Illinois
Environmental
Protection Agency

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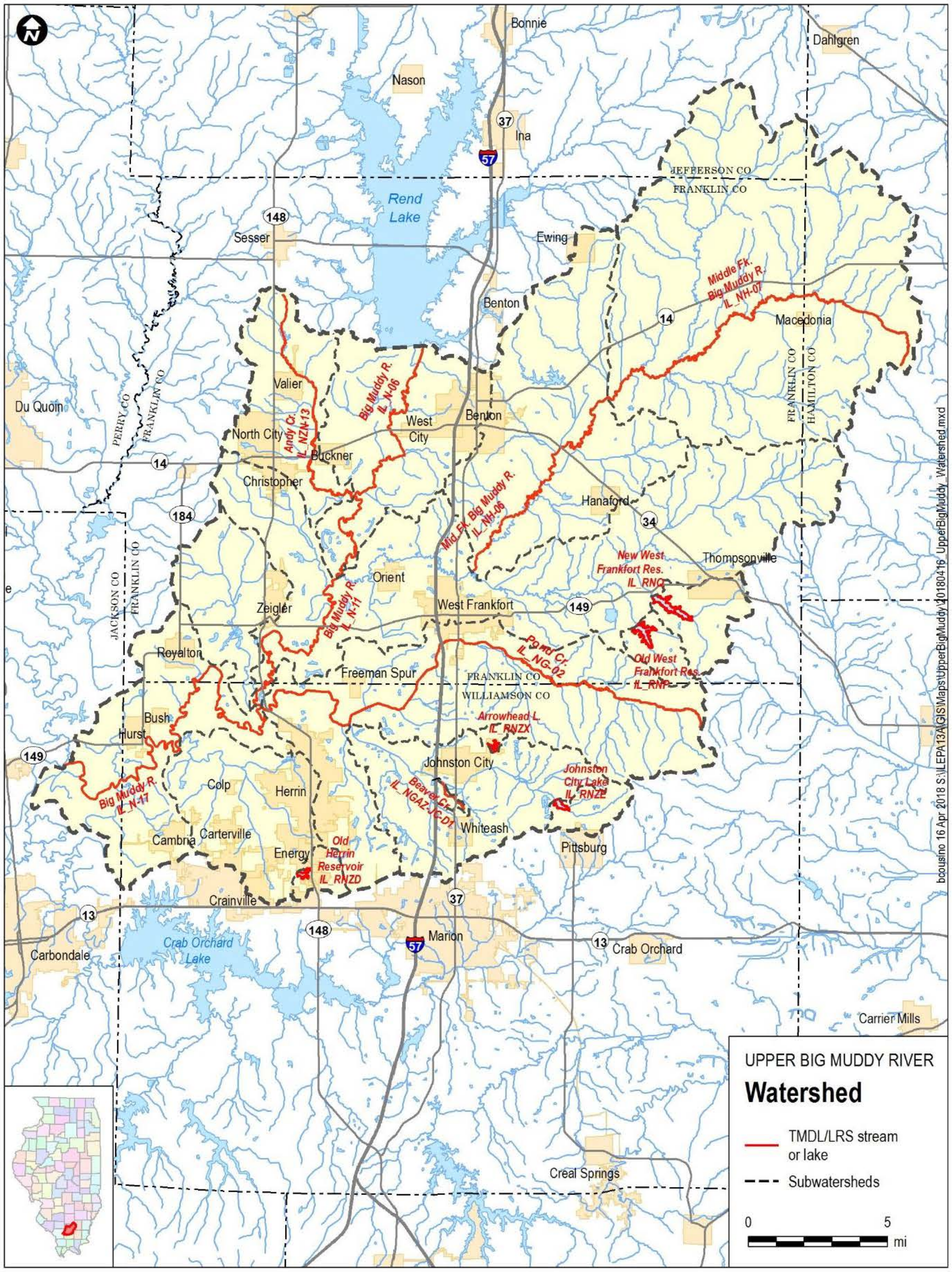
May 2019

IEPA/BOW/IL-2019-004

Upper Big Muddy River Watershed TMDL Report



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TMDL Development for the Upper Big Muddy River Watershed, Illinois

This file contains the following documents:

1) U.S. EPA Approval letter and Decision Document for the Final TMDL Report
2) TMDL Report
3) Watershed Implementation Plan

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

MAY 1 5 2019

REPLY TO THE ATTENTION OF:
WW-16J

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

Dear Mr. Sofat:

The U.S. Environmental Protection Agency has conducted a complete review of the final Total Maximum Daily Loads (TMDL) for segments within the Upper Big Muddy River watershed (UBMRW), including support documentation and follow up information. The UBMRW is in southern Illinois in portions of Franklin, Hamilton, Jackson and Williamson Counties. The UBMRW TMDLs address impaired primary contact recreation due to excessive bacteria, aquatic life impairments for dissolved oxygen, iron and manganese and aesthetic quality impairments due to excessive nutrients.

EPA has determined that the UBMRW TMDLs meet the requirements of Section 303(d) of the Clean Water Act and EPA's implementing regulations set forth at 40 C.F.R. Part 130. Therefore, EPA approves Illinois's two bacteria TMDLs, one dissolved oxygen TMDL, one iron TMDL, one manganese TMDL and five total phosphorus TMDLs. 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 efforts in submitting these TMDLs and look forward to future TMDL submissions by the State of Illinois. If you have any questions, please contact Mr. David Pfeifer, Acting Chief of the Watersheds and Wetlands Branch, at 312-353-9024.

Sincerely,

Joan M. Tanaka

Joan M. Tanaka
Acting Director, Water Division

Enclosure
cc: Abel Haile, IEPA

TMDL: Upper Big Muddy River watershed bacteria, dissolved oxygen, iron, manganese and total phosphorus TMDLs, Franklin, Hamilton, Jackson, Jefferson and Williamson Counties, IL
Date: May 15, 2019

DECISION DOCUMENT FOR THE UPPER BIG MUDDY RIVER WATERSHED TMDLS, FRANKLIN, HAMILTON, JACKSON, JEFFERSON & WILLIAMSON COUNTIES, IL

Section 303(d) of the Clean Water Act (CWA) and EPA's implementing regulations at 40 C.F.R. Part 130 describe the statutory and regulatory requirements for approvable TMDLs. Additional information is generally necessary for EPA to determine if a submitted TMDL fulfills the legal requirements for approval under Section 303(d) and EPA regulations, and should be included in the submittal package. Use of the verb "must" below denotes information that is required to be submitted because it relates to elements of the TMDL required by the CWA and by regulation. Use of the term "should" below denotes information that is generally necessary for EPA to determine if a submitted TMDL is approvable. These TMDL review guidelines are not themselves regulations. They are an attempt to summarize and provide guidance regarding currently effective statutory and regulatory requirements relating to TMDLs. Any differences between these guidelines and EPA's TMDL regulations should be resolved in favor of the regulations themselves.

1. Identification of Water body, Pollutant of Concern, Pollutant Sources, and Priority Ranking

The TMDL submittal should identify the water body as it appears on the State's/Tribe's 303(d) list. The water body should be identified/georeferenced using the National Hydrography Dataset (NHD), and the TMDL should clearly identify the pollutant for which the TMDL is being established. In addition, the TMDL should identify the priority ranking of the water body and specify the link between the pollutant of concern and the water quality standard (see Section 2 below).

The TMDL submittal should include an identification of the point and nonpoint sources of the pollutant of concern, including location of the source(s) and the quantity of the loading, e.g., lbs/per day. The TMDL should provide the identification numbers of the NPDES permits within the water body. Where it is possible to separate natural background from nonpoint sources, the TMDL should include a description of the natural background. This information is necessary for EPA's review of the load and wasteload allocations, which are required by regulation.

The TMDL submittal should also contain a description of any important assumptions made in developing the TMDL, such as:

(1) the spatial extent of the watershed in which the impaired water body is located;
(2) the assumed distribution of land use in the watershed (e.g., urban, forested, agriculture);
(3) population characteristics, wildlife resources, and other relevant information affecting the characterization of the pollutant of concern and its allocation to sources;
(4) present and future growth trends, if taken into consideration in preparing the TMDL (e.g., the TMDL could include the design capacity of a wastewater treatment facility); and

(5) an explanation and analytical basis for expressing the TMDL through *surrogate measures*, if applicable. *Surrogate measures* are parameters such as percent fines and turbidity for sediment impairments; chlorophyll a and phosphorus loadings for excess algae; length of riparian buffer; or number of acres of best management practices.

Comment:

Location Description/Spatial Extent:

The Upper Big Muddy River Watershed (UBMRW) (HUC-8 #07140106) covers approximately 490 square miles (approx. 313,435 acres) in southern Illinois in portions of Franklin, Hamilton, Jackson, Jefferson and Williamson Counties. The UBMRW is in the Mississippi River Basin and surface waters in the UBMRW generally flow from the north-northeast to the south-southwest. The main stem of the Big Muddy River eventually empties into the main stem of the Mississippi River in Jackson County near the La-Rue-Pine Hills Ecological Area.

The Illinois UBMRW TMDLs address two segments impaired due to excessive bacteria, 3 segments which demonstrate aquatic life impairments due to excessive iron, manganese and decreased dissolved oxygen conditions and five segments which show aesthetic quality impairments due to excessive total phosphorus (Table 1 of this Decision Document).

Table 1: Big Muddy River Watershed impaired waters addressed by this TMDL

Water body name	Assessment Unit ID	Affected Use	Pollutant or stressor	TMDL
Bacteria TMDLs				
Big Muddy River	IL_N-11	Primary Contact Recreation	Fecal Coliform	Fecal Coliform TMDL
Middle Fork Big Muddy River	IL_NH-06	Primary Contact Recreation	Fecal Coliform	Fecal Coliform TMDL
Dissolved Oxygen TMDLs				
Lake Creek	IL_NGA-02	Aquatic Life	Ammonia/nitrogen	Dissolved Oxygen TMDL (addressed via an ammonia-nitrogen TMDL)
Iron TMDL				
Andy Creek	IL_NZN-13	Aquatic Life	Iron	Iron TMDL
Manganese TMDL				
Beaver Creek	IL_NGAZ-JC-D1	Aquatic Life	Manganese	Manganese TMDL
Total Phosphorus TMDLs				
Herrin Old Reservoir	IL_RNZD	Aesthetic quality	Phosphorus	TP TMDL
Johnson City Reservoir	IL_RNZE	Aesthetic quality	Phosphorus	TP TMDL
Arrowhead (Williamson) Reservoir	IL_RNZX	Aesthetic quality	Phosphorus	TP TMDL
West Frankfort Old Reservoir	IL_RNP	Aesthetic quality	Phosphorus	TP TMDL
West Frankfort New Reservoir	IL_RNQ	Aesthetic quality	Phosphorus	TP TMDL

Land Use:

Land use in the UBMRW is predominantly agricultural, with approximately 58% of the land use in the UBMRW used for cultivated crops and/or grassland, pasture and hay lands (Table 2 of this Decision Document). The UBMRW also is comprised of forested lands (27%) and developed lands (12%), open water (2%) and wetlands (1%).

Table 2: Big Muddy River Watershed Land Cover - based on 2011 National Land Cover Database (NLCD)

Land Use / Land Cover Category	Acreage	Percentage
Cultivated Crops	107,348	34.25%
Forest	84,922	27.09%
Grassland/Pasture/Hay	75,733	24.16%
Developed, Open Space	20,648	6.59%
Developed, Low Intensity	14,156	4.52%
Open Water	4,604	1.47%
Wetlands	3,088	0.99%
Developed, Medium Intensity	2,440	0.78%
Developed, High Intensity	383	0.12%
Barren Land	112	0.04%
TOTALS	313,434	100%

Problem Identification:

Bacteria TMDLs: The two impaired segments in the UBMRW were included on the 2016 Illinois 303(d) list due to excessive bacteria. Water quality monitoring within the UBMRW indicated that these segments were not attaining their designated aquatic recreation uses due to measured exceedances of the bacteria criteria. Excessive bacteria can negatively impact recreational uses (e.g., swimming, wading, boating, fishing etc.) and public health. At elevated levels, bacteria may cause illness within humans who have contact with or ingest bacteria laden water. Recreation-based contact can lead to ear, nose, and throat infections, and stomach illness.

Dissolved oxygen impairment addressed via an ammonia-nitrogen TMDL: Illinois Environmental Protection Agency (IEPA) identified one segment, Lake Creek (IL_NGA-02), as demonstrating degraded oxygen concentrations within the water column. Low dissolved oxygen concentrations can negatively impact aquatic life use. The decrease in dissolved oxygen can stress benthic macroinvertebrates and fish. Elevated levels of nutrients (e.g., in Lake Creek, ammonia-nitrogen) within the water column, can reduce dissolved oxygen in the water column, and cause large shifts in dissolved oxygen and pH throughout the day. Shifting chemical conditions within the water column may stress aquatic biota (i.e., fish and macroinvertebrate species). In some instances, degradations in aquatic habitats or water quality have reduced fish populations or altered fish communities from those communities supporting sport fish species to communities which support more tolerant rough fish species.

Iron TMDL: IEPA identified one segment, Andy Creek (IL_NZN-13), with elevated concentrations of dissolved iron. Elevated concentrations of dissolved iron can negatively impact aquatic species by disturbing normal metabolic and osmoregulatory functions. Aquaculture studies have also demonstrated that increased dissolved iron concentrations in the water column may negatively impact gill functionality in certain fish species and thus reduce biodiversity in certain stream environments.

Excessive iron within the water column may harm aquatic species such as fish and macroinvertebrates. Certain metals species dissolve in water and may be absorbed by fish and other aquatic organisms. Small concentrations of certain dissolved metals may be, in the short term, toxic to fish and aquatic species and, in the long term, may bioaccumulate in certain aquatic species.

Manganese TMDL: IEPA identified one segment, Beaver Creek (IL_NGAZ-JC-D1), with elevated concentrations of dissolved manganese. Elevated dissolved manganese concentrations in the water column have many of the same negative effects of dissolved iron on fish species and biodiversity of the water column and benthic environments.

Excessive manganese within the water column may harm aquatic species such as fish and macroinvertebrates. Certain metals species dissolve in water and may be absorbed by fish and other aquatic organisms. Small concentrations of certain dissolved metals may be, in the short term, toxic to fish and aquatic species and, in the long term, may bioaccumulate in certain aquatic species.

Total phosphorus TMDLs: The five total phosphorus segments identified in Table 1 of this Decision Document were included on the 2016 Illinois 303(d) list due to excessive nutrients (phosphorus). Water quality monitoring demonstrated that these segments were not attaining their designated aesthetic quality uses due to excessive nutrients. Water quality monitoring within the UBMRW was completed at several locations and the data collected during these efforts served as the foundation for modeling efforts completed in this TMDL study.

While TP is an essential nutrient for aquatic life, elevated concentrations of TP can lead to nuisance algal blooms that negatively impact aquatic life and recreation (swimming, boating, fishing, etc.). Algal decomposition depletes dissolved oxygen levels within the water column. The decreases in dissolved oxygen can stress benthic macroinvertebrates and fish. Depletion of oxygen in the water column can also lead to conditions where phosphorus is released from bottom sediments (i.e. internal loading). Also, excess algae can shade the water column which limits the distribution of aquatic vegetation. Aquatic vegetation stabilizes bottom sediments and is an important habitat for macroinvertebrates and fish.

Priority Ranking:

The water bodies addressed by the UBMRW TMDLs were given a priority ranking for TMDL development due to: the impairment impacts on aquatic life, recreation, the public value of the impaired water resource and completing TMDLs as part of the Illinois basin monitoring process.

Pollutants of Concern:

The pollutants of concern are bacteria (fecal coliform), iron, manganese and nutrients (i.e., ammonia-nitrogen and total phosphorus (TP)).

Source Identification (point and nonpoint sources):

Point Source Identification: The potential point sources to the UBMRW are:

<u>UBMRW bacteria TMDLs:</u>

National Pollutant Discharge Elimination Systems (NPDES) permitted facilities: NPDES permitted facilities may contribute bacteria loads to surface waters through discharges of treated wastewater. Permitted facilities must discharge treated wastewater according to their NPDES permit. IEPA determined that the facilities in Table 3 of this Decision Document were contributing bacteria to waters in the UBMRW and assigned these facilities a portion of the bacteria wasteload allocation (WLA).

Table 3: NPDES facilities which contribute point source pollutant loading in the Upper Big Muddy River Watershed TMDLs

Bacteria WLAs assigned to NPDES facilities in the UBMRW			
Permit #	**Facility Name**	**Impaired Reach**	**WLA***
			Fecal coliform load (fecal coliform colonies/day)
ILG580083	Valier STP	IL_N-11	6.06E+08
ILG580215	West City STP	IL_N-11	7.75E+08
ILG580221	Hanaford STP	IL_N-11 & IL_NH-96	3.18E+08
ILG580272	Orient STP	IL_N-11	5.56E+08
IL0050466	LB Camping Sesser STP	IL_N-11	3.86E+07
IL0061760	Hill City Apartments - Benton	IL_N-11 & IL_NH-96	3.03E+07
IL0065111	Rend Lake Conservation District STP	IL_N-11 & IL_NH-96	3.79E+09
IL0020851	Christopher STP	IL_N-11	5.81E+09
IL0022365	Benton Northwest STP	IL_N-11	7.65E+09
IL0031704	West Frankfort STP	IL_N-11	1.06E+10
Dissolved Oxygen/Ammonia-Nitrogen WLAs assigned to NPDES facilities in the UBMRW			
DO TMDL (ammonia-nitrogen)			**Ammonia-Nitrogen load (lbs/day)**
IL0029301	Johnson City STP	IL_NGA-02	6.88
Total Phosphorus WLAs assigned to NPDES facilities in the UBMRW			
TP TMDL			**Total Phosphorus load (lbs/day)**
IL0072478	Thompsonville STP	IL_RNQ	0.67

** = Design average flow was used to calculate the WLA.*

Municipal Separate Storm Sewer Systems (MS4): IEPA determined that the UBMRW does not have MS4s which contribute pollutants to surface waters in the UBMRW.

Concentrated Animal Feedlot Operations (CAFOs): IEPA determined that the UBMRW does not have CAFOs which contribute pollutants to surface waters in the UBMRW.

Combined Sewer Overflows (CSOs) and Sanitary Sewer Overflows (SSOs): IEPA determined that the UBMRW does not have CSOs nor SSOs which contribute pollutants to surface waters in the UBMRW.

UBMRW dissolved oxygen impairment addressed via an ammonia-nitrogen TMDL:
NPDES permitted facilities: NPDES permitted facilities may contribute ammonia-nitrogen loads to surface waters through discharges of treated wastewater. Permitted facilities must discharge treated wastewater according to their NPDES permit. IEPA determined that one facility (i.e., the Johnson City Sewage Treatment Plant (STP) (IL0029301)) in Table 3 of this Decision Document was contributing ammonia-nitrogen to the Lake Creek (IL_NGA-02) segment and assigned this facility a portion of the ammonia-nitrogen WLA.

UBMRW iron TMDL:
IEPA determined that there were no permitted sources contributing to the Andy Creek (IL_NZN-13) iron TMDL. WLAs were set at 0.

UBMRW manganese TMDL:
IEPA determined that there were no permitted sources contributing to the Beaver Creek (IL_NGAZ-JC-D1) manganese TMDL. WLAs were set at 0.

UBMRW total phosphorus TMDLs:
NPDES permitted facilities: NPDES permitted facilities may contribute phosphorus loads to surface waters through discharges of treated wastewater. Permitted facilities must discharge treated wastewater according to their NPDES permit. IEPA determined that one facility in Table 3 (i.e., the Thompsonville STP (IL0072478)) was contributing phosphorus to waters in the UBMRW and assigned this facility a portion of the phosphorus WLA.

Nonpoint Source Identification: The potential nonpoint sources to the UBMRW are:

UBMRW bacteria TMDLs:
Stormwater from agricultural land use practices and feedlots near surface waters: Animal Feeding Operations (AFOs) in close proximity to surface waters can be a source of bacteria to water bodies in the UBMRW. These areas may contribute bacteria via the mobilization and transportation of pollutant laden waters from feeding, holding and manure storage sites. Runoff from agricultural lands may contain significant amounts of bacteria which may lead to impairments in the UBMRW. Feedlots generate manure which may be spread onto fields. Runoff from fields with spread manure can be exacerbated by tile drainage lines, which channelize the stormwater flows and reduce the time available for bacteria to die-off.

Unrestricted livestock access to streams: Livestock with access to stream environments may add bacteria directly to the surfaces waters or resuspend particles that had settled on the stream bottom. Direct deposition of animal wastes can result in very high localized bacteria counts and may contribute to downstream impairments. Smaller animal facilities may add bacteria to surface waters via wastewater from these facilities or stormwater runoff from near-stream pastures.

Discharges from septic systems or unsewered communities: Failing septic systems are a potential source of bacteria within the UBMRW. Septic systems generally do not discharge directly into a water body, but effluents from septic systems may leach into groundwater or pond at the surface where they can be washed into surface waters via stormwater runoff events. Age, construction and use of septic systems can vary throughout a watershed and influence the bacteria contribution from these systems.

Non-regulated urban runoff: Runoff from urban areas (e.g., urban, residential, commercial or industrial land uses) can contribute bacteria to local water bodies. Stormwater from urban areas, which drain impervious surfaces, may introduce bacteria derived from wildlife or pet droppings to surface waters.

Wildlife: Wildlife is a known source of bacteria in water bodies as many animals spend time in or around water bodies. Deer, geese, ducks, raccoons, and other animals all create potential sources of bacteria. Wildlife contributes to the potential impact of contaminated runoff from animal habitats, such as urban park areas, forest, and rural areas.

UBMRW dissolved oxygen impairment addressed via an ammonia-nitrogen TMDL:
Stormwater from agricultural land use practices and feedlots near surface waters: AFOs in close proximity to surface waters can be a source of ammonia-nitrogen inputs to water bodies in the UBMRW. These areas may contribute ammonia-nitrogen inputs via the mobilization and transportation of pollutant laden waters from feeding, holding and manure storage sites. Runoff from agricultural lands may contain significant amounts of ammonia-nitrogen which may lead to impaired conditions in Lake Creek (IL_NGA-02). Feedlots generate manure which may be spread onto fields. Runoff from fields with spread manure can be exacerbated by agricultural tile drainage lines, which channelize the stormwater flows to local surface waters.

Non-regulated urban runoff: Runoff from urban areas (urban, residential, commercial or industrial land uses) can contribute ammonia-nitrogen inputs to local water bodies. Stormwater from urban areas, which drain impervious surfaces, may introduce ammonia-nitrogen inputs (derived from wildlife or pet droppings) to surface waters.

Discharges from septic systems or unsewered communities: Failing septic systems are a potential source of ammonia and/or nutrients within the UBMRW. Septic systems generally do not discharge directly into a water body, but effluents from septic systems may leach into groundwater or pond at the surface where they can be washed into surface waters via stormwater runoff events. Age, construction and use of septic systems can vary throughout a watershed and influence the nutrient contribution from these systems.

Upstream lake inputs: Lakes and reservoirs in the watershed may be sources of nutrients, including ammonia-nitrogen, especially to streams immediately downstream of the lake or reservoir. IEPA explained that flow-through lakes and reservoirs in the UBMRW may act as traps for nutrients and sediment and these parameters may be re-introduced into stream environments depending on flow conditions in the lake or reservoir (e.g., flooding conditions).

Wildlife: Wildlife is a known source of ammonia-nitrogen inputs in water bodies as many animals spend time in or around water bodies. Deer, geese, ducks, raccoons, and other animals all create potential sources of ammonia-nitrogen inputs. Wildlife contributes to the potential impact of contaminated runoff from animal habitats, such as urban park areas, forest, and rural areas.

UBMRW iron TMDL:

Stormwater from agricultural land use practices: Soil erosion from agricultural areas may enter stream environments during precipitation runoff events such as storms, or from localized land disturbances from animal operations. Iron in the soils may dissolve out into the water column, especially in water bodies with low dissolved oxygen concentrations. Agricultural tile drainage lines, which channelize the stormwater flows can exacerbate the transmission of runoff and soils to stream environments. Animals grazing or watering near the streams can also disturb the soils and streambanks, adding iron-bound soil particulate matter to surface waters.

Stream channelization and stream erosion: Eroding streambanks and channelization efforts may add dissolved metals such as iron to local surface waters. Iron may be added if there is particulate iron bound with eroding soils from riparian areas. Eroding riparian areas may be linked to soil inputs within the water column and potentially to changes in flow patterns. Changes in flow patterns may also encourage down-cutting of the streambed and streambanks. Stream channelization efforts can increase the velocity of flow (via the removal of the sinuosity of a natural channel) and disturb the natural sedimentation processes of the streambed.

Legacy and ongoing mining inputs: In its Stage 1 UBMRW Report, IEPA explained that in certain areas of the watershed (e.g., Franklin and Williamson Counties) there were active and/or closed mine operations. Stormwater runoff from active and legacy/inactive mining areas may contribute dissolved and particulate metals from mining waste/spoil piles and legacy mining areas which are in the process of being reclaimed. Mining dewatering efforts of pits and underground areas may also introduce dissolved and particulate metals to surface waters.

UBMRW manganese TMDL:

Stormwater from agricultural land use practices: Soil erosion from agricultural areas may enter stream environments during precipitation runoff events such as storms, or from localized land disturbances from animal operations. Manganese in the soils may dissolve out into the water column, especially in water bodies with low dissolved oxygen concentrations. Agricultural tile drainage lines, which channelize the stormwater flows can exacerbate the transmission of runoff and soils to stream environments. Animals grazing or watering near the streams can also disturb the soils and streambanks, adding manganese-bound soil particulate matter to surface waters.

Stream channelization and stream erosion: Eroding streambanks and channelization efforts may add dissolved metals such as manganese to local surface waters. Manganese may be added if there is particulate manganese bound with eroding soils from riparian areas. Eroding riparian areas may be linked to soil inputs within the water column and potentially to changes in flow patterns. Changes in flow patterns may also encourage down-cutting of the streambed and streambanks. Stream channelization efforts can increase the velocity of flow (via the removal of the sinuosity of a natural channel) and disturb the natural sedimentation processes of the streambed.

Legacy and ongoing mining inputs: In its Stage 1 UBMRW Report, IEPA explained that in certain areas of the watershed (e.g., Franklin and Williamson Counties) there were active and/or closed mine operations. Stormwater runoff from active and legacy/inactive mining areas may contribute dissolved and particulate metals from mining waste/spoil piles and legacy mining areas which are in the process of being reclaimed. Mining dewatering efforts of pits and underground areas may also introduce dissolved and particulate metals to surface waters.

UBMRW total phosphorus TMDL:

Internal loading: The release of phosphorus from lake sediments contributes internal phosphorus loading to the lakes in the UBMRW. Phosphorus may build up in the bottom waters of the lake and may be resuspended or mixed into the water column when the thermocline decreases and the lake water mixes.

Stormwater runoff from agricultural land use practices: Runoff from agricultural lands may contain significant amounts of nutrients, organic material and organic-rich sediment which may lead to impairments in the UBMRW. Manure spread onto fields is often a source of phosphorus, and can be exacerbated by tile drainage lines, which channelize the stormwater. Tile lined fields and channelized ditches enable particles to move more efficiently into surface waters. Phosphorus, organic material and organic-rich sediment may be added via surface runoff from upland areas which are being used for Conservation Reserve Program (CRP) lands, grasslands, and agricultural lands used for growing hay or other crops. Stormwater runoff may contribute nutrients and organic-rich sediment to surface waters from livestock manure, fertilizers, vegetation and erodible soils.

Stream channelization and stream erosion: Eroding streambanks and channelization efforts may add nutrients, organic material and organic-rich sediment to local surface waters. Nutrients may be added if there is particulate phosphorus bound with eroding soils. Eroding riparian areas may be linked to soil inputs within the water column and potentially to changes in flow patterns. Changes in flow patterns may also encourage down-cutting of the streambed and streambanks. Stream channelization efforts can increase the velocity of flow (via the removal of the sinuosity of a natural channel) and disturb the natural sedimentation processes of the streambed.

Discharges from septic systems or unsewered communities: Failing septic systems are a potential source of nutrients within the UBMRW. Septic systems generally do not discharge directly into a water body, but effluents from septic systems may leach into groundwater or pond at the surface where they can be washed into surface waters via stormwater runoff events. Age, construction and use of septic systems can vary throughout a watershed and influence the nutrient contribution from these systems.

