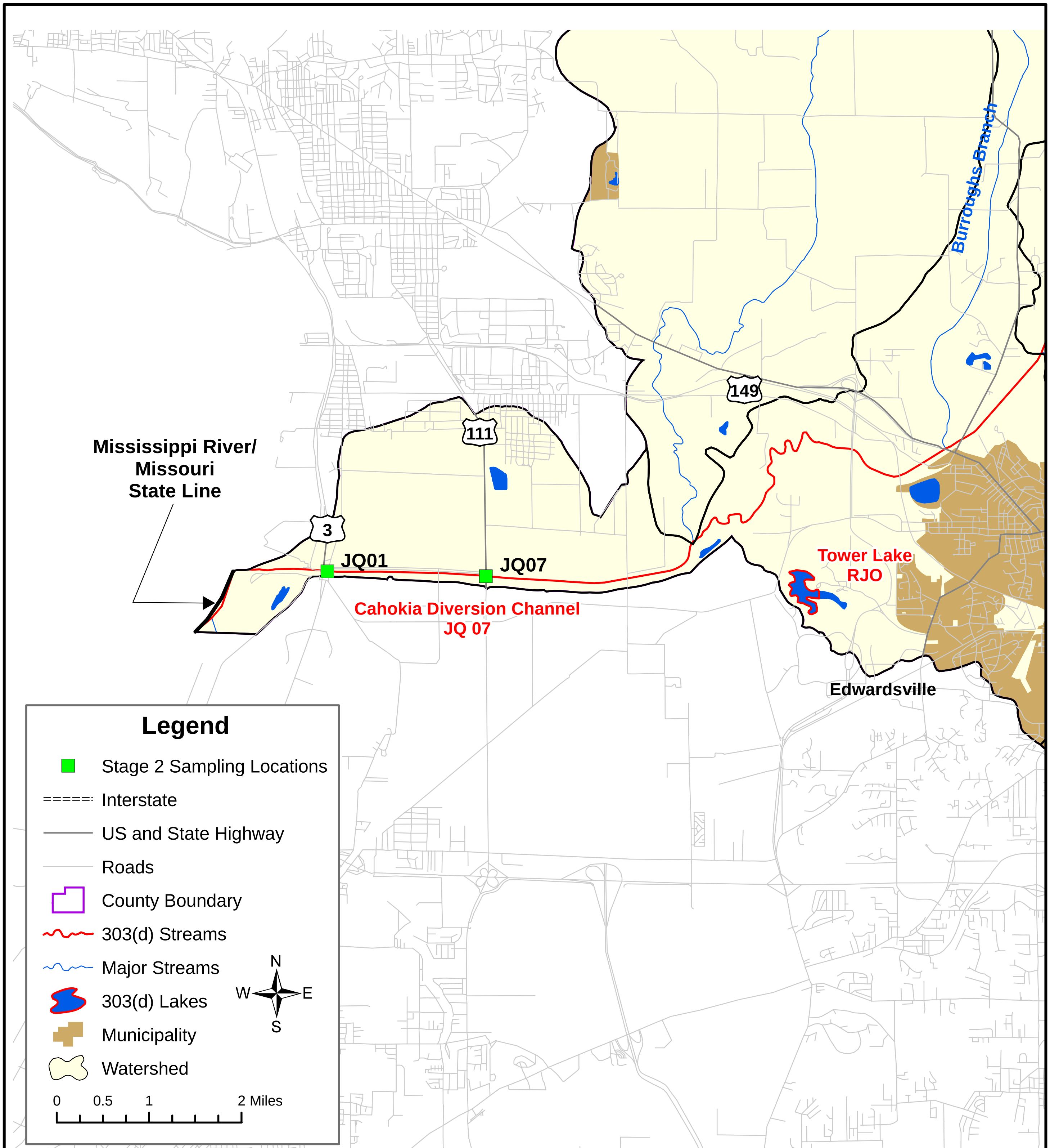

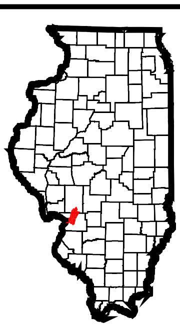

Figure 2-2:
Stage 2 Sampling Locations
Cahokia Creek/Holiday Shores Lake Watershed

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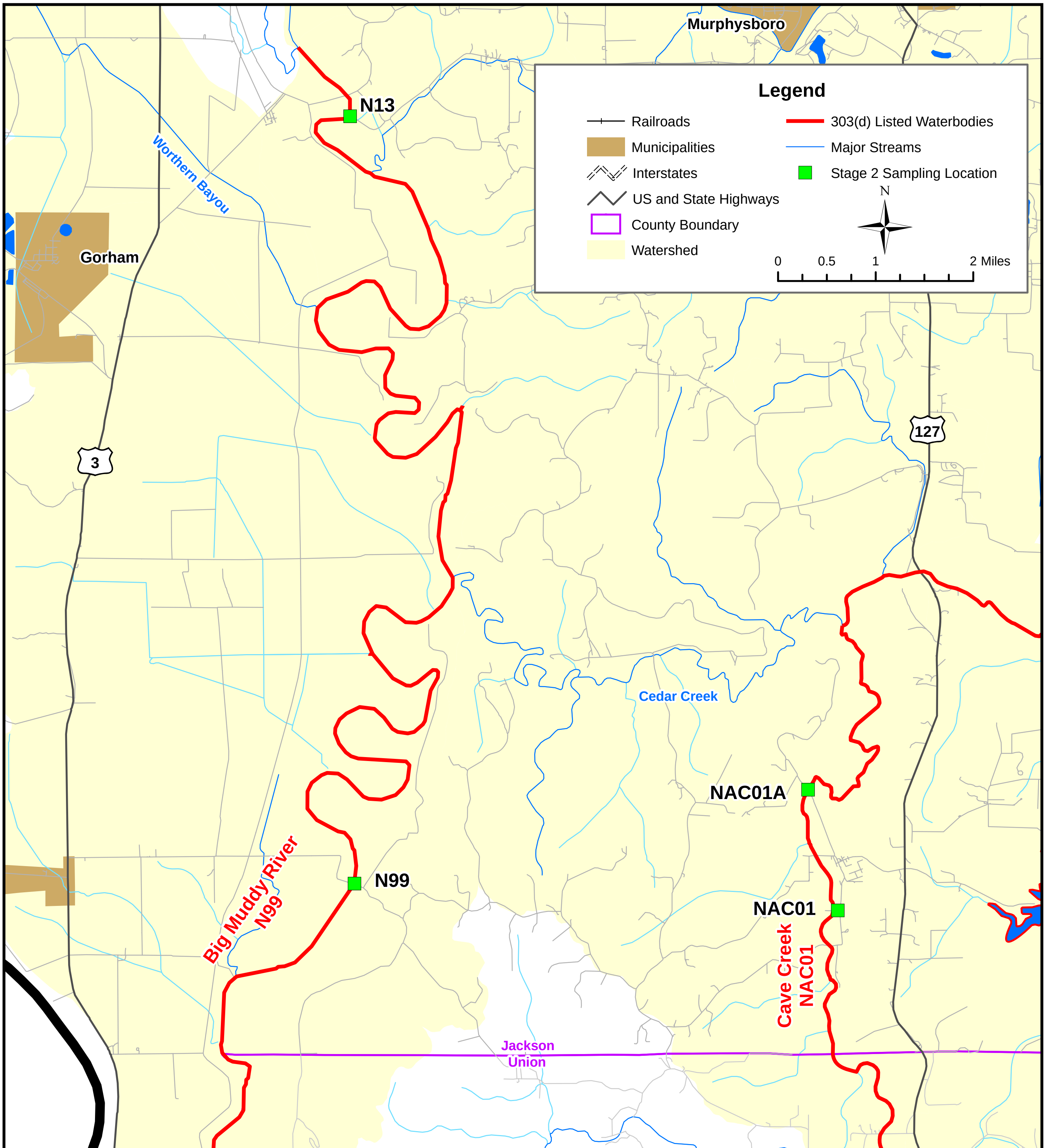

Figure 2-3
Stage 2 Sampling Locations
Cedar Creek - Cedar Lake Watershed

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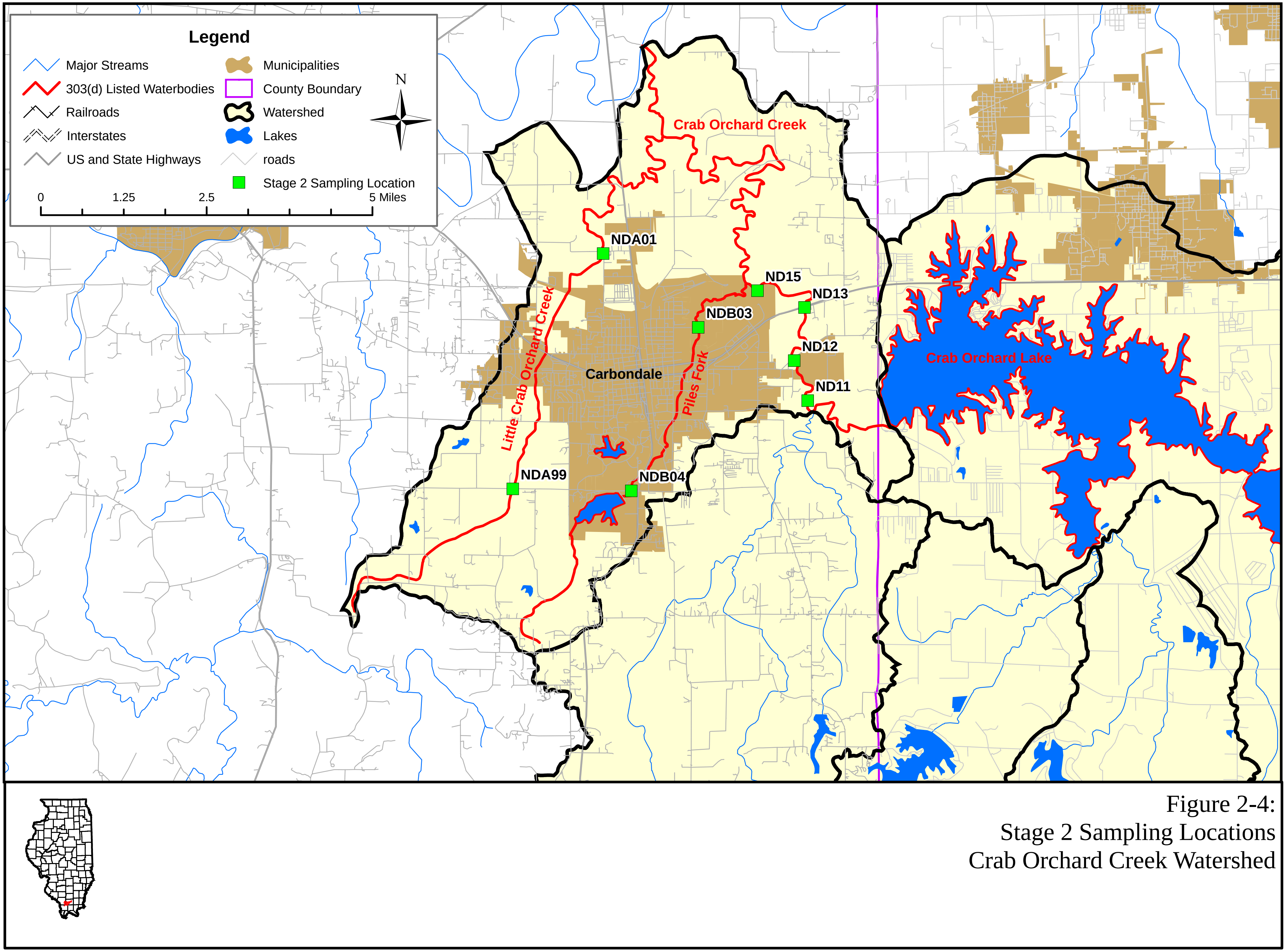

Figure 2-4:
Stage 2 Sampling Locations
Crab Orchard Creek Watershed

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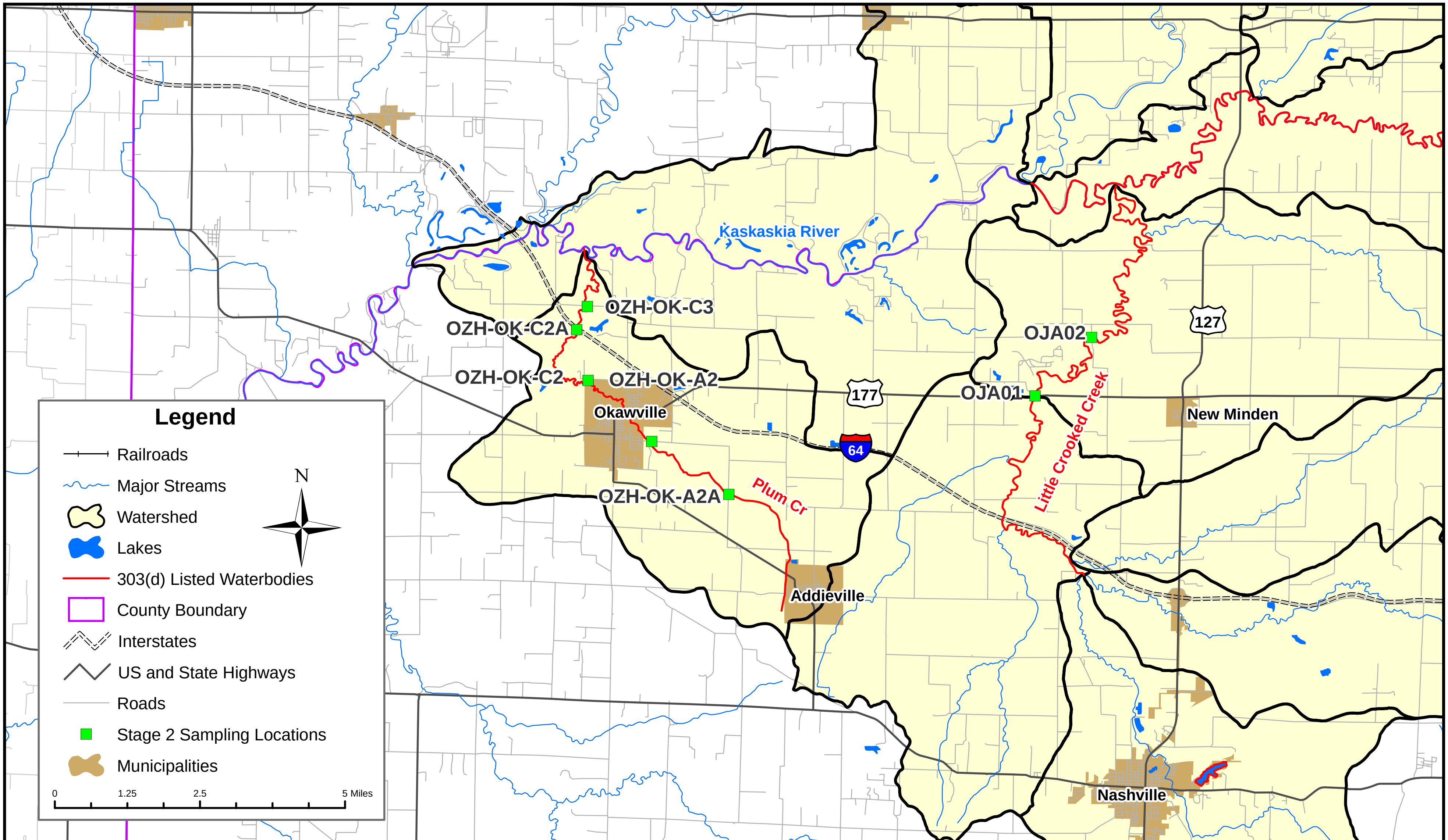

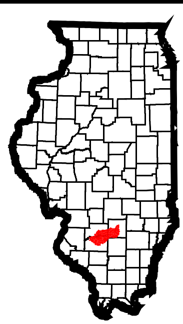

Figure 2-5
Stage 2 Sampling Locations
Crooked Creek Watershed

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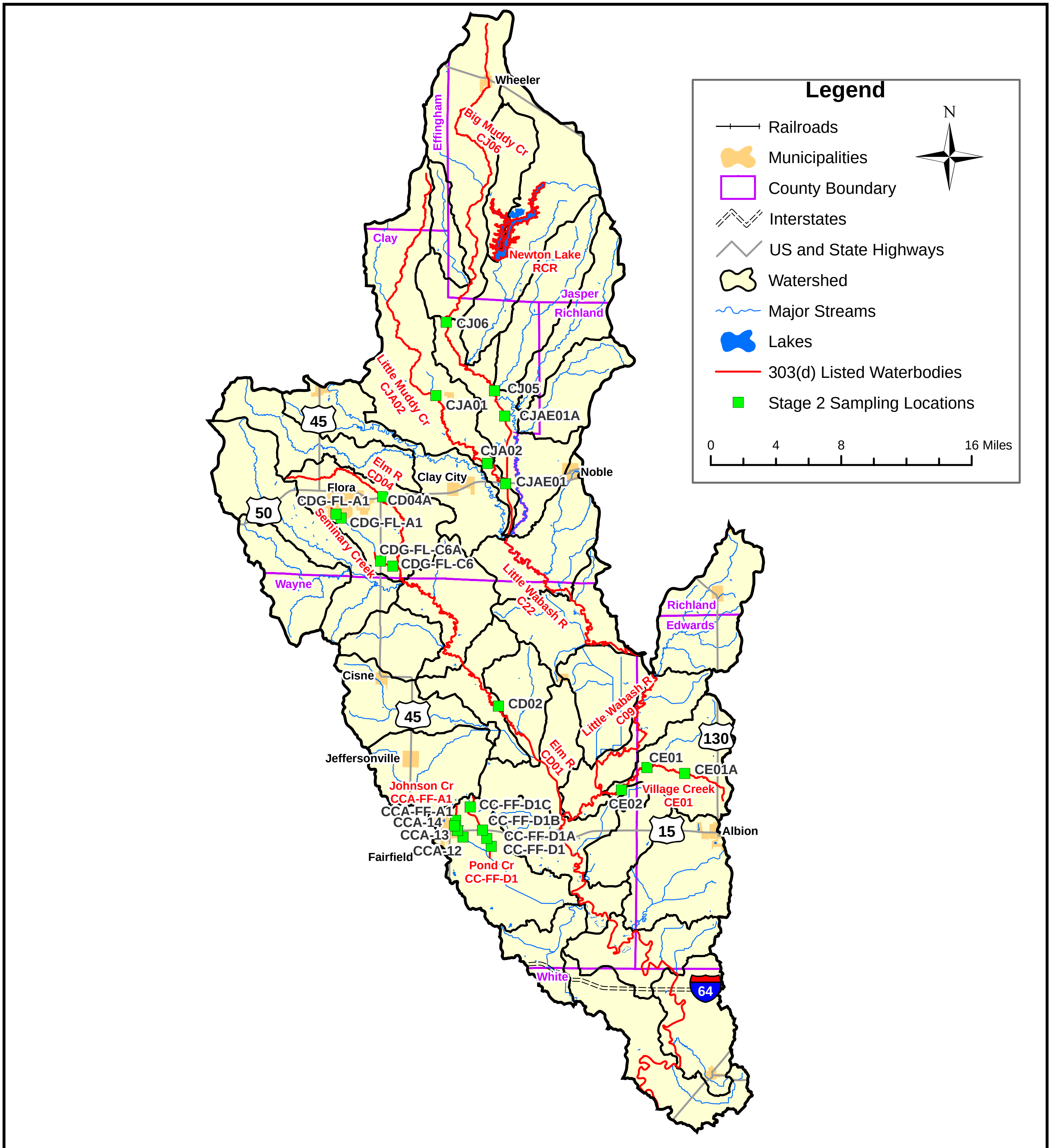

Figure 2-6:
Stage 2 Sampling Locations
Little Wabsash River Watershed

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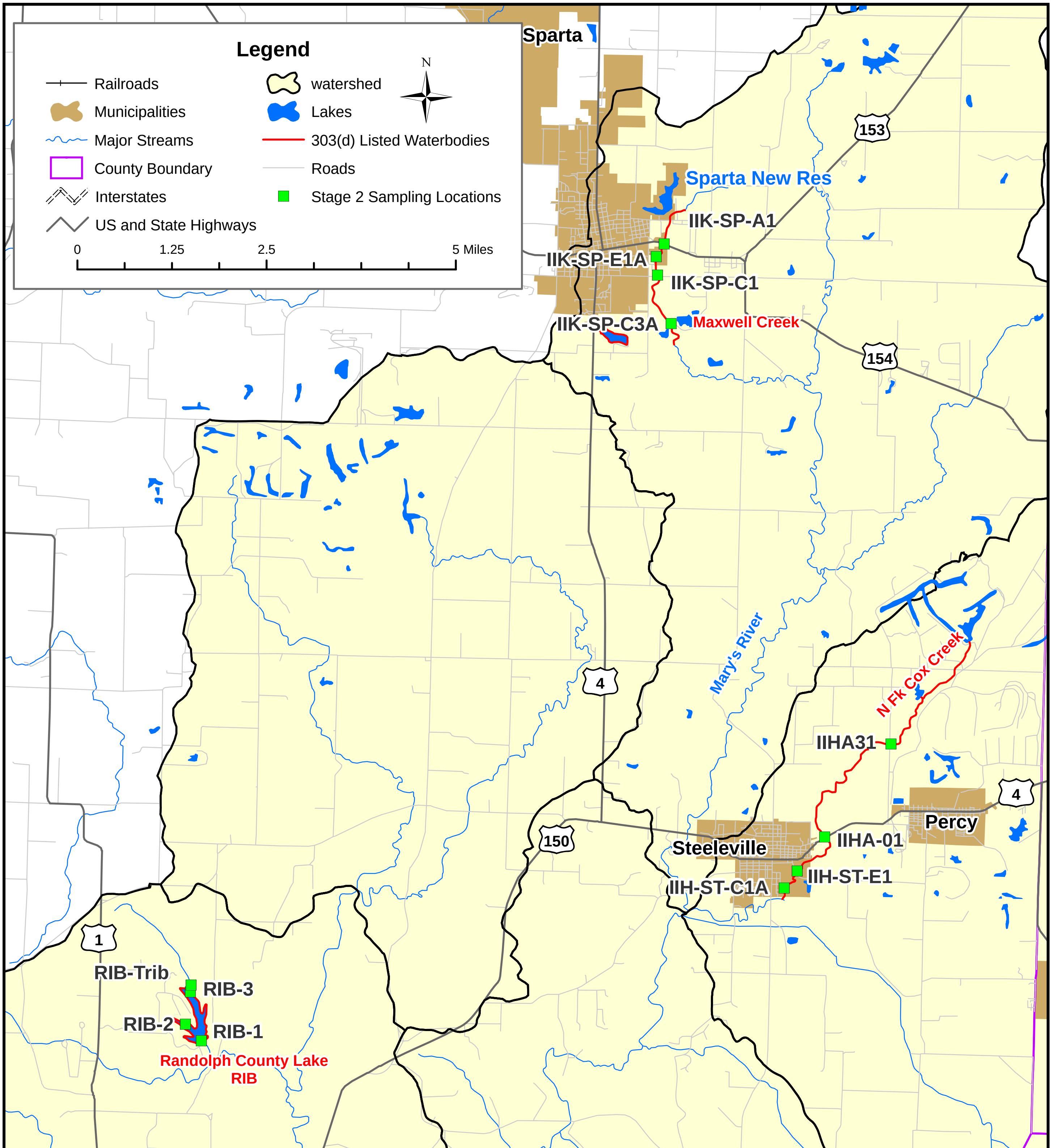

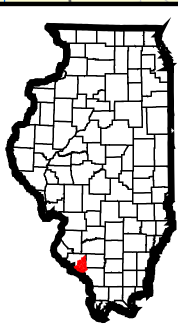

Figure 2-7:
Stage 2 Sampling Locations
Marys River - North Fork Cox Creek Watershed

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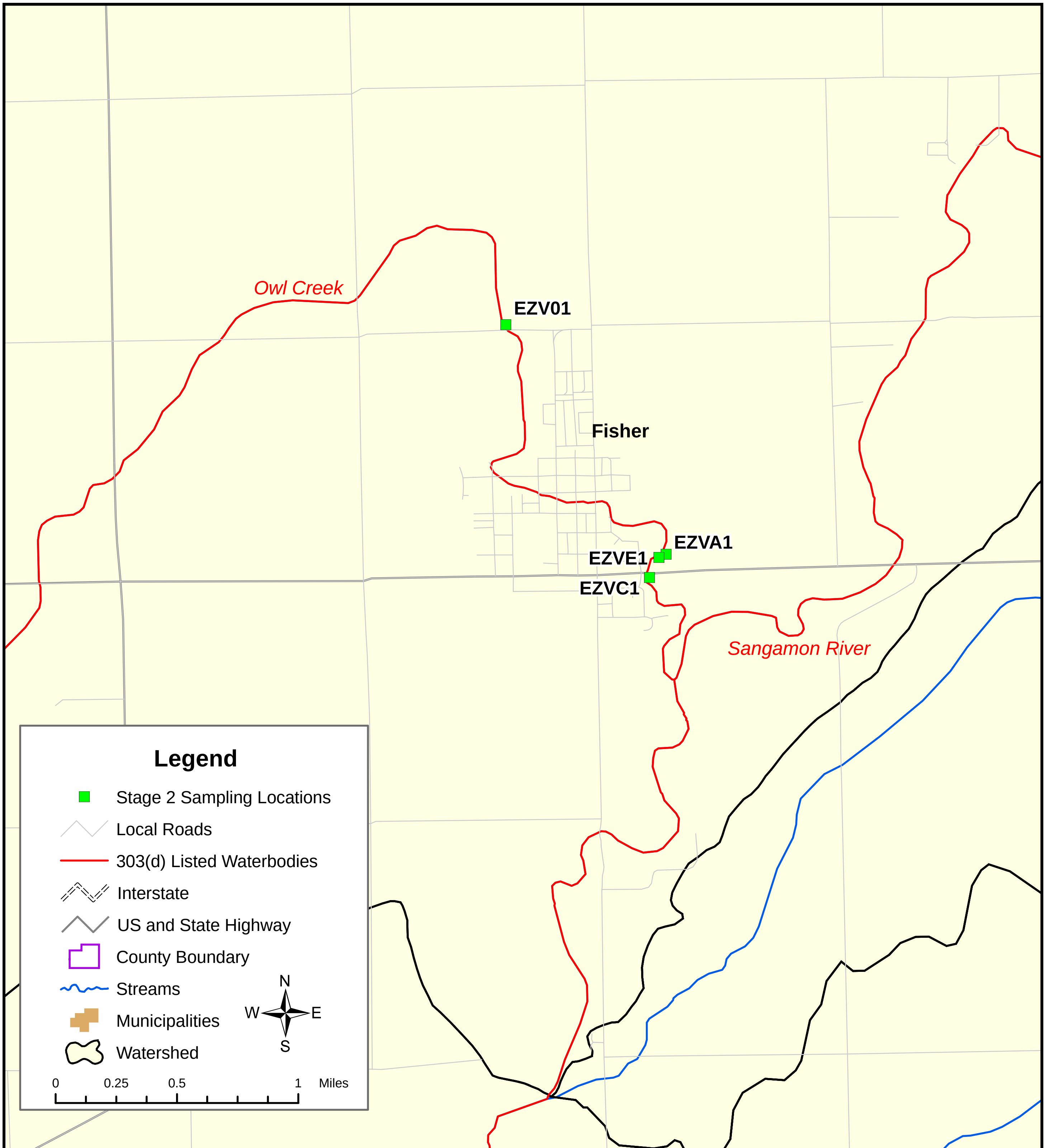

Figure 2-8:
Stage 2 Sampling Locations
Sangamon River - Lake Decatur Watershed

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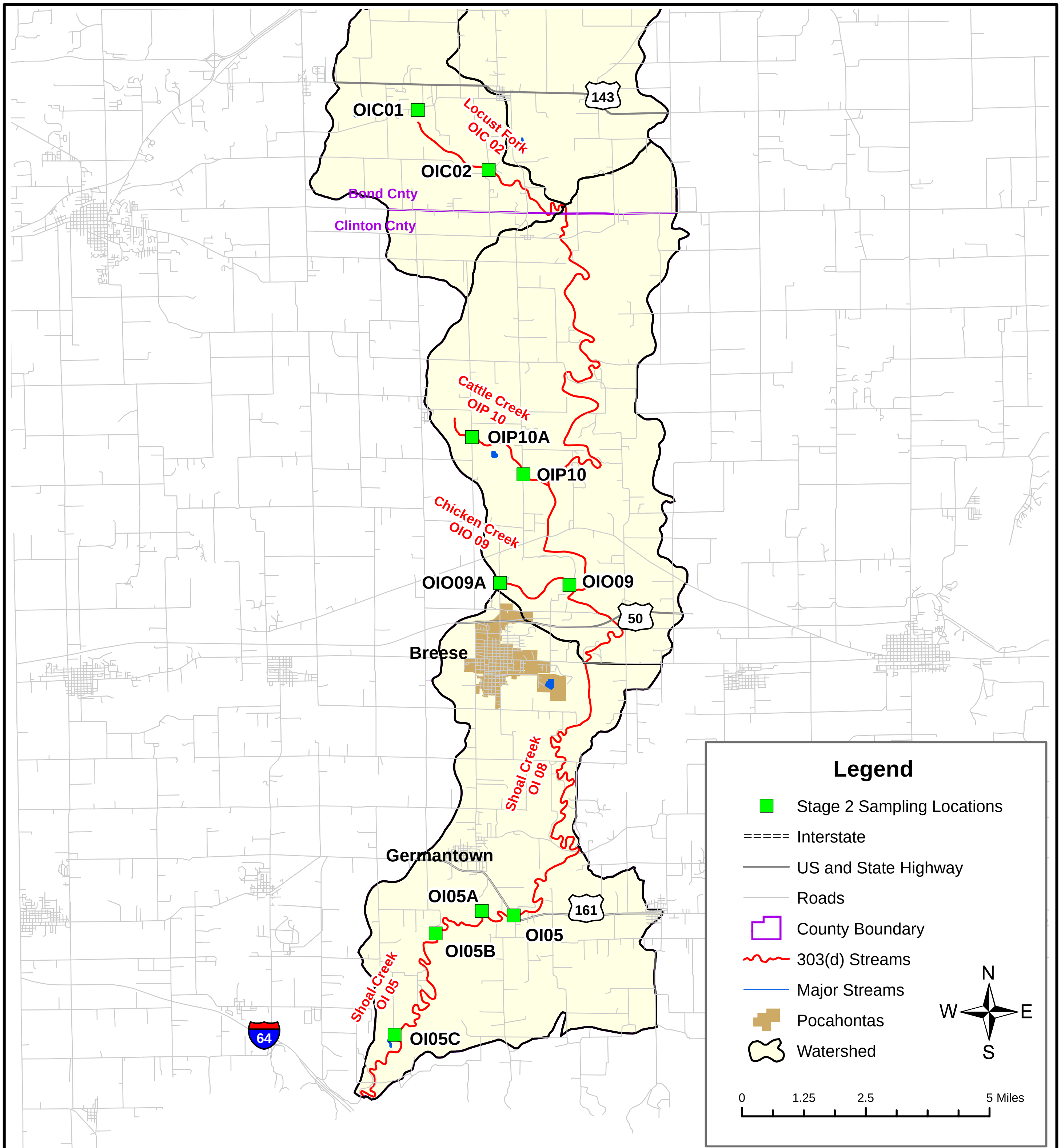

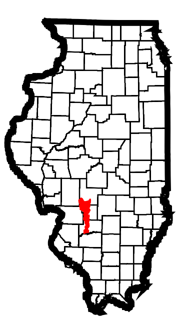

Figure 2-9:
Stage 2 Sampling Locations
Shoal Creek Watershed

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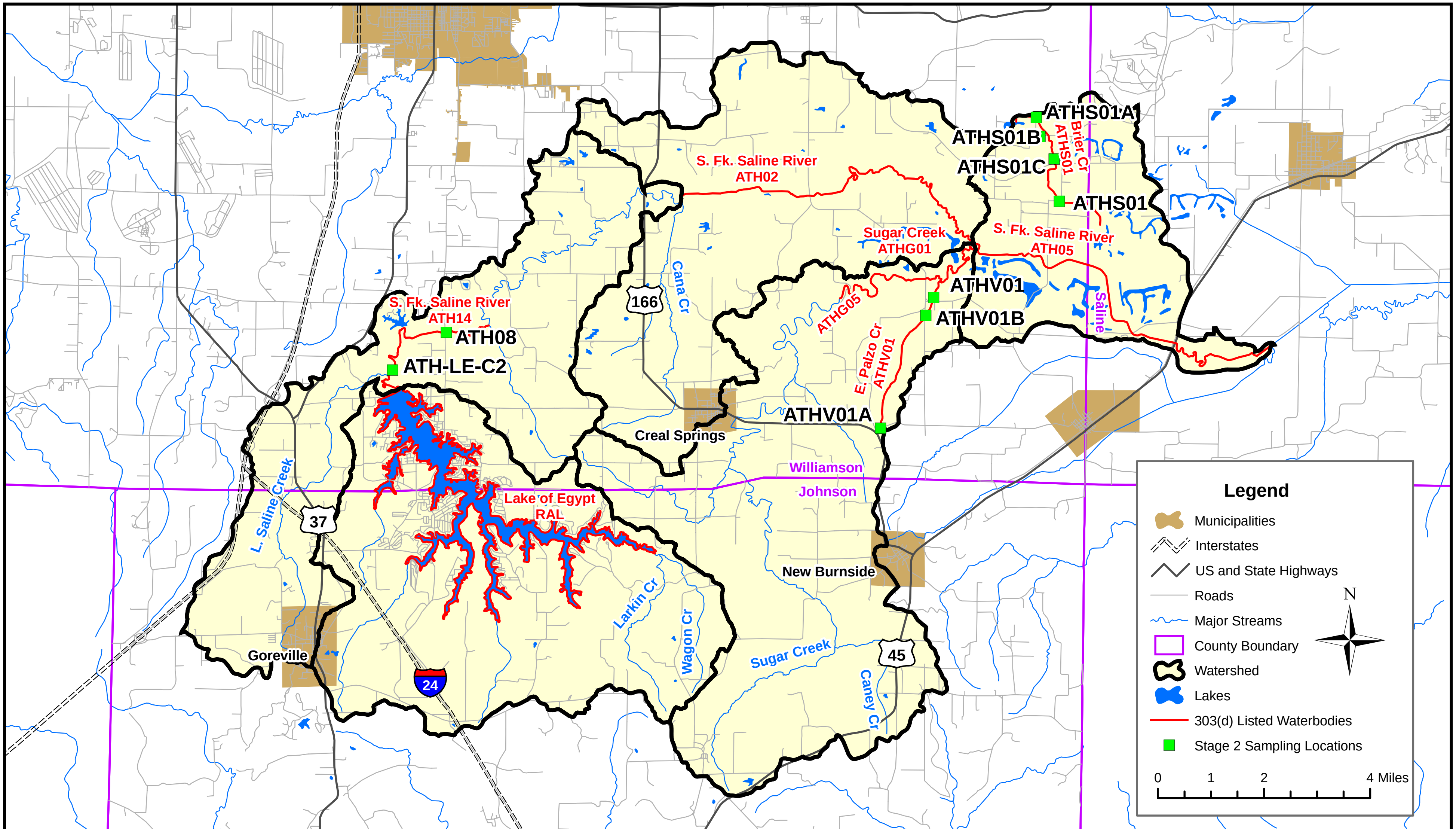

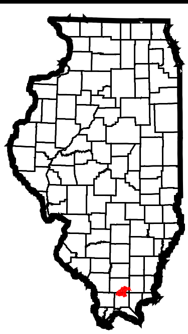

Figure 2-10
Stage 2 Sampling Locations
South Fork Saline River - Lake of Egypt Watershed

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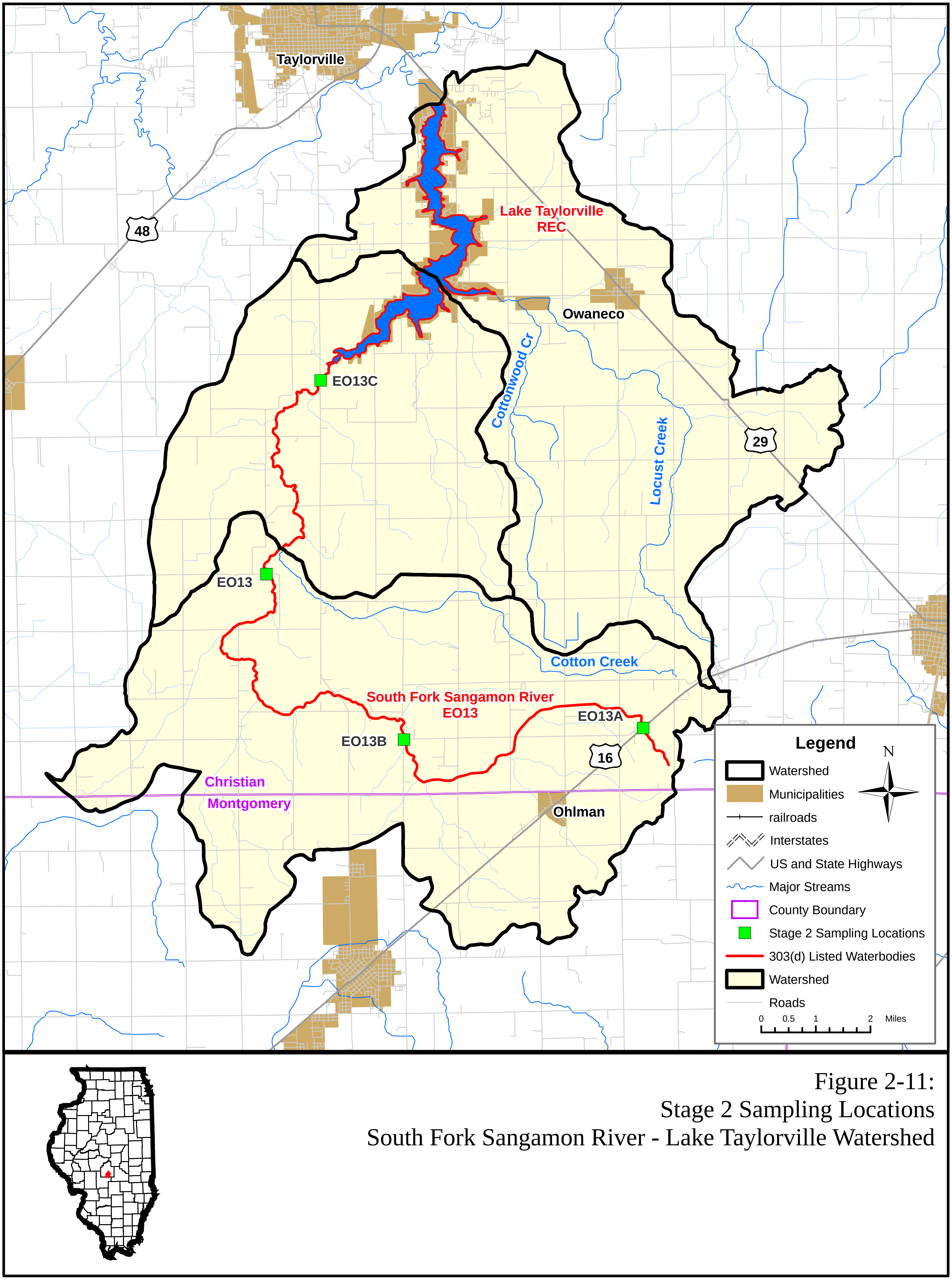

Figure 2-11:
Stage 2 Sampling Locations
South Fork Sangamon River - Lake Taylorville Watershed

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Table 2-2: Field Measurements

Watershed	Water body	Sample Site	Latitude	Longitude	Date	Time	pH (s.u.)	Conductivity (uS/cm)	Turbidity (NTU)	DO (mg/l)	Temp. °C	Depth (ft)
Bay Creek	Cedar Creek	AJF16	37.4661	88.7508	9/25/2006	18:00	6.5	117.0	7.8	8.9	63.9	NA
	Cedar Creek	AJF16	37.4661	88.7508	11/3/2006	11:05	7.2	164.5	8.6	11.0	7.0	NA
	Cedar Creek	AJF16A	37.4954	88.7592	9/25/2006	18:15	6.6	81.0	15.6	9.4	64.0	NA
	Cedar Creek	AJF16A	37.4954	88.7592	11/2/2006	13:30	7.3	101.8	5.4	11.6	9.2	NA
	Bay Creek Ditch	AJK01	37.3245	88.6337	9/25/2006	15:58	6.3	74.0	17.2	5.6	66.6	NA
	Bay Creek Ditch	AJK01	37.3245	88.6337	10/31/2006	8:15	7.2	91.6	20.4	8.2	12.8	NA
	Bay Creek Ditch	AJK01A	37.3282	88.6747	9/25/2006	NOT SAMPLED *Site flooded over banks into surrounding fields with no access/alternate site not located*						NA
	Bay Creek Ditch	AJK01A	37.3282	88.6747	10/31/2006	8:45	7.1	91.1	44.5	6.1	13.2	NA
Cahokia Creek/Holiday Shores Lake	Cahokia Diversion Ditch	JQ01	38.8054	90.1023	8/31/2006	13:40	7.4	606.7	62.3	3.4	23.9	NA
	Cahokia Diversion Ditch	JQ01	38.8054	90.1023	10/17/2006	14:45	8.3	459.8	92.9	9.6	12.6	NA
	Cahokia Diversion Ditch	JQ07	38.8050	90.0673	8/31/2006	14:45	7.4	498.6	68.0	5.3	23.0	NA
	Cahokia Diversion Ditch	JQ07	38.8050	90.0673	10/17/2006	14:15	8.3	427.0	115.8	9.4	12.8	NA
Cedar Creek	Big Muddy River	N13	37.7392	89.4284	9/7/2006	11:15	7.6	646.1	45.5	8.1	29.9	NA
	Big Muddy River	N13	37.7392	89.4284	11/1/2006	10:45	7.1	319.1	258.5	8.2	11.2	NA
	Big Muddy River	N99	37.6252	89.4284	9/7/2006	12:15	7.7	749.5	40.2	10.1	23.6	NA
	Big Muddy River	N99	37.6252	89.4284	11/1/2006	9:45	7.4	333.4	188.4	7.8	11.5	NA
	Cave Creek	NAC01	37.6154	89.3395	9/11/2006	11:45	7.8	288.4	N/A	7.6	20.4	NA
	Cave Creek	NAC01	37.6154	89.3395	11/1/2006	11:45	7.8	213.2	24.0	10.6	9.8	NA
	Cave Creek	NAC01A	37.6380	89.5660	9/11/2006	11:15	7.5	330.3	N/A	4.9	20.5	NA
	Cave Creek	NAC01A	37.6380	89.5660	11/1/2006	12:15	7.7	227.7	20.6	10.1	10.2	NA
Crab Orchard Creek	Crab Orchard Creek	ND11	37.7198	89.1717	9/6/2006	12:15	7.3	385.9	N/A	5.2	20.1	NA
	Crab Orchard Creek	ND11	37.7198	89.1717	11/1/2006	14:00	7.7	229.6	26.7	10.1	11.7	NA
	Crab Orchard Creek	ND12	37.7286	89.1753	9/6/2006	13:15	7.3	502.7	N/A	6.4	24.2	NA
	Crab Orchard Creek	ND12	37.7286	89.1753	11/1/2006	15:00	7.7	233.4	52.2	10.4	11.7	NA
	Crab Orchard Creek	ND13	37.7402	89.1723	9/6/2006	15:00	7.4	494.1	N/A	6.0	22.2	NA
	Crab Orchard Creek	ND13	37.7402	89.1723	11/1/2006	15:45	7.3	234.7	19.0	11.1	11.8	NA
	Crab Orchard Creek	ND15	37.7440	89.1852	9/6/2006	16:30	7.0	470.0	N/A	6.8	22.4	NA
	Crab Orchard Creek	ND15	37.7440	89.1852	11/1/2006	NOT SAMPLED *Site located behind Walmart parking lot and not accessible due to large chain link fence/no available alternate sites*						NA
	Little Crab Orchard Creek	NDA01	37.7525	89.2276	9/6/2006	18:00	7.3	242.5	N/A	2.1	19.2	NA
	Little Crab Orchard Creek	NDA01	37.7525	89.2276	11/2/2006	8:30	7.0	225.5	30.4	8.2	6.3	NA
	Little Crab Orchard Creek	NDA99	37.7011	89.2531	9/9/2006	NOT SAMPLED *Site dry and road crossings in the vacinity of site were also dry*						NA
	Little Crab Orchard Creek	NDA99	37.7011	89.2531	11/2/2006	10:30	8.7	190.5	17.0	12.3	5.5	NA
	Piles Fork	NDB03	37.7361	89.2016	9/7/2006	10:00	7.3	404.0	7.4	1.6	18.5	NA
	Piles Fork	NDB03	37.7361	89.2016	11/2/2006	9:15	7.7	240.7	25.5	10.3	7.3	NA
	Piles Fork	NDB04	37.7004	89.2205	9/9/2006	7:40	7.7	753.7	7.8	3.6	17.6	NA
	Piles Fork	NDB04	37.7004	89.2205	11/2/2006	11:00	8.1	154.9	56.5	11.5	10.2	NA
Crooked Creek	Little Crooked Creek	OJA-01	38.4416	89.4170	9/7/2006	17:45	7.0	274.0	22.5	3.7	20.3	NA
	Little Crooked Creek	OJA-01	38.4416	89.4170	10/19/2006	14:05	7.5	335.4	84.1	4.7	12.0	NA
	Little Crooked Creek	OJA-02	38.4564	89.3992	9/8/2006	11:15	7.0	284.8	20.2	3.1	19.7	NA
	Little Crooked Creek	OJA-02	38.4564	89.3992	10/19/2006	14:35	7.3	332.5	48.1	3.8	12.4	NA
	Plum Creek	OZH-OK-A2	38.4290	89.5387	9/8/2006	14:00	7.9	663.3	10.4	6.8	23.9	NA
	Plum Creek	OZH-OK-A2	38.4290	89.5387	10/19/2006	10:50	7.6	390.6	51.8	5.3	11.2	NA
	Plum Creek	OZH-OK-A2A	38.4160	89.5140	9/8/2006	16:45	7.8	503.2	56.9	8.5	22.3	NA
	Plum Creek	OZH-OK-A2A	38.4160	89.5140	10/19/2006	11:20	7.8	341.6	74.7	9.0	9.8	NA
	Plum Creek	OZH-OK-C2	38.4441	89.5592	9/8/2006	12:45	7.3	367.1	11.2	1.1	18.8	NA
	Plum Creek	OZH-OK-C2	38.4441	89.5592	10/19/2006	10:15	7.4	361.7	66.4	2.5	12.0	NA
	Plum Creek	OZH-OK-C2A	38.4568	89.5630	9/8/2006	17:30	7.8	977.9	13.4	4.6	20.7	NA
	Plum Creek	OZH-OK-C2A	38.4568	89.5630	10/19/2006	13:40	7.7	433.1	48.8	3.2	11.5	NA
	Plum Creek	OZH-OK-C3	38.4626	89.5598	9/8/2006	15:00	7.7	983.2	38.5	4.1	21.2	NA
	Plum Creek	OZH-OK-C3	38.4626	89.5598	10/19/2006	9:35	7.5	384.1	556.5	5.2	11.7	NA

Table 2-2: Field Measurements

Watershed	Water body	Sample Site	Latitude	Longitude	Date	Time	pH (s.u.)	Conductivity (uS/cm)	Turbidity (NTU)	DO (mg/l)	Temp. °C	Depth (ft)
Little Wabash	Little Wabash River	C09	38.4407	88.2581	1/25/2005	14:00	7.3	415	42	12.1	1.1	NA
	Little Wabash River	C09	38.4407	88.2581	3/17/2005	8:00	8.3	700	23	14.9	7	NA
	Little Wabash River	C09	38.4407	88.2581	4/19/2005	14:30	7.8	535	50	7.3	18.8	NA
	Little Wabash River	C09	38.4407	88.2581	5/9/2005	10:30	7.3	738	60	6.7	19.7	NA
	Little Wabash River	C09	38.4407	88.2581	6/23/2005	7:30	7.7	690	47	5.1	26	NA
	Little Wabash River	C09	38.4407	88.2581	8/23/2005	13:00	7.2	290	70	4.2	27.1	NA
	Little Wabash River	C09	38.4407	88.2581	9/27/2005	16:00	7.8	533	25	7.5	24.6	NA
	Little Wabash River	C09	38.4407	88.2581	10/27/2005	14:00	7.8	550	11	8.7	11.7	NA
	Little Wabash River	C09	38.4407	88.2581	12/6/2005	13:00	7.6	375	70	11.8	1.6	NA
	Little Wabash River	C09	38.4407	88.2581	2/1/2006	13:00	7.6	390	200	9.3	6.8	NA
	Little Wabash River	C09	38.4407	88.2581	3/15/2006	10:00	6.6	150	130	6.2	12.4	NA
	Little Wabash River	C09	38.4407	88.2581	4/18/2006	16:00	7.9	572	40	8.1	20.1	NA
	Little Wabash River	C09	38.4407	88.2581	4/26/2006	10:00	7.8	580	59	7.2	17.7	NA
	Little Wabash River	C09	38.4407	88.2581	5/1/2006	9:45	7.5	543	75	6.4	16.2	NA
	Little Wabash River	C09	38.4407	88.2581	5/10/2006	10:00	7.4	475		6.2	18.5	NA
	Little Wabash River	C09	38.4407	88.2581	5/17/2006	11:00	7.4	421	70	7.4	14.7	NA
	Little Wabash River	C09	38.4407	88.2581	5/24/2006	9:45	7.5	473		6.6	18.9	NA
	Little Wabash River	C09	38.4407	88.2581	5/31/2006	10:20	7.2	352		4	25.3	NA
	Little Wabash River	C09	38.4407	88.2581	6/7/2006	10:15	7.2	345		4.3	23.3	NA
	Little Wabash River	C09	38.4407	88.2581	6/15/2006	8:50	7.4	536	55	5.2	23.9	NA
	Little Wabash River	C09	38.4407	88.2581	6/22/2006	10:05	7.5	608	65	4.4	28.4	NA
	Little Wabash River	C09	38.4407	88.2581	6/27/2006	10:40	7.44	462	64	4.9	24.17	NA
	Little Wabash River	C09	38.4407	88.2581	7/5/2006	10:30	7.2	321		4.4	27.5	NA
	Little Wabash River	C09	38.4407	88.2581	7/12/2006	10:30	7.3	456		3.8	25.3	NA
	Little Wabash River	C09	38.4407	88.2581	7/20/2006	10:00	7.4	372		4.8	29.4	NA
	Little Wabash River	C09	38.4407	88.2581	7/27/2006	10:00	7.2	239		4.8	26.4	NA
	Little Wabash River	C09	38.4407	88.2581	8/1/2006	8:30	7.3	306	65	4.5	30.3	NA
	Little Wabash River	C09	38.4407	88.2581	8/8/2006	11:05	7.3	392	55	4.75	28.4	NA
	Little Wabash River	C33	38.2699	88.1377	4/18/2006	11:00	7.1	418	35	4.4	19.8	NA
	Little Wabash River	C33	38.2699	88.1377	4/26/2006	12:15	7.7	607	56	6	19	NA
	Little Wabash River	C33	38.2699	88.1377	5/1/2006	11:45	7.7	597	58	6.8	16.8	NA
	Little Wabash River	C33	38.2699	88.1377	5/10/2006	12:20	7.3	409		5.3	18.7	NA
	Little Wabash River	C33	38.2699	88.1377	5/17/2006	14:00	7.4	462	90	7.2	15.5	NA
	Little Wabash River	C33	38.2699	88.1377	5/24/2006	12:15	7.4	494		6.4	19.9	NA
	Little Wabash River	C33	38.2699	88.1377	5/31/2006	12:40	7.2	449		3.9	25.4	NA
	Little Wabash River	C33	38.2699	88.1377	6/7/2006	12:30	6.8	286		3	23.01	NA
	Little Wabash River	C33	38.2699	88.1377	6/15/2006	11:05	7.5	511	45	8.1	25.1	NA
	Little Wabash River	C33	38.2699	88.1377	6/22/2006	12:00	7.2	546	38	3	29.8	NA
	Little Wabash River	C33	38.2699	88.1377	6/27/2006	11:50	7.4	548	61	4.8	26.17	NA
	Little Wabash River	C33	38.2699	88.1377	7/5/2006	13:00	7.3	334		5.8	29	NA
	Little Wabash River	C33	38.2699	88.1377	7/12/2006	12:30	7.1	326		3.4	25.3	NA
	Little Wabash River	C33	38.2699	88.1377	7/20/2006	12:20	6.9	247		3.4	29.9	NA
	Little Wabash River	C33	38.2699	88.1377	7/27/2006	12:10	7.5	308		6.4	27.4	NA
	Little Wabash River	C33	38.2699	88.1377	8/1/2006	10:30	7.3	296	40	4.7	30.8	NA
	Little Wabash River	C33	38.2699	88.1377	8/8/2006	13:30	7.3	361	40	4.9	29.8	NA
	Johnson Creek	CCA12	38.3732	88.3449	9/9/2006	13:05	8.2	1402.0	13.4	14.2	28.4	NA
	Johnson Creek	CCA12	38.3732	88.3449	11/14/2006	9:45	7.5	651.4	645.5	7.7	7.0	NA
	Johnson Creek	CCA13	38.3789	88.3511	9/9/2006	14:30	8.6	1517.0	3.1	14.9	25.4	NA
	Johnson Creek	CCA13	38.3789	88.3511	11/14/2006	10:15	7.7	649.4	19.0	12.8	8.1	NA
	Johnson Creek	CCA14A	38.3830	88.3546	9/9/2006	15:25	7.6	836.0	3.6	5.7	21.6	NA

Table 2-2: Field Measurements

Watershed	Water body	Sample Site	Latitude	Longitude	Date	Time	pH (s.u.)	Conductivity (uS/cm)	Turbidity (NTU)	DO (mg/l)	Temp. °C	Depth (ft)
Little Wabash (cont.)	Johnson Creek	CCA14A	38.3830	88.3546	11/14/2006	10:25	7.7	694.2	2.4	12.5	8.0	NA
	Johnson Creek	CCAFFA1A	38.3881	88.3535	9/10/2006	10:50	7.4	788.0	5.9	3.8	19.8	NA
	Johnson Creek	CCAFFA1A	38.3881	88.3535	11/14/2006	10:45	7.4	789.8	4.3	12.3	7.5	NA
	Pond Creek	CCFFD1	38.3648	88.3130	9/9/2006	10:30	7.7	576.0	8.6	7.1	19.5	NA
	Pond Creek	CCFFD1	38.3648	88.3130	10/31/2006	10:10	7.6	8719.7	29.2	8.2	3.8	NA
	Pond Creek	CCFFD1A	38.3720	88.3181	9/9/2006			NOT SAMPLED *Site Dry/no available alternate sites*				NA
	Pond Creek	CCFFD1A	38.3720	88.3181	11/9/2006	12:15	7.3	742.5	9.1	11.2	13.6	NA
	Pond Creek	CCFFD1B	38.3793	88.3230	9/9/2006	11:45	7.5	784.0	10.0	8.6	22.9	NA
	Pond Creek	CCFFD1B	38.3793	88.3230	11/9/2006	11:35	7.3	827.9	4.1	12.1	12.7	NA
	Pond Creek	CCFFD1C	38.3999	88.3370	9/10/2006	12:10	8.0	3941.0	17.8	11.9	19.3	NA
	Pond Creek	CCFFD1C	38.3999	88.3370	10/31/2006	11:20	8.8	1394.0		14.4	4.4	NA
	Elm River	CD01	38.5184	88.1320	1/26/2005	13:00	7.1	388	36	9.1	1.4	NA
	Elm River	CD01	38.5184	88.1320	3/15/2005	11:30	8.4	950	7.2	14.6	6.2	NA
	Elm River	CD01	38.5184	88.1320	4/20/2005	11:30	7.4	670	60	6.7	20.1	NA
	Elm River	CD01	38.5184	88.1320	5/5/2005	13:00	7.5	625	27	7.6	13.8	NA
	Elm River	CD01	38.5184	88.1320	6/23/2005	10:00	7.5	1050	22	5.2	24.7	NA
	Elm River	CD01	38.5184	88.1320	8/18/2005	11:00	7.6	730	34	3.6	24.6	NA
	Elm River	CD01	38.5184	88.1320	9/29/2005	11:30	7.6	700	17	3.6	18.5	NA
	Elm River	CD01	38.5184	88.1320	10/18/2005	11:30	7.5	680	8.2	5.9	15	NA
	Elm River	CD01	38.5184	88.1320	12/8/2005	10:30	7.4	321	65	9.6	0.3	NA
	Elm River	CD01	38.5184	88.1320	2/1/2006	15:00	7.5	430	80	9.1	7	NA
	Elm River	CD01	38.5184	88.1320	3/1/2006	13:30	7.4	840	42	10.2	9.1	NA
	Elm River	CD01	38.5184	88.1320	4/6/2006	11:00	7.3	440	90	8.6	13.5	NA
	Elm River	CD01	38.5184	88.1320	4/18/2006	14:30	7.3	670	40	5.6	20.9	NA
	Elm River	CD01	38.5184	88.1320	4/26/2006	11:15	7.5	860		6.2	15.9	NA
	Elm River	CD01	38.5184	88.1320	5/1/2006	11:00	7.4	958		5.9	15.2	NA
	Elm River	CD01	38.5184	88.1320	5/10/2006	11:10	7.2	489		5	18.2	NA
	Elm River	CD01	38.5184	88.1320	5/17/2006	9:30	7.1	484	35	7	13.8	NA
	Elm River	CD01	38.5184	88.1320	5/24/2006	11:20	7.2	594		5.7	18.5	NA
	Elm River	CD01	38.5184	88.1320	5/31/2006	11:30	7.2	605		3.8	25.7	NA
	Elm River	CD01	38.5184	88.1320	6/7/2006	11:25	7	346		4.5	23.4	NA
	Elm River	CD01	38.5184	88.1320	6/15/2006	9:50	7.1	622		4.6	22.5	NA
	Elm River	CD01	38.5184	88.1320	6/22/2006	11:15	7.1	443		4.6	27.9	NA
	Elm River	CD01	38.5184	88.1320	6/27/2006	9:15	6.77	229	91	5	21.95	NA
	Elm River	CD01	38.5184	88.1320	7/5/2006	11:50	7.2	588		3.6	26.6	NA
	Elm River	CD01	38.5184	88.1320	7/12/2006	11:30	7.2	569		4.2	23.9	NA
	Elm River	CD01	38.5184	88.1320	7/20/2006	11:15	7	285		2.8	28.2	NA
	Elm River	CD01	38.5184	88.1320	7/27/2006	11:05	7.1	346		3.5	25.8	NA
	Elm River	CD01	38.5184	88.1320	8/1/2006	9:20	7.3	382		4	27.8	NA
	Elm River	CD01	38.5184	88.1320	8/8/2006	12:20	7.1	425		4.1	26.3	NA
	Elm River	CD02	38.6751	88.4362	9/8/2006	17:45	7.5	344.0	15.9	8.1	23.2	NA
	Elm River	CD02	38.6751	88.4362	11/8/2006			NOT SAMPLED *Miscommunication between field crews caused error in sampling*				NA
	Elm River	CD02A	38.4894	88.3051	9/12/2006	12:51	7.2	404.0	15.7	3.8	22.0	NA
	Elm River	CD02A	38.4894	88.3051	11/8/2006			NOT SAMPLED *Miscommunication between field crews caused error in sampling*				NA
	Seminary Creek	CDFGLC6	38.6180	88.4384	9/8/2006	12:25	7.7	708.0	4.2	6.6	19.5	NA
	Seminary Creek	CDFGLC6	38.6180	88.4384	11/8/2006	17:00	7.5	527.6	17.5	10.5	12.4	NA
	Seminary Creek	CDFGLC6A	38.6135	88.4245	9/8/2006	11:10	7.7	720.0	201.2	7.0	20.1	NA
	Seminary Creek	CDFGLC6A	38.6135	88.4245	11/8/2006	16:45	7.3	561.7	15.1	12.0	13.5	NA
	Seminary Creek	CDGFLA1	38.6561	88.4832	9/8/2006	15:40	7.9	558.0	7.0	10.0	22.0	NA
	Seminary Creek	CDGFLA1	38.6561	88.4832	11/8/2006	14:45	7.3	385.0	12.5	14.3	12.7	NA

Table 2-2: Field Measurements

Watershed	Water body	Sample Site	Latitude	Longitude	Date	Time	pH (s.u.)	Conductivity (uS/cm)	Turbidity (NTU)	DO (mg/l)	Temp. °C	Depth (ft)
Little Wabash (cont.)	Seminary Creek	CDGFLA1A	38.6595	88.4890	9/8/2006	13:45	7.4	362.0	22.7	2.6	19.0	NA
	Seminary Creek	CDGFLA1A	38.6595	88.4890	11/8/2006	15:50	7.2	429.8	16.8	15.1	12.7	NA
	Village Creek	CE01	38.4348	88.1369	9/6/2006	17:30	8.1	610.0	11.4	9.9	24.9	NA
	Village Creek	CE01	38.4348	88.1369	11/14/2006	8:45	7.5	697.9	8.0	10.6	6.8	NA
	Village Creek	CE01A	38.4294	88.0943	9/12/2006	17:05	7.2	327.0	145.2	5.8	22.6	NA
	Village Creek	CE01A	38.4294	88.0943	11/9/2006	13:45	7.2	607.2	8.7	11.2	14.2	NA
	Village Creek	CE02	38.4150	88.1659	9/6/2006	15:20	7.8	568.0	15.7	7.9	25.0	NA
	Village Creek	CE02	38.4150	88.1659	11/9/2006	12:55	7.5	587.4	14.1	10.7	13.1	NA
	Big Muddy Creek	CJ05	38.7693	88.3093	9/7/2006	16:45	8.2	63.1	11.4	10.5	23.6	NA
	Big Muddy Creek	CJ05	38.7693	88.3093	11/8/2006	11:30	7.4	457.0	32.5	12.4	8.3	NA
	Big Muddy Creek	CJ06	38.8298	88.3642	9/7/2006	18:10	7.5	588.0	34.6	4.9	21.8	NA
	Big Muddy Creek	CJ06	38.8298	88.3642	11/8/2006	11:00	7.3	455.1	15.8	11.6	10.6	NA
	Little Muddy Creek	CJA01	38.7647	88.3760	9/12/2006	10:20	7.0	321.0	9.5	3.4	20.9	NA
	Little Muddy Creek	CJA01	38.7647	88.3760	11/13/2006	12:00	7.0	267.9	113.2	10.1	7.4	NA
	Little Muddy Creek	CJA02	38.7047	88.3174	9/7/2006	14:20	6.8	554.0	45.9	2.8	20.4	NA
	Little Muddy Creek	CJA02	38.7047	88.3174	11/8/2006	12:30	7.0	497.0	35.8	9.3	10.4	NA
	Big Muddy Diversion Ditch	CJAE01	38.6865	88.2967	9/7/2006	12:10	7.1	1946.0	26.9	9.1	22.2	NA
	Big Muddy Diversion Ditch	CJAE01	38.6865	88.2967	11/8/2006	13:05	7.3	478.2	30.8	10.8	11.7	NA
	Big Muddy Diversion Ditch	CJAE01A	38.7467	88.2977	9/7/2006	15:45	8.1	908.0	6.5	10.3	24.3	NA
	Big Muddy Diversion Ditch	CJAE01A	38.7467	88.2977	11/13/2006	12:30	7.6	452.9	37.8	9.8	8.2	NA
Mary's River/North Fork Cox Creek	North Fork Cox Creek	IIHA01	38.0114	89.6460	9/9/2006	17:40	7.9	2073.0	N/A	10.0	22.0	NA
	North Fork Cox Creek	IIHA01	38.0114	89.6460	10/18/2006	14:25	8.3	2995.0	13.5	8.1	15.4	NA
	North Fork Cox Creek	IIHA31	38.0293	89.6303	9/9/2006	17:10	8.2	3491.0	N/A	9.6	23.9	NA
	North Fork Cox Creek	IIHA31	38.0293	89.6303	10/18/2006	14:45	8.4	3215.0	8.5	8.6	15.5	NA
	North Fork Cox Creek	IIHA-STC1	38.0015	89.6557	9/9/2006	16:15	7.8	3019.0	N/A	7.1	21.9	NA
	North Fork Cox Creek	IIHA-STC1	38.0015	89.6557	10/18/2006	14:00	8.1	1990.0	20.0	7.0	14.9	NA
	North Fork Cox Creek	IIHA-STE1	38.0048	89.6526	9/9/2006	15:45	7.8	3422.0	N/A	6.9	20.7	NA
	North Fork Cox Creek	IIHA-STE1	38.0048	89.6526	10/18/2006	13:40	8.0	2505.0	16.3	6.0	14.7	NA
	Maxwell Creek	IIKSPA1	38.1242	89.6870	9/7/2006	NOT SAMPLED						NA
	Maxwell Creek	IIKSPA1	38.1242	89.6870	10/17/2006	*Site dry during both visits/available alternate locations also dry*						NA
	Maxwell Creek	IIKSPC1	38.1182	89.6885	9/7/2006	15:30	7.3	968.1	4.8	2.0	24.3	NA
	Maxwell Creek	IIKSPC1	38.1182	89.6885	10/17/2006	8:20	7.1	561.5	22.3	20.2	18.4	NA
	Maxwell Creek	IIKSPC3A	38.1090	89.6850	9/7/2006	15:00	7.5	997.0	4.4	2.6	21.6	NA
	Maxwell Creek	IIKSPC3A	38.1090	89.6850	10/17/2006	8:45	7.5	457.8	19.2	6.5	15.4	NA
	Maxwell Creek	IIKSPE1A	38.1218	89.6889	9/7/2006	NOT SAMPLED						NA
	Maxwell Creek	IIKSPE1A	38.1218	89.6889	10/17/2006	*Site dry during both visits/available alternate locations also dry*						NA
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:00	9.1	279.7	N/A	13.9	25.6	1
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:02	9.1	279.5	N/A	13.9	24.9	2
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:04	9.1	279.2	N/A	13.8	24.7	3
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:06	9.1	278.8	N/A	13.9	24.6	4
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:08	9.0	279.3	N/A	13.2	24.4	5
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:10	9.0	279.7	N/A	12.6	24.3	6
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:12	8.9	280.4	N/A	11.8	24.2	7
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:14	8.2	286.0	N/A	6.2	23.9	8
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:16	7.8	287.4	N/A	4.4	23.7	9
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:18	7.6	288.9	N/A	2.5	23.5	10
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:20	7.3	290.3	N/A	0.3	23.1	11
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:22	7.3	296.0	N/A	0.1	22.7	12
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:24	7.1	317.6	N/A	0.0	21.2	13
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:26	7.1	332.7	N/A	0.0	18.5	14
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:28	7.1	330.3	N/A	0.0	17.1	15

Table 2-2: Field Measurements

Watershed	Water body	Sample Site	Latitude	Longitude	Date	Time	pH (s.u.)	Conductivity (uS/cm)	Turbidity (NTU)	DO (mg/l)	Temp. °C	Depth (ft)
Mary's River/North Fork Cox Creek (cont.)	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:30	7.1	329.6	N/A	0.0	16.1	16
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:32	7.1	329.9	N/A	0.0	14.7	17
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:34	7.1	330.0	N/A	0.0	13.6	18
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:36	7.1	332.4	N/A	0.0	12.4	19
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:38	7.1	335.4	N/A	0.0	11.8	20
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:40	7.1	341.7	N/A	0.0	11.3	21
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:42	7.1	347.9	N/A	0.0	10.9	22
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:44	7.1	350.1	N/A	0.0	10.8	23
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:46	7.1	352.6	N/A	0.0	10.6	24
	Randolph County Lake	RIB-1	37.9707	89.7962	9/9/2006	12:48	7.0	363.8	N/A	0.0	10.2	25
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	8.0	306.1	5.6	7.1	15.8	0
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	7.8	305.0	6.7	5.4	15.7	3.28
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	7.8	304.9	5.9	5.4	15.7	6.56
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	7.8	303.6	6.6	5.3	15.6	9.84
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	7.7	303.5	7.1	5.3	15.6	13.12
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	7.6	304.0	11.9	4.5	13.3	16.4
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	7.5	371.4	9.8	0.6	12.7	19.68
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	7.6	392.9	8.3	0.5	10.9	22.96
	Randolph County Lake	RIB-1	37.9707	89.7962	10/18/2006	10:25	7.5	435.0	63.4	0.3	10.1	26.24
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:00	9.0	286.4	N/A	13.3	27.0	1
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:02	9.0	282.2	N/A	13.8	26.8	2
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:04	9.1	279.7	N/A	14.7	25.0	3
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:06	9.0	280.2	N/A	14.3	24.7	4
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:08	8.9	282.2	N/A	12.5	24.4	5
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:10	8.6	286.3	N/A	9.0	24.1	6
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:12	8.1	290.2	N/A	6.0	24.0	7
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:14	7.8	292.2	N/A	4.0	23.9	8
	Randolph County Lake	RIB-2	37.9738	89.8000	9/9/2006	14:16	7.7	292.7	N/A	3.1	23.8	9
	Randolph County Lake	RIB-2	37.9738	89.8000	10/18/2006	12:05	8.0	304.9	10.3	7.1	16.0	0
	Randolph County Lake	RIB-2	37.9738	89.8000	10/18/2006	12:05	7.9	304.5	7.0	6.7	15.9	3.28
	Randolph County Lake	RIB-2	37.9738	89.8000	10/18/2006	12:05	7.8	304.5	6.6	6.4	15.9	6.56
	Randolph County Lake	RIB-2	37.9738	89.8000	10/18/2006	12:05	7.8	304.5	6.3	6.3	15.8	9.84
	Randolph County Lake	RIB-3	37.9800	89.7990	9/9/2006	13:00	9.0	283.0	N/A	13.2	26.4	1
	Randolph County Lake	RIB-3	37.9800	89.7990	9/9/2006	13:02	9.0	283.3	N/A	12.9	26.5	2
	Randolph County Lake	RIB-3	37.9800	89.7990	9/9/2006	13:04	9.0	281.0	N/A	12.8	25.8	3
	Randolph County Lake	RIB-3	37.9800	89.7990	9/9/2006	13:06	9.0	280.4	N/A	12.9	25.0	4
	Randolph County Lake	RIB-3	37.9800	89.7990	9/9/2006	13:08	9.0	279.7	N/A	12.9	24.6	5
	Randolph County Lake	RIB-3	37.9800	89.7990	9/9/2006	13:10	9.0	279.7	N/A	12.6	24.5	6
	Randolph County Lake	RIB-3	37.9800	89.7990	10/18/2006	11:15	8.0	305.0	8.8	7.9	16.0	0
	Randolph County Lake	RIB-3	37.9800	89.7990	10/18/2006	11:15	7.9	304.7	8.7	7.1	16.0	3.28
	Randolph County Lake	RIB-3	37.9800	89.7990	10/18/2006	11:15	7.8	304.7	10.4	6.7	16.0	6.56
	Randolph County Lake Tributary	RIB-Trib	37.9813	89.7988	9/9/2006	13:20	9.0	284.0	N/A	12.9	28.4	NA
	Randolph County Lake Tributary	RIB-Trib	37.9813	89.7988	10/18/2006	11:45	8.1	341.7	46.3	8.3	16.2	NA
Sangamon River/Lake Decatur	Owl Creek	EZV01	40.3254	88.3531	8/30/2006	12:50	7.4	669.0	50.8	8.5	21.2	NA
	Owl Creek	EZV01	40.3254	88.3531	11/2/2006	9:25	8.2	856.7		12.2	5.1	NA
	Owl Creek	EZVA1	40.3115	88.3409	8/30/2006	11:05	7.7	606.9	52.3	6.5	19.0	NA
	Owl Creek	EZVA1	40.3115	88.3409	11/2/2006	10:33	8.2	856.3		11.8	4.7	NA
	Owl Creek	EZVC1	40.3101	88.3423	8/30/2006	10:25	7.3	1450.0	25.6	5.0	21.0	NA
	Owl Creek	EZVC1	40.3101	88.3423	11/2/2006	12:20	8.1	990.7		11.7	6.0	NA
	Owl Creek	EZVE1	40.3113	88.3415	8/30/2006	10:45	7.5	1497.0	20.3	11.1	21.5	NA
	Owl Creek	EZVE1	40.3113	88.3415	11/2/2006	12:59	8.3	859.8		12.5	6.1	NA

Table 2-2: Field Measurements

Watershed	Water body	Sample Site	Latitude	Longitude	Date	Time	pH (s.u.)	Conductivity (uS/cm)	Turbidity (NTU)	DO (mg/l)	Temp. °C	Depth (ft)
Shoal Creek	Shoal Creek	OI05	38.5361	89.5213	9/1/2006	12:35	7.5	563.4	38.7	9.1	22.9	NA
	Shoal Creek	OI05	38.5361	89.5213	10/17/2006	11:30	7.9	604.4	39.7	8.5	12.0	NA
	Shoal Creek	OI05A	38.5370	89.5330	9/1/2006	NOT SAMPLED						NA
	Shoal Creek	OI05A	38.5370	89.5330	10/17/2006	*Site located at end of private road with chained fence/alternate location not located*						NA
	Shoal Creek	OI05B	38.5333	89.5496	9/1/2006	14:20	7.8	542.2	43.0	10.8	26.2	NA
	Shoal Creek	OI05B	38.5333	89.5496	10/17/2006	11:15	7.9	542.4	72.7	8.7	12.3	NA
	Shoal Creek	OI05C	38.5020	89.5661	9/1/2006	15:40	7.8	535.3	43.5	10.2	23.5	NA
	Shoal Creek	OI05C	38.5020	89.5661	10/16/2006	10:30	8.0	578.9	46.0	9.4	12.1	NA
	Locust Fork	OIC01	38.7715	89.5556	8/31/2006	NOT SAMPLED *Site dry/no other road crossings on segment*						NA
	Locust Fork	OIC01	38.7715	89.5556	10/19/2006	12:20	7.8	401.1	24.3	3.8	10.0	NA
	Locust Fork	OIC02	38.7536	89.5288	8/31/2006	17:50	8.0	499.6	23.2	9.4	24.2	NA
	Locust Fork	OIC02	38.7536	89.5288	10/17/2006	13:00	7.7	422.2	26.9	5.2	14.2	NA
	Chicken Creek	OIO09	38.6407	89.5025	9/1/2006							NA
	Chicken Creek	OIO09	38.6407	89.5025	10/17/2006	NOT SAMPLED						NA
	Chicken Creek	OIO09A	38.6373	89.5260	9/1/2006	*Sites dry during both visits/sites located at only two road crossings on segment*						NA
	Chicken Creek	OIO09A	38.6373	89.5260	10/17/2006							NA
	Cattle Creek	OIP10	38.6649	89.5170	8/31/2006	NOT SAMPLED *Site dry/no other road crossings on segment*						NA
	Cattle Creek	OIP10	38.6649	89.5170	10/17/2006	12:05	7.9	928.0	105.6	2.0	14.2	NA
	Cattle Creek	OIP10A	38.6744	89.5359	8/31/2006	NOT SAMPLED						NA
	Cattle Creek	OIP10A	38.6744	89.5359	10/17/2006	*Site dry/no other road crossings on segment*						NA
South Fork Saline River/Lake of Egypt	South Fork Saline River	ATH08	37.6399	88.9281	9/26/2006	10:20	7.1	165.0	0.6	8.7	23.6	NA
	South Fork Saline River	ATH08	37.6399	88.9281	10/31/2006	11:15	6.6	213.1	10.0	8.8	19.0	NA
	South Fork Saline River	ATH14	NA	NA	9/26/2006	NOT SAMPLED						NA
	South Fork Saline River	ATH14	NA	NA	10/31/2006	*Sites located on private property and/or not accessible by roads*						NA
	South Fork Saline River	ATHLEC1	NA	NA	9/26/2006	*No other road crossings available on segment*						NA
	South Fork Saline River	ATHLEC1	NA	NA	10/31/2006							NA
	South Fork Saline River	ATHLEC2	37.6295	88.9465	9/26/2006	9:45	6.6	81.0	15.6	9.4	18.1	NA
	South Fork Saline River	ATHLEC2	37.6295	88.9465	10/31/2006	12:00	6.8	137.7	11.6	9.6	17.1	NA
	Briers Creek	ATHS01	37.6766	88.7178	9/11/2006	11:30	7.6	1997.0	2.0	9.1	21.3	NA
	Briers Creek	ATHS01	37.6766	88.7178	9/27/2006	9:00	7.3	1392.0	3.4	10.2	15.5	NA
	Briers Creek	ATHS01	37.6766	88.7178	10/30/2006	16:30	7.1	1281.0	19.6	9.4	13.7	NA
	Briers Creek	ATHS01	37.6766	88.7178	11/15/2006	10:25	7.0	700.1	185.3	4.6	9.4	NA
	Briers Creek	ATHS01A	37.6995	88.7257	9/11/2006	10:00	7.1	765.0	5.6	9.7	17.9	NA
	Briers Creek	ATHS01A	37.6995	88.7257	9/27/2006	11:30	7.5	817.0	1.9	9.7	17.0	NA
	Briers Creek	ATHS01A	37.6995	88.7257	11/2/2006	12:00	8.0	862.8	3.0	8.5	9.5	NA
	Briers Creek	ATHS01A	37.6995	88.7257	11/15/2006	11:10	6.8	226.1	36.3	5.4	10.2	NA
	Briers Creek	ATHS01B	37.6943	88.7245	9/11/2006	10:25	7.2	507.0	6.2	9.5	17.8	NA
	Briers Creek	ATHS01B	37.6943	88.7245	9/27/2006	10:35	6.7	500.0	0.5	9.7	17.3	NA
	Briers Creek	ATHS01B	37.6943	88.7245	11/2/2006	12:20	7.4	726.7	2.9	9.9	9.5	NA
	Briers Creek	ATHS01B	37.6943	89.7640	11/15/2006	11:30	6.8	198.9	69.1	4.0	10.0	NA
	Briers Creek	ATHS01C	37.6882	88.7195	9/11/2006	12:55	6.8	2071.0	21.5	6.3	19.0	NA
	Briers Creek	ATHS01C	37.6882	88.7195	9/27/2006	9:30	7.0	1571.0	2.2	9.8	15.1	NA
	Briers Creek	ATHS01C	37.6882	88.7195	10/31/2006	14:30	7.4	1296.0	4.5	9.4	12.0	NA
	Briers Creek	ATHS01C	37.6882	88.7195	11/15/2006	10:45	7.0	848.6	90.7	8.8	9.5	NA
	East Palzo Creek	ATHV01	37.6502	88.7608	9/11/2006	10:40	6.9	375.0	16.4	6.7	22.7	NA
	East Palzo Creek	ATHV01	37.6502	88.7608	9/27/2006	NOT SAMPLED *Site flooded over road with no safe access/no other road crossings on segment*						NA
	East Palzo Creek	ATHV01	37.6502	88.7608	10/31/2006	13:40	6.5	490.6	14.2	7.6	12.4	NA
	East Palzo Creek	ATHV01	37.6502	88.7608	11/15/2006	10:00	6.3	554.5	200.0	5.1	9.4	NA
	East Palzo Creek	ATHV01A	37.6143	88.7788	9/11/2006	8:25	7.2	1878.0	1.7	6.6	18.8	
	East Palzo Creek	ATHV01A	37.6143	88.7788	9/27/2006	NOT SAMPLED						NA
	East Palzo Creek	ATHV01A	37.6143	88.7788	10/31/2006	*Site dry/no other road crossings on segment*						NA
	East Palzo Creek	ATHV01A	37.6143	88.7788	11/15/2006	9:05	6.8	158.9	81.9	9.0	9.4	NA
	East Palzo Creek	ATHV01B	37.6452	88.7635	9/11/2006	8:55	6.9	481.0	28.8	6.0	19.1	NA
	East Palzo Creek	ATHV01B	37.6452	88.7635	9/26/2006	12:30	6.2	405.0	4.6	10.9	17.4	NA
	East Palzo Creek	ATHV01B	37.6452	88.7635	10/31/2006	13:00	6.4	498.2	23.8	8.7	12.4	NA
	East Palzo Creek	ATHV01B	37.6452	88.7635	11/15/2006	9:35	6.1	435.0	243.8	5.6	9.4	NA