Wetland and Forest Sources: Phosphorus, organic material and organic-rich sediment may be added to surface waters by stormwater flows through wetland and forested areas in the UBMRW. Storm events may mobilize phosphorus through the transport of suspended solids and other organic debris.

Wildlife: Wildlife is a known source of nutrients in water bodies as many animals spend time in or around water bodies. Deer, geese, ducks, raccoons, and other animals all create potential sources of nutrients. Wildlife contributes to the potential impact of contaminated runoff from animal habitats, such as urban park areas, forest, and rural areas.

Future Growth:

Franklin, Jackson and Williamson counties demonstrated a slight increase in population from the 2000 to 2010 census cycles (Stage 1 Report, Section 2.6). Population growth in the UBMRW was small and IEPA did not account for any future growth as it developed the TMDLs for the UBMRW. The WLA and load allocations (LA) for the UBMRW TMDLs were calculated for all current and future sources. Any expansion of point or nonpoint sources will need to comply with the respective WLA and LA values calculated in the UBMRW TMDLs.

The EPA finds that the TMDL document submitted by IEPA satisfies the requirements of the first criterion.

2. Description of the Applicable Water Quality Standards and Numeric Water Quality Target

The TMDL submittal must include a description of the applicable State/Tribal water quality standard, including the designated use(s) of the water body, the applicable numeric or narrative water quality criterion, and the antidegradation policy (40 C.F.R. §130.7(c)(1)). EPA needs this information to review the loading capacity determination, and load and wasteload allocations, which are required by regulation.

The TMDL submittal must identify a numeric water quality target(s) – a quantitative value used to measure whether or not the applicable water quality standard is attained. Generally, the pollutant of concern and the numeric water quality target are, respectively, the chemical causing the impairment and the numeric criteria for that chemical (e.g., chromium) contained in the water quality standard. The TMDL expresses the relationship between any necessary reduction of the pollutant of concern and the attainment of the numeric water quality target. Occasionally, the pollutant of concern is different from the pollutant that is the subject of the numeric water quality target (e.g., when the pollutant of concern is phosphorus and the numeric water quality target is expressed as Dissolved Oxygen (DO) criteria). In such cases, the TMDL submittal should explain the linkage between the pollutant of concern and the chosen numeric water quality target.

Comment:

Section 3 of the final TMDL document explains that water bodies in the UBMRW are not meeting their General Use designation. The Illinois Pollution Control Board (IPCB) defines General Use standards as those 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."*

Under the General Use classification, waters are further designated as impaired for aquatic life use, aesthetic quality use and primary contact recreational use. Table 1 of this Decision Document shows the various water body segments and their associated impaired uses.

Primary contact uses, defined as

> *"any recreational or other water use in which there is prolonged and intimate contact with the water (where the physical configuration of the water body permits it) involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard, such as swimming and water skiing"* (35 Ill. Adm. Code 301.355)

are protected for all General Use waters.

The applicable General Use water quality standards (WQS) for the UBMRW TMDL water bodies are established in Illinois Administrative Rules Title 35, Environmental Protection; Subtitle C, Water Pollution; Chapter I, Pollution Control Board; Part 302, Water Quality Standards, Subpart B. Table 4 of this Decision Document lists applicable water quality standards of the UBMRW TMDLs.

Table 4: Water quality standards and targets utilized within the Upper Big Muddy River Watershed TMDL

Parameter	Units	TMDL Targets
Numeric Water Quality Standards for addressing the Bacteria (fecal coliform) impaired segments within the UBMRW		
Total Fecal Coliform[1]	cfu / 100 mL	400 in < 10% of samples[2]
		Geometric Mean[3] < 200
Numeric Water Quality Criterion for addressing the Dissolved Oxygen impaired segments within the UBMRW		
Dissolved Oxygen (DO)	mg/L	No value should be less than 5.0 mg/L[4]
Numeric Water Quality Target for addressing the Iron impaired segments within the UBMRW		
Iron	mg/L	1.0
Numeric Water Quality Target for addressing the Manganese impaired segments within the UBMRW		
Manganese	mg/L	4.85 [5]
Numeric Water Criterion for addressing the Nutrient impaired segments within the UBMRW		
Total Phosphorus (TP)	mg/L	0.05

[1] = Fecal Coliform standards apply only between May 1 and October 31

[2] = Standard shall not be exceeded by more than 10% of the samples collected during any 30-day period

[3] = Geometric mean based on minimum of 5 samples taken over not more than a 30-day period

[4] = The DO TMDL for the Lake Creek (IL_NGA-02) segment was calculated using a load (lbs/day) assigned to ammonia-nitrogen (See Section 3 of this Decision Document and Section 5.2 of the final TMDL document).

[5] = The chronic water quality standard of 4.85 mg/L was calculated based on a hardness measurement of 383 mg/L which was measured in the field at the same time of manganese measurements in IL_NGZA-JC-D1

Bacteria TMDL target: The bacteria TMDL target employed for the UBMRW bacteria TMDL is the 200 colony forming units (cfu) per 100 mL (200 cfu/100 mL) portion of the standard. IEPA believes that using the 200 cfu/100 mL portion of the standard for TMDL calculations will result in the greatest bacteria reductions within the UBMRW and will result in the attainment of the 400 cfu/100 mL portion of the standard. While the bacteria TMDLs will focus on the geometric mean portion of the water quality standard, attainment of both parts of the water quality standard is required.

Dissolved oxygen impairment addressed via an ammonia-nitrogen TMDL target: The dissolved oxygen target for the UBMRW dissolved oxygen TMDL (i.e., the Lake Creek (IL_NGA-02) segment) is 5.0 mg/L. The DO TMDL was calculated to attain an ammonia-nitrogen load (lbs/day) as IEPA determined that ammonia-nitrogen is the pollutant linked to the DO impairment in the Lake Creek segment (Section 5.2 of the final TMDL document). Ammonia-nitrogen values (e.g., monthly average effluent limits for permitted facilities) used in the QUAL-2E modeling were selected by IEPA and described in Section 5.2 of the final TMDL document.

Iron TMDL target: The iron TMDL target for the UBMRW iron TMDL is 1.0 mg/L.

Manganese TMDL target: The manganese TMDL target for the UBMRW manganese TMDL is 4.85 mg/L. This target is based on the chronic water quality standard equation,

$WQS = e^{A+B \ln(H)} * 0.9812$

Where A = 4.0635, B = 0.7467 and ln(H) = the natural logarithm of a hardness (H) measurement (mg/L)

TP TMDL target: The phosphorus TMDL target for the UBMRW phosphorus TMDLs is 0.05 mg/L.

The EPA finds that the TMDL document submitted by IEPA satisfies the requirements of the second criterion.

3. Loading Capacity - Linking Water Quality and Pollutant Sources

A TMDL must identify the loading capacity of a water body for the applicable pollutant. EPA regulations define loading capacity as the greatest amount of a pollutant that a water can receive without violating water quality standards (40 C.F.R. §130.2(f)).

The pollutant loadings may be expressed as either mass-per-time, toxicity or other appropriate measure (40 C.F.R. §130.2(i)). If the TMDL is expressed in terms other than a daily load, e.g., an annual load, the submittal should explain why it is appropriate to express the TMDL in the unit of measurement chosen. The TMDL submittal should describe the method used to establish the cause-and-effect relationship between the numeric target and the identified pollutant sources. In many instances, this method will be a water quality model.

The TMDL submittal should contain documentation supporting the TMDL analysis, including the basis for any assumptions; a discussion of strengths and weaknesses in the analytical process; and results from any water quality modeling. EPA needs this information to review the loading capacity determination, and load and wasteload allocations, which are required by regulation.

TMDLs must take into account *critical conditions* for steam flow, loading, and water quality parameters as part of the analysis of loading capacity (40 C.F.R. §130.7(c)(1)). TMDLs should define applicable *critical conditions* and describe their approach to estimating both point and nonpoint source loadings under such *critical conditions*. In particular, the TMDL should discuss the approach used to compute and allocate nonpoint source loadings, e.g., meteorological conditions and land use distribution.

Comment:

UBMRW bacteria TMDLs: IEPA used the geometric mean (**200 cfu/100 mL**) of the bacteria (fecal coliform) WQS to calculate loading capacity values for the bacteria TMDLs. IEPA believes the geometric mean of the bacteria WQS provides the best overall characterization of the status of the watershed. EPA agrees with this assertion, as stated in the preamble of, *"The Water Quality Standards for Coastal and Great Lakes Recreation Waters Final Rule"* (69 FR 67218-67243, November 16, 2004) on page 67224, "…the geometric mean is the more relevant value for ensuring that appropriate actions are taken to protect and improve water quality because it is a more reliable measure, being less subject to random variation, and more directly linked to the underlying studies on which the 1986 bacteria criteria were based." IEPA stated that the bacteria TMDLs will focus on the geometric mean portion of the water quality standard (200 cfu/100 mL) and that it expects that by attaining the 200 cfu/100 mL portion of the bacteria (fecal coliform) WQS the 400 cfu /100 mL portion of the bacteria (fecal coliform) WQS will also be attained. EPA finds these assumptions to be reasonable.

Typically loading capacities are expressed as a mass per time (e.g., pounds per day). However, for fecal coliform loading capacity calculations, mass is not always an appropriate measure because fecal coliform is expressed in terms of colony forming units. This approach is consistent with the EPA's regulations which define "load" as "an amount of matter that is introduced into a receiving water" (40 CFR §130.2). To establish the loading capacities for the UBMRW bacteria TMDLs, IEPA used Illinois's WQS for fecal coliform (200 cfu/100 mL). A loading capacity is, "the greatest amount of loading that a water can receive without violating water quality standards" (40 CFR §130.2). Therefore, a loading capacity set at the WQS will assure that the water does not violate WQS. IEPA's bacteria (fecal coliform) TMDL approach is based upon the premise that all discharges (point and nonpoint) must meet the WQS when entering the water body. If all sources meet the WQS at discharge, then the water body should meet the WQS and the designated use.

Flow duration curves (FDC) were created for the two segments in the UBMRW which had bacteria TMDLs calculated to address their bacteria impaired waters. The FDCs were developed using flow data collected at USGS gage #05595820 on Casey Fork near Mount Vernon, IL. Neither the Big Muddy River (IL_N-11) bacteria segment nor the Middle Fork Big Muddy (IL_NH-06) bacteria segment had a USGS gage located in their direct subwatershed, therefore, IEPA employed flow measurements from a nearby, upstream USGS gage (i.e., #05595820), to estimate flows for ungaged segments in the UBMRW. IEPA used the following drainage area ratio (DAR) equation to estimate flows in unaged subwatersheds:

$Q_{ungaged} = (A_{ungaged} / A_{gaged}) * Q_{gaged}$

where,

$Q_{ungaged}$ = Flow at the ungaged location
Q_{gaged} = Flow at USGS gage station (e.g., #05595820)
$A_{ungaged}$ = Drainage area of the ungaged location
A_{gaged} = Drainage area of the USGS gage location (e.g., #05595820)

- For the Big Muddy River bacteria segment (IL_N-11), #05595820 is upstream of the Big Muddy River segment, therefore, flow data from this USGS gage was adjusted for the FDC calculations based on a DAR calculation.
- For the Middle Fork Big Muddy bacteria segment (IL_NH-06), #05595820 is upstream of the Middle Fork Big Muddy segment, therefore, flow data from this USGS gage was adjusted for the FDC calculations based on a DAR calculation.

Flow data focused on dates within the recreation season (May 1 to October 31). Daily stream flows were necessary to implement the load duration curve (LDC) approach.

FDCs graphs have flow duration interval (percentage of time flow exceeded) on the X-axis and discharge (flow per unit time) on the Y-axis. The FDC were transformed into a LDC by multiplying individual flow values by the bacteria WQS (200 cfu/100 mL) and then multiplying that value by a conversion factor. The resulting points are plotted onto a load duration curve graph. The LDC graph for the Upper Big Muddy River (IL_N-11) segment has flow duration interval (percentage of time flow exceeded) on the X-axis and bacteria (fecal coliform) concentrations (number of bacteria per unit time) on the Y-axis (Figure 4-5 of the final TMDL document). The curved line on a LDC graph represents the TMDL of the respective flow conditions observed at that location.

Water quality monitoring was completed for the bacteria impaired segments of the UBMRW and measured fecal coliform concentrations were converted to individual sampling loads by multiplying the sample concentration by the instantaneous flow measurement observed/estimated at the time of sample collection. The individual sampling loads were plotted on the same figure with the created LDC (Figures 4-5 and 4-9 of the final TMDL document).

LDC plots were subdivided into three flow regimes; high flow conditions (exceeded 0–30% of the time), normal flow conditions (exceeded 30–70% of the time) and low flow conditions (exceeded 70–100% of the time). LDC plots can be organized to display individual sampling loads with the calculated LDC. Watershed managers can interpret LDC graphs with individual sampling points plotted alongside the LDC to understand the relationship between flow conditions and water quality exceedances within the watershed. Individual sampling loads which plot above the LDC represent violations of the WQS and the allowable load under those flow conditions at those locations. The difference between individual sampling loads plotting above the LDC and the LDC, measured at the same flow, is the amount of reduction necessary to meet WQS.

The strengths of using the LDC method are that critical conditions and seasonal variation are considered in the creation of the FDC by plotting hydrologic conditions over the flows measured during the recreation season. Additionally, the LDC methodology is relatively easy to use and cost-effective. The weaknesses of the LDC method are that nonpoint source allocations cannot be assigned to specific sources, and specific source reductions are not quantified. Overall, IEPA believes and EPA concurs that the strengths outweigh the weaknesses for the LDC method.

Implementing the results shown by the LDC requires watershed managers to understand the sources contributing to the water quality impairment and which Best Management Practices (BMPs) may be the most effective for reducing bacteria loads based on flow magnitudes. Different sources will contribute bacteria loads under varying flow conditions. For example, if exceedances are significant during high flow events this would suggest storm events are the cause and implementation efforts can target BMPs that will reduce stormwater runoff and consequently bacteria loading into surface waters. This allows for a more efficient implementation effort.

The calculated bacteria TMDLs for the Upper Big Muddy River segment (IL_N-11) and the Middle Fork Big Muddy (IL_NH-06) segment are presented in Table 5 of this Decision Document. The load allocations were calculated after the determination of the WLA, and the Margin of Safety (MOS) (10% of the loading capacity). Load allocations (e.g., stormwater runoff from agricultural land use practices and feedlots, septic systems, wildlife inputs etc.) were not split among individual nonpoint contributors. Instead, load allocations were combined into a categorical LA to cover all nonpoint source contributions.

Table 5: Bacteria TMDLs for the Upper Big Muddy River Watershed are located at the end of this Decision Document

Table 5 of this Decision Document reports multiple points on the loading capacity curve. However, the components of the TMDL equation could be illustrated for any point on the entire loading capacity curve. The LDC method can be used to display collected bacteria monitoring data and allows for the estimation of load reductions necessary for attainment of the bacteria WQS. Using this method, daily loads were developed based upon the flow in the water body. Loading capacities were determined for the segment for multiple flow regimes. This allows the TMDL to be represented by an allowable daily load across all flow conditions. Table 5 of this Decision Document identifies the loading capacity for the water body at each flow regime. Although there are numeric loads for each flow regime, the actual LDC is what is being approved for this TMDL.

Table 5 of the Decision Document presents IEPA's loading reduction estimates for the bacteria TMDL. These loading reductions (i.e., the percent reduction row at the bottom of each TMDL table) were calculated from field sampling data collected within each individual bacteria impaired segment of the UBMRW. IEPA explained that its load reduction estimates are likely more conservative since they are based on a limited water quality data set.

EPA concurs with the data analysis and LDC approach utilized by IEPA in its calculation of loading capacities, wasteload allocations, load allocations and the margin of safety for the bacteria TMDLs of the UBMRW. The methods used for determining the TMDL are consistent with U.S. EPA technical memos.[1]

UBMRW dissolved oxygen impairment addressed via an ammonia-nitrogen TMDL: IEPA used the Enhanced Stream Water Quality Model (QUAL2E) to aid in its calculation of a dissolved oxygen TMDL for the Lake Creek (IL_NGA-02) segment in the UBMRW. QUAL2E is a steady-state, one-dimensional water quality model which allows users to simulate fate and transport of water quality parameters in stream environments while varying flow conditions of that stream environment. IEPA explained that QUAL2E was chosen to define the relationship between external oxygen-demanding loads and observed dissolved oxygen concentrations in the stream segments of the UBMRW (Section 4.1 of the final TMDL document).

IEPA used field dissolved oxygen measurements collected in September 2015 and other municipal water quality data from the Johnston City Sewage Treatment Plant (STP) (ILG0029301) to run its QUAL2E model simulations. Input loads were adjusted until the minimum dissolved oxygen load (5.0 mg/L) was met and this process helped determine the loading capacity for the Lake Creek (IL_NGA-02) segment (Table 6 of this Decision Document).

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[1] U.S. Environmental Protection Agency. August 2007. *An Approach for Using Load Duration Curves in the Development of TMDLs*. Office of Water. EPA-841-B-07-006. Washington, D.C.

Table 6: Dissolved Oxygen TMDL - Lake Creek (IL_NGA-02)

Allocation	Ammonia Nitrogen (lbs/day)
WLA - Johnson City STP (ILG0029301)	6.88
Wasteload Allocation TOTAL	6.88
Load Allocation	0.54
Margin of Safety (10%)	0.83
Loading Capacity	**8.25**

EPA supports the data analysis and modeling approach utilized by IEPA in its calculation of WLA, LA and MOS for the dissolved oxygen TMDL. Additionally, EPA concurs with the loading capacities calculated by the IEPA in its UBMRW dissolved oxygen TMDL. EPA finds IEPA's approach for calculating the loading capacity for its UBMIRW dissolved oxygen TMDL to be reasonable and consistent with EPA guidance.

UBMRW iron TMDL: IEPA developed a LDC to calculate a iron TMDL for Andy Creek (IL_NZN-13). The same LDC development strategy was employed for the iron TMDL as was used to calculate the bacteria LDC values. IEPA used flow measurements from USGS gage #05597500 on Crab Orchard Creek near Marion, IL and DAR calculations to estimate flows for Andy Creek (IL_NZN-13) which were employed in the creation of FDC and LDC for the iron TMDL. The FDC were transformed into LDC by multiplying individual flow values by the iron TMDL target (1.0 mg/L) and then multiplying that value by a conversion factor.

An iron TMDL was calculated (Table 7 of this Decision document) by IEPA. The LA value was calculated after the determination of the WLA, and the MOS. Load allocations (e.g., stormwater runoff from agricultural land use practices) was not split among individual nonpoint contributors. Instead, load allocations were combined into one value to cover all nonpoint source contributions. Table 7 of this Decision Document reports ten values (i.e., the midpoints of the 10-percent flow regimes) on the loading capacity curve. However, the components of the TMDL equation could be illustrated for any point on the entire loading capacity curve.

The LDC method can be used to display collected iron monitoring data and allows for the estimation of load reductions necessary for attainment of the water quality standard. Using this method, daily loads were developed based upon the flow in the water body. Loading capacities were determined for Andy Creek (IL_NZN-13) for multiple flow regimes. This allows the TMDL to be represented by an allowable daily load across all flow conditions. Although there are numeric loads for each flow regime, the LDC is what is being approved for this TMDL.

Table 7: The iron TMDL for the Upper Big Muddy River Watershed is located at the end of this Decision Document

EPA supports the data analysis and modeling approach utilized by IEPA in its calculation of WLA, LA and MOS for the iron TMDL. Additionally, EPA concurs with the loading capacities calculated by the IEPA in its UBMRW iron TMDL. EPA finds IEPA's approach for calculating the loading capacity for its UBMRW iron TMDL to be reasonable and consistent with EPA guidance.

UBMRW manganese TMDL: IEPA developed a LDC to calculate a manganese TMDL for Beaver Creek (IL_NGAZ-JC-D1). The same LDC development strategy was employed for the manganese TMDL as was used to calculate the bacteria and iron LDC values. IEPA used flow measurements from USGS gage #05597500 on Crab Orchard Creek near Marion, IL and DAR calculations to estimate flows for Beaver Creek (IL_NGAZ-JC-D1) which were employed in the creation of FDC and LDC for the manganese TMDL. The FDC were transformed into LDC by multiplying individual flow values by the manganese TMDL target (4.85 mg/L) and then multiplying that value by a conversion factor.

A manganese TMDL was calculated (Table 8 of this Decision document) by IEPA. The LA value was calculated after the determination of the WLA, and the MOS. Load allocations (e.g., stormwater runoff from agricultural land use practices) was not split among individual nonpoint contributors. Instead, load allocations were combined into one value to cover all nonpoint source contributions. Table 8 of this Decision Document reports ten values (i.e., the midpoints of the 10-percent flow regimes) on the loading capacity curve. However, the components of the TMDL equation could be illustrated for any point on the entire loading capacity curve.

The LDC method can be used to display collected iron monitoring data and allows for the estimation of load reductions necessary for attainment of the water quality standard. Using this method, daily loads were developed based upon the flow in the water body. Loading capacities were determined for Beaver Creek (IL_NGAZ-JC-D1) for multiple flow regimes. This allows the TMDL to be represented by an allowable daily load across all flow conditions. Although there are numeric loads for each flow regime, the LDC is what is being approved for this TMDL.

Table 8: The manganese TMDL for the Upper Big Muddy River Watershed is located at the end of this Decision Document

EPA supports the data analysis and modeling approach utilized by IEPA in its calculation of WLA, LA and MOS for the manganese TMDL. Additionally, EPA concurs with the loading capacities calculated by the IEPA in its UBMRW manganese TMDL. EPA finds IEPA's approach for calculating the loading capacity for its UBMIRW manganese TMDL to be reasonable and consistent with EPA guidance.

UBMRW total phosphorus TMDLs: IEPA used the U.S. Army Corps of Engineers (USACE) BATHTUB model to calculate the loading capacities for the UBMRW TP TMDLs. The BATHTUB model was utilized to link observed phosphorus water quality conditions and estimated phosphorus loads to in-lake water quality estimates. IEPA has previously employed BATHTUB successfully in other lake TMDLs in Illinois. BATHTUB is a steady-state annual or seasonal model that predicts a lake's growing season (e.g., June 1 to September 30) average surface water quality. BATHTUB utilizes annual or seasonal time-scales which are appropriate because watershed TP loads are normally impacted by seasonal conditions.

BATHTUB has built-in statistical calculations which account for data variability and provide a means for estimating confidence in model predictions. BATHTUB employs a mass-balance TP model that accounts for water and TP inputs from tributaries, direct watershed runoff, the atmosphere, and sources internal to the lake, and outputs through the lake outlet, water loss via evaporation, and TP sedimentation and retention in the lake sediments. BATHTUB provides flexibility to tailor model inputs to specific lake morphometry, watershed characteristics and watershed inputs. The BATHTUB model also allows IEPA to assess different impacts of changes in nutrient loading. BATHTUB allows the user the choice of several different mass-balance TP models for estimating loading capacity.

The loading capacity of the TP lake TMDLs were determined through the use of BATHTUB and the Canfield-Bachmann subroutine and then allocated to the WLA, LA, and MOS (Section 4.3 of the Decision Document). To simulate the load reductions needed to achieve the WQS, a series of model simulations were performed. Each simulation reduced the total amount of TP entering each of the water bodies during the growing season and computed the anticipated water quality response within the lake. The goal of the modeling simulations was to identify the loading capacity appropriate (i.e., the maximum allowable load to the system) necessary to attain WQS.

The BATHTUB modeling efforts were used to calculate the loading capacity for each lake. The loading capacity is the maximum phosphorus load which each of these water bodies can receive over an annual period and still meet the TP nutrient water quality targets (Table 9 of this Decision Document). Loading capacities were determined using Canfield-Bachmann equations from BATHTUB. The model equations were originally developed from data taken from over 704 lakes. The model estimates in-lake phosphorus concentration by calculating net phosphorus loss (e.g., phosphorus sedimentation) from annual phosphorus loads as functions of inflows to the lake, lake depth, and hydraulic flushing rate. To estimate loading capacity, the model is rerun, each time reducing current loads to the lake until the model result shows that in-lake total phosphorus would meet the applicable water quality standards.

IEPA subdivided the loading capacity among the WLA, LA, and MOS components of the TMDL (Table 9 of this Decision Document). These calculations were based on the critical condition, the summer growing season, which is typically when the water quality in each lake is typically degraded and phosphorus loading inputs are the greatest.

Table 9: Total Phosphorus TMDLs for the Upper Big Muddy River Watershed

Allocation	*Total Phosphorus*	
	(kg/day)	*(lbs./day)*
Herrin Old Reservior (IL_RNZD)		
Wasteload Allocation	0.00	0.00
Load Allocation	0.21	0.46
Margin of Safety (10%)	0.02	0.05
Loading Capacity	**0.23**	**0.51**
Johnson City Reservoir (IL_RNZE)		
Wasteload Allocation	0.00	0.00
Load Allocation	0.43	0.95
Margin of Safety (10%)	0.05	0.11
Loading Capacity	**0.48**	**1.06**
Arrowhead (Williamson) Reservoir (IL_RNZX)		
Wasteload Allocation	0.000	0.000
Load Allocation	0.076	0.170
Margin of Safety (10%)	0.008	0.020
Loading Capacity	**0.084**	**0.190**
West Frankfort Old Reservoir (IL_RNP)		
Wasteload Allocation	0.00	0.00
Load Allocation	0.45	0.98

Margin of Safety (10%)	0.05	0.11
Loading Capacity	**0.50**	**1.09**
West Frankfort New Reservoir (IL_RNQ)		
WLA - Thompsonville STP (IL0072478)	0.73	1.6
Wasteload Allocation - TOTAL	0.73	1.6
Load Allocation	0.09	0.2
Margin of Safety (10%)	0.09	0.2
Loading Capacity	**0.91**	**2.0**

EPA supports the data analysis and modeling approach utilized by IEPA in its calculation of WLA, LA and MOS for the total phosphorus TMDLs. Additionally, EPA concurs with the loading capacities calculated by the IEPA in its UBMRW total phosphorus TMDLs. EPA finds IEPA's approach for calculating the loading capacity for its UBMIRW total phosphorus TMDLs to be reasonable and consistent with EPA guidance.

The EPA finds that the TMDL document submitted by IEPA satisfies the requirements of the third criterion.

4. Load Allocations (LA)

EPA regulations require that a TMDL include LAs, which identify the portion of the loading capacity attributed to existing and future nonpoint sources and to natural background. Load allocations may range from reasonably accurate estimates to gross allotments (40 C.F.R. §130.2(g)). Where possible, load allocations should be described separately for natural background and nonpoint sources.

Comment:
IEPA determined the LA calculations for each of the TMDLs based on the applicable WQS. IEPA recognized that LAs for each of the individual TMDLs addressed by the UBMRW TMDLs can be attributed to different nonpoint sources. The calculated LA values for the are applicable across all flow conditions (Tables 5-9 of this Decision Document). IEPA identified several nonpoint sources which contribute bacteria and phosphorus loads to the surface waters of the UBMRW, including; non-regulated urban stormwater runoff, stormwater from agricultural and feedlot areas, failing septic systems and wildlife (i.e., deer, geese, ducks, raccoons, turkeys and other animals). For the iron and manganese TMDLs, IEPA identified agricultural runoff and mining related runoff as nonpoint sources. For the dissolved oxygen TMDL, which was addressed via an ammonia-nitrogen loading calculation, IEPA noted that nonpoint source runoff is not a significant source (Table 6 of this Decision Document) of the loading capacity, but nonpoint sources why may contribute are agricultural runoff, septic inputs and wildlife.

IEPA did not determine individual load allocation values for each of these potential nonpoint source considerations but aggregated the nonpoint sources into a categorical LA value.

EPA finds IEPA's approach for calculating the LA to be reasonable and consistent with EPA guidance.

The EPA finds that the TMDL document submitted by IEPA satisfies the requirements of the fourth criterion.

5. Wasteload Allocations (WLAs)

EPA regulations require that a TMDL include WLAs, which identify the portion of the loading capacity allocated to individual existing and future point source(s) (40 C.F.R. §130.2(h), 40 C.F.R. §130.2(i)). In some cases, WLAs may cover more than one discharger, e.g., if the source is contained within a general permit.

The individual WLAs may take the form of uniform percentage reductions or individual mass based limitations for dischargers where it can be shown that this solution meets WQSs and does not result in localized impairments. These individual WLAs may be adjusted during the NPDES permitting process. If the WLAs are adjusted, the individual effluent limits for each permit issued to a discharger on the impaired water must be consistent with the assumptions and requirements of the adjusted WLAs in the TMDL. If the WLAs are not adjusted, effluent limits contained in the permit must be consistent with the individual WLAs specified in the TMDL. If a draft permit provides for a higher load for a discharger than the corresponding individual WLA in the TMDL, the State/Tribe must demonstrate that the total WLA in the TMDL will be achieved through reductions in the remaining individual WLAs and that localized impairments will not result. All permittees should be notified of any deviations from the initial individual WLAs contained in the TMDL. EPA does not require the establishment of a new TMDL to reflect these revised allocations as long as the total WLA, as expressed in the TMDL, remains the same or decreases, and there is no reallocation between the total WLA and the total LA.

Comment:
UBMRW bacteria TMDLs: IEPA identified ten NPDES permitted facilities (Table 3 of this Decision Document) which contribute bacteria loads to the UBMRW bacteria TMDLs (Table 5 of this Decision Document). For most of the calculated WLAs, the WLA was calculated based on the facility's design average flow and the fecal coliform WQS (200 cfu/100 mL).

UBMRW dissolved oxygen impairment addressed via an ammonia-nitrogen TMDL: IEPA determined that there was one NPDES permitted facility, the Johnson City STP (IL0029301), which contributed ammonia-nitrogen loading to the Lake Creek (IL_NGA-02) segment and therefore, calculated a WLA for this facility. The WLA was based on the permitted design average flow for the facility and the facility's current NPDES effluent limit concentration for ammonia nitrogen (1.5 mg/L) (Table 5-1 of the final TMDL document).

UBMRW iron TMDL: The WLA was set to zero (WLA = 0) for the Andy Creek (IL_NZN-13) iron TMDL.

UBMRW manganese TMDL: The WLA was set to zero (WLA = 0) for the Beaver Creek (IL_NGAZ-JC-D1) manganese TMDL.

UBMRW total phosphorus TMDLs: IEPA determined that there was one NPDES permitted facility, the Thompsonville STP (IL0072478), which contributed phosphorus loading to the West Frankfort New Reservoir segment and therefore, calculated a WLA for this facility. The WLA was based on the facility's design average flow and the target effluent concentration for the facility (1.0 mg/L) (Section 5.11.2 of the final TMDL document).

The other four total phosphorus TMDLs, Herrin Old Reservoir (IL_RNZD), Johnson City Reservoir (IL_RNZE), Arrowhead (Williamson) Reservoir (IL_NRZX) and West Frankfort Old Reservoir (IL_RNP) had WLAs set to zero (WLA = 0).

EPA finds IEPA's approach for calculating the WLA for the UBMRW TMDLs to be reasonable and consistent with EPA guidance.

The EPA finds that the TMDL document submitted by IEPA satisfies the requirements of the fifth criterion.

6. Margin of Safety (MOS)

The statute and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality (CWA §303(d)(1)(C), 40 C.F.R. §130.7(c)(1)). EPA's 1991 TMDL 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. If the MOS is implicit, the conservative assumptions in the analysis that account for the MOS must be described. If the MOS is explicit, the loading set aside for the MOS must be identified.

Comment:

All TMDLs in the UBMRW incorporated an explicit Margin of Safety (MOS) of 10%. The explicit MOS was applied by reserving approximately 10% of the total loading capacity, and then allocating the remaining loads to point (WLA) and nonpoint sources (LA) (Tables 5-9 of this Decision Document).

The use of the LDC approach minimized variability associated with the development of the UBMRW TMDLs because the calculation of the loading capacity was a function of flow multiplied by the target value. The MOS was set at 10% to account for uncertainty due to field sampling error, basing assumptions on water quality monitoring with low sample sizes, and imperfect water quality targets. A 10% MOS was considered appropriate, because the target values used in this TMDL had a firm technical basis and the estimated flows are believed to be relatively accurate because they were estimated based on a USGS gage located with or just outside of the subwatershed with the impaired segments.

The margin of safety is appropriate because the use of the LDC provides an accurate account of existing stream conditions (calculated by multiplying daily flows by existing pollutant levels), and an accurate account of the stream's loading capacity (calculated by multiplying daily flows by the appropriate water quality target). In other words, there is a good fit between observed (existing) data and predicted data using the LDC approach, thus providing a relatively accurate determination of the TMDL reductions needed. IEPA accounts for any uncertainty in this method by incorporating the MOS.

For the total phosphorus TMDLs, IEPA also noted that an implicit MOS is included in the loadings. IEPA believes the default values used in the BATHTUB model are conservative, as they are based upon a wide range of lakes and reservoirs in the East and Midwest.

UBMRW bacteria TMDLs:
An additional conservative assumption which was applied to the bacteria TMDL development was that IEPA did not use a rate of decay, or die-off rate of pathogen species, in the TMDL calculations or in the creation of load duration curve for fecal coliform. Bacteria have a limited capability of surviving outside their hosts, and normally a rate of decay would be incorporated into the TMDL development process. IEPA determined that it was more conservative to use the WQS (200 cfu/100 mL) and not to apply a rate of decay, which could result in a discharge limit greater than the WQS.

As stated in *EPA's Protocol for Developing Pathogen TMDLs* (EPA 841-R-00-002), many different factors affect the survival of pathogens, including the physical condition of the water. These factors include, but are not limited to sunlight, temperature, salinity, and nutrient deficiencies. These factors vary depending on the environmental condition/circumstances of the water, and therefore it would be difficult to assert that the rate of decay caused by any given combination of these environmental variables was sufficient to meet the WQS of 200 cfu/100 mL. Thus, it is more conservative to apply the State's WQS as the water quality target for TMDL development, because this standard must be met at all times under all environmental conditions.

The EPA finds that the TMDL document submitted by IEPA contains an appropriate MOS satisfying the requirements of the sixth criterion.

7. Seasonal Variation

The statute and regulations require that a TMDL be established with consideration of seasonal variations. The TMDL must describe the method chosen for including seasonal variations. (CWA §303(d)(1)(C), 40 C.F.R. §130.7(c)(1)).

Comment:
IEPA properly accounted for seasonality for the bacteria, iron and manganese TMDLs by use of the LDC method (or the related loading capacity approach), which inherently accounts for seasonal variation by using daily flows over a multi-year period (Section 5 of the TMDL). LDC process for TMDL development efforts accounted for seasonal variation by utilizing streamflows over a wide range of flow conditions. For many of the LDC-based TMDLs in the UBMRW, runoff is the main transport mechanism which delivers pollutant loading into surface water environments. LDC graphs can provide insight toward understanding under which flow regimes/conditions exceedances of the WQS or water quality targets are occurring, and whether there is any seasonal flow component to those flow conditions (i.e., spring melt, summer precipitation events during lower flow periods, etc.)

As an example, bacterial loads vary by season, typically reaching higher numbers in the dry summer months when low flows and bacterial growth rates contribute to their abundance and reaching relatively lower values in colder months when bacterial growth rates attenuate and loading events, driven by stormwater runoff events aren't as frequent. Bacterial WQS need to be met between May 1st to October 31st, regardless of the flow condition. The development of the LDCs utilized estimated flow data from the nearby USGS gages (Table 27 of the final TMDL document). Flow data from the USGS gages represent a variety of flow conditions occurring in the recreation season. LDCs incorporated this flow information which was deemed representative of differing flow conditions and seasonal variability observed during the recreation season.

IEPA properly accounted for seasonality in the phosphorus TMDLs by use of monthly average precipitation records over a multi-year period in the BATHTUB model (Sections 5.11 of the TMDL). EPA agrees that this properly accounts for seasonal variations.

The EPA finds that the TMDL document submitted by IEPA satisfies the requirements of the seventh criterion.

8. Reasonable Assurance

When a TMDL is developed for waters impaired by point sources only, the issuance of a NPDES permit(s) provides the reasonable assurance that the wasteload allocations contained in the TMDL will be achieved. This is because 40 C.F.R. 122.44(d)(1)(vii)(B) requires that effluent limits in permits be consistent with, "the assumptions and requirements of any available wasteload allocation" in an approved TMDL.

When a TMDL is developed for waters impaired by both point and nonpoint sources, and the WLA is based on an assumption that nonpoint source load reductions will occur, EPA's 1991 TMDL Guidance states that the TMDL should provide reasonable assurances that nonpoint source control measures will achieve expected load reductions in order for the TMDL to be approvable. This information is necessary for EPA to determine that the TMDL, including the load and wasteload allocations, has been established at a level necessary to implement water quality standards.

EPA's August 1997 TMDL Guidance also directs Regions to work with States to achieve TMDL load allocations in waters impaired only by nonpoint sources. However, EPA cannot disapprove a TMDL for nonpoint source-only impaired waters, which do not have a demonstration of reasonable assurance that LAs will be achieved, because such a showing is not required by current regulations.

<u>Comment:</u>

IEPA outlines its reasonable assurance efforts in Section 7 of the final TMDL document. Additionally, the *Watershed Implementation Plan to Achieve the TMDLs and Load Reduction Strategy in the Upper Big Muddy River Watershed* (March 2019) document (i.e., the UBMRW Implementation Plan) from IEPA outlines management measures and programs which will be employed to attain the loading capacities and allocations calculated for the impaired reaches within the UBMRW. The UBMRW Implementation Plan was developed to meet EPA's required *Nine Minimum Elements* of a watershed management plan (i.e., the Nine Element Plan).

The recommendations made by IEPA will be successful at improving water quality if a local group takes ownership and follows through on implementation activities. Currently the UBMRW does not have a primary watershed group to take on these, and other tasks. IEPA recommends that a watershed group be formed with stakeholders from Lake Creek Watershed Council, the Great Egypt Regional Planning and Development Commission, NRCS, local county Soil and Water Conservation Districts (SWCD) (e.g., Franklin County SWCD), IEPA, county level Health Departments, the Illinois Farm Bureau and other farm service agencies and other interested local parties.

The UBMRW Implementation Plan anticipates that implementation will begin in the watershed, via BMPs and education and outreach programming, in the coming years. IEPA also explained that mitigation suggestions, which fall outside of regulatory authority, will require commitment from state agencies and local stakeholders to carry out the suggested actions.

Reasonable assurance that the WLA set forth will be implemented is provided by regulatory actions. According to 40 CFR 122.44(d)(1)(vii)(B), NPDES permit effluent limits must be consistent with assumptions and requirements of all WLAs in an approved TMDL. IEPA's NPDES permit program is one of the implementing programs for ensuring WLA are consistent with the TMDL. Current NPDES permits will remain in effect until the permits are reissued, provided that IEPA receives the NPDES permit renewal application prior to the expiration date of the existing NPDES permit.

Reasonable assurances that nonpoint source reductions will be achieved for all pollutants are described in Section 7 of the final TMDL document and also in greater detail in the UBMRW Implementation Plan. The UBMRW TMDL implementation efforts will be achieved through federal, state and local action. Federal funding, via the Section 319 grants program, can provide money to implement voluntary nonpoint source programs within the UBMRW.

The UBMRW Implementation Plan outlines various BMPs that, when implemented will reduce pollutant inputs to surface waters of the UBMRW. In Table 4-7 of the UBMRW Implementation Plan document, IEPA lists site-specific BMP costs and the expected acreage which specific BMPs will be employed in the UBMRW. In Section 4.6 of the UBMRW Implementation Plan, IEPA describes financial programming which may assist with funding implementation activities in the UBMRW. These programs include USDA-NRCS Environmental Quality Incentives Program (EQIP), USDA-NRCS Conservation Stewardship Program (CSP), USDA-NRCS Agricultural Conservation Easement Program (ACEP), USDA-NRCS Conservation Reserve Program (CRP), the Conservation Reserve Enhancement Program (CREP) and other programs at the state level. Table 6-2 of the UBMRW Implementation Plan provides an estimated implementation schedule of actions and activities in the watershed that can reduce bacteria loads into water bodies in the UBMRW. These actions address immediate (1-4 years), mid-term (5-10 years) and long-term (continuous) timeframes.

The EPA finds that this criterion has been adequately addressed.

9. Monitoring Plan to Track TMDL Effectiveness

EPA's 1991 document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA 440/4-91-001), recommends a monitoring plan to track the effectiveness of a TMDL, particularly when a TMDL involves both point and nonpoint sources, and the WLA is based on an assumption that nonpoint source load reductions will occur. Such a TMDL should provide assurances that nonpoint source controls will achieve expected load reductions and, such TMDL should include a monitoring plan that describes the additional data to be collected to determine if the load reductions provided for in the TMDL are occurring and leading to attainment of water quality standards.

Comment:
Section 7 of the UBMRW Implementation Plan includes contains discussion on future monitoring within the UBMRW and milestones. Continued water quality monitoring within the basin is supported by IEPA. Additional water quality monitoring results could provide insight into the success or failure of BMP systems designed to reduce bacteria loading into the surface waters of the watershed. Local watershed managers would be able to reflect on the progress of the various pollutant removal strategies and would have the opportunity to change course if observed progress is unsatisfactory.

Progress of TMDL implementation will be measured through monitoring efforts focused on:

- Tracking implementation of BMPs in the watershed;
- Estimating the effectiveness of BMPs;
- Additional monitoring of point source discharges in the watershed;
- Continued monitoring of impaired stream segments and tributaries;
- Monitoring storm-based high flow events; and
- Low flow monitoring in impaired stream segments.

IEPA anticipates continuing its ambient water quality monitoring in the UBMRW. The state conducts routine water quality monitoring (i.e., physical, chemical and biological parameters) on a rotating watershed basis. In addition to state efforts USACE, U.S. Geological Survey (USGS) and various wastewater treatment facilities are expected to continue their monitoring efforts in the UBMRW. Continuation of IEPA water quality monitoring efforts and coordinating data sharing with other entities in the UBMRW (e.g., USACE and USGS) will provide some water quality information for IEPA and local watershed managers to evaluate whether nor not water quality is improving in the UBMRW over time.

Water quality monitoring is a critical component of the adaptive management strategy employed as part of the implementation efforts utilized in the UBMRW. Water quality information will aid watershed managers in understanding how BMP pollutant removal efforts are impacting water quality. Water quality monitoring combined with an annual review of BMP efficiency will provide information on the success or failure of BMP systems designed to reduce pollutant loading into water bodies of the UBMRW. Watershed managers will have the opportunity to reflect on the progress or lack of progress and will have the opportunity to change course if progress is unsatisfactory.

The EPA finds that this criterion has been adequately addressed.

10. Implementation

EPA policy encourages Regions to work in partnership with States/Tribes to achieve nonpoint source load allocations established for 303(d)-listed waters impaired by nonpoint sources. Regions may assist States/Tribes in developing implementation plans that include reasonable assurances that nonpoint source LAs established in TMDLs for waters impaired solely or primarily by nonpoint sources will in fact be achieved. In addition, EPA policy recognizes that other relevant watershed management processes may be used in the TMDL process. EPA is not required to and does not approve TMDL implementation plans.

Comment:

IEPA outlined its approach to addressing point and nonpoint source pollution in its UBMRW Implementation Plan (Section 4). The findings from the UBMRW TMDLs will be used to inform the selection of implementation activities in the UBMRW. IEPA outlined the importance of prioritizing areas within the UBMRW, education and outreach efforts with local partners, and partnering with local stakeholders to improve water quality within the watershed.

UBMRW bacteria TMDLs:

The potential BMPs which, if installed and maintained in identified critical areas, would likely result in decreases in bacteria to surface waters of the UBMRW are:

- ***Filter strips and riparian buffers***– Can filter storm event runoff from cropland via vegetation which enhances infiltration and traps pollutant loads from overland flow.
- ***Exclusion fencing*** – Reducing livestock access to stream environments will lower the opportunity for direct transport of bacteria to surface waters. The installation of exclusion fencing near stream and river environments to prevent direct access for livestock
- ***Feedlot BMPs*** - installing alternative water supplies, and installing stream crossings between pastures, would work to reduce the influxes of bacteria and improve water quality within the watershed.
- ***Private septic system inspection and maintenance program*** - Septic systems are believed to be a source of bacteria to waters in the UBMRW. Failing systems are expected to be identified and addressed via upgrades to those septic systems not meeting local health ordinances. Septic system improvement priority should be given to those failing systems adjacent to surface waters (i.e., streams or lakes).
- ***Pasture management*** - Introducing rotational grazing to increase grass coverage in pastures and maintaining appropriate numbers of livestock per acre for grazing, can also aid in the reduction of bacteria inputs.
- ***Agricultural stormwater BMPs*** **–** Conservation tillage and or cover crop usage will slow overland flow during storm events.

UBMRW dissolved oxygen impairment addressed via an ammonia-nitrogen TMDL:

IEPA explained in its *Watershed Implementation Plan to Achieve the TMDLs and Load Reduction Strategy in the Upper Big Muddy River Watershed* document (Section 1) that the primary source of impairment for the Lake Creek (IL_NGA-02) segment was from the Johnson City STP (IL0029301) and that implementation efforts would focus on improving the performance of this permitted facility.

UBMRW iron TMDL: The potential BMPs which, if installed and maintained, would likely result in decreases in iron to surface waters of the UBMRW are:

- ***Filter strips, riparian buffers, bank stabilization and erosion control*** – Protection of streambanks within the watershed through planting of vegetated/buffer areas with grasses, legumes, shrubs or trees will mitigate sediment, with iron bound particulates, inputs into surface waters. These areas will filter stormwater runoff before the runoff enters the surface waters of the UBMRW. These BMPs can filter storm event runoff from cropland via vegetation which enhances infiltration and traps pollutant loads from overland flow.
- ***Agricultural stormwater BMPs*** **–** Conservation tillage and or cover crop usage will slow overland flow during storm events.

- ***Sediment basins*** – Can be effective measures to capture sediment inputs via structurally engineered detention basins prior to those sediment inputs entering surface water environments in the UBMRW.

UBMRW manganese TMDL: The potential BMPs which, if installed and maintained, would likely result in decreases in manganese to surface waters of the UBMRW are:

- ***Filter strips, riparian buffers, bank stabilization and erosion control*** – Protection of streambanks within the watershed through planting of vegetated/buffer areas with grasses, legumes, shrubs or trees will mitigate sediment, with manganese bound particulates, inputs into surface waters. These areas will filter stormwater runoff before the runoff enters the surface waters of the UBMRW. These BMPs can filter storm event runoff from cropland via vegetation which enhances infiltration and traps pollutant loads from overland flow.
- ***Agricultural stormwater BMPs –*** Conservation tillage and or cover crop usage will slow overland flow during storm events.
- ***Sediment basins*** – Can be effective measures to capture sediment inputs via structurally engineered detention basins prior to those sediment inputs entering surface water environments in the UBMRW.

UBMRW total phosphorus TMDLs: The potential BMPs which, if installed and maintained, would likely result in decreases in phosphorus to surface waters of the UBMRW are:

- ***Filter strips, riparian buffers, bank stabilization and erosion control*** – Protection of streambanks within the watershed through planting of vegetated/buffer areas with grasses, legumes, shrubs or trees will mitigate phosphorus inputs into surface waters. These areas will filter stormwater runoff before the runoff enters the surface waters of the UBMRW. An assessment of lakeshore erosional areas should be completed to evaluate areas where erosion control strategies (e.g., planting deep-rooted vegetation in areas thought to be eroding) could be implemented in the watersheds which drain to the five phosphorus impaired water bodies.
- ***Nutrient management*** – These strategies involve reducing nutrient transport from fields and minimizing soil loss. Specific practices would include; erosion control through conservation tillage, reduction of winter spreading of fertilizers, elimination of fertilizer spreading near open inlets and sensitive areas, installation of stream and lake shore buffer strips and nutrient management planning.
- ***Phosphorus-based lawn fertilizer restrictions*** – Runoff from urban and suburban areas may include phosphorus-based fertilizers. Reducing stormwater input from residential lawns, golf courses and other urban/suburban surfaces will reduce the phosphorus inputs to surface waters. Some of these practices could include; rain gardens, municipal street sweeping efforts, lake shore buffer strips, vegetation management and water quality educational programs which aim to inform the general public on nutrient reduction efforts and their impact on water quality.
- ***Private septic system inspection and maintenance program*** - Septic systems are believed to be a source of nutrients to waters in the UBMRW. Failing systems are expected to be identified and addressed via upgrades to those septic systems not meeting local health ordinances. Septic system improvement priority should be given to those failing systems adjacent to surface waters (i.e., streams or lakes).
- ***In-lake phosphorus loading (internal loading)*** - Internal nutrient loads may be addressed to meet the TMDL allocations of the UBMRW phosphorus TMDLs.

- *Hypolimnetic aeration:* Increasing oxygen at selected depths in a lake may enhance oxygen transfer efficiencies and reduce internal loading from phosphorus laden lake bottom sediments.
- *Phosphorus inactivation from aluminum addition (i.e., aluminum sulfate or alum):* The addition of chemical reactants (e.g., aluminum sulfate) in order for those reactants to permanently bind phosphorus into the lake bottom sediments. This effort could decrease phosphorus releases from sediment into the lake water column during anoxic conditions.
- *Dredging of lake bottom sediments:* IEPA explained that phosphorus release from lake bottom sediments is greatest from the recently deposited phosphorus rich layers of lake sediments. Removing this material, via dredging efforts, will contribute to reductions in internal loading.

***Education and Outreach Efforts* -** Increased education and outreach efforts to the general public bring greater awareness to the issues surrounding bacteria, dissolved oxygen, iron, manganese and phosphorus contamination and strategies for reducing loading and transport of these pollutants should be prioritized as part of the overall implementation strategy.

The EPA finds that this criterion has been adequately addressed.

11. Public Participation

EPA policy is that there should be full and meaningful public participation in the TMDL development process. The TMDL regulations require that each State/Tribe must subject calculations to establish TMDLs to public review consistent with its own continuing planning process (40 C.F.R. §130.7(c)(1)(ii)). In guidance, EPA has explained that final TMDLs submitted to EPA for review and approval should describe the State's/Tribe's public participation process, including a summary of significant comments and the State's/Tribe's responses to those comments. When EPA establishes a TMDL, EPA regulations require EPA to publish a notice seeking public comment (40 C.F.R. §130.7(d)(2)).

Provision of inadequate public participation may be a basis for disapproving a TMDL. If EPA determines that a State/Tribe has not provided adequate public participation, EPA may defer its approval action until adequate public participation has been provided for, either by the State/Tribe or by EPA.

Comment:

The public participation section of the TMDL submittal is found in Section 8 of the final TMDL document. Throughout the development of the UBMRW TMDLs the public was given various opportunities to participate. Initial UBMRW TMDL public meetings were held in November and December of 2013 in West Frankfort, Illinois. IEPA described the watershed plan, the TMDL process and answered questions posed by those in attendance. The public comment period for the draft TMDL opened on November 15, 2018 and concluded on December 15, 2018. IEPA posted the draft TMDL online at (https://www2.illinois.gov/epa/public-notices/Documents/1_UpperBigMuddy_Stage3_Draft%20Report_20181015_clean.pdf) for the public comment period. IEPA held a public meeting on November 15, 2018 in West Frankfort, IL to present its public notice TMDL draft and discuss its findings.

IEPA received public comments during the public comment period and those comments are presented in Attachment 8 of the final TMDL document. IEPA's responses to those comments are presented in Attachment 9 of the final TMDL document in IEPA's UBMRW Responsiveness Summary. Many of the comments were related to southern Illinois mining topics with a majority of the commenters concerned about the impact of active and closed mining operations on surface water quality (i.e., impact of increased chloride and sulfate discharges to surface waters in the UBMRW), surface water quantity (i.e., flooding), potential loss of recreational opportunities, potential loss of biological diversity in the UBMRW (i.e., diminished fish species and freshwater mussel population) and potential property loss and/or negative impacts of proposed mining permit revisions.

Commenters also requested clarification and additional description related to;

- IEPA's selection of water quality targets used to develop TMDL and Load Reduction Strategy endpoints;
- IEPA's rationale for removing segments from its 303(d) list for sulfate;
- IEPA's analysis of dissolved oxygen data and its use of DO data in its QUAL-2E modeling efforts;
- IEPA's efforts to address NPDES permit violations for certain permittees in the UBMRW and
- Various shortcomings identified by the commenters in IEPA's UBMRW Implementation Plan (e.g., source and monitoring discussion deficiencies, funding and reasonable assurance discussion deficiencies, etc.)

EPA reviewed the comments and IEPA responses and determined that IEPA responded to the comments and adjusted the UBMRW TMDL and UBMRW Implementation Plan accordingly. In response to comments, IEPA included a TMDL addressing chloride for Pond Creek (IL_NG-02) as part of its final April 29, 2019 UBMRW TMDL submittal but as noted in Section 12 of this Decision Document, subsequently withdrew the chloride TMDL for the Pond Creek segment. IEPA submitted all comments received during the public notice period and its response summary with the final TMDL submittal packet received by the EPA on April 29, 2019.

The EPA finds that the TMDL document submitted by IEPA satisfies the requirements of this eleventh element.

12. Submittal Letter

A submittal letter should be included with the TMDL submittal, and should specify whether the TMDL is being submitted for a *technical review* or *final review and approval*. Each final TMDL submitted to EPA should be accompanied by a submittal letter that explicitly states that the submittal is a final TMDL submitted under Section 303(d) of the Clean Water Act for EPA review and approval. This clearly establishes the State's/Tribe's intent to submit, and EPA's duty to review, the TMDL under the statute. The submittal letter, whether for technical review or final review and approval, should contain such identifying information as the name and location of the water body, and the pollutant(s) of concern.

Comment:
The EPA received the final Upper Big Muddy River watershed TMDL document, submittal letter and accompanying documentation from IEPA on April 29, 2019. The submittal letter explicitly stated that the final TMDLs referenced in Table 1 of this Decision Document were being submitted to EPA pursuant to Section 303(d) of the Clean Water Act for EPA review and approval. The submittal letter also included the name and location of the water bodies and the causes/pollutants of concern. This TMDL was submitted per the requirements under Section 303(d) of the Clean Water Act and 40 CFR 130.

IEPA shared a letter with EPA on May 6, 2019 which formally withdrew a chloride TMDL for Pond Creek (IL_NG-02) which was included in the final April 29, 2019 UBMRW TMDL submittal. IEPA explained that it would re-submit the Pond Creek chloride TMDL to EPA after IEPA had completed a public notice period for this TMDL and supporting documentation.

The EPA finds that the TMDL transmittal letter submitted for the Upper Big Muddy River watershed TMDLs by IEPA satisfies the requirements of this twelfth element.

13. Conclusion

After a full and complete review, the EPA finds that the two (2) bacteria, one (1) dissolved oxygen, 1 iron, 1 manganese and five (5) total phosphorus TMDLs satisfy all elements of approvable TMDLs. This TMDL approval is for **10 TMDLs**, addressing segments for primary contact recreation use, aquatic life use and aesthetic quality impairments (Table 1 of this Decision Document).

The EPA's approval of these TMDLs extends to the water bodies which are identified above with the exception of any portions of the water bodies that are within Indian Country, as defined in 18 U.S.C. Section 1151. The EPA is taking no action to approve or disapprove TMDLs for those waters at this time. The EPA, or eligible Indian Tribes, as appropriate, will retain responsibilities under the CWA Section 303(d) for those waters.