Table 2-2: Field Measurements

Watershed	Water body	Sample Site	Latitude	Longitude	Date	Time	pH (s.u.)	Conductivity (uS/cm)	Turbidity (NTU)	DO (mg/l)	Temp. °C	Depth (ft)
South Fork Sangamon River/ Lake Taylorville	South Fork Sangamon River	EO13	39.4072	89.3164	8/30/2006	18:10	7.3	719.3	7.2	6.3	20.4	NA
	South Fork Sangamon River	EO13	39.4072	89.3164	11/2/2006	16:50	7.7	528.5		6.5	6.1	NA
	South Fork Sangamon River	EO13A	39.2700	89.1880	8/30/2006	19:55	7.3	754.7	7.6	9.7	21.6	NA
	South Fork Sangamon River	EO13A	39.2700	89.1880	11/2/2006	NOT SAMPLED *Miscommunication between field crews caused error in sampling*						NA
	South Fork Sangamon River	EO13B	39.3630	89.2700	8/30/2006	19:25	7.6	1112.0	60.1	8.3	21.6	NA
	South Fork Sangamon River	EO13B	39.3630	89.2700	11/2/2006	NOT SAMPLED *Miscommunication between field crews caused error in sampling*						NA
	South Fork Sangamon River	EO13C	39.4590	89.2970	8/30/2006	18:55	7.0	56.9	96.0	3.8	21.1	NA
	South Fork Sangamon River	EO13C	39.4590	89.2970	11/2/2006	16:25	8.2	954.1		5.8	6.4	NA

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Table 2-3: Data Associated with Impairment Status

Watershed	Water body	Sample Site	Date	Time	Causes of Impairment												
					pH[1]	DO[1]	Total Mn	Sulfates	TDS	Total Boron	Dissolved Zinc [6]	Dissolved Iron	Total Silver	Dissolved Copper [6]	TP	Atrazine [5]	Ammonia
					s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L
Bay Creek	Cedar Creek	AJF16	9/25/2006	18:00		8.9	0.25										
			11/3/2006	11:05		11.0	0.12										
		AJF16A	9/25/2006	18:15		9.4	0.23										
			11/2/2006	13:30		11.6	0.08										
	Bay Creek Ditch	AJK01	9/25/2006	15:58		5.6	0.16										
			10/31/2006	8:15		8.2	0.05										
		AJK01A	10/31/2006	8:45		6.1	0.06										
Cahokia Creek/Holiday Shores Lake	Cahokia Diversion Ditch	JQ07	10/4/2006	16:35		5.3								ND			
			10/17/2006	14:15		9.4								ND			
		JQ01	10/4/2006	16:20		**3.4**								ND			
			10/17/2006	14:45		9.6								ND			
Cedar Creek	Big Muddy River	N99	9/7/2006	12:15		10.1		186									
			11/1/2006	9:45		7.8		75									
		N13	9/7/2006	11:15		8.1		144									
			11/1/2006	10:45		8.2		68									
	Cave Creek	NAC01	9/11/2006	11:45		7.6											
			11/1/2006	11:45		10.6											
		NAC01A	9/11/2006	11:15		**4.9**											
			11/1/2006	12:15		10.1											
Crab Orchard Lake	Crab Orchard Creek	ND11	9/6/2006	12:15	7.3	5.2	1.00										
			11/1/2006	14:00	7.7	10.1	0.26										
		ND12	9/6/2006	13:15	7.3		0.17										
			11/1/2006	15:00	7.7		ND										
		ND13	9/6/2006	15:00		6.0											
			11/1/2006	15:45		11.1											
		ND15	9/6/2006	16:30		6.8											
	Little Crab Orchard Creek	NDA01	9/6/2006	18:00		**2.1**	**2.00**										
			11/2/2006	8:30		8.2	0.20										
		NDA99	11/2/2006	10:30		12.3	0.03										
	Piles Fork	NDB03	9/7/2006	10:00		**1.6**											
			11/2/2006	9:15		10.3											
		NDB04	9/9/2006	7:40		**3.6**											
			11/2/2006	11:00		11.5											
Crooked Creek	Plum Creek	OZH-OK-A2	9/8/2006	14:00		6.8	0.65										
			10/19/2006	10:50		5.3	0.33										
		OZH-OK-A2A	9/8/2006	16:25		8.5	0.20										
			10/19/2006	11:20		9.0	0.22										
		OZH-OK-C2	9/8/2006	12:45		**1.1**											
			10/19/2006	10:15		**2.5**											
		OZH-OK-C2A	9/8/2006	17:30		**4.6**											
			10/19/2006	13:40		**3.2**											
		OZH-OK-C3	9/9/2006	15:00		**4.1**	0.30										
			10/19/2006	9:35		5.2	0.77										
	Little Crooked Creek	OJA-01	9/7/2006	17:45		**3.7**	0.14										
			10/19/2006	14:05		**4.7**	0.17										
		OJA-02	9/8/2006	11:15		**3.1**	0.14										
			10/19/2006	14:35		**3.8**	0.17										

Table 2-3: Data Associated with Impairment Status

Watershed	Water body	Sample Site	Date	Time	Causes of Impairment												
					pH(1)	DO(1)	Total Mn	Sulfates	TDS	Total Boron	Dissolved Zinc (6)	Dissolved Iron	Total Silver	Dissolved Copper (6)	TP	Atrazine (5)	Ammonia
					s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L
Little Wabash	Village Creek	CE01	9/6/2006	17:30		9.9	0.17										
			11/14/2006	8:45		10.6	0.10										
		CE02	9/6/2006	15:20		7.9	0.80										
			11/9/2006	12:55		10.7	0.11										
		CE01A	9/12/2006	17:05		5.8	0.41										
			11/9/2006	13:45		11.2	0.08										
	Johnson Creek	CCAFFA1A	9/10/2006	10:50		**3.8**											
			11/14/2006	10:45		12.3											
		CCA12	9/9/2006	13:05		14.2											
			11/14/2006	9:45		7.7											
		CCA13	9/9/2006	14:30		14.9											
			11/14/2006	10:15		12.8											
		CCA14A	9/9/2006	15:25		5.7											
			11/14/2006	10:25		12.5											
	Pond Creek	CCFFD1	9/9/2006	10:30		7.1											
			10/31/2006	10:10		8.2											
		CCFFD1A	11/9/2006	12:15		11.2											
		CCFFD1B	9/9/2006	11:45		8.6											
			11/9/2006	11:35		12.1											
		CCFFD1C	9/10/2006	12:10		11.9											
			10/31/2006	11:20		14.4											
	Seminary Creek	CDGFLA1	9/8/2006	15:40		10.0											
			11/8/2006	14:45		14.3											
		CDGFLA1A	9/8/2006	13:45		**2.6**											
			11/8/2006	15:50		15.1											
		CDFGLC6	9/8/2006	12:25		6.6											
			11/8/2006	17:00		10.5											
		CDFGLC6A	9/8/2006	11:10		7.0											
			11/8/2006	16:45		12.0											
	Big Muddy Creek	CJ06	9/7/2006	18:10		**4.9**	0.54										
			11/8/2006	11:00		11.6	0.39										
		CJ05	9/7/2006	16:45		10.5	0.04										
			11/8/2006	11:30		12.4	0.07										
	Little Muddy Creek	CJA02	9/7/2006	4:20		**2.8**	**1.30**										
			11/8/2006	12:30		9.3	0.39										
		CJA01	9/12/2006	10:20		**3.4**	**1.30**										
			11/13/2006	12:00		10.1	0.17										
	Big Muddy Diversion Ditch	CJAE01	9/7/2006	12:10		9.1											
			11/8/2006	13:05		10.8											
		CJAE01A	9/7/2006	15:45		10.3											
			11/13/2006	12:30		9.8											

Table 2-3: Data Associated with Impairment Status

Watershed	Water body	Sample Site	Date	Time	Causes of Impairment												
					pH[1]	DO[1]	Total Mn	Sulfates	TDS	Total Boron	Dissolved Zinc [6]	Dissolved Iron	Total Silver	Dissolved Copper [6]	TP	Atrazine [5]	Ammonia
					s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L
Little Wabash	Elm River	CD02A	9/12/2006	12:51		**3.8**											
		CD02	9/8/2006	17:45		8.1											
		CD01	4/18/2006	14:30												0.12	
			4/26/2006	11:15												0.16	
			5/1/2006	11:00												0.27	
			5/17/2006	9:30												**19.00**	
			5/24/2006	11:20												**15.00**	
			5/31/2006	11:30												8.30	
			6/7/2006	11:25												5.70	
			6/15/2006	9:50												2.80	
			6/22/2006	11:15												1.20	
			6/27/2006	9:15												4.20	
			7/5/2006	11:50												2.40	
			7/12/2006	11:30												0.92	
			7/20/2006	11:15												2.40	
			7/27/2006	11:05												2.60	
			8/1/2006	9:20												2.60	
			8/8/2006	12:20												1.60	
	Little Wabash River	C33 [4]	4/18/2006	11:00												0.55	
			4/26/2006	12:15			**0.35**									1.10	
			5/1/2006	11:45			**0.50**									0.71	
			5/10/2006	12:20			**0.41**										
			5/17/2006	14:00												**19.00**	
			5/24/2006	12:15			**0.38**									8.10	
			5/31/2006	12:40			**0.37**									**13.00**	
			6/7/2006	12:30			**0.44**									6.30	
			6/15/2006	11:05												5.30	
			6/22/2006	12:00			**0.76**									2.60	
			6/27/2006	11:50												2.50	
			7/5/2006	13:00			**0.50**									1.70	
			7/12/2006	12:30			**0.54**									1.00	
			7/20/2006	12:20			**0.46**									2.30	
			7/27/2006	12:10												0.64	
			8/1/2006	10:30												0.66	
			8/8/2006	13:30												0.50	

Table 2-3: Data Associated with Impairment Status

Watershed	Water body	Sample Site	Date	Time	Causes of Impairment												
					pH[1]	DO[1]	Total Mn	Sulfates	TDS	Total Boron	Dissolved Zinc [6]	Dissolved Iron	Total Silver	Dissolved Copper [6]	TP	Atrazine [5]	Ammonia
					s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L
Little Wabash	Little Wabash River	C09	3/17/2005	8:00		14.9											
			4/19/2005	14:30		7.3											
			5/9/2005	10:30		6.7											
			6/23/2005	7:30		5.1											
			8/23/2005	13:00		**4.2**											
			9/27/2005	16:00		7.5											
			10/27/2005	14:00		8.7											
			12/6/2005	13:00		11.8											
			2/1/2006	12:30		9.3											
			3/15/2006	10:00		6.2											
			4/18/2006	16:00												0.27	
			4/26/2006	10:00									ND			0.62	
			5/1/2006	9:45									ND			0.59	
			5/10/2006	10:00									ND				
			5/17/2006	11:00									ND			**20.00**	
			5/24/2006	9:45									ND			6.30	
			5/31/2006	10:20									ND			**24.00**	
			6/7/2006	10:15									ND			4.20	
			6/15/2006	8:50									ND			1.80	
			6/22/2006	10:05									ND			1.20	
			6/27/2006	10:40									ND			1.50	
			7/5/2006	10:30									ND			1.20	
			7/12/2006	10:30									ND			0.96	
			7/20/2006	10:00									ND			1.60	
			7/27/2006	10:00									ND			0.72	
			8/1/2006	8:30									ND			0.63	
			8/8/2006	11:05									ND			0.40	
			8/18/2006	16:00									ND				
Mary's River/North Fork Cox Creek	North Fork Cox Creek	IIHA31	9/9/2006	17:10				**1610**	**3110**								
			10/18/2006	14:45				**1830**	**2830**								
		IIHA01	9/9/2006	17:40				**1850**	**3090**								
			10/18/2006	14:25				**1630**	**2540**								
		IIHA-STE1	9/9/2006	15:40					**3090**								
			10/18/2006	13:40					**1340**								
		IIHA-STC1	9/9/2006	16:15					**2530**								
			10/18/2006	14:00					**1400**								
	Maxwell Creek	IIKSPC1	9/7/2006	15:30		**2.0**											
			10/17/2006	8:20		20.2											
		IIKSPC3A	9/7/2006	15:00		**2.6**											
			10/17/2006	8:45		6.5											
	Randolph County Lake	RIB-1[3]	9/9/2006	12:00											0.04		
			10/18/2006	10:45											**0.130**		
		RIB-2 [3]	9/9/2006	14:00											0.04		
			10/18/2006	12:05											**0.053**		
		RIB-3 [3]	9/9/2006	13:00											0.04		
			10/18/2006	11:15											**0.100**		

Table 2-3: Data Associated with Impairment Status

Watershed	Water body	Sample Site	Date	Time	Causes of Impairment												
					pH[1]	DO[1]	Total Mn	Sulfates	TDS	Total Boron	Dissolved Zinc[6]	Dissolved Iron	Total Silver	Dissolved Copper[6]	TP	Atrazine[5]	Ammonia
					s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L
Sangamon River/ Lake Decatur	Owl Creek	EZV01	8/30/2006	12:50		8.5											
			11/2/2006	9:25		12.2											
		EZVA1	8/30/2006	11:05		6.5											
			11/2/2006	10:33		11.8											
		EZVE1	8/30/2006	10:45		11.1											
			11/2/2006	12:59		12.5											
		EZVC1	8/30/2006	10:25		**5.0**											
			11/2/2006	12:20		11.7											
Shoal Creek	Shoal Creek	OI05	9/1/2006	12:35		9.1											
			10/17/2006	11:30		8.5											
		OI05B	9/1/2006	14:20		10.8											
			10/17/2006	11:15		8.7											
		OI05C	9/1/2006	15:40		10.2											
			10/16/2006	10:30		9.4											
	Locust Fork	OIC01	10/19/2006	12:20		**3.8**	0.18										
		OIC02	8/31/2006	17:50		9.4	0.35										
			10/17/2006	13:00		5.2	0.08										
	Cattle Creek	OIP10	10/17/2006	12:05		**2.0**			928[2]					0.021			5.8
South Fork Saline River/ Lake of Egypt	Briers Creek	ATHS01	9/11/2006	11:30	7.6	9.1	0.65	**1250**	**1960**		0.020	0.310	ND				
			9/27/2006	9:00	7.3	10.2	**2.00**	**951**	**1490**		0.022	ND	ND				
			10//2006	11:30							ND	ND					
			10/30/2006	16:30			**1.50**	**656**	**1120**		0.035	ND	ND				
			11/15/2006	10:25			**1.40**	281	469		0.028	**1.10**	ND				
		ATHS01A	9/27/2006	11:30	7.5	9.7	0.10	294	678		ND	**1.10**	ND				
			10/4/2006	10:50							ND	ND					
			11/2/2006	12:00	8.0	8.5	0.11	219	597		0.012	ND	ND				
			11/15/2006	11:10	6.8	5.4	0.12	65	213		ND	**1.40**	ND				
		ATHS01B	9/13/2006	10:40			0.18	143	418			ND	ND				
			9/27/2006	10:35	6.7	9.7	0.17	196	414		ND	ND	ND				
			10/4/2006	11:05							0.013	ND					
			11/2/2006	12:20	7.4	9.9	0.22	373	608		0.018	ND	ND				
			11/15/2006	11:30	6.8	**4.0**						**2.10**					
		ATHS01C	9/11/2006	12:55			**8.70**	**1290**	**2150**			**5.00**	ND				
			9/27/2006	9:30	7.0	9.8	**4.10**	**1100**	**1660**		ND	0.78	ND				
			10/4/2006	11:20							ND	**2.20**					
			10/31/2006	14:30	7.4	9.4	**1.90**	**691**	**1190**		ND	0.17	ND				
			11/15/2006	10:45	7.0	8.8	0.93	338	667		ND	0.470	ND				

Table 2-3: Data Associated with Impairment Status

Watershed	Water body	Sample Site	Date	Time	pH(1)	DO(1)	Total Mn	Sulfates	TDS	Total Boron	Dissolved Zinc (6)	Dissolved Iron	Total Silver	Dissolved Copper (6)	TP	Atrazine (5)	Ammonia
					Causes of Impairment												
					s.u.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L	mg/L
South Fork Saline River/ Lake of Egypt	East Palzo Creek	ATHV01A	9/11/2006	10:40	6.9	6.7	**1.40**		**1560**			ND					
			10/31/2006	13:40	6.5	7.6	**1.80**		375			0.160		ND			
			11/15/2006	10:00	**6.3**	5.1	0.09		211			**2.60**		ND			
		ATHV01	9/11/2006	10:40	6.9	6.7	0.38		262			ND					
			10/4/2006	12:30								0.13		ND			
			10/31/2006	13:40	6.5	7.6	**1.80**		375			0.16		ND			
			11/15/2006	10:00	**6.3**	5.1	**2.10**		324			0.340		ND			
		ATHV01B	9/11/2006	8:55	6.9	6.0	0.41		388			ND					
			9/26/2006	12:30	**6.2**	10.9	1.00		323			ND		ND			
			10/4/2006	11:50								ND		ND			
			10/31/2006	13:00	**6.4**	8.7	**1.60**		341			ND		ND			
			11/15/2006	9:35	**6.1**	5.6	**1.60**		225			0.100		ND			
	South Fork Saline River	ATHLEC2	9/26/2006	9:45		9.4											
			10/31/2006	12:00		9.6											
		ATH08	9/26/2006	10:20		8.7											
			10/31/2006	11:15		8.8											
South Fork Sangamon River/ Lake Taylorville	South Fork Sangamon River	EO13A	8/30/2006	19:55		9.7	0.61			0.05							
		EO13	8/30/2006	18:10		6.3	0.49			0.20							
			11/2/2006	16:50		6.5	0.33			0.08							
		EO13B	8/30/2006	19:25		8.3	**1.18**			0.20							
		EO13C	8/30/2006	18:55		**3.8**	**5.49**			0.27							
			11/2/2006	16:25		5.8	0.38			0.13							

Shaded cells indicate exceedances of the applicable water quality standard

1 pH and DO values in this table represent field parameters sampled using the In-Site 9500 Profiler. Continuous DO and pH data are available in Appendix D.

2 Value shown is for conductivity. TDS standard corresponds to 1667 uS/cm specific conductance

3 Values shown were collected at one-foot depth.

4 Segment C33 is a source of public water. Therefore the applicable manganese standard is 150 ug/L.

5 Chronic criteria for atrazine is 9 ug/L and a single exceedance of this value indicates a potential cause of impairment

6 Corresponding hardness values were used to calculate standards. Analytical data can be found in Appendix C.

Section 3
Quality Assurance Review

A review was conducted to assess the quality and usability of data generated from Stage 2 work activities and to review compliance with the original sampling plan and objectives developed for the QAPP. Field and laboratory methods were deemed in accordance with the QAPP. Minor deviations from the original plan occurred and all are discussed below.

3.1 Deviations from original Sampling Plan (QAPP)

The following issues and/or concerns developed during the sampling events:

- Sampling during the week of September 25^{th} followed a heavy precipitation event which resulted in high stream flows and flooding at Bay Creek Ditch segment AJK01A and East Palzo Creek segment ATHV01.
- In-field filtering was not performed for dissolved phosphorus or dissolved metal samples. Illinois EPA requested additional information on this procedure. CDM along with ARDL, Inc drafted text for Illinois EPA to validate this sampling practice. Total versus dissolved samples are discussed further in section 3.2.2.
- All locations on Chicken Creek (OIO09) were dry during both sample periods; therefore no samples were collected for this segment.
- The following sites had no water during either sampling event: Maxwell Creek IIKSPA1 and IIKSPE1A, and Cattle Creek OIP10A. Alternate locations were not found.
- Access was not available to the following sites during either sampling event: Shoal Creek OIO5A, South Fork Saline River sites ATH14 and ATHLEC1. Alternate locations were not found.
- Site EZVA1 on Owl Creek was moved from the location proposed in the QAPP to the intersection of Owl Creek and County Road 3100 due to better stream flow.
- Only one round of sampling was conducted at the following sites due to access or water volume issues (refer to Table 2-2 for specific dates and issues): Locust Fork OIC01, Cattle Creek OIP10, Crab Orchard Creek ND15, Little Crab Orchard Creek NDA99, Pond Creek CCFFD1A, East Palzo Creek ATHV01 and ATHV01A, and Bay Creek Ditch AJK01A.
- Due to field crew error only one round of sampling was conducted at South Fork Sangamon River EO13A and EO13B and Elm River locations CD02 and CD02A.

3.2 Data Verification and Validation

A data quality review was performed on all laboratory data. The review consisted of an evaluation of laboratory QC and field QC samples. Laboratory QC included an evaluation of method blanks, matrix spikes, matrix spike duplicates, laboratory control samples and holding times. Field QC included an evaluation of field duplicates. No decontamination rinsate blanks were collected.

No laboratory violation resulted in the qualification of CDM collected data. While some matrix spikes had percent recoveries outside of the established limits, all other QC associated with the samples were acceptable. When a matrix spike was reported outside of the control limits, the laboratory control samples had percent recoveries within the established control limits, indicating a matrix effect on the sample analysis and no need to qualify the data. All samples were analyzed within the control limits.

An evaluation of the phosphorus data (total versus dissolved) was performed to determine the effects of filtering the samples immediately versus waiting up to 48 to 64 hours. All samples were received by the laboratories on ice and at 4^0C (+/-). A total of 161 samples have been analyzed for both total and dissolved phosphorus by method 365.2. Of the 161 samples, a total of 10 samples sets had a phosphorus concentration of greater than 1 mg/L (100 times higher than the reporting limit and considered significant when controlling based on RPDs). One of these samples had relative percent difference (RPD) between the total and dissolved fraction of the sample of greater than 100. Precision values of less that 25 % RPD are considered acceptable for sample results reported significantly above the reporting limit. Sample EO13C had total phosphorus measured at 2.09 mg/L and dissolved phosphorus measured at 0.52 mg/L. The TSS measured in this sample was 159 mg/L. The suspended solids contained in this sample may have absorbed the available phosphorus, but all other results in samples with phosphorus concentrations above 1mg/L show that this reaction is not taking place. Sampling or analytical variations may explain the elevated RPD between the sample and the duplicate. Total phosphorus and dissolved phosphorus results for samples with phosphorus concentrations above 1 mg/L are not significantly different.

Looking at all other results, there does not appear to be a correlation between the difference of total and dissolved phosphorus and the TSS concentration. Suspended solids absorbing dissolved phosphorus would be the likely mechanism for lowering the dissolved phosphorus concentrations. Based on the lack of this correlation, dissolved phosphorus concentration would not be significantly different if the samples were filtered immediately versus filtering at the laboratory 48-hours after collection.

Finally, field and laboratory quality control data were collected to assess bias associated between field and laboratory methods. Positive sample results and relative percent difference (RPD) are presented in Table 3-1.

3.3 Data Quality Objectives

The data generated during the Stage 2 investigation conformed to the data quality objectives established in the QAPP. A completeness criterion of 90% was established and easily achieved. No data have been qualified that were collected by CDM personnel and analyzed by ARDL, Inc or Prairie Analytical laboratories. Data qualifiers were applied to some of the data collected by Illinois EPA personnel. All qualifiers are included with the laboratory data contained in Appendix C.

Table 3-1: Duplicate Pair Sample Results

SampleLocation	Parameter	Result	Units	Collection Date	RPD(%)
AJK01-DUP	Solids, total suspended	24.2	MG/L	9/25/2006	
AJK01	Solids, total suspended	25	MG/L	9/25/2006	3.252033
ATHS01A-DUP	Hardness (CA/MG)	435.1	MG CACO3/L	11/2/2006	
ATHS01A	Hardness (CA/MG)	445	MG CACO3/L	11/2/2006	2.249744
ATHS01A-DUP	Solids, total dissolved	604	MG/L	11/2/2006	
ATHS01A	Solids, total dissolved	597	MG/L	11/2/2006	-1.1657
ATHS01A-DUP	Chloride	5.13	MG/L	9/27/2006	
ATHS01A	Chloride	5.1	MG/L	9/27/2006	-0.64556
ATHS01A-DUP	Solids, total dissolved	675	MG/L	9/27/2006	
ATHS01A	Solids, total dissolved	678	MG/L	9/27/2006	0.443459
ATHS01A-DUP	Sulfate	290.63	MG/L	9/27/2006	
ATHS01A	Sulfate	294	MG/L	9/27/2006	1.154242
ATHS01C-DUP	Chloride	5.38	MG/L	9/11/2006	
ATHS01C	Chloride	5.4	MG/L	9/11/2006	0.388903
ATHS01C-DUP	Sulfate	1297.83	MG/L	9/11/2006	
ATHS01C	Sulfate	1290	MG/L	9/11/2006	-0.60514
ATHS01-FIELDDUP	Alkalinity	113	MG/L	10/30/2006	
ATHS01	Alkalinity	108	MG/L	10/30/2006	-4.52489
ATHS01-FIELDDUP	Chloride	4.9	MG/L	10/30/2006	
ATHS01	Chloride	4.9	MG/L	10/30/2006	0
ATHS01-FIELDDUP	Hardness (CA/MG)	673	MG CACO3/L	10/30/2006	
ATHS01	Hardness (CA/MG)	668	MG CACO3/L	10/30/2006	-0.74571
ATHS01-FIELDDUP	Iron	68200	MG/KG	10/30/2006	
ATHS01	Iron	93800	MG/KG	10/30/2006	31.60494
ATHS01-FIELDDUP	Manganese	1130	MG/KG	10/30/2006	
ATHS01	Manganese	1480	MG/KG	10/30/2006	26.81992
ATHS01-FIELDDUP	Manganese	1.5	MG/L	10/30/2006	
ATHS01	Manganese	1.5	MG/L	10/30/2006	0
ATHS01-FIELDDUP	Nitrate-Nitrite	0.06	MG/L	10/30/2006	
ATHS01	Nitrate-Nitrite	0.06	MG/L	10/30/2006	-11.9658
ATHS01-FIELDDUP	Phosphorus, diss	0.05	MG/L	10/30/2006	
ATHS01	Phosphorus, diss	0.05	MG/L	10/30/2006	8.163265
ATHS01-FIELDDUP	Phosphorus, total	0.04	MG/L	10/30/2006	
ATHS01	Phosphorus, total	0.03	MG/L	10/30/2006	-26.8657
ATHS01-FIELDDUP	Solids, total	69.7	%	10/30/2006	
ATHS01	Solids, total	74.5	%	10/30/2006	6.65742
ATHS01-FIELDDUP	Solids, total dissolved	1040	MG/L	10/30/2006	
ATHS01	Solids, total dissolved	1070	MG/L	10/30/2006	2.843602
ATHS01-FIELDDUP	Solids, total suspended	4.3	MG/L	10/30/2006	
ATHS01	Solids, total suspended	5.6	MG/L	10/30/2006	26.26263
ATHS01-FIELDDUP	Sulfate	662	MG/L	10/30/2006	
ATHS01	Sulfate	604	MG/L	10/30/2006	-9.16272
ATHS01-FIELDDUP	Zinc	106	MG/KG	10/30/2006	
ATHS01	Zinc	116	MG/KG	10/30/2006	9.009009
ATHS01-FIELDDUP	Zinc, diss	0.02	MG/L	10/30/2006	
ATHS01	Zinc, diss	0.03	MG/L	10/30/2006	8.333333
ATHS01-DUP	Alkalinity	60.9	MG/L	11/15/2006	
ATHS01	Alkalinity	56.8	MG/L	11/15/2006	-6.96686
ATHS01-DUP	Hardness (CA/MG)	340.14	MG CACO3/L	11/15/2006	
ATHS01	Hardness (CA/MG)	337	MG CACO3/L	11/15/2006	-0.92743
ATHS01-DUP	Solids, total dissolved	481	MG/L	11/15/2006	

Table 3-1: Duplicate Pair Sample Results (continued)

SampleLocation	Parameter	Result	Units	Collection Date	RPD(%)
ATHS01	Solids, total suspended	151	MG/L	11/15/2006	-104.43
ATHS01-DUP	Hardness (CA/MG)	1035.17	MG CACO3/L	9/27/2006	
ATHS01	Hardness (CA/MG)	1030	MG CACO3/L	9/27/2006	-0.50069
ATHV01B-DUP	Alkalinity	15.3	MG/L	9/26/2006	
ATHV01B	Alkalinity	15.3	MG/L	9/26/2006	0
ATHV01B-DUP	Solids, total	72.5	%	9/26/2006	
ATHV01B	Solids, total	71.9	%	9/26/2006	-0.83102
CCFFD1-DUP	Chlorophyll	5.5	MG/CU.M.	9/9/2006	
CCFFD1	Chlorophyll	5	MG/CU.M.	9/9/2006	-9.52381
CE01A-DUP	Solids, total suspended	134	MG/L	9/12/2006	
CE01A	Solids, total suspended	137	MG/L	9/12/2006	2.214022
CJA02-DUP	Biological Oxygen Demand	4	MG/L	11/8/2006	
CJA02	Biological Oxygen Demand	3.7	MG/L	11/8/2006	-7.79221
EO13-DUP	Biological Oxygen Demand	6.3	MG/L	11/2/2006	
EO13	Biological Oxygen Demand	6.3	MG/L	11/2/2006	0
EO13-DUP	Solids, total suspended	8.4	MG/L	11/2/2006	
EO13	Solids, total suspended	7.6	MG/L	11/2/2006	-10
IIAA01-DUP	Chloride	21.71	MG/L	9/9/2006	
IIAA01	Chloride	21.7	MG/L	9/9/2006	-0.0258
IIAA01-DUP	Sulfate	1832.11	MG/L	9/9/2006	
IIAA01	Sulfate	1850	MG/L	9/9/2006	0.971725
IIHA01-DUP	Chloride	21.71	MG/L	9/9/2006	
IIHA01	Chloride	21.7	MG/L	9/9/2006	-0.0258
IIHA01-DUP	Sulfate	1832.11	MG/L	9/9/2006	
IIHA01	Sulfate	1850	MG/L	9/9/2006	0.971725
IIHA31-DUP	Hardness (CA/MG)	1290.87	MG CACO3/L	9/9/2006	
IIHA31	Hardness (CA/MG)	1300	MG CACO3/L	9/9/2006	0.704783
IIHA31-DUP	Hardness (CA/MG)	1306.27	MG CACO3/L	10/18/2006	
IIHA31	Hardness (CA/MG)	1280	MG CACO3/L	10/18/2006	-2.0315
IIHA31-DUP	Chloride	19.5	MG/L	10/18/2006	
IIHA31	Chloride	19.4	MG/L	10/18/2006	-0.51363
IIHA31-DUP	Solids, total dissolved	2850	MG/L	10/18/2006	
IIHA31	Solids, total dissolved	2830	MG/L	10/18/2006	-0.70423
IIHA31-DUP	Sulfate	1783.35	MG/L	10/18/2006	
IIHA31	Sulfate	1830	MG/L	10/18/2006	2.582091
IIHA-STE1-DUP	Solids, total dissolved	3100	MG/L	9/9/2006	
IIHA-STE1	Solids, total dissolved	3090	MG/L	9/9/2006	-0.3231
IIKSPC3A-DUP	Biological Oxygen Demand	11	MG/L	9/7/2006	
IIKSPC3A	Biological Oxygen Demand	11	MG/L	9/7/2006	0
JQ01-DUP	Chlorophyll	11.8	MG/CU.M.	8/31/2006	
JQ-01	Chlorophyll	13.2	MG/CU.M.	8/31/2006	11.2
JQ01-DUP	Hardness (CA/MG)	221.3	MG CACO3/L	8/31/2006	
JQ-01	Hardness (CA/MG)	221	MG CACO3/L	8/31/2006	-0.13565
ND11-DUP	Solids, total suspended	16.2	MG/L	11/1/2006	
ND11	Solids, total suspended	15	MG/L	11/1/2006	-7.69231
ND11-DUP	Alkalinity	90.2	MG/L	9/6/2006	
ND11	Alkalinity	90.2	MG/L	9/6/2006	0
NDA01-DUP	Solids, total suspended	18.2	MG/L	9/6/2006	
NDA01	Solids, total suspended	16.6	MG/L	9/6/2006	-9.1954
NDB04-DUP	Chlorophyll	26.9	MG/CU.M.	11/2/2006	
NDB04	Chlorophyll	25.7	MG/CU.M.	11/2/2006	-4.56274
OI05C-DUP	Biological Oxygen Demand	4.6	MG/L	9/1/2006	
OI05C	Biological Oxygen Demand	5.1	MG/L	9/1/2006	10.30928
OIC02-DUP	Solids, total suspended	14	MG/L	8/31/2006	
OIC02	Solids, total suspended	13.7	MG/L	8/31/2006	-2.16606
OIC02-DUP	Solids, total suspended	18.5	MG/L	10/17/2006	

Table 3-1: Duplicate Pair Sample Results (continued)

SampleLocation	Parameter	Result	Units	Collection Date	RPD(%)
OIC02	Solids, total suspended	16.8	MG/L	10/17/2006	-9.63173
OIP10-DUP	Hardness (CA/MG)	278.52	MG CACO3/L	10/17/2006	
OIP10	Hardness (CA/MG)	286	MG CACO3/L	10/17/2006	2.650039
OZH-OK-A2A-DUP	Chlorophyll	155.4	MG/CU.M.	9/8/2006	
OZH-OK-A2A	Chlorophyll	126	MG/CU.M.	9/8/2006	-20.8955

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Section 4
Conclusions

Data collected during Stage 2 have been deemed adequate and usable for Stage 3 TMDL development (see discussion in Section 3). Table 4-1 contains information for each segment sampled during Stage 2 with regards to its impairment status. The table contains information on the number of historic samples available prior to Stage 2 data collection, the number of historic violations as well as the date of the last recorded violation. The intention of this table is to assist any future determination on the impairment status of the Stage 2 stream segments.

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Table 4-1: Impairment Status

Watershed	Stream Name	Segment	Parameter of Concern	Historic Data Count	Number of Historic Violations	Date of Last Recorded Violation	Stage 2 Data Count	Number of Violations	Suggested Status
Bay Creek	Cedar Creek	AJF16	Dissolved Oxygen	1	1	2000	Continuous	0	Delist
			Manganese	1	0	-	4	0	Delist
	Bay Creek Ditch	AJK01	Dissolved Oxygen	3	3	1987	Continuous	Multiple	Impaired
			Manganese	3	3	1987	3	0	Delist
Cahokia Creek/ Holiday Shores Lake	Cahokia Diversion Ditch	JQ07	Dissolved Oxygen	147	130	2005	Continuous	Multiple	Impaired
			Copper	5	1	1998	4	0	Delist
Cedar Creek	Big Muddy River	N99	Dissolved Oxygen	3	1	2002	Continuous	*	Impaired
			Sulfates	3	0	-	4	0	Delist
	Cave Creek	NAC01	Dissolved Oxygen	2	1	1995	Continuous	1	Impaired
Crab Orchard Lake	Crab Orchard Creek	ND11	Dissolved Oxygen	2	1	2000	Continuous	Multiple	Impaired
			Manganese	2	2	2000	2	0	Delist
			pH	3	2	2004	Continuous	Multiple	Impaired
	Crab Orchard Creek	ND12	pH	3	1	2004	Continuous	0	Delist
			Manganese	2	1	2000	2	0	Delist
	Crab Orchard Creek	ND13	Dissolved Oxygen	4	4	2000	Continuous	Multiple	Impaired
	Little Crab Orchard Creek	NDA01	Dissolved Oxygen	2	1	1995	Continuous	Multiple	Impaired
			Manganese	2	1	1995	3	1	Impaired
	Piles Fork	NDB03	Dissolved Oxygen	2	1	1995	Continuous	Multiple	Impaired
Crooked Creek	Plum Creek	OZH-OK-A2	Dissolved Oxygen	1	1	2002	Continuous	Multiple	Impaired
	Plum Creek		Manganese	1	1	2002	4	0	Delist
	Plum Creek	OZH-OK-C2	Dissolved Oxygen	1	1	2002	Continuous	Multiple	Impaired
	Plum Creek	OZH-OK-C3	Dissolved Oxygen	1	1	2002	Continuous	Multiple	Impaired
	Plum Creek		Manganese	1	1	2002	2	0	Delist
	Little Crooked Creek	OJA-01	Dissolved Oxygen	5	4	2002	Continuous	Multiple	Impaired
			Manganese	5	2	2002	4	0	Delist

Table 4-1: Impairment Status

Watershed	Stream Name	Segment	Parameter of Concern	Historic Data Count	Number of Historic Violations	Date of Last Recorded Violation	Stage 2 Data Count	Number of Violations	Suggested Status
Little Wabash	Little Wabash River	C09	Dissolved Oxygen	43	7	2003	Continuous	Multiple	Impaired
			Silver	43	1	2002	18	0	Delist
			Atrazine	2	1	1991	16	2	Impaired
		C33	Dissolved Oxygen	5	3	2002	Continuous	Multiple	Impaired
			Manganese	5	5	2002	10	10	Impaired
			Atrazine	NA	NA	NA	16	2	Impaired
	Village Creek	CE01	Dissolved Oxygen	1	0	NA	Continuous	Multiple	Impaired
			Manganese	1	1	2002	6	0	Delist
	Johnson Creek	CCAFFA1	Dissolved Oxygen	1	1	1997	Continuous	Multiple	Impaired
	Pond Creek	CCFFD1	Dissolved Oxygen	1	1	1997	Continuous	Multiple	Impaired
	Elm River	CD01	Atrazine	8	3	2002	16	2	Impaired
		CD02	Dissolved Oxygen	3	2	2003	Continuous	Multiple	Impaired
	Seminary Creek	CDGFLA1	Dissolved Oxygen	1	1	1998	Continuous	Multiple	Impaired
	Seminary Creek	CDFGLC6	Dissolved Oxygen	1	1	1998	Continuous	Multiple	Impaired
	Big Muddy Creek	CJ06	Dissolved Oxygen	3	1	2002	Continuous	Multiple	Impaired
			Manganese	2	1	2002	6	0	Delist
	Little Muddy Creek	CJA02	Dissolved Oxygen	4	3	2002	Continuous	Multiple	Impaired
			Manganese	4	3	2002	4	2	Impaired
	Big Muddy Diversion Ditch	CJAE01	Dissolved Oxygen	1	0	2000	Continuous	Multiple	Impaired
Mary's River/ North Fork Cox Creek	North Fork Cox Creek	IIHA31	Sulfates	2	2	1995	4	4	Impaired
			TDS	2	2	1995	4	4	Impaired
	North Fork Cox Creek	IIHA-STC1	TDS	1	1	1995	4	2	Impaired
	Maxwell Creek	IIKSPC1A	Dissolved Oxygen	2	2	19999	Continuous	Multiple	Impaired
	Randolph County Lake	RIB	Total Phosphorus	11	3	1993	6	2	Impaired
Sangamon River/ Lake Decatur	Owl Creek	EZV	Dissolved Oxygen	3	1	1998	Continuous	Multiple	Impaired

Table 4-1: Impairment Status

Watershed	Stream Name	Segment	Parameter of Concern	Historic Data Count	Number of Historic Violations	Date of Last Recorded Violation	Stage 2 Data Count	Number of Violations	Suggested Status
Shoal Creek	Shoal Creek	OI05	Dissolved Oxygen	3	1	2002	Continuous	0	Delist
	Locust Fork	OIC01	Dissolved Oxygen	3	1	1991	Continuous	Multiple	Impaired
			Manganese	3	1	1991	2	0	Delist
	Chicken Creek	OIO09	Dissolved Oxygen	2	1	1991	0	0	No Water
	Cattle Creek	OIP10	Dissolved Oxygen	3	2	1991	Continuous	Multiple	Impaired
			Ammonia	3	1	1991	1	0	Delist
			TDS	3	1	1991	1	0	Delist
South Fork Saline River/ Lake of Egypt	Briers Creek	ATHS01	Zinc	2	2	1993	13	0	Delist
			Iron	3	3	1993	16	3	Impaired
			Manganese	3	3	1993	8	4	Impaired
			Silver	3	1	1993	12	0	Delist
			Sulfates	3	3	1993	16	6	Impaired
			TDS	2	1	1993	16	9	Impaired
			pH	3	3	1993	Continuous	0	Delist
			Dissolved Oxygen	2	1	1993	Continuous	1	Impaired
	East Palzo Creek	ATHV01	Copper	3	2	1993	5	0	Delist
			Iron	3	3	1993	7	1	Impaired
			Manganese	3	3	1993	7	3	Impaired
			TDS	0		-	7	1	Impaired
			pH	3	3	1993	Continuous	Multiple	Impaired
	South Fork Saline River	ATH14	Dissolved Oxygen	8	1	2000	Continuous	0	Delist
South Fork Sangamon/ Lake Taylorville	South Fork Sangamon River	EO13	Dissolved Oxygen	1	1	1989	Continuous	Multiple	Impaired
			Boron	1	1	1989	6	0	Delist
			Manganese	1	1	1989	6	2	Impaired

* Continuous data did not violate the 5.0 mg/L instantaneous DO standard, however, continuous data collected at site N13 experienced more than 16 hours below 6.0 mg/L in a 24 hour period

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For Appendices, please contact Jennifer Clarke at the Illinois EPA for information.

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TMDL Development for the Crab Orchard Creek Watershed, Illinois

STAGE THREE REPORT

FINAL REPORT
May 30, 2008

Submitted to:
Illinois Environmental Protection Agency
1021 N. Grand Avenue East
Springfield, IL 62702

Submitted by:
Tetra Tech

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1.0 BACKGROUND

The Crab Orchard Creek watershed has a drainage area of approximately 289 square miles (185,000 acres) and is a portion of the 8-digit hydrologic unit code (05597500) as defined by USGS Geological Survey (USGS). Located in southern Illinois and flowing in a westerly direction, the Crab Orchard Creek watershed drains portions of land within Johnson, Williamson, Union, and Jackson counties until its confluence with Big Muddy River. Approximately 62 percent of the watershed lies within Williamson County and 25 percent lies within Jackson County. Small portions of the watershed also lie in Union (11%), and Johnson (2%) counties (Figure 1). The predominant soil type is fine-grained soils made up of silts and clays.

Major tributaries to Crab Orchard Creek include Limb Branch, Wolf Creek, Grassy Creek, Little Grassy Creek, Indian Creek, Piles Fork, and Little Crab Orchard Creek. Approximately 94,700 people reside in the watershed, with the city of Carbondale being the largest population center (19,600) followed by the city of Marion (16,000). Agriculture is the dominant land use in this watershed (45%) and other land uses include upland forest (22%), wetland and surface waters (19%), urban space (9%), and forested areas (4%). Figure 2 illustrates the different land uses in the Crab Orchard Creek watershed.

Table 1 identifies the Crab Orchard Creek watershed impaired segments for which Total Maximum Daily Loads (TMDLs) are addressed in this report.

Table 1. 2006 303(d) List Information for the Crab Orchard Creek Watershed

Waterbody Name	Waterbody Segment	Segment and Lake Size (Segment Length in Miles, Lake Area in Acres)	Cause of Impairment	Impaired Designated Use
Crab Orchard Creek	ND 01	9.61	Total Fecal Coliform	Primary Contact
Crab Orchard Creek	ND 02	1.92	Manganese	Aquatic Life
			Dissolved Oxygen	
Crab Orchard Creek	ND 04	13.93	Dissolved Oxygen	Aquatic Life
			Sulfates	
			Manganese	
			Total Dissolved Solids (TDS)	
Crab Orchard Creek	ND 11	0.95	pH	Aquatic Life
			Dissolved Oxygen	
Crab Orchard Creek	ND 13	1.5	Manganese	Aquatic Life
			Dissolved Oxygen	
Little Crab Orchard Creek	NDA 01	12.21	Manganese	Aquatic Life
			Dissolved Oxygen	
Piles Fork	NDB 03	7	Dissolved Oxygen	Aquatic Life
Crab Orchard Lake	RNA	6,965	Total Phosphorus	Fish Consumption & Aesthetic Quality
Carbondale City Lake	RNI	135.6	Manganese	Public Water Supplies, Aesthetic Quality, & Aquatic Life
			Total Phosphorus	
Marion Reservoir	RNL	220	Manganese	Public Water Supplies & Aesthetic Quality
			Total Phosphorus	
Herrin New Reservoir	RNZC	46.1	Manganese	Public Water Supplies & Aesthetic Quality
Campus Lake	RNZH	40	Total Phosphorus	Fish consumption & Aesthetic Quality

A TMDL is defined as “the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and natural background” such that the capacity of the waterbody to assimilate pollutant loadings is not exceeded. A TMDL is also required to be developed with seasonal variations and must include a margin of safety that addresses the uncertainty in the analysis. The overall goals and objectives in developing TMDLs for the above listed water bodies include:

- Assess the water quality of the impaired water bodies and identify key issues associated with the impairments and potential pollutant sources.

- Use the best available science and available data to determine the maximum load the water bodies can receive and fully support all of their designated uses.

- Use the best available science and available data to determine current loads of pollutants to the impaired water bodies.

- If current loads exceed the maximum allowable load, determine the load reduction that is needed.

- Identify feasible and cost-effective actions that can be taken to reduce loads.

- Inform and involve the public throughout the project to ensure that key concerns are addressed and the best available information is used.

- Submit a final TMDL report to USEPA for review and approval.

The TMDL process is being initiated in three stages. Stage 1 (IEPA, 2007) involved characterization of the watershed, assessment of the available water quality data, identification of additional data needs for the development of credible TMDLs and recommendation of potential technical approaches for TMDL development (Appendix D). Stage 2 involved collecting additional chemical water quality data, continuous dissolved oxygen measurements, channel morphology, and discharge measurements at five monitoring locations in Crab Orchard Creek watershed (Appendix E). This report addresses Stage 3 of the TMDL process which involves modeling and TMDL analysis of the parameters of concern for the Crab Orchard Creek watershed impaired segments.

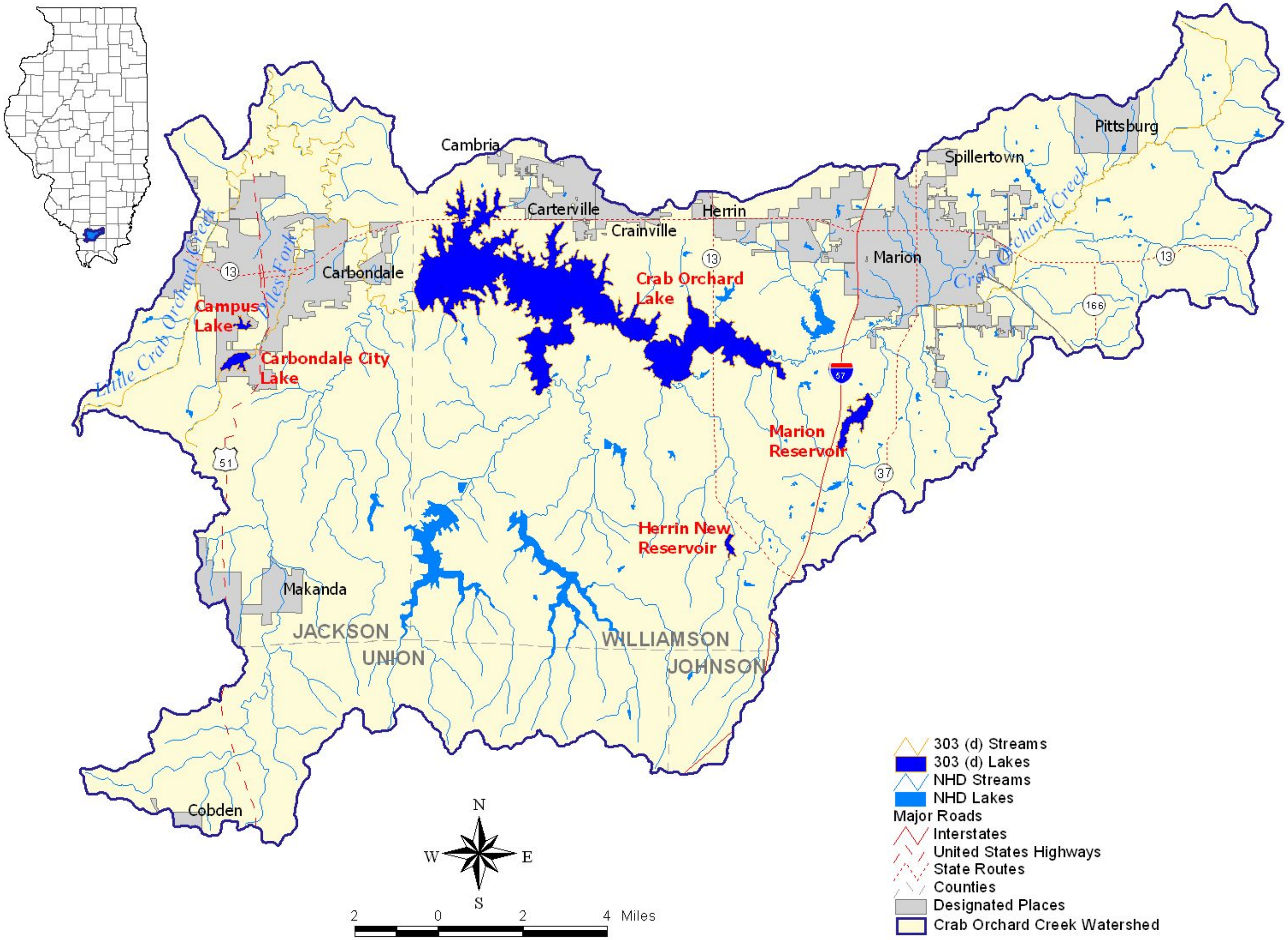

Figure 1. Location of the Crab Orchard Creek Watershed

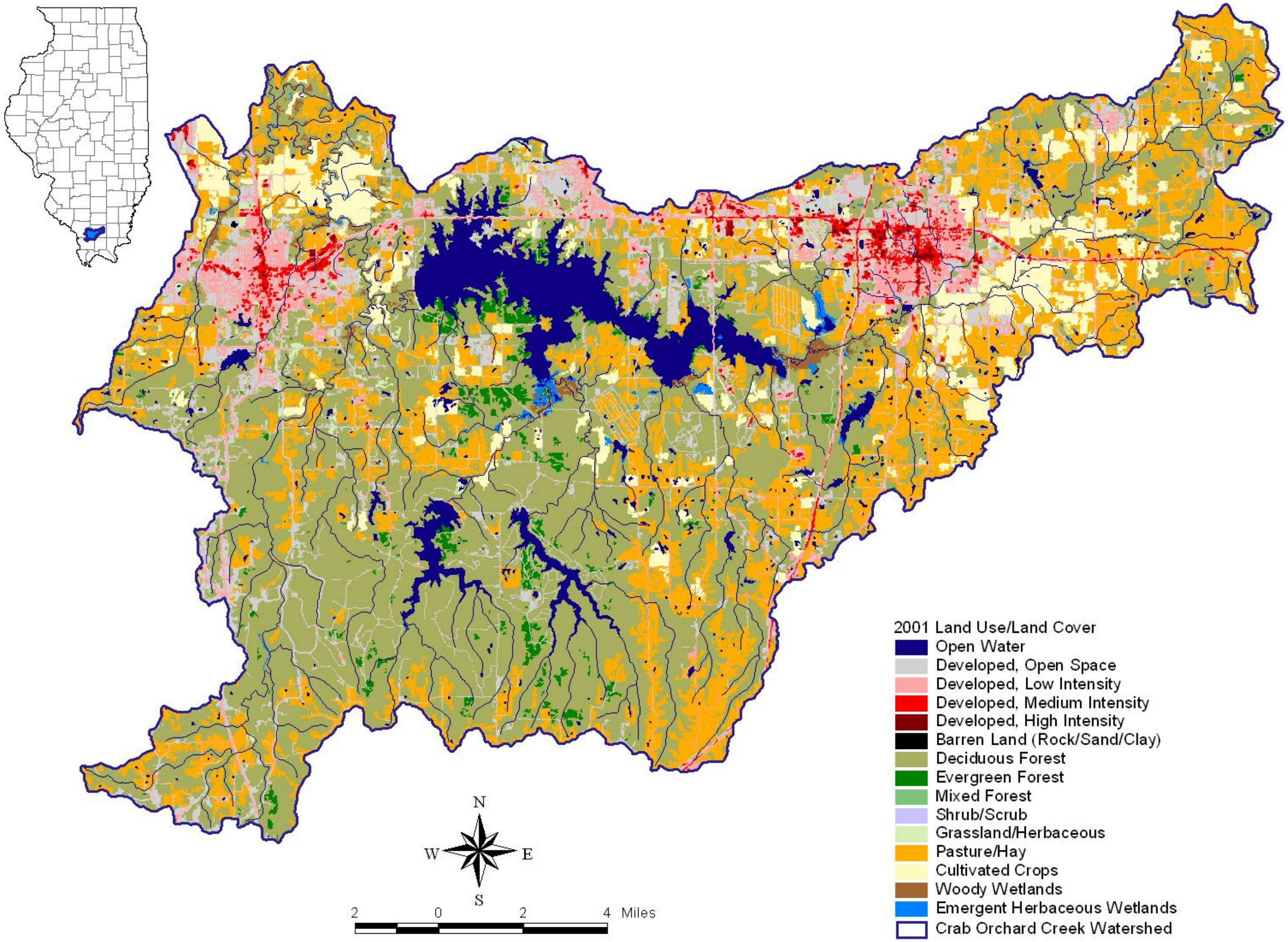

Figure 2. Land Use in the Crab Orchard Creek Watershed

2.0 APPLICABLE WATER QUALITY STANDARDS

The purpose of developing a TMDL is to identify the pollutant loads that a waterbody can receive and still achieve water quality standards. Under the Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters. These standards represent a level of water quality that will support the Clean Water Act's goals. Water quality standards consist of three components: designated uses, numeric or narrative criteria, and an anti-degradation policy. A description of the water quality standards that apply to this watershed's TMDL is presented below and detailed comparisons of the available water quality data to the standards are provided in Appendix D and Appendix E.

2.1 Use Support Guidelines

IEPA uses rules and regulations adopted by the Illinois Pollution Control Board (IPCB) to assess the designated use support for Illinois water bodies. The following are the use support designations provided by the IPCB that apply to water bodies in the Crab Orchard Creek watershed:

General Use Standards - These standards protect for aquatic life, wildlife, agricultural, primary contact (where physical configuration of the waterbody permits it, any recreational or other water use in which there is prolonged and intimate contact with the water involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard, such as swimming and water skiing), secondary contact (any recreational or other water use in which contact with the water is either incidental or accidental and in which the probability of ingesting appreciable quantities of water is minimal, such as fishing, commercial and recreational boating, and any limited contact incident to shoreline activity), and most industrial uses. These standards are also designed to ensure the aesthetic quality of the state's aquatic environment.

Public and food processing water supply standards – These standards are cumulative with the general use standards and apply to waters of the state at any point at which water is withdrawn for treatment and distribution as a potable supply to the public or for food processing. Waters of the state are generally designated for public and food processing use.

Numeric water quality standards used for TMDL development in the Crab Orchard Creek watershed are listed below for lakes (Table 2) and streams (Table 3). Table 4 displays the standards that apply to each impaired waterbody in the Crab Orchard Creek watershed.

Table 2. Summary of Water Quality Standards for the Crab Orchard Creek Watershed Lake Impairments.

Parameter	Units	General Use Water Quality Standard	Public and Food Processing Water Supplies	Section for Regulatory Citation [a]
Manganese	µg/L	1,000	150	General use: 302.208 Public Water Supply: 302.304
Total Phosphorus	mg/L	0.05[b]	No numeric standard	302.205

[a]All IEPA water quality standards are published by the Illinois Pollution Control Board under Title 35: Environmental Protection Subtitle C: Water Pollution Chapter I: Pollution Control Board. Part 302. Water Quality Standards. Subpart A: General Water Quality Provisions.
[b] Standard only applies in lakes/reservoirs that are greater than 20 acres in surface area and in any stream at the point where it enters such a lake/reservoir.

Table 3. Summary of Water Quality Standards for the Crab Orchard Creek Watershed Stream Impairments.

Parameter	Units	General Use Water Quality Standard	Public and Food Processing Water Supplies	Section for Regulatory Citation[d]
Dissolved Oxygen	mg/L	5.0 instantaneous minimum 6.0 minimum during at least 16 hours of any 24 hour period	No numeric standard	302.206
Fecal coliform[a]	cfu/100 mL	400 in <10% of samples[b] Geomean < 200[c]	Geomean[d] <2,000	General use: 302.209 Public Water Supply: 302.306
Manganese	µg/L	1,000	150	General use: 302.208 Public Water Supply: 302.304
pH	S.U.	> 6.5 and <9.0	No numeric standard	302.204
Sulfates	mg/L	500	No numeric standard	302.208
TDS	mg/L	1,000	No numeric standard	302.208

[a] Fecal coliform standards are for the recreation season only (May through October)
[b] Standard shall not be exceeded by more than 10% of the samples collected during a 30 day period
[c] Geometric mean based on minimum of 5 samples taken over not more than a 30 day period
[d] All IEPA water quality standards are published by the Illinois Pollution Control Board under Title 35: Environmental Protection Subtitle C: Water Pollution Chapter I: Pollution Control Board. Part 302. Water Quality Standards. Subpart A: General Water Quality Provisions.

Table 4. Standards that apply to the impaired waterbodies in the Crab Orchard Creek watershed

Waterbody Name	Waterbody Segment	Cause of Impairment	Impaired Designated Use	Applicable Water Quality Standard
Crab Orchard Creek	ND 01	Total Fecal Coliform	Primary Contact	400 cfu/100 mL in <10% of samples Geomean < 200 cfu/100 mL
Crab Orchard Creek	ND 02	Manganese	Aquatic Life	1000 µg/L
		Dissolved Oxygen		5.0 instantaneous minimum 6.0 minimum during at least 16 hours of any 24 hour period
Crab Orchard Creek	ND 04	Dissolved Oxygen	Aquatic Life	5.0 instantaneous minimum 6.0 minimum during at least 16 hours of any 24 hour period
		Sulfates		500 mg/L
		Manganese		1000 µg/L
		Total Dissolved Solids (TDS)		1000 mg/L
Crab Orchard Creek	ND 11	pH	Aquatic Life	> 6.5 and <9.0
		Dissolved Oxygen		5.0 instantaneous minimum 6.0 minimum during at least 16 hours of any 24 hour period
Crab Orchard Creek	ND 13	Manganese	Aquatic Life	1000 µg/L
		Dissolved Oxygen		5.0 instantaneous minimum 6.0 minimum during at least 16 hours of any 24 hour period
Little Crab Orchard Creek	NDA 01	Manganese	Aquatic Life	1000 µg/L
		Dissolved Oxygen		5.0 instantaneous minimum 6.0 minimum during at least 16 hours of any 24 hour period
Piles Fork	NDB 03	Dissolved Oxygen	Aquatic Life	5.0 instantaneous minimum 6.0 minimum during at least 16 hours of any 24 hour period
Crab Orchard Lake	RNA	Total Phosphorus	Fish Consumption & Aesthetic Quality	0.05 mg/L
Carbondale City Lake	RNI	Manganese	Public Water Supplies, Aesthetic Quality, & Aquatic Life	150 µg/L
		Total Phosphorus		0.05 mg/L
Marion Reservoir	RNL	Manganese	Public Water Supplies & Aesthetic Quality	150 µg/L
		Total Phosphorus		0.05 mg/L
Herrin New Reservoir	RNZC	Manganese	Public Water Supplies & Aesthetic Quality	150 µg/L
Campus Lake	RNZH	Total Phosphorus	Fish consumption & Aesthetic Quality	0.05 mg/L

3.0 TECHNICAL ANALYSIS

This section of the report addresses the technical approaches applied to calculate TMDLs for total fecal coliform, sulfates, manganese, total dissolved solids, pH, total phosphorus, manganese, and dissolved oxygen. Load duration curves were used to estimate the current and allowable loads of total fecal coliform, sulfates, total dissolved solids, and manganese loads for impaired streams in the Crab Orchard Creek watershed. QUAL2K modeling was used to simulate in-stream dissolved oxygen concentrations and pH for impaired streams in the Crab Orchard Creek watershed and pollutant load reductions that are needed to meet the water quality standards. BATHTUB was used to model total phosphorus in the impaired lakes within the Crab Orchard Creek watershed and the pollutant load reductions that are needed to meet water quality standards. Table 5 presents the listed water bodies and the corresponding modeling approach used to address each TMDL.

Table 5. 303(d) List Information and Modeling Approaches for the Crab Orchard Creek Watershed

Waterbody Name	Segment	Cause of Impairment	Modeling Approach
Crab Orchard Creek	ND 01	Total Fecal Coliform	Load Duration Curve
Crab Orchard Creek	ND 02	Manganese	Load Duration Curve
		Dissolved Oxygen	QUAL2K
Crab Orchard Creek	ND 04	Dissolved Oxygen	QUAL2K
		Sulfates	Load Duration Curve
		Manganese	Load Duration Curve
		Total Dissolved Solids (TDS)	Load Duration Curve
Crab Orchard Creek	ND 11	pH	QUAL2K
		Dissolved Oxygen	QUAL2K
Crab Orchard Creek	ND 13	Manganese	Load Duration Curve
		Dissolved Oxygen	QUAL2K
Little Crab Orchard Creek	NDA 01	Manganese	Load Duration Curve
		Dissolved Oxygen	QUAL2K
Piles Fork	NDB 03	Dissolved Oxygen	QUAL2K
Crab Orchard Lake	RNA	Total Phosphorus	BATHTUB
Carbondale City Lake	RNI	Manganese	BATHTUB/Causal Linkage
		Total Phosphorus	BATHTUB
Marion Reservoir	RNL	Manganese	BATHTUB/Causal Linkage
		Total Phosphorus	BATHTUB
Herrin New Reservoir	RNZC	Manganese	BATHTUB/Causal Linkage
Campus Lake	RNZH	Total Phosphorus	BATHTUB

3.1 Load Duration Curves

Load reductions for fecal coliform (segment ND 01), manganese (segments ND 02, ND 13, NDA 01, ND 04), sulfate (segment ND 04) and total dissolved solids (segment ND 04) are required to meet the water quality standard in Crab Orchard Creek. Flow duration analysis looks at the cumulative frequency of historic flow data over a specified period of time. The steps taken to develop each load duration curve are as follow.

- A flow duration curve for the stream was developed by plotting the flow data against the duration intervals to produce a logarithmic graph. The data for the curve was generated by first ranking the daily flow data from highest to lowest and then calculating the percent of days these flows were exceeded.
- The flow curve is translated into a load duration curve by multiplying by the water quality standard and a conversion factor. The equation used to calculate the load is:

  TMDL Load = Flow x Water Quality Standard x Conversion Factor

  The resulting data points are graphed against the duration interval to produce a curve.
- Each water quality sample is converted to a load by using the formula above but replacing the water quality standard with the observed water quality sample value. The individual load is then plotted as a point..
- Points that are observed above the curve represent deviations from the water quality standard and the allowable total maximum daily load. Points below the curve represent compliance with the water quality standards.
- The area beneath the TMDL curve is the loading capacity of the stream.
- For calculating a representative daily load that must be reduced to meet the water quality standards, the median point for each flow interval is calculated.
- The reduction amount is calculated by comparing the TMDL median allowable daily load with the maximum load of all values within a specific flow interval. The difference between the median TMDL load and the maximum load is the load that must be reduced to meet water quality standards.

Flow duration intervals are expressed in percentage, with zero corresponding to the highest discharge (i.e. flood conditions) and 100 to the lowest (i.e. drought conditions). The flow regimes for this analysis were divided into five categories or “hydrologic zones” as follows:

- High flow zone: flows that plot in the 0 to 10-percentile range, related to flood flows.
- Moist zone: flows in the 10 to 40-percentile range, related to wet weather conditions.
- Mid-range zone: flows in the 40 to 60 percentile range, median stream flow conditions;
- Dry zone: flows in the 60 to 90-percentile range, related to dry weather flows.
- Low flow zone: flows in the 90 to 100-percentile range, related to drought conditions.

The use of duration curve zones allows analysis of general patterns by conveying information about distribution of the data within each zone. These zones provide additional insight about conditions and patterns associated with the impairment (USEPA, 2006).

Load duration curves were developed for total dissolved solids, manganese and sulfate in ND04 to determine the load reduction in the stream and to assess existing and allowable loads. The load duration curve approach was also used to determine load reductions in ND02, ND13 and NDA01 for manganese and in ND01 for fecal coliform.

The load duration approach helps to identify the issues surrounding the impairment and to roughly differentiate between sources. Table 6 summarizes the relationship between the five hydrologic zones and potentially contributing source areas.

The load reduction approach also considers critical conditions and seasonal variation in the TMDL development as required by the Clean Water Act and EPA's implementing regulations. Because the approach establishes loads based on a representative flow regime, it inherently considers seasonal variations and critical conditions attributed to flow conditions. Seasonal variations are incorporated because flow is very closely tied to seasons. For example, the Stage 1 report indicates that flows at the Crab Orchard Creek near Marion average between 20 and 50 cfs from November through June, and decrease to less than 10 cfs from July through October. Critical conditions are addressed because daily allowable loads are identified for each possible in-stream condition, including peak flood events, extreme droughts, and all flows in between (including critical events not directly related to flows, such as fertilizer applications).

Table 6. Relationship between Load Duration Curve Zones and Contributing Sources.

Contributing Source Area	Duration Curve Zone				
	High	Moist	Mid-Range	Dry	Low
Point source				M	H
Livestock direct access to streams				M	H
On-site wastewater systems	M	M-H	H	H	H
Riparian areas		H	H	M	
Stormwater: Impervious		H	H	H	
Combined sewer overflow (CSO)	H	H	H		
Stormwater: Upland	H	H	M		
Field drainage: Natural condition	H	M			
Field drainage: Tile system	H	H	M-H	L-M	
Bank erosion	H	M			
Note: Potential relative importance of source area to contribute loads under given hydrologic condition (H: High; M: Medium; L: Low)					

Daily average flows at the U.S. Geological Survey (USGS) Gage 05597500 were available from 1951 to 2007. The gage is located just upstream of the town of Marion, Illinois at segment ND04 of Crab Orchard Creek. The station is approximately seven miles upstream of Crab Orchard Lake. Data from the USGS gage was utilized to extrapolate the flows at segments ND01, ND02, ND13 and NDA01 using the weighted drainage area ratio. The ratio of flow to watershed area at the USGS gage was multiplied by the watershed area of each segment to calculate the respective flow at each location.

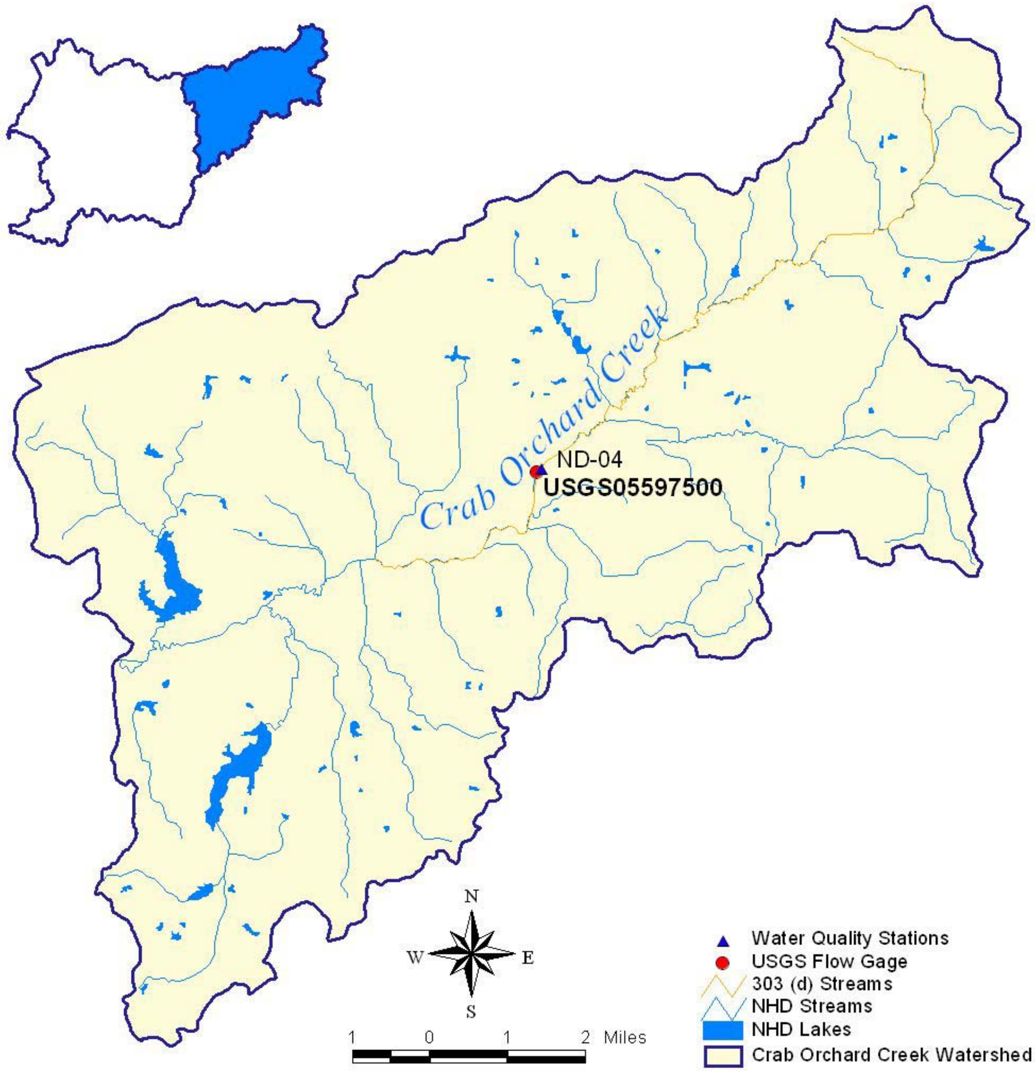

Figure 3. USGS Gage and ND04 Water Quality Station in Crab Orchard Creek Watershed

3.2 QUAL2K Model

The QUAL2K (Chapra, et.al., 2005) water quality model was selected for the development of dissolved oxygen TMDLs in Crab Orchard Creek watershed. QUAL2K is supported by U.S. EPA and has been used extensively for TMDL development and point source permitting issues across the country, especially for issues related to dissolved oxygen concentrations. The QUAL2K model is suitable for simulating hydraulics and water quality conditions of a small river. It is a one-dimensional model with the assumption of a completely mixed system for each computational cell. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. The model allows for multiple waste discharges, water withdrawals, tributary flows, and incremental inflows and outflows. The processes employed in QUAL2K address nutrient cycles, algal growth, and dissolved oxygen dynamics. Two QUAL2K models (current load model and reduced load model) were set up for each impaired stream segment to address low dissolved oxygen conditions. The impaired streams and corresponding impaired segments are Crab Orchard Creek (ND-02, ND-04, ND-11, and ND-13), Little Crab Orchard Creek (NDA-01), and Piles Fork (NDB-03).

Illinois' water quality standard requires a minimum dissolved oxygen concentration of 5 mg/L within the impaired streams. A 10 percent margin of safety (MOS) was explicitly incorporated into the oxygen standard, thus, the final TMDL endpoint was set at 5.5 mg/L of dissolved oxygen. Once the model was setup and calibrated, CBOD and NH4 loads from nonpoint sources were reduced until the TMDL endpoint of 5.5 mg/L was achieved at any point along the stream segment. Final loads after CBOD and NH4 reductions for each impaired segment are summarized in the TMDL tables in Section 5.2 A detailed discussion of the QUAL2K model is included in Appendix B.

3.3 BATHTUB Model

The USACE BATHTUB model (Walker, 1987) was selected for modeling water quality in Crab Orchard Lake, Marion Reservoir, Herrin New Reservoir, Carbondale City Lake and Campus Lake. BATHTUB performs steady-state water and phosphorus balance calculations in a spatially segmented hydraulic network, which accounts for pollutant transport and sedimentation. In addition, the BATHTUB model automatically incorporates internal phosphorus loadings into its calculations. Eutrophication-related water quality conditions (e.g., phosphorus, nitrogen, chlorophyll a, and transparency) are predicted using empirical relationships previously developed and tested for reservoir applications. BATHTUB was determined to be appropriate because it addresses the parameter of concern (phosphorus) and has been used previously for reservoir TMDLs in Illinois and elsewhere. A detailed discussion for each of the individual BATHTUB models is included in Appendix C.

The BATHTUB model requires input data such as evaporation rates, mean annual precipitation, reservoir morphometry, in-lake water quality concentrations and tributary flows and concentrations. Lake morphometry data were available from Stage 1 report (IEPA, 2007) and are summarized in Table 7.

Table 7. Lake Data for Crab Orchard Creek Watershed Lakes

Lake	Parameter	Value
Crab Orchard Lake	Normal Pool Volume (ac-ft)	70,746
	Normal Pool Surface Area (ac)	6,965
	Maximum Depth (ft)	27.5
	Mean Depth (ft)	11.9
Carbondale City Lake	Normal Pool Volume (ac-ft)	480
	Normal Pool Surface Area (ac)	136
	Maximum Depth (ft)	13.0
	Mean Depth (ft)	7.1
Marion Reservoir	Normal Pool Volume (ac-ft)	966
	Normal Pool Surface Area (ac)	220
	Maximum Depth (ft)	16.2
	Mean Depth (ft)	10.7
Herrin New Reservoir	Normal Pool Volume (ac-ft)	411
	Normal Pool Surface Area (ac)	40
	Maximum Depth (ft)	24.5
	Mean Depth (ft)	19
Campus Lake	Normal Pool Volume (ac-ft)	158
	Normal Pool Surface Area (ac)	40
	Maximum Depth (ft)	13.1
	Mean Depth (ft)	10.5

The USGS gage 05597500 located on Crab Orchard Creek near Marion, Illinois is the only available flow gage within the watershed. The flow data recorded at this station was used to estimate tributary flows for the impaired lakes in Crab Orchard Creek watershed. Based on the weighted drainage area ratio, tributary flows were calculated using the following formulae:

$$Q_{ungaged} = A_{ungaged} / A_{gaged} \times Q_{gaged}$$

Where,

$Q_{ungaged}$: Flow at the mouth of ungaged tributary entering the lake.
Q_{gaged}: Flow recorded at USGS station
$A_{ungaged}$: Drainage area of the tributary entering the lake
A_{gaged}: Drainage area at USGS station

There are four major tributary streams flowing into Crab Orchard Lake. Figure 4 shows Crab Orchard Lake with its major tributaries and the water quality stations with available data.

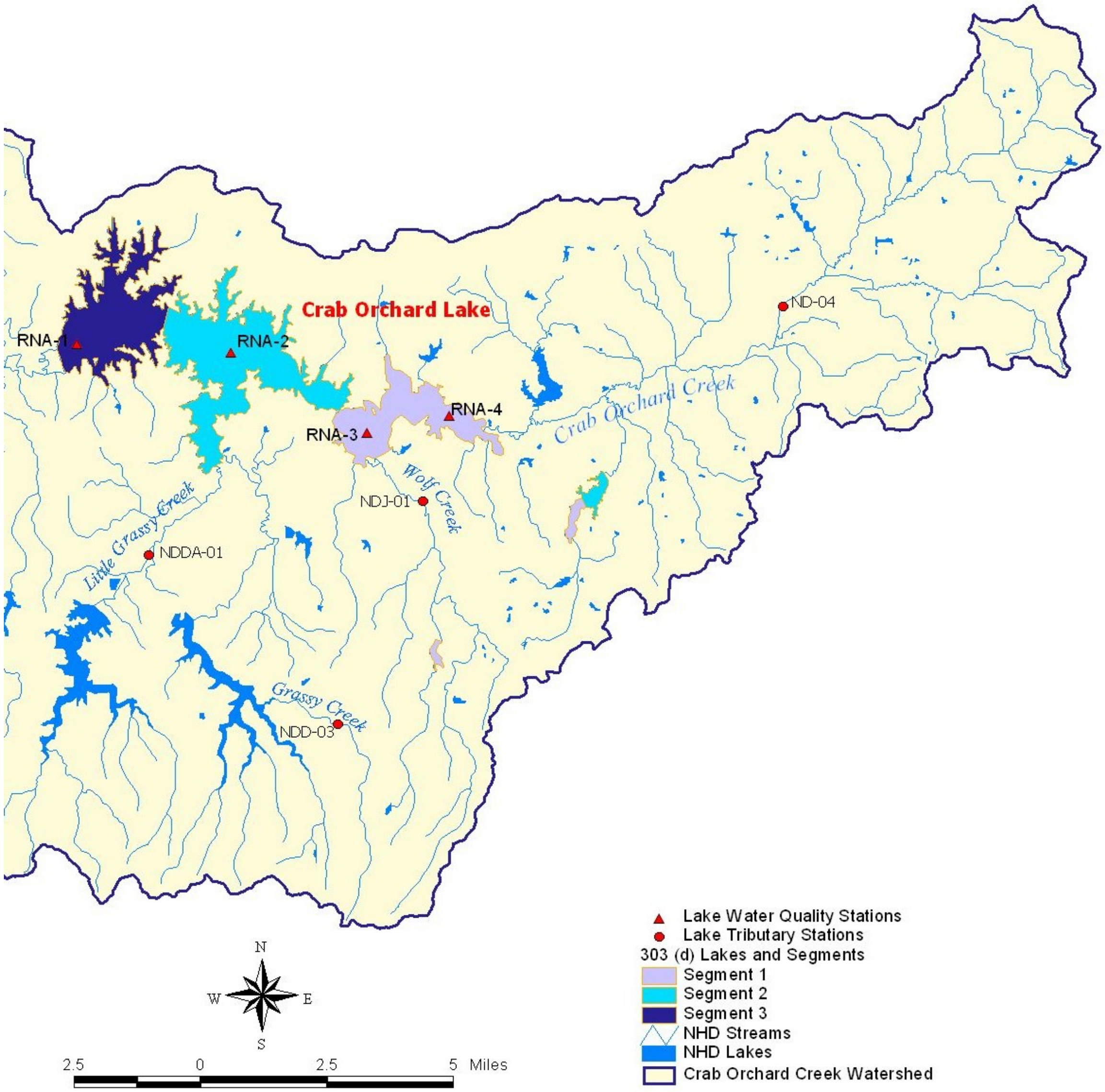

Figure 4. Crab Orchard Lake, Tributaries and Available Water Quality Stations

Phosphorus loads into the Crab Orchard Lake are calculated from mean annual flows and available phosphorus concentration data measured at the tributaries. Water quality data recorded at the ND04 station were used to derive tributary loads from Crab Orchard Creek. For estimating the phosphorus load from Crab Orchard Creek, regression equations for total phosphorus and ortho-phosphorus were developed using data collected at ND-04 station from January 1990 through August 2002. The regression equations are shown in Appendix C. The other tributary streams draining into Crab Orchard Lake are Wolf Creek, Grassy Creek and Little Grassy Creek. For these tributaries, limited water quality data are available and the mean concentration of all years was used when a modeled year concentration was not available.

For Marion Reservoir, Limb Branch is the main tributary stream flowing into the reservoir. Incoming flows for Limb Branch were estimated using the weighted drainage area ratio and flow data measured at the USGS station in Crab Orchard Creek. There are no monitoring stations available with water quality data upstream of Marion Reservoir. Figure 5 shows Marion Reservoir with its major tributary and in-lake water quality stations with available data.

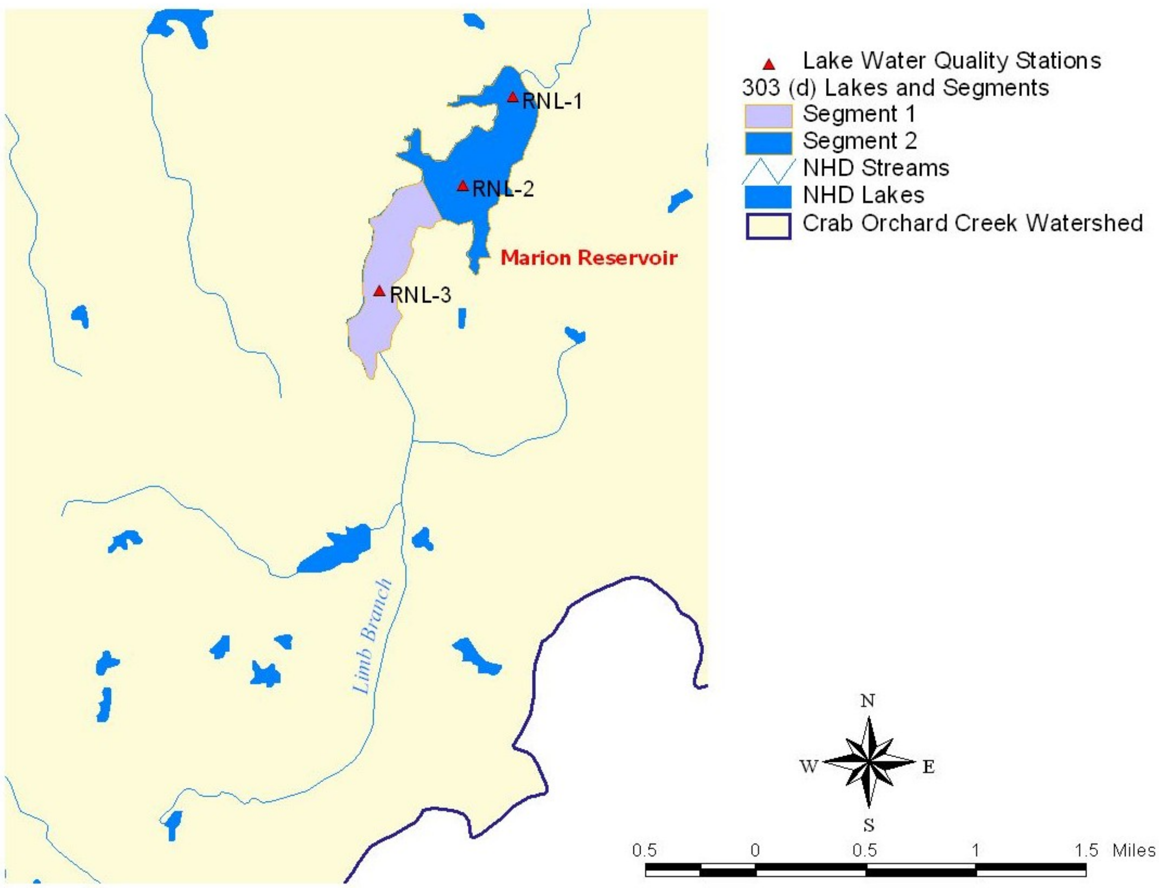

Figure 5. Marion Reservoir, Tributaries and Available Water Quality Stations

For Herrin New Reservoir, Middle Wolf Creek is the main tributary stream flowing into the reservoir. Incoming flows for Middle Wolf Creek were estimated using the weighted drainage area ratio and flow data measured at the USGS station in Crab Orchard Creek. There are no monitoring stations available with water quality data upstream of Herrin New Reservoir. Figure 6 shows Herrin New Reservoir with its major tributary and in-lake water quality stations with available data.

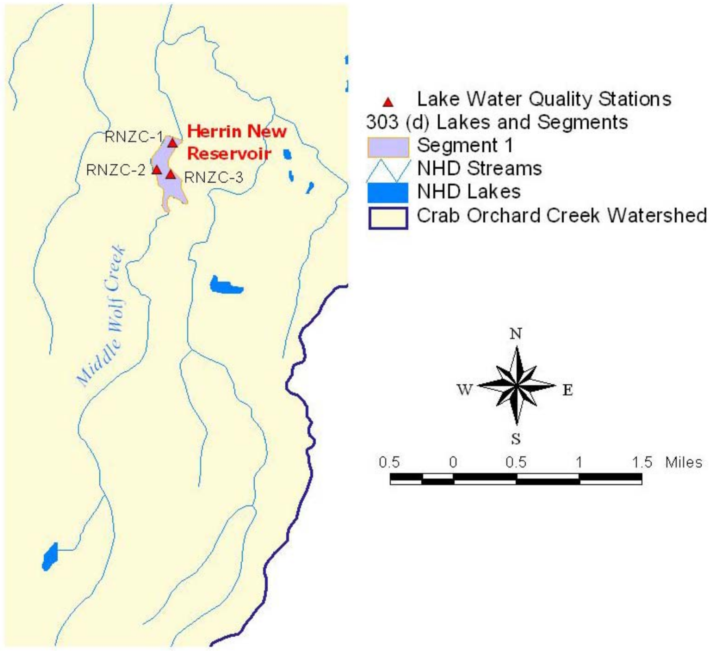

Figure 6. Herrin New Reservoir, Tributaries and Available Water Quality Stations

For Carbondale City Lake, Piles Fork is the main tributary stream flowing into the lake. There are no water quality data available on Piles Fork upstream of Carbondale City Lake. 0 shows Carbondale City Lake with its major tributary and in-lake water quality stations with available data.

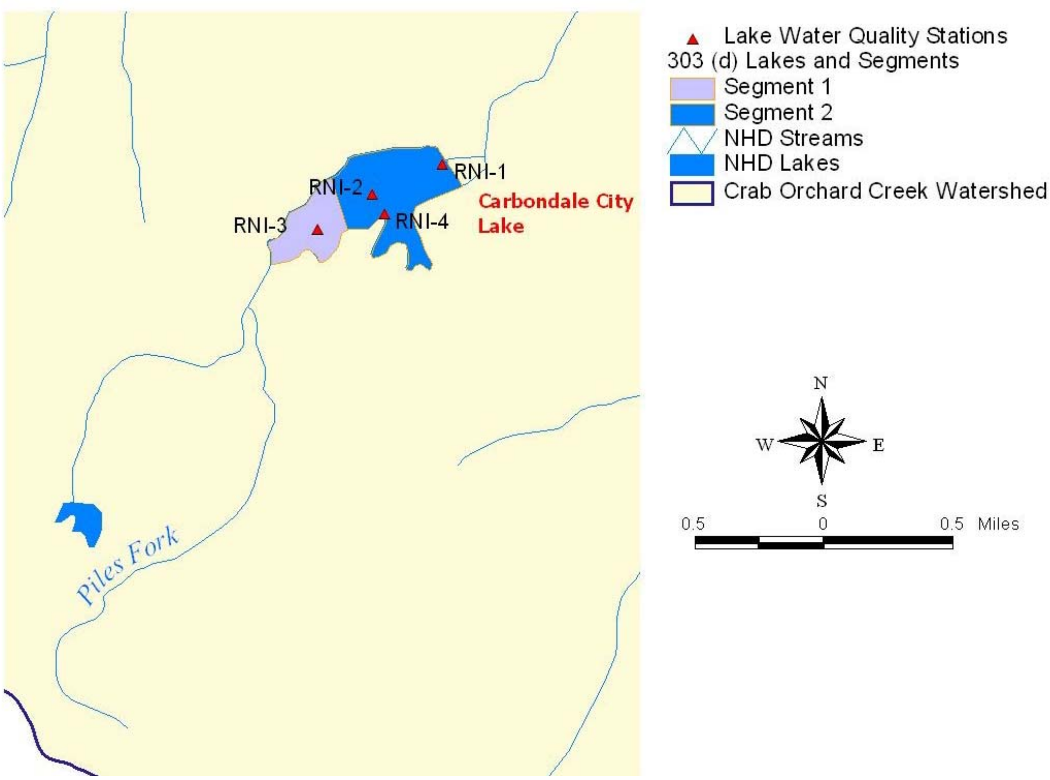

Figure 7. Carbondale City Lake, Tributaries and Available Water Quality Stations

For Campus Lake, there are no tributary streams flowing into the lake. Loading to Campus Lake is mainly from overland flow (direct runoff). Overland flows were estimated using landuse and typical runoff coefficients and were added to the model as tributary flows. Figure 8 shows Campus Lake and the water quality stations with available data.

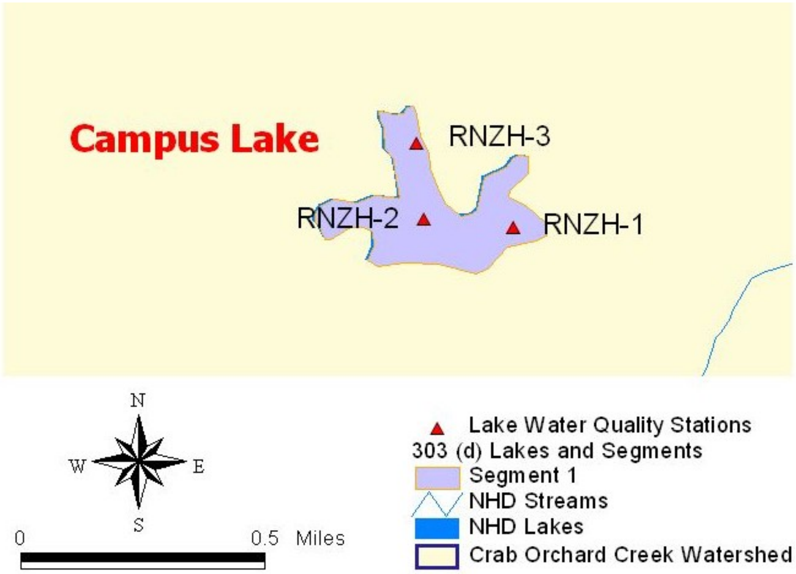

Figure 8. Campus Lake with Available Water Quality Stations

The impaired lakes in Crab Orchard Creek watershed receive nutrient loads from tributary streams, atmospheric deposition, direct runoff, and point sources (where applicable). The BATHTUB model includes rates of direct deposition to the lake surface for total nitrogen and total phosphorus. Direct atmospheric deposition of phosphorus to a lake surface is generally considered insignificant compared to watershed loading rates. In the absence of site-specific data, the BATHTUB default total phosphorus load of 0.27 lb/ac/yr (30 mg/m2/yr) was used for direct atmospheric deposition to the lake for all years modeled. Loadings from direct runoff to the lakes were estimated using land use data, literature based concentrations (Polls and Lanyon, 1980), and typical runoff estimates for each land use.

In addition to total phosphorus loads, the model requires input of inorganic phosphorus loads. Ortho phosphorus refers to dissolved inorganic phosphorus that is available for algae absorption and was assumed to be equal to dissolved phosphorus.

Internal loading rates reflect nutrient recycling from bottom sediments. Internal phosphorus loading is already accounted for in the BATHTUB pre-calibrated nutrient retention models. For Marion Reservoir, Herrin New Reservoir, Carbondale City Lake and Campus Lake, no internal phosphorus loading was added to the BATHTUB models since reverse applications were used to simulate in-lake concentrations. For Crab Orchard Lake, the external loads calculated from tributary streams were under-estimated. Therefore, an internal loading rate of 15.5 mg/m2/day was added to the upstream lake segment. The Nürnberg method (1984) was chosen to approximate the internal loads.

BATHTUB was set up to simulate nutrient lake responses for the years with available water quality data. Table 8 summarizes mean tributary flows and watershed loads for each of the impaired lakes in Crab Orchard Creek watershed, for the years simulated.

Predicted concentrations in the lake were calibrated against observed concentration by adjusting the model coefficient factors in BATHTUB. These factors govern the rate at which the various modeled parameters change concentrations due to decay, plant uptake, settling, etc. Factors for Crab Orchard Lake were set to 2.95, 1.28, and 0.85 for phosphorus in segments 1, 2 and 3, respectively. A calibration factor of 1 indicates that no adjustment to the model is needed. For Marion Reservoir, Herrin New Reservoir, Carbondale City Lake and Campus Lake, a ‘reverse’ BATHTUB application was developed to estimate the tributary loading. A calibration factor of 1 was used in these models and phosphorus loads were adjusted to match observed in-lake concentrations.

Table 8. Annual Flows and Watershed Loading to Crab Orchard Creek Watershed Lakes.

Waterbody	Year	Stream Flow (cfs)	TP Load (lb/day)
Crab Orchard Lake	1991	201	365.2
	1994	290	321.7
	1996	187	669.4
	1997	353	419.2
	2000	203	384.0
Marion Reservoir	1997	5	9.9
	2000	12.8	3.3
Herrin New Reservoir	1996	2.6	11.1
Carbondale City Lake	1991	3.3	13.3
	1997	2.3	5.0
	2000	5.9	2.5
Campus Lake	1996	0.3*	0.6
	1997	0.3*	0.6
	1998	0.3*	0.5

Notes:
* Data represents overland flow (no tributary stream)

4.0 POLLUTANT SOURCES

The Crab Orchard Creek watershed contains waterbodies listed for impairments due to total phosphorus, dissolved oxygen, manganese, sulfate, pH and fecal coliform. Some of the impairments, including phosphorus, manganese and dissolved oxygen, occur throughout the watershed. Both point and nonpoint sources contribute to the impairments.

This section describes each major source category, as well as the impacts and contributions to pollutant loadings in this watershed. The source categories discussed in this section include point source dischargers, onsite wastewater treatment systems, crop production, animal operations, streambank and lake shore erosion, internal loading from lake bottom sediments, historic and active coal mining operations, domestic pets, and wildlife populations. Additional information on these sources, as well as ways to reduce their loads, can be found in the Crab Orchard Creek TMDL Implementation Plan.

4.1 Point Source Dischargers

There are 33 facilities regulated by the National Pollutant Discharge Elimination System that are allowed to discharge industrial or municipal wastewater to waterbodies located in the Crab Orchard Creek watershed. The permitted facilities discharge to Crab Orchard Creek segment ND01 (1), segment ND04 (5); segments ND11 (15), and segment ND13 (1); Piles Fork segment NDB03 (3); Little Crab Orchard Creek segment NDA01 (3); Marion Reservoir (1); and Crab Orchard Lake and its tributaries (4). The details on the average daily flows, permit numbers, average loadings and facility information are provided in the Stage Three Report (IEPA, 2008).

4.1.1 Fecal Coliform

Effluent from sewage treatment plants treating domestic and/or municipal waste contains fecal coliform bacteria which come from sanitary sewage. Sewage treatment plants, located throughout the watershed, are likely the main point source inputs of fecal coliform in the Crab Orchard Creek watershed. Though the permits do not require that facilities monitor fecal coliform in the primary effluent, concentrations that occur from excessive flows through the combined sewer overflows (CSO) must be monitored. The EPA Water Discharge Permits Query (PCS) contains little data for facilities concerning the fecal coliform concentrations measured during CSOs.

Loads from treatment plants’ primary and excessive flow discharge pipes are difficult to quantify given the lack of monitoring data. Meeting fecal coliform water quality standards may require that these facilities disinfect and monitor the primary effluent. This implementation plan addresses plant upgrades to include a disinfection process step and controlling combined sewer overflows.

4.1.2 Manganese and Sulfate

There are three facilities with permits to discharge manganese and sulfate in the Crab Orchard Creek watershed (Marion Southeast STP, Freeman United Coal Mine, and LLC Classic Mine). However, two of these facilities are currently being reclaimed and the other facility is suspended.

4.1.3 Dissolved Oxygen

Impacts on dissolved oxygen concentrations resulting from point source dischargers may be due to nutrient induced eutrophication, oxidation of ammonia and other compounds, or degradation of biodegradable organic material. Most of the NPDES permitted dischargers in the watershed are required to monitor the amount of carbonaceous biochemical oxygen demand (CBOD) in their effluent.

4.1.4 Phosphorus

In the watershed, there are five point source dischargers to Crab Orchard Lake and one point source discharger to Marion Reservoir that are required to monitor their effluent for total phosphorus (Table 9).

Table 9. Average Daily Phosphorus Loads from Facilities Carrying Permit Limitations.

Facility Name	Permit Number	Receiving Stream	TP Load (lb/d)
Marion Southeast STP	IL0029734	ND04/RNA	18.58
Verizon Communications	IL0059625	RNA	0.11
Crab Orchard Estates-Hughes	IL0053830	RNA	0.06
Marion WTP	ILG640158	RNA	5.56
SI Bowling & Rec Center	IL0054101	RNA	0.23
U.S. Penitentiary WTP	IL0074829	RNL	0.09

4.2 Onsite Wastewater Treatment Systems

Onsite wastewater treatment systems are not typically a significant source of pollutant loading if they are operating as designed. However, if the failure rates of systems in this watershed are high, the loading from this source may be significant. In Williamson County, where 90 percent of the septic systems in the Crab Orchard Creek watershed are located, 60 to 70 percent of the systems are not maintained well (IEPA, 2007). Approximately 5,330 onsite wastewater treatment systems are present in the Crab Orchard watershed.

The impaired Campus and Carbondale City lakes are located in Jackson County, which is served by a municipal sewer system. In Williamson County, where Crab Orchard Lake is located, the municipalities are served by sewer systems as well. Franklin-Williamson Bi-County Health Department has reported that pollutants from failing septic systems drain to Crab Orchard Lake.

Pollutant loading rates from properly functioning onsite wastewater systems are typically insignificant. However, if systems are placed on unsuitable soils, not maintained properly, or are connected to subsurface drainage systems, loading rates to receiving waterbodies may be relatively high. It is suggested that each system in the watershed be inspected to accurately quantify the loading from this source. Systems older than 20 years and those located close to the lakes or streams should be prioritized for inspection.

4.2.1 Fecal Coliform

Even properly functioning onsite wastewater systems can contribute fecal coliform loading to the surrounding environment. Fecal coliform impairments occur throughout the Crab Orchard Creek watershed. Approximately 5,330 wastewater treatment systems are located within the watershed. In a properly functioning septic system, wastewater effluent leaves the septic tank and percolates through the system drainfield. Typically, by the time effluent reaches the groundwater zone, Fecal coliform concentrations have been reduced by 99.99 percent by natural processes (Siegrist et al., 2000). Failing systems that short circuit the soil adsorption field, result in ponding on the ground surface, or backup into homes, and will have concentrations typical of raw (untreated) sewage. Direct discharge systems that intentionally bypass the drainfield by connecting the septic tank directly to a waterbody or other transport line (such as an agricultural tile drain) will also have concentrations similar to raw sewage.

4.2.2 Dissolved Oxygen

Septic systems contribute nutrient loads to the environment that may result in eutrophication (excessive plant/algae growth and decay) of streams and lakes. The systems also discharge substances that consume oxygen during decomposition, referred to as biochemical oxygen demand or BOD. Once these substances reach the streams and lakes in the watershed, their decay will consume oxygen and decrease concentrations.

4.2.3 Phosphorus

In a properly functioning septic system, wastewater effluent leaves the septic tank and percolates through the system drainfield. Phosphorus is removed from the wastewater by adsorption to soil particles. Plant uptake by vegetation growing over the drainfield is assumed negligible since all of the phosphorus is removed in the soil treatment zone. Failing systems that either short circuit the soil adsorption field or cause effluent to pool at the ground surface are assumed to retain phosphorus through plant uptake only (average annual uptake rate of 0.2 g/capita/day). Direct discharge systems that intentionally bypass the drainfield by connecting the septic tank effluent directly to a waterbody or other transport line (such as an agricultural tile drain) do not allow for soil zone treatment or plant uptake.

4.3 Crop Production

Out of approximately 83,464 acres of land devoted to agricultural activities in the Crab Orchard Creek watershed, about 37,000 acres (20 percent) are used for production of corn, soybeans, wheat, and other small grains. Due to application of commercial fertilizer, manure, and pesticides, as well as increased rates of erosion, pollutant loads from croplands are relatively high compared to other land uses. This section describes the mechanisms of pollutant loading from farmland for each of the pollutants causing impairments in the watershed.

4.3.1 Manganese

Impairments due to manganese occur throughout the Crab Orchard Creek watershed, and crop production could be a significant contributor. Manganese is found naturally in the environment in groundwater and soils. Because crop production tends to increase rates of erosion, the sediment bound manganese loads tend to increase as a result of this land use. In addition, much of the land farmed in this watershed is classified as highly erodible.

Typical concentrations of manganese in Southern Illinois range from 4 to 200 milligrams of manganese per kilogram of soil (mg/kg) with an average value of 23 mg/kg (Ebelhar, 2007). Based on data presented by Czapar et al. (2006), conventional chisel plow crop production activities in Midwestern states result in sediment loads of 7.5 tons/ac/yr. Approximately 37,000 acres of land are used for crop production in the Crab Orchard watershed.

4.3.2 Dissolved Oxygen

Crop production activities likely have indirect impacts on dissolved oxygen concentrations. Issues related to eutrophication will be mitigated by controlling phosphorus loads. Runoff concentrations and sediment-bound levels of biodegradable organic material should be negligible (excluding fields that spread manure for fertilizer).

4.3.3 Phosphorus

Crop production is a secondary land use throughout the Crab Orchard watershed. Based on data presented by Gentry et al. (2007), phosphorus loading rates from tiled agricultural fields in east-central Illinois range from 0.5 to 1.5 lb/ac/yr (comparable data were not identified for southern Illinois).

4.3.4 Animal Operations

Pollutant loading from animal operations can be a problem in both confined and pasture-based systems. Though the exact location of animal operations in the watershed is not known, countywide statistics indicate that a large number of livestock, swine, and poultry may exist.

Agricultural animal operations are a potential source of pollutant loading if adequate best management practices (BMPs) are not in place to protect surface waters. Livestock operations either consist of confined or pasture-based systems. If a confined operation has greater than 1,000 animal units or is determined to threaten water quality, the operation requires a federal Concentrated Animal Feeding Operation (CAFO) permit. CAFOs are required to develop a nutrient management plan (NMP) as part of the permitting process (USEPA, 2003). NMPs consists of manure management and disposal strategies that minimize the release of excess nutrients into surface and groundwater. The CAFO NMPs are based on NRCS standards and technical expertise.

The Stage One Report for the Crab Orchard Creek watershed (IEPA, 2007) summarizes the estimated number of livestock and poultry based on the 2002 Census of Agriculture data for Williamson, Jackson, Union and Johnson Counties. An area-weighted method was used to estimate the number of animals in the Crab Orchard Creek watershed (Table 10).

Table 10. Estimated Number of Livestock and Poultry in the Crab Orchard Creek Watershed.

Animal	Total No. of Animals
Poultry	236
Beef cattle	3,637
Dairy cattle	182
Other cattle: heifers, bulls, calves, etc.	7,261
Hogs and pigs	4,247
Sheep and lambs	121
Horses and ponies	503

4.3.5 Fecal Coliform

Fecal coliform impairments occur throughout the Crab Orchard Creek watershed. Each county in the watershed contains animal operations that likely contribute to this load. The county statistics are presented in the Stage One Report for cattle, poultry, swine, and sheep in the watershed (IEPA, 2007).

4.3.6 Dissolved Oxygen and Phosphorus

Dissolved oxygen impairments due to animal operations may result from the breakdown of organic material in the streams and lakes or eutrophication due to excessive nutrients which leads to eventual algal decay as well as nighttime respiration. It should be noted that animals with access to streambanks will exacerbate dissolved oxygen problems by increasing bank erosion and decreasing canopy cover. This impact is difficult to quantify, but can be controlled by animal management BMPs as discussed in the Implementation Plan.

4.4 Streambank and Lake Shore Erosion

Streambank and lake shore erosion are potential source of nutrients and sediments to the impaired lakes in Crab Orchard Creek watershed. Damage caused by the flooding of agricultural lands along the main channel is prevalent in the watershed. Erosion caused by excessive runoff is of great concern, as it contributes to the overall water quality problems within the watershed. Both phosphorus and manganese contribute to the composition of sediment and once this sediment reaches the lakes, these elements may be released through biological and chemical transformations. Release of phosphorus may increase rates of algal and plant growth (eutrophication), which leads to issues with dissolved oxygen concentrations, water treatability, and aesthetics. Manganese also effects water treatment operations and is detrimental to aquatic life at high concentrations.

In addition to the release of phosphorus and manganese, erosion will also reduce the stability of streambanks by undercutting the roots of established vegetation and altering the stream channel itself. Loss of vegetative canopy and widening of a stream channel will allow more sunlight to reach the water column which may increase rates of eutrophication, increase water temperatures, and decrease the amount of dissolved oxygen the water can hold.

The Illinois Department of Natural Resources (IDNR) has begun an inventory of streams in the State for inclusion in the Illinois Stream Information System (ISIS). So far, all reaches in the state draining at least 10 square miles are included in the database. For those stream channels and lake shores that have not yet been inventoried by IDNR, the most cost-effective way to assess erosion is to visually inspect representative reaches of each channel or lake and rank the channel stability using a bank erosion index. Banks or shorelines ranked moderately to severely eroding could be targeted for stabilization efforts. A more time and resource intensive method is to determine the rate of erosion by inserting bank pins and measuring the rate of recession. Once soil loss estimates are obtained, reaches can be prioritized for restoration and protection.

The Marion County has an estimated 8,800 acres of cropland that is highly erodible. The average sedimentation rate is 319,200 tons/year and the total deposited sediment in Crab Orchard Lake is 104,000 tons/year (WCSWCD, 2007). Typical concentrations of manganese in Southern Illinois range from 4 to 200 milligrams of manganese per kilogram of soil (mg/kg) with an average value of 23 mg/kg (Ebelhar, 2007).

4.5 Internal Loading from Lake Bottom Sediments

Several lakes/reservoirs in the Crab Orchard Creek watershed are listed for pollutants that may be released from bottom sediments in anoxic lakes. Carbondale City Lake, Crab Orchard Lake, Marion Reservoir and Campus Lake are listed for phosphorus and Carbondale City Lake, Marion and Herrin New Reservoir are listed for manganese.

Both manganese and phosphorus may be released internally from lake sediments when oxygen concentrations near the bottom of the lake reach low levels. Low dissolved oxygen in lakes may be caused by degradation of organic material or respiration of algae in the absence of sunlight. Conditions for low dissolved oxygen are more severe during the summer months when the water temperatures are higher resulting in naturally lower dissolved oxygen concentrations.

4.5.1 Manganese

Manganese concentrations range from 0.25 to 0.38 mg/L in Carbondale City Lake, 0.10 to 0.62 mg/L in Marion Reservoir, and 0.12 to 2.20 mg/L in Herrin New Reservoir. Manganese concentrations from bottom deposits range from 540 to 2,200 mg/L in Carbondale City Lake, 480 to 4,000 mg/L in Marion Reservoir, and 1,200 to 2,900 mg/L in Herrin New Reservoir. The manganese data indicate higher concentrations near the lake bottom, suggesting it is likely that the bottom sediments are releasing manganese. Collection of additional manganese data in the lakes and its tributaries will allow for a quantitative estimate of this source. If internal loading is deemed a significant source, then the inlake management measures may be necessary.

4.5.2 Phosphorus

Phosphorus concentrations in Crab Orchard Lake range from 0.08 mg/L to 0.220 mg/L. Other lake concentrations are: Campus Lake - 0.010 to 0.045 mg/L; Marion Reservoir - 0.053 to 0.085 mg/L; and Carbondale City Lake 0.049 to 0.211 mg/L. Estimating the fraction of phosphorus in the water column that originates from re-suspended sediment stores is difficult with the current data. More intensive water quality studies of the lake and its tributaries would be required to estimate the significance of this load.

4.6 Historic Coal Mining Operations

Historic coal mining operations are prevalent in the northeastern part of the watershed around Segment ND 04 of Crab Orchard Creek. Most of the historic mining operations are concentrated around the city of Pittsburg and Spillertown in the Crab Orchard Creek Watershed. Water that infiltrates into the historically mined area comes into contact with the exposed coal seams or mine waste and becomes loaded with acidity, metals, and sulfates and later discharges at topographically low points along segment ND04 of the watershed.

Three permitted mines were observed in the vicinity of the drainage area for Segment ND04. The permitted NPDES facilities are:

- Freeman United Coal Mining (FUCM) - permit number IL0004865
- Illinois LLC-Classic Mine (LLC Classic) - permit number IL0060372
- Delta Mine Holding Company (DMHC) - permit number IL0060402

Both the Illinois LLC-Classic Mine and DMHC are in reclamation and no active mining occur at these facilities. The DMHC facility received runoff from a very limited watershed and rarely discharges to Crab Orchard Creek. The other two coal mine facilities (LLC-Classic and FUCM) have been identified as point sources which either discharge a significant flow or potentially discharge sediment and nutrient loads. Sulfate and manganese data from 2002 to 2005 were available for LLC-Classic Mine. FUCM is the only facility that is required to monitor or control sulfate and manganese based on their permit. The FUCM coal cleaning plant has been dismantled since the time it was suspended (Phifer, 2007). There are currently 4 employees at the mine recovering coal fines and doing coal refuse pile reclamation. The mine discharges water to Crab Orchard Creek only in response to precipitation events and dust control (which is performed on an as needed basis).

4.7 Domestic Pets and Wildlife Populations

Domestic pets such as cats and dogs and wildlife animals such as deer, geese, ducks, etc., can be significant sources of pollutant loading in watersheds that have high densities of urban populations or in rural communities with relatively undisturbed land use patterns. In the Crab Orchard Creek watershed, where the majority of land is used for agricultural production, these sources are likely not significant relative to the loading from animal operations, point source dischargers, and failing onsite wastewater systems.

4.8 Lawn Fertilizers

Another potential source of nutrients to the impaired lakes is lawn fertilizer application from residential properties surrounding the lakes. Nutrients in lawn fertilizers from residential areas are carried to lakes by runoff and can be a major seasonal source of phosphorus. Loading rates from lawn fertilizers (residential land use) have been reported at 0.68 lb/ac/yr to 1.96 lb/ac/yr for total phosphorus (Loehr, et.al., 1989). The number of residential properties surrounding the impaired lakes in Crab Orchard Creek watershed is unknown.

5.0 TMDL

A TMDL is the maximum amount of a pollutant that a waterbody can receive without violating the water quality standards. TMDLs are composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources (including natural background levels). In addition, the TMDL must include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between effluent limitations and water quality. A TMDL can be defined by the equation:

$$\text{TMDL} = \sum \text{WLAs} + \sum \text{LAs} + \text{MOS}$$

A TMDL must identify the loading capacity of a waterbody for the applicable pollutant. USEPA regulations define loading capacity as the greatest amount of a pollutant that a waterbody can receive without violating water quality standards. The loading capacity provides a reference that guides pollutant reduction efforts needed to bring water bodies into compliance with the water quality standards. A summary of the TMDL allocations for the Crab Orchard Creek watershed is presented in the following sections of this report.

5.1 Loading Capacity for Fecal Coliform, Sulfate, Total Dissolved Solids and Manganese

The load duration curve approach was used to determine the load capacity of streams in Crab Orchard Creek watershed impaired by fecal coliform, sulfate, total dissolved solids and manganese. The loading curve provides an estimate of the loading capacity for various flow regimes and the loading capacity is based on the median observed load for each flow category (e.g. 5th, 25th, 50th, 75th and 95th percentiles).

The following sections provide a summary of the load duration curve analysis for segments ND01, ND02, ND04, ND13 and NDA01 of the Crab Orchard Creek watershed. Appendix A includes the details of the load duration analysis performed for these segments.

5.1.1 Loading Capacity of Crab Orchard Creek Segment ND01

Crab Orchard Creek segment ND01 is 9.61 miles long from the confluence with Piles Fork downstream to the confluence with Big Muddy River. This segment drains approximately 207 square miles of land which is primarily agricultural (soybean) and rural grassland. Segment ND01 is listed as impaired for fecal coliform. A total of 57 fecal coliform samples were available for the load duration analysis and existing and allowable fecal coliform loads were calculated for this segment.

The general use water quality standard for fecal coliform states that the standard of 200 per 100 mL not be exceeded by the geometric mean of at least five samples, nor can 10 percent of the samples collected exceed 400 per 100 mL in protected waters, except as provided in 35 Ill. Adm. Code 302.209(b). Samples must be collected over a 30 day period and the standard applies during the months of May through October. Therefore, only fecal coliform data and flows observed during these months were used for the load duration analysis.

There are 23 NPDES permitted facilities that discharge upstream of Crab Orchard Creek segment ND01:

- Reed Station MHP - permit number ILG551008
- Southern Il Univ-C Lit Grassy - permit number IL0047899
- Bush MHP STP #2-Carbondale - permit number IL0046060
- Chateau Apartments - permit number ILG551058
- Corner One Stop - Carbondale - permit number ILG551016

- Frost Mobile Home Park - permit number IL0047635
- Giant City School - permit number IL0025844
- IL DOC-Giant City State Park - permit number IL0049531
- Meadowbrook Estates MHP - permit number IL0038423
- Pleasant Hill MHP - permit number ILG551059
- Pleasant Valley MHP - permit number IL0047601
- Southern Mobile Home Park - permit number ILG551077
- United Methodist Camp - permit number IL0045632
- Unity Point Elm School District 140 - permit number IL0045748
- University Heights MHP - permit number IL0038415
- Wildwood Mobile Home Park - permit number ILG551093
- S.I. Properties LLC - permit number ILG551066
- Beazer East Inc-Carbondale - permit number IL0000400
- SIU-Carbondale - permit number IL0072320
- M&M Rentals MHP - permit number ILG551017
- Lenore Basin Corp-Union Hills - permit number ILG551037
- Lilac Basin Corp.-Union Hill - permit number IL0046221
- Tan Tara 2 Mobile Home Park - permit number IL0049077

Of these facilities, only two (M&M Rentals and Tan Tara 2 MHPs) have permit limits for fecal coliform. All other facilities are not required to monitor fecal coliform because they have a disinfection exemption, which allows them to discharge wastewater without disinfection. All of these treatment facilities are required to comply with the geometric mean fecal coliform water quality standard of 200 cfu/100 mL at the closest point downstream where recreational use occurs in the receiving water or where the water flows into a fecal-impaired segment. Facilities with year-round disinfection exemptions may be required to provide the Agency with updated information to demonstrate compliance with these requirements. Facilities directly discharging into a fecal-impaired segment may have their year-round disinfection exemption revoked through future NPDES permitting actions. Fecal coliform WLAs were estimated based on the assumption that the permitted facilities operate under a disinfection exemption which limits fecal coliform effluent to 200 count/100 ml.

Within each flow regime, load reductions are based on the difference between the current load and the TMDL load. For segment ND01, load reductions using the maximum current load are extremely high. Therefore, the geometric mean of all data points above the curve was compared to the TMDL load to provide for a more realistic percentage reduction in this segment. Table 11 presents the TMDL summary for segment ND01. Results of the load duration analysis indicate that fecal coliform observations exceed the loading limit throughout the entire flow ranges. Reductions of fecal coliform required to meet the TMDL during the five flow zones range from 82 to 98 percent.

Table 11. Fecal Coliform TMDL Summary for Crab Orchard Creek Segment ND01

Station ND01 TMDL		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Pollutant	**TMDL Component**	**0-10**	**10-40**	**40-60**	**60-90**	**90-100**
Fecal Coliform (G-org/day)	Current Load (Geomean)[1]	97,498.13	985.05	160.44	71.58	2.92
	LA	2052.86	138.94	28.53	7.06	0.01
	TMDL= LA+WLA+MOS	2,163.17	148.52	32.29	9.69	2.26
	WLA	5.22	5.22	5.22	5.22	5.22
	MOS (5%)[2]	108.16	7.43	1.61	0.48	0.10
	TMDL Reduction (%)	98	86	82	90	98

[1]Existing load calculated based on geometric mean of samples within each flow range because maximum load is extremely high and results in unrealistic load reductions.

Potential sources of fecal coliform in this segment include municipal point sources, livestock, agriculture, non-irrigated crop production, private sewage systems, urban runoff and wildlife. Livestock and animal feeding operations are prevalent throughout Marion County and are major contributors of fecal coliform to segment ND01. In addition, private surface systems are also common in the area and if not treated properly can release untreated sewage to local waterways. IEPA has estimated that between 20 and 60 percent of surface discharging systems statewide are failing or have failed suggesting that such systems may be a significant source of pollutants (IEPA, 2004). Wildlife, including birds and terrestrial animals, can be potential sources of fecal coliform as well.

5.1.2 Loading Capacity of Crab Orchard Creek Segment ND02

Crab Orchard Creek segment ND02 is 1.92 miles long and extends from the Crab Orchard Lake spillway downstream to the confluence with Indian Creek. This segment drains approximately 199 square miles with primarily rural grassland and agricultural land uses. Segment ND02 is listed as impaired for manganese. A total of 60 manganese samples were available for the load duration analysis. The general use water quality standard of 1000 µg/L for manganese was applied to develop the allowable loading capacity for segment ND02. Out of 60 manganese samples, only two loads exceeded the water quality standard. There are no NPDES facilities that are allowed to discharge in this segment.

Table 12 presents the TMDL summary for segment ND02. Results indicate that load reductions are needed for the moist (67%) and dry (56%) flow conditions. For all other flow conditions, the loads observed were below the threshold TMDL load and therefore no reductions are required.

The high manganese levels in segment ND02 may be attributed to natural background conditions including soil with naturally-occurring manganese concentrations or accumulations. Releases of manganese from river bottom sediments and from Crab Orchard Lake bottom sediments are also potential sources of manganese. Since point sources are not identified, the observed manganese levels in segment ND02 most likely reflect natural background conditions.

Table 12. Manganese TMDL Summary for Crab Orchard Creek Segment ND02

Station ND02 TMDL		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Pollutant	**TMDL Component**	**0-10**	**10-40**	**40-60**	**60-90**	**90-100**
Total Manganese (lb/day)	Current Load	-	67.43	-	2.33	-
	LA	246.36	23.27	20.50	1.07	0.15
	TMDL= LA+WLA+MOS	259.33	24.5	21.58	1.13	0.16
	WLA(lb/day)	0	0	0	0	0
	MOS (5%)	12.97	1.23	1.08	0.06	0.01
	Reduction	-	67%	-	56%	-

5.1.3 Loading Capacity of Crab Orchard Creek Segment ND04

Crab Orchard Creek segment ND04 is 13.93 miles long and is located upstream of U.S. Highways 37 and northeast of Marion, Illinois. This segment drains approximately 31 square miles of land use/land cover which is primarily pasture grassland (41%), deciduous forest (25%) and cultivated crops (21%). Segment ND04 is impaired by manganese, total dissolved solids (TDS), and sulfate. A total of 147 manganese samples, 115 sulfate samples, and 4 TDS samples were available for the load duration analysis. Existing and allowable loads of manganese, TDS and sulfate were calculated for segment ND04.

Three permitted mines and two sewage treatment plants (STP) discharge into segment ND04. The permitted NPDES facilities are:

- Freeman United Coal Mining (FUCM) - permit number IL0004685
- Illinois LLC-Classic Mine (LLC Classic) - permit number IL0060372
- Delta Mine Holding Company (DMHC) - permit number IL0060402
- Crab Orchard Community Unit School District #3-STP - permit number IL0037311
- Marion Southeast – Sewage Treatment Plant (MS-STP) - permit number IL0029734

There are no NPDES facilities that report effluent TDS concentrations in this segment of Crab Orchard Creek. Two NPDES facilities that are permitted to discharge manganese and sulfates in this segment are FUCM and LLC Classic. MS-STP is also permitted to discharge manganese.

Table 13 presents the TMDL summary for segment ND04. Results of the load duration analysis indicate that reductions in manganese and sulfate loads are not required for high flow conditions. Manganese load reductions of 50 and 70 percent and sulfate load reduction of 76 and 46 percent are required to meet the water quality standard for moist and mid-range flows, respectively. Manganese and sulfate load reductions in dry and low flow conditions are significantly high (greater than 91%). The WLA was assumed constant for all flow regimes except for low flow conditions when the estimated WLA was higher than the TMDL load. In this case, the WLA was set equal to the TMDL minus the MOS.

TDS concentrations and conductivity (specific conductance) were measured once during moist condition and three times during dry conditions no reductions of TDS are required in Crab Orchard Creek segment ND04.

Table 13. Manganese, Sulfate and Total Dissolved Solid TMDL Summary for Crab Orchard Creek Segment ND04

Station ND04 TMDL		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Pollutant	**TMDL Component**	**0-10**	**10-40**	**40-60**	**60-90**	**90-100**
Total Manganese (lb/day)	Current Load	699.32	148.93	61.49	20.78	1.99
	LA	817.43	74.14	17.75	0.93	0.01
	TMDL= LA+WLA+MOS	863.36	80.94	21.58	3.89	0.54
	WLA: FUCM	0.35	0.35	0.35	0.35	0.35
	WLA: LLC Classic	0.09	0.09	0.09	0.09	0.09
	WLA: DMHC	n/a	n/a	n/a	n/a	n/a
	WLA: STP	2.31	2.31	2.31	2.31	0.06
	MOS (5%)	43.17	4.05	1.08	0.19	0.03
	Reduction	0%	50%	71%	96%	99%
Total Sulfate (lb/day)	Current Load	-	159,306	16,502	9,713	1,398
	LA	409,267	40,466	9,423	966	-
	TMDL= LA+WLA+MOS	431,680	43,468	10,792	1,889	270
	WLA: FUCM	520	520	520	520	243
	WLA: LLC Classic	309	309	309	309	-
	WLA: DMHC	n/a	n/a	n/a	n/a	n/a
	WLA: STP	n/a	n/a	n/a	n/a	n/a
	MOS (5%)	21,584	2,173	540	94	14
	Reduction	-	76%	46%	91%	99%
Total Dissolved Solids (lb/day)	Current Load	-	-	-	-	-
	TMDL (lb/day)	884,944	80,940	21,584	3,777	540
	LA	796,450	72,846	19,426	3,399	486
	WLA: Mines	0	0	0	0	0
	WLA: STP	n/a	n/a	n/a	n/a	n/a
	MOS (10%	88494	8094	2158	378	54
	Reduction	n/a	n/a	n/a	n/a	n/a

Potential sources of manganese and sulfate in this segment include resource extraction and surface mining. Surface mining was historically prevalent around segment ND04, as evidenced by three permitted mining facilities located in the vicinity of the Crab Orchard Creek. Out of three mines that were located around ND04, two are under reclamation and one is suspended.

5.1.4 Loading Capacity of Crab Orchard Creek Segment ND13

Crab Orchard Creek segment ND13 is 1.5 miles long and is located between Highway 13 and the confluence with Piles Fork. This segment drains approximately 252 square miles and the upstream land use consists of primarily deciduous forest (34%), developed land (43%) and cultivated crops (14%). Segment ND13 is impaired by manganese. The general use water quality standard of 1000 µg/L for manganese was applied to develop TMDL loads for segment ND13. Only two manganese samples, collected in 2000, were available for load duration analysis at this site. Existing and allowable loads were calculated for Crab Orchard Creek segment ND13.

There are two NPDES facilities that are permitted to discharge to segment ND13:

- San Pat Apartments (S.I. Properties LLC) - permit number ILG551066
- M&M Rentals MHP - permit number ILG551017

Manganese loads for these facilities were not calculated because sampling for manganese is not required by the discharge permits for these facilities and they are not expected to be significant sources of manganese. Therefore, WLAs of zero were specified for these facilities as part of this TMDL.

Table 14 presents the TMDL summary for segment ND13. The manganese data were collected during dry flow conditions and only one sample exceeded the threshold limit. An overall reduction of 84 percent is required during dry flow conditions to meet the water quality standard. Because there are only two samples available for manganese, it is recommended that future monitoring be conducted to allow for a more thorough water quality assessment in Crab Orchard Creek segment ND13.

Table 14. Manganese TMDL Summary for Crab Orchard Creek Segment ND13

Station ND02 TMDL		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Pollutant	**TMDL Component**	**0-10**	**10-40**	**40-60**	**60-90**	**90-100**
Total Manganese (lb/day)	Current Load	No Data	No Data	No Data	172.83	No Data
	LA	6403.05	624.69	156.15	27.33	3.90
	TMDL= LA+WLA+MOS	7114.50	694.10	173.50	30.37	4.34
	WLA	0	0	0	0	0
	MOS (10%)	711.45	69.41	17.35	3.04	0.43
	Reduction	No Data	No Data	No Data	84%	No Data

Possible sources of manganese loads in segment ND13 may be attributed to natural background conditions and release of manganese from river bottom sediments.

5.1.5 Loading Capacity of Crab Orchard Creek Segment NDA01

Little Crab Orchard Creek (Segment NDA01) is 12.21 miles long and flows north to segment ND01. Little Crab Orchard Creek drains approximately 9 square miles and the upstream land use consists of primarily pasture grassland (28%), deciduous forest (29%), and developed land (27%). Little Crab Orchard Creek is impaired by manganese. Five manganese samples were available for load duration analysis, two of which were sampled on 1995, one in 1996 and one in 2006. Existing and allowable loads were calculated using the load duration curve approach. The manganese water quality standard of 1000 μg/L was used to develop TMDL loads for this segment.

There are three NPDES facilities that are permitted to discharge in Little Crab Orchard Creek:

- Lilac Basin Corp - Union Hill (Lilac) - permit number IL0046221
- Lenore Basin Corp – Union Hills (Lenore) - permit number ILG551037
- Tan Tara 2 Mobile Home Park (TTMHP) - permit number IL0049077

WLAs of zero for these facilities were specified as part of this TMDL because these facilities do not discharge manganese.

Table 15 presents the TMDL summary for Little Crab Orchard Creek. Manganese data were collected during moist, mid-range and dry flow conditions. Only one sample exceeded the threshold limit during dry flow conditions. An overall load reduction of twenty-two percent is required during dry flow conditions to meet the general use water quality standard for manganese. Because there are only five samples available for manganese, it is recommended that future monitoring be conducted to allow for a more thorough water quality assessment in Little Crab Orchard Creek.

Possible sources of manganese impairment at NDA01 may be attributed to natural background conditions and release of manganese from river bottom sediments. Since the point sources are not significant contributors, the observed manganese levels in segment NDA01 are likely due to the natural geochemical environment and most likely reflect natural background conditions.

Table 15. Manganese TMDL Summary for Segment NDA01, Little Crab Orchard Creek

Station NDA01 TMDL		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Pollutant	**TMDL Component**	**0-10**	**10-40**	**40-60**	**60-90**	**90-100**
Total Manganese (lb/day)	Current Load	No Data	-	-	1.31	No Data
	LA	233.40	22.50	5.83	1.02	0.15
	TMDL= LA+WLA+MOS	259.34	25.00	6.48	1.14	0.16
	WLA: Lilac	n/a	n/a	n/a	n/a	n/a
	WLA: Lenore	n/a	n/a	n/a	n/a	n/a
	WLA: TTMHP	n/a	n/a	n/a	n/a	n/a
	MOS (10%)	25.93	2.50	0.65	0.11	0.02
	Reduction	No Data	-	-	22%	No Data

5.1.6 Wasteload Allocations

The WLAs for the NPDES permitted facilities were determined by multiplying the facility's design flow by the appropriate effluent limit. Average maximum flow was utilized to calculate WLAs if design flow information was not provided.

There are 23 NPDES permitted facilities that discharge upstream of Crab Orchard Creek segment ND01. Of these facilities, only two (M&M Rentals and Tan Tara 2 MHPs) have permit limits for fecal coliform. All other facilities are not required to monitor fecal coliform because they have a disinfection exemption, which allows them to discharge wastewater without disinfection. All of these treatment facilities are required to comply with the geometric mean fecal coliform water quality standard of 200 cfu/100 mL at the closest point downstream where recreational use occurs in the receiving water or where the water flows into a fecal-impaired segment. Facilities with year-round disinfection exemptions may be required to provide the Agency with updated information to demonstrate compliance with these requirements. Facilities directly discharging into a fecal-impaired segment may have their year-round disinfection exemption revoked through future NPDES permitting actions. Fecal coliform WLAs were estimated based on the assumption that the permitted facilities operate under a disinfection exemption which limits fecal coliform effluent to 200 count/100 ml.

There are no NPDES facilities that discharge into Crab Orchard Creek segment ND02. Therefore, no manganese WLAs were specified for segment ND02 as part of this TMDL.

Five NPDES facilities, including two sewage treatment plants (STP) and three historic coal mines discharge to segment ND04. LLC-Classic Mine and DMHC are in reclamation with no active mining taking place at these facilities. The single outfall from the DMHC facility receives runoff from a small watershed and discharges rarely to Crab Orchard Creek. Therefore, WLA from DMHC for manganese, sulfate, and TDS were set to zero. FUCM and LLC Classic facilities measure sulfate and manganese concentrations and WLA estimates were included in the TMDL analysis. Sulfate and manganese data for LLC-Classic Mine were available from 2002 to 2005 and for FUCM from January 2006 to June 2007. The average flow was utilized to calculate the sulfate and manganese loads at FUCM because operations at this facility were suspended in 1985. The coal cleaning plant at FUCM has been dismantled since the time it was suspended. There are currently 4 employees at the mine recovering coal fines and doing coal refuse pile reclamation. The mine discharges water to the Crab Orchard Creek only in response to precipitation and dust control on as needed basis (Phifer, 2007). Marion Southeast STP contributes manganese to segment ND04 thus WLA for this facility were included in the TMDL analysis. None of the five NPDES facilities discharging to ND04 measure TDS concentrations. Therefore, no WLAs for TDS were specified for segment ND04 as part of this TMDL.

There are two NPDES facilities that are permitted to discharge to segment ND13 and three NPDES facilities that are permitted to discharge in Little Crab Orchard Creek (segment NDA01). Manganese WLAs of zero were established for these facilities because sampling for manganese is not required by the discharge permits and these facilities are not expected to be significant sources of manganese.

Table 16 presents a summary of the NPDES facilities with allowable WLAs, flows, and discharge pipe location.

Table 16. WLA for NPDES Facilities in the Crab Orchard Creek watershed

Facility name	Permit #	Design Flow (MGD)	Parameters	WLA[1]	Outfall Pipes
Freeman United Coal Mine	IL0004685	n/a	Manganese	0.35	001, 01A
LLC Classic Mine	IL0060372	n/a	Manganese	0.09	001, 002, 003, 004
Marion Southeast STP	IL0029734	4.95	Manganese	2	007
Freeman United Coal Mine	IL004685	n/a	Sulfate	520	001, 005, 007, 010, 01A
LLC Classic Mine	IL0060372	n/a	Sulfate	309	001, 002, 003, 004
Reed Station MHP	ILG551008	0.032	Fecal coliform	0.24	-
Southern Il Univ-C Lit Grassy	IL0047899	0.058	Fecal coliform	0.44	-
Bush MHP STP #2-Carbondale	IL0046060	0.01	Fecal coliform	0.08	-
Chateau Apartments	ILG551058	0.026	Fecal coliform	0.20	-
Corner One Stop - Carbondale	ILG551016	0.01	Fecal coliform	0.08	-
Frost Mobile Home Park	IL0047635	0.013	Fecal coliform	0.10	-
Giant City School	IL0025844	0.005	Fecal coliform	0.04	-
IL DOC-Giant City State Park	IL0049531	0.015	Fecal coliform	0.11	-
Meadowbrook Estates MHP	IL0038423	0.012	Fecal coliform	0.09	-
Pleasant Hill MHP	ILG551059	0.031	Fecal coliform	0.23	-
Pleasant Valley MHP	IL0047601	0.054	Fecal coliform	0.41	-
Southern Mobile Home Park	ILG551077	0.029	Fecal coliform	0.22	-
United Methodist Camp	IL0045632	0.009	Fecal coliform	0.07	-
Unity Point Elm School District 140	IL0045748	0.029	Fecal coliform	0.22	-
University Heights MHP	IL0038415	0.039	Fecal coliform	0.30	-
Wildwood Mobile Home Park	ILG551093	0.02	Fecal coliform	0.15	-
S.I. Properties LLC	ILG551066	0.06	Fecal coliform	0.45	-
Beazer East Inc-Carbondale	IL0000400	0.153	Fecal coliform	1.16	-
SIU-Carbondale	IL0072320	0.027	Fecal coliform	0.20	-
M&M Rentals MHP	ILG551017	0.003	Fecal coliform	0.02	-
Lenore Basin Corp-Union Hills	ILG551037	0.006	Fecal coliform	0.05	-
Lilac Basin Corp.-Union Hill	IL0046221	0.009	Fecal coliform	0.07	-
Tan Tara 2 Mobile Home Park	IL0049077	0.035	Fecal coliform	0.26	-
Crab Orchard Community Unit School District #3-STP	IL0037311	0.005	Fecal coliform	0.04	-

[1] Units are lbs/day for manganese and sulfate and G-org/day for fecal coliform.

5.1.7 Load Allocation

The load allocation represents the total discharges from various nonpoint sources in the watershed. The load allocations are based on subtracting the margin of safety (MOS) and wasteload allocation (WLA) from the allowable loads. The load allocations for impaired segments ND01, ND02, ND04, ND13, and NDA01 in Crab Orchard Creek watershed are presented in Appendix A.

5.1.8 Margin of Safety

Section 303(d) of the Clean Water Act and USEPA's regulations at 40CFR 130.7 require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety (MOS) which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." The margin of safety can either be implicitly incorporated into conservative assumptions used to develop the TMDL or added as a separate component of the TMDL (USEPA, 1999). Different margins of safety were used depending on the amount of available data with which to estimate current loads. Sites with greater than 50 samples received a five percent margin of safety, whereas sites with less than 50 samples received a 10 percent margin of safety. This approach is summarized below:

- ND-01 57 fecal samples: 5%
- ND-02 60 manganese samples: 5%
- ND-04 5 TDS samples: 10%
- ND-04 115 sulphate samples: 5%
- ND-04 147 manganese samples: 5%
- ND-13 2 manganese samples: 10%
- NDA-01 5 manganese samples: 10%

5.1.9 Critical Conditions and Seasonality

Section 303(d)(1)(C) of the Clean Water Act and USEPA's regulations at 40CFR 130.7 (c)(1) require that a TMDL be established that addresses seasonal variations normally found in the natural system. The Clean Water Act requires that TMDLs take into account critical conditions for stream flow, loading, and water quality parameters as part of the analysis of loading capacity. Critical conditions refer to the periods when greatest reductions of pollutants are needed. The load duration curve approach inherently considers seasonal variations and critical conditions attributed to flow variations because the approach establishes loads based on a representative flow regime.

It is difficult to identify critical conditions for some pollutants in the watershed due to the lack of observed data. Seasonal variations for fecal coliform TMDL are addressed by only assessing conditions during the season when the water quality standard applies (May through October). Unlike for fecal coliform, there is no standard set for manganese, sulfate and TDS for a particular season. The standard is set for the whole year. The load duration curve approach accounts for seasonality by evaluating allowable loads on a daily basis over the entire range of observed flows and presenting daily allowable loads that vary with different flow conditions. Since flow and seasons are closely related, the allowable loads should also be closely related. For example, the Stage 1 report indicates that flows at the Crab Orchard Creek near Marion average between 20 and 50 cfs from November through June, and decrease to less than 10 cfs from July through October. A long-term flow record was used for the load duration curves (56 years) and therefore the full range of potential flows is represented in the analysis.

5.2 Loading Capacity for Dissolved Oxygen

The following sections summarize the QUAL2K analysis and resulting TMDLs for Crab Orchard Creek (segments ND02, ND04, ND11, and ND13), Piles Fork (NDB03), and Little Crab Orchard Creek (NDA01). Table 17 and Table 18 list the CBOD and ammonia load reductions from nonpoint sources that are required to achieve a minimum dissolved oxygen concentration of 5.0 mg/L in the impaired stream segments. For modeling of DO loads using QUAL2K, reductions were applied to nonpoint source only. Some of the impaired segments (e.g., ND04 and ND11) have significant contributions from point sources. However, load reductions were not applied to point sources because these facilities are currently permitted to discharge into Crab Orchard Creek.

Loading capacities to address the dissolved oxygen impairments are made for carbonaceous biochemical oxygen demand (CBOD) and total ammonia. CBOD measures the rate of oxygen uptake by micro-organisms in a sample of water and is an indication of the amount of biodegradable carbon in organic matter. Total ammonia is the sum of ammonia (NH_3) and ammonium (NH_4+) and is significant because the conversion of ammonium to nitrate by bacteria consumes dissolved oxygen.

5.2.1 CBOD Loading Capacity

Table 17 displays the CBOD loading capacity (TMDL), load allocations, wasteload allocations, and percentage reductions necessary to meet the dissolved oxygen standard. Reductions of CBOD range from 13 to 99.9 percent with likely sources similar to the sources of fecal coliform (i.e., livestock and runoff from animal feeding operations and failing onsite wastewater treatment systems).

Table 17 indicates that significant load reductions from nonpoint sources would be needed to achieve the dissolved oxygen water quality standard in ND02. It is unknown at this time whether the nonpoint source load reductions are even feasible, given that much of this load is associated with natural background sources during these low flow periods when the dissolved oxygen problem is most prevalent. For example, leaf fall from vegetation near the water's edge, aquatic plants, and drainage from organically rich areas like swamps and bogs are all natural sources of material that consumes oxygen. Based on these considerations no TMDL will be developed at this time and instead methods to reduce pollutant loadings and increase in-stream re-aeration will be outlined in the Implementation Plan.

Table 17. QUAL2K Results for CBOD

Carbonaceous biochemical oxygen demand	Current Loads (lb/day)	Reduced Loads/LA (lb/day)	NPS Reduction Percentage	WLA (lb/day)	TMDL (lb/day)
Crab Orchard Creek (ND02)	13.01	0.01	99.9	0	0.01
Crab Orchard Creek (ND04)	168.62	82.89	51	126.85	209.74
Crab Orchard Creek (ND11)	22.64	9.97	56	13.97	23.93
Crab Orchard Creek (ND13)	356.74	311.19	13	2.34	313.53
Piles Fork (NDB03)	5.25	2.38	55	2.70	5.08
Little Crab Orchard Creek (NDA01)	46.60	24.52	47	2.49	27.01

Notes: NPS = Nonpoint Sources; LA = Load Allocation; WLA = Wasteload Allocation

5.2.2 Ammonia Loading Capacity

Table 18 displays the ammonia loading capacity (TMDL), load allocations, wasteload allocations, and percent reductions necessary to meet the dissolved oxygen standard. Percentage reductions from nonpoint sources range from 5 to 73 percent to reach the TMDL values.

Table 18. QUAL2K Results for Ammonia

Ammonia	Current Loads (lb/day)	Reduced Loads/LA (lb/day)	NPS Reduction Percentage	WLA (lb/day)	TMDL (lb/day)
Crab Orchard Creek (ND02)	0.24	0.13	45	0	0.13
Crab Orchard Creek (ND04)	83.93	22.26	73	16.73	38.99
Crab Orchard Creek (ND11)	2.15	1.06	51	1.93	2.99
Crab Orchard Creek (ND13)	256.29	243.95	5	0	243.95
Piles Fork (NDB03)	0.77	0.43	44	0	0.43
Little Crab Orchard Creek (NDA01)	5.8	2.06	64	1.5	3.56

Notes: NPS = Nonpoint Sources; LA = Load Allocation; WLA = Wasteload Allocation

5.2.3 Wasteload Allocation

There are 23 NPDES facilities draining to the 303 (d) listed streams within the Crab Orchard Creek watershed. As required by the Clean Water Act, WLAs were developed for each of these facilities as part of the TMDL development process. Table 19 shows the individual WLAs for each facility.

Table 19. WLA for NPDES Permitted Facilities in Crab Orchard Creek Watershed

NPDES	Segment ID	Flow (cfs)	CBOD (lb/day)	NH4 (lb/day)
Crab Orchard Grade Hs	ND04	0.009	0.26	0.26
Marion Southeast STP	ND04	7.67	126.59	16.47
Southern Il Univ-C Lit Grassy	ND11	0.058	0.98	0.62
Bush MHP STP #2-Carbondale	ND11	0.010	0.36	0.07
Chateau Apartments	ND11	0.026	0.67	-
Corner One Stop - Carbondale	ND11	0.010	0.71	0.07
Frost Mobile Home Park	ND11	0.013	0.50	-
Giant City School	ND11	0.005	0.10	0.06
IL DOC-Giant City State Park	ND11	0.015	0.001	0.25
Meadowbrook Estates MHP	ND11	0.012	0.47	0.15
Pleasant Hill MHP	ND11	0.031	0.99	-
Pleasant Valley MHP	ND11	0.054	0.93	-
Southern Mobile Home Park	ND11	0.029	2.57	-
United Methodist Camp	ND11	0.009	0.33	-
Unity Point Elm School District 140	ND11	0.029	2.12	0.25
University Heights MHP	ND11	0.039	1.24	0.46
Wildwood Mobile Home Park	ND11	0.020	1.99	-
S.I. Properties LLC	ND13	0.06	2.34	-
Beazer East Inc-Carbondale	NDB03	0.153	2.38	-
SIU-Carbondale	NDB03	0.027	0.32	-
Lenore Basin Corp-Union Hills	NDA01	0.006	0.24	-
Lilac Basin Corp.-Union Hill	NDA01	0.009	0.21	0.27
Tan Tara 2 Mobile Home Park	NDA01	0.035	2.03	1.23

5.2.4 Load Allocation

Load allocation represents the allowable loads from nonpoint source. The load allocations are based on subtracting the margin of safety (MOS) and wasteload allocation (WLA) from the total allowable loads. The load allocations for dissolved oxygen impaired segments ND04, ND11, ND13, NDB03, and NDA01 in Crab Orchard Creek watershed are presented in Table 17 and Table 18.

5.2.5 Margin of Safety

The Clean Water Act requires that a TMDL include a margin of safety (MOS) to account for uncertainties in the relationship between pollutants loads and receiving water quality. USEPA guidance explains that the MOS may be implicit (i.e., incorporated into the TMDL through conservative assumptions in the analysis) or explicit (i.e., expressed in the TMDL as loadings set aside for the MOS). A 10 percent margin of safety (MOS) was explicitly incorporated into the TMDLs by identifying load reductions that will achieve a minimum dissolved oxygen concentration of 5.5 mg/L instead of 5.0 mg/L.

5.2.6 Critical Conditions and Seasonality

Section 303(d)(1)(C) of the Clean Water Act and USEPA's regulations at 40 CFR 130.7(c)(1) require that a TMDL be established that addresses seasonal variations normally found in natural systems. The lowest dissolved oxygen typically occurs during the summer months with high water temperature and low flow conditions. The critical dates selected for the TMDLs were during conditions of low flow and the summer's high water temperature which are known to create low dissolved oxygen in the targeted streams. If the low dissolved oxygen concentration exhibited during the critical date is controlled, IEPA expects that the dissolved oxygen concentration will be above the water quality criteria during any other seasonal conditions of the streams.

5.3 Loading Capacity for Total Phosphorus

The BATHTUB model was used to identify the load reductions necessary to achieve the target total phosphorus (TP) concentration in the Crab Orchard watershed lakes. The following sections provide a summary of the BATHTUB results for Crab Lake, Marion Reservoir, Herrin New Reservoir, Carbondale City Lake and Campus Lake. Table 20 to Table 24 summarize the mean TP concentrations in the impaired lakes after necessary reductions are applied to meet the TMDL target. The lake TP allocations are provided in Table 27.

5.3.1 Crab Orchard Lake Loading Capacity

The total phosphorus target for Crab Orchard Lake is 0.05 mg/L. To meet the phosphorus target in Crab Orchard Lake for all years, an 80 percent reduction in phosphorus loads is required. Table 20 shows the mean annual total phosphorus concentrations if an 80 percent load reduction is implemented.

Table 20. Mean Annual Total Phosphorus Concentrations in Crab Orchard Lake with 80 Percent Reduction in Loading

Year	Lake TP (mg/L)
1991	0.048
1994	0.042
1996	0.049
1997	0.041
2000	0.050

Excessive algal production, lakeshore erosion, and release of nutrients from lake-bottom sediments are potential causes of impairment responsible for high phosphorus loadings. These and other potential sources will be more fully investigated during development of the implementation plan.

5.3.2 Marion Reservoir Loading Capacity

The total phosphorus target for Marion Reservoir is 0.05 mg/L. Marion Reservoir is also listed as being impaired due to total manganese, which is considered to be a side-effect of the phosphorus impairment. Excessive phosphorus loadings are believed to be exerting negative effects on the aquatic ecosystem by increasing algal and aquatic plant life production (Sharpley et al., 1994). Excessive algal production leads to anoxic conditions in the bottom of the lake and release of manganese from the bottom sediments. IEPA believes that attaining the total phosphorus target of 0.05 mg/L will result in shifting plant production back to natural levels, which in turn will result in manganese concentrations falling below the water quality standard. To meet the phosphorus target in Marion Reservoir for all years, a 58 percent reduction in phosphorus loads is required. Table 21 shows the mean annual total phosphorus concentrations if a 58 percent load reduction is implemented.

Table 21. Mean Annual Total Phosphorus Concentrations in Marion Reservoir with 58 Percent Reduction in Loading

Year	Reservoir TP (mg/L)
1997	0.049
2000	0.030

5.3.3 Herrin New Reservoir Loading Capacity

Herrin New Reservoir is listed as being impaired due to total manganese, which is considered to be a side-effect of phosphorus impairment. The total phosphorus target for Herrin New Reservoir is 0.05 mg/L. To meet the phosphorus target in Herrin New Reservoir in 1996, a 73 percent reduction of phosphorus load is required. Table 22 shows the mean annual total phosphorus concentration if a 73 percent load reduction is implemented.

Table 22. Mean Annual Total Phosphorus Concentration in Herrin New Reservoir with 73 Percent Reduction in Loading

Year	Reservoir TP (mg/L)
1996	0.050

5.3.4 Carbondale City Lake Loading Capacity

The total phosphorus target for Carbondale City Lake is 0.05 mg/L. Carbondale City Lake is also impaired by manganese, which is considered to be a side-effect of the phosphorus impairment. Excessive phosphorus loadings are believed to be exerting negative effects on the aquatic ecosystem by increasing algal and aquatic plant life production (Sharpley et al., 1994). Excessive algal production leads to anoxic conditions in the bottom of the lake and release of manganese from the bottom sediments. IEPA believes that attaining the total phosphorus target of 0.05 mg/L will result in shifting plant production back to natural levels, which in turn will result in manganese concentrations falling below the water quality standard. To meet the phosphorus target in Carbondale City Lake for all years, a 90 percent reduction of phosphorus load is required. Table 23 shows the mean annual total phosphorus concentrations if a 90 percent load reduction is implemented.

Table 23. Mean Annual Total Phosphorus Concentrations in Carbondale City Lake with 90 Percent Reduction in Loading

Year	Lake TP (mg/L)
1991	0.050
1997	0.019
2000	0.015

5.3.5 Campus Lake Loading Capacity

The total phosphorus target for Campus Lake is 0.05 mg/L. To meet the phosphorus target for all years, a 33 percent reduction of phosphorus load is required. Table 24 shows the mean annual total phosphorus concentrations if a 33 percent reduction is implemented.

Table 24. Mean Annual Total Phosphorus Concentrations in Campus Lake with 33 Percent Reduction in Loading

Year	Lake TP (mg/L)
1991	0.046
1994	0.050
1996	0.048

5.3.6 Wasteload Allocation

There are five permitted dischargers to Crab Orchard Lake and one permitted discharger to Marion Reservoir. Table 25 and Table 26 show the wasteload allocations in Crab Orchard Lake and Marion Reservoir. Marion Southeast STP is the only facility that reports total phosphorus concentrations. For this facility, the average phosphorus concentration of 0.45 mg/l and the design flow were use to calculate the WLA. For the other facilities, a phosphorus concentration of 3.5 mg/l was used to calculate the WLAs. There are no permitted dischargers of total phosphorus to Herrin New Reservoir, Carbondale City Lake or Campus Lake. Therefore, total phosphorus wasteload allocations for these lakes are zero.

Table 25. Total Phosphorus Wasteload Allocation to Crab Orchard Lake

Waste Facilities	Discharge (cfs)	Load lb/day
Marion Southeast STP	7.673	18.58
Verizon Communications	0.006	0.11
Crab Orchard Estates-Hughes	0.003	0.06
Marion WTP	0.295	5.56
SI Bowling & Rec Center	0.012	0.23

Table 26. Wasteload Allocation to Marion Reservoir

Waste Facilities	Discharge (cfs)	Load lb/day
U.S. Penitentiary WTP	0.005	0.09

5.3.7 Load Allocation

The allocations of loads for the impaired lakes in Crab Orchard Creek watershed is presented in Table 27. The existing loads are the average annual loads to each lake based on the years with available data. The loading capacity was calculated based on the percentage reduction from existing loads determined in the modeling analysis. Ten percent of the loading capacity is reserved for a margin of safety (as required by the Clean Water Act; see Section 4.3.8 for more information on the margin of safety). The load allocation is calculated as the loading capacity minus the wasteload allocation minus the margin of safety.

Table 27. TMDL Summary for the lakes in Crab Orchard Watershed.

Lake	Category	Phosphorus (lb/day)
Crab Orchard Lake	Existing Load	431.9
	Reduction	80%
	Loading Capacity	88.3
	Wasteload Allocation	24.5
	Margin of Safety (10%)	8.8
	Load Allocation	54.9
Marion Reservoir	Existing Load	6.6
	Reduction	58%
	Loading Capacity	2.8
	Wasteload Allocation	0.1
	Margin of Safety (10%)	0.3
	Load Allocation	2.4
Herrin New Reservoir	Existing Load	11.1
	Reduction	73%
	Loading Capacity	3.1
	Wasteload Allocation	-
	Margin of Safety (10%)	0.3
	Load Allocation	2.7
Carbondale City Lake	Existing Load	6.9
	Reduction	90%
	Loading Capacity	0.7
	Wasteload Allocation	-
	Margin of Safety (10%)	0.1
	Load Allocation	0.6
Campus Lake	Existing Load	0.6
	Reduction	33%
	Loading Capacity	0.4
	Wasteload Allocation	-
	Margin of Safety (10%)	0.04
	Load Allocation	0.3

5.3.8 Margin of Safety

Section 303(d) of the Clean Water Act and USEPA's regulations at 40 CFR 130.7 require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." The margin of safety can either be implicitly incorporated into conservative assumptions used to develop the TMDL or added as a separate explicit component of the TMDL (USEPA, 1999). A ten percent explicit margin of safety has been incorporated into the Crab Orchard creek watershed lake TMDLs by reserving a portion of the loading capacity.

A relatively low explicit margin of safety was selected because of the good calibration results in each lake:

- Crab Orchard Lake: average relative error of 13 percent

- Marion Reservoir: average relative error of 0 percent (“reverse” BATHTUB model)
- Herrin New Reservoir: average relative error of -2 percent
- Carbondale City Lake: average relative error of 0 percent (“reverse” BATHTUB model)
- Campus Lake: average relative error of 0 percent (“reverse” BATHTUB model)

An implicit MOS is also associated with the recommended phosphorus loading reductions resulting in lake water quality being better than the water quality standard in most years except for the most critical years.

5.3.9 Critical Conditions and Seasonality

Section 303(d)(1)(C) of the Clean Water Act and USEPA’s regulations at 40 CFR 130.7(c)(1) require that a TMDL be established that addresses seasonal variations normally found in natural systems. Seasonal variation is represented in Crab Orchard Creek watershed lakes as conditions were modeled on an annual basis. Modeling on an annual basis takes into account the seasonal effects the lakes undergo during a given year. Since the pollutant source can be expected to contribute loadings in different quantities during different time periods, this TMDL focus on average annual loadings rather than specifying different loadings by season. Because an average annual basis was used for TMDL development, it is assumed that any critical condition is accounted for within the analysis.