ATTACHMENTS

Attachment #1: Table 5: Bacteria TMDLs for the Upper Big Muddy River Watershed

Attachment #2: Table 7: Iron TMDL for the Upper Big Muddy River Watershed

Attachment #3: Table 8: Manganese TMDL for the Upper Big Muddy River Watershed

Table 5: Bacteria TMDLs in the Upper Big Muddy River Watershed

Allocation	**Flow Zone**	**High Flows**			**Normal Flows**				**Low Flows**		
	Flow Exceedance Range (%)	**0 - 10**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**50 - 60**	**60 - 70**	**70 - 80**	**80 - 90**	**90 - 100**
	Source	*Fecal coliform load (colony forming units (cfu)/day)*									
Upper Big Muddy River (IL_N-11)											
Wasteload Allocation	WLA- Valier STP (ILG580083)	6.06E+08	6.06E+08	6.06E+08	6.06E+08	6.06E+08	6.06E+08	6.06E+08	6.06E+08	6.06E+08	6.06E+08
	WLA - West City STP (ILG580215)	7.57E+08	7.57E+08	7.57E+08	7.57E+08	7.57E+08	7.57E+08	7.57E+08	7.57E+08	7.57E+08	7.57E+08
	WLA - Hanaford STP (ILG580221)	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08
	WLA - Orient STP (ILG580272)	5.69E+08	5.69E+08	5.69E+08	5.69E+08	5.69E+08	5.69E+08	5.69E+08	5.69E+08	5.69E+08	5.69E+08
	WLA - LB Camping Sesser STP (IL0050466)	3.86E+07	3.86E+07	3.86E+07	3.86E+07	3.86E+07	3.86E+07	3.86E+07	3.86E+07	3.86E+07	3.86E+07
	WLA - Hill City Apartments - Benton (IL0061760)	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07
	WLA - Rend Lake Conservation District STP (IL0065111)	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09
	WLA - Christopher STP (IL0020851)	5.81E+09	5.81E+09	5.81E+09	5.81E+09	5.81E+09	5.81E+09	5.81E+09	5.81E+09	5.81E+09	5.81E+09

	WLA - Benton Northwest STP (IL0022365)	7.65E+09	7.65E+09	7.65E+09	7.65E+09	7.65E+09	7.65E+09	7.65E+09	7.65E+09	7.65E+09	7.65E+09
	WLA - West Frankfort STP (IL0031704)	1.06E+10	1.06E+10	1.06E+10	1.06E+10	1.06E+10	1.06E+10	1.06E+10	1.06E+10	1.06E+10	1.06E+10
	Wasteload Allocation Total	3.02E+10	3.02E+10	3.02E+10	3.02E+10	3.02E+10	3.02E+10	3.02E+10	3.02E+10	3.02E+10	3.02E+10
Load Allocation		3.53E+13	2.95E+12	1.24E+12	7.25E+11	4.27E+11	2.48E+11	1.41E+11	7.71E+10	4.73E+10	3.14E+10
Margin of Safety		*Implicit MOS*									
Loading Capacity		**3.53E+13**	**2.98E+12**	**1.27E+12**	**7.55E+11**	**4.57E+11**	**2.78E+11**	**1.71E+11**	**1.07E+11**	**7.75E+10**	**6.16E+10**
Percent Reduction		95.6%			94.4%				4.8%		
Upper Big Muddy River (IL_NH-06)											
Wasteload Allocation	WLA - Hanaford STP (ILG580221)	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08	3.18E+08
	WLA - Hill City Apartments - Benton (IL0061760)	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07	3.03E+07
	WLA - Rend Lake Conservation District STP (IL0065111)	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09	3.79E+09
	Wasteload Allocation Total	4.14E+09	4.14E+09	4.14E+09	4.14E+09	4.14E+09	4.14E+09	4.14E+09	4.14E+09	4.14E+09	4.14E+09
Load Allocation		1.82E+13	1.53E+12	6.50E+11	3.84E+11	2.31E+11	1.39E+11	8.38E+10	5.10E+10	3.57E+10	2.75E+10
Margin of Safety		*Implicit MOS*									
Loading Capacity		**1.82E+13**	**1.53E+12**	**6.54E+11**	**3.88E+11**	**2.35E+11**	**1.43E+11**	**8.79E+10**	**5.51E+10**	**3.98E+10**	**3.16E+10**
Percent Reduction		99%			99.7%				88.6%		

Table 7: Iron TMDL in the Upper Big Muddy River Watershed

Allocation	**Flow Zone**	**High Flows**			**Normal Flows**				**Low Flows**		
	Flow Exceedance Range (%)	**0 - 10**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**50 - 60**	**60 - 70**	**70 - 80**	**80 - 90**	**90 - 100**
	Source	*Iron (lbs./day)*									
Andy Creek (IL_NZN-13)											
Wasteload Allocation	**Wasteload Allocation Total**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Load Allocation		2287.00	194.00	74.80	43.70	23.40	11.90	5.00	2.20	0.94	0.24
Margin of Safety (10%)		254.00	22.00	8.30	4.90	2.60	1.30	0.55	0.25	0.10	0.03
Loading Capacity		**2541.00**	**216.00**	**83.10**	**48.60**	**26.00**	**13.20**	**5.55**	**2.45**	**1.04**	**0.27**
Percent Reduction		9.9%			--				--		

Table 8: Manganese TMDL in the Upper Big Muddy River Watershed

Allocation	**Flow Zone**	**High Flows**			**Normal Flows**				**Low Flows**		
	Flow Exceedance Range (%)	**0 - 10**	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**50 - 60**	**60 - 70**	**70 - 80**	**80 - 90**	**90 - 100**
	Source	*Iron (lbs./day)*									
Beaver Creek (IL_NGAZ-JC-D1)											
Wasteload Allocation	**Wasteload Allocation Total**	--	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--	--
Load Allocation		--	28.20	11.00	6.40	3.40	1.70	0.73	0.32	--	--
Margin of Safety (10%)		--	3.10	1.20	0.70	0.40	0.20	0.08	0.04	--	--
Loading Capacity		--	**31.30**	**12.20**	**7.10**	**3.80**	**1.90**	**0.81**	**0.36**	--	--
Percent Reduction		--			24.4%				--		

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TMDL Report

Upper Big Muddy Watershed

Prepared for:
Illinois EPA

Final Report
May 2019

LimnoTech
Water Environment | Scientists Engineers

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Upper Big Muddy River Watershed Total Maximum Daily Load

Prepared for:
Illinois EPA

Final Report
May 2019

Prepared by:
LimnoTech

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Executive Summary

Section 303(d) of the 1972 Clean Water Act requires States to define impaired waters and identify them on a list, which is called the 303(d) list. The State of Illinois 303(d) lists are published every two years and are available at: https://www2.illinois.gov/epa/topics/water-quality/watershed-management/tmdls/Pages/303d-list.aspx. This report focuses on assessments based on the 2012 303(d) list (IEPA, 2012), which was the version that was final at the start of this project. Section 303(d) of the Clean Water Act and USEPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not meeting designated uses under technology-based controls. The TMDL process establishes the allowable loading of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and instream conditions. This allowable loading represents the maximum quantity of the pollutant that the waterbody can receive without exceeding water quality standards. The TMDL also takes into account a margin of safety, which reflects scientific uncertainty, as well as the effects of seasonal variation. By following the TMDL process, States can establish water quality-based controls to reduce pollution from both point and nonpoint sources, and restore and maintain the quality of their water resources (USEPA, 1991).

Load Reduction Strategies (LRSs) are being completed for causes that do not have numeric standards. LRSs for causes of impairment with target criteria will consist of loading capacity and the percent reduction needed to meet the target criteria.

The following waterbodies in the Upper Big Muddy River watershed are listed on the 2012-2018 Illinois Section 303(d) List of Impaired Waters (IEPA, 2012) as not meeting their designated uses. IEPA conducted additional sampling in 2015 on 6 of the waterbodies to support the modeling presented in this report. This document presents TMDLs for the following segments and reservoirs to allow these waterbodies to fully support their designated uses:

- Upper Big Muddy River (IL_N-11)
- Andy Cr. (IL_NZN-13)
- Lake Cr. (IL_NGA-02)
- Pond Cr. (IL_NG-02)
- Beaver Cr. (IL_NGAZ-JC-D1)
- Middle Fork Big Muddy (IL_NH-06)
- Arrowhead (Williamson) Lake (IL_RNZX)
- Herrin Old Reservoir (IL_RNZD)
- Johnston City Lake (IL_RNZE)
- West Frankfort Old Lake (IL_RNP)
- West Frankfort New Lake (IL_RNQ)

LRSs for the following water bodies are also presented:

- Upper Big Muddy River (IL_N-06, IL_N-11, IL_N-17)
- Pond Cr. (IL_NG-02)
- Middle Fork Big Muddy (IL_NH-07)

This report covers each step of the TMDL process and is organized as follows:

- Problem Identification
- Stage 2 Sampling
- Development of Numeric Targets
- Development of Water Quality Models
- TMDL Development
- LRS Development
- Public Participation and Involvement
- Adaptive Implementation Process
- Clean Water Act Section 319

Illinois EPA conducts TMDLs following a three-stage process. Stage 1 includes watershed characterization, data analysis and model selection. Stage 2 involves data collection, and is conducted if necessary. Stage 3 includes model calibration and application, and TMDL and implementation plan development. Upper Big Muddy River Watershed Stage 1 work began in September, 2013. A public meeting to present the Stage 1 findings and the draft Stage 1 report was held in December 2013. The final Stage 1 report was completed in January, 2014 (Attachment 1), and recommended additional monitoring for dissolved oxygen modeling, and the delisting of the following stream segments for the noted impairments:

- Andy Cr. / IL_NZN-13 – Manganese
- Hurricane Creek / IL_NF-01 – Lindane
- M. Fk. Big Muddy / IL_NH-06 – Manganese
- M. Fk. Big Muddy / IL_NH-07 – Manganese
- Prairie Cr. / IL_NZM-01 – Sulfates

Stage 2 low flow sampling was conducted in 2015 to support dissolved oxygen modeling on several stream segments in the Upper Big Muddy River watershed. As a result of this sampling and data analysis, the following stream segments are recommended for delisting based on either the waters meeting the water quality standards during the sampling period, or the low dissolved ozygen conditions were flow related:

- Big Muddy R. / IL_N-17 - Dissolved Oxygen (Sampling met WQS)
- M. Fk. Big Muddy / IL_NH-06 - Dissolved Oxygen (Low DO is due to high sediment oxygen demand / low flow)
- M. Fk. Big Muddy / IL_NH-07 - Dissolved Oxygen (Low DO is due to high sediment oxygen demand / low flow)
- Andy Creek / IL_NZN-13 - Dissolved Oxygen (Low DO is due to high sediment oxygen demand / low flow)
- Pond Cr. / IL_NG-02 - Dissolved Oxygen (Sampling met WQS)

Further data analysis as a part of the Stage 3 TMDL/LRS preparation on the following segments has indicated that the listed impairment may not currently exist:

- Hurricane Creek / IL_NF-01 - Sedimentation/Siltation
- Herrin Old / IL_RNZD - Total Suspended Solids (TSS)
- Johnston City / IL_RNZE - Total Suspended Solids (TSS)
- West Frankfort Old / IL_RNP - Total Suspended Solids (TSS)
- West Frankfort New/ IL_RNQ - Total Suspended Solids (TSS)
- Lake Cr. / IL_NGA-02 - Phosphorus (Total)
- Big Muddy R. / IL_N-11 - Sulfates

The results of these data alayses will be reevaluated during the next 303(d) listing cycle to determine if these stream segments should continue to be listed as impaired.

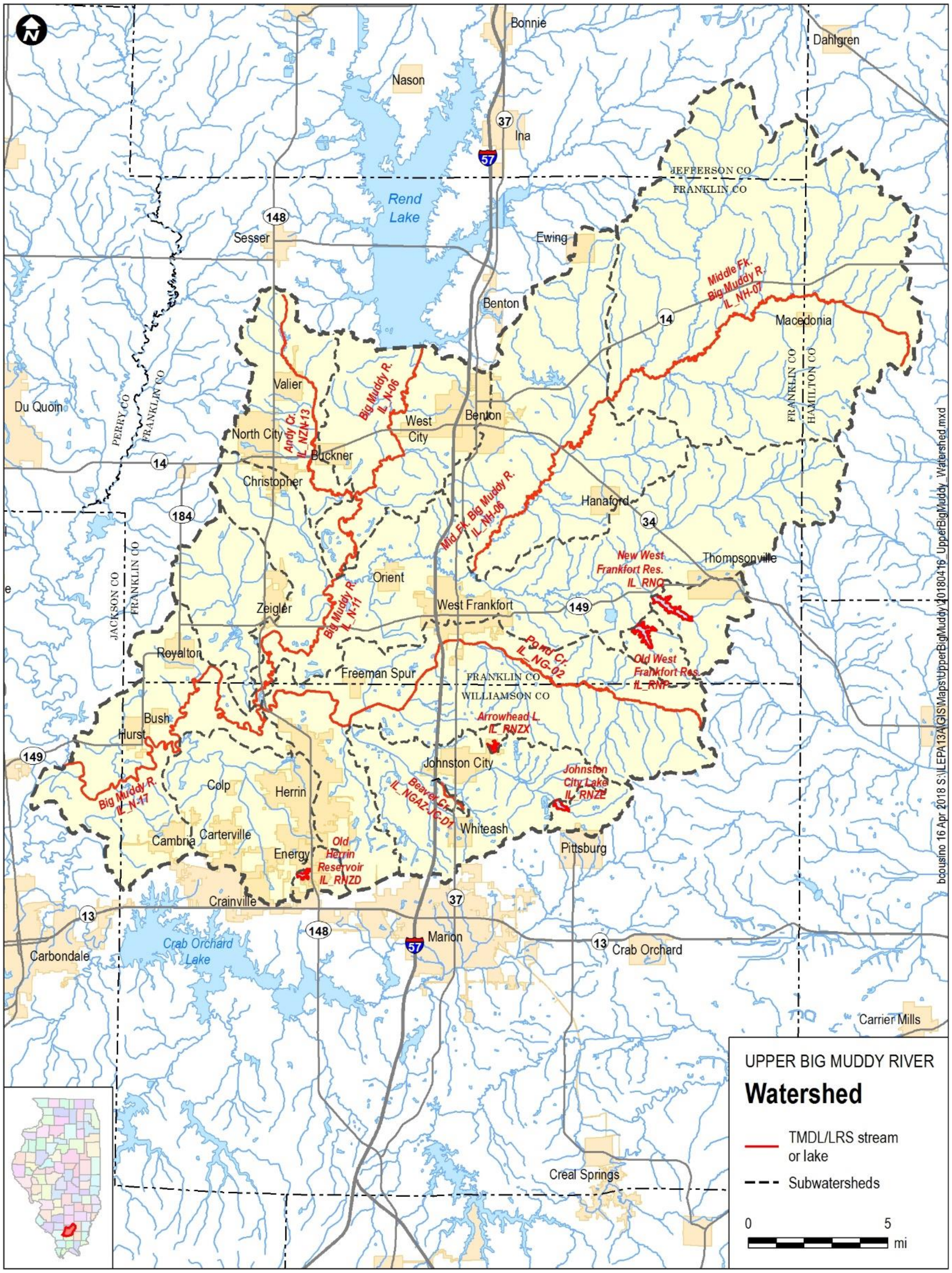

Figure 1-1. Upper Big Muddy River Watershed

1

Problem Identification

The impaired waterbodies within the Upper Big Muddy River watershed listed by the IEPA are listed below (Table 1-1), with the parameters (causes) they are listed for, and the impairment status of each designated use. The waterbodies that are proposed for delisting in the Table below are based on one of the following reasons:

1. Analysis of the data provided under Stage 1 that the existing data did not support the listed impairments.
2. Analysis of the data collected during the Stage 2 sampling performed for IEPA indicated that the impairments may not currently exist.
3. Analysis of the data collected during the Stage 2 sampling performed for IEPA indicated that the impairments are due to low flow conditions, not pollutant loading.
4. Based on a comparison of TSS data to the LRS target concentration developed by IEPA, it was determined that TSS reduction is not needed.
5. Based on a comparison of TP data to the LRS target concentration developed by IEPA, it was determined that TP reduction is not needed.

Table 1-1. Impaired Waterbody Summary

Waterbody/ Segment ID	Size (mile/ac)	Impaired Designated Use	Impairment Cause	Proposed Action
Big Muddy R. / IL_N-06	15.13 mi	Aquatic life	Sedimentation/Siltation	Prepare LRS
Big Muddy R. / IL_N-11	11.48 mi	Aquatic life	Sulfates	**Delist (1)**
		Primary contact recreation	Fecal Coliform	Prepare TMDL
		Aquatic life	Sedimentation/Siltation, TSS	Prepare LRS
Big Muddy R. / IL_N-17	21.48 mi	Aquatic life	Dissolved Oxygen	**Delist (2)**
		Aquatic life	Sedimentation/Siltation, TSS	Prepare LRS
Hurricane Creek / IL_NF-01	10.6 mi	Aquatic life	Lindane	**Delist (1)**
		Aquatic life	Sedimentation/Siltation	**Delist (4)**
Prairie Cr. / IL_NZM-01	9.06 mi	Aquatic life	Sulfates	**Delist (1)**
Andy Cr. / IL_NZN-13	11.7 mi	Aquatic life	Iron	Prepare TMDL
		Aquatic life	Manganese	Delist (1)
		Aquatic life	Dissolved Oxygen	Delist (3)
Herrin Old / IL_RNZD	51.3 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
		Aesthetic Quality	Total Suspended Solids (TSS)	**Delist (4)**

Waterbody/ Segment ID	Size (mile/ac)	Impaired Designated Use	Impairment Cause	Proposed Action
Pond Cr. / IL_NG-02	23.53 mi	Aquatic life	Chloride	Additional monitoring recommended
		Aquatic life	Dissolved Oxygen	**Delist (2)**
		Aquatic life	Sedimentation/Siltation	Prepare LRS
Lake Cr. / IL_NGA-02	12.33 mi	Aquatic life	Dissolved Oxygen	Prepare TMDL
		Aquatic life	Phosphorus (Total)	**Delist (5)**
Beaver Cr. / IL_NGAZ-JC-D1	1.7 mi	Aquatic life	Manganese	Prepare TMDL
Johnston City / IL_RNZE	64 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
		Aesthetic Quality	Total Suspended Solids (TSS)	**Delist (4)**
Arrowhead (Williamson) / IL_RNZX	30 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
M. Fk. Big Muddy / IL_NH-06	12.52 mi	Primary contact recreation	Fecal Coliform	Prepare TMDL
		Aquatic life	Dissolved Oxygen	**Delist (3)**
		Aquatic life	Manganese	**Delist (1)**
M. Fk. Big Muddy / IL_NH-07	19.74 mi	Aquatic life	Dissolved Oxygen	**Delist (3)**
		Aquatic life	Manganese	**Delist (1)**
		Aquatic life	Sedimentation/Siltation	Prepare LRS
West Frankfort Old / IL_RNP	146 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
		Aesthetic Quality	Total Suspended Solids (TSS)	**Delist (4)**
West Frankfort New/ IL_RNQ	214 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
		Aesthetic Quality	Total Suspended Solids (TSS)	**Delist (4)**

A Chloride TMDL for Pond Cr. (IL_NG-02) was not developed based on the Stage 1 Report's recommendation. However, Illinois EPA will gather additional low flow data to verify if impairment still exists and proceed accordingly (either develop TMDL, or delist the segment in the next cycle of the 2020 Integrated Report). Delisting of the stream segments identified in Table 1-1 will occur as a part of a future 303(d) listing process based on the reasons noted above. TMDLs are currently only being developed for pollutants that have numerical water quality standards. Load Reduction Strategies (LRSs) are being developed for pollutants that do not have numerical water quality standards. All of the waterbodies that are being addressed in this Stage 3 report and the implementation plan are summarized in Table 1-2 below.

Table 1-2. TMDL & LRS Waterbody Summary

Waterbody/ Segment ID	Size (mile/ac)	Impaired Designated Use	Impairment Cause	Proposed Action
Big Muddy R. / IL_N-06	15.13 mi	Aquatic life	Sedimentation/Siltation	Prepare LRS
Big Muddy R. / IL_N-11	11.48 mi	Primary contact recreation	Fecal Coliform	Prepare TMDL
		Aquatic life	Sedimentation/Siltation, TSS	Prepare LRS
Big Muddy R. / IL_N-17	21.48 mi	Aquatic life	Sedimentation/Siltation, TSS	Prepare LRS

Waterbody/ Segment ID	Size (mile/ac)	Impaired Designated Use	Impairment Cause	Proposed Action
Andy Cr. / IL_NZN-13	11.7 mi	Aquatic life	Iron	Prepare TMDL
Herrin Old / IL_RNZD	51.3 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
Pond Cr. / IL_NG-02	23.53 mi	Aquatic life	Sedimentation/Siltation	Prepare LRS
Lake Cr. / IL_NGA-02	12.33 mi	Aquatic life	Dissolved Oxygen	Prepare TMDL
Beaver Cr. / IL_NGAZ-JC-D1	1.7 mi	Aquatic life	Manganese	Prepare TMDL
Johnston City / IL_RNZE	64 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
Arrowhead (Williamson) / IL_RNZX	30 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
M. Fk. Big Muddy / IL_NH-06	12.52 mi	Primary contact recreation	Fecal Coliform	Prepare TMDL
M. Fk. Big Muddy / IL_NH-07	19.74 mi	Aquatic life	Sedimentation/Siltation	Prepare LRS
West Frankfort Old / IL_RNP	146 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL
West Frankfort New/ IL_RNQ	214 ac	Aesthetic Quality	Phosphorus (Total)	Prepare TMDL

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2

Stage 2 Sampling

The Stage 1 report recommended additional sampling be conducted during low flow conditions to support dissolved oxygen modeling in support of TMDL development. In 2015, IEPA conducted Stage 2 sampling to support dissolved oxygen TMDL modeling. Samples were collected in September and October of 2015, and data were reported for CBOD5, BOD5, Nitrite-Nitrate Nitrogen, Ammonia, total kjeldahl nitrogen (TKN), total phosphorus, dissolved phosphorus, chlorophyll a, total suspended solids and volatile suspended solids, and sediment oxygen demand (SOD). Flow, velocity and channel morphometry were also recorded during sampling.

Figure 2-1 shows the locations sampled in 2015. The data collected at these locations were used in the dissolved oxygen modeling described in this report. TMDLs and LRSs for other parameters were based on existing data, previously collected by IEPA and described in the Stage 1 report (Attachment 1).

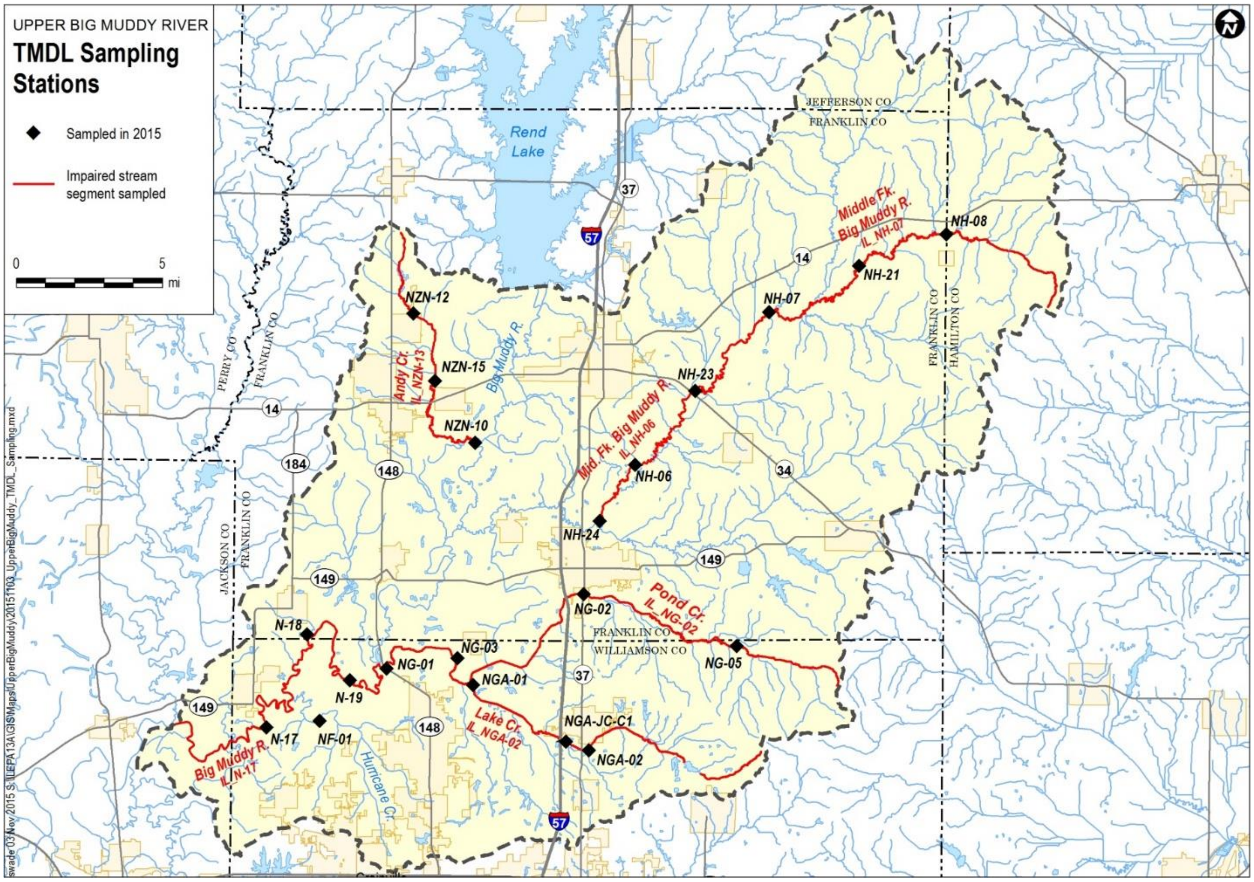

Figure 2-1. 2015 Sampling Locations in the Upper Big Muddy River Watershed

3

Development of Numeric Targets

Designated use, use support and water quality criteria for waterbodies in the Upper Big Muddy River watershed have been previously described in the Stage 1 Report (Attachment 1). This section describes the development of numeric TMDL and LRS targets.

3.1 Development of TMDL and LRS Targets

The TMDL target is a numeric endpoint specified to represent the level of acceptable water quality that is to be achieved by implementing the TMDL. Where possible, the water quality criterion for the pollutant of concern is used as the numeric endpoint.

3.1.1 Phosphorus (Total)

The General Use standards for phosphorus are in Section 302.205 of Title 35. For the phosphorus TMDLs in the lakes within the Upper Big Muddy River watershed, the target is set at the water quality criterion for total phosphorus of 0.05 mg/L.

When appropriate numeric standards do not exist, surrogate parameters must be selected to represent protection of the designated use. For streams and rivers in the Upper Big Muddy River watershed, IEPA has developed a total phosphorus LRS target of 0.217 mg/L (IEPA, 2016). This target is based on an average of validated, real-world data (1999-2013) for the nearby Upper Kaskaskia watershed, which contains several streams that are in full support of aquatic life. This LRS target was ultimately not used to develop a total phosphorus LRS because the average phosphorus concentrations measured in the stream segments listed for TP impairment were below this LRS target concentration.

3.1.2 Dissolved Oxygen

The General Use standards for dissolved oxygen are in Section 302.206 of Title 35. For the Upper Big Muddy River watershed dissolved oxygen TMDLs in streams, the target is set at the water quality criterion for daily minimum dissolved oxygen of 5.0 mg/L recognizing that this is the more conservative of the seasonal minimal dissolved oxygen criteria (recall that between August and February, the minimum is 3.5 mg/L). The QUAL2E models used to calculate the TMDLs predicts a daily average dissolved oxygen concentration and does not directly predict daily minimum values. QUAL2E results can be translated into a form comparable to a daily minimum, by subtracting the observed difference between daily average and daily minimum dissolved oxygen from the model output.

3.1.3 Iron

The General Use standards for iron are in Section 302.208 of Title 35. A single-value standard of 1.0 mg/L applies to dissolved iron, and this is the target used for TMDL development for the Andy Creek (IL_NZN-13) segment.

3.1.4 Chloride

The General Use standards for chloride are in Section 302.208 of Title 35. A single-value standard of 500 mg/L applies to chloride, and this is the target used for TMDL development for the Pond Creek (IL_NG-02) segment.

3.1.5 Manganese

The General Use standards for manganese are in Section 302.208 of Title 35. The water quality standards for dissolved manganese are given by the following equations:

Acute Standard:

$WQS = e^{A+Bln(H)} \times 0.9812$

where A = 4.9187 and B = 0.7467;

and ln(H) is the natural logarithm of the hardness in mg/L.

Chronic Standard:

$WQS = e^{A+Bln(H)} \times 0.9812$

where A = 4.0635 and B = 0.7467;

and ln(H) is the natural logarithm of the hardness in mg/L.

The chronic standard was used to develop the manganese TMDL for Beaver Cr. (IL_NGAZ-JC-D) in the Upper Big Muddy River watershed. The calculated target for this stream segment is shown in section 4.2.6.