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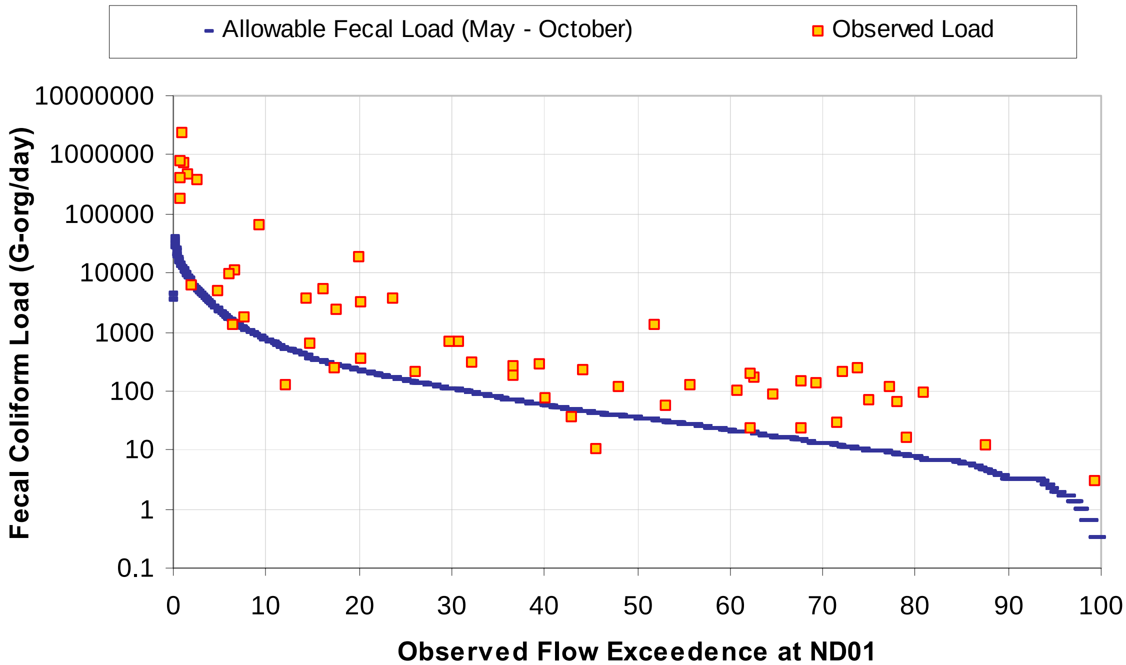
Appendix A : Load Duration Analysis

A.1 Fecal Coliform -vs- Flow at Segment ND-01

1. Load Exceedence Analysis

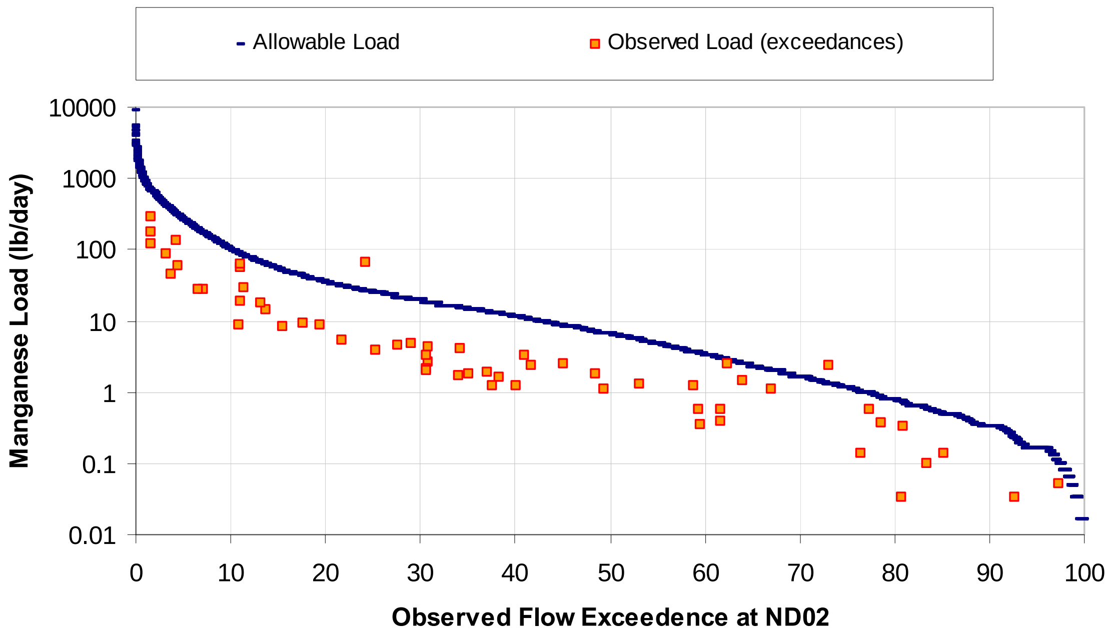


2. Estimated TMDL Loads by Flow Exceedence Range

Flow Exceedence Ranges	Sample Distribution	Median Observed flow (cfs)	Allowable Load (G-org/day)	Observed Load (G-org/day)	Estimated Reduction (%)
0-10	14	442.19	2163.17	97498.13	98%
10 -40	17	30.36	148.52	985.05	85%
40-60	8	6.60	32.29	160.44	80%
60-90	17	1.98	9.69	71.58	86%
90-100	1	0.46	2.26	2.92	23%

A.2 Manganese -vs- Flow at Segment ND-02

1. Load Exceedence Analysis

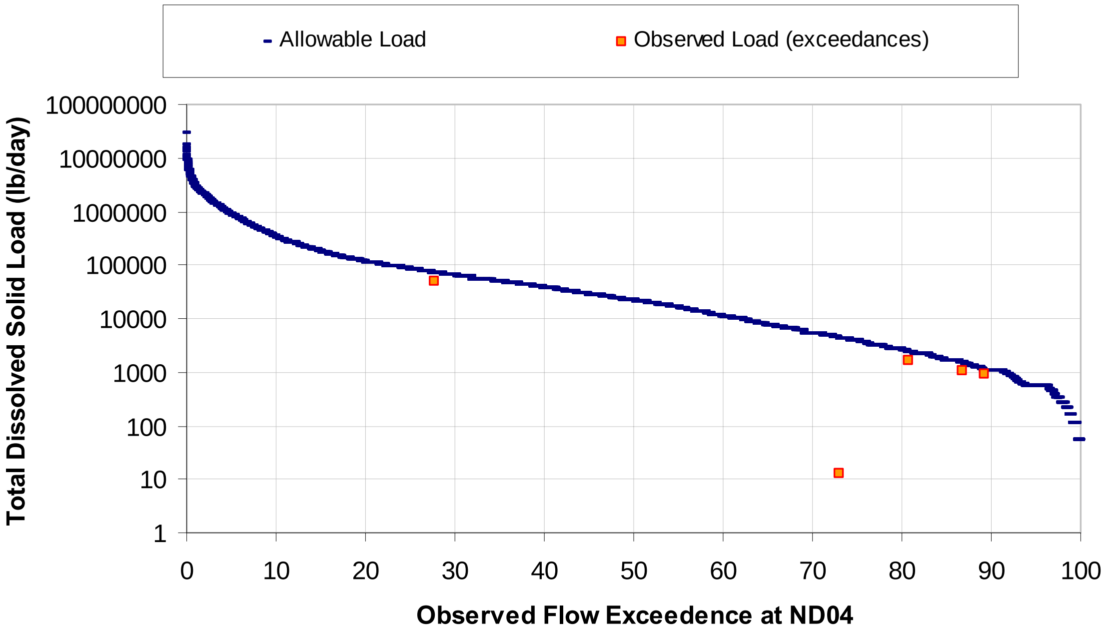


2. Estimated TMDL Loads by Flow Exceedence Range

Flow Exceedence Ranges	Sample Distribution	Median Observed flow (cfs)	Allowable Load (G-org/day)	Observed Load (G-org/day)	Estimated Reduction (%)
0-10	9	48.06	259.33	-	-
10 -40	26	4.51	24.50	67.43	67%
40-60	10	4.00	21.58	-	-
60-90	13	0.21	1.13	2.33	56%
90-100	2	0.04	0.16	-	-

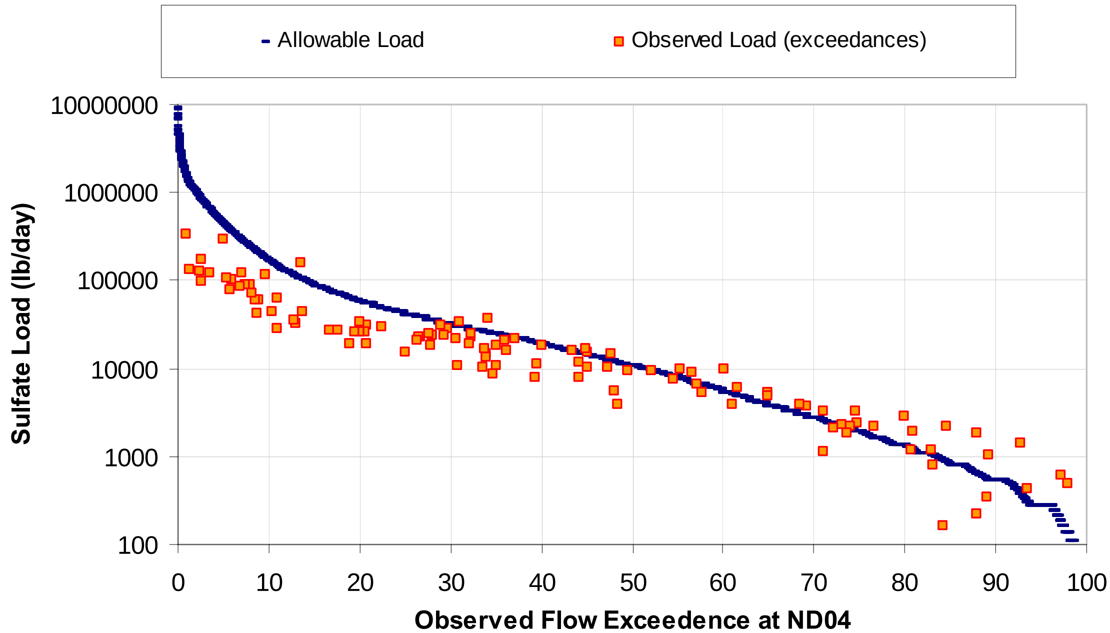
A.3 Total Dissolved Solids -vs- Flow at Segment ND-04

1. Load Exceedence Analysis



A.4 Sulfate -vs- Flow at Segment ND-04

1. Load Exceedence Analysis

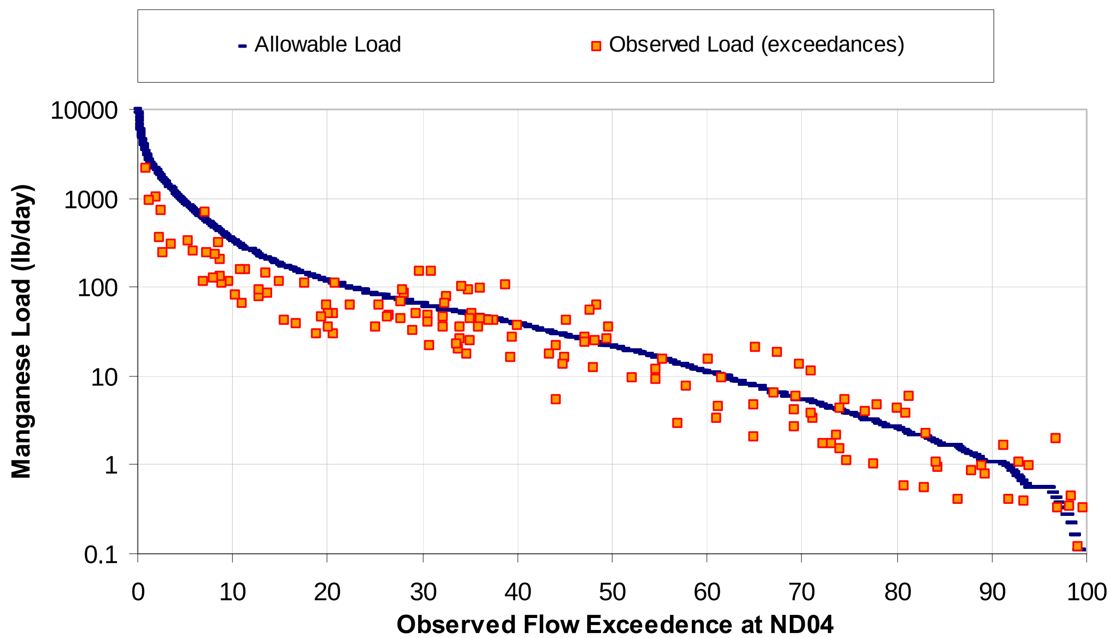


2. Estimated TMDL Loads by Flow Exceedence Range

Flow Exceedence Ranges	Sample Distribution	Median Observed flow (cfs)	Allowable Load (G-org/day)	Observed Load (G-org/day)	Estimated Reduction (%)
0-10	19	160	431,680	-	-
10 -40	47	16	43,168	159,306	76%
40-60	18	4	10,792	16,502	46%
60-90	27	0.70	1,889	9,713	91%
90-100	4	0.10	270	1,398	100%

A.5 Manganese -vs- Flow at Segment ND-04

1. Load Exceedence Analysis

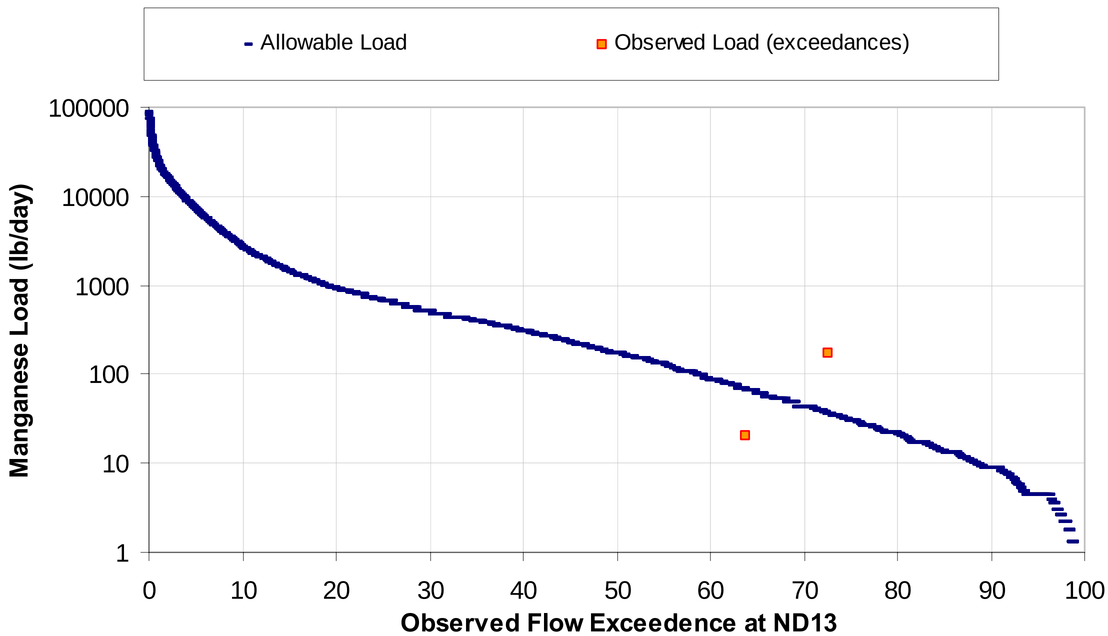


2. Estimated TMDL Loads by Flow Exceedence Range

Flow Exceedence Ranges	Sample Distribution	Median Observed flow (cfs)	Allowable Load (G-org/day)	Observed Load (G-org/day)	Estimated Reduction (%)
0-10	19	164	863.4	699.3	0%
10 -40	58	15	80.9	148.9	50%
40-60	21	4	21.6	61.5	71%
60-90	38	0.70	3.89	20.8	96%
90-100	11	0.50	0.54	2.0	100%

A.6 Manganese -vs- Flow at Segment ND-13

1. Load Exceedence Analysis

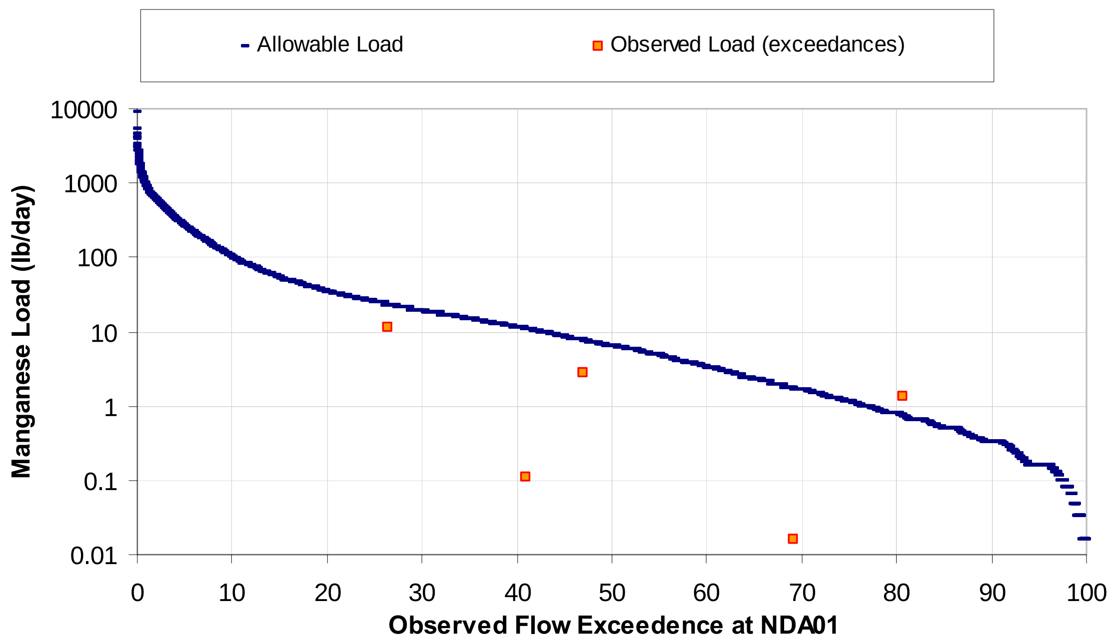


2. Estimated TMDL Loads by Flow Exceedence Range

Flow Exceedence Ranges	Sample Distribution	Median Observed flow (cfs)	Allowable Load (G-org/day)	Observed Load (G-org/day)	Estimated Reduction (%)
0-10	0	1,318.50	7,114.50	No Data	No Data
10 -40	0	128.60	694.10	No Data	No Data
40-60	0	32.15	173.50	No Data	No Data
60-90	2	5.63	30.37	172.83	84%
90-100	0	0.80	4.34	No Data	No Data

A.7 Manganese -vs- Flow at Segment NDA-01

1. Load Exceedence Analysis



2. Estimated TMDL Loads by Flow Exceedence Range

Flow Exceedence Ranges	Sample Distribution	Median Observed flow (cfs)	Allowable Load (G-org/day)	Observed Load (G-org/day)	Estimated Reduction (%)
0-10	0	48.06	259.34	No Data	No Data
10 -40	1	4.80	25	-	-
40-60	2	1.20	6.48	-	-
60-90	2	0.21	1.14	1.31	22%
90-100	0	0.03	0.16	No Data	No Data

Appendix B : QUAL2K Modeling

B.1 Dissolved Oxygen Model (QUAL2K)

The QUAL2K water quality model was selected for the development of Crab Orchard Creek watershed dissolved oxygen TMDLs. QUAL2K is supported by U.S. EPA and has been used extensively for TMDL development and point source permitting issues across the country, especially for issues related to dissolved oxygen concentrations. The QUAL2K model is suitable for simulating hydraulics and water quality conditions of small rivers and creeks. It is a one-dimensional model with the assumption of a completely mixed system for each computational cell. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. The model allows for multiple waste discharges, water withdrawals, nonpoint source loading, tributary flows, and incremental inflows and outflows. The processes employed in QUAL2K address nutrient cycles, algal growth, and dissolved oxygen dynamics. Two QUAL2K models are set up for each impaired stream to address low dissolved oxygen conditions. The impaired streams are Piles Fork, Little Crab Orchard Creek, and Crab Orchard Creek.

B.2 QUAL2K Model Setup

This section of the appendix describes the process that was used to setup the QUAL2K models for the Crab Orchard Creek watershed.

B.2.1 Stream Segmentation

Each impaired stream was segmented into a series of sub-segments in the QUAL2K model. The sub-segments are referred to as reaches in the QUAL2K model and the reaches are also broken down in equally-spaced elements or computational units. Flow and mass balance calculations are performed within these units at each time step that the user specifies.

Crab Orchard Creek has four impaired segments including ND-02, ND-04, ND-11, and ND-13. The QUAL2K model for ND-02 segment was divided in two reaches (4 elements in total) with lengths of 0.66 km and 2.4 km. The QUAL2K model for ND-04 consists of three reaches (8 elements in total) with the length of each reach ranging from 5.3 km to 11.7 km. The total modeled length of the creek is 22.4 km. The QUAL2K model for ND-11 consists of two reaches (4 elements in total) with a total length of 1.5 km. The QUAL2K model for ND-13 consists of two reaches (4 elements in total) with lengths of 1.2 km each. The QUAL2K model for Piles Fork consists of three reaches (11 elements in total) with the length of each reach ranging from 3.1 to 4.3 km. The total modeled length of the creek is 11.3 km. The QUAL2K model for Little Crab Orchard Creek consists of seven reaches (18 elements in total) with the length of each reach ranging from 2.3 to 3.5 km. The total modeled length of the creek is 19.7 km. The reach length for each QUAL2K model was determined in relation to hydrogeometry of the streams, tributaries locations, point and nonpoint source locations, and flow and water quality sampling points.

B.2.2 Geometry, Elevation and Weather Data

Measurement data, such as flow, river width and average water depth are available at several locations throughout the impaired segments. The Manning Formula was selected for the QUAL2K model to simulate flow, water depth, and water velocity. The selected Manning's n value was in the range of 0.04 to 0.055. The cross sectional stream geometry was configured as trapezoidal in each QUAL2K model. The bottom stream widths were estimated from the river widths measured in the field, USGS topographic maps, and aerial maps. Elevation data and slopes for each stream segment were estimated using USGS topographic maps. The hourly weather data for air temperature, dew point temperature, wind speed, and cloud cover were retrieved from the National Climatic Data Center (NCDC) web site. The weather data from Marion Regional Station was used for all of the QUAL2K models because of the availability of the type of data and the proximity to all the impaired streams. Table B-1 show the hourly weather data for September 7 to 9, 2006 that was used in the QUAL2K models.

Table B-1. Hourly Weather Data for September 7 to 9, 2006 from Marion Regional Station

Date	Time (hr)	Wind Speed (m/s)	Sky Conditions	Temperature (C)	Dew Point (C)
9/7/06	10.05	0	BKN	59.0	13.9
9/7/06	11.05	0	SCT	59.0	13.9
9/7/06	12.00	0	CLR	59.0	13.9
9/7/06	12.45	0	***	****	
9/7/06	13.45	0	CLR	68.0	17.8
9/7/06	14.45	0	CLR	72.0	17.2
9/7/06	15.45	0	CLR	77.0	17.2
9/7/06	16.45	0	SCT	82.0	15.0
9/7/06	17.45	2.24	CLR	81.0	13.9
9/7/06	18.49	3.13	SCT	82.0	15.0
9/7/06	19.51	2.68	SCT	82.0	13.9
9/7/06	20.51	2.68	SCT	82.0	12.8
9/7/06	21.49	2.24	SCT	82.0	13.9
9/7/06	22.53	2.68	CLR	82.0	13.9
9/8/06	00.05	0	CLR	73.0	17.8
9/8/06	01.05	0	CLR	70.0	17.8
9/8/06	02.05	0	CLR	68.0	17.2
9/8/06	03.05	0	CLR	66.0	17.2
9/8/06	04.05	0	CLR	64.0	16.1
9/8/06	05.05	0	CLR	64.0	17.2
9/8/06	06.05	0	CLR	64.0	16.1
9/8/06	07.05	0	CLR	63.0	16.1
9/8/06	08.05	0	OVC	61.0	15.0
9/8/06	09.05	0	BKN	61.0	16.1
9/9/06	00.05	0	CLR	25.0	16.1
9/9/06	00.25	0	CLR	23.9	16.1
9/9/06	00.45	0	CLR	22.2	17.2
9/9/06	01.05	0	CLR	21.1	17.2
9/9/06	01.25	0	CLR	21.1	17.2
9/9/06	01.45	0	CLR	20.0	17.2
9/9/06	02.05	0	CLR	20.0	17.2
9/9/06	02.25	0	CLR	18.9	17.2
9/9/06	02.45	0	CLR	18.9	16.1
9/9/06	03.05	0	CLR	17.8	16.1
9/9/06	03.25	0	CLR	18.9	16.1
9/9/06	03.45	0	CLR	17.8	16.1
9/9/06	04.05	0	CLR	17.8	16.1
9/9/06	04.25	0	CLR	17.8	16.1
9/9/06	04.45	0	CLR	17.2	16.1
9/9/06	05.05	0	CLR	17.2	16.1

Date	Time (hr)	Wind Speed (m/s)	Sky Conditions	Temperature (C)	Dew Point (C)
9/9/06	10.25	0	BKN	16.1	15.0
9/9/06	10.45	0	CLR	15.0	13.9
9/9/06	11.05	0	OVC	15.0	13.9
9/9/06	11.25	0	BKN	15.0	15.0
9/9/06	11.51	0	BKN	15.0	13.9
9/9/06	12.51	0	SCT	17.2	16.1
9/9/06	13.54	0	SCT	21.1	17.2
9/9/06	15.00	0	CLR	25.0	16.1
9/9/06	15.49	2.24	CLR	27.8	15.0
9/9/06	16.46	2.68	CLR	28.9	12.8
9/9/06	17.48	0	CLR	30.0	12.8
9/9/06	18.45	0	CLR	30.0	12.2
9/9/06	19.45	0	SCT	30.0	13.9
9/9/06	20.45	1.34	CLR	28.9	12.8
9/9/06	21.46	0	CLR	30.0	12.8
9/9/06	22.52	0	CLR	27.8	18.9

B.2.3 Boundary conditions

The QUAL2K model requires model boundary conditions. It uses the headwater data group to define upstream boundary conditions of model domain. The closest upstream water quality station with measured data was used to populate the headwater data. Headwater flow conditions for all of the QUAL2K models developed for the Crab Orchard Creek watershed were derived by the area weighted estimation method. This method entails that the closest available flow measurement to the headwater starting point is multiplied by the ratio of the area upstream of the starting point to the area contributing to the flow measurement point.

The point sources data group defines the condition of point source discharges from facilities or small tributaries that enter simulated stream segments. The point source facilities discharging into the impaired streams in Crab Orchard Creek Watershed are summarized in Table B-3.

The diffuse sources data group defines the discharges and withdraws from non point source. Runoff was accounted for in QUAL2K as diffuse inflow and was modeled as line sources. QUAL2K then, distributes the nonpoint source flow along the segment using a length-weighted method. Water quality data for nonpoint sources was assumed based on model calibration.

B.2.4 Critical Conditions

Critical conditions for dissolved oxygen were determined to be during the summer low flow conditions. This is due to an excessive loading of oxygen consuming material that causes poor water quality during low flows and high water temperature. Continuous data measurements of dissolved oxygen, temperature, pH, and conductivity were collected during September and November of 2006 in Segments ND-11, ND-13, NDA-01 and NDB-03. In order to determine critical dates for each impaired segment, dissolved oxygen data collected from September 6, 2006 to September 10, 2006 were used as the basis for the modeling. These collection dates were selected because flows in the streams were low and temperatures were high, which created low oxygen conditions in the streams. The mean of the dissolved oxygen data within each impaired segment was calculated separately. The mean values of dissolved oxygen between the two dates were compared and the lower one was selected as an indication of the critical date for the stream. Table B-2 shows the calculated means for dissolved oxygen in each of the impaired streams. The highlighted dissolved oxygen value indicates the lower mean dissolved oxygen, thus, the critical date for the stream. The QUAL2K model was run for each impaired stream using the data collected during the critical date.

Table B-2. Mean Dissolved Oxygen (mg/L) at Each Impaired Stream

Name	9/7/2006	9/7/2006	9/8/2006	9/9/2006	9/10/2006
Crab Orchard Creek Segment ND-11	5.02	4.87	4.69	4.31	3.15*
Crab Orchard Creek Segment ND-13	5.31	5.21	5.00	4.78	4.62*
Little Crab Orchard Cr. Segment NDA-01	1.65	1.35	1.39	1.29	1.39*
Piles Fork Segment NDB-03	-	0.45	0.65	0.63	0.92*

Notes:
* Mean values for less than 11 hours of data

B.2.5 Point Source Loads

There are 24 identified point sources discharging into the impaired segments. The table below shows the summary of the point source data that were incorporated in the QUAL2K models.

Table B-3. Point Source Data Summary

Stream Name	Facility Name & NPDES	Discharging point(km) *	Flow (m^3/s)	BOD5 (mg/L)	NH3 (ug/L)	Dissolved Oxygen (mg/L)
Crab Orchard Creek ND-04	Freeman United Coal - IL0004685	18	0.0175	NA	NA	NA
Crab Orchard Creek ND-04	Crab Orchard Grade HS - IL0037311	10.6	0.0003	5.27	5,396	7.93
Crab Orchard Creek ND-04	Marion Southeast STP - IL0029734	0.4	0.2172	3.06	398	7.07
Crab Orchard Creek ND-11	Southern IL Univ-C Lit Grassy	1.520	0.0016	2.23	1980.00	6.0**
Crab Orchard Creek ND-11	Bush MHP STP #2-Carbondale	1.520	0.0003	7.97	1350.00	5.45
Crab Orchard Creek ND-11	Chateau Apartments	1.520	0.0007	3.83	NA	6.0**
Crab Orchard Creek ND-11	Corner One Stop - Carbondale	1.520	0.0003	8.88	1350.00	6.0**
Crab Orchard Creek ND-11	Frost Mobile Home Park	1.520	0.0004	7.26	NA	6.0**
Crab Orchard Creek ND-11	Giant City School	1.520	0.0015	3.49	2030.00	8.30
Crab Orchard Creek ND-11	IL DOC-Giant City State Park	1.520	0.0006	14.80	3000.00	11.09
Crab Orchard Creek ND-11	Meadowbrook Estates MHP	1.520	0.0003	7.44	2360.00	6.0**
Crab Orchard Creek ND-11	Pleasant Hill MHP	1.520	0.0009	6.38	NA	6.0**
Crab Orchard Creek ND-11	Pleasant Valley MHP	1.520	0.0015	1.33	NA	6.0**
Crab Orchard Creek ND-11	Southern Mobile Home Park	1.520	0.0008	16.20	NA	6.0**
Crab Orchard Creek	United Methodist Camp	1.520	0.0003	6.56	NA	6.0**

Stream Name	Facility Name & NPDES	Discharging point(km) *	Flow (m^3/s)	BOD5 (mg/L)	NH3 (ug/L)	Dissolved Oxygen (mg/L)
ND-11						
Crab Orchard Creek ND-11	Unity Point Elm Sch Dist 140	1.520	0.0008	13.40	1590.00	6.0**
Crab Orchard Creek ND-11	University Heights MHP	1.520	0.0011	5.94	2200.00	7.17
Crab Orchard Creek ND-11	Wildwood Mobile Home Park	1.520	0.0006	19.00	NA	6.0**
Crab Orchard Creek ND-13	S.I. Properties LLC - ILG551066	2.290	0.0018	6.68	NA	NA
Little Crab Orchard Creek NDA-01	LENORE BASIN CORP-UNION HILLS - ILG551037	16.360	0.0002	7.72	NA	NA
Little Crab Orchard Creek NDA-01	LILAC BASIN CORP.-UNION HILL - IL0046221	16.360	0.0003	4.36	5590.00	9.68
Little Crab Orchard Creek NDA-01	TAN TARA 2 MOBILE HOME PARK - IL0049077	5.610	0.0010	10.74	6511.00	NA
Piles Fork NDB-03	BEAZER EAST INC-CARBONDALE - IL0000400	1.520	0.0043	2.88	NA	NA
Piles Fork NDB-03	SIU-CARBONDALE - IL0072320	5.800	0.0008	2.20	NA	NA

Notes:
* The stream starting point in km from downstream end of segment
** Standard permit limit used because concentration was not available
NA: not available

B.3 QUAL2K Model Calibration

This section of the appendix describes the process that was used to calibrate the QUAL2K model for the Crab Orchard Creek watershed and presents the calibration results.

B.3.1 Flow and Water Depth Simulations

Flows and water depths were simulated by the QUAL2K models for all impaired streams. Each model simulated the critical date’s flow, velocity and depth condition. The flows considered in the models are boundary headwater inflows, point and nonpoint source inflows and the abstraction of flow by groundwater or other mechanisms. The primary uncertainty of flow input is related to the estimation of nonpoint source inflows and groundwater outflows. Sensitivity analysis was conducted by adjusting these flows to generate model results similar to the available flows and depths data. Depths and velocities for each reach were calculated using Manning’s equation. Figure B-1 through Figure B-6 show the comparisons of flows and depths between the modeled results and the observed data.

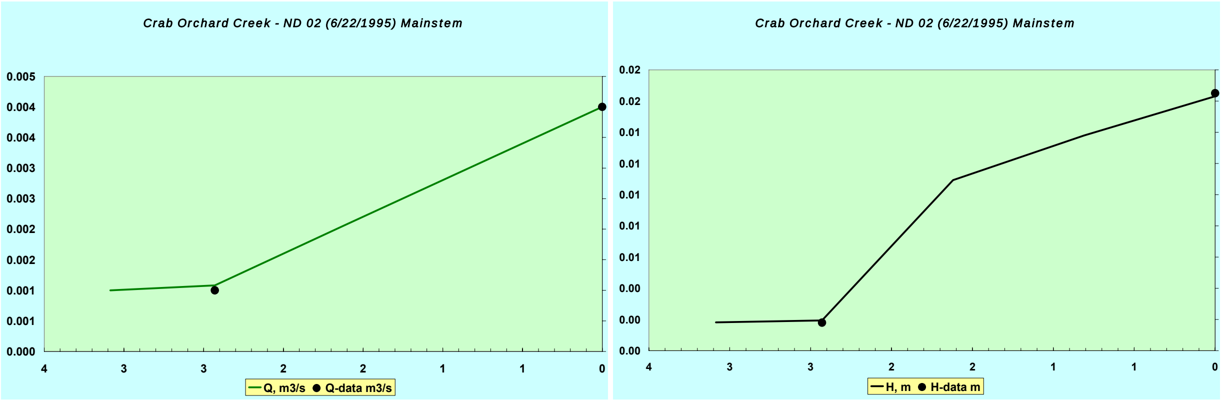


Figure B-1. Comparisons of observed and simulated flow (left) and depth (right) in Crab Orchard Creek segment ND-02

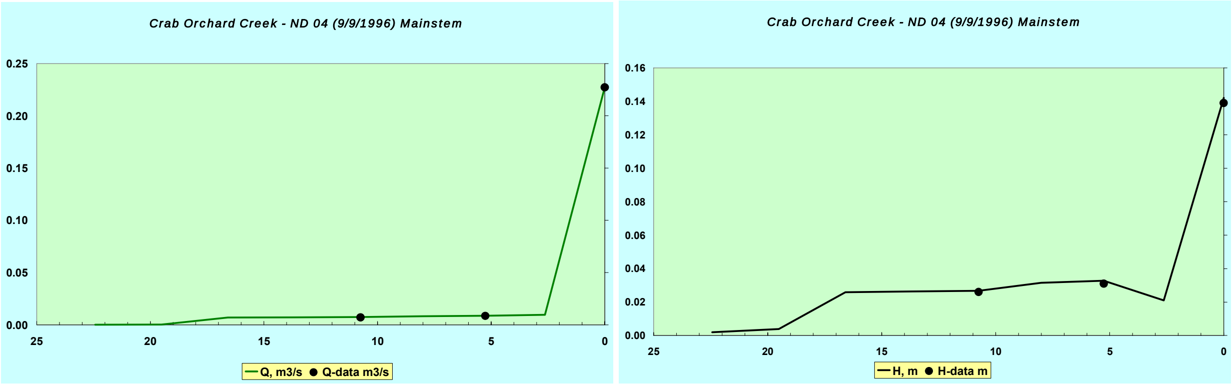


Figure B-2. Comparisons of observed and simulated flow (left) and depth (right) in Crab Orchard Creek segment ND-04

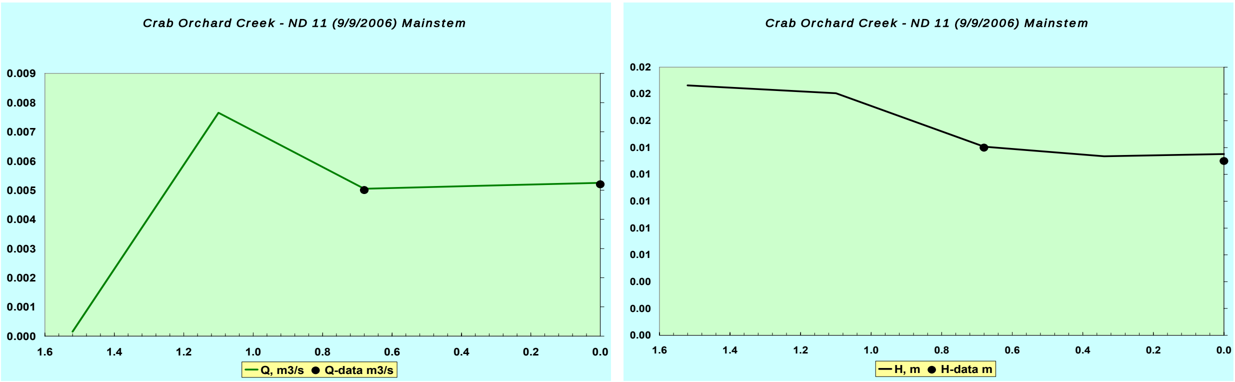


Figure B-3. Comparisons of observed and simulated flow (left) and depth (right) in Crab Orchard Creek segment ND-11

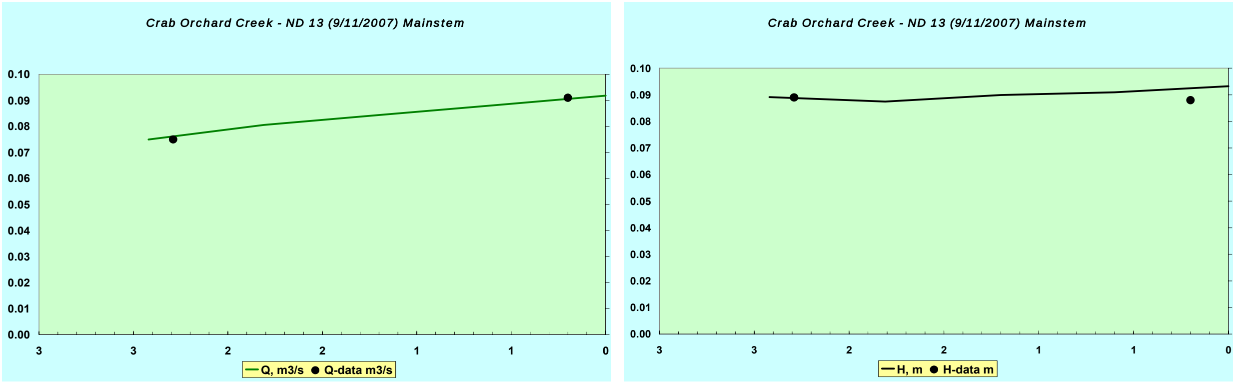


Figure B-4. Comparisons of observed and simulated flow (left) and depth (right) in Crab Orchard Creek segment ND-13

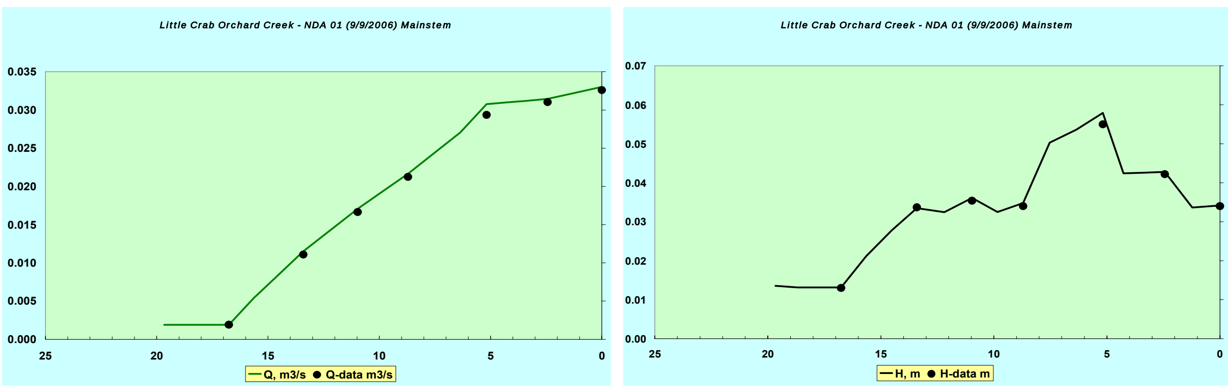


Figure B-5. Comparisons of observed and simulated flow (left) and depth (right) in Little Crab Orchard Creek segment NDA-01

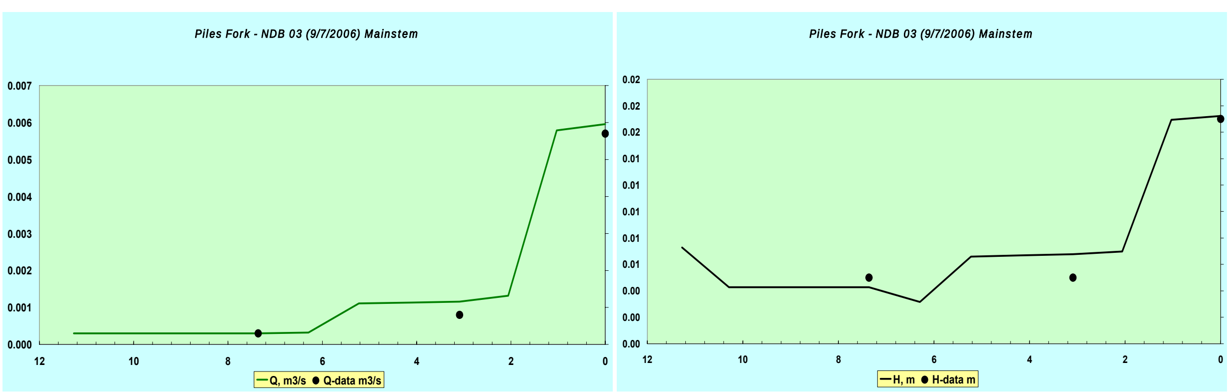


Figure B-6. Comparisons of observed and simulated flow (left) and depth (right) in Piles Fork segment NDB-03

B.3.2 Water Quality Calibration

Each QUAL2K model was calibrated against the observed water quality parameters, such as BOD5, ammonium, dissolved oxygen, and temperature for the critical dates. BOD typically consists of two parts; carbonaceous oxygen demand (CBOD) and nitrogenous oxygen demand. Nitrogenous oxygen demand usually occurs slower than CBOD oxygen demand so the observed BOD5 is regarded as similar to the "fast reacting CBOD" modeling parameter in QUAL2K. Thus, the fast reacting CBOD results were compared with the available BOD5 data. Both "fast reacting and slowly reacting" CBOD were added as nonpoint loads during the model calibration process. Slowly reacting CBOD increases due to detritus dissolution and is lost through hydrolysis and oxidation. Fast reacting CBOD is gained through the dissolution of detritus and the hydrolysis of slowly-reacting CBOD and is lost through oxidation and denitrification.

QUAL2K models were set up so that only CBOD hydrolysis and oxidation, nitrification of ammonium, and denitrification of nitrate could be considered. Nonpoint source inflow loading was added to the impaired segments to calibrate the QUAL2K models by matching the observed water quality concentrations. Sensitivity analysis was conducted to determine the input loadings of the parameters from non-point source by adjusting the loads during the calibration period. The reaction rates for hydrolysis, oxidation, nitrification, and denitrification were selected within the range of the literature values (Brown and Barnwell, 1987). Figure B-7 through Figure B-18 show the results of the model calibrations for temperature, dissolved oxygen, BOD5, and ammonium.

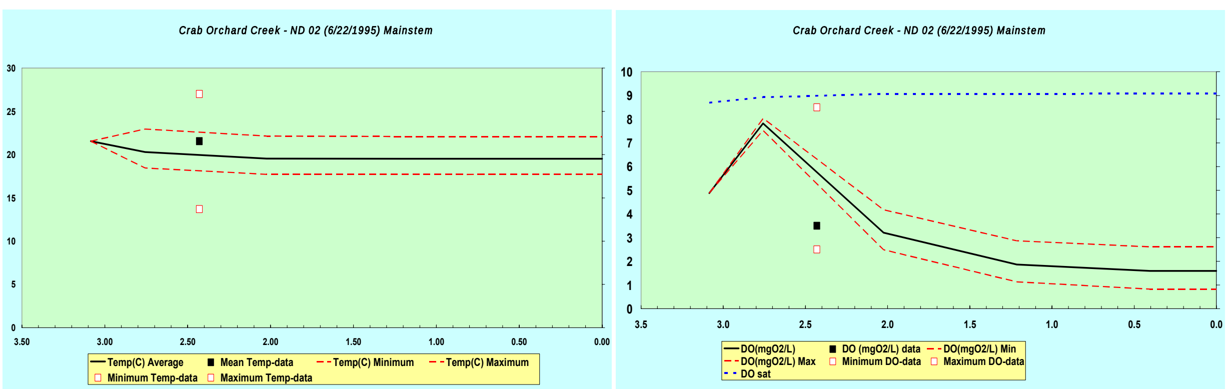


Figure B-7. Temperature (left) and dissolved oxygen (right) calibration in Crab Orchard Creek segment ND-02

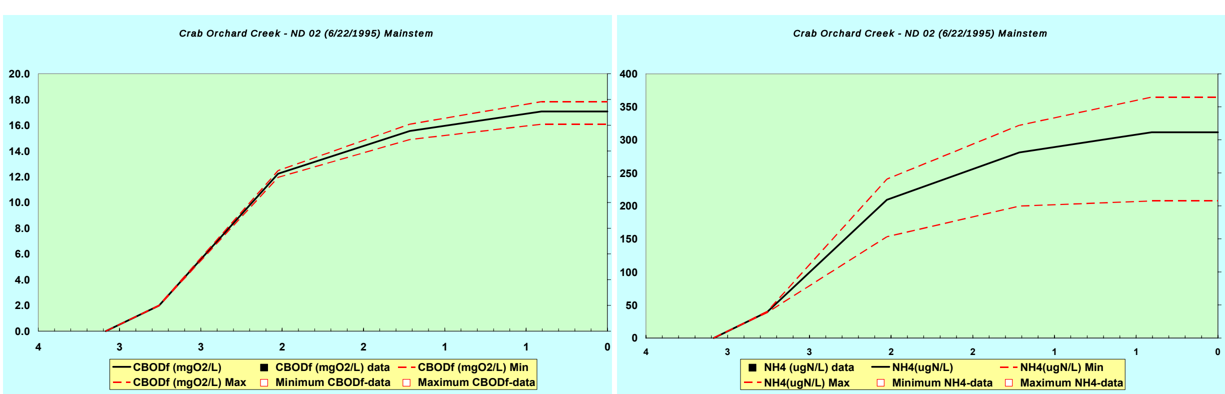


Figure B-8. CBOD (left) and ammonium (right) calibration in Crab Orchard Creek segment ND-02

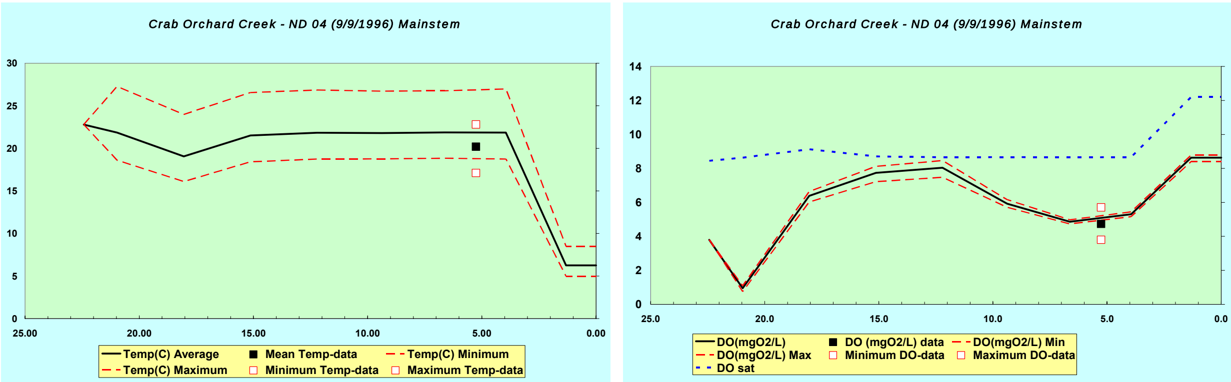


Figure B-9. Temperature (left) and dissolved oxygen (right) calibration in Crab Orchard Creek segment ND-04

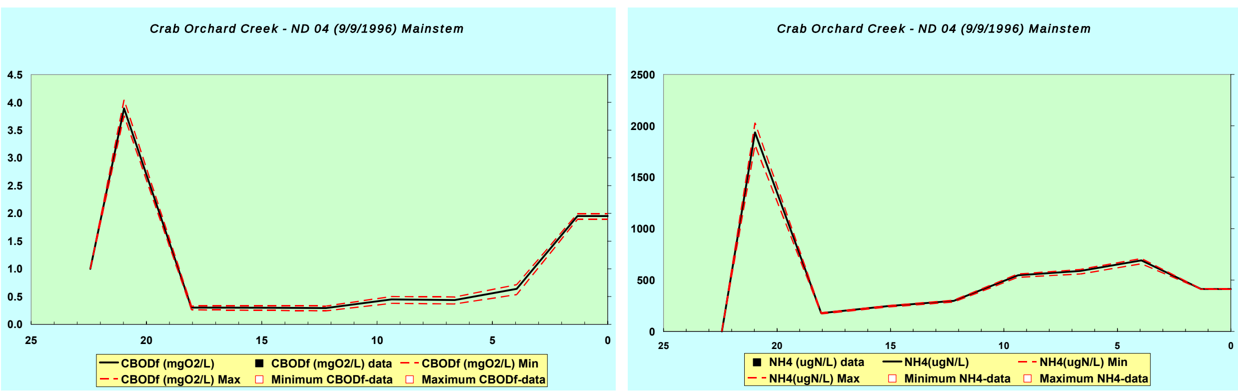


Figure B-10. CBOD (left) and ammonium (right) calibration in Crab Orchard Creek segment ND-04

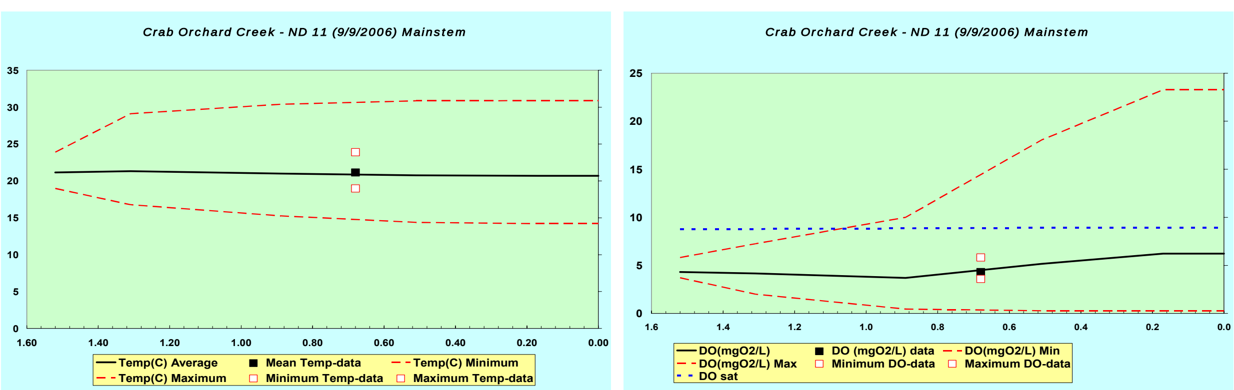


Figure B-11. Temperature (left) and dissolved oxygen (right) calibration in Crab Orchard Creek segment ND-11

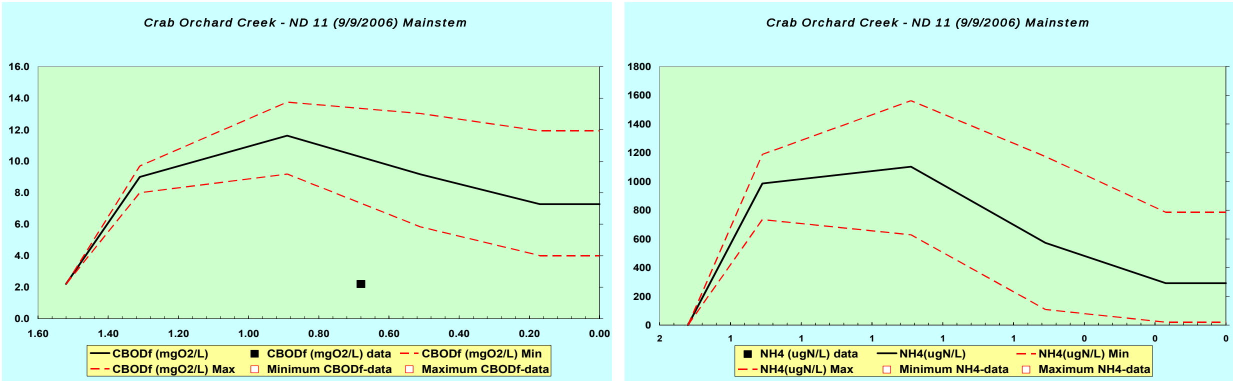


Figure B-12. CBOD (left) and ammonium (right) calibration in Crab Orchard Creek segment ND-11

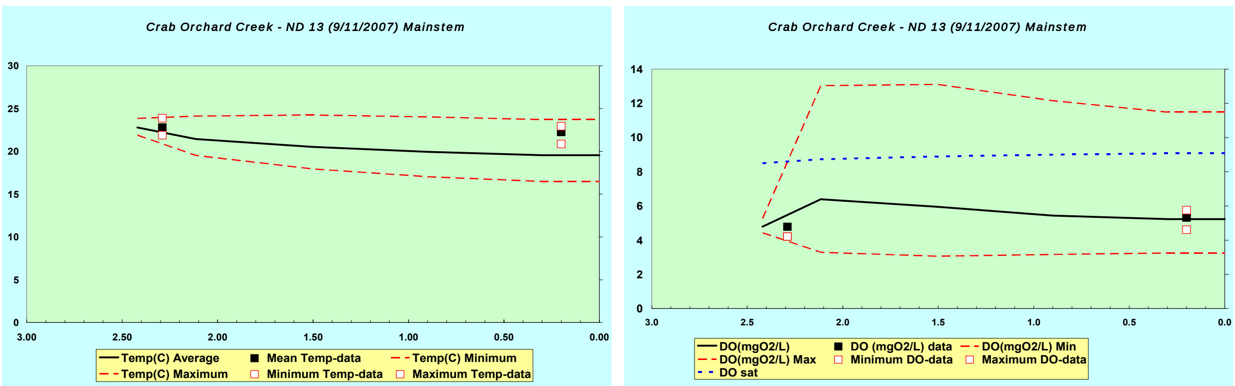


Figure B-13. Temperature (left) and dissolved oxygen (right) calibration in Crab Orchard Creek segment ND-13

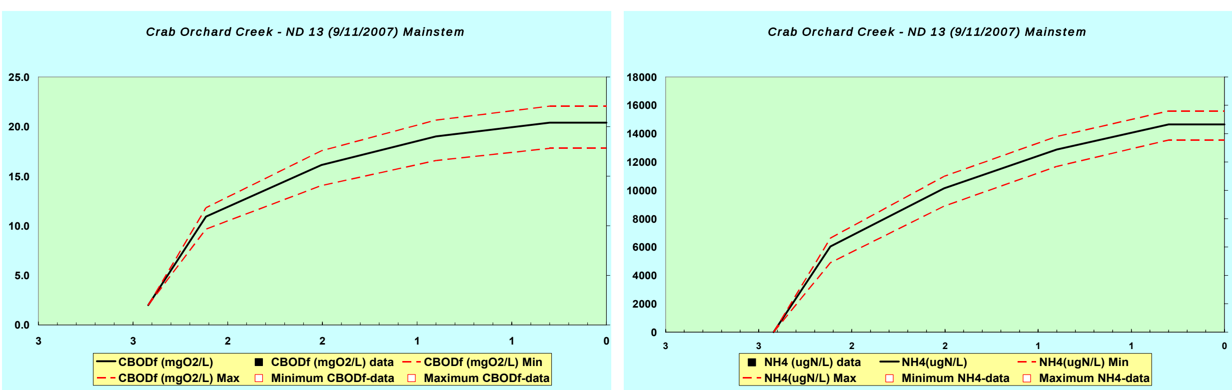


Figure B-14. CBOD (left) and ammonium (right) calibration in Crab Orchard Creek segment ND-13

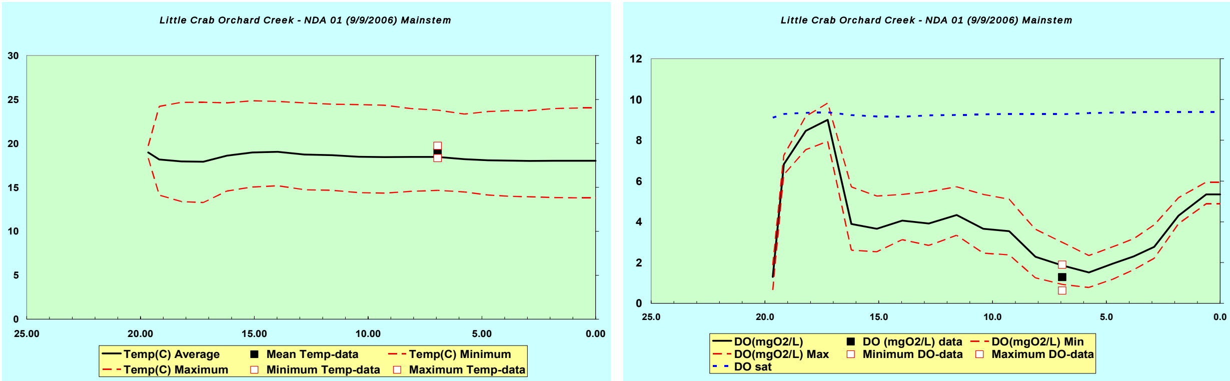


Figure B-15. Temperature (left) and dissolved oxygen (right) calibration in Little Crab Orchard Creek segment NDA-01

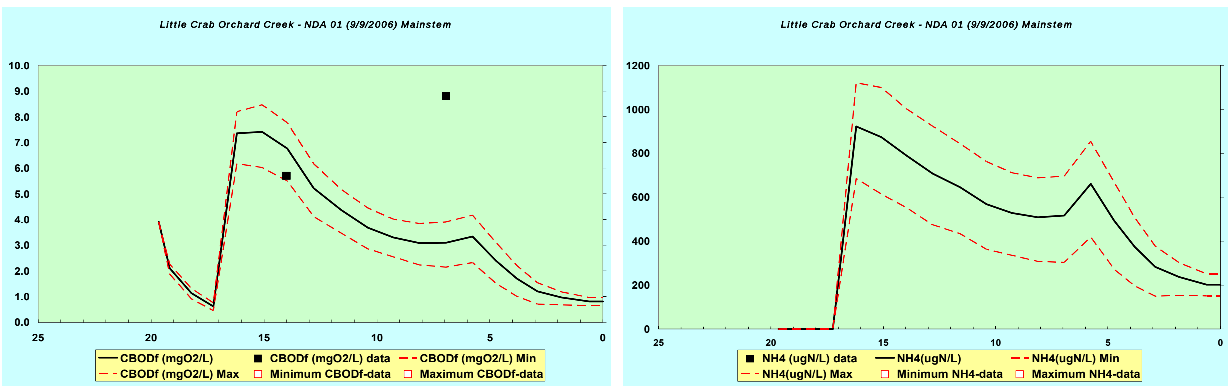


Figure B-16. CBOD (left) and ammonium (right) calibration in Little Crab Orchard Creek segment NDA-01

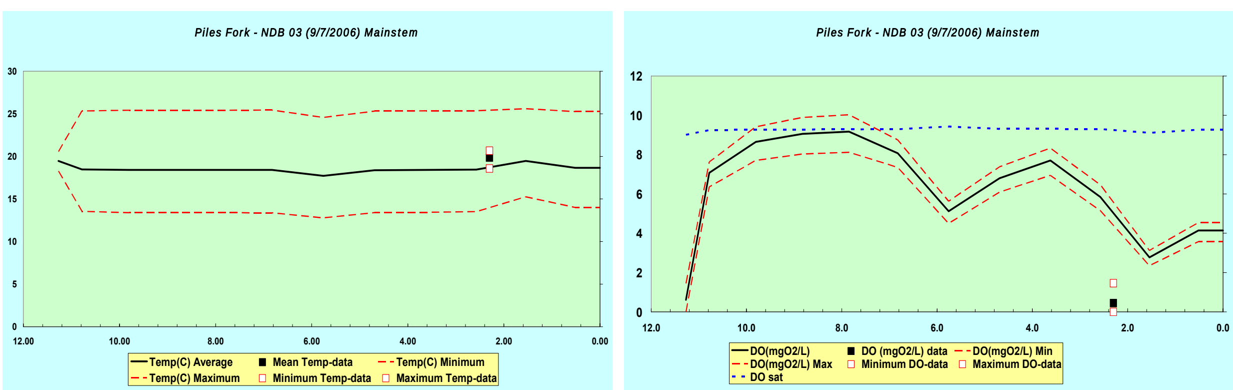


Figure B-17. Temperature (left) and dissolved oxygen (right) calibration in Piles Fork segment NDB-03

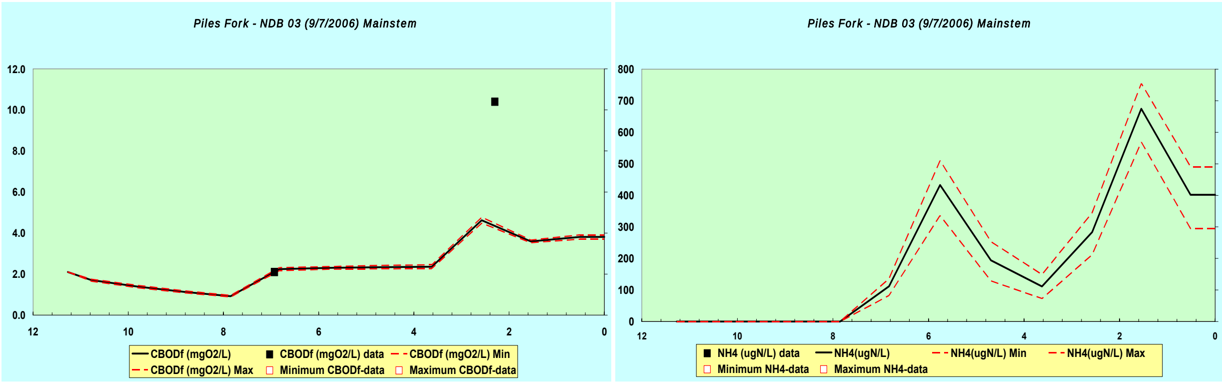


Figure B-18. CBOD (left) and ammonium (right) calibration in Piles Fork segment NDB-03

B.4 Load Reductions

Illinois' water quality standard requires a minimum of 5 mg/L of dissolved oxygen. A 10 percent margin of safety (MOS) was explicitly incorporated into the oxygen standard, thus, the final TMDL endpoint was set to be 5.5mg/L of oxygen. CBOD and NH4 loads from nonpoint sources were reduced to meet this endpoint. If the estimated dissolved oxygen in the stream was less than 5.5 mg/l during the calibration process, dissolved oxygen was re-set to 5.5mg/l by reducing CBOD and NH4 nonpoint loads. If the estimated dissolved oxygen in the stream was higher than 5.5mg/l during the calibration process, the value was unchanged. Figure B-19 through Figure B-24 below show the dissolved oxygen results after the loads were reduced for CBOD and NH4. Final loads for each impaired segment are displayed in the TMDL tables in Section 5.2 of the main report.

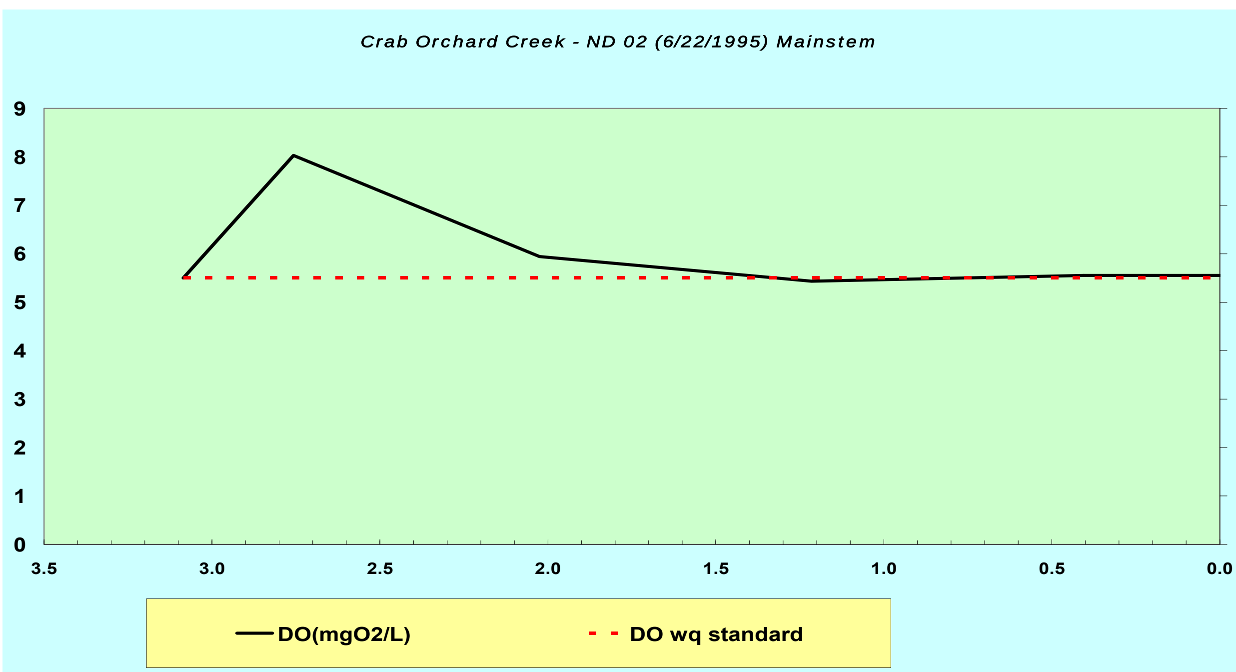


Figure B-19. Dissolved oxygen concentration after the load reduction scenario was incorporated in QUAL2K model for Crab Orchard Creek Segment ND-02

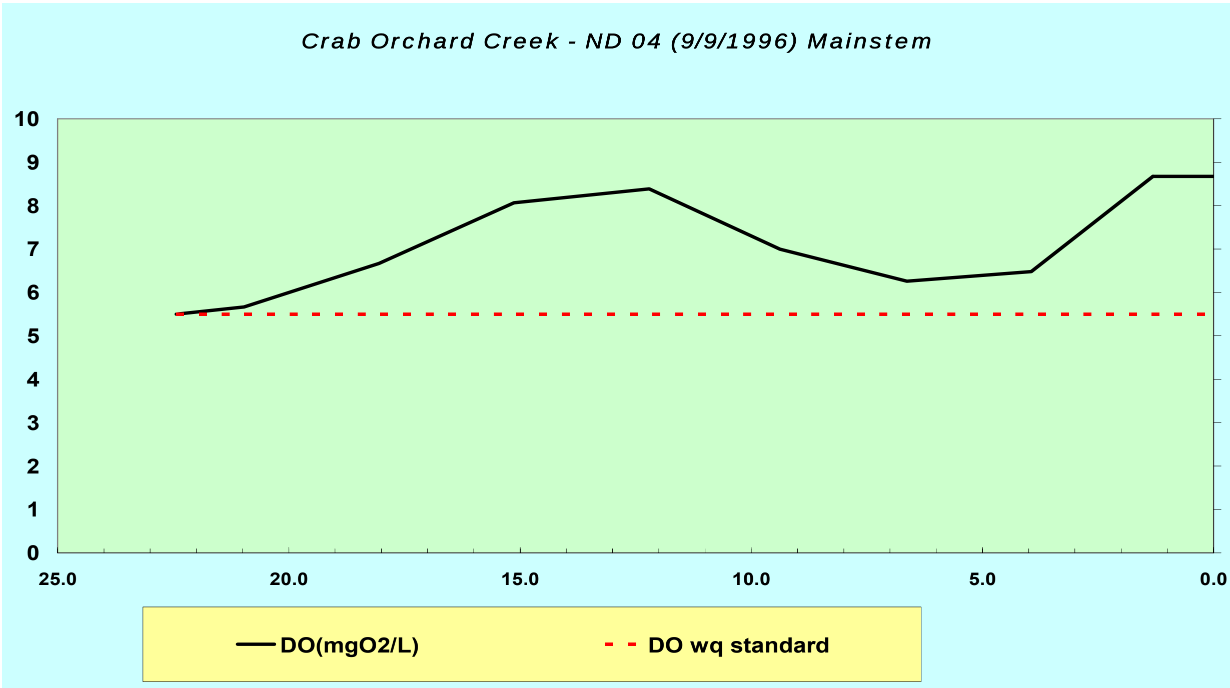


Figure B-20. Dissolved oxygen concentration after the load reduction scenario was incorporated in QUAL2K model for Crab Orchard Creek Segment ND-04

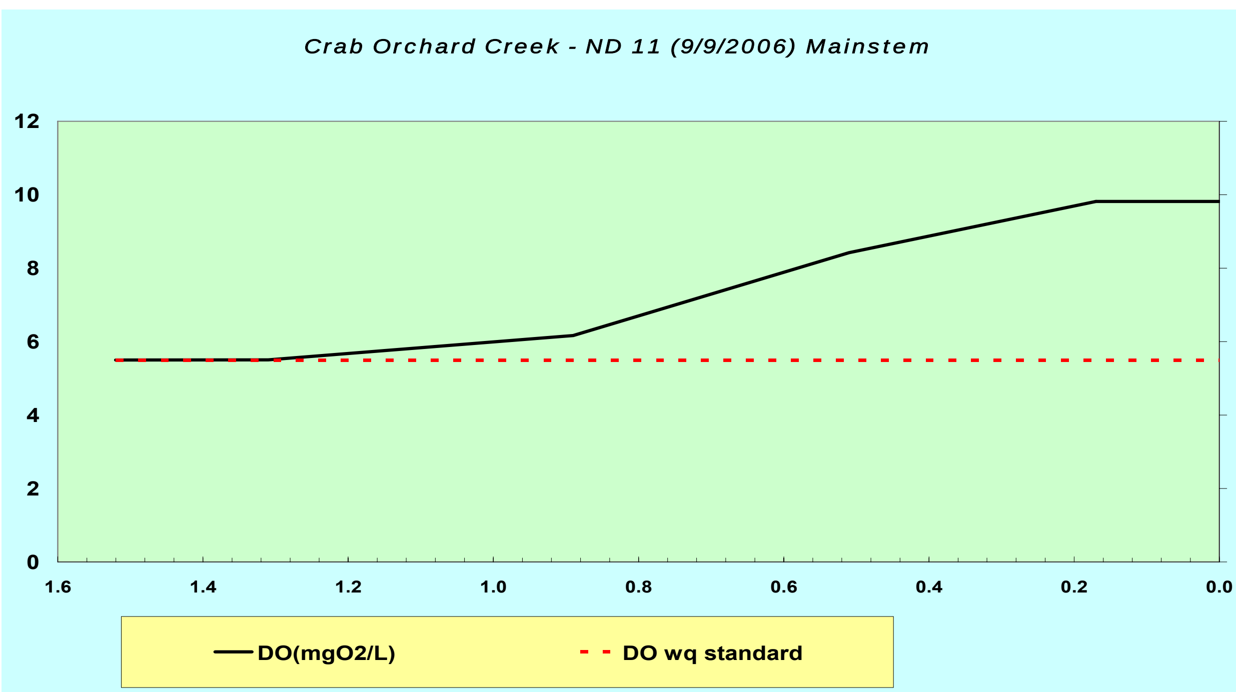


Figure B-21. Dissolved oxygen concentration after the load reduction scenario was incorporated in QUAL2K model for Crab Orchard Creek Segment ND-11

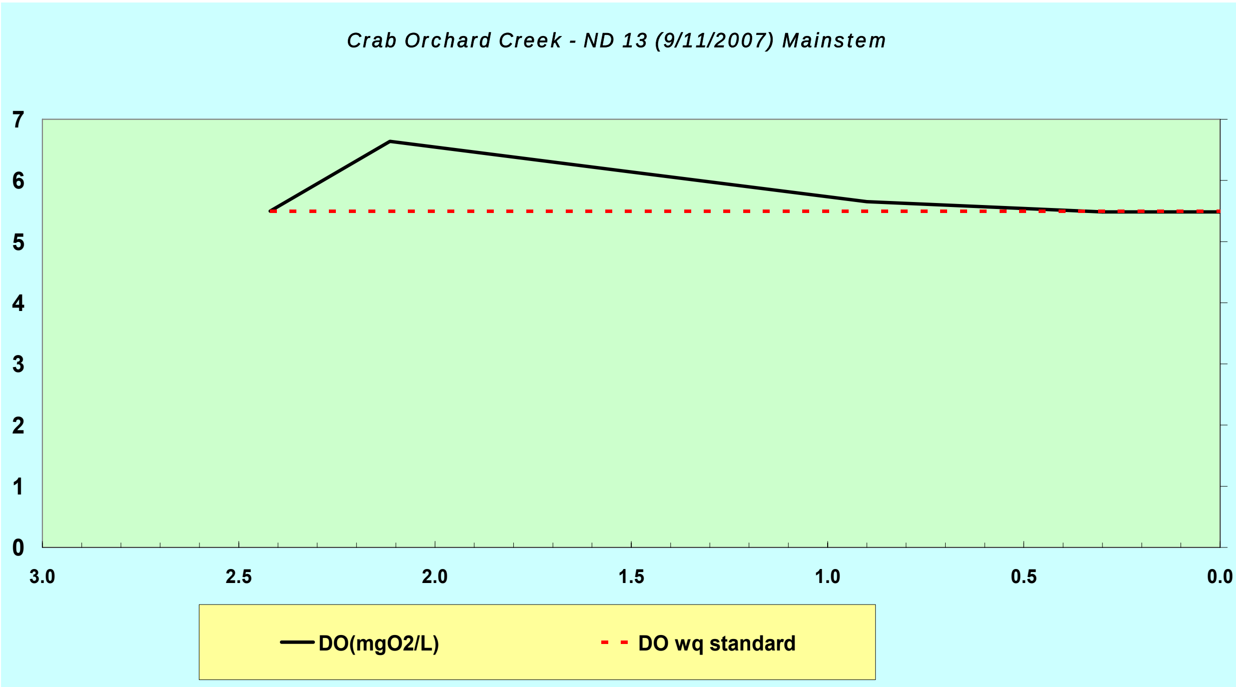


Figure B-22. Dissolved oxygen concentration after the load reduction scenario was incorporated in QUAL2K model for Crab Orchard Creek Segment ND-13

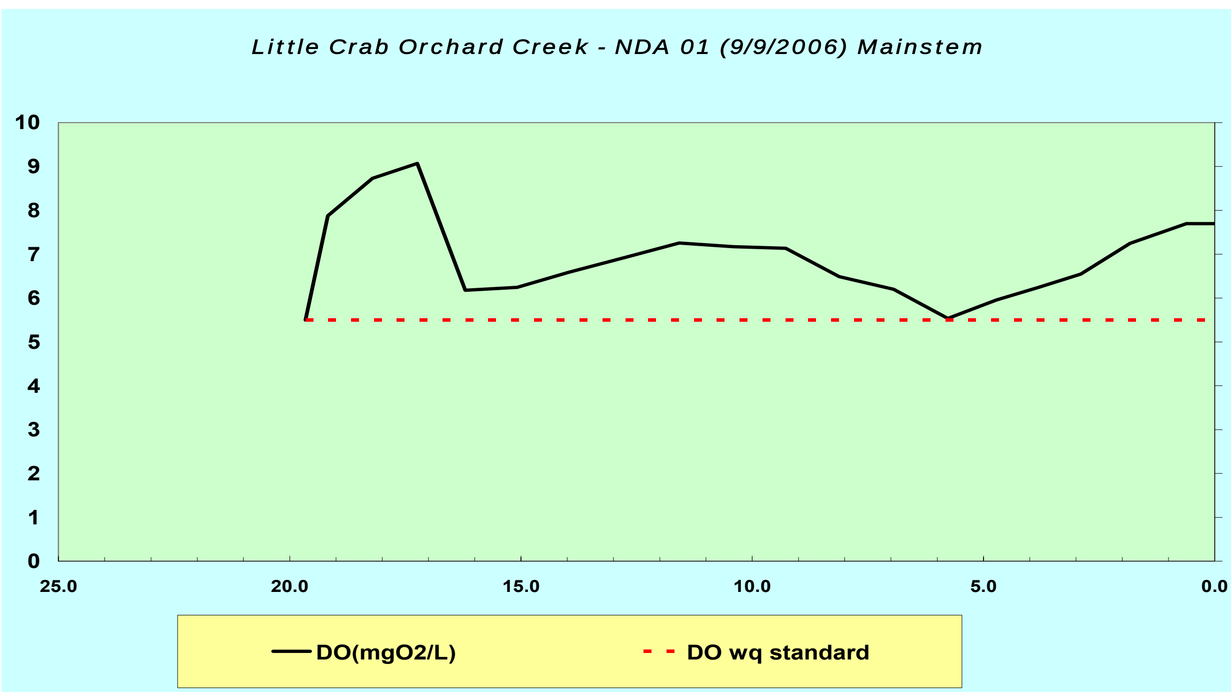


Figure B-23. Dissolved oxygen concentration after the load reduction scenario was incorporated in QUAL2K model for Little Crab Orchard Creek

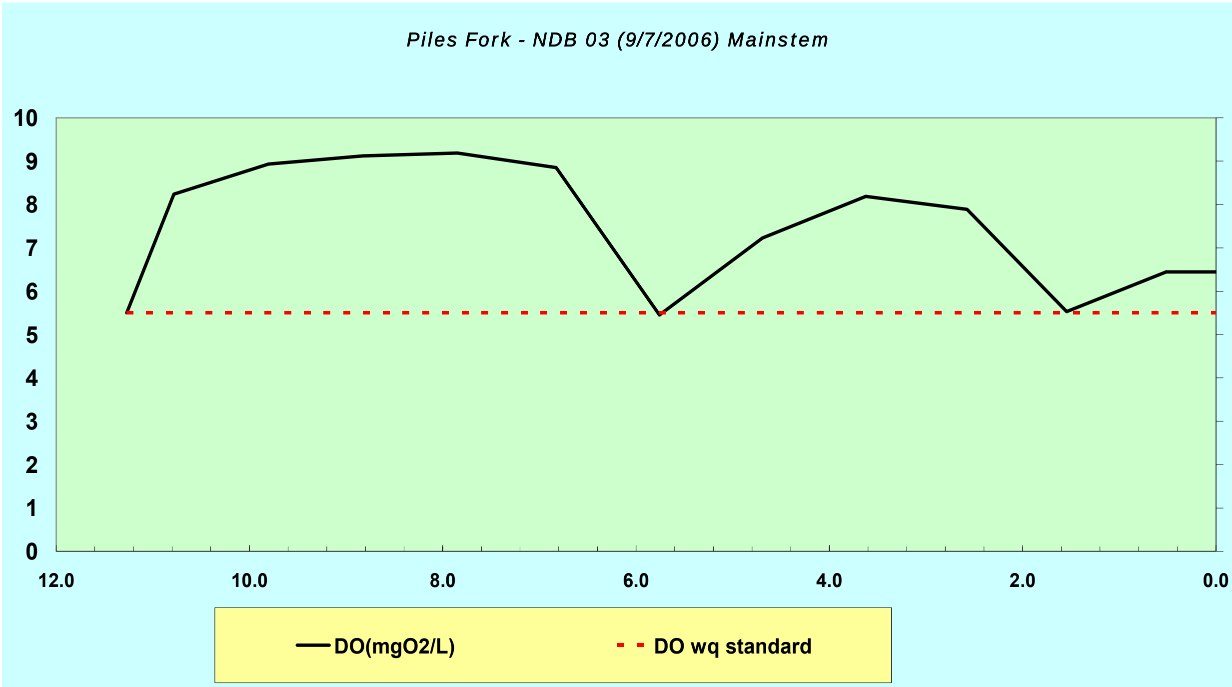


Figure B-24. Dissolved oxygen concentration after the load reduction scenario was incorporated in QUAL2K model for Piles Fork

B.5 QUAL2K model input files

B.5.1 Crab Orchard Creek Segment ND-02

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	**Crab Orchard Creek - ND 02**	
Saved file name	**CrabOrchard_ILND02**	
Directory where file saved	**L:\I-intercompany\I4358\Modeling\Qual2K**	
Month	**6**	
Day	**22**	
Year	**1995**	
Time zone	**Central**	
Daylight savings time	**Yes**	
Calculation:		
Calculation step	**0.0625**	**hours**
Final time	**3**	**day**
Solution method (integration)	**Euler**	
Solution method (pH)	**Bisection**	
Program determined calc step	**0.046875**	**hours**
Time of last calculation	**0.04**	**minutes**
Time of sunrise	**5:35 AM**	
Time of solar noon	**12:58 PM**	
Time of sunset	**8:21 PM**	
Photoperiod	**14.78**	**hours**

ID	Number of Headwaters*	1										
No. 1	Reach No.*	Headwater Name	Flow*	Elevation	Weir				Rating Curves			
			Rate		Height	Width	adam	bdam	Velocity		Depth	
			(m^3/s)	(m)	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
	1	Mainstem headwater	0.001	121.920	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
	Headwater Water Quality	Units	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM
	Temperature	C	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55
	Conductivity	umhos	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Inorganic Solids	mgD/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dissolved Oxygen	mg/L	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
	CBODslow	mgO2/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CBODfast	mgO2/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic Nitrogen	ugN/L	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00
	NH4-Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NO3-Nitrogen	ugN/L	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50
	Organic Phosphorus	ugP/L	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80
	Inorganic Phosphorus (SRP)	ugP/L	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00
	Phytoplankton	ugA/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Detritus (POM)	mgD/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pathogen	cfu/100 mL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alkalinity	mgCaCO3/L	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
	pH	s.u.	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
No. 2	Reach No.*	Headwater Name	Flow*	Elevation	Weir				Rating Curves			
			Rate		Height	Width	adam	bdam	Velocity		Depth	
			(m^3/s)	(m)	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent

Manning Formula					Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion
Slope	n	m	Slope	Slope	m2/s
0.015	0.0400	12.19	0.50	0.25	0.00

10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM
21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55	21.55
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00	290.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50	197.50
44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80	44.80
95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00	95.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 02 (6/22/1995)
Reach Data:

Reach for diel plot	1					
Element for diel plot	1	Reach	Headwater	Reach		
Reach	Downstream	Number	Reach	length	Downstream	
Label	end of reach label			(km)	Latitude	Longitude
Dowstream of Lake Dam		1	Yes	0.66	37.71	89.16
		2		2.43	37.72	89.17

								Hydraulic Model (Weir Overrides Manning Formula; Manning Formula Override Rating Curves)							
Elevation		Downstream						Weir				Rating Curves			
Upstream	Downstream	Latitude			Longitude			Height	Width	adam	bdam	Velocity		Depth	
(m)	(m)	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
121.920	112.780	37.00	42	36	89.00	9	36	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
112.780	111.250	37.00	43	12	89.00	10	12	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000

Manning Formula					Prescribed	Bottom	Bottom	Prescribed	Prescribed	Prescribed	Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion	Algae	SOD	SOD	CH4 flux	NH4 flux	Inorg P flux
Slope	n	m	Slope	Slope	m2/s	Coverage	Coverage	gO2/m2/d	gO2/m2/d	mgN/m2/d	mgP/m2/d
0.0140	0.0400	12.19	0.2500	0.2500	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0006	0.0400	6.10	0.3330	0.3330	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 02 (6/22/1995)
Diffuse Source Data:

*** The headwater of the mainstem (or tributary) where the diffuse source enters.**

	Headwater	Headwater	Location		Diffuse	Diffuse		Spec	Inorg	Diss	CBOD	CBOD
			Up	Down	Abstraction	Inflow	Temp	Cond	SS	Oxygen	slow	fast
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos	mgD/L	mg/L	mgO2/L	mgO2/L
	1	Mainstem headwater	2.50	0.00		0.0030					5.00	30.00

Organic	Ammon	Nitrate	Organic	Inorganic	Phyto				
N	N	N	P	P	plankton	Detritus	Pathogen	Alk	pH
ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	ug/L	mgD/L	cfu/100 ml	mgCaCO3/L	
1000.00	400.00	1000.00	300.00	300.00				100.00	7.00

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 02 (6/22/1995)
Water Column Rates

Parameter	*Value*	*Units*	*Symbol*
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.5	m/d	v_i
Oxygen:			
Reaeration model	Tsivoglou-Neal		
User reaeration coefficient α	3.93		α
User reaeration coefficient β	0.5		β
User reaeration coefficient γ	1.5		γ
Temp correction	1.024		$\square_a$
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	0.001	/d	k_{hc}
Temp correction	1.07		$\square_{hc}$
Oxidation rate	0.1	/d	k_{dcs}
Temp correction	1.047		$\square_{dcs}$
Fast CBOD:			
Oxidation rate	1	/d	k_{dc}
Temp correction	1.047		$\square_{dc}$
Organic N:			
Hydrolysis	0.5	/d	k_{hn}
Temp correction	1.07		$\square_{hn}$
Settling velocity	0.05	m/d	v_{on}
Ammonium:			
Nitrification	0.1	/d	k_{na}
Temp correction	1.07		$\square_{na}$
Nitrate:			
Denitrification	0.1	/d	k_{dn}
Temp correction	1.07		$\square_{dn}$
Sed denitrification transfer coeff	0	m/d	v_{di}
Temp correction	1.07		$\square_{di}$

Organic P:			
Hydrolysis	0.1	/d	k_{hp}
Temp correction	1.07		ξ_{hp}
Settling velocity	0.01	m/d	v_{op}
Inorganic P:			
Settling velocity	0.8	m/d	v_{ip}
Inorganic P sorption coefficient	0.01	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	0	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		ξ_{gp}
Respiration rate	0.2	/d	k_{rp}
Temp correction	1.07		ξ_{rp}
Death rate	0.2	/d	k_{dp}
Temp correction	1.07		ξ_{dp}
Nitrogen half sat constant	25	ugN/L	k_{sPp}
Phosphorus half sat constant	5	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.5	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	50	$mgA/m^2/d$ or /d	C_{gb}
Temp correction	1.07		ξ_{gb}
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.1	/d	k_{rb}
Temp correction	1.07		ξ_{rb}
Excretion rate	0.05	/d	k_{eb}
Temp correction	1.07		ξ_{db}
Death rate	0.1	/d	k_{db}
Temp correction	1.07		ξ_{db}
External nitrogen half sat constant	300	ugN/L	k_{sPb}
External phosphorus half sat constant	100	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lb}
Ammonia preference	25	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	ξ_{mN}
Maximum uptake rate for phosphorus	5	mgP/mgA/d	ξ_{mP}
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		ξ_{dt}
Fraction of dissolution to fast CBOD	1.00		F_f
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		ξ_{dx}
Settling velocity	1	m/d	v_x
Light efficiency factor	1.00		ξ_{path}
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

QUAL2K

Stream Water Quality Model

Crab Orchard Creek - ND 02 (6/22/1995)

Light Parameters and Surface Heat Transfer Models:

Parameter	*Value*	*Unit*	
Photosynthetically Available Radiation	0.47		
Background light extinction	0.2	/m	k_{eb}
Linear chlorophyll light extinction	0.0088	1/m-(ugA/L)	$\square_{p}$
Nonlinear chlorophyll light extinction	0.054	1/m-(ugA/L)2/3	$\square_{pn}$
ISS light extinction	0.052	1/m-(mgD/L)	$\square_{\square}$
Detritus light extinction	0.174	1/m-(mgD/L)	$\square_{\square}$
Solar shortwave radiation model			
Atmospheric attenuation model for solar	Bras		
Bras solar parameter (used if Bras solar model is selected)			
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	2		n_{fac}
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)			
atmospheric transmission coefficient (0.70-0.91, default 0.8)	0.8		a_{tc}
Downwelling atmospheric longwave IR radiation			
atmospheric longwave emissivity model	Brunt		
Evaporation and air convection/conduction			
wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer		
Sediment heat parameters			
Sediment thermal thickness	15	cm	H_s
Sediment thermal diffusivity	0.0064	cm^2/s	$\square_s$
Sediment density	1.6	g/cm^3	$\square_s$
Water density	1	g/cm^3	$\square_w$
Sediment heat capacity	0.4	$cal/(g\ ^oC)$	C_{ps}
Water heat capacity	1	$cal/(g\ ^oC)$	C_{pw}
Sediment diagenesis model			
Compute SOD and nutrient fluxes	No		

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	**Crab Orchard Creek - ND 02**	
Saved file name	**CrabOrchard_ILND02_reduction**	
Directory where file saved	**L:\I-intercompany\I4358\Modeling\Qual2K**	
Month	**6**	
Day	**22**	
Year	**1995**	
Time zone	**Central**	
Daylight savings time	**Yes**	
Calculation:		
Calculation step	**0.0625**	**hours**
Final time	**3**	**day**
Solution method (integration)	**Euler**	
Solution method (pH)	**Bisection**	
Program determined calc step	**0.046875**	**hours**
Time of last calculation	**0.27**	**minutes**
Time of sunrise	**5:35 AM**	
Time of solar noon	**12:58 PM**	
Time of sunset	**8:21 PM**	
Photoperiod	**14.78**	**hours**

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 02 (6/22/1995)
Diffuse Source Data:

*** The headwater of the mainstem (or tributary) where the diffuse source enters.**

	Headwater	Headwater	Location		Diffuse	Diffuse		Spec	Inorg	Diss	CBOD	CBOD
			Up	Down	Abstraction	Inflow	Temp	Cond	SS	Oxygen	slow	fast
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos	mgD/L	mg/L	mgO2/L	mgO2/L
	1	Mainstem headwater	2.50	0.00		0.0030					5.00	0.01

Organic	Ammon	Nitrate	Organic	Inorganic	Phyto				
N	N	N	P	P	plankton	Detritus	Pathogen	Alk	pH
ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	ug/L	mgD/L	cfu/100 ml	mgCaCO3/L	
1000.00	200.00	1000.00	300.00	300.00				100.00	7.00

B.5.2 Crab Orchard Creek Segment ND-04

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	**Crab Orchard Creek - ND 04**	
Saved file name	**CrabOrchard_ILND04**	
Directory where file saved	**L:\I-intercompany\I4358\Modeling\Qual2K**	
Month	**9**	
Day	**9**	
Year	**1996**	
Time zone	**Central**	
Daylight savings time	**Yes**	
Calculation:		
Calculation step	**0.0625**	**hours**
Final time	**3**	**day**
Solution method (integration)	**Euler**	
Solution method (pH)	**Bisection**	
Program determined calc step	**0.046875**	**hours**
Time of last calculation	**0.06**	**minutes**
Time of sunrise	**6:32 AM**	
Time of solar noon	**12:52 PM**	
Time of sunset	**7:12 PM**	
Photoperiod	**12.66**	**hours**

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 04 (9/9/1996)
Headwater Data:

Note: ** required field*

ID	*Number of Headwaters**	1										
No. 1	*Reach No.**	*Headwater Name*	*Flow**	*Elevation*	*Weir*				**Rating Curves**			
			Rate		*Height*	*Width*	*adam*	*bdam*	*Velocity*		*Depth*	
			(m^3/s)	*(m)*	*(m)*	0.0000			*Coefficient*	*Exponent*	*Coefficient*	*Exponent*
	1	Mainstem headwater	0.000100	164.590	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
	Headwater Water Quality	*Units*	*12:00 AM*	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*	*9:00 AM*
	Temperature	C	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80
	Conductivity	umhos	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00
	Inorganic Solids	mgD/L										
	Dissolved Oxygen		3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80
	CBODslow	mgO2/L	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	CBODfast	mgO2/L	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Organic Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NH4-Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NO3-Nitrogen	ugN/L	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
	Organic Phosphorus	ugP/L	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
	Inorganic Phosphorus (SRP)	ugP/L	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
	Phytoplankton	ugA/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Detritus (POM)	mgD/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pathogen	cfu/100 mL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alkalinity	mgCaCO3/L	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00
	pH	s.u.	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90

Manning Formula					*Prescribed*								
Channel	*Manning*	*Bot Width*	*Side*	*Side*	*Dispersion*								
Slope	*n*	*m*	*Slope*	*Slope*	*m2/s*								
0.00260959	0.0500	3.05	0.25	0.25	0.00								
10:00 AM	*11:00 AM*	*12:00 PM*	*1:00 PM*	*2:00 PM*	*3:00 PM*	*4:00 PM*	*5:00 PM*	*6:00 PM*	*7:00 PM*	*8:00 PM*	*9:00 PM*	*10:00 PM*	*11:00 PM*
22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.80
1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00	1950.00
3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00	114.00
6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 04 (9/9/1996)
Reach Data:

Reach for diel plot	1									
Element for diel plot	2	Reach	Headwater	Reach			Location		Element
Reach	Downstream	Number	Reach	length	Downstream		Upstream	Downstream	Number
Label	end of reach label			(km)	Latitude	Longitude	(km)	(km)	>=1
		1	Yes	11.68	37.76	88.85	22.430	10.750	4
		2		5.49	37.73	88.89	10.750	5.260	2
		3		5.26	37.72	88.93	5.260	0.000	2

								Hydraulic Model (Weir Overrides Manning Formula; Manning Formula Override Rating Curves)							
Elevation		Downstream						Weir				Rating Curves			
Upstream	Downstream	Latitude			Longitude			Height	Width	adam	bdam	Velocity		Depth	
(m)	(m)	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
164.590	134.110	37.00	45	36	88.00	51	0	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
134.110	131.060	37.00	43	48	88.00	53	24	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
131.060	124.970	37.00	43	12	88.00	55	48	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000

Manning Formula					Prescribed	Bottom	Bottom	Prescribed	Prescribed	Prescribed	Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion	Algae	SOD	SOD	CH4 flux	NH4 flux	Inorg P flux
Slope	n	m	Slope	Slope	m2/s	Coverage	Coverage	gO2/m2/d	gO2/m2/d	mgN/m2/d	mgP/m2/d
0.0026	0.0500	3.05	0.2500	0.2500	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0006	0.0450	5.00	0.3000	0.3300	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0012	0.0400	7.00	0.5000	0.5000	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 04 (9/9/1996)
Water Column Rates

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.3	m/d	v_i
Oxygen:			
Reaeration model	Tsivoglou-Neal		
User reaeration coefficient α	2		α
User reaeration coefficient β	0.5		β
User reaeration coefficient γ	1.5		γ
Temp correction	1.024		$\square_a$
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	5	/d	k_{hc}
Temp correction	1.07		$\square_{hc}$
Oxidation rate	2	/d	k_{dcs}
Temp correction	1.047		$\square_{dcs}$
Fast CBOD:			
Oxidation rate	8	/d	k_{dc}
Temp correction	1.047		$\square_{dc}$
Organic N:			
Hydrolysis	5	/d	k_{hn}
Temp correction	1.07		$\square_{hn}$
Settling velocity	0.1	m/d	v_{on}
Ammonium:			
Nitrification	0.5	/d	k_{na}
Temp correction	1.07		$\square_{na}$
Nitrate:			
Denitrification	2	/d	k_{dn}
Temp correction	1.07		$\square_{dn}$
Sed denitrification transfer coeff	0.08	m/d	v_{di}
Temp correction	1.07		$\square_{di}$

Organic P:			
Hydrolysis	0	/d	k_{hp}
Temp correction	1.07		$\square_{hp}$
Settling velocity	0	m/d	v_{op}
Inorganic P:			
Settling velocity	0.2	m/d	v_{ip}
Inorganic P sorption coefficient	0	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	0.05	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		$\square_{gp}$
Respiration rate	0.2	/d	k_{rp}
Temp correction	1.07		$\square_{rp}$
Death rate	0.2	/d	k_{dp}
Temp correction	1.07		$\square_{dp}$
Nitrogen half sat constant	25	ugN/L	k_{sPp}
Phosphorus half sat constant	5	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.5	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	50	$mgA/m^2/d$ or /d	C_{gb}
Temp correction	1.07		$\square_{gb}$
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.1	/d	k_{rb}
Temp correction	1.07		$\square_{rb}$
Excretion rate	0.05	/d	k_{eb}
Temp correction	1.07		$\square_{db}$
Death rate	0.1	/d	k_{db}
Temp correction	1.07		$\square_{db}$
External nitrogen half sat constant	300	ugN/L	k_{sPb}
External phosphorus half sat constant	100	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lb}
Ammonia preference	25	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	$\square_{mN}$
Maximum uptake rate for phosphorus	5	mgP/mgA/d	$\square_{mP}$
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		$\square_{dt}$
Fraction of dissolution to fast CBOD	1.00		F_f
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		$\square_{dx}$
Settling velocity	1	m/d	v_x
Light efficiency factor	1.00		$\square_{path}$
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

QUAL2K

Stream Water Quality Model

Crab Orchard Creek - ND 04 (9/9/1996)

Light Parameters and Surface Heat Transfer Models:

Parameter	*Value*	*Unit*	
Photosynthetically Available Radiation	**0.47**		
Background light extinction	**0.2**	*/m*	k_{eb}
Linear chlorophyll light extinction	**0.0088**	*1/m-(ugA/L)*	$\square_p$
Nonlinear chlorophyll light extinction	**0.054**	*1/m-(ugA/L)2/3*	$\square_{pn}$
ISS light extinction	**0.052**	*1/m-(mgD/L)*	$\square_{\square}$
Detritus light extinction	**0.174**	*1/m-(mgD/L)*	$\square_{\square}$
Solar shortwave radiation model			
Atmospheric attenuation model for solar	**Bras**		
Bras solar parameter (used if Bras solar model is selected)			
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	**2**		n_{fac}
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)			
atmospheric transmission coefficient (0.70-0.91, default 0.8)	**0.8**		a_{tc}
Downwelling atmospheric longwave IR radiation			
atmospheric longwave emissivity model	**Brunt**		
Evaporation and air convection/conduction			
wind speed function for evaporation and air convection/conduction	**Brady-Graves-Geyer**		
Sediment heat parameters			
Sediment thermal thickness	**15**	*cm*	H_s
Sediment thermal diffusivity	**0.0064**	*cm^2/s*	$\square_s$
Sediment density	**1.6**	*g/cm^3*	$\square_s$
Water density	**1**	*g/cm^3*	$\square_w$
Sediment heat capacity	**0.4**	*$cal/(g\ ^oC)$*	C_{ps}
Water heat capacity	**1**	*$cal/(g\ ^oC)$*	C_{pw}
Sediment diagenesis model			
Compute SOD and nutrient fluxes	**No**		

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 04 (9/9/1996)
Diffuse Source Data:

** The headwater of the mainstem (or tributary) where the diffuse source enters.*

	Headwater	Headwater	Location		Diffuse	Diffuse		Spec	Inorg	Diss
			Up	Down	Abstraction	Inflow	Temp	Cond	SS	Oxygen
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos	mgD/L	mg/L
	1	Mainstem headwater	22.43	10.75		0.0008	18.00	1800.00		
	1	Mainstem headwater	10.75	5.26		0.0011	18.00	1800.00		
	1	Mainstem headwater	5.26	0.00		0.0015	18.00	1800.00		

CBOD	CBOD	Organic	Ammon	Nitrate	Organic	Inorganic	Phyto				
slow	fast	N	N	N	P	P	plankton	Detritus	Pathogen	Alk	pH
mgO2/L	mgO2/L	ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	ug/L	mgD/L	cfu/100 ml	mgCaCO3/L	
	35.00	1000.00	4000.00							100.00	7.00
	35.00	1000.00	4000.00		120.00	300.00				100.00	7.00
	35.00	1000.00	4000.00		120.00	300.00				140.00	6.70

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 04 (9/9/1996)
Point Source Data:

** The headwater of the mainstem (or tributary) where the point source enters.*

	Headwater	Headwater	Location	Point		Temperature			Spe
				Abstraction	Inflow	mean	range/2	time of	mean
Name	ID*	Name	km	m3/s	m3/s	°C	°C	max	umhos
Freeman United Coal - IL0004685	1	Mainstem headwater	18.000		0.0065				
Crab Orchard Grade HS - IL0037311	1	Mainstem headwater	10.600		0.0003				
Marion Southeast STP - IL0029734	1	Mainstem headwater	0.400		0.2172				

Dissolved Oxygen			Fast CBOD			Ammonia N			Alkalinity			pH
mean	range/2	time of	mean	range/2	time of	mean	range/2	time of	mean	range/2	time of	mean
mg/L	mg/L	max	mgO2/L	mgO2/L	max	ugN/L	ugN/L	max	mgCaCO3/L	mgCaCO3/L	max	s.u.
									93.50	0.00	12:00 AM	10.30
7.93	0.00	1:00 AM	5.27	0.00	1:00 AM	5396.00	0.00	1:00 AM	100.00			7.30
7.07	0.00	2:00 AM	3.06	0.00	2:00 AM	398.00	0.00	2:00 AM	100.00			7.50

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	**Crab Orchard Creek - ND 04**	
Saved file name	**CrabOrchard_ILND04_reduction**	
Directory where file saved	**L:\I-intercompany\I4358\Modeling\Qual2K**	
Month	**9**	
Day	**9**	
Year	**1996**	
Time zone	**Central**	
Daylight savings time	**Yes**	
Calculation:		
Calculation step	**0.0625**	**hours**
Final time	**3**	**day**
Solution method (integration)	**Euler**	
Solution method (pH)	**Bisection**	
Program determined calc step	**0.046875**	**hours**
Time of last calculation	**0.07**	**minutes**
Time of sunrise	**6:32 AM**	
Time of solar noon	**12:52 PM**	
Time of sunset	**7:12 PM**	
Photoperiod	**12.66**	**hours**

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 04 (9/9/1996)
Diffuse Source Data:

** The headwater of the mainstem (or tributary) where the diffuse source enters.*

Name	Headwater ID*	Headwater Name	Location Up km	Location Down km	Diffuse Abstraction m3/s	Diffuse Inflow m3/s	Temp C	Spec Cond umhos	Inorg SS mgD/L	Diss Oxygen mg/L	CBOD slow mgO2/L
	1	Mainstem headwater	22.43	10.75		0.0008	18.00	1800.00			
	1	Mainstem headwater	10.75	5.26		0.0011	18.00	1800.00			
	1	Mainstem headwater	5.26	0.00		0.0015	18.00	1800.00			

CBOD fast mgO2/L	Organic N ugN/L	Ammon N ugN/L	Nitrate N ugN/L	Organic P ugP/L	Inorganic P ugP/L	Phyto plankton ug/L	Detritus mgD/L	Pathogen cfu/100 ml	Alk mgCaCO3/L	pH
5.00	1000.00	500.00							100.00	7.00
20.00	1000.00	2000.00		120.00	300.00				100.00	7.00
20.00	1000.00	4000.00		120.00	300.00				140.00	6.70

B.5.3 Crab Orchard Creek Segment ND-11

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	**Crab Orchard Creek - ND 11**	
Saved file name	**CrabOrchard_ILND11**	
Directory where file saved	**L:\I-intercompany\I4358\Modeling\Qual2K**	
Month	**9**	
Day	**9**	
Year	**2006**	
Time zone	**Central**	
Daylight savings time	**Yes**	
Calculation:		
Calculation step	**0.0625**	**hours**
Final time	**3**	**day**
Solution method (integration)	**Euler**	
Solution method (pH)	**Bisection**	
Program determined calc step	**0.046875**	**hours**
Time of last calculation	**0.04**	**minutes**
Time of sunrise	**6:33 AM**	
Time of solar noon	**12:53 PM**	
Time of sunset	**7:13 PM**	
Photoperiod	**12.67**	**hours**

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 11 (9/9/2006)
Headwater Data:

*Note: * required field*

ID	Number of Headwaters*	1										
No. 1	Reach No.*	Headwater Name	Flow*	Elevation	Weir				Rating Curves			
			Rate		Height	Width	adam	bdam	Velocity		Depth	
			(m^3/s)	(m)	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
	1	Mainstem headwater	0.00015	111.250	0.0000	0.0000	1.2500	0.9000	1.0200	0.430	0.9800	0.450
	Headwater Water Quality	Units	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM
	Temperature	C	20.63	20.37	20.12	19.90	19.68	19.46	19.25	19.04	18.98	19.21
	Conductivity	umhos	409.21	407.27	405.54	404.65	402.87	400.93	399.29	397.22	396.54	397.87
	Inorganic Solids	mgD/L										
	Dissolved Oxygen	mg/L	4.07	4.00	3.97	3.94	4.00	3.96	3.98	3.94	3.87	3.86
	CBODslow	mgO2/L	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
	CBODfast	mgO2/L	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
	Organic Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NH4-Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NO3-Nitrogen	ugN/L	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00
	Organic Phosphorus	ugP/L	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
	Inorganic Phosphorus (SRP)	ugP/L	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
	Phytoplankton	ugA/L	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	Detritus (POM)	mgD/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pathogen	cfu/100 mL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alkalinity	mgCaCO3/L	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
	pH	s.u.	7.18	7.17	7.17	7.19	7.20	7.20	7.20	7.20	7.19	7.19

Manning Formula					Prescribed								
Channel	Manning	Bot Width	Side	Side	Dispersion								
Slope	n	m	Slope	Slope	m2/s								
0.00072619	0.0400	9.14	0.33	0.33	0.00								
10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM
19.73	20.23	21.02	21.78	22.57	23.90	23.86	23.63	23.30	22.89	22.43	22.09	21.76	21.47
402.33	405.54	410.56	415.22	422.24	433.51	432.88	430.97	429.11	426.90	423.50	421.82	419.35	417.52
4.22	4.41	4.72	5.03	5.41	5.82	5.33	5.03	4.53	4.19	4.04	3.86	3.78	3.71
2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00
50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
7.19	7.20	7.20	7.20	7.21	7.22	7.20	7.19	7.18	7.17	7.16	7.16	7.16	7.16

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 11 (9/9/2006)
Reach Data:

Reach for diel plot	1										
Element for diel plot	2	Reach	Headwater	Reach			Location		Element	Eleva
Reach	Downstream	Number	Reach	length	Downstream		Upstream	Downstream	Number	Upstream
Label	end of reach label			(km)	Latitude	Longitude	(km)	(km)	>=1	(m)
	headwater	1	Yes	0.84	37.73	89.17	1.520	0.680	2	111.250
		2		0.68	37.73	89.17	0.680	0.000	2	110.640

Hydraulic Model (Weir Overrides Manning Formula; Manning Formula Override Rating Curves)													
Downstream						Weir				Rating Curves			
Latitude			Longitude			Height	Width	adam	bdam	Velocity		Depth	
Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
37.00	43	48	89.00	10	12	0.0000	0.0000	1.2500	0.9000	0.0000	0.0000	0.0000	0.0000
37.00	43	48	89.00	10	12	0.0000	0.0000	1.2500	0.9000	0.0000	0.0000	0.0000	0.0000

Manning Formula					Prescribed	Bottom	Bottom	Prescribed	Prescribed	Prescribed	Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion	Algae	SOD	SOD	CH4 flux	NH4 flux	Inorg P flux
Slope	n	m	Slope	Slope	m2/s	Coverage	Coverage	gO2/m2/d	gO2/m2/d	mgN/m2/d	mgP/m2/d
0.0007	0.0400	9.14	0.3300	0.3300	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0009	0.0400	9.14	0.3300	0.3300	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 11 (9/9/2006)
Water Column Rates

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.3	m/d	v_i
Oxygen:			
Reaeration model	Tsivoglou-Neal		
User reaeration coefficient α	3.93		α
User reaeration coefficient β	0.5		β
User reaeration coefficient γ	1.5		γ
Temp correction	1.024		$\square_a$
Reaeration wind effect	Banks-Herrera		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	0.1	/d	k_{hc}
Temp correction	1.07		$\square_{hc}$
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		$\square_{dcs}$
Fast CBOD:			
Oxidation rate	5	/d	k_{dc}
Temp correction	1.047		$\square_{dc}$
Organic N:			
Hydrolysis	0.1	/d	k_{hn}
Temp correction	1.07		$\square_{hn}$
Settling velocity	0.01	m/d	v_{on}
Ammonium:			
Nitrification	7	/d	k_{na}
Temp correction	1.07		$\square_{na}$
Nitrate:			
Denitrification	1	/d	k_{dn}
Temp correction	1.07		$\square_{dn}$
Sed denitrification transfer coeff	0.1	m/d	v_{di}
Temp correction	1.07		$\square_{di}$
Organic P:			
Hydrolysis	0.01	/d	k_{hp}
Temp correction	1.07		$\square_{hp}$
Settling velocity	0.1	m/d	v_{op}
Inorganic P:			
Settling velocity	0.001	m/d	v_{ip}
Inorganic P sorption coefficient	0	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	0.05	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		$\square_{gp}$
Respiration rate	0.2	/d	k_{rp}
Temp correction	1.07		$\square_{rp}$
Death rate	0.2	/d	k_{dp}
Temp correction	1.07		$\square_{dp}$
Nitrogen half sat constant	25	ugN/L	k_{sPp}
Phosphorus half sat constant	5	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.5	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	50	$mgA/m^2/d$ or /d	C_{gb}
Temp correction	1.07		$\square_{gb}$
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.1	/d	k_{rb}
Temp correction	1.07		$\square_{rb}$
Excretion rate	0.05	/d	k_{eb}
Temp correction	1.07		$\square_{db}$
Death rate	0.1	/d	k_{db}
Temp correction	1.07		$\square_{db}$
External nitrogen half sat constant	300	ugN/L	k_{sPb}
External phosphorus half sat constant	100	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lb}
Ammonia preference	25	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	$\square_{mN}$
Maximum uptake rate for phosphorus	5	mgP/mgA/d	$\square_{mP}$
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		$\square_{dt}$
Fraction of dissolution to fast CBOD	1.00		F_f
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		$\square_{dx}$
Settling velocity	1	m/d	v_x
Light efficiency factor	1.00		$\square_{path}$
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

Crab Orchard Creek - ND 11 (9/9/2006)
Light Parameters and Surface Heat Transfer Models:

Parameter	*Value*	*Unit*	
Photosynthetically Available Radiation	0.47		
Background light extinction	0.2	*/m*	k_{eb}
Linear chlorophyll light extinction	0.0088	*1/m-(ugA/L)*	Ξ_p
Nonlinear chlorophyll light extinction	0.054	*1/m-(ugA/L)2/3*	Ξ_{pn}
ISS light extinction	0.052	*1/m-(mgD/L)*	Ξ_{Ξ}
Detritus light extinction	0.174	*1/m-(mgD/L)*	Ξ_{Ξ}
Solar shortwave radiation model			
Atmospheric attenuation model for solar	Bras		
Bras solar parameter (used if Bras solar model is selected)			
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	2		n_{fac}
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)			
atmospheric transmission coefficient (0.70-0.91, default 0.8)	0.8		a_{tc}
Downwelling atmospheric longwave IR radiation			
atmospheric longwave emissivity model	Brunt		
Evaporation and air convection/conduction			
wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer		
Sediment heat parameters			
Sediment thermal thickness	15	*cm*	H_s
Sediment thermal diffusivity	0.0064	*cm^2/s*	Ξ_s
Sediment density	1.6	*g/cm^3*	Ξ_s
Water density	1	*g/cm^3*	Ξ_w
Sediment heat capacity	0.4	*cal/(g ^{o}C)*	C_{ps}
Water heat capacity	1	*cal/(g ^{o}C)*	C_{pw}
Sediment diagenesis model			
Compute SOD and nutrient fluxes	No		

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 11 (9/9/2006)
Diffuse Source Data:

*** The headwater of the mainstem (or tributary) where the diffuse source enters.**

	Headwater	Headwater	Location		Diffuse	Diffuse		Spec	Inorg	Diss	CBOD
			Up	Down	Abstraction	Inflow	Temp	Cond	SS	Oxygen	slow
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos	mgD/L	mg/L	mgO2/L
	1	Mainstem headwater	1.52	0.68	0.0102						
	1	Mainstem headwater	1.52	0.68		0.0050	22.00	420.00			
	1	Mainstem headwater	0.68	0.00		0.0002	22.00	420.00			

CBOD	Organic	Ammon	Nitrate	Organic	Inorganic	Phyto				
fast	N	N	N	P	P	plankton	Detritus	Pathogen	Alk	pH
mgO2/L	ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	ug/L	mgD/L	cfu/100 ml	mgCaCO3/L	
30.00		4000.00		180.00	190.00				100.00	7.00
30.00		4000.00		180.00	190.00				100.00	7.00

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 11 (9/9/2006)
Point Source Data:

** The headwater of the mainstem (or tributary) where the point source enters.*

	Headwater	Headwater	Location	Point		Temperature			Specific Condu
				Abstraction	Inflow	mean	range/2	time of	mean
Name	ID*	Name	km	m3/s	m3/s	°C	°C	max	umhos
Southern IL Univ-C Lit Grassy	1	Mainstem headwater	1.520		0.0016	22.00			413.17
Bush MHP STP #2-Carbondale	1	Mainstem headwater	1.520		0.0003	22.00			413.17
Chateau Apartments	1	Mainstem headwater	1.520		0.0007	22.00			413.17
Corner One Stop - Carbondale	1	Mainstem headwater	1.520		0.0003	22.00			413.17
Frost Mobile Home Park	1	Mainstem headwater	1.520		0.0004	22.00			413.17
Giant City School	1	Mainstem headwater	1.520		0.0002	22.00			413.17
IL DOC-Giant City State Park	1	Mainstem headwater	1.520		0.0004	22.00			413.17
Meadowbrook Estates MHP	1	Mainstem headwater	1.520		0.0003	22.00			413.17
Pleasant Hill MHP	1	Mainstem headwater	1.520		0.0009	22.00			413.17
Pleasant Valley MHP	1	Mainstem headwater	1.520		0.0015	22.00			413.17
Southern Mobile Home Park	1	Mainstem headwater	1.520		0.0008	22.00			413.17
United Methodist Camp	1	Mainstem headwater	1.520		0.0003	22.00			413.17
Unity Point Elm Sch Dist 140	1	Mainstem headwater	1.520		0.0008	22.00			413.17
University Heights MHP	1	Mainstem headwater	1.520		0.0011	22.00			413.17
Wildwood Mobile Home Park	1	Mainstem headwater	1.520		0.0006	22.00			413.17

Dissolved Oxygen			Fast CBOD			Ammonia N			Alkalinity	pH
mean	range/2	time of	mean	range/2	time of	mean	range/2	time of	mean	mean
mg/L	mg/L	max	mgO2/L	mgO2/L	max	ugN/L	ugN/L	max	mgCaCO3/L	s.u.
6.00			3.14		12:00 AM	1980.00		12:00 AM	100.00	6.93
5.45			6.87		12:00 AM	1350.00		12:00 AM	100.00	6.95
6.00			4.73		12:00 AM				100.00	6.95
6.00			13.29		12:00 AM	1350.00		12:00 AM	100.00	7.04
6.00			7.26		12:00 AM				100.00	6.94
8.30			3.49		12:00 AM	2030.00		12:00 AM	100.00	6.93
11.09			0.01		12:00 AM	3000.00		12:00 AM	100.00	7.70
6.00			7.44		12:00 AM	2360.00		12:00 AM	100.00	6.87
6.00			5.95		12:00 AM				100.00	6.96
6.00			3.20		12:00 AM				100.00	7.00
6.00			16.20		12:00 AM				100.00	7.38
6.00			6.56		12:00 AM				100.00	7.20
6.00			13.40		12:00 AM	1590.00		12:00 AM	100.00	7.38
7.17			5.94		12:00 AM	2200.00		12:00 AM	100.00	6.97
6.00			18.33		12:00 AM				100.00	7.37

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	Crab Orchard Creek - ND 11	
Saved file name	CrabOrchard_ILND11_reduction	
Directory where file saved	L:\I-intercompany\I4358\Modeling\Qual2K	
Month	9	
Day	9	
Year	2006	
Time zone	Central	
Daylight savings time	Yes	
Calculation:		
Calculation step	0.0625	hours
Final time	3	day
Solution method (integration)	Euler	
Solution method (pH)	Bisection	
Program determined calc step	0.046875	hours
Time of last calculation	0.04	minutes
Time of sunrise	6:33 AM	
Time of solar noon	12:53 PM	
Time of sunset	7:13 PM	
Photoperiod	12.67	hours

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 11 (9/9/2006)
Diffuse Source Data:

** The headwater of the mainstem (or tributary) where the diffuse source enters.*

			Location		Diffuse	Diffuse		Spec	CBOD	Ammon	Organic	Inorganic	
	Headwater	Headwater	Up	Down	Abstraction	Inflow	Temp	Cond	fast	N	P	P	Alk
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos	mgO2/L	ugN/L	ugP/L	ugP/L	ngCaCO3/L
	1	Mainstem headwater	1.52	0.68	0.0102								
	1	Mainstem headwater	1.52	0.68		0.0050	22.00	420.00	5.00	800.00	180.00	190.00	100.00
	1	Mainstem headwater	0.68	0.00		0.0002	22.00	420.00	5.00	800.00	180.00	190.00	100.00

B.5.4 Crab Orchard Creek Segment ND-13

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	**Crab Orchard Creek - ND 13**	
Saved file name	**CrabOrchard_ILND13**	
Directory where file saved	**L:\I-intercompany\I4358\Modeling\Qual2K**	
Month	**9**	
Day	**11**	
Year	**2007**	
Time zone	**Central**	
Daylight savings time	**Yes**	
Calculation:		
Calculation step	**0.0625**	**hours**
Final time	**3**	**day**
Solution method (integration)	**Euler**	
Solution method (pH)	**Bisection**	
Program determined calc step	**0.046875**	**hours**
Time of last calculation	**0.04**	**minutes**
Time of sunrise	**6:35 AM**	
Time of solar noon	**12:53 PM**	
Time of sunset	**7:11 PM**	
Photoperiod	**12.60**	**hours**

Stream Water Quality Model
Crab Orchard Creek - ND 13 (9/11/2007)
Headwater Data:

Note: ** required field*

ID	Number of Headwaters*	1										
No. 1	Reach No.*	Headwater Name	Flow*	Elevation	Weir				Rating Curves			
			Rate		Height	Width	adam	bdam	Velocity		Depth	
			(m^3/s)	(m)	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
	1	Mainstem headwate	0.075	110.030	0.0000	0.0000	1.2500	0.9000	0.0000	0.0000	0.0000	0.0000
	Headwater Water Quality	Units	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM
	Temperature	C	23.63	23.33	23.07	22.82	22.61	22.44	22.30	22.14	22.00	21.89
	Conductivity	umhos	512.95	510.61	508.50	508.22	507.20	506.82	506.76	505.75	505.32	504.58
	Inorganic Solids	mgD/L										
	Dissolved Oxygen	mg/L	5.26	5.08	4.84	4.87	4.67	4.47	4.46	4.55	4.43	4.43
	CBODslow	mgO2/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CBODfast	mgO2/L	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Organic Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NH4-Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NO3-Nitrogen	ugN/L	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00
	Organic Phosphorus	ugP/L	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00
	Inorganic Phosphorus (SRP)	ugP/L	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
	Phytoplankton	ugA/L	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00
	Detritus (POM)	mgD/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pathogen	cfu/100 mL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alkalinity	mgCaCO3/L	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
	pH	s.u.	7.44	7.43	7.42	7.41	7.41	7.40	7.39	7.40	7.39	7.39

Manning Formula					Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion
Slope	n	m	Slope	Slope	m2/s
0.0002	0.0400	12.00	0.50	0.25	0.00

10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM
21.89	21.97	22.09	22.36	22.69	22.92	22.97	23.05	23.12	23.21	23.37	23.62	23.76	23.86
501.42	499.13	504.05	506.02	507.31	511.25	511.68	519.36	520.88	522.58	524.92	527.69	529.67	531.48
4.47	4.54	4.58	4.70	4.93	4.99	4.94	4.80	4.93	4.87	5.01	4.95	5.04	5.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00	6400.00
130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00	130.00
300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
7.39	7.38	7.39	7.40	7.40	7.40	7.41	7.41	7.41	7.42	7.43	7.44	7.48	7.48

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 13 (9/11/2007)
Reach Data:

Reach for diel plot		1									
Element for diel plot		2	Reach	Headwater	Reach			Location		Element	Eleva
Reach	Downstream		Number	Reach	length	Downstream		Upstream	Downstream	Number	Upstream
Label	end of reach label				(km)	Latitude	Longitude	(km)	(km)	>=1	(m)
			1	Yes	1.22	37.74	89.18	2.420	1.200	2	110.030
			2		1.20	37.75	89.19	1.200	0.000	2	109.730

								Hydraulic Model (Weir Overrides Manning Formula; Manning Formula Override Rating Curves)							
Elevation		Downstream						Weir				Rating Curves			
Upstream	Downstream	Latitude			Longitude			Height	Width	adam	bdam	Velocity		Depth	
(m)	(m)	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
110.030	109.730	37.00	44	24	89.00	10	48	0.0000	0.0000	1.2500	0.9000	0.0000	0.0000	0.0000	0.0000
109.730	109.420	37.00	45	0	89.00	11	24	0.0000	0.0000	1.2500	0.9000	0.0000	0.0000	0.0000	0.0000

Manning Formula					Prescribed	Bottom	Bottom	Prescribed	Prescribed	Prescribed	Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion	Algae	SOD	SOD	CH4 flux	NH4 flux	Inorg P flux
Slope	n	m	Slope	Slope	m2/s	Coverage	Coverage	gO2/m2/d	gO2/m2/d	mgN/m2/d	mgP/m2/d
0.0002	0.0400	12.00	0.3700	0.3700	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0003	0.0400	12.00	0.3300	0.3300	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 13 (9/11/2007)
Water Column Rates

Parameter	*Value*	*Units*	*Symbol*
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.3	m/d	v_i
Oxygen:			
Reaeration model	Churchill		
User reaeration coefficient α	0		α
User reaeration coefficient β	0		β
User reaeration coefficient γ	0		γ
Temp correction	1.024		π_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	0.1	/d	k_{hc}
Temp correction	1.07		π_{hc}
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		π_{dcs}
Fast CBOD:			
Oxidation rate	2.5	/d	k_{dc}
Temp correction	1.047		π_{dc}
Organic N:			
Hydrolysis	0.2	/d	k_{hn}
Temp correction	1.07		π_{hn}
Settling velocity	0.01	m/d	v_{on}
Ammonium:			
Nitrification	0.2	/d	k_{na}
Temp correction	1.07		π_{na}
Nitrate:			
Denitrification	1	/d	k_{dn}
Temp correction	1.07		π_{dn}
Sed denitrification transfer coeff	0.1	m/d	v_{di}
Temp correction	1.07		π_{di}

Organic P:			
Hydrolysis	0.1	/d	k_{hp}
Temp correction	1.07		π_{hp}
Settling velocity	1.5	m/d	v_{op}
Inorganic P:			
Settling velocity	0.1	m/d	v_{ip}
Inorganic P sorption coefficient	0	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	0.1	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		π_{gp}
Respiration rate	0.2	/d	k_{rp}
Temp correction	1.07		π_{rp}
Death rate	0.2	/d	k_{dp}
Temp correction	1.07		π_{dp}
Nitrogen half sat constant	25	ugN/L	k_{sPp}
Phosphorus half sat constant	5	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.5	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	50	$mgA/m^2/d$ or /d	C_{gb}
Temp correction	1.07		π_{gb}
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.1	/d	k_{rb}
Temp correction	1.07		π_{rb}
Excretion rate	0.05	/d	k_{eb}
Temp correction	1.07		π_{db}
Death rate	0.1	/d	k_{db}
Temp correction	1.07		π_{db}
External nitrogen half sat constant	300	ugN/L	k_{sPb}
External phosphorus half sat constant	100	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lb}
Ammonia preference	25	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	π_{mN}
Maximum uptake rate for phosphorus	5	mgP/mgA/d	π_{mP}
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		π_{dt}
Fraction of dissolution to fast CBOD	1.00		F_f
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		π_{dx}
Settling velocity	1	m/d	v_x
Light efficiency factor	1.00		π_{path}
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 13 (9/11/2007)
Light Parameters and Surface Heat Transfer Models:

Parameter	*Value*	*Unit*	
Photosynthetically Available Radiation	0.47		
Background light extinction	0.2	/m	k_{eb}
Linear chlorophyll light extinction	0.0088	1/m-(ugA/L)	H_p
Nonlinear chlorophyll light extinction	0.054	1/m-(ugA/L)2/3	H_{pn}
ISS light extinction	0.052	1/m-(mgD/L)	H_H
Detritus light extinction	0.174	1/m-(mgD/L)	H_H
Solar shortwave radiation model			
Atmospheric attenuation model for solar	Bras		
Bras solar parameter (used if Bras solar model is selected)			
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	2		n_{fac}
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)			
atmospheric transmission coefficient (0.70-0.91, default 0.8)	0.8		a_{tc}
Downwelling atmospheric longwave IR radiation			
atmospheric longwave emissivity model	Brunt		
Evaporation and air convection/conduction			
wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer		
Sediment heat parameters			
Sediment thermal thickness	15	cm	H_s
Sediment thermal diffusivity	0.0064	cm^2/s	H_s
Sediment density	1.6	g/cm^3	H_s
Water density	1	g/cm^3	H_w
Sediment heat capacity	0.4	$cal/(g\ ^oC)$	C_{ps}
Water heat capacity	1	$cal/(g\ ^oC)$	C_{pw}
Sediment diagenesis model			
Compute SOD and nutrient fluxes	Yes		

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Diffuse Source Data:

** The headwater of the mainstem (or tributary) where the diffuse source enters.*

Name	Headwater ID*	Headwater Name	Location Up km	Location Down km	Diffuse Abstraction m3/s	Diffuse Inflow m3/s	Temp C	Spec Cond umhos	Inorg SS mgD/L	Diss Oxygen mg/L	CBOD slow mgO2/L
	1	Mainstem headwater	2.42	0.00		0.0150	25.00	500.00			

CBOD fast mgO2/L	Organic N ugN/L	Ammon N ugN/L	Nitrate N ugN/L	Organic P ugP/L	Inorganic P ugP/L	Phyto plankton ug/L	Detritus mgD/L	Pathogen cfu/100 ml	Alk mgCaCO3/L	pH
30.00		5000.00		0.00	0.00	0.00	0.00	0.00	100.00	7.00

QUAL2K
Stream Water Quality Model
Crab Orchard Creek - ND 13 (9/11/2007)
Point Source Data:

** The headwater of the mainstem (or tributary) where the point source enters.*

Name	Headwater ID*	Headwater Name	Location km	Point Abstraction m3/s	Point Inflow m3/s	Temperature mean °C	Fast CBOD mean mgO2/L	Fast CBOD range/2 mgO2/L	Fast CBOD time of max
S.I. Properties LLC - ILG551066	1	Mainstem headwater	2.290		0.0018	25.00	6.68	0.00	12:00 AM

Alkalinity mean mgCaCO3/L	pH mean s.u.	pH range/2 s.u.	pH time of max
100.00	7.01	0.00	12:00 AM

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Diffuse Source Data:

*** The headwater of the mainstem (or tributary) where the diffuse source enters.**

	Headwater	Headwater	Location		Diffuse	Diffuse		Spec	Inorg	Diss	CBOD
			Up	Down	Abstraction	Inflow	Temp	Cond	SS	Oxygen	slow
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos	mgD/L	mg/L	mgO2/L
	1	Mainstem headwater	2.42	0.00		0.0150	25.00	500.00			

CBOD	Organic	Ammon	Nitrate	Organic	Inorganic	Phyto				
fast	N	N	N	P	P	plankton	Detritus	Pathogen	Alk	pH
mgO2/L	ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	ug/L	mgD/L	cfu/100 ml	mgCaCO3/L	
5.00		500.00		0.00	0.00	0.00	0.00	0.00	100.00	7.00

B.5.5 Little Crab Orchard Creek Segment NDA-01

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	**Little Crab Orchard Creek - NDA 01**	
Saved file name	**LittleCrabOrchard_ILNDA01**	
Directory where file saved	**L:\I-intercompany\I4358\Modeling\Qual2K**	
Month	**9**	
Day	**9**	
Year	**2006**	
Time zone	**Central**	
Daylight savings time	**Yes**	
Calculation:		
Calculation step	**0.0625**	**hours**
Final time	**3**	**day**
Solution method (integration)	**Euler**	
Solution method (pH)	**Bisection**	
Program determined calc step	**0.046875**	**hours**
Time of last calculation	**0.30**	**minutes**
Time of sunrise	**6:33 AM**	
Time of solar noon	**12:54 PM**	
Time of sunset	**7:14 PM**	
Photoperiod	**12.67**	**hours**

QUAL2K
Stream Water Quality Model
Little Crab Orchard Creek - NDA 01 (9/9/2006)
Headwater Data:

Note: ** required field*

ID	Number of Headwaters*	1										
No. 1	Reach No.*	Headwater Name	Flow*	Elevation	Weir				Rating Curves			
			Rate		Height	Width	adam	bdam	Velocity		Depth	
			(m^3/s)	(m)	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
	1	Mainstem headwater	0.002	164.590	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000

Headwater Water Quality	Units	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM
Temperature	C	19.28	19.11	18.98	18.84	18.68	18.54	18.39	18.33	18.34	18.36
Conductivity	umhos	224.16	223.45	223.15	222.61	221.65	221.31	220.87	220.89	220.49	221.43
Inorganic Solids	mgD/L										
Dissolved Oxygen	mg/L	1.87	1.74	1.41	1.38	1.39	1.35	1.18	1.24	1.13	1.20
CBODslow	mgO2/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CBODfast	mgO2/L	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90
Organic Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH4-Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO3-Nitrogen	ugN/L	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Organic Phosphorus	ugP/L	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00
Inorganic Phosphorus (SRP)	ugP/L	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
Phytoplankton	ugA/L	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
Detritus (POM)	mgD/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pathogen	cfu/100 mL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alkalinity	mgCaCO3/L	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
pH	s.u.	7.26	7.24	7.23	7.22	7.23	7.22	7.22	7.22	7.20	7.22

Manning Formula					Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion
Slope	n	m	Slope	Slope	m2/s
0.008	0.0550	1.52	0.35	0.35	0.00

10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM
18.41	18.51	18.72	18.87	18.98	19.13	19.19	19.29	19.43	19.50	19.59	19.68	19.70	19.71
222.15	223.02	223.02	223.55	224.52	224.25	224.43	225.48	226.71	227.14	228.06	227.91	228.27	228.74
1.12	1.05	1.09	1.39	1.76	1.81	1.59	1.56	1.32	1.23	0.87	0.90	0.65	0.79
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00	170.00
120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
7.22	7.20	7.23	7.23	7.23	7.23	7.21	7.21	7.20	7.18	7.18	7.18	7.16	7.17

QUAL2K
Stream Water Quality Model
Little Crab Orchard Creek - NDA 01 (9/9/2006)
Reach Data:

Reach for diel plot	1											
Element for diel plot	2	Reach	Headwater	Reach			Location		Element	Elevation	
Reach	Downstream	Number	Reach	length	Downstream		Upstream	Downstream	Number	Upstream	Downstream
Label	end of reach label			(km)	Latitude	Longitude	(km)	(km)	>=1	(m)	(m)
		1	Yes	2.90	37.69	89.28	19.660	16.760	3	164.590	138.680
		2		3.35	37.71	89.25	16.760	13.410	3	138.680	126.490
		3		2.44	37.73	89.25	13.410	10.970	2	126.490	119.790
		4		2.26	37.74	89.24	10.970	8.710	2	119.790	116.430
		5		3.53	37.76	89.23	8.710	5.180	3	116.430	113.390
		6		2.74	37.77	89.21	5.180	2.440	3	113.390	110.640
		7		2.44	37.78	89.21	2.440	0.000	2	110.640	106.680

Hydraulic Model (Weir Overrides Manning Formula; Manning Formula Override Rating Curves)														
Downstream						Weir				Rating Curves			
Latitude			Longitude			Height	Width	adam	bdam	Velocity		Depth	
Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
37.00	41	24	89.00	16	48	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
37.00	42	36	89.00	15	0	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
37.00	43	48	89.00	15	0	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
37.00	44	24	89.00	14	24	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
37.00	45	36	89.00	13	48	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
37.00	46	12	89.00	12	36	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
37.00	46	48	89.00	12	36	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000

Manning Formula					Prescribed	Bottom	Bottom	Prescribed	Prescribed	Prescribed	Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion	Algae	SOD	SOD	CH4 flux	NH4 flux	Inorg P flux
Slope	n	m	Slope	Slope	m2/s	Coverage	Coverage	gO2/m2/d	gO2/m2/d	mgN/m2/d	mgP/m2/d
0.0089	0.0550	1.52	0.3000	0.3000	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0036	0.0550	3.05	0.3000	0.3000	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0027	0.0550	4.57	0.3300	0.3300	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0015	0.0400	6.10	0.3300	0.3300	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0009	0.0500	6.10	0.3300	0.3300	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0010	0.0400	7.62	0.3500	0.3500	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0016	0.0400	9.14	0.3500	0.3500	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000

QUAL2K
Stream Water Quality Model
Little Crab Orchard Creek - NDA 01 (9/9/2006)
Water Column Rates

Parameter	*Value*	*Units*	*Symbol*
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.2	m/d	v_{i}
Oxygen:			
Reaeration model	Tsivoglou-Neal		
User reaeration coefficient α	3.93		α
User reaeration coefficient β	0.5		β
User reaeration coefficient γ	1.5		γ
Temp correction	1.024		$^{o}{}_{a}$
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	0.1	/d	k_{hc}
Temp correction	1.07		$^{o}{}_{hc}$
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		$^{o}{}_{dcs}$
Fast CBOD:			
Oxidation rate	8	/d	k_{dc}
Temp correction	1.047		$^{o}{}_{dc}$
Organic N:			
Hydrolysis	0.2	/d	k_{hn}
Temp correction	1.07		$^{o}{}_{hn}$
Settling velocity	0.1	m/d	v_{on}
Ammonium:			
Nitrification	7	/d	k_{na}
Temp correction	1.07		$^{o}{}_{na}$
Nitrate:			
Denitrification	0.1	/d	k_{dn}
Temp correction	1.07		$^{o}{}_{dn}$
Sed denitrification transfer coeff	7	m/d	v_{di}
Temp correction	1.07		$^{o}{}_{di}$
Organic P:			
Hydrolysis	0.01	/d	k_{hp}
Temp correction	1.07		$^{o}{}_{hp}$
Settling velocity	0.1	m/d	v_{op}
Inorganic P:			
Settling velocity	0.5	m/d	v_{ip}
Inorganic P sorption coefficient	0	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	0.5	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		$^{o}{}_{gp}$
Respiration rate	0.2	/d	k_{rp}
Temp correction	1.07		$^{o}{}_{rp}$
Death rate	0.2	/d	k_{dp}
Temp correction	1.07		$^{o}{}_{dp}$
Nitrogen half sat constant	25	ugN/L	k_{sPp}
Phosphorus half sat constant	5	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.5	m/d	v_{a}
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	50	$mgA/m^2/d$ or /d	C_{gb}
Temp correction	1.07		$^{o}{}_{gb}$
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.1	/d	k_{rb}
Temp correction	1.07		$^{o}{}_{rb}$
Excretion rate	0.05	/d	k_{eb}
Temp correction	1.07		$^{o}{}_{db}$
Death rate	0.1	/d	k_{db}
Temp correction	1.07		$^{o}{}_{db}$
External nitrogen half sat constant	300	ugN/L	k_{sPb}
External phosphorus half sat constant	100	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lb}
Ammonia preference	25	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	$^{o}{}_{mN}$
Maximum uptake rate for phosphorus	5	mgP/mgA/d	$^{o}{}_{mP}$
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		$^{o}{}_{dt}$
Fraction of dissolution to fast CBOD	1.00		F_{f}
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		$^{o}{}_{dx}$
Settling velocity	1	m/d	v_{x}
Light efficiency factor	1.00		$^{o}{}_{path}$
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

QUAL2K
Stream Water Quality Model
Little Crab Orchard Creek - NDA 01 (9/9/2006)
Light Parameters and Surface Heat Transfer Models:

Parameter	*Value*	*Unit*	
Photosynthetically Available Radiation	0.47		
Background light extinction	0.2	*/m*	k_{eb}
Linear chlorophyll light extinction	0.0088	*1/m-(ugA/L)*	[illegible] $_{p}$
Nonlinear chlorophyll light extinction	0.054	*1/m-(ugA/L)2/3*	[illegible] $_{pn}$
ISS light extinction	0.052	*1/m-(mgD/L)*	[illegible]
Detritus light extinction	0.174	*1/m-(mgD/L)*	[illegible]
Solar shortwave radiation model			
Atmospheric attenuation model for solar	Bras		
Bras solar parameter (used if Bras solar model is selected)			
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	2		n_{fac}
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)			
atmospheric transmission coefficient (0.70-0.91, default 0.8)	0.8		a_{tc}
Downwelling atmospheric longwave IR radiation			
atmospheric longwave emissivity model	Brunt		
Evaporation and air convection/conduction			
wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer		
Sediment heat parameters			
Sediment thermal thickness	15	*cm*	H_s
Sediment thermal diffusivity	0.0064	*cm^2/s*	[illegible] $_{s}$
Sediment density	1.6	*g/cm^3*	[illegible] $_{s}$
Water density	1	*g/cm^3*	[illegible] $_{w}$
Sediment heat capacity	0.4	*$cal/(g\ ^oC)$*	C_{ps}
Water heat capacity	1	*$cal/(g\ ^oC)$*	C_{pw}
Sediment diagenesis model			
Compute SOD and nutrient fluxes	No		

QUAL2K
Stream Water Quality Model
Little Crab Orchard Creek - NDA 01 (9/9/2006)
Diffuse Source Data:

** The headwater of the mainstem (or tributary) where the diffuse source enters.*

			Location		Diffuse	Diffuse		Spec
	Headwater	Headwater	Up	Down	Abstraction	Inflow	Temp	Cond
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos
	1	Mainstem headwater	19.66	16.76		0.0000	25.00	225.00
	1	Mainstem headwater	16.76	13.41		0.0092	25.00	225.00
	1	Mainstem headwater	13.41	10.97		0.0056	25.00	225.00
	1	Mainstem headwater	10.97	8.71		0.0046	25.00	225.00
	1	Mainstem headwater	8.71	5.18		0.0081	25.00	225.00
	1	Mainstem headwater	5.18	2.44		0.0007	25.00	225.00
	1	Mainstem headwater	2.44	0.00		0.0016	25.00	225.00

CBOD	Organic	Ammon	Nitrate	Organic	Inorganic	Phyto				
fast	N	N	N	P	P	plankton	Detritus	Pathogen	Alk	pH
mgO2/L	ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	ug/L	mgD/L	cfu/100 ml	mgCaCO3/L	
25.00	200.00	3000.00	20.00	100.00	200.00	0.00	0.00	0.00	100.00	7.00
25.00	200.00	3000.00	20.00	100.00	200.00				100.00	7.00
25.00	800.00	4000.00	20.00	100.00	200.00				100.00	7.00
25.00	800.00	4000.00	20.00	300.00	200.00				100.00	7.00
25.00	800.00	4000.00	20.00	300.00	200.00				100.00	7.00
25.00	800.00	5000.00	20.00	300.00	200.00				100.00	7.00
25.00	800.00	5000.00	20.00	300.00	200.00				100.00	7.00

QUAL2K
Stream Water Quality Model
Little Crab Orchard Creek - NDA 01 (9/9/2006)
Point Source Data:

** The headwater of the mainstem (or tributary) where the point source enters.*

				Point		Dissolved Oxygen		
	Headwater	Headwater	Location	Abstraction	Inflow	mean	range/2	time of
Name	ID*	Name	km	m3/s	m3/s	mg/L	mg/L	max
'LENORE BASIN CORP-UNION HILLS - ILG551	1	Mainstem headwater	16.360		0.0002			
'LILAC BASIN CORP.-UNION HILL - IL0046221	1	Mainstem headwater	16.360		0.0003	9.68	0.00	12:00 AM
TAN TARA 2 MOBILE HOME PARK - IL0049077	1	Mainstem headwater	5.610		0.0010			

Fast CBOD			Ammonia N			Alkalinity	pH		
mean	range/2	time of	mean	range/2	time of	mean	mean	range/2	time of
mgO2/L	mgO2/L	max	ugN/L	ugN/L	max	mgCaCO3/L	s.u.	s.u.	max
7.72	0.00	12:00 AM				100.00	6.95	0.00	12:00 AM
4.36	0.00	12:00 AM	5590.00	0.00	12:00 AM	100.00	7.11	0.00	12:00 AM
10.74	0.00	12:00 AM	6511.00	0.00	12:00 AM	100.00	7.00	0.00	12:00 AM

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	**Little Crab Orchard Creek - NDA 01**	
Saved file name	**LittleCrabOrchard_ILNDA01_reduction**	
Directory where file saved	**L:\I-intercompany\I4358\Modeling\Qual2K**	
Month	**9**	
Day	**9**	
Year	**2006**	
Time zone	**Central**	
Daylight savings time	**Yes**	
Calculation:		
Calculation step	**0.0625**	**hours**
Final time	**3**	**day**
Solution method (integration)	**Euler**	
Solution method (pH)	**Bisection**	
Program determined calc step	**0.046875**	**hours**
Time of last calculation	**0.13**	**minutes**
Time of sunrise	**6:33 AM**	
Time of solar noon	**12:54 PM**	
Time of sunset	**7:14 PM**	
Photoperiod	**12.67**	**hours**

QUAL2K
Stream Water Quality Model
Little Crab Orchard Creek - NDA 01 (9/9/2006)
Diffuse Source Data:

**** The headwater of the mainstem (or tributary) where the diffuse source enters.***

			Location		Diffuse		Spec	CBOD	Organic	Ammon	Nitrate	Organic	Inorganic	
	Headwater	Headwater	Up	Down	Inflow	Temp	Cond	fast	N	N	N	P	P	Alk
Name	ID*	Name	km	km	m3/s	C	umhos	mgO2/L	ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	mgCaCO3/
	1	Mainstem headwater	19.66	16.76	0.0000	25.00	225.00	13.00	200.00	1000.00	20.00	100.00	200.00	100.00
	1	Mainstem headwater	16.76	13.41	0.0092	25.00	225.00	13.00	200.00	1000.00	20.00	100.00	200.00	100.00
	1	Mainstem headwater	13.41	10.97	0.0056	25.00	225.00	13.00	800.00	1000.00	20.00	100.00	200.00	100.00
	1	Mainstem headwater	10.97	8.71	0.0046	25.00	225.00	13.00	800.00	1000.00	20.00	300.00	200.00	100.00
	1	Mainstem headwater	8.71	5.18	0.0081	25.00	225.00	13.00	800.00	1000.00	20.00	300.00	200.00	100.00
	1	Mainstem headwater	5.18	2.44	0.0007	25.00	225.00	13.00	800.00	1000.00	20.00	300.00	200.00	100.00
	1	Mainstem headwater	2.44	0.00	0.0016	25.00	225.00	13.00	800.00	1000.00	20.00	300.00	200.00	100.00

B.5.6 Piles Fork Segment NDB-03

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	Piles Fork - NDB 03	
Saved file name	PilesFork_ILNDB03	
Directory where file saved	L:\I-intercompany\I4358\Modeling\Qual2K	
Month	9	
Day	7	
Year	2006	
Time zone	Central	
Daylight savings time	Yes	
Calculation:		
Calculation step	0.0625	hours
Final time	3	day
Solution method (integration)	Euler	
Solution method (pH)	Bisection	
Program determined calc step	0.046875	hours
Time of last calculation	0.19	minutes
Time of sunrise	6:31 AM	
Time of solar noon	12:54 PM	
Time of sunset	7:17 PM	
Photoperiod	12.75	hours

Stream Water Quality Model
Piles Fork - NDB 03 (9/7/2006)
Headwater Data:

Note: **** required field***

ID	Number of Headwaters*	1										
No. 1	Reach No.*	Headwater Name	Flow*	Elevation	Weir				Rating Curves			
			Rate		Height	Width	adam	bdam	Velocity		Depth	
			(m^3/s)	(m)	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
	1	Mainstem headwater	0.0003	170.690	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
	Headwater Water Quality	Units	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM
	Temperature	C	19.69	19.52	19.34	19.16	18.91	18.73	18.54	18.33	18.27	18.37
	Conductivity	umhos	362.54	361.27	360.90	359.50	358.37	357.13	355.33	353.76	353.22	354.36
	Inorganic Solids	mgD/L										
	Dissolved Oxygen	mg/L	0.99	0.94	0.76	0.85	0.86	0.89	0.85	0.80	0.79	0.63
	CBODslow	mgO2/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CBODfast	mgO2/L	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
	Organic Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NH4-Nitrogen	ugN/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NO3-Nitrogen	ugN/L	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
	Organic Phosphorus	ugP/L	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
	Inorganic Phosphorus (SRP)	ugP/L	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
	Phytoplankton	ugA/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Detritus (POM)	mgD/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pathogen	cfu/100 mL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alkalinity	mgCaCO3/L	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	pH	s.u.	7.24	7.24	7.24	7.24	7.25	7.27	7.26	7.26	7.26	7.26

Manning Formula					Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion
Slope	n	m	Slope	Slope	m2/s
0.01	0.0550	0.61	0.33	0.33	0.00

10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM
19.68	18.69	18.98	19.61	19.62	19.83	20.06	20.25	20.36	20.56	20.49	20.31	20.09	19.92
352.47	347.32	350.17	354.36	354.23	354.69	356.84	359.40	358.84	364.67	366.12	366.28	364.82	363.62
1.46	0.34	0.29	0.24	0.25	0.15	0.28	0.18	0.09	0.13	0.00	1.15	0.87	0.97
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.30	7.19	7.17	7.15	7.14	7.12	7.13	7.13	7.13	7.15	7.15	7.24	7.24	7.24

QUAL2K
Stream Water Quality Model
Piles Fork - NDB 03 (9/7/2006)
Reach Data:

Reach for diel plot	1										
Element for diel plot	2	Reach	Headwater	Reach			Location		Element	Eleva
Reach	Downstream	Number	Reach	length	Downstream		Upstream	Downstream	Number	Upstream
Label	end of reach label			(km)	Latitude	Longitude	(km)	(km)	>=1	(m)
		1	Yes	3.91	37.69	89.24	11.270	7.360	4	170.690
		2		4.27	37.73	89.20	7.360	3.090	4	134.110
		3		3.09	37.75	89.19	3.090	0.000	3	115.820

			Hydraulic Model (Weir Overrides Manning Formula; Manning Formula Override Rating Curves)										
Downstream						Weir				Rating Curves			
Latitude			Longitude			Height	Width	adam	bdam	Velocity		Depth	
Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	(m)	(m)			Coefficient	Exponent	Coefficient	Exponent
37.00	41	36	89.00	14	8	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
37.00	43	46	89.00	12	11	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000
37.00	44	44	89.00	11	18	0.0000	0.0000	1.2500	0.9000	0.0000	0.000	0.0000	0.000

Manning Formula					Prescribed	Bottom	Bottom	Prescribed	Prescribed	Prescribed	Prescribed
Channel	Manning	Bot Width	Side	Side	Dispersion	Algae	SOD	SOD	CH4 flux	NH4 flux	Inorg P flux
Slope	n	m	Slope	Slope	m2/s	Coverage	Coverage	gO2/m2/d	gO2/m2/d	mgN/m2/d	mgP/m2/d
0.0094	0.0550	1.52	0.2500	0.2500	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0043	0.0500	3.66	0.2800	0.2800	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000
0.0021	0.0400	4.57	0.3300	0.3300	0.00	50.00%	50.00%	0.00	0.0000	0.0000	0.0000

QUAL2K
Stream Water Quality Model
Piles Fork - NDB 03 (9/7/2006)
Water Column Rates

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.3	m/d	v_i
Oxygen:			
Reaeration model	Tsivoglou-Neal		
User reaeration coefficient α	3.93		α
User reaeration coefficient β	0.5		β
User reaeration coefficient γ	1.5		γ
Temp correction	1.024		θ_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	0.1	/d	k_{hc}
Temp correction	1.07		θ_{hc}
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		θ_{dcs}
Fast CBOD:			
Oxidation rate	1	/d	k_{dc}
Temp correction	1.047		θ_{dc}
Organic N:			
Hydrolysis	0.2	/d	k_{hn}
Temp correction	1.07		θ_{hn}
Settling velocity	0.1	m/d	v_{on}
Ammonium:			
Nitrification	8	/d	k_{na}
Temp correction	1.07		θ_{na}
Nitrate:			
Denitrification	0.5	/d	k_{dn}
Temp correction	1.07		θ_{dn}
Sed denitrification transfer coeff	0.5	m/d	v_{di}
Temp correction	1.07		θ_{di}

Organic P:			
Hydrolysis	0.01	/d	k_{hp}
Temp correction	1.07		θ_{hp}
Settling velocity	0.5	m/d	v_{op}
Inorganic P:			
Settling velocity	2	m/d	v_{ip}
Inorganic P sorption coefficient	0.5	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	0.01	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		θ_{gp}
Respiration rate	0.2	/d	k_{rp}
Temp correction	1.07		θ_{rp}
Death rate	0.2	/d	k_{dp}
Temp correction	1.07		θ_{dp}
Nitrogen half sat constant	25	ugN/L	k_{sPp}
Phosphorus half sat constant	5	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.5	m/d	v_a
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	50	$mgA/m^2/d$ or /d	C_{gb}
Temp correction	1.07		θ_{gb}
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.1	/d	k_{rb}
Temp correction	1.07		θ_{rb}
Excretion rate	0.05	/d	k_{eb}
Temp correction	1.07		θ_{db}
Death rate	0.1	/d	k_{db}
Temp correction	1.07		θ_{db}
External nitrogen half sat constant	300	ugN/L	k_{sPb}
External phosphorus half sat constant	100	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lb}
Ammonia preference	25	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	θ_{mN}
Maximum uptake rate for phosphorus	5	mgP/mgA/d	θ_{mP}
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		θ_{dt}
Fraction of dissolution to fast CBOD	1.00		F_f
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		θ_{dx}
Settling velocity	1	m/d	v_x
Light efficiency factor	1.00		θ_{path}
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

QUAL2K
Stream Water Quality Model
Piles Fork - NDB 03 (9/7/2006)
Light Parameters and Surface Heat Transfer Models:

Parameter	*Value*	*Unit*	
Photosynthetically Available Radiation	**0.47**		
Background light extinction	**0.2**	*/m*	k_{eb}
Linear chlorophyll light extinction	**0.0088**	*1/m-(ugA/L)*	8_{p}
Nonlinear chlorophyll light extinction	**0.054**	*1/m-(ugA/L)2/3*	8_{pn}
ISS light extinction	**0.052**	*1/m-(mgD/L)*	8_{8}
Detritus light extinction	**0.174**	*1/m-(mgD/L)*	8_{8}
Solar shortwave radiation model			
Atmospheric attenuation model for solar	**Bras**		
Bras solar parameter (used if Bras solar model is selected)			
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	**2**		n_{fac}
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)			
atmospheric transmission coefficient (0.70-0.91, default 0.8)	**0.8**		a_{tc}
Downwelling atmospheric longwave IR radiation			
atmospheric longwave emissivity model	**Brunt**		
Evaporation and air convection/conduction			
wind speed function for evaporation and air convection/conduction	**Brady-Graves-Geyer**		
Sediment heat parameters			
Sediment thermal thickness	**15**	*cm*	H_{s}
Sediment thermal diffusivity	**0.0064**	*cm^2/s*	8_{s}
Sediment density	**1.6**	*g/cm^3*	8_{s}
Water density	**1**	*g/cm^3*	8_{w}
Sediment heat capacity	**0.4**	*cal/(g ^oC)*	C_{ps}
Water heat capacity	**1**	*cal/(g ^oC)*	C_{pw}
Sediment diagenesis model			
Compute SOD and nutrient fluxes	**No**		

QUAL2K
Stream Water Quality Model
Piles Fork - NDB 03 (9/7/2006)
Diffuse Source Data:

** The headwater of the mainstem (or tributary) where the diffuse source enters.*

	Headwater	Headwater	Location		Diffuse	Diffuse		Spec	Inorg	Diss
			Up	Down	Abstraction	Inflow	Temp	Cond	SS	Oxygen
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos	mgD/L	mg/L
	1	Mainstem headwater	11.27	7.36		0.0000				
	1	Mainstem headwater	7.36	3.09		0.0001	22.00	400.00		3.00
	1	Mainstem headwater	3.09	0.00		0.0005	25.00	400.00		3.00

CBOD	CBOD	Organic	Ammon	Nitrate	Organic	Inorganic	Phyto				
slow	fast	N	N	N	P	P	plankton	Detritus	Pathogen	Alk	pH
mgO2/L	mgO2/L	ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	ug/L	mgD/L	cfu/100 ml	mgCaCO3/L	
										100.00	7.00
	30.00	200.00	6000.00	1000.00	300.00	500.00				100.00	7.00
	30.00	200.00	6000.00	1000.00	300.00	500.00				100.00	7.00

QUAL2K
Stream Water Quality Model
Piles Fork - NDB 03 (9/7/2006)
Point Source Data:

** The headwater of the mainstem (or tributary) where the point source enters.*

	Headwater	Headwater	Location	Point	Temperature	Specific Cond	Fast CBOD	Ammonia N	Inorganic P
				Inflow	mean	mean	mean	mean	mean
Name	ID*	Name	km	m3/s	°C	umhos	mgO2/L	ugN/L	ugP/L
SIU-CARBONDALE - IL0072320	1	Mainstem headwater	5.800	0.0008		320.00	2.20	1500.00	
BEAZER EAST INC-CARBONDALE - IL0000400	1	Mainstem headwater	1.520	0.0043	25.00	350.00	2.88	1500.00	100.00

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.07

System ID:		
River name	Piles Fork - NDB 03	
Saved file name	PilesFork_ILNDB03_reduction	
Directory where file saved	L:\I-intercompany\I4358\Modeling\Qual2K	
Month	9	
Day	7	
Year	2006	
Time zone	Central	
Daylight savings time	Yes	
Calculation:		
Calculation step	0.0625	hours
Final time	3	day
Solution method (integration)	Euler	
Solution method (pH)	Bisection	
Program determined calc step	0.046875	hours
Time of last calculation	0.16	minutes
Time of sunrise	6:31 AM	
Time of solar noon	12:54 PM	
Time of sunset	7:17 PM	
Photoperiod	12.75	hours

QUAL2K
Stream Water Quality Model
Piles Fork - NDB 03 (9/7/2006)
Diffuse Source Data:

** The headwater of the mainstem (or tributary) where the diffuse source enters.*

			Location		Diffuse	Diffuse		Spec	Inorg	Diss
	Headwater	Headwater	Up	Down	Abstraction	Inflow	Temp	Cond	SS	Oxygen
Name	ID*	Name	km	km	m3/s	m3/s	C	umhos	mgD/L	mg/L
	1	Mainstem headwater	11.27	7.36		0.0000				
	1	Mainstem headwater	7.36	3.09		0.0001	22.00	400.00		3.00
	1	Mainstem headwater	3.09	0.00		0.0005	25.00	400.00		3.00

CBOD	Organic	Ammon	Nitrate	Organic	Inorganic		
fast	N	N	N	P	P	Alk	pH
mgO2/L	ugN/L	ugN/L	ugN/L	ugP/L	ugP/L	ngCaCO3/L	
						100.00	7.00
5.00	200.00	500.00	1000.00	300.00	500.00	100.00	7.00
5.00	200.00	500.00	1000.00	300.00	500.00	100.00	7.00

Appendix C : BATHTUB Model

C.0 Estimating Existing Loads and Flows to the Crab Orchard Watershed

U.S. Army Corps of Engineer's BATHTUB model was used to link tributary nutrient loads with observed water quality data in the lakes. BATHTUB performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network that relates advective and diffusive transport, and nutrient sedimentation. Eutrophication-related water quality parameters (total phosphorus, chlorophyll-a, transparency) can be predicted using empirical relationships derived from assessments of reservoir data. Table C-1 lists the impaired water bodies, their major tributary streams and their impairment.