3.1.6 Fecal Coliform

The General Use standards for fecal coliform bacteria are in Section 302.209 of Title 35. During the months May through October (swimming-season), based on a minimum of five samples taken over not more than a 30 day period, fecal coliform bacteria shall not exceed a geometric mean of 200 per 100 mL, nor shall more than 10% of the samples during any 30 day period exceed 400 per 100 mL. For fecal coliform TMDLs in the Upper Big Muddy River watershed, the target is conservatively set at the water quality criterion of 200 colony forming units (cfu)/100 mL.

3.1.7 Total Suspended Solids (TSS)

When appropriate numeric standards do not exist, surrogate parameters must be selected to represent protection of the designated use. For all streams and rivers in the Upper Big Muddy River watershed, IEPA has developed a LRS target of 32.2 mg/L TSS (IEPA, 2016). This target is based on an average of validated, real-world data (1999-2013) for the nearby Upper Kaskaskia watershed, which contains several streams that are in full support of aquatic life.

Based on an average of validated, real-world data for these streams over a period from 1999 to 2013, the load reduction targets for all streams in this watershed are as follows:

- Total Suspended Solids: 32.2 milligrams/liter

For all lakes in the watershed, the load reduction targets are as follows:

- Total Suspended Solids: 23 milligrams/liter

4
Development of Water Quality Models

Water quality models are used to define the relationship between pollutant loading and the resulting water quality. This section describes the modeling to support TMDL and LRS development, and is divided into the following sections:

- QUAL2E modeling for dissolved oxygen TMDL
- Load Duration Curve approach for fecal coliform, sulfate, iron, manganese, and chloride TMDLs
- BATHTUB modeling for total phosphorus TMDLs for reservoirs.

The remainder of this section describes the TSS modeling to support the TSS LRS.

4.1 QUAL2E Model for the Dissolved Oxygen TMDLs

The QUAL2E water quality model was used to define the relationship between external oxygen-demanding loads and the resulting concentrations of dissolved oxygen in the Lake Cr. (IL_NGA-02) stream segment in the Upper Big Muddy River watershed.

In addition, QUAL2E to was used to model the the dissolved oxygen in Pond Creek (IL_) and Andy Creek (IL_NZN-13) to determine if the observed low dissolved oxygen was based on pollutant loads, or low flow conditions. Based on the results of those models, no TMDLs were developed for those stream segments.

QUAL2E is a one-dimensional stream water quality model applicable to dendritic, well-mixed streams. It assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the main direction of flow. The model allows for multiple waste discharges, water withdrawals, tributary flows, and incremental inflows and outflows.

4.1.1 Model Selection

A discussion of the model selection process for the Upper Big Muddy River watershed is provided in the Stage 1 report (Attachment 1).

The QUAL2E model (Brown and Barnwell, 1987) was selected to address dissolved oxygen impairments in the Upper Big Muddy River watershed. QUAL2E is the most commonly used water quality model for addressing low flow conditions.

4.1.2 Modeling Approach

The approach selected for the dissolved oxygen TMDL consists of using data collected during 2015 low flow season surveys to define the current water quality of the river, and using the QUAL2E model to define the extent to which loads must be reduced to meet water quality standards. This is the recommended approach presented in the Stage 1 report.

4.1.3 QUAL2E Model Inputs

This section gives an overview of the model inputs required for QUAL2E application, and how they were derived. The following categories of inputs are required for QUAL2E:

- Model options (title data)
- Model segmentation

- Hydraulic characteristics
- Reach kinetic coefficients
- Initial conditions
- Incremental inflow conditions
- Headwater characteristics
- Point source flows and loads

4.1.3.a Model Options

This portion of the model input parameters defines the specific water quality constituents to be simulated. QUAL2E was set up to simulate temperature, biochemical oxygen demand, the nitrogen series, phosphorus, algae and dissolved oxygen.

4.1.4 Andy Cr. (IL_NZN-13) QUAL2E Model Application

This sections described the application of the QUAL2E model to the above noted stream segment.

4.1.4.a Model Segmentation

The QUAL2E model divides the river being simulated into discrete segments (called "reaches") that are considered to have constant channel geometry and hydraulic characteristics. Reaches are further divided into "computational elements", which define the interval at which results are provided. Andy Creek QUAL2E model consists of two reaches, which are comprised of a varying number of computational elements. Computational elements were specified to have a fixed length of 0.20 miles. Reaches are defined with respect to water quality monitoring stations and tributaries. Model segmentation is presented below in Table 4-1 and Figure 4-1.

Table 4-1. Andy Creek QUAL2E Segmentation

Reach	River miles	Number of computational elements	Other features
1	8.25 – 5.0	13	NZN-12, Valier STP, NZN-15
2	5.0 – 0.0	20	NZN-10

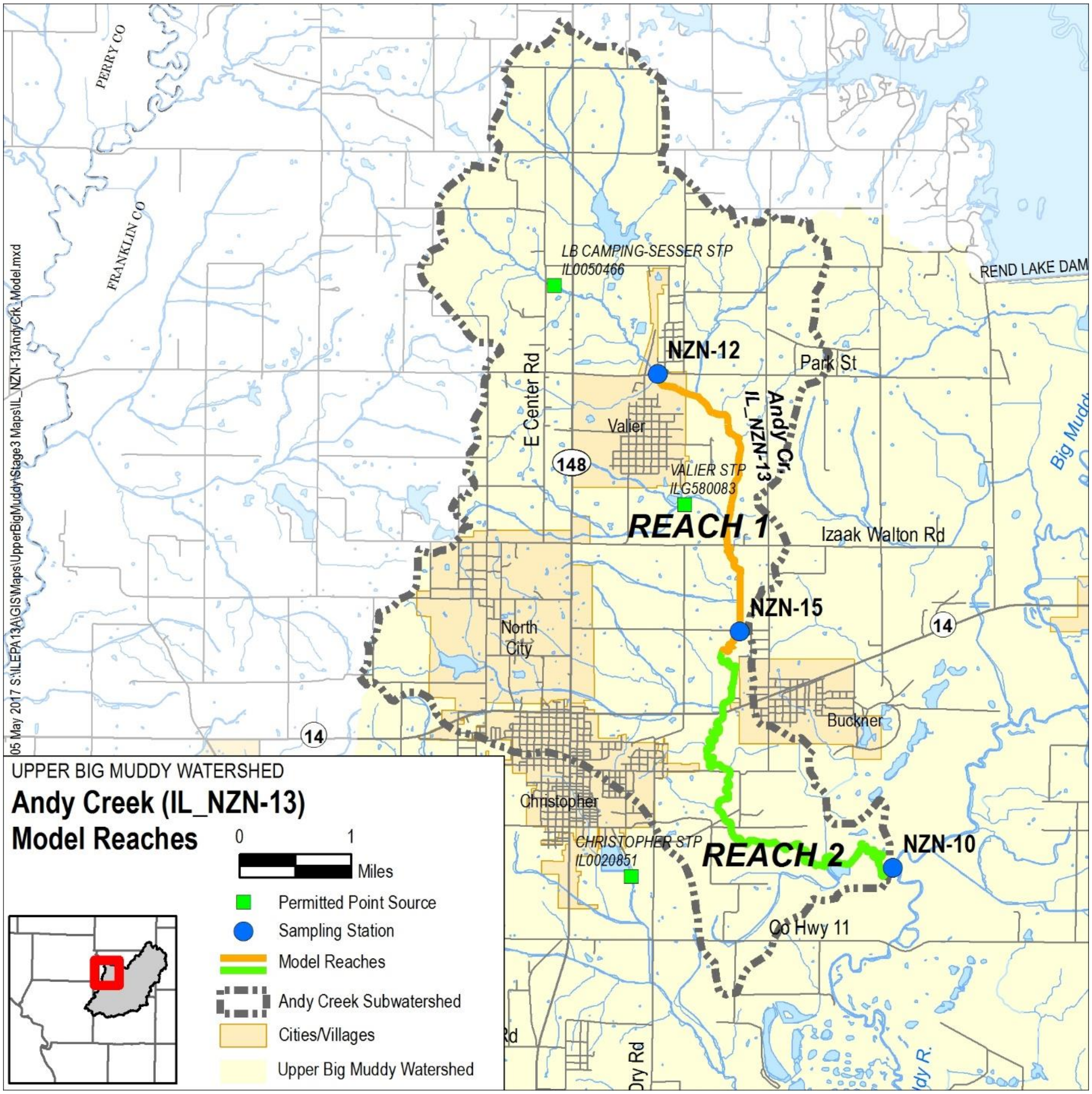

Figure 4-1. Andy Creek QUAL2E Segmentation

4.1.4.b *Hydraulic characteristics*

A functional representation was used to describe the hydraulic characteristics of the system. For each reach, velocity and depth were specified, based on measurements taken during the September 23, 2015 field survey.

4.1.4.c *Reach Kinetic Coefficients*

Kinetic coefficients were initially set at values commonly used in past QUAL2E applications from Illinois. The appropriateness of these initial values were assessed during the model calibration process, where these coefficients were refined as necessary (within accepted ranges taken from the scientific literature) to allow model results to best describe observed water quality data.

4.1.4.d Initial Conditions

Initial model conditions were based on field observations, flow measurements, and water quality data collected during 2015. Specifically, observed concentrations of ammonia, phosphorus, organic nitrogen, nitrate and chlorophyll a were used to specify initial conditions.

4.1.4.e Incremental Inflow Conditions

Incremental inflows were calculated using a drainage area ratio and field measured flows. Increases in flows were added to each reach incrementally to represent non-monitored tributaries (flows were increasing from upstream to downstream). Concentrations for these incremental inflows were considered to have concentrations at typical background levels, and temperatures consistent with the mainstem. Other flows came from the headwater and point sources.

4.1.4.f Headwater Characteristics

Headwater characteristics were based on the flow/water quality measurements collected at the more upstream IEPA station (NZN-12).

4.1.4.g Point Source Flows and Loads

There are two permitted NPDES discharges from sewage treatment plants in the Andy Creek watershed. The NPDES permits are for the LB Camping Sesser STP (IL0050466) and the Valier STP (ILG580083). (Attachment 1, Section 2.9).

The model considers one permitted point source that discharges to Andy Creek via a small tributary. The upsrtream point source (LB Camping Sesser STP) is assumed to contribute no load or small loads (based on discharge monitoring report (DMR) data and some assumptions where data was not available), and any impacts on the DO impairments to Andy Creek at the downstream stations would be incorporated into the model by using the sampling data collected at station NZN-12 as the upstream boundary conditions. See Table 4-2 for details of when data were used, and when assumptions were made.

Table 4-2. Andy Creek (IL_NZN-13) Concentrations of QUAL2E model inputs

Model input point	Flow (cfs)	Temp. (Deg F)	DO (mg/L)	CBOD5 (mg/L)	Ammonia (mg/L)	Source
Headwater	0.10	63.7	4.47	1	0.05	Data collected at NZN-12
Valier STP discharge to Reach 1	0.06	70	8.70	10.90	5.80	DMR data (flow, CBOD5, DO, Ammonia)
Incremental inflow to Reach 1	0.145	65.0	4.5	1	0.00	Calculated from flow balance. Water quality specified based on typical background levels.

4.1.4.h QUAL2E Model Calibration

QUAL2E model calibration consisted of:

- Applying the model with all inputs specified as above
- Comparing model results to observed dissolved oxygen, BOD, ammonia, and chlorophyll data
- Adjusting model coefficients to provide the best comparison between model predictions and observed dissolved oxygen data.

The QUAL2E dissolved oxygen calibration for Andy Creek is discussed below. The model was initially applied with the model inputs as specified above. Observed data for the low flow survey conducted on September 23, 2015 was used for calibration purposes.

QUAL2E was calibrated to match the observed average dissolved oxygen concentrations measured at two locations (NZN-15 and NZN-10) on the mainstem of the creek. The data collected at NZN-12 was used to define the upstream boundary conditions. The initial BOD calibration was deemed successful, albeit not totally conclusive, as the majority of observed data (as well as model predictions) for both parameters were below laboratory detection limits. Similarly, the initial coefficients used to describe chlorophyll a correctly replicated observed low observed field concentrations and confirmed that algal productivity was not an important component of the dissolved oxygen budget.

Model results initially over-predicted observed dissolved oxygen data. Model calibration was attained by adjusting reach-specific sediment oxygen demand, with calibration values ranging from 0.054 to 0.065 mg/sq. ft./day. Those values were initially based on the SOD measurement taken at NZN-15 of 0.065 mg/sq. ft./day. The resulting dissolved oxygen predictions compared well to the measured concentrations as shown in Figure 4-2. The QUAL2E model output files from the calibration runs are included in Attachment 3.

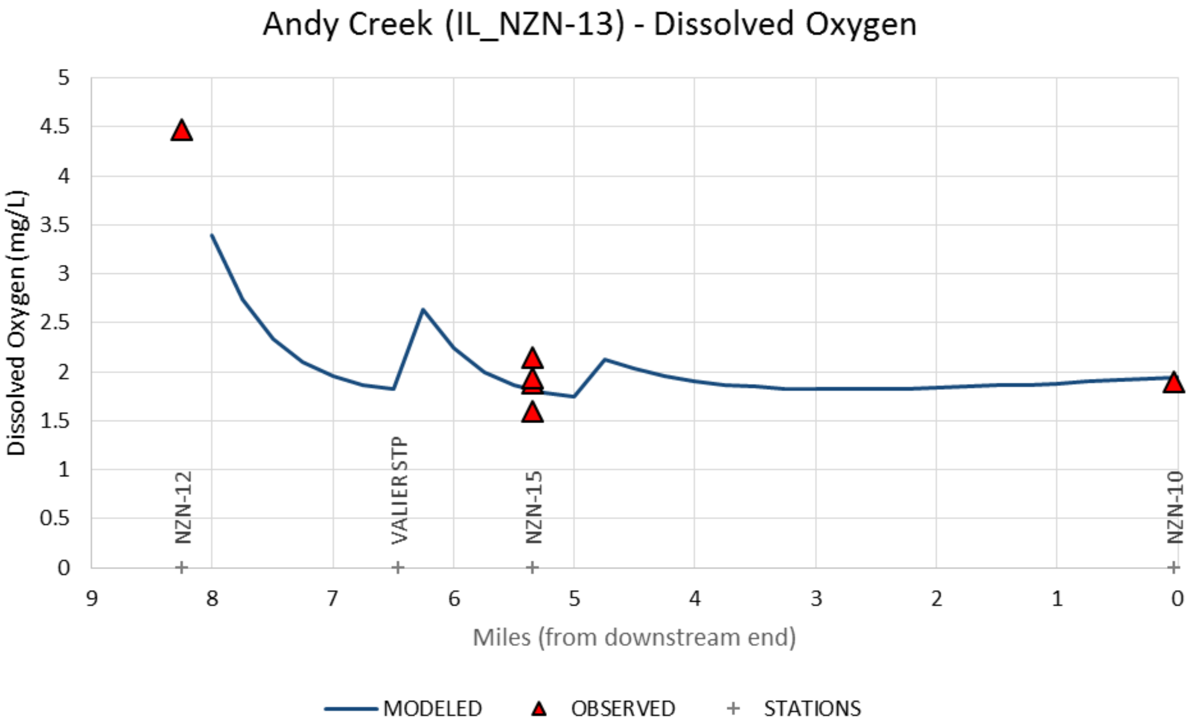

Figure 4-2. QUAL2E DO Calibration for Andy Creek for 9/23/2015 Sampling Survey

4.1.5 Lake Cr. (IL_NGA-02) QUAL2E Model Application

This sections described the application of the QUAL2E model to the above noted stream segment.

4.1.5.a Model Segmentation

The QUAL2E model divides the river being simulated into discrete segments (called "reaches") that are considered to have constant channel geometry and hydraulic characteristics. Reaches are further divided into "computational elements", which define the interval at which results are provided. The Lake Creek QUAL2E model consists of two reaches, which are comprised of a varying number of computational elements. Computational elements were specified to have a fixed length of 0.25 miles. Reaches are defined with respect to water quality monitoring stations and tributaries. Model segmentation is presented below in Table 4-3 and Figure 4-3. The division between reaches 1 and 2 was determined based on the location of additional tributaries that contribute additional flow to the stream which would be expected to change the hydraulic characteristics of the reach.

Table 4-3. Lake Creek QUAL2E Segmentation

Reach	River miles	Number of computational elements	Other features
1	3.25 – 5.25	8	NGA-02, Johnston City STP, NGA-JC-C1
2	0 – 3.25	14	NGA-01

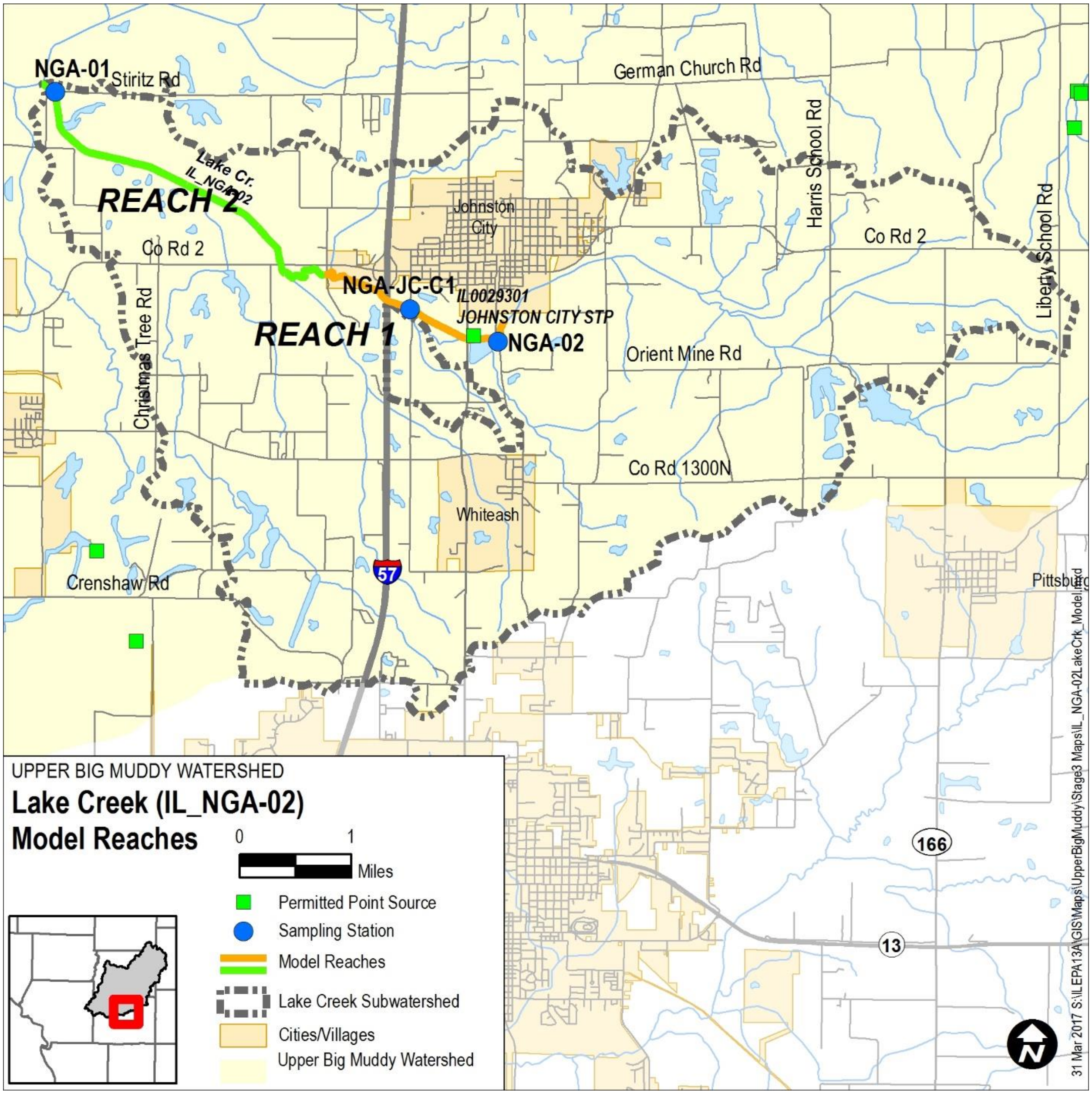

Figure 4-3. Lake Creek (IL_NGA-02) QUAL2E Model Segmentation

4.1.5.b *Hydraulic characteristics*

A functional representation was used to describe the hydraulic characteristics of the system. For each reach, velocity and depth were specified, based on measurements taken during the August, September and October 2015 field surveys.

4.1.5.c *Reach Kinetic Coefficients*

Kinetic coefficients were initially set at values commonly used in past QUAL2E applications from Illinois. The appropriateness of these initial values were assessed during the model calibration process, where these coefficients were refined as necessary (within accepted ranges taken from the scientific literature) to allow model results to best describe observed water quality data.

4.1.5.d Initial Conditions

Initial model conditions were based on field observations taken during 2015 and USGS flow measurements. Specifically, observed concentrations of ammonia, phosphorus, organic nitrogen, nitrate and chlorophyll a were used to specify initial conditions.

4.1.5.e Incremental Inflow Conditions

Incremental inflows were calculated using a drainage area ratio and measured USGS flows. Increases in flows were added to each reach incrementally to represent non-monitored tributaries (flows were increasing from upstream to downstream). Concentrations for these incremental inflows were considered to have concentrations at typical background levels, and temperatures consistent with the mainstem. Other flows came from the headwater and point sources.

4.1.5.f Headwater Characteristics

Headwater characteristics were based on the flow/water quality measurements collected at the more upstream IEPA station (NGA-02).

4.1.5.g Point Source Flows and Loads

There is one permitted NPDES discharges in the Lake Creek watershed. It is for the Johnston City STP (IL0029301), a municipal sewage treatment plant. See Table 4-4 for details of when data were used, and when assumptions were made.

Table 4-4. Lake Creek (IL_NGA-02) Concentrations of QUAL2e model inputs

Model input point	Flow (cfs)	Temp. (Deg F)	DO (mg/L)	$CBOD_5$ (mg/L)	Ammonia (mg/L)	Source
Headwater	0.10	63.7	4.47	1	0.05	Data collected at NGA-02, or calculated from flow balance.
Johnston City STP discharge to Reach 1	0.75	70	7.6	14.2	8.90	DMR data (flow, CBOD5, DO), data from NGA-JC-C1 (Ammonia).
Incremental inflow to Reach 2	4.69	65.0	9.0	1	0.00	Calculated from flow balance. Water quality specified based on typical background levels.

It is noted that DMR data from the September 2015 for Johnston City STP indicate that the monthly average CBOD5 concentration (14.2 mg/l) exceeded the permit limit of 10 mg/L, along with effluent violations of daily maximum and monthly average ammonia nitrogen concentrations, although it is uncertain whether the effluent limit violations were occurring specifically during the time of the survey. The of $CBOD_5$ in the Johnston City STP were based on the September 2015 DMR for that facility. The $CBOD_5$ and DO concentrations used to characterize the point load in the QUAL2E model were the monthly averages. The daily maximum $CBOD_5$ was 17 mg/L, but there is no information on whether that occurred on the date of the sampling. The ammonia nitrogen concentration used in the model to characterize the point load was based on the observed concentration at station NGA-JC-C1, which is higher than the reported daily maximum value for ammonia nitrogen in the DMR. The effluent sampling frequency for ammonia nitrogen required in the NPDES permit for the Johnston City STP is only two days per month, so it is possible that higher concentrations could occur between samples. The flow used was the daily average flow for the month reported in the DMR of 0.488 MGD, which is lower than the design average flow for the facility of 0.55 MGD.

4.1.5.h QUAL2E Model Calibration

QUAL2E model calibration consisted of:

- Applying the model with all inputs specified as above
- Comparing model results to observed dissolved oxygen, BOD, ammonia, and chlorophyll data
- Adjusting model coefficients to provide the best comparison between model predictions and observed dissolved oxygen data.

The QUAL2E dissolved oxygen calibration for Lake Creek (IL_NGA-02) is discussed below. The model was initially applied with the model inputs as specified above. Observed data for the low flow survey conducted in 2015 was used for calibration purposes.

QUAL2E was calibrated to match the observed average dissolved oxygen concentrations measured at two locations (NGA-01, and NGA-JC-C1) on the mainstem of the creek. Data collected at station NGA-02 was used to characterize the upstream boundary conditions. The initial DO and ammonia calibration was deemed successful. Similarly, the initial coefficients used to describe chlorophyll a correctly replicated observed low observed field concentrations and confirmed that algal productivity was not an important component of the dissolved oxygen budget in the area downstream of the Johnston City STP discharge.

The reach-specific sediment oxygen demand values entered in the model for Reach 1 of 0.079 g/sq. ft./day was based on an SOD test run at NGA-02. The sediment oxygen demand values entered in the model for Reach 2 of 0.06 g/sq. ft./day was adjusted to match the observed downstream data. The resulting dissolved oxygen predictions compared well to the measured concentrations during the survey, as shown in Figure 4-4. The QUAL2E model output files from the calibration runs are included in Attachment 3.

Based on the components of dissolved oxygen mass balance in the QUAL2E model output files, the largest components of the oxygen deficit in the stream immediately downstream of the Johnston City STP were due to the sediment oxygen demand, and the oxygen consumed for nitrification of ammonia and nitrite. Although SOD is one of the dominant sources of the oxygen deficit, the true cause is a lack of base flow (which greatly exacerbates the effect of SOD).

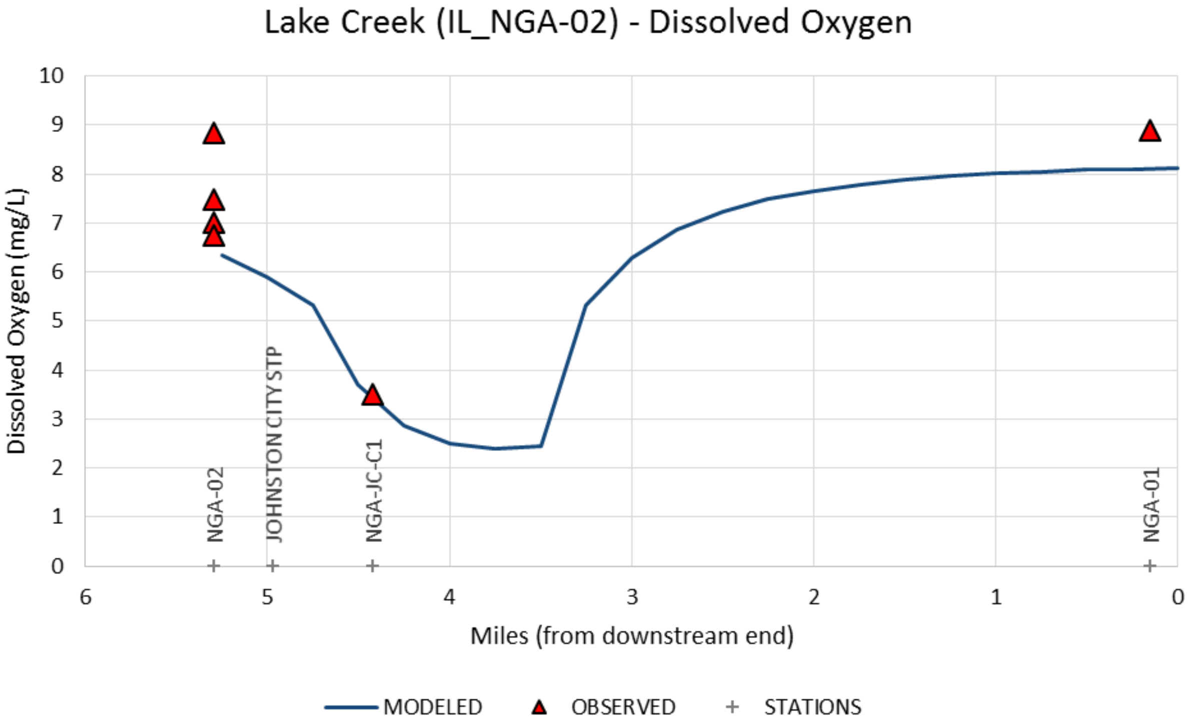

Figure 4-4. QUAL2E DO Calibration for Lake Creek for 9/24/2015 Sampling Survey

4.2 Load Duration Curve Approach

A load duration curve approach was used in the fecal coliform, sulfate, iron, chloride, and manganese analyses for streams in the Upper Big Muddy watershed. A load-duration curve is a graphical representation of observed pollutant load compared to maximum allowable load over the entire range of flow conditions. The load duration curve provides information to:

- Help identify the issues surrounding the problem and differentiate between point and nonpoint source problems, as discussed immediately below;
- Address frequency of deviations (how many samples lie above the curve vs. those that plot below); and
- Aid in establishing the level of implementation needed, by showing the magnitude by which existing loads exceed standards for different flow conditions.