Table C-1. Impaired Lakes in Crab Orchard Watershed and Their Tributaries

No	Waterbody	Segment ID	Tributaries	Impairment(s)
1	Crab Orchard Lake	RNA	Crab Orchard Creek, Wolf Creek, Grassy Creek, Little Grassy Creek	Phosphorus
3	Marion Reservoir	RNL	Limb Branch	Phosphorus and Manganese
2	Herrin New Reservoir	RNZC	Wolf Creek	Manganese
4	Carbondale City Lake	RNI	Piles Fork	Phosphorus and Manganese
5	Campus Lake	RNZH	-	Phosphorus

The model input data requires information describing watershed characteristics, tributary nutrient loads, and lake or reservoir morphology.

BATHTUB simulates loads and lake concentrations for summer and annual season averaging periods. Annual and summer models were developed to determine the appropriate averaging period. Annual simulations were selected for all the lakes because their turnover ratio is greater than two and they have a long nutrient residence time of more than 0.2 years.

Global parameters like precipitation, evaporation and change in storage are included for each model. Precipitation and evaporation data presented in Table C-2 were obtained from the Carbondale Station which is part of the Illinois Climate Network Station. Change in storage was estimated based on the differences in depths measured at the lakes.

Table C-2. Precipitation and Evaporation in Crab Orchard Watershed

Year	Average Precipitation (in)	Average Evaporation (in)
1991	29.82	44.71
1996	48.55	43.69
1997	43.39	43.77
1998	42.18	44.46
2000	44.26	44.07

Nutrient loads to the lakes were calculated from atmospheric deposition, tributary streams, direct runoff, and point sources (where applicable). The BATHTUB model includes rates of direct deposition to the lake surface for total nitrogen and total phosphorus. Direct atmospheric deposition of phosphorus to a lake surface is generally considered insignificant compared to watershed loading rates. In the absence of site-specific data, the BATHTUB default total phosphorus load of 0.27 lb/ac/yr (30 mg/m2/yr) was used for direct atmospheric deposition to the lake for all years modeled.

Phosphorus loads into the lakes are calculated from mean annual flows and available phosphorus concentration data measured at the tributaries. The USGS gage Station 05597500 located on Crab Orchard Creek near Marion, Illinois is the only available flow gage within the watershed. Incoming flows from the tributary streams to the lakes were scaled using the drainage area ratios and the flow data measured at this USGS station.

Loadings from direct runoff to the lakes were estimated using land use data, literature based concentrations (Polls and Lanyon, 1980), and typical runoff estimates for each land use.

In addition to total phosphorus loads, the model requires input of inorganic phosphorus loads. Ortho phosphorus refers to dissolved inorganic phosphorus that is available for algae absorption and was assumed to be equal to dissolved phosphorus.

The BATHTUB model output includes tabular and/or graphic displays of segment hydraulics, water and nutrient balances, predictions of phosphorus concentrations, transparency, chlorophyll-a concentrations, oxygen depletion, and nutrient loads. Statistics relating observed and predicted values are also provided by the model.

This appendix discusses the BATHTUB model for Crab Orchard Lake (Section C.1), Marion Reservoir (Section C.2), Herrin New Reservoir (Section C.3), Carbondale City Lake (Section C.4) and the Campus Lake (Section C.5). For each lake, the subsequent subsections represent detail information on the watershed loading, morphometry data, internal loading, in-lake water quality data, and model results along with estimated total phosphorus reduction loads.

C.1 Crab Orchard Lake Watershed Loading

There are four major tributary streams flowing into Crab Orchard Lake. Limited water quality data were collected at Wolf Creek, Grassy Creek and Little Grassy Creek tributaries. Sufficient water quality data was collected on the Crab Orchard Creek farther upstream of Crab Orchard Lake, at station ND-04.

The USGS station 05597500, located on Crab Orchard Creek, was used to calculate mean annual flows. Table C-3 summarizes the drainage area to the water quality monitoring station along with the drainage area of the tributaries. Incoming flows for the major tributary streams were scaled using the flow data measured at Crab Orchard Creek USGS station. For each tributary, the flow was estimated by the ratio of drainage area of tributary to drainage area at USGS station. The drainage area at USGS station is approximately 31.37 square miles.

Table C-3. Drainage Areas of Tributaries to Crab Orchard Lake

Tributary	Water Quality Station	Drainage Area at Station (mi2)	Drainage Area at Lake (mi2)
Crab Orchard Creek	ND-04	31.37	123.06
Grassy Creek	-	-	29.3
Wolf Creek	-	-	17.27
Little Grassy Creek		-	24.23

The water quality station ND-04, located on Crab Orchard Creek, is the only available monitoring station with sufficient data within the Crab Orchard Lake watershed. Water quality data recorded at this station is used to derive loads downstream in Crab Orchard Creek. For estimating the phosphorus data for Crab Orchard Creek, regression equations for total phosphorus and ortho-phosphorus were developed using data collected at ND-04 station from January 1990 through August 2002. Table C-4 represents the regression equations developed to estimate phosphorus loads from Crab Orchard Creek.

Table C-4. Regression Equations for Estimating Phosphorus Loads from Crab Orchard Creek

Station	Total Phosphorus Load (lb/day)	Ortho-Phosphorus Load (lb/day)
ND-04	0.0039Q2 + 0.1853Q	0.0002Q2 + 0.386Q

Three of the tributary streams (Wolf Creek, Grassy Creek and Little Grassy Creek) entering the lake have limited measured phosphorus concentration data. For these tributaries, the mean concentration of all years was used when a modeled year concentration was not available.

Table C-5 summarizes the annual watershed loads and mean annual flows from tributary streams to Crab Orchard Lake.

Table C-5. Mean Annual Flows and Watershed Loading to Crab Orchard Lake

Year	Stream Flow (cfs)				TP Load (lb/day)
	Crab Orchard Creek	Wolf Creek	Grassy Creek	Little Grassy Creek	
1991	128	18	30	25	365.2
1994	184	26	44	36	321.7
1996	119	17	28	23	669.4
1997	224	32	53	44	419.2
2000	129	18	31	25	384.0

There are five pollutant point sources with permitted discharges in the Crab Orchard Lake watershed. Marion Southeast STP and Marion WTP are the major point source contributors and were included in the BATHTUB models. Table C-6 shows the wasteload allocation due to permitted discharges.

Table C-6. Wasteload Allocation in Crab Orchard Lake Watershed

Waste Facilities	Discharge (cfs)	Load (lb/day)
Marion Southeast STP	7.67	18.58
Verizon Communications	0.01	0.11
Crab Orchard Estates-Hughes	0.003	0.06
Marion WTP	0.29	5.56
SI Bowling & Rec Center	0.01	0.23

C.1.1 Crab Orchard Lake Morphometry

Crab Orchard Lake was divided into three segments, or reservoir zones, linked in a network according to the lake's morphometric features and available water quality stations. Table C-7 shows the lake segment inputs that were used in the models.

Dissolved oxygen (DO) concentrations and depth profiles measured at Crab Orchard Lake during the spring and summer months of 2000 were used to estimate the hypolimnetic and mixed layer depths. Thermal stratification in the lake was apparent from the DO profiles at the segment near the dam. The profiles show the upper layer (epilimnetic zone) is isolated from the lower layer (hypolimnetic zone) by a DO gradient or thermocline from June to August. The thermocline is used to estimate the mixed layer depth for segments RNA-1. The mixed layer depth for segments RNA-2 and RNA-3/RNA-4 were calculated using the BATHTUB regression model since a direct estimate was not available.

Table C-7. Morphometry Data of Crab Orchard Lake

WQ station	Area (ac)	Mean Depth (m)	Length (km)	Volume (m3)	Mixed Layer Depth(m)	Hypolimnetic Depth (m)
RNA-1	2277.0	7.3	3.9	67,407,316	1.5	3.0
RNA-2	3161.2	3.7	6.3	47,961,179	3.7*	0.0
RNA-3/RNA 4	1526.8	1.7	5.4	1,0734,697	1.7*	0.0

Notes:
* Mixed layer depth estimated using BATHTUB regression model

C.1.2 Crab Orchard Lake Internal Loading

Internal loading rates reflect nutrient recycling from bottom sediments. Internal phosphorus loading is already accounted for in the BATHTUB pre-calibrated nutrient retention models. However, the external loads calculated from tributary streams (as explained in Section C.1) are under-estimated and therefore, an internal load was added to the model to match observed lake concentrations. The Nürnberg method (Nürnberg, 1984) was chosen to approximate the internal load. This method uses mean depth, flushing rate, average inflow, and average outflow concentrations to estimate internal load. For Crab Orchard Lake, an internal load of 0.14 lb/ac/day (15.55 mg/m2-day) was used for all modeled years at the upstream lake segment.

C.1.3 Crab Orchard Lake Water Quality Data Summary

Water quality data for Crab Orchard Lake were obtained from STORET and Illinois EPA databases. Mean annual total phosphorus, chlorophyll-a, and secchi depth are summarized in Table C-8.

Table C-8. Mean Annual Water Quality Parameters for Crab Orchard Lake

Year	Total Phosphorus (mg/L)	Chlorophyll-a (µg/L)	Secchi Depth (in)
1991	0.177	72.50	19.7
1994	0.153	84.30	19.7
1996	0.080	21.30	19.7
1997	0.153	82.40	19.7
2000	0.092	62.00	23.6

C.1.4 Crab Orchard Lake BATHTUB Modeling Results

The BATHTUB model was set up to simulate total phosphorus response in Crab Orchard Lake for the years 1991, 1994, 1996, 1997 and 2000 when total phosphorus data were available. A second order available phosphorus model was used to simulate phosphorus concentrations and the exponential phosphorus/chlorophyll-a relationship model (by Jones & Bachman) was used to predict mean chlorophyll-a. For all models, nutrient calibration factors were applied to total phosphorus and chlorophyll-a concentrations. The calibration factors were adjusted within the default ranges so that the average ratio of simulated to observed nutrient concentrations was close to 1.

Table C-9 compares the simulated and observed total phosphorus concentrations in Crab Orchard Lake. Results are also illustrated in Figure C-1. The observed phosphorus concentrations from 1996 were significantly lower than the other sampled years because only two samples were collected earlier in the summer.

Table C-9. Simulated and Observed Phosphorus Concentrations in Crab Orchard Lake

Year	Simulated TP (mg/L)	Observed TP (mg/L)	Relative Error
1991	0.14	0.18	-22.2%
1994	0.12	0.15	-20.0%
1996	0.14	0.08	75.0%
1997	0.12	0.15	-20.0%
2000	0.14	0.09	55.6%

Whether or not total phosphorus concentrations are over predicted or under predicted depends on the annual flow rate condition. Because of the data set used to estimate stream loading, the regression equations are under predicting loading patterns especially under low flows. If more data are collected, more accurate load inputs to the BATHTUB model can be done.

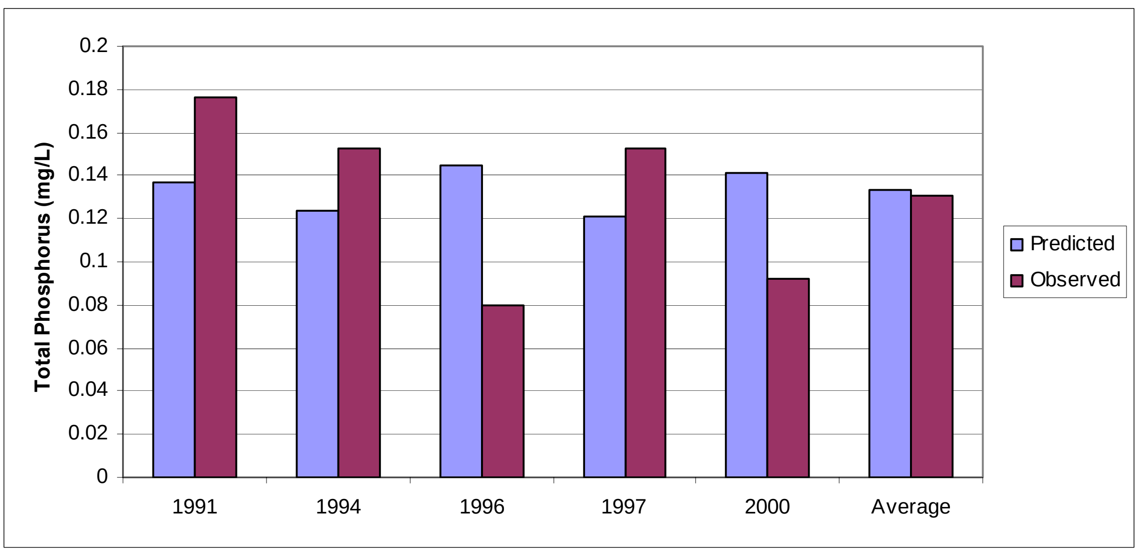

Figure C-1. Comparison of Simulated and Observed Total Phosphorus Concentrations in Crab Orchard Lake

C.1.5 Crab Orchard Lake Total Phosphorus Reductions

The total phosphorus target for Crab Orchard Lake is 0.05 mg/L. According to the observed phosphorus data in the lake, the target is exceeded every year modeled. In order to meet the target during all years, an 80 percent reduction of phosphorus load is required. Table C-10 shows the mean annual total phosphorus concentrations if an 80 percent reduction is implemented.

Table C-10. Mean Annual Total Phosphorus Concentrations in Crab Orchard Lake with 80 Percent Reductions in Loading

Year	Lake Crab TP (mg/L)
1991	0.05
1994	0.04
1996	0.05
1997	0.04
2000	0.05

C.2 Marion Reservoir Watershed Loading

Limb branch is the only tributary stream flowing into the Marion Reservoir. There are no monitoring stations available with water quality data upstream of Marion Reservoir. The drainage area for Limb branch, upstream of the Marion Reservoir is shown in Table C-11.

Table C-11. Drainage Area of Tributary to Marion Reservoir

Tributary	Drainage Area at Reservoir (mi2)
Limb Branch	4.77

The USGS station 05597500, located on Crab Orchard Creek, was used to calculate mean annual flows. Incoming flows for Limb branch were scaled using the flow data measured at Crab Orchard Creek USGS station. The flow was estimated by the ratio of drainage area of tributary to drainage area at USGS station.

A ‘reverse’ BATHTUB application was developed because no water quality data on Limb Branch was available. In the ‘reverse’ BATHTUB model, phosphorus concentrations were adjusted such that the ratio of observed and estimated phosphorus concentrations in Marion Reservoir is close to 1. Annual watershed loads and mean annual flow from Limb branch to Marion Reservoir are summarized in Table C-12.

Table C-12. Mean Annual Flows and Watershed Loading to Marion Reservoir

Year	Stream Flow (cfs)	TP Load (lb/day)
1997	5.0	9.87
2000	12.8	3.34

There is one pollutant point sources with permitted discharge in the Marion Reservoir watershed. U.S. Penitentiary WTP is the point source contributors and was included in the BATHTUB models. Table C-13 shows the wasteload allocation due to permitted discharges.

Table C-13. Wasteload Allocation in Marion Reservoir Watershed

Waste Facilities	Discharge (cfs)	Load (lb/day)
U.S. Penitentiary WTP	0.005	0.09

C.2.1 Marion Reservoir Morphometry

Marion Reservoir was divided into two segments, or reservoir zones, linked in a network according to the reservoir's morphometric features and available water quality stations. Table C-14 shows the lake segment inputs that were used in the models.

Dissolved oxygen (DO) concentrations and depth profiles measured at Marion Reservoir during early summer 2000 were used to estimate the hypolimnetic and mixed layer depths. Thermal stratification in the lake was apparent from the DO profiles at the segment near the dam. The profiles show the epilimnetic zone is isolated from the hypolimnetic zone by a DO gradient or thermocline from June to August. The thermocline is used to estimate the mixed layer depth for segment RNL-1/RNL-2.

Table C-14. Morphometry Data of Marion Reservoir

WQ station	Area (ac)	Mean Depth (m)	Length (km)	Volume (m3)	Mixed Layer Depth (m)	Hypolimnetic Depth (m)
RNL-1/RNL-2	132.0	4.3	1.1	2,303,568	1.4	1.5
RNL-3	88.0	1.2	1.3	423,424	1.2*	0.0

Notes:
* Mixed layer depth estimated using BATHTUB regression model

C.2.2 Marion Reservoir Internal Loading

Internal loading rates reflect nutrient recycling from bottom sediments. Internal phosphorus loading is already accounted for in the BATHTUB pre-calibrated nutrient retention models. No internal phosphorus loading was added to the Marion Reservoir BATHTUB models because a reverse application was used to simulate in-lake concentrations.

C.2.3 Marion Reservoir Water Quality Data Summary

Water quality data for Marion Reservoir were obtained from STORET and Illinois EPA databases. Mean annual total phosphorus, chlorophyll-a, and secchi depth are summarized in Table C-15

Table C-15. Annual Average Water Quality Parameters for Marion Reservoir

Year	Total Phosphorus (mg/L)	Chlorophyll-a (µg/L)	Secchi Depth (in)
1997	0.9	41.80	23.6
2000	0.06	61.10	23.6

C.2.4 Marion Reservoir BATHTUB Modeling Results

The BATHTUB model was set up to simulate phosphorus response in Marion Reservoir for the years 1997 and 2000 when total phosphorus data were available. A second order available phosphorus model was used to simulate phosphorus concentrations and the phosphorus/light/ flushing rate model was used to predict mean chlorophyll-a. Using 'reverse' BATHTUB, the tributary total phosphorus concentrations were adjusted so the simulated in-lake concentrations match the observed in-lake concentrations. A calibration factor of 1 was used for all parameters which indicate that no adjustment to the model is needed. Table C-16 compares the simulated and observed total phosphorus concentrations in Marion Reservoir.

Table C-16. Simulated and Observed Phosphorus Concentrations in Marion Reservoir

Year	Simulated TP (mg/L)	Observed TP (mg/L)
1997	0.09	0.09
2000	0.06	0.06

During the reverse BATHTUB application, several simulations were made to accurately predict total phosphorus loading patterns. Final predicted and observed concentrations are illustrated in Figure C-2.

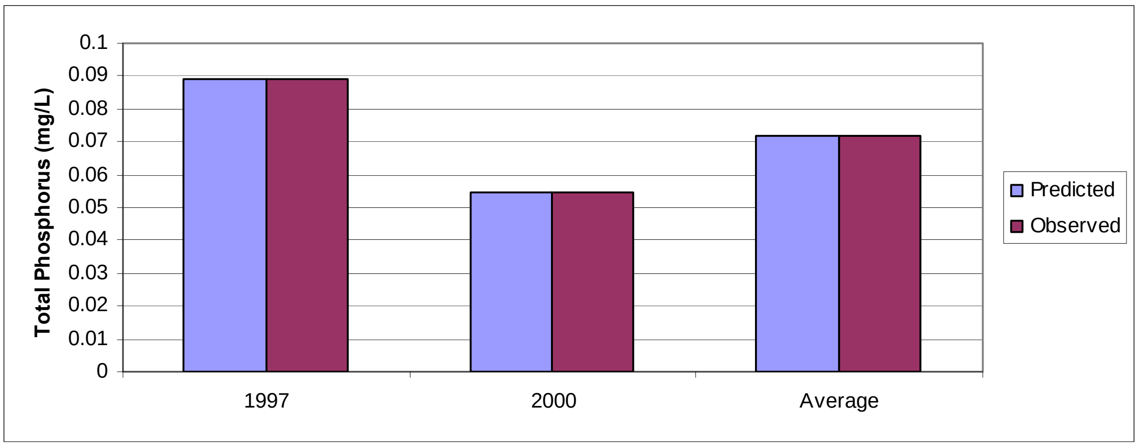

Figure C-2. Comparison of Simulated and Observed Total Phosphorus Concentrations in Marion Reservoir

C.2.5 Marion Reservoir Total Phosphorus Reductions

The total phosphorus target for Marion Reservoir is 0.05 mg/L. According to the observed phosphorus data, the target is exceeded in all years modeled. In order to meet the target during all years, a 58 percent reduction of total phosphorus load is required. Table C-17 shows the annual average total phosphorus concentrations if a 58 percent reduction is implemented.

Table C-17. Mean Annual Total Phosphorus Concentration in Marion Reservoir with 58 Percent Reduction in Loading

Year	Reservoir TP (mg/L)
1997	0.05
2000	0.03

C.3 Herrin New Reservoir Watershed Loading

Wolf Creek is the only tributary stream flowing into the Herrin New Reservoir. There are no monitoring stations available with water quality data upstream of Herrin New Reservoir. The drainage area for Wolf Creek, upstream of Herrin New Reservoir is shown in Table C-18.

Table C-18. Drainage Area of Tributary to Herrin New Reservoir

Tributary	Drainage Area at Reservoir (mi2)
Wolf Creek	2.78

The USGS station 05597500, located on Crab Orchard Creek, was used to calculate mean annual flows. Incoming flows for Wolf Creek were scaled using the flow data measured at Crab Orchard Creek USGS station. The flow was estimated by the ratio of drainage area of tributary to drainage area at USGS station.

A ‘reverse’ BATHTUB application was developed because no water quality data on Wolf Creek was available. In the ‘reverse’ BATHTUB model, phosphorus concentrations were adjusted such that the ratio of observed and estimated phosphorus concentrations in Herrin New Reservoir is close to 1. Annual watershed loads and mean annual flow from Limb branch to Marion Reservoir are summarized in Table C-19.

Table C-19. Mean Annual Flows and Watershed Loading to Herrin New Reservoir

Year	Stream Flow (cfs)	TP Load (lb/day)
1996	2.6	11.10

Currently, no permitted point sources discharge in the Herrin New Reservoir watershed.

C.3.1 Herrin New Reservoir Morphometry

Herrin New Reservoir was considered as a single segment or reservoir zone according to the reservoir’s morphometric features and available water quality stations. Table C-20 shows the lake segment inputs that were used in the model.

Dissolved oxygen (DO) concentrations and depth profiles measured at Herrin New Reservoir during late spring and early summer of 2000 were used to estimate the hypolimnetic and mixed layer depths. Thermal stratification in the lake was apparent from the DO profiles at the segment near the dam. The profiles show the epilimnetic zone is isolated from the hypolimnetic zone by a DO gradient or thermocline from June to October.

Table C-20. Morphometry data of Herrin New Reservoir

WQ station	Area (ac)	Mean Depth (m)	Length (km)	Volume (m3)	Mixed Layer Depth (m)	Hypolimnetic Depth(m)
RNZC-1/2/3	40.0	5.8	1.1	93,744	2.9	3.0

C.3.2 Herrin New Reservoir Internal Loading

Internal loading rates reflect nutrient recycling from bottom sediments. Internal phosphorus loading is already accounted for in the BATHTUB pre-calibrated nutrient retention models. No internal phosphorus loading was added to the Herrin New Reservoir BATHTUB models because a reverse application was used to simulate in-lake concentrations.

C.3.3 Herrin New Reservoir Water Quality Data Summary

Water quality data for Herrin New Reservoir were obtained from STORET and Illinois EPA databases. The mean annual phosphorus concentration in Herrin New Reservoir was 0.04 mg/L which is below the TP standard (0.05mg/L). Therefore, only concentrations that exceeded the standard were considered in the model. Mean annual total phosphorus, chlorophyll-a, and secchi depth used in the BATHTUB model are summarized in Table C-21.

Table C-21. Annual Average Water Quality Parameters for Herrin New Reservoir

Year	Total Phosphorus (mg/L)	Chlorophyll-a (µg/L)	Secchi Depth (in)
1996	0.112	30.70	51.2

C.3.4 Herrin New Reservoir BATHTUB Modeling Results

The BATHTUB model was set up to simulate phosphorus response in Herrin New Reservoir for the year of 1996 when total phosphorus data was available. A second order available phosphorus model was used to simulate phosphorus concentrations and the phosphorus/chlorophyll-a linear relationship model was used to predict mean chlorophyll-a. Using ‘reverse’ BATHTUB, the tributary total phosphorus concentrations were adjusted so the simulated in-lake concentrations match the observed in-lake concentrations. A calibration factor of 1 was used for all parameters which indicate that no adjustment to the model is needed. Table C-22 compares the simulated and observed total phosphorus concentrations in Herrin New Reservoir.

Table C-22. Simulated and Observed Total Phosphorus Concentrations in Herrin New Reservoir.

Year	Simulated TP (mg/L)	Observed TP (mg/L)
1996	0.110	0.112

During the reverse BATHTUB application, several simulations were made to accurately predict total phosphorus loading patterns. Final predicted and observed concentrations are shown in Figure C-3.

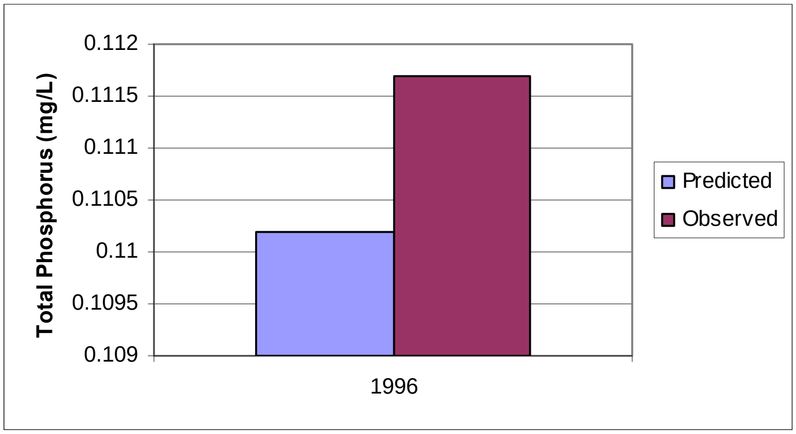

Figure C-3. Comparison of Simulated and Observed Total Phosphorus Concentrations in Herrin New Reservoir

C.3.5 Herrin New Reservoir Total Phosphorus Reductions

The total phosphorus target for Herrin New Reservoir is 0.05 mg/L. In order to meet the target for 1996, a 73 percent reduction of total phosphorus load is required. Table C-23 shows the mean annual total phosphorus concentrations if a 73 percent reduction is implemented.

Table C-23. Mean Annual Total Phosphorus Concentration in Herrin New Reservoir with 73 Percent Reductions in Loading

Year	TP (mg/L)
1996	0.050

C.4 Carbondale City Lake Watershed Loading

Piles Fork is the only tributary stream flowing into Carbondale City Lake. There are no monitoring stations available with water quality data upstream of the lake. The drainage area of Piles Fork, upstream of Carbondale City Lake is shown in Table C-24.

Table C-24. Drainage Area of Tributary to Carbondale City Lake

Tributary	Drainage Area at Lake (mi2)
Piles Fork	2.20

The USGS station 05597500, located on Crab Orchard Creek, was used to calculate mean annual flows. Incoming flows for Piles Fork were scaled using the flow data measured at Crab Orchard Creek USGS station. The flow was estimated by the ratio of drainage area of tributary to drainage area at USGS station.

A ‘reverse’ BATHTUB application was developed because no water quality data on Piles Fork was available. In the ‘reverse’ BATHTUB model, phosphorus concentrations were adjusted such that the ratio of observed and estimated phosphorus concentrations in Carbondale City Lake is close to 1. Annual watershed loads and mean annual flows from Piles Fork to Carbondale City Lake are summarized in Table C-25.

Table C-25. Mean Annual Flows and Watershed Loading to Carbondale City Lake

Year	Stream Flow (cfs)	TP Load (lb/day)
1991	3.3	13.25
1997	2.3	5.04
2000	5.9	2.47

Currently, no permitted point sources discharge in the Carbondale City Lake watershed.

C.4.1 Carbondale City Lake Morphometry

Carbondale City Lake was divided into two segments, or reservoir zones, linked in a network according to the reservoir’s morphometric features and available water quality stations. Table C-26 shows the lake segment inputs that were used in the models.

Dissolved oxygen (DO) concentrations and depth profiles measured at Carbondale City Lake during early summer of 2000 were used to estimate the hypolimnetic and mixed layer depths. Thermal stratification in the lake was apparent from the DO profiles at the segment near the dam. The profiles show the epilimnetic zone is isolated from the hypolimnetic zone by a DO gradient or thermocline from June to August. The thermocline is used to estimate the mixed layer depth for segment RNI-1/RNI-2.

Table C-26. Morphometry data of Carbondale City Lake

WQ station	Area (ac)	Mean Depth (m)	Length (km)	Volume (m3)	Mixed Layer Depth (m)	Hypolimnetic Depth(m)
RNI-1/RNI-2	92.0	2.8	0.7	1,060,518	2.4	0.9
RNI-3	44.0	0.8	0.6	141,257	0.8*	0.0

Notes:
* Mixed layer depth estimated using BATHTUB regression model

C.4.2 Carbondale City Lake Internal Loading

Internal loading rates reflect nutrient recycling from bottom sediments. Internal phosphorus loading is already accounted for in the BATHTUB pre-calibrated nutrient retention models. No internal phosphorus loading was added to the Carbondale City Lake BATHTUB models because a reverse application was used to simulate in-lake concentrations.

C.4.3 Carbondale City Lake Water Quality Data Summary

Water quality data for Carbondale City Lake were obtained from STORET and Illinois EPA databases. For Year 2000, the mean annual phosphorus concentration in Carbondale City Lake was 0.048 mg/L which is below the TP standard (0.05mg/L). Therefore, only concentrations that exceeded the standard were considered in the model for year 2000. Mean annual total phosphorus, chlorophyll-a, and secchi depth for Carbondale City Lake used in the BATHTUB model are summarized in Table C-27.

Table C-27. Annual Average Water Quality Parameters for Carbondale City Lake

Year	Total Phosphorus (mg/L)	Chlorophyll-a (μg/L)	Secchi Depth (in)
1991	0.211	85.80	11.8
1997	0.095	49.70	19.7
2000	0.074	28.30	15.7

C.4.4 Carbondale City Lake BATHTUB Modeling Results

The BATHTUB model was set up to simulate phosphorus response in Carbondale City Lake for the years 1991, 1997 and 2000 when total phosphorus data were available. A second order available phosphorus model was used to simulate phosphorus concentrations and the phosphorus/light/ flushing rate model was used to predict mean chlorophyll-a. Using 'reverse' BATHTUB, the tributary total phosphorus concentrations were adjusted so the simulated in-lake concentrations match the observed in-lake concentrations. A calibration factor of 1 was used for all parameters which indicate that no adjustment to the model is needed. Table C-28 compares the simulated and observed total phosphorus concentrations in Carbondale City Lake.

Table C-28. Simulated and Observed Phosphorus Concentrations in Carbondale City Lake

Year	Simulated TP (mg/L)	Observed TP (mg/L)
1991	0.211	0.211
1997	0.094	0.095
2000	0.074	0.074

During the reverse BATHTUB application, several simulations were made to accurately predict total phosphorus loading patterns. Final predicted and observed concentrations are shown in Figure C-4.

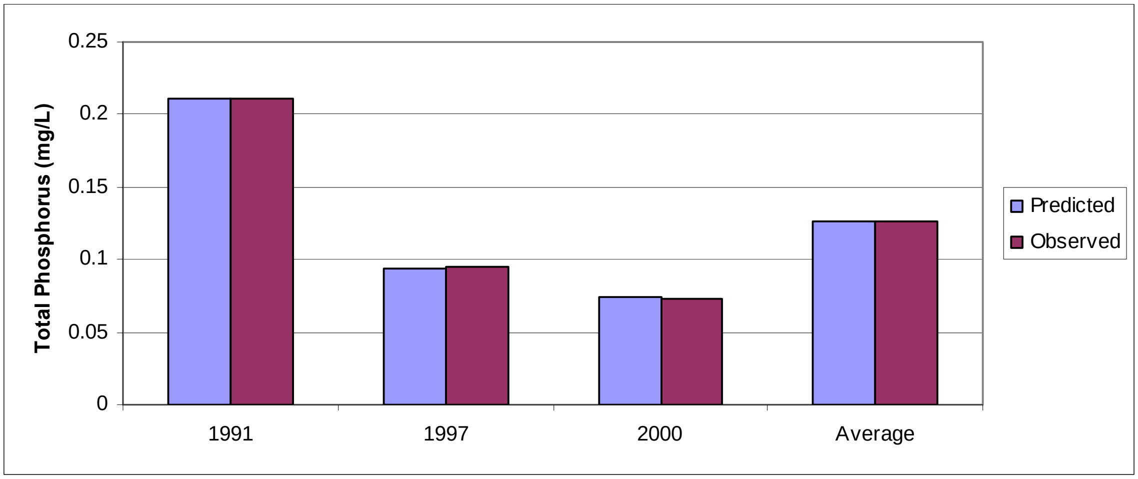

Figure C-4. Comparison of Simulated and Observed Total Phosphorus Concentrations in Carbondale City Lake

C.4.5 Carbondale City Lake Total Phosphorus Reductions

The total phosphorus target for Carbondale City Lake is 0.05 mg/L. In order to meet the target during all years, a 90 percent reduction of phosphorus load is required. Table C-29 shows the annual average total phosphorus concentrations if a 90 percent reduction is implemented.

Table C-29. Mean Annual Total Phosphorus Concentration in Carbondale City Lake with 90 Percent Reduction in Loading

Year	Lake TP (mg/L)
1991	0.050
1997	0.019
2000	0.015

C.5 Campus Lake Watershed Loading

There are no tributary streams flowing into Campus Lake. Loading to Campus Lake is mainly from overland flow (direct runoff). Flows were estimated using landuse and typical runoff coefficients. The drainage area for Campus Lake is shown in Table C-30.

Table C-30. Drainage Area of Overland Flow to Campus Lake

Tributary	Drainage Area at Lake (mi2)
Overland Flow	0.42

A ‘reverse’ BATHTUB application was developed because water quality data from the lake’s drainage area was not available. In the ‘reverse’ BATHTUB model, phosphorus concentrations were adjusted such that the ratio of observed and estimated phosphorus concentrations in Campus Lake is close to 1. Mean annual watershed loads and mean annual flows to Campus Lake are summarized in Table C-31

Table C-31. Mean Annual Flows and Watershed Loading to Campus Lake

Year	Flow (cfs)	TP Load (lb/day)
1996	0.3	0.57
1997	0.3	0.57
1998	0.3	0.52

Currently, no permitted point sources discharge in the Campus Lake watershed.

C.5.1 Campus Lake Morphometry

Campus Lake was considered as a single segment or reservoir zone according to the reservoir's morphometric features and available water quality stations. Table C-32 shows the lake segment inputs that were used in the model.

Campus Lake has a maximum depth of 12 feet near the dam. Dissolved oxygen (DO) concentrations and depth profiles are not available for this lake to determine if stratification in the lake is significant. A hypolimnetic depth of zero was assumed given that Campus Lake is not considerably deep compared to the other lakes in Crab Orchard Creek watershed. The mixed layer depth was estimated using the BATHTUB regression model.

Table C-32. Morphometry data of Campus Lake

WQ station	Area (ac)	Mean Depth (m)	Length (km)	Volume (m3)	Mixed Layer Depth (m)	Hypolimnetic Depth(m)
RNZH-1, 2 & 3	40.0	3.2	0.8	516,089	3.2	0.0

C.5.2 Campus Lake Internal Loading

Internal loading rates reflect nutrient recycling from bottom sediments. Internal phosphorus loading is already accounted for in the BATHTUB pre-calibrated nutrient retention models. Internal phosphorus loading was not added to the Campus Lake BATHTUB models because a reverse application was used to simulate in-lake concentrations.

C.5.3 Campus Lake Water Quality Data Summary

Water quality data for Campus Lake were obtained from STORET and Illinois EPA databases. For all the 3 years, the mean annual phosphorus concentrations in Campus Lake were below the TP standard (0.05mg/L). Therefore, only concentrations that exceeded the standard were considered in the model. Mean annual total phosphorus, chlorophyll-a, and secchi depth for Campus Lake are summarized in Table C-33.

Table C-33. Annual Average Water Quality Parameters for Campus Lake

Year	Total Phosphorus (mg/L)	Chlorophyll-a (µg/L)	Secchi Depth (in)
1996	0.058	36.30	35.4
1997	0.064	31.80	66.9
1998	0.061	26.80	43.3

C.5.4 Campus Lake BATHTUB Modeling Results

The BATHTUB model was set up to simulate phosphorus response in Campus Lake for years 1996 through 1998 when total phosphorus data were available. A second order available phosphorus model was used to simulate phosphorus concentrations. The phosphorus/light/ flushing rate model and the exponential phosphorus/chlorophyll-a relationship model (by Jones & Bachman) were used to predict mean chlorophyll-a. A calibration factor of 1 was used for all parameters which indicate that no adjustment to the model is needed. Table C-34 compares the simulated and observed total phosphorus concentrations in Campus Lake.

Table C-34. Simulated and Observed Phosphorus Concentrations in Campus Lake

Year	Simulated TP (mg/L)	Observed TP (mg/L)
1996	0.058	0.058
1997	0.064	0.064
1998	0.061	0.061

During the reverse BATHTUB application, several simulations were made to accurately predict total phosphorus loading patterns. Final predicted and observed concentrations are shown in Figure C-5.

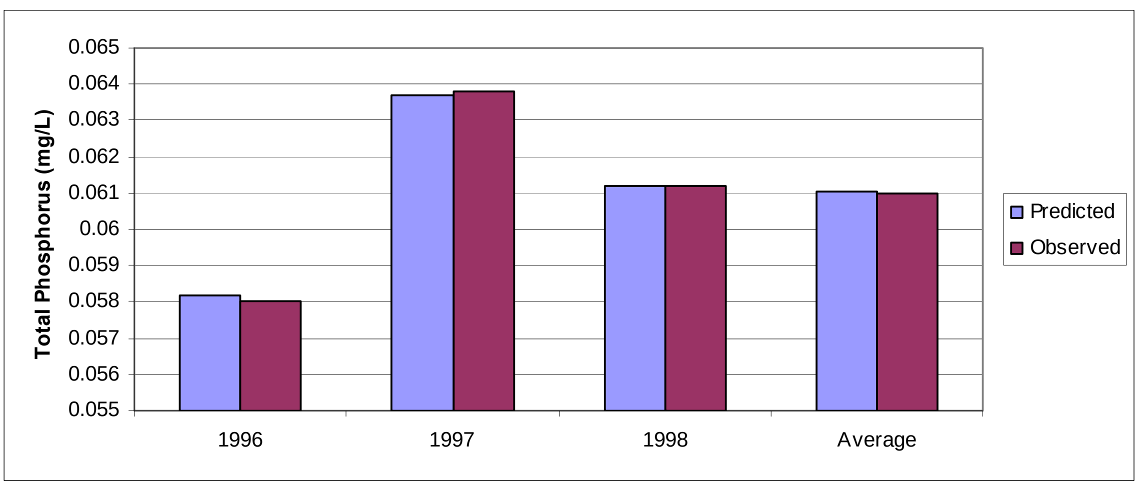

Figure C-5. Comparison of Simulated and Observed Total Phosphorus Concentrations in Campus Lake

C.5.5 Campus Lake Total Phosphorus Reductions

The total phosphorus target for Campus Lake is 0.05 mg/L. In order to meet the target during all years, a 33 percent reduction of phosphorus load to the lake is required. Table C-35 shows the mean annual total phosphorus concentrations if a 33 percent reduction is implemented.

Table C-35. Mean Annual Total Phosphorus Concentration in Campus Lake with 33 Percent Reduction in Loading

Year	Lake TP (mg/L)
1991	0.046
1994	0.050
1996	0.048

Appendix D : Stage 1 Report

Appendix E : Stage 2 Report

Appendix F : Responsiveness Summary

Responsiveness Summary

This responsiveness summary responds to substantive questions and comments received during the public comment period from April 1, 2008 through May 1, 2008 postmarked, including those from the April 2, 2008 public meeting discussed below.

What is a TMDL?

A Total Maximum Daily Load (TMDL) is the sum of the allowable amount of a pollutant that a water body can receive from all contributing sources and still meet water quality standards or designated uses. The Crab Orchard Creek TMDL report contains a plan detailing the actions necessary to reduce pollutant loads to the impaired water bodies and ensure compliance with applicable water quality standards. The Illinois EPA implements the TMDL program in accordance with Section 303(d) of the federal Clean Water Act and regulations thereunder.

Background

The watershed targeted for TMDL development is the Crab Orchard Creek watershed and encompasses 62 percent of land area of the watershed is within Williamson County , Jackson County (25%), Union County, (11%) Johnson County (2%).The watershed has a drainage area of 289 square miles (185,000 acres). Land use in the watershed is predominately agriculture. The Clean Water Act and USEPA regulations require that states develop TMDLs for waters on the Section 303(d) List. Illinois EPA is currently developing TMDLs for pollutants that have numeric water quality standards. The Crab Orchard Watershed is listed on the Illinois EPA 2006 Section 303(d) List as being impaired therefore a TMDL was developed for, dissolved oxygen, total fecal coliform, manganese, total phosphorus, total dissolved solids and pH. The Illinois EPA contracted with Tetra Tech to prepare a TMDL report for the Crab Orchard watershed.

PUBLIC MEETINGS

Public meetings were held in the City of Carbondale on September 27, 2006 and April 2, 2008. The Illinois EPA provided public notice for the meeting by placing display ads in the Southern Illinoisan and Marion Daily Republican. This notice gave the date, time, location, and purpose of the meeting. The notice also provided references to obtain additional information about this specific site, the TMDL Program and other related issues. Approximately 150 individuals and organizations were also sent the public notice by first class mail. The draft TMDL Report was available for review at the Carbondale Public Library and Crab Orchard Public Library and also on the Agency's web page at http://www.epa.state.il.us/water/tmdl .

A public meeting started at 6:00 p.m. on Wednesday, April 2, 2008. It was attended by approximately 10 people and concluded at 7:30 p.m. with the meeting record remaining open until midnight, May 2, 2008.

Questions and Comments

1. Are golf courses a source of phosphorus?

Response: Golf courses do contribute pesticides, nitrogen and phosphorus to waterways but they have not been measured independently to estimate the amount of pollutant loading from a golf course.

2. Explain how phosphorus is a source from animal operations and pets?

Response: Phosphorus runoff from animal operations and pets is in the manure can be washed into waterways during storm events if not disposed of correctly.

3. Are land fills a problem?

Response: Depending on the location, a landfill, can be a possible source of contamination into groundwater or surface water. Landfills are taken into account when doing a TMDL.

4. Are all nonpoint pollution control programs being funded?

Response: Illinois EPA 319 Non Point Source Pollution Control funding is available through grants and cost share match funds and is still being funded. However, funding through the U.S.D.A. will depend on the provisions in the farm bill.

5. How long is the comment period?

Response: The comment period is 30 days after the public meeting.

6. How is manganese a problem in the water?

Response: Neither iron nor manganese in water present a health or safety hazard. However, their presence in water may cause taste, staining, and accumulation problems. Because iron and manganese are chemically similar, they cause similar problems. Iron will cause reddish-brown staining of laundry, porcelain, dishes, utensils, and even glassware. Manganese acts in a similar way but causes a brownish-black stain. Soaps and detergents do not remove these stains, and the use of chlorine bleach and alkaline builders (such as sodium carbonate) can actually intensify the stains. Iron and manganese deposits will build up in pipelines, pressure tanks, water heaters, and water softeners. This reduces the available quantity and pressure of the water supply. Iron and manganese accumulations become an economic problem when water supply or softening equipment must be replaced. There are also associated increased energy costs, like pumping water through constricted pipes or heating water with heating rods coated with iron or manganese minerals.

Crab Orchard Creek Watershed TMDL Implementation Plan

FINAL REPORT

March 6, 2008

Submitted to:
Illinois Environmental Protection Agency
1021 N. Grand Avenue East
Springfield, IL 62702

Submitted by:
Tetra Tech

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KEY FINDINGS

The Illinois Environmental Protection Agency (IEPA) has identified several waterbodies in the Crab Orchard Creek watershed as impaired by total phosphorus, dissolved oxygen, manganese, sulfates, pH, and fecal coliform. As required by the Clean Water Act, Total Maximum Daily Loads (TMDL) were developed to address these impairments. The results of the TMDL study for the Crab Orchard Creek watershed indicate that significant reductions are needed to attain water quality standards throughout the drainage area for each pollutant.

The largest potential sources of fecal coliform and BOD loading in the watershed are animal operations and failing onsite wastewater treatment systems. The likely source of sulfate loading is abandoned coal mining sites within the watershed. The largest potential sources of total phosphorus and manganese loading into the impaired lakes in the watershed are animal operations, crop production, and streambank and lake shore erosion.

For animal operations in the Crab Orchard Creek watershed, the most cost-effective BMPs (with known costs) are filter strips and constructed wetlands. Grassed waterways, alternative watering systems and cattle exclusion from streams are also low cost BMP alternatives. However, these BMPs are typically less effective at reducing phosphorus and fecal coliform loading when compared to the more expensive manure composting and grazing land management strategies.

Conservation tillage practices offer the best reductions for all pollutants of concern and are among the least expensive options. Because impairments associated with crop production occur in most areas of the watershed, encouraging conservation tillage practices should be a top priority. Other cost-effective BMPs that reduce phosphorus and manganese delivery to streams include grassed waterways and nutrient management plans.

Pollutant loads associated with failing onsite wastewater systems likely do not contribute to large scale impairments because the density of these systems is relatively low. However, localized impacts may be significant, especially where septic systems are located near impaired lakes. Reducing the number of failing systems will require ongoing education of system owners, periodic inspections, regular maintenance, and system replacement when needed.

Erosion and lake sediments may be contributing significant loads of phosphorus and manganese to the impaired waterbodies in Crab Orchard Creek watershed. For lakes experiencing high rates of phosphorus or manganese inputs from bottom sediments, inlake controls such artificial circulation are cost effective.

Sewage treatment plants (STPs) are another potential source contributing phosphorus, BOD, and fecal coliform loads to Crab Orchard Creek. It is not likely that IEPA will require these plants to upgrade beyond present treatment. However, the State may require facilities to submit fecal coliform monitoring data to determine if a disinfection exemption is still appropriate.

Drainage from abandoned coal mines in the watershed is lowering pH and elevating sulfate concentrations in adjacent streams. While reclaiming abandoned mined sites can be extremely costly, there are a number of different passive treatment methods that have been implemented in other mining impacted watersheds of the region. Some alternatives include aerobic and anaerobic wetlands, open limestone channels, anoxic limestone drains, vertical flow reactors, and pyrolusite process water treatment systems.

The implementation of BMPs in this watershed should occur in a phased approach: Phase I will provide education and incentives to farmers in the watershed to encourage the use of BMPs; Phase II will occur during and following Phase I and will involve implementation of BMPs including filter strips, constructed wetlands, conservation tillage (through voluntary participation of farmers in the watershed), proper maintenance of onsite wastewater treatment systems, inlake controls, the nine minimum controls for CSOs, and submittal of fecal coliform monitoring data by the STPs in the watershed.

Measuring the effectiveness of these BMPs will require continued sampling of water quality over the next several years and this monitoring will determine whether or not these BMPs are capable of attaining the water quality standards of the Crab Orchard Creek watershed.

Implementation of Phase III should be determined based on the results of post-implementation water quality monitoring. If the results show that the water quality standards are not being met after implementation of the Phase II BMPs, then regional or high cost BMPs may be needed to further improve water quality.

1.0 INTRODUCTION

The Clean Water Act and USEPA regulations require that states develop Total Maximum Daily Loads (TMDLs) for waters identified as impaired on the Section 303(d) lists. Several waterbodies in the Crab Orchard Creek watershed are listed on the 2006 Illinois 303(d) list. Table 1-1 summarizes the impaired waterbodies in the Crab Orchard Creek watershed for which TMDLs have been developed. Figure 1-1 shows the location of the impaired waterbodies.

Table 1-1. 2006 303(d) List Information for Crab Orchard Creek Watershed.

Waterbody Name	Waterbody Segment	Segment and Lake Size (Segment Length in Miles, Lake Area in Acres)	Cause of Impairment	Impaired Designated Use
Crab Orchard Creek	ND 01	9.61	Total Fecal Coliform	Primary Contact
Crab Orchard Creek	ND 02	1.92	Manganese	Aquatic Life
			Dissolved Oxygen	
Crab Orchard Creek	ND 04	13.93	Dissolved Oxygen	Aquatic Life
			Sulfates	
			Manganese	
			Total Dissolved Solids (TDS)	
Crab Orchard Creek	ND 11	0.95	pH	Aquatic Life
			Dissolved Oxygen	
Crab Orchard Creek	ND 13	1.5	Manganese	Aquatic Life
			Dissolved Oxygen	
Little Crab Orchard Creek	NDA 01	12.21	Manganese	Aquatic Life
			Dissolved Oxygen	
Piles Fork	NDB 03	7	Dissolved Oxygen	Aquatic Life
Crab Orchard Lake	RNA	6,965	Total Phosphorus	Fish Consumption & Aesthetic Quality
Carbondale City Lake	RNI	135.6	Manganese	Public Water Supplies, Aesthetic Quality, & Aquatic Life
			Total Phosphorus	
Marion Reservoir	RNL	220	Manganese	Public Water Supplies & Aesthetic Quality
			Total Phosphorus	
Herrin New Reservoir	RNZC	46.1	Manganese	Public Water Supplies & Aesthetic Quality
Campus Lake	RNZH	40	Total Phosphorus	Fish consumption & Aesthetic Quality

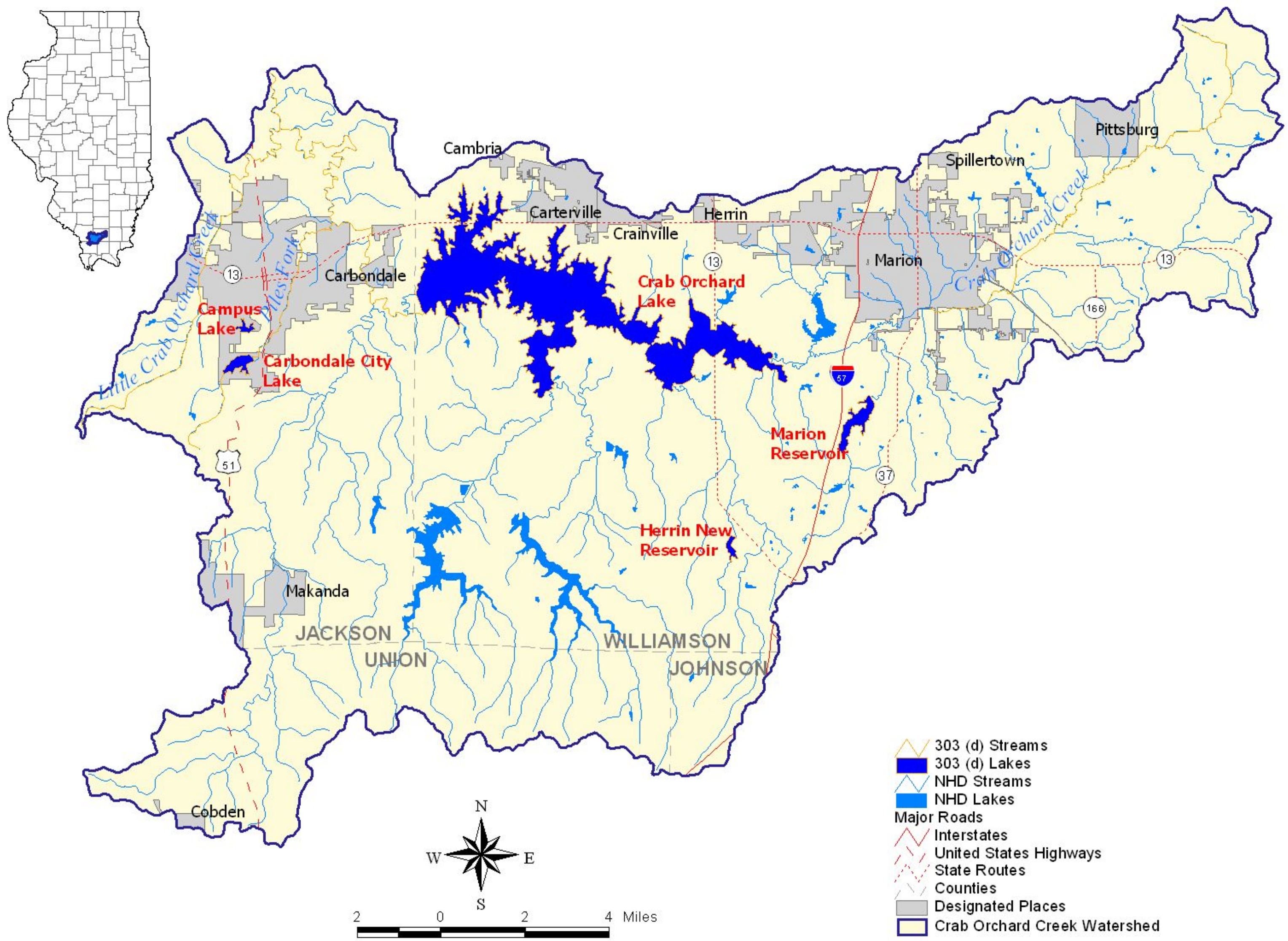

Figure 1-1. 303(d) Listed Waterbodies in the Crab Orchard Creek Watershed.

IEPA is currently developing TMDLs for pollutants that have numeric water quality standards. Of the pollutants impairing waterbodies in the Crab Orchard Creek watershed, total phosphorus, dissolved oxygen, manganese, sulfates, TDS, pH, and fecal coliform have numeric water quality standards. IEPA believes that addressing these impairments should lead to an overall improvement in water quality due to the interrelated nature of the listed pollutants.

The TMDL process is divided into three stages. Stage One was completed in January 2007 and involved the characterization of the watershed, an assessment of the available water quality data, and identification of potential technical approaches. Stage Two was completed in March 2007 and involved additional data collection. Stage Three includes modeling, TMDL development, and the preparation of this implementation plan outlining how the TMDL reductions will be achieved.

TMDLs for the waterbodies in Crab Orchard Creek watershed were developed using load duration curves and the QUAL2K and BATHTUB models. Due to the number of listed segments in the watershed, this report only summarizes the results of the TMDL process. Details for each TMDL can be found in the Stage Three report for the Crab Orchard Creek watershed available online at:

http://www.epa.state.il.us/water/tmdl/

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2.0 DESCRIPTION OF WATERBODY AND WATERSHED CHARACTERISTICS

The purpose of this section of the report is to provide a brief background of the Crab Orchard Creek watershed. More detailed information on the soils, topography, land use/land cover, climate, and population are available in the Stage One Report (IEPA, 2007).

The Crab Orchard Creek watershed has a drainage area of approximately 289 square miles (185,000 acres). Approximately 62 percent of the watershed lies within Williamson County and 25 percent lies in Jackson County. Small portions of the watershed also cover Union (11%), and Johnson (2%) counties (Figure 1-1). Crab Orchard creek drains to the west until its confluence with the Big Muddy River. USGS Geological Survey (USGS) gage 05597500 located in Crab Orchard Creek near Marion, Illinois is the only available flow gage in the watershed with current data. Approximately 94,700 people reside in the watershed area, with the city of Carbondale being the largest population center (19,600) followed by the city of Marion (16,000).

The predominant soil type in the watershed is fine-grained soils composed of silts and clays. Hydrologic soil groups B, C, and D are found within the Crab Orchard Creek watershed with the majority of the watershed falling into category C. Major tributaries to Crab Orchard Creek include Limb Branch, Wolf Creek, Grassy Creek, Little Grassy Creek, Indian Creek, Piles Fork, and Little Crab Orchard Creek.

Agriculture is the dominant land use in this watershed (45%) followed by upland forest (22%), wetland and surface waters (19%), urban space (9%), and forested areas (4%). Figure 2-1 illustrates the different land uses in the Crab Orchard Creek watershed.

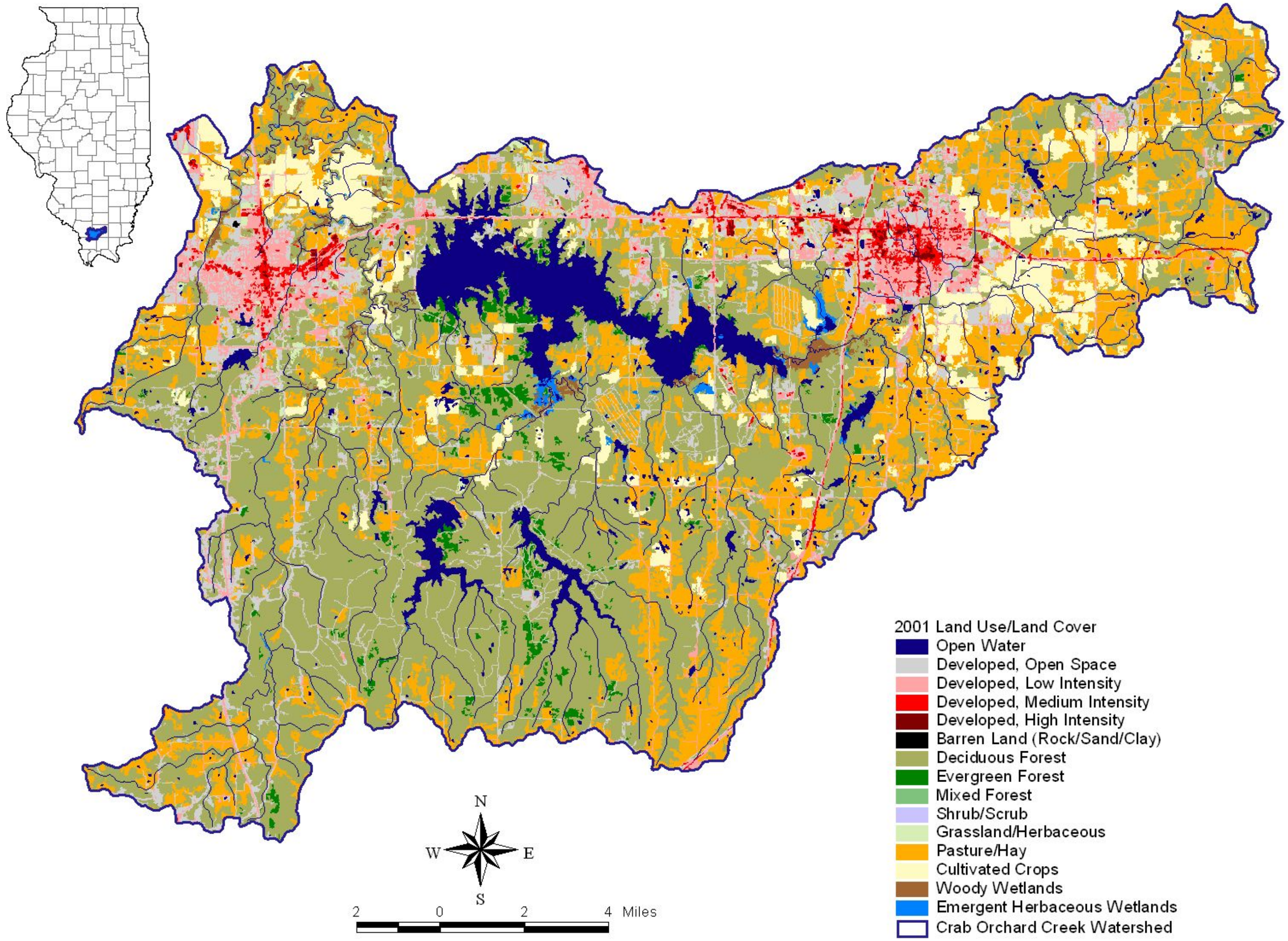

Figure 2-1. Land Use/Land Cover in Crab Orchard Creek Watershed

3.0 WATER QUALITY STANDARDS, IMPAIRMENTS, AND TMDL ALLOCATIONS

The streams and lakes of the Crab Orchard Creek watershed are currently listed for several impairments. Those parameters that carry numeric water quality standards (total phosphorus, dissolved oxygen, manganese, sulfates, TDS, pH, and fecal coliform) are addressed in this implementation plan. This section presents the applicable water quality standards for each parameter, a summary of the available water quality data, and TMDL allocations in the watershed. Detailed discussions of the available water quality data and TMDL development are presented in the Stage One Report (IEPA, 2007) and Stage Three Report (IEPA, 2008), respectively. For the purposes of this report, which is targeted for stakeholders in the watershed, loads for mass-based pollutants are expressed in pounds per day or pounds per year.

To assess the designated use support for Illinois waterbodies, the IEPA uses rules and regulations adopted by the Illinois Pollution Control Board (IPCB). The following use support designations are applicable to the Crab Orchard Creek watershed:

General Use Standards - These standards protect for aquatic life, wildlife, agricultural use, primary contact recreation, secondary contact recreation, and most industrial uses. Primary contact recreation includes any recreational or other water use in which there is prolonged and intimate contact with the water involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard, such as swimming and water skiing. Secondary contact recreation includes any recreational or other water use in which contact with the water is either incidental or accidental and in which the probability of ingesting appreciable quantities of water is minimal, such as fishing, commercial and recreational boating, and any limited contact incident to shoreline activity. These standards are also designed to ensure the aesthetic quality of the state's aquatic environment.

Public and Food Processing Water Supply Standards – These standards are cumulative with the general use standards and apply to waters of the state at any point at which water is withdrawn for treatment and distribution as a potable supply to the public or for food processing.

3.1 Fecal Coliform

Fecal coliform is a commonly used indicator to test for the presence of fecal matter and pathogenic organisms. Fecal coliform concentrations are usually reported as the number of bacterial colonies, or colony forming units (cfu), observed in 100 milliliters (ml) of sample. The abbreviated units for this measurement are cfu/100 mL. The TMDL for fecal coliform is reported as a daily load in G-org/day (giga-organisms per day, or billion organisms per day).

3.1.1 Water Quality Standards

The fecal coliform water quality standards vary by season and designated use. During the months of May through October, waterbodies with the general use designation can have no more than 10 percent of samples collected within a 30-day period exceed 400 cfu/100 mL, and the geometric mean of at least five samples collected within a 30-day period is not to exceed 200 cfu/100 mL. From November through April, no numeric standard applies for general use waters.

3.1.2 Impairments in Crab Orchard Creek Watershed

One segment, ND01, in Crab Orchard Creek watershed is listed for fecal coliform. Fecal coliform data collected during the months of May through October were used for TMDL development. Table 3-1 summarizes the fecal coliform data for segment ND01.

Table 3-1. Summary of Fecal Coliform Data in Crab Orchard Creek, Segment ND01.

Waterbody Name (Segment ID)	Number of Samples	Minimum (cfu/100mL)	Geometric Mean (cfu/100mL)	Maximum (cfu/100mL)	Exceedance[1] (percent)
Crab Orchard Creek (ND01)	57	10	251	7,900	56

[1]Percentage of samples collected from May through October exceeding the 200 cfu/100 mL standard.

3.1.3 TMDL Allocations

The fecal coliform TMDL for impairments in Crab Orchard Creek segment ND01 is based on a load duration curve approach which determines load reductions for each of five flow conditions. The allocations and load reductions for the listed segment in each flow percentile are summarized in Table 3-2. Values presented in the tables are given in G-org/day with the exception of the TMDL reductions which are presented as percentages.

Table 3-2. Fecal Coliform Reductions by Flow Conditions for Crab Orchard Creek Segment ND01.

Fecal Coliform TMDL (G-org/day)		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Segment	TMDL Component	0-10	10-40	40-60	60-90	90-100
Crab Orchard Creek (ND01)	Current Load (Geomean)[1]	97,498.1	985.1	160.4	71.6	2.9
	LA	2,055.0	141.1	30.7	9.2	2.2
	TMDL= LA+WLA+MOS	2,163.2	148.5	32.3	9.7	2.3
	WLA	0	0	0	0	0
	MOS (5%)[2]	108.2	7.4	1.6	0.5	0.1
	TMDL Reduction (%)	98%	85%	80%	86%	23%

[1]Existing load calculated based on geometric mean of samples within each flow range.
[2] MOS of 5% was assumed because of high availability of data within all flow ranges.

3.2 Sulfate

3.2.1 Water Quality Standards

The water quality standard for sulfate in waters designated for general use is 500 mg/L.

3.2.2 Impairments in the Crab Orchard Creek Watershed

One segment, ND04, in the Crab Orchard Creek watershed is listed for violation of the sulfate standards. Table 3-3 summarizes the sulfate data collected in the impaired waterbody.

Table 3-3. Summary of Sulfate Data Collected in t Crab Orchard Creek Segment ND04.

Waterbody Name (Segment ID)	Number of Samples	Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Exceedance (percent)
Crab Orchard Creek (ND04)	115	53	419	1,850	28

3.2.3 TMDL Allocations

The sulfate TMDL for Crab Orchard Creek segment ND04 was developed using a load duration curve approach which calculates load reductions for each of five flow conditions. The allocations and load reductions for the listed segment in each flow percentile are summarized in Table 3-4. Values presented in the tables are given in pounds per day (lb/day) with the exception of the TMDL reductions which are given as percentages.

Table 3-4. Sulfate Reductions by Flow Conditions for Crab Orchard Creek Segment ND04.

Sulfate TMDL (lb/day)		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Segment	TMDL Component	0-10	10-40	40-60	60-90	90-100
Crab Orchard Creek (ND04)	Current Load	-	159,306	16,502	9,713	1,398
	LA	387,683	35,594	8,883	870	0
	TMDL= LA+WLA+MOS	431,680	43,468	10,792	1,889	270
	WLA: FUCM	520	520	520	520	243
	WLA: LLC Classic	309	309	309	309	0
	WLA: DMHC	n/a	n/a	n/a	n/a	n/a
	WLA: STP	n/a	n/a	n/a	n/a	n/a
	MOS (10%)	43,168	4,047	1,079	189	27
	Reduction	-	76%	46%	91%	100%

3.3 Manganese

3.3.1 Water Quality Standards

The water quality standard for manganese is 1,000 µg/L in the streams and lakes designated for general use in Crab Orchard Creek watershed. An additional manganese water quality standard of 150 µg/L is applied to lakes that are used for public and food processing water supply.

3.3.2 Impairments in the Crab Orchard Creek Watershed

Four stream segments designated for aquatic life and three lakes designated for public water supply are impaired for manganese in the Crab Orchard Creek watershed. Table 3-5 summarizes the manganese data collected in these impaired waterbodies.

Table 3-5. Summary of Manganese Data Collected in the Listed Segments of Crab Orchard Creek Watershed.

Waterbody Name (Segment ID)	Number of Samples	Minimum (µg/L)	Average (µg/L)	Maximum (µg/L)	Exceedance (percent)
Crab Orchard Creek (ND02)	60	50	300	2,600	3
Crab Orchard Creek (ND04)	147	150	900	5,940	28
Crab Orchard Creek (ND13)	2	310	2,600	4,800	50
Little Crab Orchard Creek (NDA01)	5	10	500	1,800	20
Carbondale City Lake (RNI)	5	250	310	380	100
Marion Reservoir (RNL)	5	100	396	620	80
Herrin New Reservoir (RNZC)	5	120	882	2,200	80

3.3.3 TMDL Allocations

Two different methodologies were utilized to develop manganese TMDLs for the impaired stream and lake segments. For the stream and river segments, the load duration approach was used and allocations for manganese were calculated for five flow conditions. The allocations and load reductions for the listed stream segments in each flow percentile are summarized in Table 3-6. Values presented in the tables are given in pounds per day (lb/day) with the exception of the TMDL reductions which are given as percentages.

Allocations for Crab Orchard Creek, Carbondale City Lake, and Marion Reservoir are based on the BATHTUB lake model and are based on simulated annual averge conditions. The allocations and load reductions for the listed lake segments were calculated using total phosphorus as a surrogate for manganese and are summarized in Table 3-10.

Table 3-6. Manganese TMDL Allocations for Stream Segments in Crab Orchard Creek Watershed.

Manganese TMDLs (lb/day)		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Segment	TMDL Component	0-10	10-40	40-60	60-90	90-100
Crab Orchard Creek (ND02)	Current Load	-	67.43	-	2.33	-
	TMDL= LA+WLA+MOS	259.33	24.50	21.58	1.13	0.162
	LA	233.40	22.05	19.43	1.02	0.15
	WLA	0	0	0	0	0
	MOS (10%)	25.93	2.45	2.16	0.11	0.02
	TMDL Reduction	-	67%	-	56%	-
Crab Orchard Creek (ND04)	Current Load	699.32	148.93	61.49	20.78	1.99
	TMDL= LA+WLA+MOS	863.36	80.94	21.58	3.89	0.54
	LA	817.43	74.14	17.75	0.93	0.01
	WLA	2.75	2.75	2.75	2.75	0.5
	MOS (10%)	43.17	4.05	1.08	0.19	0.03
	TMDL Reduction	0%	50%	71%	96%	100%
Crab Orchard Creek (ND13)	Current Load	No Data	No Data	No Data	172.83	No Data
	TMDL= LA+WLA+MOS	7114.50	694.10	173.50	30.37	4.34
	LA	6403.05	624.69	156.15	27.33	3.90
	WLA	0	0	0	0	0
	MOS (10%)	711.45	69.41	17.35	3.04	0.43
	TMDL Reduction	No Data	No Data	No Data	84%	No Data
Little Crab Orchard Creek (NDA01)	Current Load	No Data	-	-	1.31	No Data
	TMDL= LA+WLA+MOS	259.34	25.00	6.48	1.14	0.16
	LA	LA	233.40	22.50	5.83	1.02
	WLA	n/a	n/a	n/a	n/a	n/a
	MOS (10%)	25.93	2.50	0.65	0.11	0.02
	TMDL Reduction	No Data	-	-	22%	No Data

3.4 Dissolved Oxygen

3.4.1 Water Quality Standards

The numeric water quality standard for dissolved oxygen requires that concentrations in general use designated streams in the Crab Orchard Creek watershed remain above 5 mg/L at all times and above 6 mg/L for at least 16 hours per day.

3.4.2 Impairments in the Crab Orchard Creek Watershed

Six stream segments designated for aquatic life in the Crab Orchard Creek watershed are listed for dissolved oxygen impairments. Table 3-7 summarizes the dissolved oxygen data collected in these impaired reaches.

Table 3-7. Summary of Dissolved Oxygen Data Collected in the Listed Segments of Crab Orchard Creek Watershed.

Waterbody Name (Segment ID)	Number of Samples	Minimum DO (mg/L)	Average DO (mg/L)	Maximum DO (mg/L)	Exceedance (percent)
Crab Orchard Creek (ND02)	4	2.50	4.88	8.50	25
Crab Orchard Creek (ND04)	10	3.8	7.45	10.1	20
Crab Orchard Creek (ND11)	589	2.88	4.54	12.76	52
Crab Orchard Creek (ND13)	526	4.06	6.32	9.62	56
Piles Fork (NDB03)	703	0.0	4.68	11.87	42
Little Crab Orchard Creek (NDA01)	773	0.63	4.17	8.35	56

3.4.3 TMDL Allocations

For the stream segments impaired by dissolved oxygen (DO), allocations are determined by modeling a critical day with low DO concentrations using the QUAL2K model. CBOD and NH4 loads from nonpoint sources were reduced until the TMDL endpoint for DO was achieved at any point along each stream segment. The allocations and load reductions for the listed stream segments are summarized in Table 3-8. Values presented in the tables are given in pounds per day (lb/day) with the exception of the TMDL reductions which are given as percentages.

Table 3-8. CBOD and Ammonia TMDL Allocations for Stream Segments in Crab Orchard Creek Watershed.

Segment	TMDL Component	CBOD TMDLs (lb/day)	Ammonia TMDLs (lb/day)
Crab Orchard Creek (ND02)	Current Load	13.01	0.24
	TMDL= LA+WLA+MOS	0.01	0.13
	LA	0.01	0.13
	WLA	-	-
	TMDL Reduction	99.9%	45%
Crab Orchard Creek (ND04)	Current Load	168.62	83.93
	TMDL= LA+WLA+MOS	209.74	38.99
	LA	82.89	22.26
	WLA	126.85	16.73
	TMDL Reduction	51%	73%
Crab Orchard Creek (ND11)	Current Load	22.64	2.15
	TMDL= LA+WLA+MOS	23.93	2.99
	LA	9.97	1.06
	WLA	13.97	1.93
	TMDL Reduction	56%	51%
Crab Orchard Creek (ND13)	Current Load	356.74	256.29
	TMDL= LA+WLA+MOS	313.53	243.95
	LA	311.19	243.95
	WLA	2.34	-
	TMDL Reduction	13%	5%
Piles Fork (NDB03)	Current Load	5.25	0.77
	TMDL= LA+WLA+MOS	5.08	0.43
	LA	2.38	0.43
	WLA	2.70	-
	TMDL Reduction	55%	44%
Little Crab Orchard Creek (NDA01)	Current Load	46.60	5.80
	TMDL= LA+WLA+MOS	27.01	3.56
	LA	24.52	2.06
	WLA	2.49	1.50
	TMDL Reduction	47%	64%

3.5 Total Phosphorus

3.5.1 Water Quality Standards

The numeric water quality standard for total phosphorus requires that concentrations collected one foot from the water surface remain at or below 0.05 mg/L in lakes designated for general use, with a surface area of at least 20 ac. The standard also applies to streams at the point that they enter a lake or reservoir.

The total phosphorus standard was used as a surrogate for the total manganese standard in the impaired lakes in Crab Orchard Creek watershed.

3.5.2 Impairments in the Crab Orchard Creek Watershed

Crab Orchard Lake, Marion Reservoir, Herrin New Reservoir, Carbondale City Lake and Campus Lake within the Crab Orchard Creek watershed are in violation of the numeric phosphorus or manganese standard. Table 3-9 summarizes the total phosphorus data collected in each lake.

Table 3-9. Summary of Total Phosphorus Data Collected in Newton Lake.

Waterbody Name (Segment ID)	Number of Samples	Average (mg/L)	Exceedance (percent)
Crab Orchard Lake (RNA)	67	0.169	85
Marion Reservoir (RNL)	29	0.070	69
Herrin New Reservoir (RNZC)	15	0.040	20
Carbondale City Lake (RNI)	45	0.118	73
Campus Lake (RNZH)	81	0.038	23

3.5.3 TMDL Allocations

For lakes in the Crab Orchard Creek watershed with phosphorus impairments, allocations are based on mean annual BATHTUB simulations and converted to daily allowable loads. The allocations and load reductions for the listed lake segments are summarized in Table 3-10. Values presented in the tables are given in pounds per day (lb/day) with the exception of the TMDL reductions which are given as percentages.

Table 3-10. Phosphorus TMDL Allocations for Lake Segments in Crab Orchard Creek Watershed.

Segment	TMDL Component	Phosphorus TMDL (lb/day)
Crab Orchard Lake (RNA)	Current Load	431.9
	Loading Capacity	88.3
	LA	54.9
	WLA	24.5
	MOS (10%)	8.8
	TMDL Reduction	80%
Marion Reservoir (RNL)	Current Load	6.6
	Loading Capacity	2.8
	LA	2.4
	WLA	0.1
	MOS (10%)	0.3
	TMDL Reduction	58%
Herrin New Reservoir (RNZC)	Current Load	11.1
	Loading Capacity	3.1
	LA	2.7
	WLA	-
	MOS (10%)	0.3
	TMDL Reduction	73%
Carbondale City Lake (RNI)	Current Load	6.9
	Loading Capacity	0.7
	LA	0.6
	WLA	-
	MOS (10%)	0.1
	TMDL Reduction	90%
Campus Lake (RNZH)	Current Load	0.6
	Loading Capacity	0.4
	LA	0.3
	WLA	-
	MOS (10%)	0.04
	TMDL Reduction	33%

4.0 POLLUTANT SOURCES IN THE CRAB ORCHARD CREEK WATERSHED

The Crab Orchard Creek watershed contains waterbodies listed for impairments due to total phosphorus, dissolved oxygen, manganese, sulfate, pH and fecal coliform. Some of the impairments, including phosphorus, manganese and dissolved oxygen, occur throughout the watershed. Both point and nonpoint sources contribute to the impairments.

This section describes each major source category, as well as the impacts and contributions to pollutant loadings in this watershed. The source categories discussed in this section include point source dischargers, onsite wastewater treatment systems, crop production, animal operations, streambank and lake shore erosion, internal loading from lake bottom sediments, historic and active coal mining operations, domestic pets, and wildlife populations.

4.1 Point Source Dischargers

There are 33 facilities regulated by the National Pollutant Discharge Elimination System that are allowed to discharge industrial or municipal wastewater to waterbodies located in the Crab Orchard Creek watershed. The permitted facilities discharge to Crab Orchard Creek segment ND01 (1), segment ND04 (5); segments ND11 (15), and segment ND13 (1); Piles Fork segment NDB03 (3); Little Crab Orchard Creek segment NDA01 (3); Marion Reservoir (1); and Crab Orchard Lake and its tributaries (4). The details on the average daily flows, permit numbers, average loadings and facility information are provided in the Stage Three Report (IEPA, 2008).

4.1.1 Fecal Coliform

Effluent from sewage treatment plants treating domestic and/or municipal waste contains fecal coliform bacteria which come from sanitary sewage. In Illinois, a number of these treatment plants have applied for and received disinfection exemptions, which allow a facility to discharge wastewater without disinfection. All of these treatment facilities are required to comply with the geometric mean fecal coliform water quality standard of 200 cfu/100 mL at the closest point downstream where recreational use occurs in the receiving water, or where the water flows into a fecal-impaired segment. Facilities with year-round disinfection exemptions may be required to provide the Agency with updated information to demonstrate compliance with these requirements.