4.2.1 Model Selection

A detailed discussion of the model selection process for TMDL development in the Upper Big Muddy River watershed is provided in the Stage 1 Report. The load-duration curve approach was selected because it is a simpler approach that can be supported with the available data and still support the selected level of TMDL implementation for this TMDL. The load-duration curve approach identifies broad categories of pollutant sources and the extent of control required from these source categories to attain water quality standards.

4.2.2 Approach

The load duration curve approach uses stream flows for the period of record to gain insight into the flow conditions under which exceedances of the water quality standard occur. A load-duration curve is developed by: 1) ranking the daily flow data from lowest to highest, calculating the percent of days these flows were exceeded, and graphing the results; 2) translating the flow duration curve (produced in step 1) into a load duration curve by multiplying the flows by the water quality standard; and 3) plotting observed pollutant loads (measured concentrations times stream flow) on the same graph. Observed loads that fall above the load duration curve exceed the maximum allowable load, while those that fall on or below the line do not exceed the maximum allowable load. An analysis of the observed loads relative to the load duration curve provides information on whether the pollutant source is point or nonpoint in nature. A more complete description of the load duration curve approach is provided in the Stage 1 Report.

4.2.3 Big Muddy R. / IL_N-11 – Fecal Coliform Load Duration Curve

This section describes the flow and water quality data used to support development of the load duration curve for fecal coliform bacteria on the above noted stream segment.

4.2.3.a Flow Data

Segment IL_N-11 of the Big Muddy River is located downstream of Rend Lake, so the flows in the river at that point are impacted by the reservoir storage and dam operations. When developing the load-duration curve, the reservoir storage can reduce the peak flows, and maintain a higher baseflow, making distinction between dry and wet weather related sources difficult to distinguish. To remedy that problem, daily flow measurements were used from the USGS gage on Casey Fork near Mount Vernon, IL (USGS gage number 05595820) for the period from 1999 through 2015.

Casey Fork is a tributary to the Big Muddy River upstream of Rend Lake, so flows at that location are not impacted by the reservior. This gage is located approximately 28.6 miles north of station N-11, where the water quality data was collected. This gage has a drainage area of 76.9 square miles, so all flow data from the gage are adjusted based on the drainage area ratio (DAR) to the stream segment under consideration. The drainage area within the Upper Big Muddy River watershed for segment IL-N-11 is 312.3 square miles, which does not include areas upstream of Rend Lake. The Casey Fork gage was selected based on the proximity to the stream segment under consideration, and that it is located within the same watershed, the fact that it is upstream of Rend Lake, so it is not impacted by the reservoir.

4.2.3.b Water Quality Data

Fecal coliform data collected at station N-11 by IEPA between 1999 and 2010 were used in the analysis. The data were collected as part of IEPA's ambient water quality monitoring program. Only data for the months of May-October were used because the water quality standard applies only during this period.

4.2.3.c Analysis

A flow duration curve was generated by ranking daily flow data from lowest to highest, calculating the percent of days these flows were exceeded, and graphing the results. The load duration curve for fecal coliform were generated by multiplying the flows in the duration curve by the water quality standard of 200 cfu/100 mL for fecal coliform bacteria. The load duration curve for fecal coliform is shown with a solid line in Figure 4-5. Observed pollutant loads of fecal coliform were calculated using available concentration data paired with corresponding flows, and were plotted on the same graph. The fecal coliform data used only measurements collected between May and October, since that is the period specified under Section 302.209 of Title 35.

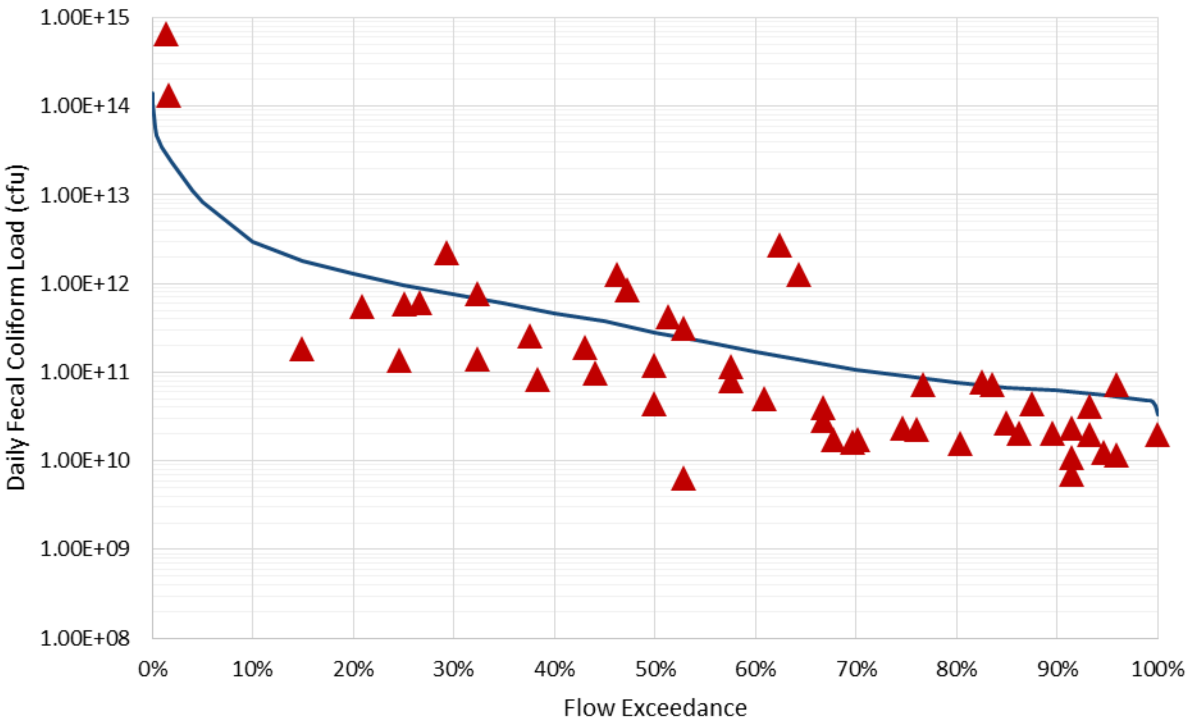

Figure 4-5. Fecal Coliform Load Duration Curve for Upper Big Muddy River (IL_N-11) with Observed Loads (triangles)

In Figure 4-5, the data show exceedances of the fecal coliform target occur over all ranges of flows, but with more exceedances (as a fraction of the samples) occuring in the higher range of flows. This indicates that wet weather sources contribute to the observed violations of the water quality standard.

4.2.4 Andy Cr. / IL_NZN-13 – Iron Load Duration Curve

This section describes the flow and water quality data used to support development of the load duration curve for dissolved iron on the above noted stream segment.

4.2.4.a Flow Data

There is no stream gage on Andy Creek that can be used to estimate the daily flows and loadings. Daily flow measurements are available for the USGS gage on Crab Orchard Creek near Marion, IL (USGS gage number 05597500) for the period from 1999 through 2015. This gage is located approximately 20.2 miles southeast of the Andy Creek watershed. This gage has a drainage area of 31.7 square miles, so all flow data from the gage are adjusted based on the drainage area ratio (DAR) to the stream segment under consideration. The stream segment under consideration has a drainage area of 20.4 square miles at its outlet. The Crab Orchard Creek gage was selected for consideration based on the drainage areas being similar in size, the proximity to the stream segment under consideration, with similar watershed land uses and topography.

4.2.4.b Water Quality Data

Dissolved iron data collected by IEPA in 2008 were used in the analysis. The data were collected as part of IEPA's ambient water quality monitoring program. There were three samples analyzed, and all three exceeded the water quality standards.

4.2.4.c Analysis

A flow duration curve was generated by ranking daily flow data from lowest to highest, calculating the percent of days these flows were exceeded, and graphing the results. A load duration curve for iron was generated by multiplying the flows in the duration curve by the water quality standard of 1.0 mg/L for dissolved iron. The load duration curve for iron is shown with a solid line in Figure 4-6. Observed pollutant loads of dissolved iron were calculated using available concentration data paired with corresponding flows, and were plotted on the same graph.

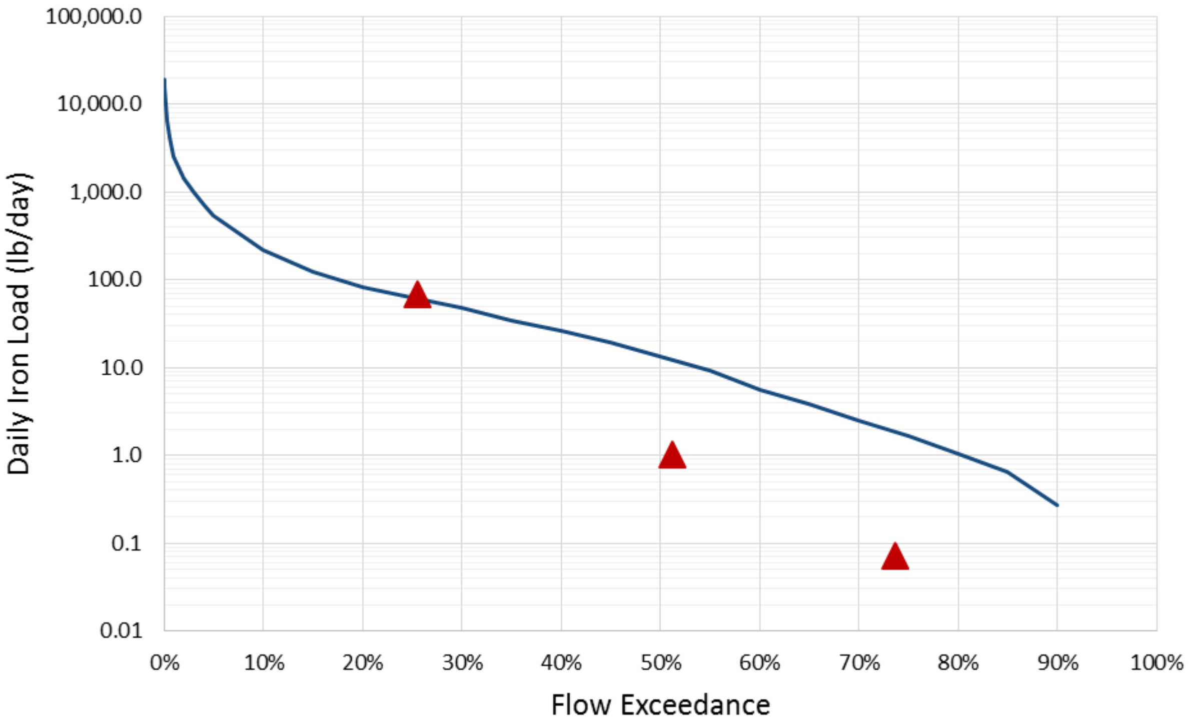

Figure 4-6: Dissolved Iron Load Duration Curve for Andy Creek (IL_NZN-13) with Observed Loads (triangles)

In Figure 4-6, the data show that the sampled data points only exceeded the dissolved iron target at the highest sampled flow. This indicates that wet weather sources or runoff contribute to the observed violation of the water quality standard.

4.2.5 Pond Cr. / IL_NG-02 – Chloride Load Duration Curve

This section describes the flow and water quality data used to support development of the load duration curve for chloride on the above noted stream segment.

4.2.5.a Flow Data

Daily flow measurements are available for the USGS gage on Crab Orchard Creek near Marion, IL (USGS gage number 05597500) for the period from 1999 through 2015. This gage has a drainage area of 31.7 square miles, so all flow data from the gage are adjusted based on the drainage area ratio (DAR) to the stream segment under consideration.

4.2.5.b Water Quality Data

Chloride data collected by IEPA between 2004 and 2008 were used in the analysis. The data were collected as part of IEPA's ambient water quality monitoring program.

4.2.5.c Analysis

A flow duration curve was generated by ranking daily flow data from lowest to highest, calculating the percent of days these flows were exceeded, and graphing the results. The load duration curve for chloride was generated by multiplying the flows in the duration curve by the water quality standard 500 mg/L for chloride. The load duration curve for chloride is shown with a solid line in Figure 4-7. Observed pollutant loads of chloride were calculated using available concentration data paired with corresponding flows, and were plotted on the same graph.

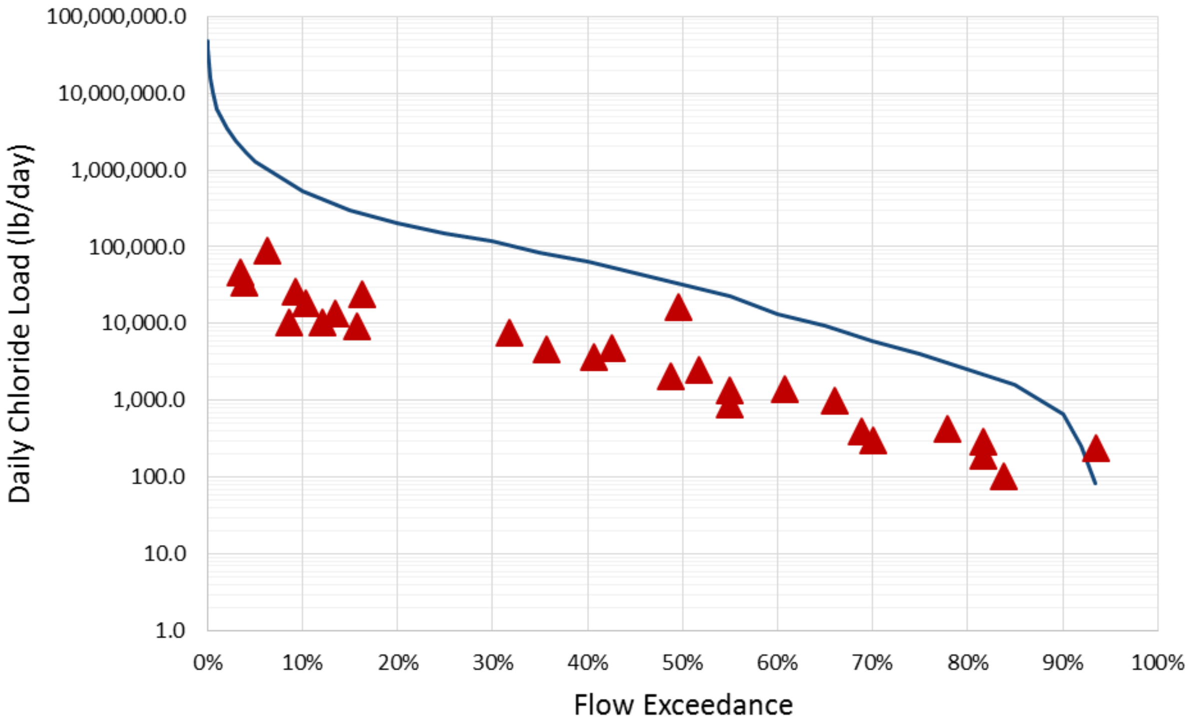

Figure 4-7: Chloride Load Duration Curve for Pond Creek (IL_NG-02) with Observed Loads (triangles)

In Figure 4-7, the data show that the single exceedance of the chloride target occurs at the lowest sampled flow. This indicates that wet weather sources do not contribute to the observed violation of the water quality standard. With the single data point showing an exceedance of the water quality standard for Chloride occurring at the very lowest flows, this indicates that the impairment may be flow related. The only exceedance of the chloride water quality standard was during the summer months, indicating that it was likely not caused by de-icing materials. Additional monitoring recommendations are contained in the Watershed Implementation Plan to achieve the TMDLs and Load Reduction Strategy in the Upper Big Muddy River watershed.

4.2.6 Beaver Cr. / IL_NGAZ-JC-D1 – Manganese Load Duration Curve

This section describes the flow and water quality data used to support development of the load duration curve for manganese on the above noted stream segment.

4.2.6.a Flow Data

Daily flow measurements are available for the USGS gage on Crab Orchard Creek near Marion, IL (USGS gage number 05597500) for the period from 1999 through 2015. This gage has a drainage area of 31.7 square miles, so all flow data from the gage are adjusted based on the drainage area ratio (DAR) to the stream segment under consideration.

The stream gage data shows that there are periods where there is no flow in the stream, This does not necessarily mean that the stream dries up, but the flows are below the threshold for stream measurement. This causes the load-duration curve to be equal to zero during these time periods.

4.2.6.b Water Quality Data

Manganese data collected by IEPA in 2008 were used in the analysis. There is only a single data point available for this analysis.

4.2.6.c Analysis

A flow duration curve was generated by ranking daily flow data from lowest to highest, calculating the percent of days these flows were exceeded, and graphing the results. The load duration curve for manganese was generated by multiplying the flows in the duration curve by the chronic water quality standard of 4.85 mg/L, which was calculated based on a hardness measurement of 383 mg/L that was field measured at the same time at the manganese measurement in this stream segment. The load duration curve for manganese is shown with a solid line in Figure 4-8. Observed pollutant loads were calculated using available concentration data paired with corresponding flows, and were plotted on the same graph.

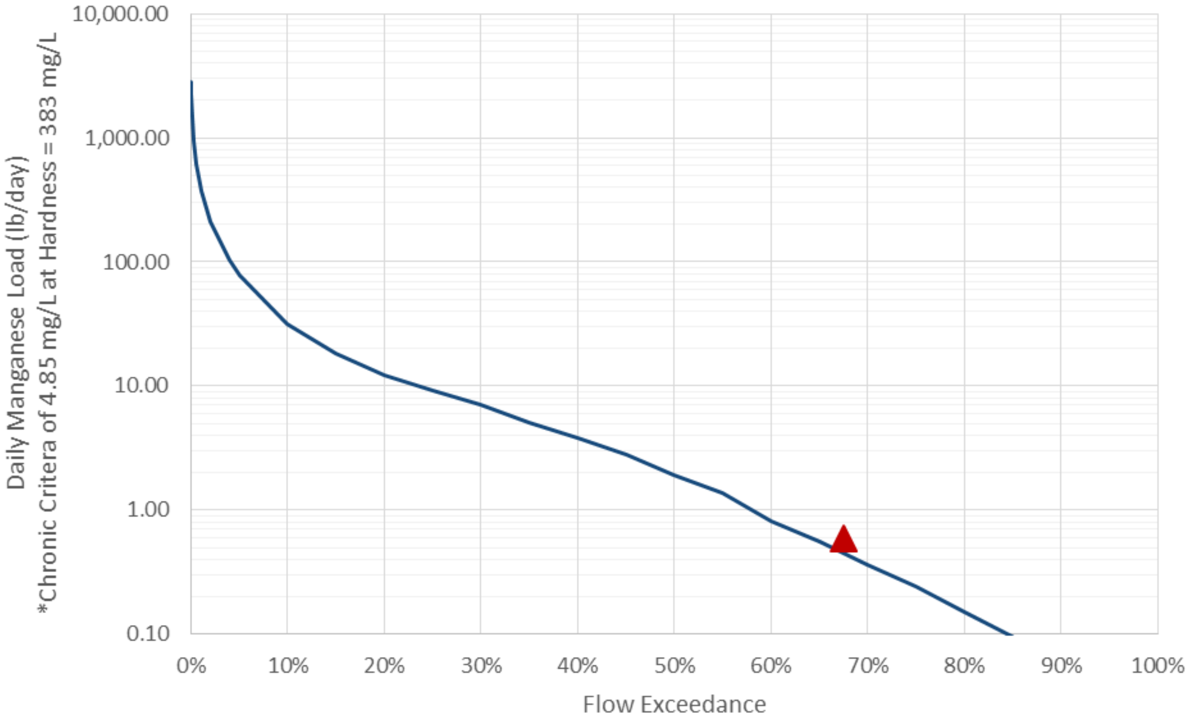

Figure 4-8: Manganese Load Duration Curve for Beaver Creek (IL_NGAZ-JC-D1 with Observed Loads (triangles)

In Figure 4-8, the data show that the single exceedance of the manganese target occurs at the lower end of the normally encountered flows (30% to 70%).

4.2.7 M. Fk. Big Muddy / IL_NH-06 – Fecal Coliform Load Duration Curve

This section describes the flow and water quality data used to support development of the load duration curve for fecal coliform bacteria on the above noted stream segment.

4.2.7.a Flow Data

There is no stream gage on this segment of the Middle Fork of the Big Muddy River that can be used to estimate the daily flows and loadings. Daily flow measurements are available for the USGS gage on Casey Fork near Mount Vernon, IL (USGS gage number 05595820) for the period from 1999 through 2015. Casey Fork is a tributary to the Big Muddy River upstream of Rend Lake, so flows at that location are not impacted by the reservoir storage and dam operations. This gage is located approximately 23.3 miles north of station NH-06, where the water quality data was collected. This gage has a drainage area of 76.9 square miles, so all flow data from the gage are adjusted based on the drainage area ratio (DAR) to the stream segment under consideration. The stream segment under consideration has a drainage area of 160.6 square miles at its outlet.

4.2.7.b Water Quality Data

Fecal coliform data collected at station NH-06 by IEPA between 1999 and 2010 were used in the analysis. The data were collected as part of IEPA's ambient water quality monitoring program. Only data for the months of May-October were used because the water quality standard applies only during this period.

4.2.7.c Analysis

A flow duration curve was generated by ranking daily flow data from lowest to highest, calculating the percent of days these flows were exceeded, and graphing the results. The load duration curve for fecal coliform were generated by multiplying the flows in the duration curve by the water quality standard of 200 cfu/100 mL for fecal coliform bacteria. The load duration curve for fecal coliform is shown with a solid line in Figure 4-9. Observed pollutant loads of fecal coliform were calculated using available concentration data paired with corresponding flows, and were plotted on the same graph. The fecal coliform data used only measurements collected between May and October, since that is the period specified under Section 302.209 of Title 35.

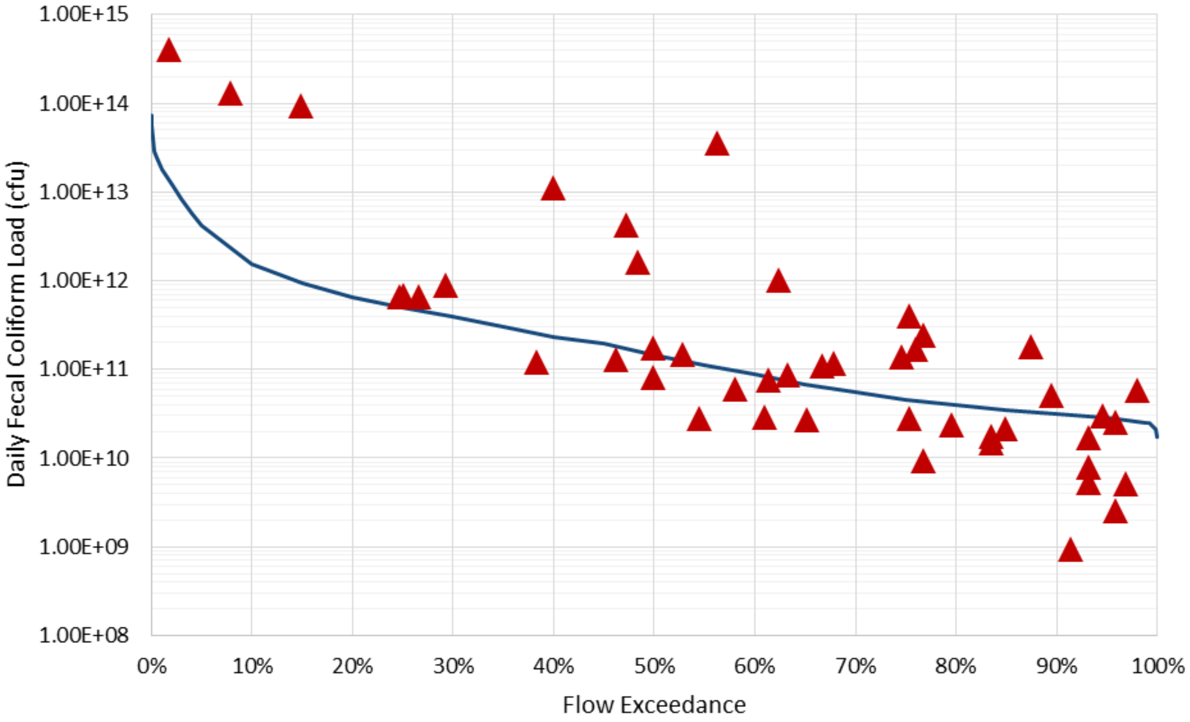

Figure 4-9. Fecal Coliform Load Duration Curve for Middle Fork Big Muddy River (IL_N-11) with Observed Loads (triangles)

In Figure 4-9, exceedances of the fecal coliform target occur over all ranges of flows, but with more exceedances in the higher range of flows. This indicates that wet weather sources are a contributing factor to the observed violations of the water quality standard, but that significant dry weather reductions are necessary as well.

4.3 BATHTUB Model

The BATHTUB model (Walker, 1986) was selected as the tool to define load reduction necessary to attain phosphorus targets in the following lakes/reservoirs located in the Upper Big Muddy River watershed:

- Herrin Old / IL_RNZD
- Johnston City / IL_RNZE
- Arrowhead (Williamson) / IL_RNZX
- West Frankfort Old / IL_RNP
- West Frankfort New/ IL_RNQ

4.3.1 Model Selection

A detailed discussion of the model selection process is provided in the Stage 1 report (Attachment 1). BATHTUB is a simple modeling tool that can predict the relationship between phosphorus load and resulting in-lake phosphorus concentrations. The BATHTUB model was selected because it does not have extensive data requirements (and can therefore be applied with existing data), yet still provides the capability for calibration to observed lake data. BATHTUB has been used previously for several reservoir TMDLs in Illinois, and has been cited as an effective tool for lake and reservoir water quality assessment and management, particularly where data are limited (Ernst et al., 1994).

BATHTUB is a software program for predicting the lake/reservoir response to nutrient loading. Because reservoir ecosystems typically have different characteristics than many natural lakes, BATHTUB was developed to specifically account for some of these differences, including the effects of non-algal turbidity on transparency and algae responses to phosphorus.

BATHTUB contains a number of empirical regression equations that have been calibrated using a wide range of lake and reservoir data sets. It can treat the lake or reservoir as a continuously stirred, mixed reactor, or it can predict longitudinal gradients in trophic state variables in a reservoir or narrow lake. These trophic state variables include in-lake total and ortho-phosphorus, organic nitrogen, hypolimnetic dissolved oxygen, metalimnetic dissolved oxygen, chlorophyll concentrations, and Secchi depth (transparency). Both tabular and graphical displays are available from the program.

4.3.2 Modeling Approach

The approach taken for the total phosphorus TMDLs consisted of using existing empirical data to define current loads to each of the lakes, and using the BATHTUB model to define the extent to which these loads must be reduced to meet water quality standards. This approach was taken because phosphorus concentrations exceed the water quality standards, often by significant amounts. Phosphorus loads will need to be reduced to a fraction of existing load in order to attain water quality standards.

4.3.3 BATHTUB Model Inputs

This section gives an overview of the model inputs required for BATHTUB application, and how they were derived for application to the reservoirs on this project. The following categories of inputs are required for BATHTUB:

- Model Options
- Global Variables
- Reservoir Segmentation
- Tributary Loads
  The model options and global variables applied universally across the 5 lakes that were modeled in BATHTUB for this this project. Those are discussed below, with the descriptions of the reservoir segmentation and tributary loads in each model contained in separate sections of this report.

4.3.3.a Model Options

BATHTUB provides a multitude of model options to estimate nutrient concentrations in a reservoir. Model options were entered as shown in Table 4-5, and the rationale for these options discussed below. No conservative substance was being simulated, so this option was not needed. The Canfield and Bachman phosphorus option was selected for phosphorus, as this is a commonly used formulation for Midwestern phosphorus TMDLs (e.g. MPCA, 2007; https://www.pca.state.mn.us/sites/default/files/wq-iw8-03e.pdf) Nitrogen was not simulated because phosphorus is the nutrient of concern.

Chlorophyll a and transparency were not simulated because the water quality target is specified as total phosphorus. The Fischer numeric dispersion model was selected, which is the default approach in BATHTUB for defining mixing between lake segments. Phosphorus calibrations were based on lake concentrations. No nitrogen calibration was required. The use of availability factors was not required and estimated concentrations were used to generate mass balance Tables.

Table 4-5. BATHTUB Model Options

Model	Model Option
Conservative substance	Not computed
Total phosphorus	Canfield and Bachman
Total nitrogen	Not computed
Chlorophyll-a	Not computed
Transparency	Not computed
Longitudinal dispersion	Fischer-numeric
Phosphorus calibration	Concentrations
Nitrogen calibration	None
Error analysis	Model and Data
Availability factors	Ignored
Mass-balance Tables	Use estimated concentrations

4.3.3.b Global Variables

The global variables required by BATHTUB consist of:

- The averaging period for the analysis
- Precipitation, evaporation, and change in lake levels
- Atmospheric phosphorus loads

BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. One decision in the application of BATHTUB is the selection of length of time over which inputs and outputs should be modeled. An annual averaging period was used for all lakes in the Upper Big Muddy watershed, consistent with the fact that tributary loading estimates represented annual average conditions.

There was no assumed increase in storage during the modeling period, to represent steady state conditions. The values selected for precipitation and change in lake levels have little influence on model predictions. Atmospheric phosphorus loads were specified using default values provided by BATHTUB.

4.3.3.c Reservoir Segmentation

BATHTUB provides the capability to divide the reservoir under study into a number of individual segments, allowing prediction of the change in phosphorus concentrations over the length of each segment. The segmentation scheme selected for the lakes modeled was designed to provide at least two segments per lake, to include segment representing the deeper conditions near the dam, and at least one upstream segment, depending on the lake and the conficuration of the primary lake sampling stations.

Table 4-6. BATHTUB Model Segmentation

Lake / Reservoir	Total Size (ac)	Model Segments
Herrin Old / IL_RNZD	51.3	2
Johnston City / IL_RNZE	64	2
Arrowhead (Williamson) / IL_RNZX	30	3
West Frankfort Old / IL_RNP	146	2
West Frankfort New/ IL_RNQ	214	3

The areas of the segments and the watersheds for the segments were determined by Geographic Information System (GIS), and maps are provided for each of the lakes provided below.

BATHTUB requires that a range of inputs be specified for each segment. These include segment surface area, length, total water depth, and depth of thermocline and mixed layer. Segment-specific values for segment depths (total, thermocline and mixed layer) were calculated from the lake monitoring data, while segment lengths and surface areas were calculated via GIS.

4.3.3.d Tributary Loads

BATHTUB requires tributary flow and nutrient concentrations for each reservoir segment. Tributary and direct drainage flows to each segment were estimated using observed flows at the USGS gaging station at on Crab Orchard Creek near Marion, IL (USGS gage number 05597500), adjusted through the use of drainage area ratios as follows:

Flow into segment = Flow at USGS gage * Segment-specific drainage area ratio

Drainage area ratio = Drainage area of watershed contributing to model segment

Drainage area of watershed contributing to USGS gage

Segment-specific drainage area ratios were calculated via GIS information.

Total phosphorus concentrations for each tributary and direct drainage inflow were estimated by dividing the watershed phosphorus load (calculated based on land use and literature phosphorus loading rates) by the tributary flow.

Average total phosphorus concentrations = Annual watershed phosphorus loads / Annual tributary flow

A complete listing of all segment-specific flows and tributary concentrations is provided in Attachment 4.

4.3.4 BATHTUB Calibration

BATHTUB model calibration consists of:

1. Applying the model with all inputs specified as above
2. Comparing model results to observed phosphorus data
3. Adjusting model coefficients to provide the best comparison between model predictions and observed phosphorus data.

Additional site-sprecific information on the calibration of the BATHTUB model application for each reservoir in the Upper Big Muddy River watershed is given in the sections below.

4.3.5 Herrin Old / IL_RNZD BATHTUB Model Application

Herrin Old Reservoir is a 51 acre lake located in Williamson County, Illinois. It is approximately 21 feet deep at its deepest point near the dam at the downstream side of the lake. Herrin Old Lake requires a TMDL for total phosphorus.

The listing and recommendation of a TMDL for total phosphorus in the Stage 1 report was based on a single water quality sample taken in 2011 that exceeded the water quality standard of 0.05 mg/L. Additional data from 2012 and 2013 was provided by IEPA for the modeling and TMDL preparation. The new data shows that the water quality sampled at the upstream stations (RNZD02 & RNZD-3) all met the water quality standards. These were all sampled at a depth of 1 ft. The only samples taken during this period that exceeded the water quality standard we taken at station RNZD-1 at depths near the bottom of the reservoir. This indicates that the internal phosphorus loading from sedimants is the primary source contributing to the impairment of the water body.

4.3.5.a Reservoir Segmentation

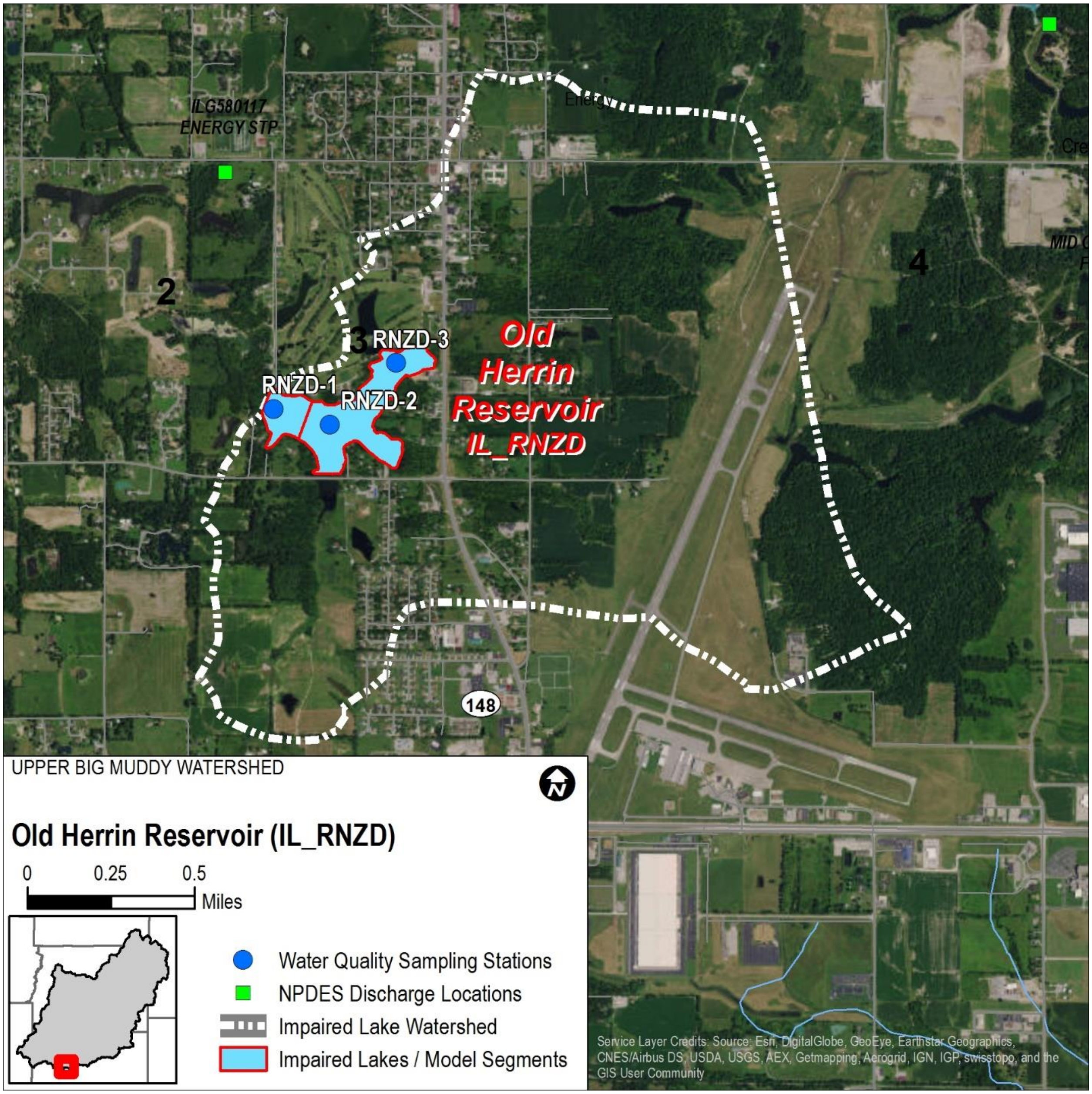

Figure 4-10. Old Herrin Reservoir (IL_RNZD) Segmentation Used in BATHTUB Model

4.3.5.b Tributary Loads

BATHTUB requires tributary flow and nutrient concentrations for each reservoir segment. Tributary and direct drainage flows to each segment were estimated using observed flows at the USGS gaging station at on Crab Orchard Creek near Marion, IL (USGS gage number 05597500), adjusted through the use of drainage area ratios as described in section 4.3.3.d above.

Annual average flow from the contributing watershed calculated using the above method was 3.2 cfs, and the annual average total phosphorus concentrations (calculated based on land use and literature phosphorus loading rates) 0.029 mg/L. This correlated well with the observed total phosphorus concentrations at the upstream sampling stations (RNZD-2 and RNZD-3). The total estimated annual watershed load is 84.3 kg/yr of total phosphorus.

A complete listing of all segment-specific flows and tributary concentrations is provided in Attachment 4.

4.3.5.c BATHTUB Calibration

The BATHTUB model was initially applied with the model inputs as specified above. Observed lake data for the year 2012 were used for calibration purposes.

BATHTUB was calibrated to match the observed reservoir-average phosphorus concentrations. Model results using default model parameters initially under-predicted the observed phosphorus, i.e. model predictions were lower than observed concentrations. Phosphorus loss rates in BATHTUB reflect a typical "net settling rate" (i.e. settling minus sediment release) observed in a range of reservoirs. Under-prediction of observed phosphorus concentrations can occur in cases of elevated phosphorus release from lake sediments. The mismatch between model and data was corrected via the addition of an internal phosphorus load of 12 mg/m^2/day in the downstream model segment (Segment 1). This internal load estimate was adjusted during the model calibration to match th observed data. The resulting modeled and observed total phosphorus concentrations are shown in Figure 4-11. BATHTUB output files are provided in Attachment 4.

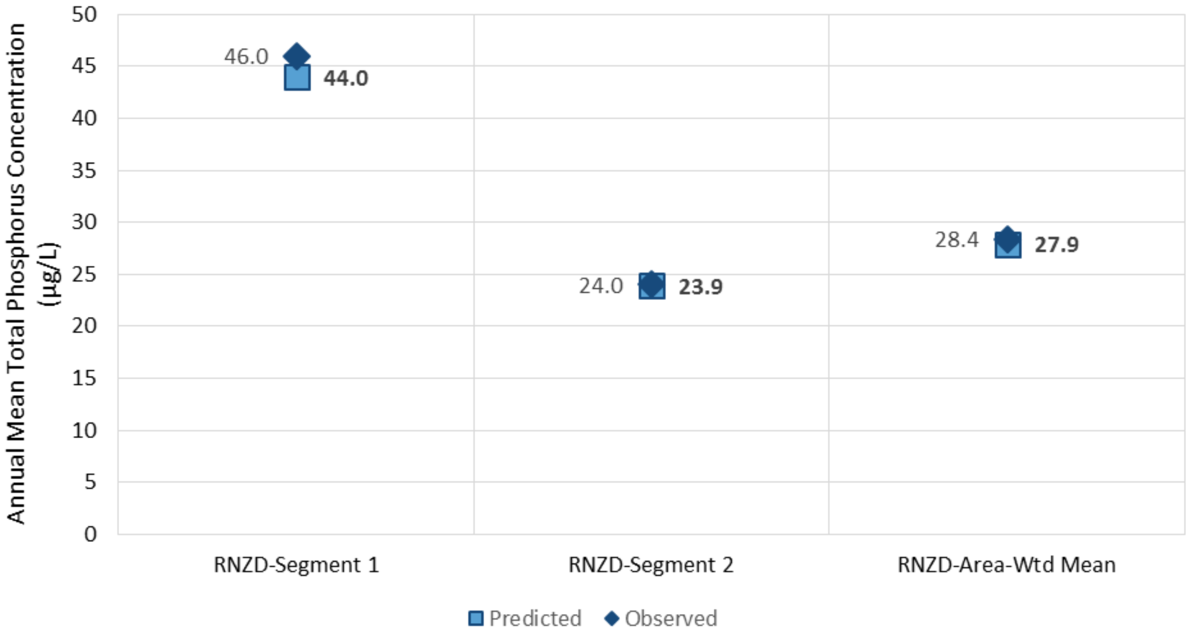

Figure 4-11. Herrin Old (IL_RNZD) BATHTUB Segment Modeled vs. Observed Total Phosphorus Concentration

4.3.6 Johnston City / IL_RNZE BATHTUB Model Application

Johnston City Lake / IL_RNZE is an impoundment of Lake Creek; it is just east of Freeman No. 4 Mine. The lake requires a TMDL for total phosphoru. The most recent water quality data for Johnston City Lake is from 2002. There are three sampling stations located within the lake, as shown in Figure 4-12 below.

4.3.6.a Reservoir Segmentation

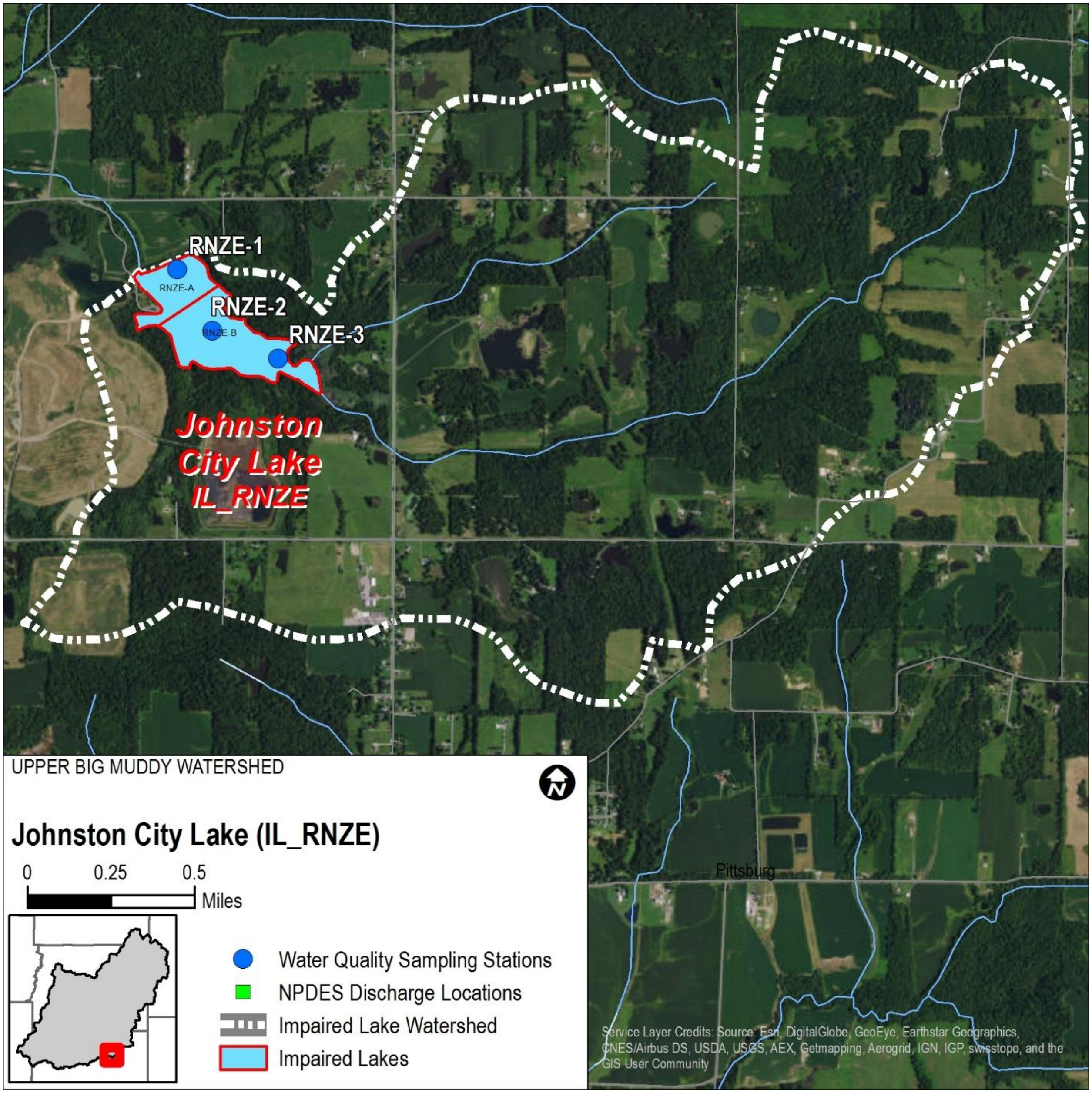

Figure 4-12. Johnston City Lake (IL_RNZE) Segmentation Used in BATHTUB Model

4.3.6.b Tributary Loads

BATHTUB requires tributary flow and nutrient concentrations for each reservoir segment. Tributary and direct drainage flows to each segment were estimated using observed flows at the USGS gaging station at on Crab Orchard Creek near Marion, IL (USGS gage number 05597500), adjusted through the use of drainage area ratios as described in section 4.3.3.d above.

Annual average flow from the contributing watershed calculated using the above method was 4.9 cfs, and the annual average total phosphorus concentrations (calculated based on land use and literature phosphorus loading rates) 0.040 mg/L. The total estimated annual watershed load is 175.5 kg/yr of total phosphorus.

A complete listing of all segment-specific flows and tributary concentrations is provided in Attachment 4.

4.3.6.c BATHTUB Calibration

The BATHTUB model was initially applied with the model inputs as specified above. Observed lake data for the year 2002 were used for calibration purposes.

BATHTUB was calibrated to match the observed reservoir-average phosphorus concentrations. Model results using default model parameters initially under-predicted the observed phosphorus, i.e. model predictions were lower than observed concentrations. Phosphorus loss rates in BATHTUB reflect a typical "net settling rate" (i.e. settling minus sediment release) observed in a range of reservoirs. Under-prediction of observed phosphorus concentrations can occur in cases of elevated phosphorus release from lake sediments. The mismatch between model and data was corrected via the addition of an internal phosphorus load of 2 mg/m²/day in the upstream model segment (Segment 2). The resulting modeled and observed total phosphorus concentrations are shown in Figure 4-13. BATHTUB output files are provided in Attachment 4.

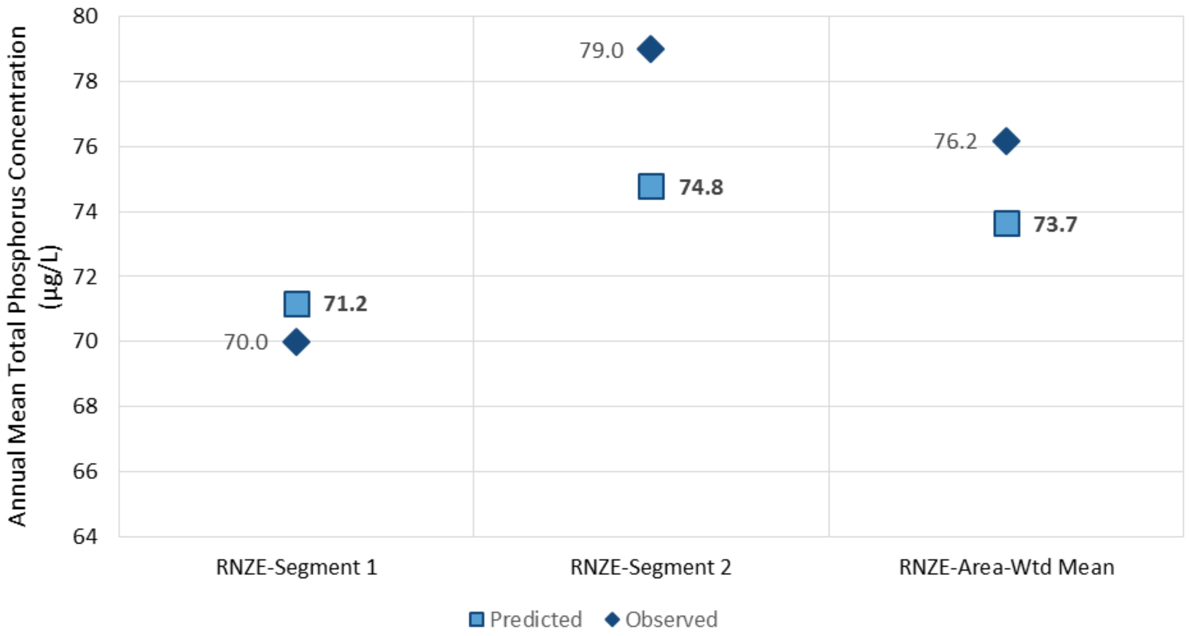

Figure 4-13. Johnston City Lake (IL_RNZE) BATHTUB Segment Modeled vs. Observed Total Phosphorus Concentration

4.3.7 Arrowhead (Williamson) / IL_RNZX BATHTUB Model Application

Arrowhead Lake (Williamson) / IL_RNZX is located just northeast of Johnston City, near Shakerag, IL. Arrowhead requires a TMDL for total phosphorus.

4.3.7.a Reservoir Segmentation

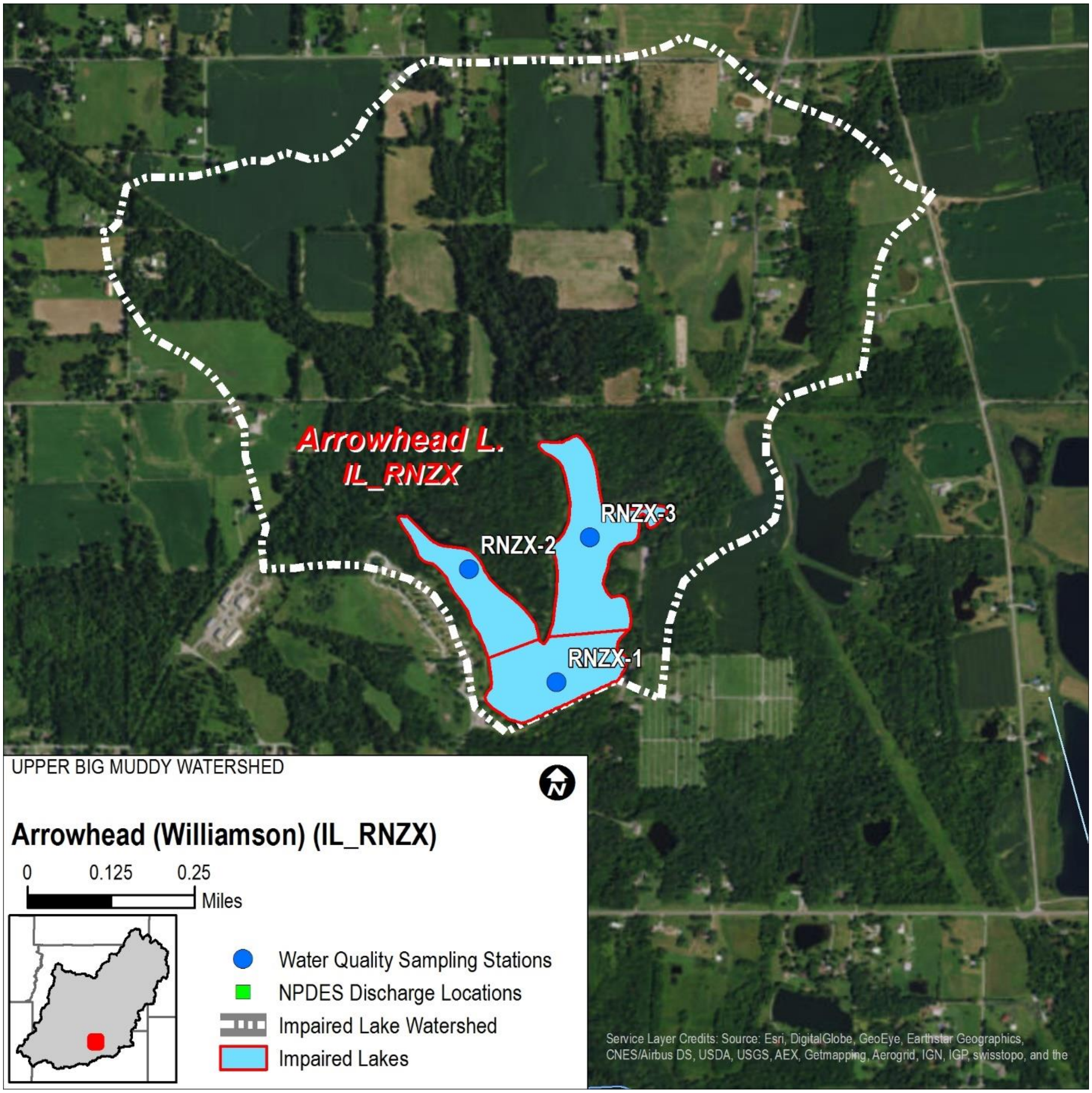

Figure 4-14. Arrowhead (Williamson) (IL_RNZX) Segmentation Used in BATHTUB Model

4.3.7.b Tributary Loads

BATHTUB requires tributary flow and nutrient concentrations for each reservoir segment. Tributary and direct drainage flows to each segment were estimated using observed flows at the USGS gaging station at on Crab Orchard Creek near Marion, IL (USGS gage number 05597500), adjusted through the use of drainage area ratios as described in section 4.3.3.d above.

Annual average flow from the contributing watershed calculated using the above method was 1.0 cfs, and the annual average total phosphorus concentration (calculated based on land use and literature phosphorus loading rates) was 0.046 mg/L. The total estimated annual watershed load is 39.7 kg/yr of total phosphorus.

A complete listing of all segment-specific flows and tributary concentrations is provided in Attachment 4.

4.3.7.c BATHTUB Calibration

The BATHTUB model was initially applied with the model inputs as specified above. Observed lake data for the year 2013 were used for calibration purposes.

BATHTUB was calibrated to match the observed reservoir-average phosphorus concentrations. Model results using default model parameters initially under-predicted the observed phosphorus, i.e. model predictions were lower than observed concentrations. Phosphorus loss rates in BATHTUB reflect a typical "net settling rate" (i.e. settling minus sediment release) observed in a range of reservoirs. Under-prediction of observed phosphorus concentrations can occur in cases of elevated phosphorus release from lake sediments. The mismatch between model and data was corrected via the addition of an internal phosphorus load of 12 mg/m²/day. The resulting modeled and observed total phosphorus concentrations are shown in Figure 4-15. BATHTUB output files are provided in Attachment 4.