Sewage treatment plants, located throughout the watershed, are likely the main point source inputs of fecal coliform in the Crab Orchard Creek watershed. Though the permits do not require that facilities monitor fecal coliform in the primary effluent, concentrations that occur from excessive flows through the combined sewer overflows (CSO) must be monitored. The EPA Water Discharge Permits Query (PCS) contains little data for facilities concerning the fecal coliform concentrations measured during CSOs.

Loads from treatment plants' primary and excessive flow discharge pipes are difficult to quantify given the lack of monitoring data. Meeting fecal coliform water quality standards may require that these facilities disinfect and monitor the primary effluent. This implementation plan addresses plant upgrades to include a disinfection process step and controlling combined sewer overflows.

There are 22 facilities upstream of segment ND01 that could discharge fecal coliform. However, none of these facilities, except for Tan Tara 2 HMP, are required to monitor for fecal coliform. Fecal coliform loads from these facilities were estimated based on the water quality standard of 200 cfu/100 mL and are presented in Table 4-1.

Table 4-1. Maximum Daily Fecal Coliform Loads from Facilities Discharging in the Watershed.

Facility Name	Permit Number	Receiving Stream	Fecal Load (G-org/d)
Reed Station MHP	ILG551008	ND01	0.16
Southern Il Univ-C Lit Grassy	IL0047899	ND11	0.28
Bush MHP STP #2-Carbondale	IL0046060	ND11	0.05
Chateau Apartments	ILG551058	ND11	0.13
Corner One Stop - Carbondale	ILG551016	ND11	0.05
Frost Mobile Home Park	IL0047635	ND11	0.06
Giant City School	IL0025844	ND11	0.02
IL DOC-Giant City State Park	IL0049531	ND11	n/a
Meadowbrook Estates MHP	IL0038423	ND11	0.06
Pleasant Hill MHP	ILG551059	ND11	0.15
Pleasant Valley MHP	IL0047601	ND11	0.26
Southern Mobile Home Park	ILG551077	ND11	0.14
United Methodist Camp	IL0045632	ND11	n/a
Unity Point Elm School District 140	IL0045748	ND11	0.14
University Heights MHP	IL0038415	ND11	0.19
Wildwood Mobile Home Park	ILG551093	ND11	0.10
S.I. Properties LLC	ILG551066	ND13	0.29
Beazer East Inc-Carbondale	IL0000400	NDB03	n/a
SIU-Carbondale	IL0072320	NDB03	n/a
Lenore Basin Corp-Union Hills	ILG551037	NDA01	0.03
Lilac Basin Corp.-Union Hill	IL0046221	NDA01	0.04
Tan Tara 2 Mobile Home Park	IL0049077	NDA01	-
Total Fecal Coliform Load (G-org/d)			**2.09**

4.1.2 Manganese and Sulfate

There are three facilities with permits to discharge manganese and sulfate in the Crab Orchard Creek watershed. Two of these facilities are currently being reclaimed and the other facility is suspended. Loads from the facilities are presented in Table 4-2 as average daily permitted loads.

Table 4-2. Average Daily Manganese and Sulfate Loads from Facilities Carrying Permit Limitations.

Facility Name	Permit Number	Receiving Stream	Manganese Load (lb/d)	Sulfate Load (lb/d)
Marion Southeast STP	IL0029734	ND04	2	n/a
Freeman United Coal Mine	IL0004685	ND04	0.35	520
LLC Classic Mine	IL0060372	ND04	0.09	309

4.1.3 Dissolved Oxygen

Impacts on dissolved oxygen concentrations resulting from point source dischargers may be due to nutrient induced eutrophication, oxidation of ammonia and other compounds, or degradation of biodegradable organic material. Most of the NPDES permitted dischargers in the watershed are required to monitor the amount of carbonaceous biochemical oxygen demand (CBOD) in their effluent. Loads from the facilities that do carry permit limits and are required to monitor their effluent are presented in Table 4-3 as average daily permitted loads.

Table 4-3. Average Daily CBOD Loads from Facilities Carrying Permit Limitations.

Facility Name	Permit Number	Receiving Stream	CBOD Load (lb/d)
Reed Station MHP	ILG551008	ND01	n/a
Southern Il Univ-C Lit Grassy	IL0047899	ND11	0.98
Bush MHP STP #2-Carbondale	IL0046060	ND11	0.36
Chateau Apartments	ILG551058	ND11	0.67
Corner One Stop - Carbondale	ILG551016	ND11	0.71
Frost Mobile Home Park	IL0047635	ND11	0.5
Giant City School	IL0025844	ND11	0.1
IL DOC-Giant City State Park	IL0049531	ND11	0.001
Meadowbrook Estates MHP	IL0038423	ND11	0.47
Pleasant Hill MHP	ILG551059	ND11	0.99
Pleasant Valley MHP	IL0047601	ND11	0.93
Southern Mobile Home Park	ILG551077	ND11	2.57
United Methodist Camp	IL0045632	ND11	0.33
Unity Point Elm School District 140	IL0045748	ND11	2.12
University Heights MHP	IL0038415	ND11	1.24
Wildwood Mobile Home Park	ILG551093	ND11	1.99
S.I. Properties LLC	ILG551066	ND13	2.34
Beazer East Inc-Carbondale	IL0000400	NDB03	2.38
SIU-Carbondale	IL0072320	NDB03	0.32
M&M Rentals MHP	ILG551017	NDB03	n/a
Lenore Basin Corp-Union Hills	ILG551037	NDA01	0.24
Lilac Basin Corp.-Union Hill	IL0046221	NDA01	0.21
Tan Tara 2 Mobile Home Park	IL0049077	NDA01	2.03
Marion Southeast STP	IL0029734	ND04	126.59
Crab Orchard Community Unit School District #3-STP	IL0037311	ND04	0.26

4.1.4 Phosphorus

In the watershed, there are five point source dischargers to Crab Orchard Lake and one point source discharger to Marion Reservoir that are required to monitor their effluent for total phosphorus. Existing phosphorus loads from the facilities that carry permit limits are presented in Table 4-4 as average daily permitted loads.

Table 4-4. Average Daily Phosphorus Loads from Facilities Carrying Permit Limitations.

Facility Name	Permit Number	Receiving Stream	TP Load (lb/d)
Marion Southeast STP	IL0029734	ND04/RNA	18.58
Verizon Communications	IL0059625	RNA	0.11
Crab Orchard Estates-Hughes	IL0053830	RNA	0.06
Marion WTP	ILG640158	RNA	5.56
SI Bowling & Rec Center	IL0054101	RNA	0.23
U.S. Penitentiary WTP	IL0074829	RNL	0.09

4.2 Onsite Wastewater Treatment Systems

Onsite wastewater treatment systems are not typically a significant source of pollutant loading if they are operating as designed. However, if the failure rates of systems in this watershed are high, the loading from this source may be significant. In Williamson County, where 90 percent of the septic systems in the Crab Orchard Creek watershed are located, 60 to 70 percent of the systems are not maintained well (IEPA, 2007). Approximately 5,330 onsite wastewater treatment systems are present in the Crab Orchard watershed.

The impaired Campus and Carbondale City lakes are located in Jackson County, which is served by a municipal sewer system. In Williamson County, where Crab Orchard Lake is located, the municipalities are served by sewer systems as well. Franklin-Williamson Bi-County Health Department has reported that pollutants from failing septic systems drain to Crab Orchard Lake.

Pollutant loading rates from properly functioning onsite wastewater systems are typically insignificant. However, if systems are placed on unsuitable soils, not maintained properly, or are connected to subsurface drainage systems, loading rates to receiving waterbodies may be relatively high. It is suggested that each system in the watershed be inspected to accurately quantify the loading from this source. Systems older than 20 years and those located close to the lakes or streams should be prioritized for inspection.

4.2.1 Fecal Coliform

Even properly functioning onsite wastewater systems can contribute fecal coliform loading to the surrounding environment. Fecal coliform impairments occur throughout the Crab Orchard Creek watershed. Approximately 5,330 wastewater treatment systems are located within the watershed. Fecal coliform loading rates from onsite wastewater systems were estimated based on population and loading rates reported in the literature.

In a properly functioning septic system, wastewater effluent leaves the septic tank and percolates through the system drainfield. Typically, by the time effluent reaches the groundwater zone, Fecal coliform concentrations have been reduced by 99.99 percent by natural processes (Siegrist et al., 2000). Failing systems that short circuit the soil adsorption field, result in ponding on the ground surface, or backup into homes, and will have concentrations typical of raw (untreated) sewage. Direct discharge systems that intentionally bypass the drainfield by connecting the septic tank directly to a waterbody or other transport line (such as an agricultural tile drain) will also have concentrations similar to raw sewage.

A properly functioning onsite wastewater treatment system typically achieves fecal coliform concentrations of 100 to 10,000 cfu/100 mL (Siegrist et al., 2000). A malfunctioning system, however, does not provide adequate soil-zone treatment, and concentrations of 1 x 10^6 to 1 x 10^8 cfu/100 mL are typical (Siegrist et al., 2000). Translating these concentrations to daily loads from the population served is achieved by assuming a wastewater generation rate. Rates reported in the literature are typically 120 gpd (gallons per day) per capita. The failure rate in the watershed is difficult to know with any certainty; therefore, fecal coliform loading rates under four scenarios were calculated to show the potential range of loading from this source. Table 4-5 shows the range of fecal coliform load if 7, 15, 30, and 60 percent of systems in the watershed are failing.

Table 4-5. Failure Rate Scenarios and Resulting Fecal Coliform Loads in the Crab Orchard Creek Watershed.

Failure Rate (%)	Load From Normal Systems (G-org/d)	Load From Failing Systems (G-org/d)	Total Load (G-org/d)
7[1]	5.2 to 517.8	3,897.1 to 389,713.3	3,902 to 390,231
15	4.7 to 473.2	8,351 to 835,100	8,356 to 835,573
30	3.9 to 389.7	16,702 to 1,670,200	16,706 to 1,670,590
60	2.2 to 222.7	33,404 to 3,340,400.1	33,406 to 3,340,623

[1] This is the average annual failure rate across the nation.

4.2.2 Dissolved Oxygen

Septic systems contribute nutrient loads to the environment that may result in eutrophication (excessive plant/algae growth and decay) of streams and lakes. The systems also discharge substances that consume oxygen during decomposition, referred to as biochemical oxygen demand or BOD. Once these substances reach the streams and lakes in the watershed, their decay will consume oxygen and decrease concentrations.

Quantifying the impacts of septic systems on dissolved oxygen concentrations is difficult because so many factors influence concentrations including decay rates of BOD, algal growth and respiration rates, reaeration rates, and other factors. This section discusses the BOD loading rates for normal and failing onsite systems. Because oxygen impairments exist in segments throughout the entire Crab Orchard Creek watershed, the total number of people served by onsite wastewater treatment systems will be used to approximate loading. With approximately 5,330 households having septic systems and an assumed household size of 2.3 people per household; 12,259 people are served by onsite wastewater treatment systems. To approximate the BOD loading from onsite wastewater systems, an estimate was calculated based on the population served by onsite systems and typical loading rates reported in the literature was assumed.

Measurements of biological oxygen demand are typically reported as a five-day biological oxygen demand or BOD_5. This value represents the amount of dissolved oxygen consumed over a five day period by biological processes that break down organic matter. Typical BOD_5 concentrations from septic tank effluent range from 140 to 200 mg/L. Reductions of approximately 90 percent occur in the drainfield of a properly functioning system (Siegrist et al., 2000). A malfunctioning system, however, does not provide adequate soil-zone treatment, and concentrations similar to tank effluent are typical. A typical effluent rate of 120 gpd (gallons per day) per capita and four failure scenarios was assumed. BOD_5 loading rates under four failure scenarios were calculated to show the range of loading from this source. Table 4-6 shows the range of BOD_5 load if 7, 15, 30, and 60 percent of the septic systems in the watershed are failing.

Table 4-6. Failure Rate Scenarios and Resulting BOD_5 Loads in the Crab Orchard Creek Watershed.

Failure Rate (%)	Load From Normal Systems (lb/d)	Load From Failing Systems (lb/d)	Total Load (lb/d)
7[1]	1,598.4 to 2,283.5	228.6 to 326.6	1,827 to 2,610
15	1,460.9 to 2,087	489.8 to 699.8	1,951 to 2,787
30	1,203.1 to 1,718.7	979.7 to 1,399.6	2,183 to 3,118
60	687.5 to 982.1	1,959.4 to 2,799.1	2,647 to 3,781

[1] This is the average annual failure rate across the nation (USEPA, 2002b).

4.2.3 Phosphorus

The waterbodies currently impaired due to total phosphorus are Crab Orchard Lake, Carbondale City Lake, Marion Reservoir, Herrin New Reservoir, and Campus Lake. To approximate the phosphorus loading rate from onsite wastewater systems, an estimate was made based on the population density, the area of the watershed, and net loading rates reported in the Generalized Watershed Loading Function (GWLF) User's manual were assumed.

Though a watershed model was not developed for the Crab Orchard watershed, the GWLF user's manual (Haith et al., 1992) reports septic tank effluent loading rates and subsequent removal rates based on the use of phosphate detergents. The GWLF model assumes a septic tank effluent phosphorus loading rate for households using phosphate detergent of 2.5 g/capita/day. The model assumes a plant uptake rate of 0.4 g/capita/day of phosphorus during the growing season and 0.0 g/capita/day during the dormant season. Assuming a 6-month growing season (May through October), the average annual plant uptake rate is 0.2 g/capita/day.

In a properly functioning septic system, wastewater effluent leaves the septic tank and percolates through the system drainfield. Phosphorus is removed from the wastewater by adsorption to soil particles. Plant uptake by vegetation growing over the drainfield is assumed negligible since all of the phosphorus is removed in the soil treatment zone. Failing systems that either short circuit the soil adsorption field or cause effluent to pool at the ground surface are assumed to retain phosphorus through plant uptake only (average annual uptake rate of 0.2 g/capita/day). Direct discharge systems that intentionally bypass the drainfield by connecting the septic tank effluent directly to a waterbody or other transport line (such as an agricultural tile drain) do not allow for soil zone treatment or plant uptake.

The USEPA Onsite Wastewater Treatment Systems Manual (2002b) estimates that septic systems fail at an average rate of 7 percent across the nation. In Williamson County, where 90 percent of the septic systems in the Crab Orchard Creek watershed are located, it has been reported that 60 to 70 percent of the septic systems are not maintained (IEPA, 2007). Phosphorus loading rates under four scenarios were calculated to show the range of loading from this source. Table 4-7 shows the phosphorus load if 7, 15, 30, and 60 percent of systems in the watershed are failing.

Table 4-7. Failure Rate Scenarios and Resulting Phosphorus Loads in the Crab Orchard Watershed.

Failure Rate (%)[1]	Total Phosphorus Load (lb/d)
7[2]	4
15	10
30	19
60	38

[1]The failure rate is base on load short circuit and load ponded
[2]This is the average annual failure rate across the nation (USEPA, 2002b)

4.3 Crop Production

Out of approximately 83,464 acres of land devoted to agricultural activities in the Crab Orchard Creek watershed, about 37,000 acres (20 percent) are used for production of corn, soybeans, wheat, and other small grains. Due to application of commercial fertilizer, manure, and pesticides, as well as increased rates of erosion, pollutant loads from croplands are relatively high compared to other land uses. This section describes the mechanisms of pollutant loading from farmland for each of the pollutants causing impairments in the watershed.

4.3.1 Manganese

Impairments due to manganese occur throughout the Crab Orchard Creek watershed, and crop production could be a significant contributor. Manganese is found naturally in the environment in groundwater and soils. Because crop production tends to increase rates of erosion, the sediment bound manganese loads tend to increase as a result of this land use. In addition, much of the land farmed in this watershed is classified as highly erodible.

Typical concentrations of manganese in Southern Illinois range from 4 to 200 milligrams of manganese per kilogram of soil (mg/kg) with an average value of 23 mg/kg (Ebelhar, 2007). Based on data presented by Czapar et al. (2006), conventional chisel plow crop production activities in Midwestern states result in sediment loads of 7.5 tons/ac/yr. Approximately 37,000 acres of land are used for crop production in the Crab Orchard watershed. Assuming a manganese concentration of 23 mg/kg of soil yields an estimated loading rate of 12,765 lb/yr or 35 lb/d.

4.3.2 Dissolved Oxygen

Crop production activities likely have indirect impacts on dissolved oxygen concentrations. Issues related to eutrophication will be mitigated by controlling phosphorus loads. Runoff concentrations and sediment-bound levels of biodegradable organic material should be negligible. This excludes fields that spread manure for fertilizer, but these loads are discussed in Section 4.4.2.

4.3.3 Phosphorus

Crop production is a secondary land use throughout the Crab Orchard watershed. Based on data presented by Gentry et al. (2007), phosphorus loading rates from tiled agricultural fields in east-central Illinois range from 0.5 to 1.5 lb/ac/yr (comparable data were not identified for southern Illinois). Based on this data, the phosphorus loads to Crab Orchard Creek watershed from crop production areas may range from 18,500 to 55,500 lb/yr (or 51 to 152 lb/d, respectively).

4.4 Animal Operations

Pollutant loading from animal operations can be a problem in both confined and pasture-based systems. Though the exact location of animal operations in the watershed is not known, countywide statistics indicate that a large number of livestock, swine, and poultry may exist.

Agricultural animal operations are a potential source of pollutant loading if adequate best management practices (BMPs) are not in place to protect surface waters. Livestock operations either consist of confined or pasture-based systems. If a confined operation has greater than 1,000 animal units or is determined to threaten water quality, the operation requires a federal Concentrated Animal Feeding Operation (CAFO) permit. CAFOs are required to develop a nutrient management plan (NMP) as part of the permitting process (USEPA, 2003). NMPs consists of manure management and disposal strategies that minimize the release of excess nutrients into surface and groundwater. The CAFO NMPs are based on NRCS standards and technical expertise.

The Stage One Report for the Crab Orchard Creek watershed (IEPA, 2007) summarizes the estimated number of livestock and poultry based on the 2002 Census of Agriculture data for Williamson, Jackson, Union and Johnson Counties. An area-weighted method was used to estimate the number of animals in the Crab Orchard Creek watershed (Table 4-8).

Table 4-8. Estimated Number of Livestock and Poultry in the Crab Orchard Creek Watershed.

Animal	Total No. of Animals
Poultry	236
Beef cattle	3,637
Dairy cattle	182
Other cattle: heifers, bulls, calves, etc.	7,261
Hogs and pigs	4,247
Sheep and lambs	121
Horses and ponies	503

4.4.1 Fecal Coliform

Fecal coliform impairments occur throughout the Crab Orchard Creek watershed. Each county in the watershed contains animal operations that likely contribute to this load. The county statistics are presented in the Stage One Report for cattle, poultry, swine, and sheep in the watershed (IEPA, 2007).

Fecal coliform loading rates are usually given as the bacterial count per animal unit per day. Large animals produce more fecal matter per animal compared to smaller animals, so the concept of animal unit is used to normalize loading from various operations. Table 4-9 lists the number of animals equivalent to one animal unit (IDA, 2001) for each of the livestock and poultry classes likely present in the watershed, as well as the fecal coliform loading rates (USEPA, 2002a; ASAE, 1998; USEPA, 1999a) from one animal unit. In addition, the table lists the total number of animal units in the watershed and resulting fecal coliform load.

Table 4-9. Animal Unit Data and Fecal Coliform Loading Rates for the Crab Orchard Creek Watershed.

Animal	Number of Animals in One Animal Unit	Number of Animal Units in Watershed	Fecal Coliform Load (G-org/au/d)	Total Fecal Coliform Load (G-org/d)
Poultry	50	4.72	9.74E+05	4.60E+06
Beef cattle	1	3,637	3.71E+04	1.35E+08
Dairy cattle	0.71	256.3380282	2.87E+04	7.36E+06
Other cattle: heifers, bulls, calves, etc.	1	7,261	3.71E+04	2.69E+08
Hogs and pigs	2.5	1,699	8.90E+01	1.51E+05
Sheep and lambs	10	12.1	2.00E+02	2.42E+03
Horses and ponies	0.5	1,006	4.20E-01	4.23E+02
Total Fecal Coliform Load from Agricultural Animals in the Crab Orchard Creek Watershed				**4.16E+08**

4.4.2 Dissolved Oxygen

Dissolved oxygen impairments due to animal operations may result from the breakdown of organic material in the streams and lakes or eutrophication due to excessive nutrients which leads to eventual algal decay as well as nighttime respiration. As total phosphorus is discussed separately in this report, the dissolved oxygen impairments caused by animal operations will be discussed relative to the loading of organic material. It should be noted that animals with access to streambanks will exacerbate dissolved oxygen problems by increasing bank erosion and decreasing canopy cover. This impact is difficult to quantify, but can be controlled by animal management BMPs as discussed in Section 5.0.

Dissolved oxygen impairments occur throughout the Crab Orchard Creek watershed. Loading rates of organic material are often expressed as the biological oxygen demand over a five day period (BOD_5). USEPA (1999a) has summarized the BOD_5 loading rates from various animal species as pounds per day per animal unit. This data along with the number of animal units in the watershed and the resulting BOD_5 load is summarized in Table 4-10.

Table 4-10. Animal Unit Data and BOD_5 Loading Rates for the Crab Orchard Watershed.

Animal	Number of Animals in One Animal Unit	Number of Animal Units in Watershed	BOD_5 Load (lb/au/d)	BOD_5 Load (lb/d)
Poultry	50	4.72	3.3	15.6
Beef cattle	1	3637	1.6	5819.2
Dairy cattle	0.71	256.3	1.6	410.1
Other cattle: heifers, bulls, calves, etc.	1	7261	1.6	11617.6
Hogs and pigs	2.5	1698.8	3.1	5266.3
Sheep and lambs	10	12.1	1.7	20.6
Horses and ponies	0.5	1006	1.7	1710.2
BOD_5 Load from Agricultural Animals in the Crab Orchard Watershed				**24,860**

4.4.3 Phosphorus

Total phosphorus loading rates are usually given as pounds per animal unit per day. Table 4-11 lists the number of animals equivalent to one animal unit (IDA, 2001) for each of the livestock and poultry classes likely present in the watershed, as well as the total phosphorus loading rate (USEPA, 2002a).

Table 4-11. Animal Unit Data and Total Phosphorus Loading Rates for the Crab Orchard Creek Watershed.

Animal	Number of Animals in One Animal Unit	Number of Animal Units in Watershed	Total Phosphorus Load (lb/au/d)	Total Phosphorus Load (lb/d)
Poultry	50	4.72	0.32	1.5
Beef cattle	1	3,637	0.16	581.9
Dairy cattle	0.71	256.34	0.14	35.9
Other cattle: heifers, bulls, calves, etc.	1	7,261	0.16	1161.8
Hogs and pigs	2.5	1,699	0.13	220.8
Sheep and lambs	10	12.1	0.05	0.6
Horses and ponies	0.5	1,006	0.16	161.0
Total Phosphorus Load from Agricultural Animals in the Crab Orchard Watershed				**2,163**

4.5 Streambank and Lake Shore Erosion

Streambank and lake shore erosion are potential source of nutrients and sediments to the impaired lakes in Crab Orchard Creek watershed. Damage caused by the flooding of agricultural lands along the main channel is prevalent in the watershed. Erosion caused by excessive runoff is of great concern, as it contributes to the overall water quality problems within the watershed. Both phosphorus and manganese contribute to the composition of sediment and once this sediment reaches the lakes, these elements may be released through biological and chemical transformations. Release of phosphorus may increase rates of algal and plant growth (eutrophication), which leads to issues with dissolved oxygen concentrations, water treatability, and aesthetics. Manganese also effects water treatment operations and is detrimental to aquatic life at high concentrations.

In addition to the release of phosphorus and manganese, erosion will also reduce the stability of streambanks by undercutting the roots of established vegetation and altering the stream channel itself. Loss of vegetative canopy and widening of a stream channel will allow more sunlight to reach the water column which may increase rates of eutrophication, increase water temperatures, and decrease the amount of dissolved oxygen the water can hold.

The Illinois Department of Natural Resources (IDNR) has begun an inventory of streams in the State for inclusion in the Illinois Stream Information System (ISIS). So far, all reaches in the state draining at least 10 square miles are included in the database. For those stream channels and lake shores that have not yet been inventoried by IDNR, the most cost-effective way to assess erosion is to visually inspect representative reaches of each channel or lake and rank the channel stability using a bank erosion index. Banks or shorelines ranked moderately to severely eroding could be targeted for stabilization efforts. A more time and resource intensive method is to determine the rate of erosion by inserting bank pins and measuring the rate of recession. Once soil loss estimates are obtained, reaches can be prioritized for restoration and protection.

The Marion County has an estimated 8,800 acres of cropland that is highly erodible. The average sedimentation rate is 319,200 tons/year and the total deposited sediment in Crab Orchard Lake is 104,000 tons/year (WCSWCD, 2007). Typical concentrations of manganese in Southern Illinois range from 4 to 200 milligrams of manganese per kilogram of soil (mg/kg) with an average value of 23 mg/kg (Ebelhar, 2007). The amount of manganese contributed to the Crab Orchard Creek watershed through sedimentation of erodible area is about 14,683 lb/yr or 40 lb/d. Several of the BMPs described in Section 5.0 that control pollutant loads and runoff volumes will also help control streambank and lakeshore erosion.

The U.S. Geological Survey (USGS), in cooperation with the Wisconsin Department of Natural Resources, used phosphorus and sediment load data from streams and soil phosphorus concentrations from the Otter Creek Watershed in two computer-based models to estimate phosphorus loads from sediments in agricultural fields (USGS, 1998). This study found that the phosphorus enrichment factor, or pounds of phosphorus per ton of soil, varies from 2.1 lb/ton (based on site-specific soil TP concentration) to 9.5 lb/ton (based on watershed outlet measurements). Using these loading rates, the estimated total phosphorus load due to shoreline erosion varies from 21.6 to 97.8 lb/d (7,888 to 35,682 lb/yr).

4.6 Internal Loading from Lake Bottom Sediments

Several lakes/reservoirs in the Crab Orchard Creek watershed are listed for pollutants that may be released from bottom sediments in anoxic lakes. Carbondale City Lake, Crab Orchard Lake, Marion Reservoir and Campus Lake are listed for phosphorus and Carbondale City Lake, Marion and Herrin New Reservoir are listed for manganese.

Both manganese and phosphorus may be released internally from lake sediments when oxygen concentrations near the bottom of the lake reach low levels. Low dissolved oxygen in lakes may be caused by degradation of organic material or respiration of algae in the absence of sunlight. Conditions for low dissolved oxygen are more severe during the summer months when the water temperatures are higher resulting in naturally lower dissolved oxygen concentrations.

4.6.1 Manganese

Manganese concentrations range from 0.25 to 0.38 mg/L in Carbondale City Lake, 0.10 to 0.62 mg/L in Marion Reservoir, and 0.12 to 2.20 mg/L in Herrin New Reservoir. Manganese concentrations from bottom deposits range from 540 to 2,200 mg/L in Carbondale City Lake, 480 to 4,000 mg/L in Marion Reservoir, and 1,200 to 2,900 mg/L in Herrin New Reservoir. The manganese data indicate higher concentrations near the lake bottom, suggesting it is likely that the bottom sediments are releasing manganese. Collection of additional manganese data in the lakes and its tributaries will allow for a quantitative estimate of this source. If internal loading is deemed a significant source, then the inlake management measures may be necessary.

4.6.2 Phosphorus

Phosphorus concentrations in Crab Orchard Lake range from 0.08 mg/L to 0.220 mg/L. Other lake concentrations are: Campus Lake - 0.010 to 0.045 mg/L; Marion Reservoir - 0.053 to 0.085 mg/L; and Carbondale City Lake 0.049 to 0.211 mg/L. Estimating the fraction of phosphorus in the water column that originates from re-suspended sediment stores is difficult with the current data. More intensive water quality studies of the lake and its tributaries would be required to estimate the significance of this load. Inlake management strategies are discussed in Section 5.0 since this pollutant source may be significant. In addition, BMPs that reduce phosphorus and BOD_5 loads in the watershed will also mitigate the low dissolved oxygen conditions that stimulate release from bottom sediments.

4.7 Historic Coal Mining Operations

Historic coal mining operations are prevalent in the northeastern part of the watershed around Segment ND 04 of Crab Orchard Creek. Most of the historic mining operations are concentrated around the city of Pittsburg and Spillertown in the Crab Orchard Creek Watershed. Water that infiltrates into the historically mined area comes into contact with the exposed coal seams or mine waste and becomes loaded with acidity, metals, and sulfates and later discharges at topographically low points along segment ND04 of the watershed.

Three permitted mines were observed in the vicinity of the drainage area for Segment ND04. The permitted NPDES facilities are:

- Freeman United Coal Mining (FUCM) - permit number IL0004865
- Illinois LLC-Classic Mine (LLC Classic) - permit number IL0060372
- Delta Mine Holding Company (DMHC) - permit number IL0060402

Both the Illinois LLC-Classic Mine and DMHC are in reclamation and no active mining occur at these facilities. The DMHC facility received runoff from a very limited watershed and rarely discharges to Crab Orchard Creek. The other two coal mine facilities (LLC-Classic and FUCM) have been identified as point sources which either discharge a significant flow or potentially discharge sediment and nutrient loads. Sulfate and manganese data from 2002 to 2005 were available for LLC-Classic Mine. FUCM is the only facility that is required to monitor or control sulfate and manganese based on their permit. The FUCM coal cleaning plant has been dismantled since the time it was suspended (Phifer, 2007). There are currently 4 employees at the mine recovering coal fines and doing coal refuse pile reclamation. The mine discharges water to Crab Orchard Creek only in response to precipitation events and dust control (which is performed on an as needed basis).

4.8 Domestic Pets and Wildlife Populations

Domestic pets such as cats and dogs and wildlife animals such as deer, geese, ducks, etc., can be significant sources of pollutant loading in watersheds that have high densities of urban populations or in rural communities with relatively undisturbed land use patterns. In the Crab Orchard Creek watershed, where the majority of land is used for agricultural production, these sources are likely not significant relative to the loading from animal operations, point source dischargers, and failing onsite wastewater systems.

4.9 Lawn Fertilizers

Another potential source of nutrients to the impaired lakes is lawn fertilizer application from residential properties surrounding the lakes. Nutrients in lawn fertilizers from residential areas are carried to lakes by runoff and can be a major seasonal source of phosphorus. Loading rates from lawn fertilizers (residential land use) have been reported at 0.68 lb/ac/yr to 1.96 lb/ac/yr for total phosphorus (Loehr, et.al., 1989). The number of residential properties surrounding the impaired lakes in Crab Orchard Creek watershed is unknown.

5.0 BEST MANAGEMENT PRACTICES

Controlling pollutant loading to the impaired reaches of the Crab Orchard Creek watershed will require implementation of various BMPs depending on the pollutant(s) of concern and major sources of loading. This section describes BMPs that may be used to reduce loading from point source dischargers, onsite wastewater treatment systems, agricultural operations, streambank and lake shore erosion, historic mining operations, and lawn fertilizers.

The net costs associated with the BMPs described in this plan depend on the cost of construction (for structural BMPs), maintenance costs (seeding, grading, etc.), and operating costs (electricity, fuel, labor, etc.). In addition, some practices require that land be taken out of farm production and converted to treatment areas, which results in a loss of income from the cash crop. On the other hand, taking land out of production does save money on future seed, fertilizer, and labor costs and this must be accounted for as well. This section presents an estimate of the yearly cost spread out over the service life of the BMP.

This section presents an estimate of the annualized cost per acre, uniformly divided over the service life of the BMP. The cost does not account for the difference between the initial capital cost and the cost incurred over the life span of the BMP. The unit cost is rounded up to the nearest quarter of a dollar. Incentive plans, carbon trading, and cost share programs are discussed separately in Section 8.0.

The costs presented in this section includes a 3 percent inflation rate and are discussed in year 2006 dollars for which gross income estimates for corn and soybean production are available. Net 2006 income estimates for corn and soybean in Illinois are presented in Table 5-1.

Table 5-1. Net income from corn and soybean in Illinois (IASS, 2006)

Production	Yield (bushel/ac)	Price ($/bushel)	Gross Income ($/ac)	Cost to Grow Crop ($/ac)	Net Income ($/ac)
Corn	173	3.30	571	372	199
Soybean	52	6.25	325	261	64
Average	113	4.78	448	316	132

5.1 Disinfection of Primary Effluent from Sewage Treatment Plants

Assuming that the majority of the sewage treatment plants in the Crab Orchard Creek watershed operate under a disinfection exemption, reducing the fecal coliform concentrations from a primary outfall of an exempt facility to 200 cfu/100 mL will require a permit change and disinfection of the effluent prior to discharge. Common disinfection techniques include chlorination, ozonation, and ultraviolet (UV) disinfection. In most cases, chlorination is the most cost-effective alternative, although residuals and oxidized compounds are toxic to aquatic life; subsequent dechlorination may be necessary prior to discharge which will increase costs similar to the other two options (USEPA, 1999b). The options most frequently employed are discussed below.

Chlorination

Chlorine compounds used for disinfection are usually either chlorine gas or hypochlorite solutions though other liquid and solid forms are available. Oxidation of cellular material destroys pathogenic organisms. The remaining chlorine residuals provide additional disinfection, but may also react with organic material to form harmful byproducts. To reduce the impacts on aquatic life from chlorine residuals and byproducts, a dechlorination step is often included in the treatment process (USEPA, 1999b). The advantages of chlorine disinfection are:

- Generally more cost-effective relative to UV disinfection or ozonation, if dechlorination is not required
- Residuals continue to provide disinfection after discharge
- Effective against a wide array of pathogens
- Capable of oxidizing some organic and inorganic compounds
- Provides some odor control
- Allows for flexible dosing

And the disadvantages of chlorine disinfection are:

- Chlorine residuals are toxic to aquatic life and may require dechlorination, which may increase costs by 30 to 50 percent
- Chlorine is highly corrosive and toxic with expensive shipping and handling costs
- Meeting Uniform Fire Code requirements can increase costs by 25 percent
- Oxidation of some organic compounds can produce toxic byproducts
- Effluent has increased concentrations of dissolved solids and chloride

More information about disinfection with chlorine is available online at
http://www.consolidatedtreatment.com/manuals/Fact_sheet_chlorine_disinfection.pdf

Ozonation

Ozone is generated onsite by passing a high voltage current through air or pure oxygen (USEPA, 1999c). The resulting gas (ozone, or O_3) provides disinfection by destroying the cell wall, damaging DNA, and breaking carbon bonds. The advantages of ozonation include:

- Ozone is more effective than chlorine and has no harmful residuals
- Ozone is generated onsite so there are no hazardous transport issues
- Short contact time of 10 to 30 minutes
- Elevates the DO of the effluent

The disadvantages are:

- More complex technology than UV light or chlorine disinfection
- Highly reactive and corrosive
- Not economical for wastewater with high concentrations of BOD, TSS, COD, or TOC
- Initial capital, maintenance, and operating costs are typically higher than for UV light or chlorine disinfection

More information about ozonation is available online at
http://www.epa.gov/owmitnet/mtb/ozon.pdf

Ultraviolet Disinfection

UV radiation is generated by passing an electrical current through a lamp containing mercury vapor. The radiation attacks the genetic material of the organisms, destroying reproductive capabilities (NSFC, 1998). The advantages of UV disinfection are:

- Highly effective
- Destruction of pathogens occurs by physical process, so no chemicals must be transported or stored
- No harmful residuals
- Easy to operate
- Short contact time (20 to 30 min)
- Requires less space than chlorination or ozonation

The disadvantages of UV disinfection are:

- Organisms can sometimes regenerate
- Turbidity and TSS can interfere with disinfection at high concentrations
- Not as cost effective compared to chlorination alone, but when fire code regulations and dechlorination are considered, costs are comparable.

More information about disinfection with UV radiation is available online at http://www.nsfc.wvu.edu/nsfc/pdf/eti/UV_Dis_tech.pdf

5.1.1 Effectiveness

Because the sewage treatment plants that operate under a disinfection exemption are not required to monitor fecal coliform concentrations in the primary effluent, it is difficult to estimate the existing load from this point source. The use of disinfection techniques to reduce fecal coliform concentrations to 200 cfu/100 mL should result in a substantial reduction in loading from this source.

5.1.2 Costs

Upgrading the existing sewage treatment plants to include disinfection prior to discharge can be achieved by utilizing chlorination, ozonation, or UV radiation processes. The costs associated with these three techniques include initial capital costs to construct additional process units, operating and maintenance costs for chemicals, electricity, labor, etc., as well as chemical storage and fire code requirements associated with the chlorination option. The USEPA compares costs of chlorination (USEPA, 1999b), ozonation (USEPA, 1999c), and UV disinfection (USEPA, 1995) in a series of fact sheets available online and Table 5-2 compares the costs for these three disinfection technologies. Annualized costs are calculated assuming a 20-year system life for each technology before major repairs would be required.

Table 5-2. Comparison of Disinfection Costs per 1 MGD of Sewage Treatment Plant Effluent.

Technology	Capital Costs	Annual Operating and Maintenance Costs	Annualized Costs ($/yr)
Chlorination (10 mg/L dosage), dechlorination, fire code regulations	$1,740,000	$82,000	$169,000
Ozonation	$380,000	$23,400	$42,400, plus cost of electricity
UV Disinfection	$795,700	$4,800 to $5,400	$44,600 to $45,200

5.2 Control of Combined Sewer Overflows (CSOs)

Combined sewer systems transport both wastewater and stormwater/snowmelt to the treatment plant. During extremely wet weather, the capacity of the system may be exceeded and when this occurs, the plants are designed to overflow to surface waterbodies such as streams or lakes. In 1994, EPA issued a list of nine minimum control measures that will reduce the frequency and volume of overflows without requiring significant engineering or construction to implement. The nine controls are listed below (USEPA, 1994):

1. Proper operating and maintenance procedures should be followed for the sewer system, treatment plant, and CSO outfalls. Periodic inspections are necessary to identify problem areas.
2. Maximize use of the collection system for storage:
    - Remove obstructions and repair valves and flow devices
    - Adjust storage levels in the sewer system
    - Restrict the rate of stormwater flows:
    - Upgrade or adjust the rate of lift stations
    - Remove obstructions in the conveyance system
3. Review and modification of pretreatment requirements to ensure that CSO impacts are minimized:
    - Minimize impacts of discharges from industrial and commercial facilities
    - May need to require more onsite storage of process wastewater or stormwater runoff
4. Maximize flow to the POTW for treatment:
    - Assess the capacity of the pumping stations, major interceptors, and individual process units
    - Identify locations of additional available capacity
    - Identify unused units or storage facilities onsite that may be used to store excess flows
5. Elimination of CSOs during dry weather:
    - Initiate an inspection program to identify dry weather overflows
    - Adjust or repair flow regulators
    - Fix gates stuck in the open position
    - Remove blockages that prevent the wastewater from entering the interceptor
    - Cleanout interceptors
    - Repair sewer lines that are infiltrated by groundwater
6. Control of solid and floatable materials in CSOs:
    - Use of baffles, screens, and racks to reduce solids
    - Street sweeping
7. Pollution prevention programs to reduce contaminants in CSOs:
    - Education, street sweeping, solid waste and recycling collection programs

8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts:
    - Notifying the public of the locations, health concerns, impacts on the environment
9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls:
    - Record the flow and duration of each CSO event as well as the total daily rainfall
    - Quality monitoring for permit requirements or modeling exercises

The USEPA Guidance for Nine Minimum Controls for Combined Sewer Overflows is available online at http://www.epa.gov/npdes/pubs/owm0030.pdf

The Water Environment Research Foundation suggests a decentralized approach to minimizing the frequency and volumes of CSO events (WERF, 2005). This approach utilizes individual site BMPs that encourage evapotranspiration and infiltration to reduce the volume of runoff, rather than storing large volumes of stormwater from larger land areas in the conventional, centralized controls. Practices that reduce CSOs include:

- Routing gutter downspouts to pervious surfaces
- Collecting rainwater in barrels and cisterns
- Using vegetative controls such as vegetated roofs, filter strips, grass swales, pocket wetlands, or rain gardens
- Porous pavement
- Infiltration ditches
- Soil amendments that improve vegetative growth and/or increase water retention
- Tree box filters.

Excessive stormwater volumes contributing to CSOs typically occur in urban areas with large amounts of impervious surface, overly compacted soil, and little pervious or open space. Because decentralized controls treat a smaller volume of stormwater runoff, they require a smaller footprint and are easier to incorporate into a pre-existing landscape as compared to the larger, more conventional practices such as stormwater detention ponds. However, retrofitting a previously developed area with BMPs does present the following challenges that must be considered during design: potential damage to roadway and building foundations, issues with standing water and mosquito breeding, and perceptions of private property owners. All of these may be overcome with proper planning and education.

The USEPA Guidance for Long-term Controls for Combined Sewer Overflows is available online at http://www.epa.gov/npdes/pubs/owm0272.pdf

5.2.1 Effectiveness

The effectiveness of CSO controls on reducing the fecal coliform load depends on the existing flows and frequencies of CSOs and the fecal coliform concentrations present in the releases. Most sewage treatment plants in Illinois, even those that discharge primary effluent under a disinfection exemption, are required to disinfect releases that occur as a result of CSOs. It may be possible to substantially reduce fecal coliform loading from this source with the controls described in this section.

5.2.2 Costs

Relative to the cost of upgrading the sewage treatment plants to include a disinfection process, instituting the nine minimum controls for CSOs should be a minimal cost to each facility. Plant operators and inspection personnel are likely already on hand to perform most of these functions if they aren't already. If the nine minimum controls are not effective in reducing the fecal coliform loading from the CSOs, the more costly long-term measures may be needed. These may include additional monitoring, modeling, and plant upgrades to provide adequate storage during wet weather events.

5.3 Proper Maintenance of Onsite Systems

The most effective BMP for managing loads from septic systems is regular maintenance. Unfortunately, most people do not think about their wastewater systems until a major malfunction occurs (e.g., sewage backs up into the house or onto the lawn). When not maintained properly, septic systems can cause the release of pathogens and excess nutrients into surface water. Good housekeeping measures relating to septic systems are listed below (Goo, 2004; CWP, 2004):

- Inspect system annually and pump system every 3 to 5 years, depending on the tank size and number of residents per household.
- Refrain from trampling the ground or using heavy equipment above a septic system (to prevent collapse of pipes).
- Prevent septic system overflow by conserving water, not diverting storm drains or basement pumps into septic systems, and not disposing of trash through drains or toilets.

Education is a crucial component of reducing pollution from septic systems. Many owners are not familiar with USEPA recommendations concerning maintenance schedules. Education can occur through public meetings, mass mailings, and radio and television advertisements.

The USEPA recommends that septic tanks be pumped every 3 to 5 years depending on the tank size and number of residents in the household. Annual inspections, in addition to regular maintenance, ensure that systems are functioning properly. An inspection program would help identify those systems that are currently connected to tile drain systems. All tanks discharging to tile drainage systems should be disconnected immediately.

Some communities choose to formally regulate septic systems by creating a database of all the systems in the area. This database usually contains information on the size, age, and type of system. All inspections and maintenance records are maintained in the database through cooperation with licensed maintenance and repair companies. These databases allow the communities to detect problem areas and ensure proper maintenance.

The County Health Departments issue permits for new onsite systems and major repairs and investigate complaints as they arise. However, at this time there is not a formal inspection and maintenance program in the Crab Orchard Creek watershed.

5.3.1 Effectiveness

The reductions in pollutant loading resulting from improved operation and maintenance of all systems in the watershed depends on the wastewater characteristics and the level of failure present in the watershed. Reducing the level of failure to 0 percent may result in the following load reductions:

- Phosphorus loads to the impaired lakes in Crab Orchard Creek watershed may be reduced by 4 to 38 lb/d (1,634 to 14,008 lb/yr), depending on the failure rate.
- BOD_5 loads to the impaired streams in Crab Orchard Creek watershed may be reduced by 108 to 1,326 lb/d, depending on the failure rate.

- Fecal coliform loads to the impaired lakes in Crab Orchard Creek watershed may be reduced by 3,896 to 3,340,066 lb/d, depending on the failure rate.

5.3.2 Costs

The cost of this BMP includes maintenance, inspection, replacement and public outreach. Maintenance of septic systems is performed by pumping the sludge that has accumulated at the bottom of the tank. The system fails due to overloading if the tank is not pumped out regularly. Pumping costs for septic tanks range from $250 to $350 based on the tank size and disposal fees. Assuming the septic system is pumped once every four years, on average, the annual cost ranges from $65 to $90.

Inspection of septic systems involves developing and maintaining a database of the onsite wastewater treatment systems in the watershed. After the initial inspection of each system and creation of the database, only systems with no subsequent maintenance records would need to be inspected. The cost for each inspection is approximately $175 per septic system (Hajjar, 2000). Assuming that all systems are inspected ones every five years, the cost per system is $35.

When replacement of septic tanks is needed, the estimated replacement cost ranges from $2,000 to $10,000. Assuming the expected useful life of a septic system is 30 years, the replacement cost per year ranges from $67 to $333.

A public outreach program can be accomplished through public meetings; mass mailings; radio, newspaper, and TV announcements to educate the homeowner about their systems and maintenance. The costs associated with outreach programs will vary depending on the level of effort. Assuming education will be given through annual public reminders, the annual cost is estimated at $1 per septic system. Table 5-3 summarizes the average annual cost per septic system. The average cost to implement an onsite wastewater treatment management program ranges from $168/system/yr to $459/system/yr.

Table 5-3. Costs Associated with Maintaining and Replacing an Onsite Wastewater Treatment System.

Action	Cost ($/system/yr)
Pumping	$65 - $90
Inspection	Up to $35
Replacement	$67 -$333
Public outreach	$1
Average Annual Cost	**$168 - $459**

5.4 Nutrient Management Plans

The development of nutrient management plans optimizes the efficient use of all sources of nutrients, including soil reserves, fertilizers, crop residue, and organic sources and minimizes the potential of water quality degradation by excess nutrient loads. The plan should address amount, source, placement, methods, and timing of plan nutrient applications. Plans for nutrient management should be developed and comply with applicable federal, state and local NRCS regulations (NRCS, 2002c).

Initial soil phosphorus concentrations are determined by onsite soil testing, which is available from local vendors. Losses through plant uptake are subtracted, and gains from organic sources such as manure application or industrial/municipal wastewater are added. The resulting phosphorus content is then compared to local guidelines to determine if fertilizer should be added to support crop growth and maintain current phosphorus levels. In some cases, the soil phosphorus content is too high, and no fertilizer should be added until stores are reduced by crop uptake to target levels.

The majority of nutrient loading from farmland occurs from fertilization with commercial and manure fertilizers (USEPA, 2003). In heavily fertilized areas, soil phosphorus content has increased significantly over natural levels. Parties responsible for reducing loads due to excessive fertilization include farmers and local agricultural service agencies that provide fertilization guidelines.

The Illinois Agronomy Handbook (IAH) lists guidelines for fertilizer application rates based on the inherent properties of the soil, the initial soil test phosphorus concentration for the field, and the crop type and expected yield. The Crab Orchard Creek watershed is located in the medium and low zones for inherent phosphorus availability. In the medium-low zone, maximum crop yields are obtained when the available phosphorus levels are maintained at 40 to 45 lb/ac. If the soil test phosphorus concentration is less than 40 to 45 lb/ac, the IAH suggests building up the phosphorus levels over a four year period to achieve a soil test phosphorus concentration of 40 to 45 lb/ac. If the soil test phosphorus concentrations are between 40 to 45 lb/ac and 60 to 65 lb/ac, maintenance-only application rates are recommended. At initial concentrations greater than 60 to 65 lb/ac, the IAH recommends that no phosphorus be applied until subsequent crop uptake reduces the starting value to 40 to 45 lb/ac (IAH, 2002).

The NRCS provides additional information on nutrient management planning at:
http://efotg.nrcs.usda.gov/references/public/IL/590.pdf

The Illinois Agronomy Handbook may be found online at:
http://iah.aces.uiuc.edu/

Nutrient fertilizers should not be applied to frozen, snow-covered or saturated soils if there is a potential risk of runoff (NRCS, 2002c). Researchers studying loads from agricultural fields in east-central Illinois found that fertilizer application to frozen ground or snow followed by a rain event could transport as much as 40 percent of the total annual phosphorus load in a single event (Gentry et al., 2007).

Nutrient management plans should also address the methods of application. Fertilizer may be applied directly to the surface, placed in bands below and to the side of seeds, or incorporated in the top several inches of the soil profile through drilled holes, injection, or tillage. Incorporation of fertilizer to a minimum depth of two inches prior to planting has shown a decrease in total phosphorus runoff concentrations of 20 percent. Figure 5-1 shows a deep placement attachment unit.

(Photo Courtesy of CCSWCD)

Figure 5-1. Deep Placement Phosphorus Attachment Unit for Strip-till Toolbar.

5.4.1 Effectiveness

The effectiveness of nutrient management plans (application rates, methods, and timing) in reducing phosphorus loading from agricultural land is site specific. The following reductions are reported in the literature:

- 35 percent average reduction of total phosphorus load reported in Pennsylvania (USEPA, 2003).
- 60 to 70 percent reduction in dissolved phosphorus concentrations and 20 percent reduction in total phosphorus concentrations when fertilizer is incorporated to a minimum depth of two inches prior to planting (HWRCI, 2005).
- 60 to 70 percent reduction in dissolved phosphorus concentrations and 20 to 50 percent reduction in total phosphorus with subsurface application, such as deep placement (HWRCI, 2005).
- 60 percent reduction in runoff concentrations of phosphorus when the following precipitation event occurred 10 days after fertilizer application, as opposed to 24 hours after application (HWRCI, 2005).
- Nutrient management plans will also reduce the dissolved oxygen impairments in the watershed by reducing the nutrients available to stimulate eutrophication.

5.4.2 Costs

The success of nutrient management plans is highly dependent on the rates, methods, and timing of the fertilizer application. Consultants in Illinois typically charge $6.50 to $19 per acre to determine the appropriate fertilizer rates. This fee includes soil testing, manure analysis, scaled maps, and site specific recommendations for fertilizer management (USEPA, 2003). The savings associated with using less fertilizer are approximately $10.75/ac during each plan cycle (4 years) as estimated by the Champaign County Soil and Water Conservation District. For subsurface application using deep placement, the Heartland Regional Water Coordination Initiative lists the cost of phosphorus fertilizer at $3.75/ac per application, over a 2 year cycle (HRWCI, 2005). Table 5-4 summarizes the annualized cost for this BMP. The average cost of using nutrient management plans ranges from $1.00/ac/yr to $4.00/ac/yr.

Table 5-4. Costs Calculations for Nutrient Management Plans.

Item	Costs (Savings) ($/ac/yr)
Soil Testing and Determination of Rates	$1.75 - $4.75
Savings on Fertilizer	($2.75)
Deep Placement of Phosphorus	$2.00
Average Annual Costs	**$1.00 - $4.00**

5.5 Conservation Tillage

Conservation tillage practices are used to control erosion and surface transport of pollutants from crop fields. Conservation tillage is defined as any tillage practice that results in at least 30 percent coverage of the soil surface by crop residuals after planting. The residuals not only provide erosion control, but also increase the organic and nutrient content in the soil and reduce the amount of carbon in the atmosphere by storing it in the soil.

Several practices are commonly used to maintain the suggested 30 percent cover:

- No-till systems disturb only a small row of soil during planting, and typically use a drill or knife to plant seeds below the soil surface.
- Strip till operations leave the areas between rows undisturbed, but remove residual cover above the seed to allow for proper moisture and temperature conditions for seed germination.
- Ridge till systems leave the soil undisturbed between harvest and planting: cultivation during the growing season is used to form ridges around growing plants. During or prior to the next planting, the top half to two inches of soil, residuals, and weed seeds are removed, leaving a relatively moist seed bed.
- Mulch till systems are any practice that results in at least 30 percent residual surface cover, excluding no-till and ridge till systems.

The NRCS provides additional information on these conservation tillage practices:

no-till and strip till:	http://efotg.nrcs.usda.gov/references/public/IL/329a.pdf
ridge till:	http://efotg.nrcs.usda.gov/references/public/IL/329b.pdf
mulch till:	http://efotg.nrcs.usda.gov/references/public/IL/329c.pdf

Corn residues are more durable and capable of sustaining the required 30 percent cover required for conservation tillage. Soybeans generate fewer residues, the residue degrades more quickly, and supplemental measures or special care may be necessary to meet the 30 percent cover requirement (UME, 1996). Figure 5-2 shows a comparison of ground cover under conventional and conservation tillage practices.

Figure 5-2. Comparison of Conventional (left) and Conservation (right) Tillage Practices.

An inventory of tillage system practices is not available specifically for the Crab Orchard Creek watershed. However, countywide tillage system surveys are performed by the Illinois Department of Agriculture every two years. It is assumed that the general tillage practice trends measured in the counties is applicable to the watershed. Table 5-5 through Table 5-8 show the most recent county-wide Illinois Soil Transect Survey (IDA, 2006) for Johnson, Williamson, Union and Jackson counties in 2006. In these tables, mulch till and no-till are considered conservation tillage practices, whereas reduced till and conventional practices do not maintain 30 percent ground cover. The majority of the agricultural fields are located in Williamson and Jackson counties. 55 to 63 percent of the crop fields surveyed in Williamson County and 33 to 45 percent in Jackson County use conservation tillage practices.

Table 5-5. Percentage of Agricultural Fields Surveyed with Indicated Tillage System in Johnson County.

Crop Field Type	Tillage Practice			
	Conventional	Reduced-till	Mulch-till	No-till
Corn	61	4	0	36
Soybean	36	0	0	64
Small Grain	0	0	0	0

Table 5-6. Percentage of Agricultural Fields Surveyed with Indicated Tillage System in Williamson County, Illinois.

Crop Field Type	Tillage Practice			
	Conventional	Reduced-till	Mulch-till	No-till
Corn	28	17	0	55
Soybean	21	21	15	42
Small Grain	38	0	0	63

Table 5-7. Percentage of Agricultural Fields Surveyed with Indicated Tillage System in Union County, Illinois.

Crop Field Type	Tillage Practice			
	Conventional	Reduced-till	Mulch-till	No-till
Corn	15	4	4	77
Soybean	11	4	5	80
Small Grain	0	0	40	60

Table 5-8. Percentage of Agricultural Fields Surveyed with Indicated Tillage System in Jackson County, Illinois.

Crop Field Type	Tillage Practice			
	Conventional	Reduced-till	Mulch-till	No-till
Corn	57	0	17	16
Soybean	54	0	18	27
Small Grain	59	0	41	0

Though no-till systems are more effective in reducing sediment loading from crop fields, they tend to concentrate phosphorus in the upper two inches of the soil profile due to surface application of fertilizer and decomposition of plant material (IAH, 2002; UME, 1996). This pool of phosphorus readily mixes with precipitation and can lead to increased concentrations of dissolved phosphorus in surface runoff. Chisel plowing may be required once every several years to reduce stratification of phosphorus in the soil profile.

5.5.1 Effectiveness

The reductions achieved by conservation tillage practices reported in the literature are summarized below:

- 68 to 76 percent reduction in total phosphorus (Czapar et al., 2006) Compared to conventional tillage practices in the Midwest.
- 50 percent reduction in sediment, and likely manganese (because pollutant is primarily sediment bound), for practices leaving 20 to 30 percent residual cover (IAH, 2002).
- 90 percent reduction in sediment, and likely manganese (because pollutant is primarily sediment bound), for practices leaving 70 percent residual cover (IAH, 2002).
- 90 percent reduction in pesticide loading for ridge till practices (USEPA, 2003).
- 67 percent reduction in pesticide loading for no-till practices (USEPA, 2003).
- 69 percent reduction in runoff losses for no-till practices, which protects streambanks from erosion and loss of canopy cover (USEPA, 2003).

5.5.2 Costs

Conservation tillage practices generally require fewer trips to the field, saving on labor, fuel, and equipment repair costs, though increased weed production may result in higher pesticide costs relative to conventional till (USDA, 1999). The HRWCI (2005) lists the operating cost for conservation tillage at $0/ac.

Depending on the type of equipment currently used, replacing conventional till equipment with no-till equipment can either result in a net savings or slight cost to the farmer. Converting conventional equipment to no-till equipment costs approximately $1.25 to $2.50/ac/yr. For new equipment, purchasing no-till equipment is less expensive than conventional equipment (Al-Kaisi et al., 2000). Table 5-9 summarizes the average annual cost for this BMP. The average cost of using conservation tillage practices ranges from $1.25/ac/yr to $2.50/ac/yr.

Table 5-9. Costs Calculations for Conservation Tillage.

Item	Costs (Savings) ($/ac/yr)
Conversion of Conventional Equipment to Conservation Tillage Equipment	$1.25 - $2.50
Operating Costs of Conservation Tillage Relative to Conventional Costs	$0
Average Annual Costs	**$1.25 - $2.50**

5.6 Cover Crops

Cover crops are grasses and legumes established for seasonal cover and conservation purposes to reduce soil erosion, improve soil organic matter, and manage excess nutrients (NRCS, 2002c). Grasses tend to have low seed costs and establish relatively quickly, but can impede cash crop development by drying out the soil surface or releasing chemicals during decomposition that may inhibit the growth of a following cash crop. Legumes take longer to establish, but are capable of fixing nitrogen from the atmosphere, thus reducing nitrogen fertilization required for the next cash crop. Legumes, however, are more susceptible to harsh winter environments and may not have adequate survival to offer sufficient erosion protection.

Planting the cash crop in wet soil that is covered by heavy surface residue from the cover crop may impede emergence by prolonging wet, cool soil conditions. Cover crops should be killed off two or three weeks prior to planting the cash crop either by application of herbicide or mowing and incorporation, depending on the tillage practices used. The National Sustainable Agriculture Information Service recommends planting ryegrass after corn harvest and hairy vetch after soybeans (Sullivan, 2003). The use of cover crops is illustrated in Figure 5-3.

(Photo Courtesy of CCSWCD)

Figure 5-3. Use of Cover Crops.

The NRCS provides additional information on cover crops at:
http://efotg.nrcs.usda.gov/references/public/IL/340.pdf

5.6.1 Effectiveness

The effectiveness of cover crops in reducing pollutant loading has been reported by several agencies. The reduction in runoff losses also reduces erosion from streambanks, further reducing manganese loads and allowing for the establishment of vegetation and canopy cover. The reported reductions are listed below:

- 50 percent reduction in soil and runoff losses with cover crops alone. When combined with no-till systems, may reduce soil loss by more than 90 percent (IAH, 2002). Manganese reductions will likely be similar.
- 70 to 85 percent reduction in phosphorus loading on naturally drained fields (HRWCI, 2005).
- Reduction in fertilizer and pesticide requirements (OSUE, 1999).
- Useful in conservation tillage systems following low-residue crops such as soybeans (USDA, 1999).

5.6.2 Costs

Researchers at Purdue University estimated the seed cost of ryegrass and hairy vetch at $12.75 and $32.00/ac/yr, respectively. Annual savings in nitrogen fertilizer are $4.00/ac for ryegrass and $30.25/ac for hairy vetch (from Champaign County Soil and Water Conservation District). Herbicide application is estimated to cost $15.25/ac/yr. These costs do not account for yield increases which may offset the overall cost. Table 5-10 summarizes the annual costs and savings associated with ryegrass and hairy vetch. The average cost of using cover crop range from $17.00/ac/yr to $24.00/ac/yr.

Table 5-10. Costs Calculations for Cover Crops.

Item	Ryegrass Cost ($/ac/yr)	Hairy Vetch Cost ($/ac/yr)
Seed Costs	$12.75	$32.00
Nitrogen Fertilizer Savings	($4.00)	($30.25)
Herbicide Costs	$15.25	$15.25
Average Annual Cost:	**$17.00 - $24.00**	

5.7 Filter Strips

Filter strips are vegetated surfaces used in agricultural and urban areas to intercept and treat runoff before it leaves the site. Filter strips are designed to treat sheet flow from adjacent surfaces by slowing runoff velocities and filtering out sediment and other pollutants, and by providing some infiltration into underlying soils. For small dairy operations, filter strips may also be used to treat milk house washings and runoff from open lots (NRCS, 2003).

Filter strip sizing is dependent on site specific features such as climate and topography, but at a minimum, the area of a filter strip should be no less than 2 percent of the drainage area for agricultural land (OSUE, 1994). The minimum filter strip width suggested by NRCS (2002a) is 30 ft. The strips are assumed to function properly with annual maintenance for 20 years before requiring replacement of soil and vegetation. Annual maintenance includes grading and seeding to ensure distributed flow across the filter and protection from erosion. Periodic removal of vegetation will encourage plant growth and uptake and remove nutrients stored in the plant material. A grass filter strip is shown in Figure 5-4.

(Photo Courtesy of CCSWCD)

Figure 5-4. Grass Filter Strip Protecting Stream from Adjacent Agriculture.

The NRCS provides additional information on filter strips at:
http://efotg.nrcs.usda.gov/references/public/IL/393.pdf

5.7.1 Effectiveness

The effectiveness of filter strips depends on many parameters. The key parameters include overland flow velocity and depth, vegetation, and width. The choice of vegetation should be based on climate conditions, intended functions of the buffer, desired by-products, and soil characteristics. Filter strips are most effective on sites with mild slopes of less than 6 percent.

Filter strips have been found to effectively remove pollutants from agricultural runoff. The following reductions are reported in the literature (USEPA, 2003; Kalita, 2000; Woerner and Lorimer, 2006):

- Field research on filter strips in Virginia and Maryland showed removal efficiencies for total phosphorus ranged from 0 to 83 percent (OSUE, 1994).
- 55 to 87 percent reduction in fecal coliform
- 65 percent reductions for sediment (and likely manganese)
- Slows runoff velocities and may reduce runoff volumes via infiltration

5.7.2 Costs

Filter strips can either be seeded with grass or sodded for immediate function. The seeded filter strips cost approximately $0.35 per sq ft to construct, and sodded filter strips cost approximately $0.75 per sq ft to construct. Assuming the filter strip area is 2 percent of the area drained (OSUE, 1994), 870 square feet of filter strip are required for each acre of agricultural land treated. Assuming a system life of 20 years (Weiss et al., 2007), the construction costs to treat one acre of land are $15.25/ac/yr for seeded and $32.75/ac/yr for sodded strips. Annual maintenance of filter strips is estimated at $0.01 per sq ft (USEPA, 2002b) for an additional cost of $9.25/ac/yr of agricultural land treated. In addition, the area converted from agricultural production to filter strip will result in a net annual income loss of $2.75 (2 percent of annual net income). Table 5-11 summarizes the cost to treat one acre of agricultural land using either a seeded or sodded filter strip. The average cost of using filter strips ranges from $27.25/ac/yr to $44.75/ac/yr.

Table 5-11. Costs Calculations for Seeded and Sodded Filter Strips.

Item	Seeded Filter Strip ($/ac/yr)	Sodded Filter Strip ($/ac/yr)
Construction Costs	$15.25	$32.75
Maintenance Costs	$9.25	$9.25
Income Loss	$2.75	$2.75
Average Annual Costs	**$27.25 - $44.75**	

Filter strips used in animal operations typically treat contaminated runoff from pastures or feedlot areas or washings from the milk houses of small dairy operations. The NRCS (2003) cost for small dairy operations (75 milk cows) assumes a filter strip area of 12,000 sq ft is required. For the pasture operations, it is assumed that a filter strip area of 12,000 sq ft (30 ft wide and 400 ft long) would be required to treat runoff from a herd of 50 cattle (NRCS, 2003).

For animal operations, it is not likely that land used for growing crops would be taken out of production for conversion to a filter strip. Table 5-12 summarizes the capital, maintenance, and annualized costs for filter strips per head of animal.

Table 5-12. Costs Calculations for Filter Strips Used at Animal Operations.

Operation	Capital Costs per Head	Annual Operation and Maintenance Costs per Head	Total Annualized Costs per Head
Small dairy (75 milking cows)	$48 per head of cattle	$1.50 per head of cattle	$4 per head of cattle
Beef or other (50 cattle)	$72 per head of cattle	$2.50 per head of cattle	$6 per head of cattle

5.8 Grassed Waterways

Grassed waterways are stormwater conveyances lined with grass that prevent erosion of the transport channel. The channel is designed to convey surface water at a non-erosive velocity and to improve water quality by providing infiltration of pollutants. They are often used to divert clean up-grade runoff around contaminated feedlots and manure storage areas (NRCS, 2003). In addition, the grassed channel reduces runoff velocities, allows for some infiltration, and filters out some particulate pollutants. Soil erodibility, slope, runoff velocity, channel depth, vegetation selection, and habitat should be considered during the design of the grassed waterways. Routine maintenance includes regular inspection and repair of damaged vegetation, erosion control, periodic mowing, and weed control. The bottom width of grassed waterways shall not exceed 100 feet (NRCS, 2000). A grassed waterway providing surface drainage for a corn field is shown in Figure 5-5

(Photo Courtesy of CCSWCD)

Figure 5-5. Grassed Waterway.

The NRCS provides additional information on grassed waterways at:
http://efotg.nrcs.usda.gov/references/public/IL/412.pdf

5.8.1 Effectiveness

The effectiveness of grass swales for treating agricultural runoff has not been quantified. The Center for Watershed Protection reports the following reductions in urban settings (Winer, 2000):

- 5 percent reduction in fecal coliform
- 68 percent reduction of total suspended solids (similar reduction likely for manganese)
- 29 percent reduction in total phosphorus (Winer, 2000).

5.8.2 Costs

Grassed waterways cost approximately $0.55 per sq ft to construct (USEPA, 2002b). These stormwater conveyances are best constructed where existing bare ditches transport stormwater, so no income loss from land conversion is expected with this practice. It is assumed that the average area required for a grassed waterway is approximately 0.1 to 0.3 percent of the drainage area, or between 44 and 131 sq ft per acre. Waterways are assumed to remove phosphorus effectively for 20 years before soil, vegetation, and drainage material need to be replaced (Weiss et al., 2007). Assuming a system life of 20 years, the construction costs range from $1.25/yr to $3.75/yr for each acre of agriculture runoff draining to a grassed waterway. Annual maintenance of grassed waterways is estimated at $0.02 per sq ft (Rouge River, 2001) for an additional cost ranging from $1.00/yr to $2.75/yr for each acre of agricultural land treated. Table 5-13 summarizes the annual costs to treat one acre of agricultural land using grassed waterways. The average cost of using grassed waterways ranges from $2.25/ac/yr to $6.50/ac/yr.

Table 5-13. Costs Calculations for Grassed Waterways.

Item	Costs ($/ac/yr)
Construction Costs	$1.25 - $3.75
Maintenance Costs	$1.00 - $2.75
Income Loss	$0
Average Annual Costs	**$2.25 - $6.50**

Grassed waterways are primarily used in animal operations to divert clean water away from pastures, feedlots, and manure storage areas. Table 5-14 provides the capital, maintenance, and annualized costs of this practice per head of cattle as summarized by NRCS (2003).

Table 5-14. Costs Calculations for Grassed Waterways Used in Cattle Operations.

Capital Costs per Head	Annual Operation and Maintenance Costs per Head	Total Annualized Costs per Head
$0.50 to $1.50	$0.02 to $0.04	$0.05 to $0.12

5.9 Riparian Buffers

Riparian buffers are corridors of trees, shrubs and/or grasses located adjacent to and up-gradient from streams and waterbodies. Preserving natural vegetation along stream corridors can effectively reduce water quality and habitat degradation associated with development and agricultural practices. The root structure of the vegetation in a buffer enhances infiltration of runoff and subsequent trapping of nonpoint source pollutants. It also serves as reinforcements in streambank soils, which helps to hold streambank material in place and minimize erosion. The riparian buffers are most effective when the runoff enters the buffer as sheet flow allowing for retention and uptake of pollutants.

Riparian buffers should consist of native plant species and may include grasses, grass-like plants, forbs, shrubs, and trees. Minimum buffer widths of 25 feet are required for water quality benefits. However, higher removal rates are provided with greater buffer widths (NCSU, 2002). The NRCS recommends riparian buffers consisting of two zones with a minimum width of 66 feet to effectively remove nutrients and sediments from runoff. The first zone consist of tree/shrubs at least 40 feet wide followed by a seeded or grass zone at least 20 feet wide (NRCS, 1999). Riparian corridors typically treat a maximum of 300 ft of adjacent land before runoff forms small channels that short circuit treatment. Buffer widths based on slope measurements and recommended plant species should conform to NRCS Field Office Technical Guidelines. A riparian buffer protecting the stream corridor from adjacent agricultural areas is shown in Figure 5-6.

(Photo Courtesy of NRCS)

Figure 5-6. Riparian Buffer between Stream Channel and Agricultural Areas.

The NRCS provides additional information on riparian buffers at:
http://efotg.nrcs.usda.gov/references/public/IL/390.pdf *and*
http://efotg.nrcs.usda.gov/references/public/IL/391.pdf

5.9.1 Effectiveness

The following reductions are reported in the literature:

- 25 to 30 percent reduction of total phosphorus for 30 ft wide buffers (NCSU, 2002)

- 70 to 80 percent reduction of total phosphorus for 60 to 90 ft wide buffers (NCSU, 2002)
- 34 to 74 percent reduction of fecal coliform for 30 ft wide buffers (Wenger, 1999)
- 62 percent reduction in BOD_5 for 200 ft wide buffers (Wenger, 1999)
- 70 to 90 percent reduction of sediment (and likely manganese) (NCSU, 2002)
- 87 percent reduction of fecal coliform for 200 ft wide buffers (Wenger, 1999)
- Increased canopy cover provides shading which may reduce water temperatures and improve dissolved oxygen concentrations (NCSU, 2002). Wenger (1999) suggests buffer width of at least 30 ft to maintain stream temperatures.
- Increased channel stability will reduce streambank erosion and manganese loads

5.9.2 Costs

The cost to construct riparian buffers is approximately $165/ac over the life of the buffer. The annual maintain cost is $42/ac of buffer or $12.75/ac/yr to treat one acre of land (Wossink and Osmond, 2001). Maintenance of a riparian buffer decreases if forested and native vegetation is used. Assuming a buffer width of 90 ft on either side of the stream channel and an adjacent treated width of 300 ft of agricultural land, one acre of buffer will treat approximately 3.3 acres of adjacent agricultural land. Assuming a system life of 30 years, the annual average construction cost is $5.50/ac of buffer or $1.75/ac/yr to treat one acre of agricultural land. The estimate income loss to convert farm land to riparian buffer is $40.40 (30 percent of the annual net income). Table 5-15 summarizes the cost to treat one acre of agricultural land with riparian buffers. The average cost of using riparian buffers is $59.25/ac/yr.

Table 5-15. Costs Calculations for Riparian Buffers.

Item	Costs ($/ac/yr)
Construction Costs	$1.75
Maintenance Costs	$12.75
Income Loss	$40.40
Average Annual Costs	**$59.25**

Restoration of riparian areas will protect the stream corridor from cattle trampling and reduce the amount of fecal material entering the channel. The cost of this BMP depends more on the length of channel to be protected, not the number of animals having channel access. The cost of restoration is approximately $100/ac to construct and $475/ac to maintain over the life of the buffer (Wossink and Osmond, 2001; NCEEP, 2004). The costs per length of channel for different buffer widths restored on both sides of a stream channel are listed in Table 5-16. A system life of 30 years is assumed.

Table 5-16. Costs Calculations for Riparian Buffers per Foot of Channel.

Width	Capital Costs per ft	Annual Operation and Maintenance Costs per ft	Total Annualized Costs per ft
30 ft on both sides of channel	$0.14	$0.02	$0.03
60 ft on both sides of channel	$0.28	$0.04	$0.05
90 ft on both sides of channel	$0.42	$0.06	$0.07
200 ft on both sides of channel	$0.93	$0.13	$0.16

5.10 Constructed Wetlands

Constructed wetlands used to treat animal wastes are typically surface flowing systems comprised of cattails, bulrush, and reed plants. Prior to treating animal waste in a constructed wetland, storage in a lagoon or pond is required to protect the wetland from high pollutant loads that may kill the vegetation or clog pore spaces. After treatment in the wetland, the effluent is typically held in another storage lagoon and then land applied (USEPA, 2002a). Alternatively, the stored effluent can be used to supplement flows to the wetland during dry periods. Constructed wetlands that ultimately discharge to a surface waterbody will require a permit, and the receiving stream must be capable of assimilating the effluent during low flow conditions (NRCS, 2002b). Figure 5-7 shows an example of a lagoon-wetland system.

(Photo courtesy of USDA NRCS.)

Figure 5-7. Constructed Wetland System for Animal Waste Treatment.

The NRCS provides additional information on constructed wetlands at
http://efotg.nrcs.usda.gov/references/public/IL/656.pdf
and
ftp://ftp.wcc.nrcs.usda.gov/downloads/wastemgmt/NEH637Ch3ConstructedWetlands.pdf

5.10.1 Effectiveness

Wetland environments treat wastewater through sedimentation, filtration, plant uptake, biochemical transformations, and volatilization. Reported pollutant reductions found in the literature are listed below:

- 42 percent reduction in total phosphorus (USEPA, 2003)

- 59 to 80 percent reduction in BOD_5 (USEPA, 2002a)
- 92 percent reduction in fecal coliform (USEPA, 2002a)
- 53 to 81 percent reduction in total suspended solids (and likely manganese) (USEPA, 2002a)

5.10.2 Costs

Researchers agree that the use of constructed wetlands for animal waste management systems are a lower cost alternative compared to conventional treatment and land application technologies. Few studies, however, actually report the costs of constructing and maintaining these systems. A Canadian study (CPAAC, 1999) evaluated the use of a constructed wetland system for treating milk house washings as well as contaminated runoff from the feedlot area and manure storage pile of a dairy operation containing 135 head of dairy cattle. The treatment system was comprised of a pond/wetland/pond/wetland/filter strip treatment train that cost $492 per head to construct. Annual operating and maintenance costs of $6.75 per head include electricity to run pumps, maintenance of pumps and berms, and dredging the wetland cells once every 10 years. Reductions in final disposal costs due to reduced phosphorus content of the final effluent were $20.75 per head and offset the costs of constructing and maintaining the wetland in seven years.

Another study evaluated the use of constructed wetlands for treatment of a 3,520-head swine operation in North Carolina. Waste removal from the swine facility occurs via slatted floors to an underlying pit that is flushed once per week. This new treatment system incorporated a settling basin, constructed wetland, and storage pond treatment system prior to land application or return to the pit for flushing.

Capital and maintenance costs reported in the literature for dairy and swine operations are summarized per head in Table 5-17. No example studies including costs were available for beef cattle operations, which should generate less liquid waste than the other two operations. It would therefore be expected that constructing a wetland for beef cattle operation would cost less than for a dairy or swine operation.

Table 5-17. Costs Calculations for Constructed Wetlands.

Example	Capital Costs per Head	Annual Operation and Maintenance Costs per Head	Total Annualized Costs per Head
Dairy farm	$492	-$14	$2.50
Swine operation	$103.75	$1.00	$4.50

Two wetlands located in central Illinois were constructed to treat an agricultural crop land of 39.7 acres. The construction cost for these wetlands ranged from 3 to 3.5 million dollars (Kovacic et al., 2006). Assuming a 50-year useful life, the cost of wetland systems ranges from $1,511/ac/yr to $1,763/ac/yr of crop area treated.

5.11 Composting

Composting is the biological decomposition and stabilization of organic material. The process produces heat that, in turn, produces a final product that is stable, free of pathogens and viable plant seeds, and can be beneficially applied to the land. Like manure storage areas, composting facilities should be located on dry, flat, elevated land at least 100 feet away from streams. The landowner should coordinate with local NRCS staff to determine the appropriate design for a composting facility based on the amount of manure generated. Extension agents can also help landowners achieve the ideal nutrient ratios, oxygen levels, and moisture conditions for composting on their site.

Composting can be accomplished by simply constructing a heap of the material, forming composting windrows, or by constructing one or more bins to hold the material. Heaps should be 3 feet wide and 5 feet high with the length depending on the amount of manure being composted. Compost does not have to be turned, but turning will facilitate the composting process (University of Missouri, 1993; PSU, 2005). Machinery required for composting includes a tractor, manure spreader, and front-end loader (Davis and Swinker, 2004). Figure 5-8 shows a poultry litter composting facility.

(Photo courtesy of USDA NRCS.)

Figure 5-8. Poultry Litter Composting Facility.

The NRCS provides additional information on composting facilities at
http://efotg.nrcs.usda.gov/references/public/IL/IL-317rev9-04.pdf
and
ftp://ftp.wcc.nrcs.usda.gov/downloads/wastemgmt/neh637c2.pdf

5.11.1 Effectiveness

Composting stabilizes the organic content of manure and reduces the volume that needs to be disposed of. In addition, the following reductions in loading are reported:

- 99 percent reduction of fecal coliform concentrations as a result of the heat produced during the composting process (Larney et. al., 2003).
- 56 percent reduction in runoff volumes and 68 percent reduction in sediment (and likely manganese) as a result of improved soil infiltration following application of composted manure (HRWCI, 2005).

5.11.2 Costs

The costs for developing a composting system include site development costs (storage sheds, concrete pads, runoff diversions, etc.), purchasing windrow turners if that system is chosen, and labor and fuel required to form and turn the piles. Cost estimates for composting systems have not been well documented and show a wide variation even for the same type of system. Costs are presented in Table 5-18 based on studies conducted in Wisconsin, Canada, and Indiana.

Researchers in Wisconsin estimated the costs of a windrow composting system using four combinations of machinery and labor (CIAS, 1996). These costs included collection and transfer of excreted material, formation of the windrow pile, turning the pile, and reloading the compost for final disposal. The Wisconsin study was based on a small dairy operation (60 head). Costs for beef cattle, swine, and layer hens were calculated based on animal units and handling weights of solid manure (NRCS, 2003). Equipment life is assumed 20 years. The costs presented in the Wisconsin study are much higher than those presented in Table 5-18 for collection, transfer, and storage of solid manure. However, the Wisconsin study presented a cost comparison of the windrow system to stacking on a remote concrete slab, and these estimates were approximately four and half times higher than the values summarized by NRCS. It is likely that the single data set used for the Wisconsin study is not representative of typical costs.

Two studies have been conducted in Canada regarding the costs of composting. The University of Alberta summarized the per ton costs of windrow composting with a front end loader compared to a windrow turner (University of Alberta, 2000). The Alberta Government presented a per ton estimate for a windrow system with turner: this estimate is quite different than the University of Alberta study. These per ton costs were converted to costs per head of dairy cattle, beef cattle, swine, and layer hens based on the manure generation and handling weights presented by NRCS (2003).

In 2001, the USEPA released a draft report titled "Alternative Technologies/Uses for Manure." This report summarizes results from a Purdue University research farm operating a 400-cow dairy operation. This farm also utilizes a windrow system with turner.

Table 5-18 summarizes the cost estimates presented in each of the studies for the various composting systems. None of these estimates include the final costs of land application of solid manure, as no phosphorus losses occur during the composting process.

Table 5-18. Costs Calculations for Manure Composting.

Equipment Used	Capital Costs per Head	Annual Operation and Maintenance Costs per Head	Total Annualized Costs per Head
2004 Costs Estimated from CIAS, 1996 – Wisconsin Study			
Windrow composting with front-end loader	$324.25 - dairy cattle $213.50 - beef cattle $1.75 - layer $23.75 - swine	$179.75 - dairy cattle $118.50 - beef cattle $1 - layer $13.25 - swine	$196 - dairy cattle $129.25 - beef cattle $1 - layer $14.25 - swine
Windrow composting with bulldozer	$266 - dairy cattle $175.25 - beef cattle $1.50 - layer $19.50 - swine	$179.75 - dairy cattle $118.50 - beef cattle $1 - layer $13.25 - swine	$193.25 - dairy cattle $127.25 - beef cattle $1 - layer $14.25 - swine
Windrow composting with custom-hire compost turner	$266 - dairy cattle $175.25 - beef cattle $1.50 - layer $19.50 - swine	$215.25 - dairy cattle $141.75 - beef cattle $1.25 - layer $15.75 - swine	$228.75 - dairy cattle $150.50 - beef cattle $1.25 - layer $16.75 - swine
Windrow composting with purchased compost	$617 - dairy cattle $406.25 - beef cattle	$234.25 - dairy cattle $154.25 - beef cattle	$265.25 - dairy cattle $174.75 - beef cattle

Equipment Used	Capital Costs per Head	Annual Operation and Maintenance Costs per Head	Total Annualized Costs per Head
turner	$3.50 - layer $45.25 - swine	$1.25 - layer $17.25 - swine	$1.50 - layer $19.50 - swine
2004 Costs Estimated from University of Alberta, 2000			
Windrow composting with front-end loader	Study presented annualized costs per ton of manure composted.		$23.75 to $47.50 - dairy cattle $15.75 to $31.25 - beef cattle $0.13 to $0.25 - layer $1.75 to $3.50 - swine
Windrow composting with compost turner	Study presented annualized costs per ton of manure composted.		$71.25 to $142.50 - dairy cattle $47.00 to $94.00 - beef cattle $0.50 to $0.75 - layer $5.25 to $10.50 - swine
2004 Costs Estimated from Alberta Government, 2004			
Windrow composting with compost turner	Study presented annualized costs per ton of manure composted.		$31.50 - dairy cattle $20.75 - beef cattle $0.25 - layer $2.25 - swine
2004 Costs Estimated from USEPA, 2001 Draft			
Windrow composting with compost turner	Study presented annualized costs per dairy cow.		$15.50 - dairy cattle $10.25 - beef cattle $0.09 - layer $1.25 - swine

5.12 Feeding Strategies

Use of dietary supplements, genetically enhanced feed, and specialized diets has been shown to reduce the nitrogen and phosphorus content of manure either by reducing the quantity of nutrients consumed or by increasing the digestibility of the nutrients. Manure with a lower nutrient content can be applied at higher rates to crop land, thus reducing transportation and disposal costs for excess manure.

Manure typically has high phosphorus content relative to plant requirements. In addition, most livestock animals are not capable of efficiently digesting phosphorus, so a large percentage passes through the animal undigested. Compounding the problem is over-supplementation of phosphorus additives relative to nutritional guidelines, particularly for dairy cattle (USEPA, 2002a).

5.12.1 Effectiveness

Most feeding strategies work to reduce the phosphorus content of manure such that the end product has a more balanced ratio of nitrogen and phosphorus. Reducing the phosphorus content of manure will result in lower phosphorus concentrations in runoff and stream systems. Feeding strategies will indirectly impact dissolved oxygen concentrations by reducing eutrophication in streams and lakes. The USEPA (2002a) reports the following reductions in phosphorus manure content:

- 40 percent reduction in the phosphorus content of swine manure if the animals are fed low-phytate corn or maize-soybean diets or given a phytase enzyme to increase assimilation by the animal.

- 30 to 50 percent reduction in the phosphorus content of poultry manure by supplementing feed with the phytase enzyme.

5.12.2 Costs

Several feeding strategies are available to reduce the phosphorus content of manure. Supplementing feed with the phytase enzyme increases the digestibility of phytate, which is difficult for animals to digest and is the form of phosphorus found in conventional feed products. Supplementing with phytase used to be expensive, but now is basically equivalent to the cost of the dietary phosphorus supplements that are required when animals are fed traditional grains (Wenzel, 2002).

Another strategy is to feed animals low-phytate corn or barley which contains more phosphorus in forms available to the animal. Most animals fed low-phytate feed do not require additional phosphorus supplementation; the additional cost of the feed is expected to offset the cost of supplements. The third strategy is to stop over-supplementing animals with phosphorus. Reducing intake to dietary requirements established by the USDA may save dairy farmers $25 per year per cow (USEPA, 2002a). Final disposal costs for manure will likely also decrease since less land will be required during the application process.

5.13 Alternative Watering Systems

A primary management tool for pasture-based systems is supplying cattle with watering systems away from streams and riparian areas. Livestock producers who currently rely on streams to provide water for their animals must develop alternative watering systems, or controlled access systems, before they can exclude cattle from streams and riparian areas. One method of providing an alternative water source is the development of off-stream watering systems using wells with tank or trough systems. These systems are often highly successful, as cattle often prefer spring or well water to surface water sources.

Landowners should work with an agricultural extension agent to properly design and locate watering facilities. One option is to collect rainwater from building roofs (with gutters feeding into cisterns) and use this water for the animal watering system to reduce runoff and conserve water use. Whether or not animals are allowed access to streams, the landowner should provide an alternative shady location and water source so that animals are encouraged to stay away from riparian areas. Figure 5-9 shows a centralized watering tank allowing access from rotated grazing plots and a barn area.

(Photo courtesy of USDA NRCS.)

Figure 5-9. Centralized Watering Tank.

The NRCS provides additional information on these alternative watering components:
Spring development:
http://efotg.nrcs.usda.gov/references/public/IL/IL-574.pdf,
Well development:
http://efotg.nrcs.usda.gov/references/public/IL/IL-642.pdf,
Pipeline:
http://efotg.nrcs.usda.gov/references/public/IL/516.pdf,
Watering facilities (trough, barrel, etc.):
http://efotg.nrcs.usda.gov/treemenuFS.aspx
in Section IV B. Conservation Practices Number 614

5.13.1 Effectiveness

The USEPA (2003) reports the following pollutant load reductions that may be achieved by supplying cattle with alternative watering locations and excluding cattle from the stream channel by structural or vegetative barrier:

- 15 to 49 percent reductions in total phosphorus loading
- 29 to 46 percent reductions in fecal coliform loading.

Some researchers have studied the impacts of providing alternative watering sites without structural exclusions and found that cattle spend 90 percent less time in the stream when alternative drinking water is furnished (USEPA, 2003). Prohibiting access to the stream channels will also prevent streambank trampling, decrease bank erosion, protect bank vegetation, and reduce the loading of organic material to the streams. As a result, dissolved oxygen concentrations will likely increase and manganese loads associated with bank erosion will decrease.

5.13.2 Costs

Alternative drinking water can be supplied by installing a well in the pasture area, pumping water from a nearby stream to a storage tank, developing springs away from the stream corridor, or piping water from an existing water supply. For pasture areas without access to an existing water supply, the most reliable alternative is installation of a well, which ensures continuous flow and water quality for the cattle (NRCS, 2003). Assuming a well depth of 250 ft and a cost of installation of $22.50 per ft, the cost to install a well is approximately, $5,625 per well. The well pump would be sized to deliver adequate water supply for the existing herd size. For a herd of 150 cattle, the price per head for installation was estimated at $37.50.

After installation of the well or extension of the existing water supply, a water storage device is required to provide the cattle access to the water. Storage devices include troughs or tanks. NRCS (2003) lists the costs of storage devices at $23 per head. Annual operating costs to run the well pump range from $9 to $22 per year for electricity (USEPA, 2003; Marsh, 2001), or up to $0.15 per head. Table 5-19 lists the capital, maintenance, and annualized costs for a well, pump, and storage system assuming a system life of 20 years.

Table 5-19. Costs Calculations for Alternative Watering Facilities.

Item	Capital Costs per Head	Annual Operation and Maintenance Costs per Head	Total Annualized Costs per Head
Installation of well	$37.50	$0	$2
Storage container	$23	$0	$1
Electricity for well pump	$0	$0.15	$0.15
Total system costs	**$60.50**	**$0.15**	**$3.15**

5.14 Cattle Exclusion from Streams

Cattle manure is a substantial source of nutrient and fecal coliform loading to streams, particularly where direct access is not restricted and/or where cattle feeding structures are located adjacent to riparian areas. Direct deposition of feces into streams may be a primary mechanism of pollutant loading during baseflow periods. During storm events, overbank and overland flow may entrain manure accumulated in riparian areas resulting in pulsed loads of nutrients, total organic carbon (TOC), biological oxygen demand (BOD), and fecal coliform bacteria into streams. In addition, cattle with unrestrained stream access typically cause severe streambank erosion.

Allowing limited or no animal access to streams will provide the greatest water quality protection. On properties where cattle need to cross streams to have access to pasture, stream crossings should be built so that cattle can travel across streams without degrading streambanks and contaminating streams with manure. Figure 5-10 shows an example of a reinforced cattle access point to minimize time spent in the stream and mass wasting of streambanks.

(Photo courtesy of USDA NRCS.)

Figure 5-10. Restricted Cattle Access Point with Reinforced Banks.

The NRCS provides additional information on use exclusion and controlled access at:
http://efotg.nrcs.usda.gov/treemenuFS.aspx
in Section IV B. Conservation Practices Number 382 and 472

5.14.1 Effectiveness

Fencing cattle from streams and riparian areas using vegetative or fencing materials will reduce streambank trampling and direct deposition of fecal material in the streams. As a result, manganese (associated with eroded sediment) and BOD_5 loads will decrease. The USEPA (2003) reports the following reductions in phosphorus and fecal coliform loading as a result of cattle exclusion practices:

- 15 to 49 percent reductions in total phosphorus loading
- 29 to 46 percent reductions in fecal coliform loading.

5.14.2 Costs

The costs of excluding cattle from streams depends more on the length of channel that needs to be protected than the number of animals on site. Fencing may also be used in a grazing land protection operation to control cattle access to individual plots. The system life of wire fences is reported as 20 years; the high tensile fence materials have a reported system life of 25 years (Iowa State University, 2005). NRCS reports that the average operation needs approximately 35 ft of additional fencing per head to protect grazing lands and streams. Table 5-20 presents the capital, maintenance, and annualized costs for four fencing materials based on the NRCS assumptions.

Table 5-20. Installation and Maintenance Costs of Fencing Material.

Material	Capital Costs per Head	Annual Operation and Maintenance Costs per Head	Total Annualized Costs per Head
Woven Wire	$43.50	$3.50	$5.75
Barbed Wire	$33.50	$2.75	$4.50
High Tensile (non-electric) 8-strand	$30.75	$1.75	$3.00
High Tensile (electric) 5-strand	$23.00	$1.50	$2.50

5.15 Grazing Land Management

While erosion rates from pasture areas are generally lower than those from row-crop areas, a poorly managed pasture can approach or exceed a well-managed row-crop area in terms of erosion rates. Grazing land protection is intended to maximize ground cover on pasture, reduce soil compaction resulting from overuse, reduce runoff concentrations of nutrients and fecal coliform, and protect streambanks and riparian areas from erosion and fecal deposition. Figure 5-11 shows an example of a pasture managed for land protection. Cows graze the left lot while the right lot is allowed a resting period to revegetate.

The NRCS provides additional information on prescribed grazing at:
http://efotg.nrcs.usda.gov/treemenuFS.aspx
in Section IV B. Conservation Practices Number 528A

And on grazing practices in general at:
http://www.glti.nrcs.usda.gov/technical/publications/nrph.html

(Photo courtesy of USDA NRCS.)

Figure 5-11. Example of a Well Managed Grazing System.

5.15.1 Effectiveness

Maintaining sufficient ground cover on pasture lands requires a proper density of grazing animals and/or a rotational feeding pattern among grazing plots. Increased ground cover will also reduce transport of sediment-bound manganese. Dissolved oxygen concentrations in streams will likely improve as the concentrations of BOD_5 in runoff are reduced proportionally with the change in number of cattle per acre.

The following reductions in loading are reported in the literature:

- 49 to 60 percent reduction in total phosphorus loading
- 40 percent reduction in fecal coliform loading as a result of grazing land protection measures (USEPA, 2003)
- 90 percent reduction in fecal coliform loading with rotational grazing (Government of Alberta, 2007).

5.15.2 Costs

The costs associated with grazing land protection include acquiring additional land if current animal densities are too high (or reducing the number of animals maintained), fencing and seeding costs, and developing alternative water sources. Establishment of vegetation for pasture areas costs from $39/ac to $69/ac based on data presented in the EPA nonpoint source guidance for agriculture (USEPA, 2003). Annual costs for maintaining vegetative cover will likely range from $6/ac to $11/ac (USEPA, 2003). If cattle are not allowed to graze plots to the point of requiring revegetation, the cost of grazing land protection may be covered by the fencing and alternative watering strategies discussed above. Table 5-21 presents the capital, maintenance, and annualized costs per acre of pasture land for grazing land management systems.

Table 5-21. Installation and Maintenance of Grazing Land Management Systems.

Item	Capital Costs per acre	Annual Maintenance Costs per acre	Total Annualized Costs per acre
Establish Vegetation in pasture areas	\$39 to \$69	\$6 to \$11	\$10 to \$20

5.16 BMPs for Abandoned Coal Mines

Land reclamation is the process of restoring an abandoned mine area to a historical or acceptable land use. The reclamation plan may be developed at any time, especially for existing properties that may change uses or conditions which require significant land use changes. Land reclamation is not always limited to mining properties, but also includes any property with degraded natural conditions (e.g., brownfields sites, neglected/ abandoned commercial properties) that may be permanently improved through actions that adjust topography and drainage, establish vegetation for erosion control and habitat, and protect surface and ground water resources. The main objectives of land reclamation are: to prevent permanent damage to the natural resources of an area; protect surface and ground water quality; control erosion and sedimentation impacts; improve fish and wildlife habitat; and provide post-mining economic use of the land.

Most of the resource extraction occurred historically in segment ND04 of Crab Orchard Creek, where the existing abandoned coal mines are located. Drainage from the abandoned coal mines can be impacted by contact with exposed soil, spoil piles, or pumped water from pits. The chemical reaction of surface and ground water with rock containing sulfur creates highly acidic water, commonly called acid mine drainage (AMD). This combination makes ferrous iron and sulfuric acid, creating acidic runoff and impacting the stream pH. Upon exposure to water and oxygen, pyrite oxidizes to form acidic drainage rich in dissolved metals. Although acid mine drainage may come from active mines, most acid mine drainage entering streams is from abandoned mine lands (Colorado Division of Minerals and Geology, 2007). The chemical reactions that occur during the formation of AMD can be summarized as this overall reaction:

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O \rightarrow 4\ Fe(OH)_3^- + 8\ H_2SO_4.$$

The product of this reaction, sulfuric acid, then leaches metals (iron, copper, zinc, manganese, cadmium and lead) from mineralized rock and keeps the metals dissolved in the water (Colorado Division of Minerals and Geology, 2007).

Reclamation of abandoned mine land can be conducted in several ways; the methods will depend upon the extent of pollution, geology and land features such as drainage pollution, and its ability to neutralize acidity naturally. Land reclamation may involve clearing site vegetation, removing contaminated topsoil and residual coal, and restoring functionality of the site for recreational, agricultural, or wildlife habitat purposes or it may involve chemical treatment. The process commonly includes restoring missing or poorly functioning natural resources (top soil, vegetation, drainage, and landscape) to blend with surrounding conditions. For example, diverting surface water upstream of a mined site to decrease the amount of water entering the mined area (and therefore reducing the possibility of creating AMD), is considered reclamation. This technique can control water volume and direction helping to minimize the effects of AMD on receiving streams. Surface diversion of runoff involves construction of drainage ditches to move surface water quickly off the site.

5.16.1 Active Chemical Treatment Systems

Active chemical treatment systems are a standard remediation technique for treatment of AMD by treating water with additions of highly alkaline chemicals such as NaOH, $Ca(OH)_2$, CaO, Na_2CO_3, or NH_3. The pH of the effluent is raised until metals precipitate out of solution and can settle out in a retention pond. AMD chemical treatment systems consist of an inflow pipe or ditch, a storage tank or bin holding the treatment chemical, a means of controlling chemical application rate, a settling pond to capture precipitate metal oxyhydroxides, and a discharge point (Skousen et al. 1998).

5.16.1.1 Effectiveness

The environmental benefits realized from abandoned mine reclamation projects are numerous and significant, including restoring land for future recreational use and improving water quality (PDEP, 2007). However, the benefits cannot be quantified because it depends greatly upon the type of reclamation adopted, geology of the site, area treated and or selection of chemical treatment system.

The selection of a chemical treatment system depends on characteristics of the effluent (pH, iron and manganese concentrations), the flow rate, the receiving stream's flow and quality and the distance from chemical addition to where the water enters a settling pond, and the settling pond's retention time. Although chemical treatment is often very efficient in promoting metal removal and neutralizing acidity, the chemicals are expensive, dangerous, and when misused can result in discharge of excessively alkaline water. Because the extent of acid mine drainage has not yet been quantified, the effectiveness of this BMP is difficult to estimate.

5.16.1.2 Costs

Reclamation projects tend to be costly and resource intensive and may not be appropriate for all abandoned mine sites in Crab Orchard Creek Watershed. For example, in Lucky Run Creek in Lackawanna County, Pennsylvania approximately 2.8 acres of land were reclaimed which involved reestablishing 1,079 linear feet of the creek (PDEP, 2003). The stream channel was reconstructed atop the impervious liner using the screened material. The reconstruction of stream bed was completed with an overall cost of $113,707.16/ acre.

Chemical treatment of acid mine drainage required to maintain effluent within legal limits was estimated at $1 million per day in the Appalachian area in 1987 (Kleinmann and Girts 1987). Cost varies widely depending on the eight chemicals used most frequently (Table 1, Skousen et al. 1998) and the specific treatment method selected. The amount of chemical needed to neutralize acidity is calculated as the amount of acidity in the effluent over a year's time (lb/year) multiplied by a chemical specific conversion factor (see Table 5-22). Since the acidity load is not available, the total cost of chemical application cannot be quantified for the Crab Orchard Creek watershed.

Table 5-22. Chemical compounds used in AMD treatment.

Common name	Chemical name	Formula	Conversion factor	1996 cost ($/ lb or gallon)
Limestone	Calcium carbonate	$CaCO_3$	1	$0.01
Pebble quicklime	Calcium oxide	CaO	0.74	$0.11
Hydrated lime	Calcium hydroxide	$Ca(OH)_2$	0.56	$0.05
Soda ash	Sodium carbonate	Na_2CO_3	1.06	$0.15
Caustic soda (solid)	Sodium hydroxide	NaOH	0.8	$0.40
20% liquid caustic	Sodium hydroxide	NaOH	784	$0.60
50% liquid caustic	Sodium hydroxide	NaOH	256	$1.25
Ammonia	Anhydrous ammonia	NH_3	0.34	$0.31

Source: Skousen et al. 1998

5.16.2 Aerobic and Anaerobic Wetlands

Aerobic and anaerobic wetlands are constructed wetlands design to passively treat drainage from mine reclamation projects. Aerobic (with oxygen) wetlands precipitate metals through oxidation whereas anaerobic (without oxygen) wetlands remove heavy metals using sulfate-reducing bacteria.

Aerobic

An aerobic wetland consists of a large surface area pond with horizontal surface flow and planted with cattails and other wetland species. Aerobic wetlands can only effectively treat water that is net alkaline (pH greater than 7). In aerobic wetland systems, metals are precipitated through oxidation reactions to form oxides and hydroxides. A typical aerobic wetland will have a water depth of six to 18 inches (PDEP 2007). Aerobic wetlands are generally effective in reducing metals (iron, manganese and arsenic) and particulate phosphorus. Wetlands generally have low to moderate effectiveness at reducing particulate phosphorus, and low to negative effectiveness at reducing dissolved phosphorus (NRCS, 2006).

Anaerobic

Compost wetlands, or anaerobic wetlands, consist of a large pond with a lower layer of organic substrate. The flow is horizontal within the substrate layer of the basin and piling the compost slightly higher than the free water surface can increase the flow within the substrate. Anaerobic wetlands rely on organic rich substrate to create the reducing condition. The compost layer typically consists of spent mushroom compost that contains about 10 percent calcium carbonate. Other compost materials include peat moss, wood chips, sawdust, or hay. A typical compost wetland will have 12 to 24 inches of organic substrate that is planted with cattails or other emergent vegetation (PDEP 2007). Limestone dissolution and the metabolic products of sulfate-reducing bacteria increases pH and also precipitates metals as sulfides, hydroxides and carbonates (Henrot and Wieder, 1990).

A study conducted in the Tara Mines in Ireland successfully demonstrated the capacity to treat metal and sulfate contaminated wastewater using natural ecosystem processes (Otte and O'Sullivan, 2006). The substrates used in the anaerobic wetlands at Tara Mines contained indigenous populations of sulfate-reducing bacteria (Otte and O'Sullivan, 2006). The systems were permanently flooded and this provided net anaerobic substrate conditions conducive to the chemical reduction of sulfate (SO4) to sulfide (S2-). This reaction occurred as the microorganisms assimilated sulfate in the absence of oxygen, thus reducing it to sulfide through the transfer of electrons produced by the simultaneous oxidation of the organic substrate. The sulfide ion is very unstable and it either reacts with other metals forming metal sulfides or with hydrogen forming hydrogen sulfide.

5.16.2.1 Effectiveness

Analysis of 73 sites in Pennsylvania indicated that aerobic and anaerobic wetlands are the best available technology for many post-mining ground water seeps with moderate pH. However, the treatment efficiency decreases for sites with net acidic discharges.

Some of the major improvements noted in previous studies inlclude:

- The effluent water after flowing through a two-celled aerobic wetland had increased pH (to 3.2), decreased acidity (43%), and decreased manganese (17%) (Hellier, 1996).
- In the Tara Mines case study, a constructed wetland treatment reduced up to 69% of the influent concentration of sulfate (Otte and O'Sullivan, 2006).
- 53 to 81 percent reduction in total suspended solids (and likely manganese) (USEPA, 2002a)
- No study was available to determine the reduction of TDS using aerobic or anaerobic wetlands.
- Sorption into organic material such as peats and soils decreased the manganese concentration by 7 percent (Brodie et al. 1988).

5.16.2.2 Cost

The average cost of creating a constructed wetland ranges from $1,250/ac/yr to $1,763/ac/yr. A study conducted in West Virginia evaluated the performance of six aerobic wetlands. The wetlands removed between 220.5 to 59,525 lb/year of acidity at the cost of $0.01/lb/yr to $3.51/lb/yr (Skousen and Ziemkiewicz, 2005).

5.16.3 Open Limestone Channels

This passive treatment method uses open ditches that are filled with cobble to small boulder sized limestone fragments. The water flows over and through the limestone which consists largely of the mineral calcite, or calcium carbonate ($CaCO_3$). Open limestone channels (OLC) may be the simplest passive treatment method and can be constructed in two ways. In the first method, a drainage ditch constructed of limestone collects contaminated acid mine drainage. The other method consists of placing limestone fragments directly in a contaminated stream. Dissolution of the limestone adds alkalinity (in the form of $CaCO_3$) and raises the pH in the water. This treatment method requires large quantities of limestone for long-term success (PDEP 2007).

The length of the channel and the channel gradient are varied for optimum performance, as they affect turbulence and the buildup of coatings (Skousan et. al., 1989). Optimum performance is observed on slopes exceeding 20%, where flow velocities keep precipitates in suspension while cleaning the limestone surface (Skousan et. al., 1989). A study indicated that the fewest problems occur in OLCs containing a 12 inch minimum size for the limestone (Ziemkiewizz and Brant, 1996).

5.16.3.1 Effectiveness

Long term use of OLC can maximize acidity treatment and metals removal. Three OLCs were installed in the Casselman River located between Boynton and Meyersdale, PA for restoring an AMD impaired river (Ziemkiewicz and Brant 1996). The mine seal at the headwaters of the tributary where the OLC was located discharged up to 6.1 tons of acid per day. The OLC established was a trapezoidal channel 1,500 feet long, 6 feet wide, and 2 feet deep installed on an 8% slope with 12 inch diameter limestone fragments. Over the two year period, the effluent acidity decreased by 47%, manganese decreased by 100% and sulfate by 28% (Ziemkiewicz and Brant 1996).

5.16.3.2 Cost

The average cost of treatment ranges between $0.012/lb/yr to $3.4/lb/yr for treating acidity (Skousen and Ziemkiewicz, 2005).

5.16.4 Anoxic Limestone Drains

An anoxic limestone drain (ALD) is a buried bed of limestone constructed to intercept subsurface mine water flow and prevent contact with atmospheric oxygen. Keeping oxygen out of the water prevents oxidation of metals and armoring of the limestone. An anoxic limestone drain can be considered a pretreatment step to increase alkalinity and raise pH before the water enters a constructed aerobic wetland.

Anoxic limestone drains also include the installation of limestone ponds at the upwelling of an AMD seep or underground discharge point. Limestone is placed in the bottom of the pond and the water flows upward through limestone adding $CaCO_3$ to the mine water. Under anoxic conditions, the limestone does not coat iron hydroxides as the ions do not precipitate. However, if a large amount of dissolved ferric and aluminum ions are present, clogging of limestone pores could occur. For waters with high sulfate (>1,500 mg/L) this method may not work efficiently as it may clog the pores (Skousan et. al. 1989). Therefore, the removal of metals with an ALD is not as efficient in some cases. The effluent pH of the treated water is typically between 6 and 7.5 using ALDs (Skousan et. al. 1989).

5.16.4.1 Effectiveness

In a study conducted in Maryland, the ALD was successful in reducing manganese by 58 percent, and successfully converted the effluent from net acidic to net alkaline (Skousan et. al. 1989). At the Brandy Camp Site in PA, an ALD treatment increased the pH from 4.3 to 6.0 and reduced the acidity of the water by 40 percent. However, no change was observed in the manganese concentration (Hellier, 1996).

5.16.4.2 Cost

In sizing an ALD, the amount of limestone that may dissolve during the design life must be accounted into the cost. In the 36 ALDs treatment studies conducted in Maryland, Ohio and West Virginia, a wide range of acid load was treated from 0 to 280,646 lb/year at the cost ranging from $0.003/lb/yr to $0.48/lb/yr (Skousen and Ziemkiewicz, 2005).

5.16.5 Vertical Flow Reactors

Vertical flow reactors were conceived as a way to overcome the alkalinity producing limitations of anoxic limestone drains and the large area requirements of compost wetlands. The vertical flow reactor consists of a treatment cell with an underdrained limestone base topped with a layer of organic substrate and standing water. The water flows vertically downward, usually from a pond, and through organic matter and limestone and is collected and discharged through a drainage system. The vertical flow reactor increases alkalinity by limestone dissolution and bacterial sulfate reduction (PDEP, 2007)

Compared to horizontal flow anaerobic wetlands, vertical flow systems greatly increase the interaction of water with organic matter and limestone. Acid water is allowed to settle 1 to 3 m over 0.1 to 0.3 m of organic compost, which is underlain by 0.5 to 1 m of limestone (Skousen et al. 1998). Below the limestone is a series of drainage pipes that convey the treated water into an aerobic pond where metals are precipitated. Sulfate reduction and iron sulfide precipitation occur in the compost treatment (Skousen et. al, 1998).

In the vertical flow reactor, the intent is usually to optimize sulfate reduction in the organic layer by causing water to flow through the organic matter. Eger found in his study that composted municipal waste and several other types of organic material supported reasonable levels of sulfate reduction (Eger, 1994). The lower pH condition, generally created due to limestone, enhances sulfate reduction rates.

5.16.5.1 Effectiveness

At the Brandy Camp site in PA, this method was utilized and after passage through the treatment system the effluent pH increased from 4.3 to 7.1. The system effectively increased alkalinity, but did not change manganese concentration (Hellier 1996). The sulfate reduction information was not available, although many studies have found that this treatment method enhances sulfate reduction rates (Hellier 1996, Skousen et. al, 1998).

5.16.5.2 Cost

Cost information for vertical flow reactors was not available.

5.16.6 Pyrolusite Process System

This is a patented process, which utilizes site-specific cultured microbes to remove manganese and sulfate from acid mine drainage. The treatment process consists of a shallow bed of limestone aggregate which is inoculated with specifically cultured microorganisms and inundated with acid mine drainage. After laboratory testing determines the proper combination, microorganisms are introduced to the limestone bed by inoculation ports located throughout the bed. The microorganisms grow on the surface of the limestone chips and oxidize the metal contaminants (such as iron and manganese) while etching away the limestone fragments, which in turn increases the alkalinity, raises the pH of water, and reduces armoring on the limestone fragments for an extended treatment lifespan. This process has been used on several acid mine sites in the western Pennsylvania with promising results (PDEP 2007). In most systems, a small wetland is located up gradient of the treatment bed to provide nutrients for the microorganisms (Gue et al. 2004).

5.16.6.1 Effectiveness

In one of the studies conducted in the Village of Mineral City, Carroll County, Ohio, AMD from the Linden mine was treated using the Pyrolusite process. The Linden system is located in a relative upstream position and the system's net-alkaline, low-metals discharge greatly assists in the top-down restoration approach being implemented within the Huff Run Watershed. It was determined that the use of Pyrolusite process reduced the acidity of the watershed by 63.6 percent and manganese by 91.86 percent. In the process, the pH was raised in excess of two 2 standard units, and high levels of alkalinity were generated from the limestone bed (Gue et. al. 2004).

5.16.6.2 Cost

The total cost for the construction of the Pyrolusite process system treating the Linden mine, was $22,181/acre and the inoculation cost for the same project was $ 6,621/acre. Therefore, the total cost for establishing a Pyrolusite process ranges from $28,802/acre to $35,000/acre.

5.17 Inlake Controls

For lakes experiencing high rates of phosphorus or manganese inputs from bottom sediments, several management measures are available to control internal loading. Hypolimnetic (bottom water) aeration involves an aerator air-release that can be positioned at a selected depth or at multiple depths to increase oxygen transfer efficiencies in the water column and reduce internal loading by establishing aerobic (with oxygen) conditions at the sediment-water interface.

Hypolimnetic aeration effectiveness in reducing phosphorus concentration depends in part on the presence of sufficient iron to bind with the phosphorus in the oxygenated waters. A mean hypolimnetic iron:phosphorus ratio greater than 3.0 is optimal to promote iron phosphate precipitation (Stauffer, 1981). The iron:phosphorus ratio in the sediments should be greater than 15 to bind phosphorus (Welch, 1992). Aeration of bottom waters will also likely inhibit the release of manganese from bottom sediments in lakes.

Phosphorus inactivation by aluminum addition (specifically aluminum sulfate or alum) to lakes has been the most widely-used technique to control internal phosphorus loading. Alum forms a polymer that binds phosphorus and organic matter. The aluminum hydroxide-phosphate complex (commonly called alum floc) is insoluble and settles to the bottom, carrying suspended and colloidal particles with it. Once on the sediment surface, alum floc retards phosphate diffusion from the sediment to the water (Cooke et al., 1993).

Artificial circulation is the induced mixing of the lake, usually through the input of compressed air, which forms bubbles that act as airlift pumps. The increased circulation raises the temperature of the whole lake (Cooke et al., 1993) and chemically oxidizes substances throughout the water column (Pastorak et al., 1981 and 1982), reducing the release of phosphorus and manganese from the sediments to the overlying water, and enlarging the suitable habitat for aerobic animals.

5.17.1 Effectiveness

Alum treatment is usually not cost effective for watershed areas less than 50 acres. In average, the removal efficiency of this treatment system is 90 percent for phosphorus and total suspended solids and 80-90 percent for heavy metals (ASCE, 2001).

If lake sediments are a significant source of phosphorus or manganese in the Crab Orchard Creek watershed, inlake controls would likely reduce the internal loading significantly. Without field measured data to quantify the internal load for each lake in the watershed, it is difficult to estimate the reduction in loading that may be seen with these controls.

5.17.2 Costs

In general, inlake controls are expensive. Hypolimnetic aerators may decrease internal loading of both phosphorus and manganese. The number and size of hypolimnetic aerators used in a waterbody depend on lake morphology, bathymetry, and hypolimnetic oxygen demand. Total cost for successful systems has ranged from $170,000 to $1.7 million (Tetra Tech, 2002). USEPA (1993) reports initial costs ranging from $340,000 to $830,000 plus annual operating costs of $60,000. System life is assumed to be 20 years.

Alum treatments are effective on average for approximately 8 years per application. Treatment cost ranges from $290/ac to $720/ac (WIDNR, 2003) including construction and maintenance. According to ASCE (2001), the construction cost of alum treatment systems is $250,000 and the maintenance cost varies from $25,000 to $50,000 per year.

Dierberg and Williams (1989) cite mean initial and annual costs for 13 artificial circulation projects in Florida of $440/ac and $190/ac/yr, respectively. The system life is assumed to be 20 years.

Table 5-23 summarizes the cost analyses for the three inlake management measures. The final column lists the annualized cost per lake surface area treated. The costs of alum treatment for Herrin New Reservoir are not included because this lake is not listed for phosphorus.

Table 5-23. Cost Comparison of Inlake Controls.

Control	Construction or Application Cost ($)	Annual Maintenance Cost
Crab Orchard Lake (6,965 acres)		
Hypolimnetic Aeration	340,000 - 830,000	$60,000
Alum Treatment	2,020,140 – 5,015,520	-
Artificial Circulation	1,323,540 – 3,065,040	$333,000
Carbondale City lake(510 acres)		
Hypolimnetic Aeration	340,000 - 830,000	$60,000
Alum Treatment	148,080 – 367,640	-
Artificial Circulation	97,020 – 224,670	$3,000
Campus Lake (271 acres)		
Hypolimnetic Aeration	340,000 - 830,000	$60,000
Alum Treatment	78,710 – 195,410	-
Artificial Circulation	51,570 – 119,420	$3,000
Marion Reservoir (1,019 acres)		
Hypolimnetic Aeration	340,000 - 830,000	$60,000
Alum Treatment	295,680 – 734,090	-
Artificial Circulation	193,720 – 448,610	$3,000
Herrin New Reservoir (221 acres)		
Hypolimnetic Aeration	340,000 - 830,000	$60,000
Artificial Circulation	2,020,140 – 5,015,520	$3,000

5.18 Infiltration Trench

This BMP is used in urbanized areas to reduce overall runoff volumes, reduce peak runoff flows, enhance ground water recharge, and remove certain soluble and particulate contaminants on small sites. A backfilled-trench system designed to collect runoff from a limited area and then provide subsurface storage and infiltration to ground water. Many designs are possible as long as adequate infiltration is assured. Pre-treatment of the runoff entering the trench is critical for maintaining the proper functioning of the system. Fine sediment such as sand sizes and smaller particles will clog the trench if it is not removed prior to reaching the infiltration zone of the trench. Pretreatment may include low-velocity grassed swales, filter strips and level spreaders. To reduce frost heaving during the winter and enhance overall infiltration, the system should ideally have a thick section of gravel to promote drainage.

Infiltration trenches are successful in removing suspended solids, particulate pollutants, coliform bacteria, organics, and some soluble forms of metals and nutrients from storm water runoff. This treatment method may be combined with detention ponds to treat stormwater from large storm events. Infiltration trenches typically utilize about 2 to 3 percent of the site draining to them, which is relatively small. In addition, infiltration trenches can fit into thin, linear areas.

5.18.1 Effectiveness

Infiltration trenches can be expected to remove up to 90 percent of sediments, metals, coliform bacteria, and BOD; and up to 60 percent of phosphorus from runoff (Schueler et. al., 1992). Pollutant removal efficiencies of 50-75 percent for total phosphorus and 75-99 percent for heavy metals are also reported (ASCE, 2001). Removal efficiencies may be improved by using stone aggregate and adding organic matter and loam to the subsoil. The stone aggregate should be washed to remove dirt and fines before placement in the trench. The addition of organic material and loam (soil composed of sand, silt, and clay in relatively even concentrations) to the trench subsoil may enhance metals removal through adsorption.

5.18.2 Cost

Infiltration trenches are somewhat expensive, when compared to other stormwater practices, in terms of cost per area treated. This BMP is most cost effective for small drainage areas. The 1993 construction cost for a relatively large infiltration trench (i.e., 6 feet deep and 4 feet wide with 2,400 cubic feet of volume) ranges from $8,000 to $19,000 (EPA, 1999a). A smaller infiltration trench (i.e., 3 feet deep and 4 feet wide with 1,200 cubic feet of volume) is estimated to cost from $3,000 to $8,500 (EPA 1999). It has been suggested that infiltration trenches function properly for 10 to 15 years before clogging occurs (ASCE, 2001). Based on the above examples, annual operation and maintenance costs would average $700 for the large trench and $325 for the small trench.

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly sited or maintained, infiltration trenches have a high failure rate. In general, maintenance costs for infiltration trenches are estimated at between 5 percent and 20 percent of the construction cost (ASCE, 2001). Table 5-24 summarizes the cost calculations for construction and maintenance of infiltration trenches.

Table 5-24. Cost Calculation for Infiltration Trench

Control	Construction or Application Cost	Annual Maintenance Cost	Total Cost ($/yr)
Infiltration Trench (Large – 6'X4')	$8,000-$19,000	$325 - $700	$1,125 - $2,600
Infiltration Trench (Small – 3'X4')	$3,000-$8,500	$325 - $700	$625 - $1,550

5.19 Grassed Swale

A grassed-lined shallow channel of variable width and depth designed for low to moderate slope areas across soils that drain well. The vegetation lining resists erosion and acts as a filter to trap particulate pollutants. Pollutants are also removed by infiltration through the soil. They are typically used to collect and direct runoff to larger BMPs (wet ponds, detention basins) for further biological and infiltration treatment. As an alternative, grassed swales may be used for detention and infiltration on land parcels that contribute a limited (small) volume of runoff. They are not appropriate for situations where runoff flow velocities are high (steep slopes). This BMP is most effective as a structure to collect and pass sheet flow runoff from small areas before it becomes erosive in character.

There are two general types of grassed swales - a dry swale, which provides water quality benefits by facilitating stormwater infiltration; and a wet swale, which uses residence time and natural growth to treat stormwater prior to discharge to a downstream surface waterbody. Dry swales are distinguished from a simple drainage/grassed channel by the addition of carefully selected, highly permeable soil (usually sandy loam), check dams, and an underdrain system. Only in special circumstances where natural soil and groundwater conditions consistently provide high infiltration will a traditional drainage/grassed channel design provide the same water quality benefits as a dry swale design. Wet swales are distinguished from the simple drainage/grassed channel by design features that maintain a saturated condition in soils at the bottom of the swale. The goal of a wet swale is to create an elongated wetland treatment system that treats stormwater through physical and biological action. Unlike dry swales, infiltration of stormwater is an undesirable condition in a wet swale because it would likely result in conditions detrimental to maintaining saturated soils necessary for supporting wetland vegetation.

5.19.1 Effectiveness

Both dry and wet swales demonstrate good pollutant removal, with dry swales providing significantly better performance for metals and total phosphorus (US DOT, 2007).

- Dry swales typically remove 65 percent of total phosphorus (TP), and between 80 and 90 percent of metals.
- Wet swale removal rates are closer to 20 percent of TP and between 40 and 70 percent of metals.
- The total suspended solids (TSS) removal for both swale types is typically between 80 and 90 percent.
- In general a well design grassed swale removes 70 percent of TSS, 30 percent of TP, and 50-90 percent of trace metals (ASCE, 2001)

5.19.2 Cost

Dry and wet swales are considered moderate and low-cost BMPs, respectively. The principal cost difference between the two swale designs arises from the cost of installing highly permeable soils and underdrain systems in a dry swale. The construction cost is $1,500 per acre served based on a nearly flat dry swale with a 10 ft bottom width, 3:1 side slopes, and a ponding depth of 1 ft. This cost estimate excludes real estate, design, and contingency costs. The cost of a dry/wet swale can also be inferred from the cost of a traditional grass swale, which typically ranges between $5 and $15 per linear foot depending on local conditions, swale dimensions, and the degree of internal storage (i.e., check dams) provided (Schueler et. al., 1992). The annual cost of maintaining grassed swale in Wiconsin is $0.58 to $1.25 per linear feet (US DOT, 2007). A life span of 10 years was assumed. Table 5-25 summarizes the cost calculations for grassed swales.

Table 5-25. Cost Calculation for Grassed Swales

Control	Construction or Application Cost (per linear Feet, LF)	Annual Maintenance Cost (per linear Feet, LF)	Total Cost ($/LF/yr)
Swale	$5- $15	$0.58 - $1.25	$1.08 - $2.75

5.20 Streambank and Shoreline Erosion BMPs

Reducing streambank and lake shore area erosion will reduce phosphorus and manganese loading and improve temperature and dissolved oxygen conditions by allowing vegetation to establish. The filter strips (Section 5.7), grassed waterways (Section 5.8), riparian areas (Section 5.9), and the agricultural BMPs that reduce erosion and the volume of runoff (sections 5.5, 5.6, 5.10) or prevent cattle access (Section 5.14) will all provide some level of streambank and lake shore erosion protection. Costs associated with BMPs that offer secondary benefits to streambank and lake erosion are discussed separately for each BMP in sections 5.5 through 5.10 and 5.14.

Streambanks and lake shores in the watershed should be inspected for signs of erosion. Banks showing moderate to high erosion rates (indicated by poorly vegetated reaches, exposed tree roots, steep banks, etc.) can be stabilized by engineering controls, vegetative stabilization, and restoration of riparian areas. The effects of peak flows and velocities from runoff areas can be mitigated by infiltration in grassed waterways and passage of runoff through filter strips.

The effectiveness and costs of streambank and shore line erosion projects is site specific and highly variable. A shoreline erosion study of Lake Bloomington in central Illinois was conducted (Midwest Streams Inc., 2005). The study recommends Stone Toe Protection (STP) applied along the eroding sections to provide stability and prevent additional recession of the bank line. The estimated STP cost for high erosion rate was $7,000 per year. Assuming a useful life of 50 years, the STP costs $3.25/yr per pound of soil saved.

5.21 Stream Restoration

Stream restoration activities usually focus on improving aquatic habitat, but can also be used to increase the amount of re-aeration from the atmosphere to the water. A proper restoration effort will involve an upfront design specific to the conditions of the reach being restored. Stagnant, slow moving, and deep waters typically have relatively low rates of re-aeration. Restorations aimed at increasing re-aeration must balance habitat needs (which include pools of deeper water) with sections of more shallow, faster flowing water. Adding structures to increase turbulence and remove excessive tree fall may also be incorporated in the restoration plan.

The effectiveness and costs of stream restorations are site specific and highly variable. Watershed planners and water resource engineers should be included in the decision making process to help determine the reaches where restoration will result in the most benefit for the watershed as a whole.

6.0 PRIORITIZATION OF IMPLEMENTATION

This section of the report summarizes the BMPs discussed in Section 5.0 in terms of effectiveness to help prioritize their implementation.

6.1 Summary of BMPs for Agricultural Land Sources

Agricultural land pollutant sources include crop production areas and animal operations. The BMPs that are applicable to agricultural land sources are summarized in Table 6-1 and the anticipated reductions for each of the main pollutants are also included for each BMP. If a BMP is not expected to significantly reduce loading of a specific parameter, the reduction for that BMP/parameter is labeled not applicable ("na"). If a BMP is expected to reduce pollutant loading, but no studies were found to quantify the reduction, then the reduction is labeled "unknown".

Table 6-1. Summary of BMPs Reducing Impairments Due to Agricultural Land Sources.

BMP	Phosphorus Reduction (percent)	BOD_5 Reduction (percent)	Manganese Reduction (percent)	Fecal Coliform Reduction (percent)	Additional Benefits for Stream Health and Dissolved Oxygen Impairments
Nutrient Management Plans	20 to 50	na	na	na	Reducing nutrient loads to streams may reduce algal growth and related dissolved oxygen problems.
Conservation Tillage	68 to 76	na	50 to 90	na	Reduces runoff losses by 69 percent, which may reduce rates of streambank erosion.
Cover Crops	70 to 85	na	90	na	Reduces runoff losses by 50 percent, which may reduce rates of streambank erosion.
Filter Strips	65	unknown	65	55 to 87	Slows rates of runoff and may reduce volume via infiltration. May reduce rates of streambank erosion.
Grassed Waterways	30	unknown	68	5	Slows rates of runoff and may reduce volume via infiltration. May reduce rates of streambank erosion.
Riparian Buffers (30 ft to 200 ft wide)	25 to 80	62	70 to 90	34 to 87	Slows runoff and volume via infiltration. Protects stream channel from erosion and canopy disturbance.
Constructed Wetlands	42	59 to 80	53 to 81	92	Slows runoff and may reduce quantity via infiltration, evaporation, and transpiration.
Manure Composting Process	na	unknown	68	99	Stabilized manure degrades more slowly and not consume oxygen as quickly as conventional manure. Application of composted manure improves soil infiltration and may reduce runoff volumes by 56 percent, potentially reducing rates of streambank erosion.
Feeding Strategies	30 to 50	na	na	na	Feeding strategies that reduce the phosphorus content of manure may improve dissolved oxygen conditions by reducing eutrophication in streams and lakes.
Alternative Watering Systems with Cattle Exclusion from Streams	15 to 49	unknown	unknown	29 to 46	Prevents streambank trampling and therefore decreases loads of manganese to the stream. Reduces direct deposition of manure into stream channel, which reduces loads of BOD_5, nutrients, and fecal coliform.
Grazing Land Management	49 to 60	unknown	unknown	40 to 90	Increased vegetative ground cover will reduce soil erosion, associated manganese and improve infiltration which should reduce runoff volumes. Improvements in dissolved oxygen concentrations should occur as a result of lower concentrations of BOD_5 in the runoff

6.2 Summary of BMPs for Coal Mining Operations

About four percent of the total watershed area in Crab Orchard Creek is mined land and approximately 440 acres of mined land are identified as requiring reclamation (WCSWCD, 2007). The Marion County USDA estimated that about 1,171 acres of abandoned mined land contributes impairment in the watershed. These mines contribute to both the pH and manganese impairments. The BMPs that are applicable to mitigating the impacts of AMD are summarized in Table 6-2 and include the anticipated reductions for each BMP and parameter. If a BMP is not expected to significantly reduce loading of a specific parameter, the reduction for that BMP is then labeled not applicable ("na"). If a BMP is expected to reduce pollutant loading, but no studies were found to quantify the reduction, then the reduction is labeled "unknown".

Table 6-2. Summary of BMPs Reducing Impairments Due to Abandoned Mine Lands.

BMP	Phosphorus Reduction (percent)	Manganese Reduction (percent)	Acidity Reduction, pH (percent)	Sulfate Reduction (percent)	Additional Benefits for Sediment and Dissolved Oxygen Impairments
Land Reclamation	unknown	unknown	unknown	unknown	Reducing nutrient loads to streams may reduce algal growth and related dissolved oxygen problems.
Aerobic/Anaerobic Wetlands	42	17 - 81	43	69	53 to 81 percent reduction in TDS. Slows runoff and may reduce quantity via infiltration, evaporation, and transpiration.
Open Limestone Channels	na	100	47	28	Significantly convert from net acidity to net alkalinity.
Anoxic Limestone Drain	na	0 - 58	40	na	Significantly convert from net acidity to net alkalinity.
Vertical Flow Reactor	na	0	65	unknown	Produces net alkalinity, enhances sulfate reduction.
Pyrolusite Process	na	92	64	unknown	Produces net alkalinity and low-metal discharge.

6.3 Summary of BMPs for Urban Land Sources.

Urban land sources of pollutants include urban runoff (transport of sediments and lawn fertilizers), point source discharges (CSOs and sewer treatment plant discharges), onsite wastewater treatment system discharges, and domestic pet waste. Based on the available data, urban land contributes to the metal loading (especially manganese), phosphorus, and suspended solids loads. BMPs that will help to reduce impairments from urban land sources are summarized in Table 6-3 and include the anticipated reductions for each BMP and parameter. If a BMP is not expected to significantly reduce loading of a specific parameter, the reduction is labeled not applicable ("na"). If a BMP is expected to reduce pollutant loading, but no studies were found to quantify the reduction, then the reduction is labeled "unknown."

Table 6-3. Summary of BMPs Reducing Impairments Due to Urban Land Sources.

BMP	Phosphorus Reduction (percent)	BOD_5 Reduction (percent)	Manganese Reduction (percent)	Fecal Coliform Reduction (percent)	Additional Benefits for Stream Health and Dissolved Oxygen Impairments
Disinfection of primary effluent from STPs	unknown	na	na	unknown	the use of this BMP should result in a substantial reduction in fecal coliform loading
Control of CSOs	unknown	na	na	unknown	the use of this BMP should result in a substantial reduction in fecal coliform loading
Maintenance of onsite septic systems	100	6 - 35	na	100	-
Infiltration trench	50 -75	90	75 - 99	90	up to 90 percent removal of sediments and organic material
Grassed swales	20 - 65	unknown	40 - 90	unknown	Typical TSS removal are 70 – 90 percent

6.4 Summary of BMPs for Stream and Lake Sediment Related Sources

Erosion in streams and lakes is a great concern as it contributes to the overall water quality degradation in the watershed. In addition, sediment transported by streams (as a result of erosion) accumulates in lakes as it is deposited onto the lake bottom. Phosphorus and manganese are released from lake bottom sediments as these pollutants typically adhere to the fine sediment particles. Marion County has estimated that approximately 8,800 acres of cropland in the watershed is highly erodible. The average sedimentation rate is 319,200 tons/year and the total deposited sediments in creeks and lakes in the Crab Orchard Creek watershed are 104,000 tons/year (WCSWCD, 2007). The BMPs that are applicable to reduce impairments related to sediments are summarized in Table 6-4 and include the anticipated reductions for each BMP and parameter. If a BMP is not expected to significantly reduce loading of a specific parameter, then the reduction is labeled not applicable ("na"). If a BMP is expected to reduce pollutant loading, but no studies were found to quantify the reduction, then the reduction is labeled "unknown."

Table 6-4. Summary of BMPs Reducing Impairments Related to Sediments.

BMP	Phosphorus Reduction (percent)	BOD_5 Reduction (percent)	Manganese Reduction (percent)	Fecal Coliform Reduction (percent)	Additional Benefits for Stream Health and Sediment Impairments
Inlake Controls	90	unknown	80 - 90	na	May have impacts on DO balances downstream of water release structures. TSS removal of 90 percent
Streambank and Shoreline Erosion BMPs	unknown	unknown	unknown	na	Improves temperature and dissolved oxygen conditions by allowing vegetation to establish
Stream Restoration	unknown	unknown	unknown	na	Improves aquatic habitat and increases the amount of re-aeration from the atmosphere to the water

7.0 MEASURING AND DOCUMENTING PROGRESS

The Illinois EPA obtains federal funds through the U.S. Environmental Protection Agency (USEPA) to conduct various monitoring programs for streams and lakes. Some of the programs available for Crab Orchard Creek watershed are described below.

7.1 Ambient Water Quality Monitoring Network

Illinois EPA operates an Ambient Water Quality Monitoring Network (AWQMN) consisting of 213 fixed stations to support surface water chemistry data needs. The water column samples are collected every six weeks. A total of 55 universal parameters including field pH, temperature, specific conductance, dissolved oxygen, suspended solids, nutrients, fecal coliform bacteria, and total and dissolved heavy metals are analyzed. Water quality samples are currently being collected at two sites on Crab Orchard Creek every six weeks. One site is upstream of Crab Orchard Lake and the other site is downstream of the lake (Shasteen, 2007).

7.2 Intensive River Basin Surveys

Intensive river basin surveys are executed on a five-year rotational basis in cooperation with the Illinois Department of Natural Resources (IDNR). The sample stations are selected based on various criteria where exhaustive or missing information is required. Data collected includes water quality, stream discharge, biological (fish and macro invertebrate) and habitat information. Fish tissue contaminant and sediment chemistry sampling are also conducted to screen for the accumulation of toxic substances. Samples are collected primarily in summer season in the month of June, July, and August. Sometimes, if the stream goes dry, a small number of samples are collected. Water chemistry, sediment chemistry and biological samples are collected during this time. The goal is to collect water chemistry samples before, during and after the collection of biological samples on the stream. The water quality monitoring of Big Muddy River Basin is due occur in 2008. As part of this program, Crab orchard Creek will be sampled (Shasteen, 2007).

7.3 Facility-Related Stream Surveys

Illinois EPA conducts facility-related stream surveys that collect samples on upstream and incrementally downstream from municipal and industrial wastewater treatment facilities. These surveys typically result in the collection of macroinvertebrate, water chemistry, stream flow and habitat data. This program primarily checks discharges coming from the treatment plant by surveying the quality of water downstream of a municipal wastewater treatment plant. The survey is generally conducted during the months of August and September. Samples are collected at one site upstream of the treatment plant and at 2-3 sites downstream of the treatment plant to determine the presence or extent of the facilities' impact on the receiving strem. Samples are collected on Crab Orchard Creek to monitor the Marion Wastewater Treatment Plant and Carbondale Wastewater Treatment Plant discharges (Shasteen, 2007).

No sampling has taken place on Piles Fork and Little Crab Orchard Creek after 1995. The former Koppers Wood-Treating site, located in the northeast corner of Carbondale, treated railroad crosses ties, utility poles and other wood products. When the plant was operating, handling and storage of chemicals caused spills, resulting in the pollution of soils and groundwater from several creeks including Piles Fork. This Piles Fork cleanup site may possibly be sampled in the spring of 2008 (USEPA, 2007).

7.4 Ambient Lake Monitoring Program

Illinois EPA conducts an Ambient Lake Monitoring Program (ALMP) annually in 50 lakes. This is an intensive monitoring program that collects samples to analyze several water quality parameters. Certain core lakes are monitored every fourth year to establish long-term trends from the monitoring database. The data is summarized annually and distributed to managers of related lake resources. A total of three samples are collected in each lake. The first sample is collected in deeper portions of the lake, near the dam and at 2 ft from the bottom of the lake. The second and third samples are collected at the mid point and upper end point of the lake. For larger lakes such as Crab Orchard Lake, four sites are sampled for water quality monitoring (Bundren, 2007).

7.5 Volunteer Lake Monitoring Program

The Volunteer Lake Monitoring Program (VLMP) serves as an educational program for citizens to learn about lake ecosystems, as well as a cost-effective method of gathering fundamental information on Illinois inland lakes. The VLMP utilizes funds provided by the federal Clean Water Act and the state-funded Conservation 2000 Program to achieve its objectives. Under this program, several water quality parameters are monitored in Crab Orchard Lake, Carbondale City Lake and Campus Lake (Nickel, 2007).

Continuous monitoring of nutrients, fecal coli form and other water quality parameters in the impaired lakes of Crab Orchard Creek watershed is highly desired. In addition to the above mentioned state-wide programs, additional data collection on the following parameters shall be useful in evaluating the effectiveness of the BMPs discussed in Section 5.0:

- Sampling of fecal coliform data at a temporal interval of five-samples-per-month (as stated in the Illinois Water Quality Standards) during the months of May to October in Crab Orchard Creek, Piles Fork, and Little Crab Orchard Creek.
- Monitoring of septic systems that discharge to tile drains which are potential fecal coliform sources.
- Inspection of onsite wastewater treatment systems in Carbondale and Marion to determine rates of failure and approximate contribution to the lake.
- Leak testing and inspecting the centralized wastewater system including sewer pipes, lagoon liner, and effluent pipeline.
- Continuous sampling of nitrate, total phosphorous, manganese and other water quality parameters should be performed during both dry and wet seasons.

Measuring the effects of the BMPs on water quality will require continued sampling of water quality parameters in lakes and tributary streams in the watershed over the next several years. Samples should be taken at specific interval stations upstream and downstream of the project sites. Measurements should continue for a minimum of two monitoring cycles to document progress and direct future management strategies.

8.0 REASONABLE ASSURANCE

USEPA requires a reasonable assurance to demonstrate that each waste load allocation and load allocation in the Crab Orchard watershed TMDL will be implemented. For point source regulation, it is required to demonstrate a reasonable assurance by procedures that ensure that enforceable NPDES permits will be issued expeditiously to implement applicable waste load allocations for point sources. For nonpoint sources, it is required to demonstrate reasonable assurance by specific procedures and mechanisms that ensure load allocations for nonpoint sources will be implemented for that waterbody. Specific procedures and mechanisms that may provide reasonable assurance for non point sources include state, federal, local ordinance, performance bonds, contract and cost-share agreement, site-specific or watershed-specific voluntary actions, and compliance audits of best management practices. As a major portion of the watershed falls under Williamson County and Jackson County, the following subsections describe some specific information for these counties.

Two of the incentive programs discussed below were administered under the 2002 Farm Bill, which expired September 30, 2007. The Conservation Reserve Program will continue to pay out existing contracts, but new enrollments will not be allowed until the bill is reinstated. No official date of reinstatement has been announced. Though the Environmental Quality Incentives Program was also part of the 2002 Farm Bill, it was extended beyond fiscal year 2007 by the Deficit Reduction Act of 2005 (Congressional Research Reports for the People, 2007).

8.1 Environmental Quality Incentives Program (EQIP)

Several cost share programs are available to farmers and landowners who voluntarily implement resource conservation practices in the Crab Orchard Creek watershed. The most comprehensive is the NRCS Environmental Quality Incentives Program (EQIP), which offers cost sharing, and incentives to farmers statewide who utilize approved conservation practices to reduce pollutant loading from agricultural lands.

- Use of vegetated filter strips will earn the farmer $100/ac/yr for three years (up to 50 acres per farmer).
- The program will also pay 60 percent of the cost to construct grassed waterways, riparian buffers, and windbreaks.
- Installation of drainage control structures on tile outlets will earn the farmer $5/ac/yr for three years for the affected drainage area as well as 60 percent of the cost of each structure.
- Sixty percent cost for constructing fences, control access points, spring and well development, pipeline, and watering facility costs are covered by the program.
- Prescribed grazing practices will earn the farmer $10/ac/yr for three years (up to 200 acres per farmer).

Williamson County has spend around $350,000-$40,000 in the last four years assisting cost share practices that include grassed waterways, water pipelines and cost-share programs made under the forestry management plan in the past year (Korando, 2007).

Jackson County assists cost share programs for practices like fencing animals out of water ways, seeding cropland to pasture or hay land, filter strips, and grassed waterways. The county is trying to change the cost share to a flat fee, which will pay 60-75% of the cost share. If the rates of installing the BMP are higher, the cost share is 40 %. (Martin, 2007).

In order to participate in the EQIP cost share program, all BMPs must be constructed according to the specifications listed for each conservation practice.

The specifications and program information can be found online at:
http://www.il.nrcs.usda.gov/programs/eqip/cspractices.html.

8.2 Wetlands Reserve Program (WRP)

The Wetlands Reserve Program (WRP) is a voluntary program under the Natural Resources Conservation Service (NRCS). It provides technical and financial assistance to eligible landowners to restore, enhance, and protect wetlands. Landowners have the option of enrolling eligible lands through permanent easements, 30-year easements, or restoration cost-share agreements. This program offers landowners an opportunity to establish, at minimal cost, long-term conservation and wildlife habitat enhancement practices and protection. WRP has an acreage enrollment limitation rather than a funding limit. Congress determines how many acres can be enrolled in the program and funding is somewhat flexible. The NRCS estimates program-funding needs based on the national average cost per acre.

Under *permanent easement*, the U.S. Department of Agriculture (USDA) pays up to 100 percent of the cost of restoring the wetland. USDA also pays up to 75 percent of restoration costs through *30-Year Easement.* USDA pays up to 75 percent of the cost of the restoration activity under *Restoration Cost-share Agreement* (generally for a minimum of 10 years) to re-establish degraded or lost wetland functions and values.

The specifications and program information can be found online at:
http://www.nrcs.usda.gov/programs/wrp/

8.3 Conservation Reserve Program (CRP)

The USDA Farm Service Agency's (FSA) Conservation Reserve Program (CRP) is a voluntary program that is available to agricultural producers to help them safeguard environmentally sensitive land. Producers enrolled in CRP plant long-term, resource-conserving covers to improve the quality of water, control soil erosion and enhance wildlife habitat. The FSA provides participants with rental payments and cost-share assistance. The duration of contract is between 10 and 15 years. To be eligible for CRP enrollment, a producer must have owned or operated the land for at least 12 months prior to close of CRP sign-up period. Cost sharing is provided to establish the vegetative cover practices.

Williamson County sends a newsletter to sign up for the program four to six times in a year. The broadcasting is also done via radio and newspaper.

Jackson County provides cost share for changing cover from cropland to grass and trees, filter strips, grassed waterways, riparian buffers and conservation cover. The county provides 50 percent cost-share for installing filter strips (Martin, 2007).

More information about this program is available online at:
http://www.nrcs.usda.gov/programs/crp/

8.4 Conservation 2000

This program is a state-supported initiative to protect natural resources by implementing strategies for maintaining the viability of Illinois' soil and water resources into the 21st century and beyond. Conservation 2000 provides funding for various agriculture-related programs. In 1995 the Illinois General Assembly passed the Conservation 2000 bill providing $100 million in funding over a 6-year period for the promotion of conservation efforts. In 1999, legislation was passed to extend the program through 2009.

General information concerning the Conservation 2000 Program can be found online at:
http://www.agr.state.il.us/Environment/conserv/

8.4.1 Conservation Practices Program (CPP)

The Agriculture Department distributes funding for the cost-share program to Illinois' soil and water conservation districts (SWCDs), which prioritize and select projects. Construction costs are divided between the state and landowners. Payments of up to 60 percent of initial costs are paid through the local SWCDs to cost share cover crops, grassed waterways, no-till systems, and pasture planting. Practices funded through this program must be maintained for at least 10 years.

In Williamson County, a 60 percent cost share is approved by the local district to cost share filter strips, diversion, grade stabilization structure, grassed waterway, pasture and hay land planting, water and sediment control practices. About $25,000 to $30,000 are utilized yearly in cost-share programs (Korando, 2007).

Jackson County supports the generation of cropland along stream banks. It supports building grassed waterways, terraces and dry dams (Martin, 2007).

More information concerning the Conservation Practices Program can be found online at:
http://www.agr.state.il.us/Environment/conserv/

8.4.2 Streambank Stabilization Restoration Program

Conservation 2000 also finances a streambank stabilization and restoration program aimed at re-establishing highly eroding streambanks. Research efforts are also funded to assess the effectiveness of vegetative and bioengineering techniques.

In Williamson County, this program is available at 75 percent cost-share and is approved by IDOA-Bureau of Land and Water Resources.

In Jackson County, riffles and longitudinal toe rock are installed to restore the streambanks and prevent the down cutting of the drainage way into the stream. Riffles include 2 ft tail rock used to back up water that acts as a natural rifle above mud and prevents erosion from the bottom of the stream. Longitudinal toe rock protects the bottom toe of slope from erosion (Martin, 2007).

More information about this program is available online at:
http://dnr.state.il.us/orep/c2000/grants/proginfo.asp?id=20

8.4.3 Illinois Clean Lakes Program

The Illinois Clean Lakes Program (ICLP) is a financial assistance program that preserves lake owners' interest and commitment to long-term, comprehensive lake management. Data generated from these monitoring studies are used to recommend lake protection/restoration practices for future implementation (Phase II).

Up to 60 percent of the Phase I study cost is provided by ICLP with the lake owner and/or other sources providing the remaining portion. A maximum fund of $75,000 is available for any Phase I project. Up to 50 percent of the Phase II study cost is provided by the state ICLP for the lake owner who has completed the Phase I study. A maximum fund of $300,000 is available for any Phase II project. The volunteers would collect samples fives times a year in two week cycle. Carbondale City Lake is under this program (Bundren, 2007).

More information about this program is available online at:
http://www.epa.state.il.us/water/conservation-2000/iclp.html

8.4.4 Sustainable Agriculture Research and Education Grant Program

The Sustainable Agricultural Research and Education (SARE) Grant Program funds research, education, and outreach efforts for sustainable agricultural practices. Private landowners, organizations, educational, and governmental institutions are all eligible for participation in this program.

More information concerning the Sustainable Agricultural Grant Program can be found online at:
http://www.sare.org/grants/

8.5 Nonpoint Source Management Program (NSMP)

The Illinois Environmental Protection Agency (IEPA) receives federal funds through Section 319(h) of the Clean Water Act to help implement Nonpoint Source Pollution Management Program. The purpose of the program is to work cooperatively with local units of government and other organizations towards a mutual goal of protecting the quality of water in the state of Illinois by controlling non point source pollution. The program emphasizes funding for implementing cost-effective, corrective, and preventative BMPs on a watershed scale. It also provides funding for the demonstration of new and innovative BMPs on a non-watershed scale as well as for the development of information/education non point source (NPS) pollution control programs.

Section 319(h) funds are awarded for the purpose of implementing approved NPS management projects. The funding is directed toward activities that result in the implementation of appropriate BMPs for the control of NPS pollution or to enhance the public's awareness of NPS pollution. Applications are accepted June 1 through August 1. The NSMP program is not utilized in Williamson County or Jackson county.

More information about this program is available online at:
http://www.epa.state.il.us/water/financial-assistance/non-point.html

8.6 Agricultural Loan Program

The Agricultural Loan Program offered through the Illinois State Treasury office provides low-interest loans to assist farmers who implement soil and water conservation practices. These loans will provide assistance for the construction, equipment, and maintenance costs that are not covered by cost share programs.

The following are the major types of loans available:

- Purchase and conservation improvement loans of real estate are provided up to a ceiling of $200,000 with 5.37% interest rate and repayment period of 40 years. Farmers involved in active farming operations are qualified for this loan. The county also provides guaranteed loan programs that are processed by the terms of a bank with FSA giving 90% guarantee (Reynolds, T. 2007).

- Direct operating loan (machinery, operation, improvements, plant crop, seeds etc.) of $200,000 with a 7 year repayment period for various farming operations. The program is also provided in collaboration with a bank (Reynolds, 2007).

More information about this program is available online at:
http://www.state.il.us/TREAS/ProgramsServices.aspx

8.7 Illinois Conservation and Climate Initiative (ICCI)

The Illinois Conservation and Climate Initiative is a joint project of the State of Illinois and the Delta Pollution Prevention and Energy Efficiency (P2/E2) Center that allows farmers and landowners to earn carbon credits when they use conservation practices. These credits are then sold to companies or agencies that are committed to reducing their greenhouse gas emissions. Grass plantings (applicable to filter strips and grassed waterways) earns 0.75 mt/ac/yr and trees planted at a density of at least 250 stems per acre earn somewhere between 3.5 to 5.4 mt/ac/yr, depending on the species planted and age of the stand. Conservation tillage earns 0.5 metric tons (1.1 US ton) of carbon per acre per year (mt/ac/yr). It requires maintaining crop rotation, which is less feasible for the southern Illinois.

Carbon credits are currently selling at around $2.50 per mt. Current exchange rates are available online at http://chicagoclimatex.com. Administrative fees of $0.14/mt plus 8 percent are subtracted from the sale price.

Program enrollment occurs through the P2/E2 Center which can be found online at http://p2e2center.org/. The requirements of the program are verified by a third party before credits can be earned.

More information about carbon trading can be found online at:
http://illinoisclimate.org/

Table 8-1 and Table 8-2 summarize the assistance programs available in the Crab Orchard Creek watershed. Table 8-3 provides contact information for local soil and water conservation districts.

Table 8-1. Summary of Assistance Programs Available for Farmers in the Crab Orchard Creek Watershed.

Assistance Program	Program Description	Contact Information
NSMP	Provides grant funding for educational programs and implementation of nonpoint source pollution controls.	Illinois Environmental Protection Agency Bureau of Water Watershed Management Section, Nonpoint Source Unit P.O. Box 19276 Springfield, IL 62794-9276 Phone: (217) 782-3362
Agricultural Loan Program	Provides low-interest loans for the construction and implementation of agricultural BMPs. Loans apply to equipment purchase as well.	Office of State Treasurer Agricultural Loan Program 300 West Jefferson Springfield, Illinois 62702 Phone: (217) 782-2072 Fax: (217) 522-1217
NRCS EQIP	Offers cost sharing and rental incentives to farmers statewide who utilize approved conservation practices to reduce pollutant loading from agricultural lands. Applies to filter strips, grassed waterways, riparian buffers, and conservation tillage.	Contact local SWCD (Table 8-3)
NRCS WRP	Offers cost sharing at minimal cost for long-term conservation and wildlife habitat enhancement practices and protection to restore wetland	
Conservation 2000 CPP	Provides up to 60 percent cost share for several agricultural BMPs: cover crops, filter strips, grassed waterways.	
Conservation 2000 Streambank Stabilization Restoration Program	Provides 75 percent cost share for establishment of riparian corridors along severely eroding stream banks. Also provides technical assistance and educational information for interested parties.	
SARE	Funds educational programs for farmers concerning sustainable agricultural practices.	
FSA CRP	Offsets income losses due to land conversion by rental agreements. Targets highly erodible land or land near sensitive waters. Provides up to 50 percent of the upfront cost to establish vegetative cover and $185/ac/yr for up to 15 years for converted land. Supports cover from cropland to grass and trees, filter strips, grass way, riparian buffer and conservation cover	
Local SWCD	Provides educational newsletters that advertise agriculture business and articles on conservation practices by SWCD, NRCS , FSA.	
ICCI	Allow farmers to earn carbon-trading credits for use of conservation tillage, grass, and tree plantings.	

Table 8-2. Assistance Programs Available for Agricultural BMPs.

BMP	Cost Share Programs and Incentives
Education and Outreach	Conservation 2000 Streambank Stabilization Restoration Program NSMP Local SWCD
Nutrient Management Plan	EQIP: $10/ac for one year, 400 ac. max.
Conservation Tillage	EQIP: $15/ac for three years, 400 ac. max. ICCI: earns 0.5 mt/ac/yr of carbon trading credit
Cover Crops	CPP: cost share of 60 percent
Filter Strips	EQIP: $100/ac for three years, 50 ac. max. CPP: 60 percent of construction costs CRP: 50 percent of the upfront cost to establish vegetative cover and $185/ac/yr for up to 15 years ICCI: earns 0.75 mt/ac/yr of carbon trading credit for each acre planted
Grassed Waterways	EQIP: 60 percent of construction costs CPP: 60 percent of construction costs CRP: 50 percent of the upfront cost to establish vegetative cover and $185/ac/yr for up to 15 years ICCI: earns 0.75 mt/ac/yr of carbon trading credit for each acre planted
Land Retirement of Highly Erodible Land or Land Near Sensitive Waters	CRP: 50 percent of the costs of establishing vegetative cover and cash incentive of $185/ac/yr for 15 years ICCI: earn between 0.75 and 5.4 mt/ac/yr of carbon trading credit depending on species planted
Restoration of Riparian Buffers	EQIP: 60 percent of construction of costs CRP: 50 percent of the costs of establishing vegetative cover and cash incentive of $185/ac/yr for 15 years ICCI: earn between 0.75 and 5.4 mt/ac/yr of carbon trading credit depending on species planted

Note: Cumulative cost shares from multiple programs will not exceed 100 percent of the cost of construction.

Table 8-3. Contact Information for Local Soil and Water Conservation Districts.

Organization Name	Address	Contact Numbers
Jackson County SWCD	1213 N. 14th Street, Murphysboro, IL 62966	Phone: 618/684-3064 (Ext. 3) Fax: 618/684-3980
Williamson County SWCD	502 Comfort Drive, Suite C, Marion, IL 62959	Phone: 618/993-5396 Fax: 618/993-3014

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9.0 IMPLEMENTATION TIMELINE

This implementation plan for the impaired waterbodies in Crab Orchard Creek watershed defines a phased approach for achieving the water quality standards (Figure 9-1). Ideally, implementing control measures on nonpoint sources of loading will be based on voluntary participation which will depend on 1) the effectiveness of the educational programs for farmers, landowners, and owners of onsite wastewater systems, and 2) the level of participation in the programs. This section outlines a schedule for implementing the control measures and determining whether or not they are sufficient to meet the water quality standards.

Phase I of this implementation plan should focus on educating farm owners about the benefits of agricultural BMPs on crop yield, soil quality, and water quality as well as cost share programs available in the watershed. It is expected that initial education through public meetings, mass mailings, TV and radio announcements, and newspaper articles could be achieved in less than 6 months. As described in Section 8.0, assistance with educational programs is available through the following agencies: the Illinois Department of Agriculture Conservation 2000 Streambank Stabilization Restoration Program, the Illinois Department of Agriculture Sustainable Agriculture Grant Program (SARE), the Illinois Environmental Protection Agency Nonpoint Source Management Program (NSMP), and the local Soil and Water Conservation Districts. During this phase, the sewage treatment plants may be asked to submit total phosphorus data to IEPA to determine if a disinfection exemption is still appropriate.

Phase II of the implementation schedule will involve voluntary participation of farmers in BMPs such as conservation tillage, manure composting, the use of filter strips, constructed wetlands, grassed waterways, riparian buffers, alternative watering systems and fencing of animals. The local Natural Resources Conservation Service office will be able to provide technical assistance and cost share information for these BMPs. In addition, initial inspections maintenance and repair of onsite wastewater treatment systems and instituting the nine minimum controls for CSOs may begin. Continued monitoring of water quality in the watershed should occur throughout this phase, which will likely take one to three years.

If pollutant concentrations measured during Phase II monitoring remain above the water quality standards, Phase III of the implementation plan will be necessary. The load reductions achieved during Phase II should be estimated by 1) identifying the areas where BMPs are in use, 2) calculating the load reductions from these BMPs, and 3) determining the impacts on pollutant concentrations measured before and after Phase II implementation. If BMPs result in decreased pollutant concentrations and there is the option of including additional areas of incorporation in the implementation process, further efforts to include more stakeholders in the voluntary program will be needed. If the Phase II BMPs are not having the desired impacts on pollutant concentrations, or additional areas of incorporation are not available, supplemental BMPs will be needed. If the preliminary controls are not effective, the more expensive, long-term measures should be implemented. If water quality standards at point source receiving and downstream segments are not being met, sewage treatment plants may be required to add disinfection. If required, this phase may last five to ten years.

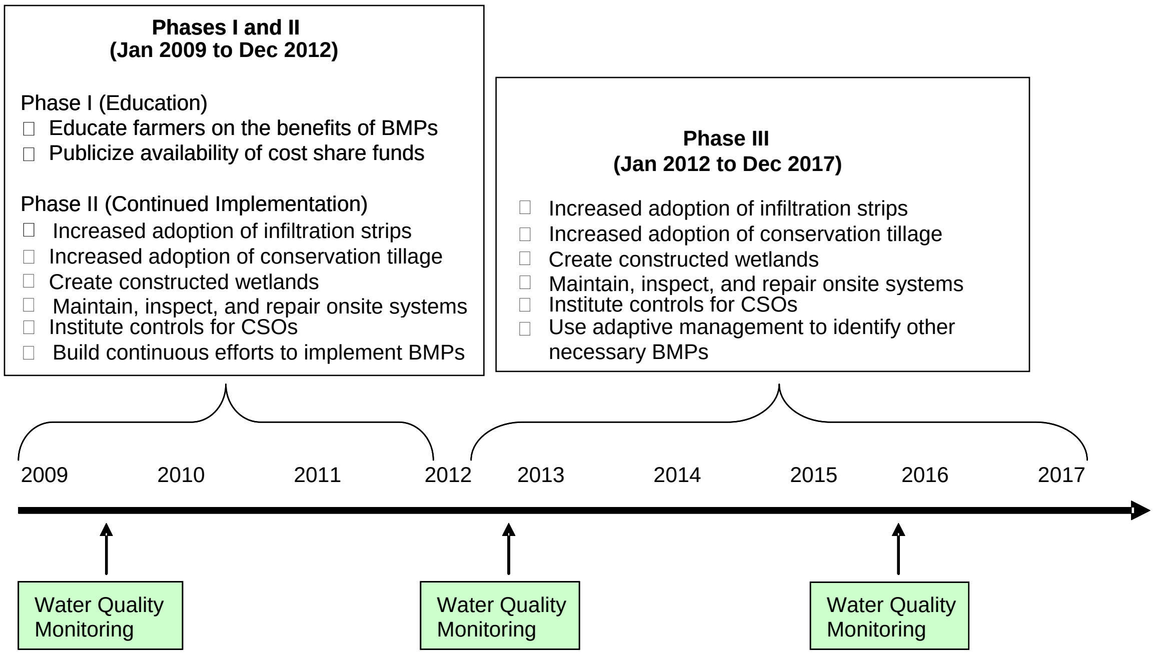

Figure 9-1. Timeline for the Crab Orchard Creek Watershed TMDL Implementation Plan.

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