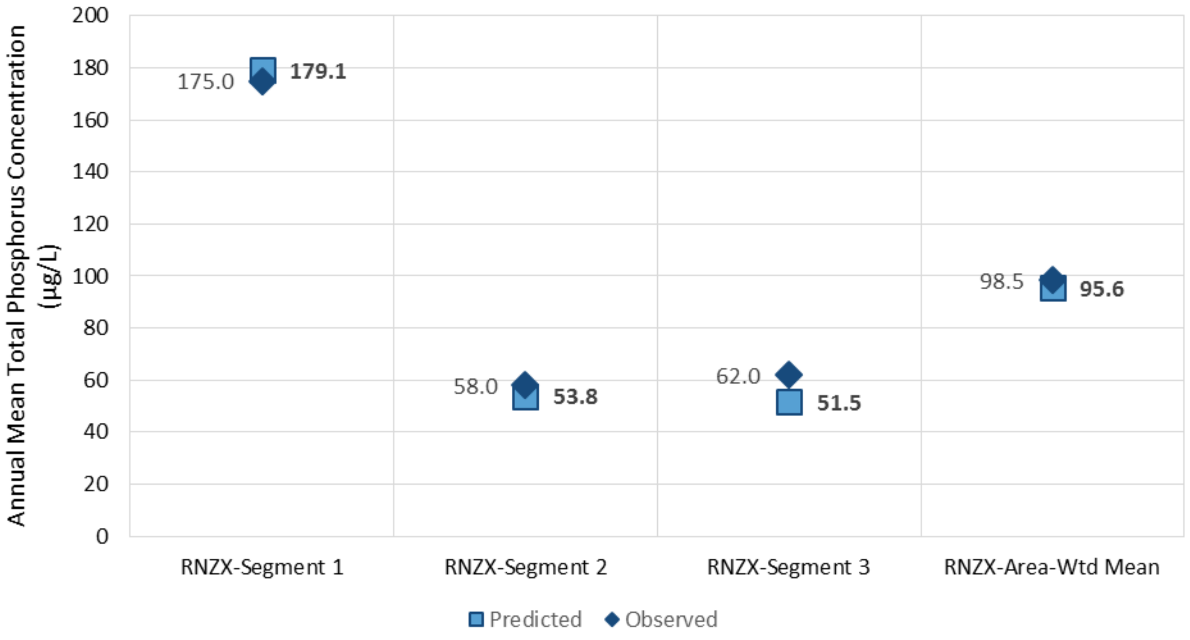

Figure 4-15. Arrowhead (Williamson) (IL_RNZX) BATHTUB Segment Modeled vs. Observed Total Phosphorus Concentration

4.3.8 West Frankfort Old / IL_RNP BATHTUB Model Application

West Frankfort Old City Lake is a 147 acre impoundment located approcimately 6 miles east of the West Frankfort in Franklin County that requires a TMDL for total phosphorus. The water quality data used to develop the BATHTUB model was collected in 2008 and 2013.

4.3.8.a Reservoir Segmentation

The BATHTUB model for the West Franklin Old Reservior, was developed with two model segments as shown in Figure 4-16, one representing the upstream monitoring stations (RNP-2 & RNP-3), and one representing the downstream station at the deepest portion of the lake (RNP-1).

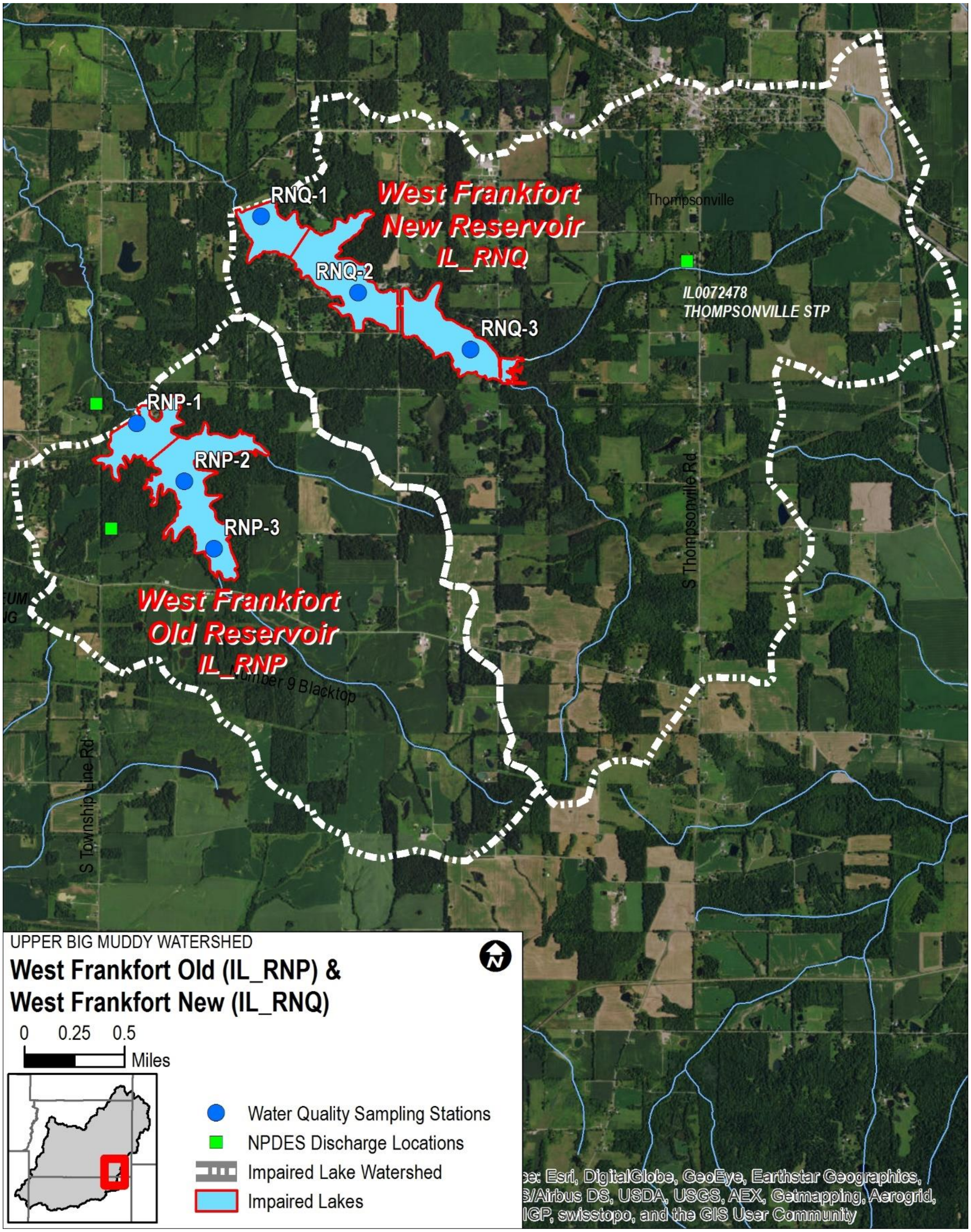

Figure 4-16. West Frankfort Old (IL_RNP) and West Frankfort New (IL_RNQ) Lake Segmentation Used in BATHTUB

4.3.8.b Tributary Loads

BATHTUB requires tributary flow and nutrient concentrations for each reservoir segment. Tributary and direct drainage flows to each segment were estimated using observed flows at the USGS gaging station at on Crab Orchard Creek near Marion, IL (USGS gage number 05597500), adjusted through the use of drainage area ratios as described in section 4.3.3.d above.

Annual average flow from the contributing watershed calculated using the above method was 5.0 cfs, and the annual average total phosphorus concentration (calculated based on land use and literature phosphorus loading rates) was 0.164 mg/L. The total estimated annual watershed load is 725.5 kg/yr (1599.5 lb/year) of total phosphorus.

4.3.8.c BATHTUB Calibration

The BATHTUB model was initially applied with the model inputs as specified above. Observed lake data for the years 2008 and 2013 were used for calibration purposes.

BATHTUB was calibrated to match the observed reservoir-average phosphorus concentrations. Model results using default model parameters initially under-predicted the observed phosphorus, i.e. model predictions were lower than observed concentrations. Phosphorus loss rates in BATHTUB reflect a typical "net settling rate" (i.e. settling minus sediment release) observed in a range of reservoirs. Under-prediction of observed phosphorus concentrations can occur in cases of elevated phosphorus release from lake sediments. The mismatch between model and data was corrected via the addition of an internal phosphorus load of 40 mg/m²/day in the downstream segment (Segment 1). The resulting modeled and observed total phosphorus concentrations are shown in Figure 4-17. BATHTUB output files are provided in Attachment 4.

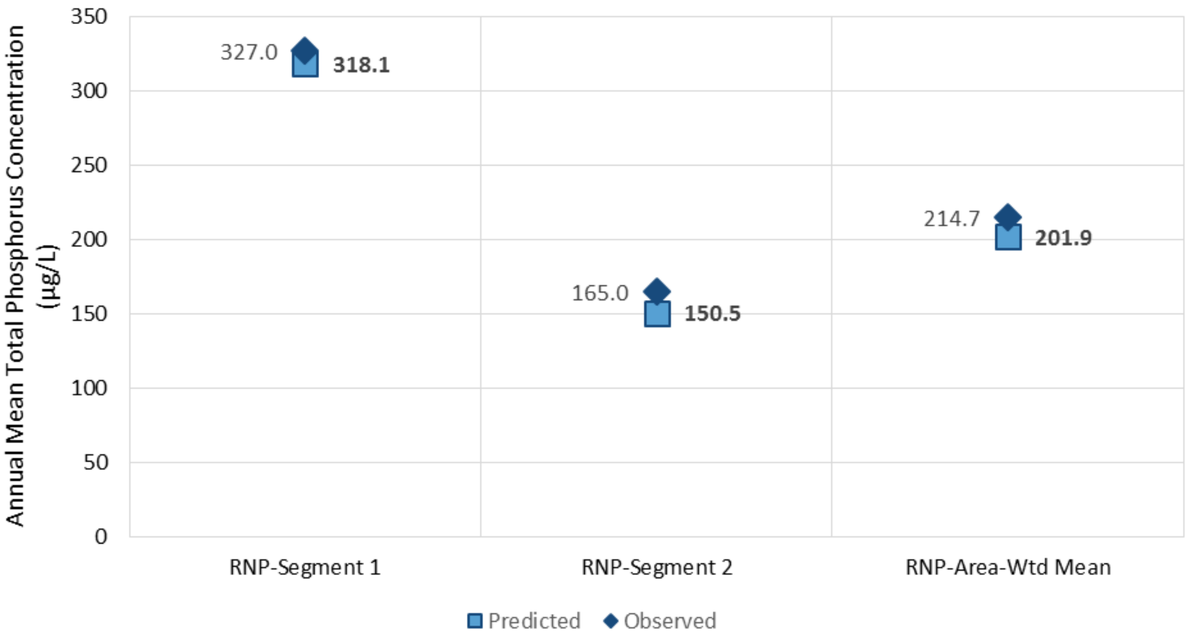

Figure 4-17. West Frankfort Old (IL_RNP) BATHTUB Segment Modeled vs. Observed Total Phosphorus Concentration

4.3.9 West Frankfort New/ IL_RNQ BATHTUB Model Application

4.3.9.a Reservoir Segmentation

West Frankfort New reservoir is located northeast of West Franklin Old Reservior, as shown in Figure 4-16. The BATHTUB model was developed with three model segments, one for each of the primary monitoring station in the lake.

4.3.9.b Tributary Loads

BATHTUB requires tributary flow and nutrient concentrations for each reservoir segment. Tributary and direct drainage flows to each segment were estimated using observed flows at the USGS gaging station at on Crab Orchard Creek near Marion, IL (USGS gage number 05597500), adjusted through the use of drainage area ratios as described in section 4.3.3.d above.

Annual average flow from the contributing watershed calculated using the above method was 10.0 cfs, and the annual average total phosphorus concentration (calculated based on land use and literature phosphorus loading rates) was 0.1116 mg/L. The total estimated annual watershed load is 1036.2 kg/yr of total phosphorus.

In addition to the watershed loads, there is a point source load from the Thompsonville STP (IL0072478). The design average flow (DAF) for the facility is 0.08 million gallons per day (MGD) and the design maximum flow (DMF) for the facility is 0.20 MGD. Treatment consists of two cell aerated lagoon and rock filter.

The average daily flows from this STP reported in the DMRs from 2008 through 2016 is 0.087 MGD. There is no water quality data for total phosphorus from this point source to use for model calibration. The total phosphorus concentration in the STP effluent was assumed to be 2.425 mg/L. With the monthly average flows reported on the DMRs for that facility, the annual average loading from the Thompsonville STP is 289.8 kg/yr (1.75 lb/day).

Based on the combined flow and loads from the sources identified above, the total annual average concentration into the reservoir is 0.148 mg/L, with a total annual loading of 1326 kg/yr (8.01 lb/day).

4.3.9.c BATHTUB Calibration

The BATHTUB model was initially applied with the model inputs as specified above. Observed lake data for the year 2013 were used for calibration purposes.

BATHTUB was calibrated to match the observed reservoir-average phosphorus concentrations. Model results using default model parameters initially under-predicted the observed phosphorus, i.e. model predictions were lower than observed concentrations. Phosphorus loss rates in BATHTUB reflect a typical "net settling rate" (i.e. settling minus sediment release) observed in a range of reservoirs. Under-prediction of observed phosphorus concentrations can occur in cases of elevated phosphorus release from lake sediments. The mismatch between model and data was corrected via the addition of internal phosphorus loads of 25 mg/m^2/day in Segment 3 (upstream), 35 mg/m^2/day in Segment 2, and 90 mg/m^2/day in Segment 1 (downstream). The resulting modeled and observed total phosphorus concentrations are shown in Figure 4-18. BATHTUB output files are provided in Attachment 4.

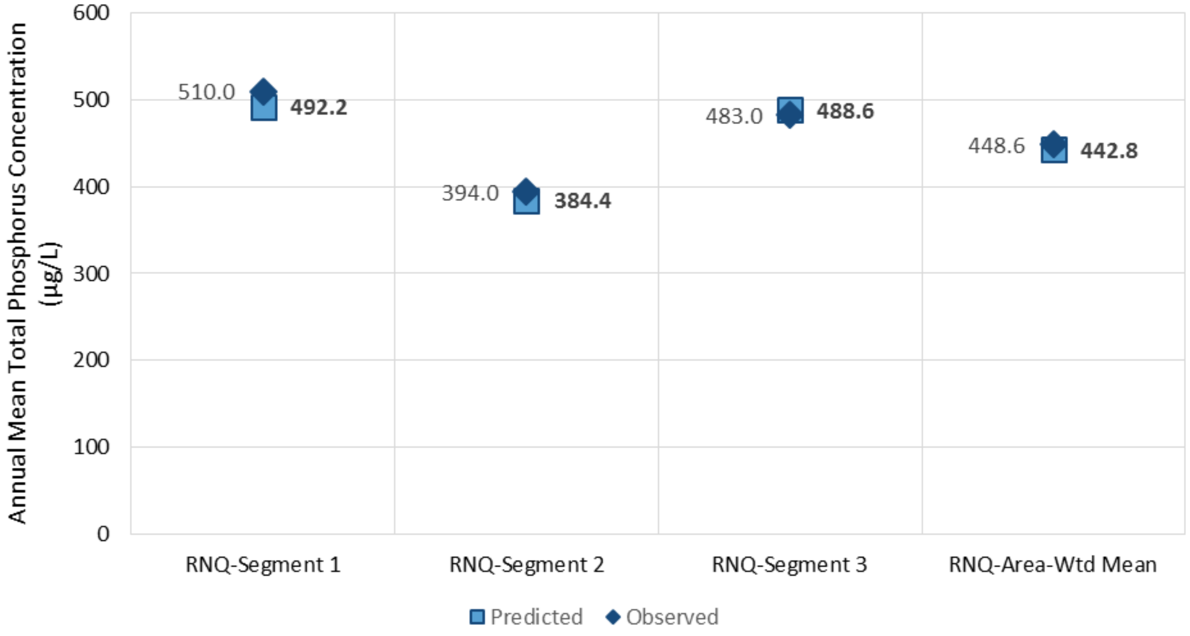

Figure 4-18. West Frankfort New (IL_RNQ) BATHTUB Segment Modeled vs. Observed Total Phosphorus Concentration

4.4 Total Suspended Solids Model for Load Reduction Strategy Development

This section describes the model selection and modeling approach for the total suspended solids load reduction strategy for the following waterbodies in the Upper Big Muddy River watershed, identified by IEPA as being impaired due to elevated total suspended solids concentrations:

- Herrin Old / IL_RNZD
- Johnston City / IL_RNZE
- West Frankfort Old / IL_RNP
- West Frankfort New/ IL_RNQ
- Big Muddy R. / IL_N-06
- Big Muddy R. / IL_N-11
- Big Muddy R. / IL_N-17
- Hurricane Creek / IL_NF-01
- Pond Cr. / IL_NG-02
- M. Fk. Big Muddy / IL_NH-07

4.4.1 Modeling Approach

The total suspended solids load reduction strategy is based on a simple empirical model using the average of all available TSS data on each waterbody, and comparing it with the LRS endpoint concentration identified in Section 3.1.

The load reduction target concentration for TSS for all streams in this watershed is 27.75 mg/L. For all lakes in the watershed, the load reduction targets concentration is 23 mg/L.

After reviewing the water quality data available, it was found that the following waterbodies have average TSS concentrations already below the target for the watershed, and therefore will not have LRSs prepared.

- Herrin Old / IL_RNZD
- Johnston City / IL_RNZE
- West Frankfort Old / IL_RNP
- West Frankfort New/ IL_RNQ
- Hurricane Creek / IL_NF-01

5

TMDL Development for the Upper Big Muddy River Watershed

This section presents the development of the TMDLs for the following waterbodies in the Upper Big Muddy River watershed:

- Upper Big Muddy River (IL_N-11) for fecal coliform
- Andy Cr. (IL_NZN-13) for iron.
- Lake Cr. (IL_NGA-02) for dissolved oxygen.
- Beaver Cr. (IL_NGAZ-JC-D1) for manganese.
- Pond Cr. (IL_NG-02) for chloride.
- Middle Fork Big Muddy (IL_NH-06) for fecal coliform.
- Arrowhead (Williamson) (IL_RNZX) for total phosphorus.
- Herrin Old (IL_RNZD) for total phosphorus.
- Johnston City (IL_RNZE) for total phosphorus.
- West Frankfort Old (IL_RNP) for total phosphorus.
- West Frankfort New (IL_RNQ) for total phosphorus.

In addition, a dissolved oxygen TMDL was planned for Andy Creek (IL_NZN-13), but after reviewing the field data and developing the QUAL2E model, it was determined that the low flows and high sediment oxygen demand were the primary causes of the low dissolved oxygen in this stream, not external pollutant loadings.

5.1 Andy Creek (IL_NZN-13) Dissolved Oxygen TMDL

A dissolved oxygen assessment was conducted for Andy Creek segment IL_NZN-13. The result of this assessment indicates that low stream flows preclude attainment of dissolved oxygen standards, even in the complete absence of external pollutant loads. For this reason, a TMDL is not being developed for dissolved oxygen. Details of the assessments are discussed below.

Two lines of assessment were used to make the determination that it is low stream flows, rather than external pollutant loads, that precludes attainment of dissolved oxygen standards:

1. Sediment oxygen demand is the dominant component of the dissolved oxygen mass balance provided by QUAL2E.
2. Setting all external loading sources to zero in the QUAL2E model does not result in attainment in dissolved oxygen standards.
3. Leaving all external loads at currently specified values, but increasing base stream flow, does result in attainment with dissolved oxygen standards.

5.1.1 Calculation of Loading Capacity

The loading capacity is defined as the maximum pollutant load that a waterbody can receive and still maintain compliance with water quality standards.

The first step in determining the loading capacity was to reduce external sources of oxygen-demanding substances to determine whether these reductions would result in the river attaining the dissolved oxygen target.

QUAL2E simulations showed that, even with incremental inflow and permitted BOD loads set to zero, compliance with the dissolved oxygen standards was not attained. Examination of model results showed that sediment oxygen demand was the dominant source of the oxygen deficit, and that DO standards could only be attained during critical periods via reduction of SOD[1].

5.2 Lake Creek (IL_NGA-02) Dissolved Oxygen TMDL

A dissolved oxygen assessment was conducted for Lake Creek segment IL_NGA-02 utilizing the data collected in September 2015 and a QUAL2E model. The QUAL2E model was calibrated to the data available, which occurred during a month when there were effluent limit violations from the Johnston City STP for both CBOD5 and ammonia nitrogen.

To determine if the effluent violations were causing the observed DO impairments, the QUAL2E model was run with modifying the input loads from the Johnston City STP to the current permit limits of 10 mg/L $CBOD_5$ (monthly average effluent limit) and 1.5 mg/L ammonia nitrogen (monthly average effluent limit), and 6.0 mg/L of dissolved oxygen (monthly average minimum) at the design average flow for the facility of 0.55 MGD.

The result of this assessment shows that if the Johnston City STP effluent meets the above noted limits. The dissolved oxygen concentration in the stream reaches a minimum level of 5.37 mg/L, which is above the 5.0 mg/L endpoint selected for the TMDL based on the State of Illinois water quality standards.

5.2.1 Calculation of Loading Capacity

The loading capacity is defined as the maximum pollutant load that a waterbody can receive and still maintain compliance with water quality standards.

The first step in determining the loading capacity was to reduce external sources of oxygen-demanding substances to determine whether these reductions would result in the river attaining the dissolved oxygen target.

QUAL2E simulations showed that with the point load $CBOD_5$ and ammonia nitrogen loads set to zero, compliance with the dissolved oxygen standards was attained with a minimum dissolved oxygen concentration of 5.38 mg/L.

Further QUAL2E simulations with adjusted BOD, dissolved oxygen, and ammonia nitrogen loads from the Johnston City STP were performed to determine the loading capacity. As noted above, QUAL2E model simulations with the input loads from the Johnston City STP set to the current permit limits of 10 mg/L $CBOD_5$ (monthly average effluent limit) and 1.5 mg/L ammonia nitrogen (monthly average effluent limit), and 6.0 mg/L of dissolved oxygen (monthly average minimum) at the design average flow for the facility of 0.55 MGD resulted in a minimum dissolved oxygen concentration of 5.37 mg/L, which is above the 5.0 mg/L endpoint selected for the TMDL based on the State of Illinois water quality standards.

Additional QUAL2E simulations were performed with the input loads from the Johnston City STP adjusted until the minimum dissolved oxygen concentration was 5.0 mg/L to determine the maximum loading capacity of the stream. The loading capacity of the stream for ammonia nitrogen was determined

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[1] Although SOD is the dominant source of the oxygen deficit, the true cause of low dissolved oxygen is a lack of base flow (which greatly exacerbates the effect of SOD). Because TMDLs cannot be written to control flow, no TMDL was developed for this stream segment.

to be 1.80 mg/L, with a $CBOD_5$ load of 11 mg/L, and 5.45 mg/L of dissolved oxygen at the design average flow for the facility. The total loading capacity for Lake Creek segment IL_NGA-02 for ammonia nitrogen is 8.25 lb/day.

5.2.2 Allocation

A TMDL consists of waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

The WLA for the Johnston City STP into Lake Creek segment IL_NGA-02 was calculated based on the permitted design average flow for the facility, and the current NPDES effluent limit concentration for ammonia nitrogen of 1.5 mg/L (monthly average limitation). The WLA for Lake Creek is presented in Table 5-1.

Table 5-1. Lake Creek Segment IL_NGA-02 Watershed Permitted Dischargers and WLAs

NPDES ID	Facility Name	Ammonia Nitrogen Effluent Concentration (mg/L)	Design average flow (MGD)	WLA (lb/day)
IL0029301	Johnston City STP	1.50	0.55	6.88

The remaining loading capacity is given to the load allocation for nonpoint sources and the margin of safety. The load allocation for nonpoint sources is not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall phosphorus load. Given a total loading capacity of 8.25 lbs/day of ammonia nitrogen, a WLA for the Johnston City STP of 6.88 lbs/day, and an explicit margin of safety of 10% (discussed below), the load allocation for Lake Creek segment IL_NGA-02 is 0.54 lbs/day.

5.2.3 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The QUAL2E model and the sampling were performed during a low flow period, which is critical for determining loads associated with low dissolved oxygen.

5.2.4 Margin of Safety

The TMDL contains an explicit margin of safety of 10%. The 10% margin of safety is considered an appropriate value based upon the generally good agreement between the QUAL2E water quality model predicted values and the observed values. Since the model reasonably reflects the conditions in the stream, a 10% margin of safety is considered to be adequate to address the uncertainty in the TMDL, based upon the data available. This margin of safety can be reviewed in the future as new data are developed. The resulting explicit total ammonia nitrogen load allocated to the margin of safety is 0.825 lbs/day for Lake Creek.

5.2.5 Reserve Capacity

Lake Creek is located in Williamson County, the population of which has increased by 8.3% between 2000 and 2010 (Stage 1 Report Section 2.6). In 2010, the U.S. Census Bureau estimated the Franklin County population at 66,357.

The Illinois Department of Public Health population projections (Shahidullah 2015) for Williamson County shows a slight population increase to 69,246 in the year 2025. Further, the Greater Egypt Regional Planning and Development Commission, referencing US Census Bureau projections, states that the population in the Greater Egypt 5-county area which includes Williamson County will be relatively steady (or slightly declining) through 2030 (GERPDC 2010).

A reserve capacity is not needed, due to the slight projected increase in population, and because, at this time IEPA is not aware of any increases in discharges from the existing point sources, or the establishment of future municipal or industrial point sources.

5.2.6 TMDL Summary

The dissolced oxygen (ammonia) TMDL for Lake Creek segment IL_NGA-02, is presented in Table 5-2.

Table 5-2. Lake Creek IL_NGA-02 TMDL Summary

Allocation	Total Ammonia Nitrogen Load (lbs/day)
Load Capacity (LC)	8.25
Wasteload Allocation (WLA)	6.88
Load Allocation (LA)	0.54
Margin of safety (10% of LC)	0.83

5.3 Upper Big Muddy River (IL_N-11) Fecal Coliform TMDL

A load capacity calculation approach was applied to support development of a fecal coliform TMDL for Upper Big Muddy River segment IL_N-11.

5.3.1 Calculation of Loading Capacity

The loading capacity is defined as the maximum pollutant load that a waterbody can receive and still maintain compliance with water quality standards.

The loading capacity for Upper Big Muddy River segment IL_N-11 was defined over a range of specified flows based on expected Upper Big Muddy River flows at the mouth of the creek. The allowable loading capacity was computed by multiplying flow by the TMDL target (200 cfu/100 mL). The fecal coliform loading capacity for IL_N-11 is presented in Table 5-3.

Table 5-3. Fecal Coliform Load Capacity (IL_N-11)

Flow Exceedance Percentile from the LDC	Upper Big Muddy River Flow (cfs)	Allowable Load (cfu/day)
99%	9.7	4.8E+10
95%	11	5.6E+10
90%	13	6.2E+10
80%	16	7.7E+10
70%	22	1.1E+11
60%	35	1.7E+11
50%	57	2.8E+11
40%	93	4.6E+11
30%	150	7.6E+11
20%	260	1.3E+12
10%	610	3.0E+12
5%	1700	8.3E+12
1%	7200	3.5E+13

The maximum fecal coliform concentrations recorded between May and October were examined for each flow duration interval, as shown in Table 5-4, in order to estimate the percent reduction in existing loads required to meet the 200 cfu/100 mL target. As shown in Table 5-4, a greater reduction is needed at higher river flows to meet the target. During these higher flow periods, fecal coliform measurements were observed to exceed 200 cfu/100 mL more frequently.

Table 5-4. Required Reductions in Existing Loads under Different Flow Conditions (IL_N-11)

Flow Percentile Interval	Upper Big Muddy River Flow (cfs)	# samples > 200/ # samples (May-Oct)	Maximum fecal coliform concentration (cfu/100 ml)	Percent Reduction to Meet Target
0 - 30	28,875 - 154	3 / 8	4,500	95.6%
30 - 70	154 - 21.9	7 / 22	3,600	94.4%
70 - 100	21.9 - 6.9	1 / 15	210	4.8%

5.3.2 Allocation

A TMDL consists of waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

The WLA for the 10 permitted sewage treatment plant discharges in the Upper Big Muddy River segment IL_N-11 watershed was calculated based on the permitted design average flow for these dischargers and a fecal coliform concentration that is consistent with meeting the TMDL target (200 cfu/100mL). Eight of the ten NPDES-permitted dischargers have disinfection exemptions, therefore, the WLA is based on the dischargers meeting 200 cfu/100 mL at the downstream end of their exempted reach. WLAs are presented in Table 5-5.

Table 5-5. Segment IL_N-11 Watershed Permitted Dischargers and WLAs

NPDES ID	Facility Name	Disinfection exemption?	Design average flow (MGD)	WLA (cfu/day)
ILG580083	VALIER STP	Yes, year-round	0.08	6.06E+08
ILG580215	WEST CITY STP	Yes, year-round	0.1	7.57E+08
ILG580221	HANAFORD STP	Yes, year-round	0.042	3.18E+08
ILG580272	ORIENT STP	Yes, year-round	0.0752	5.69E+08
IL0050466	LB CAMPING-SESSER STP	No (400 cfu / 100 mL Daily Max)	0.0051	3.86E+07
IL0061760	HILL CITY APARTMENTS-BENTON	Yes, year-round	0.004	3.03E+07
IL0065111	REND LAKE CONS. DIST. STP	Yes, year-round	0.5	3.79E+09
IL0020851	CHRISTOPHER STP	Yes, year-round	0.768	5.81E+09
IL0022365	BENTON NORTHWEST STP	No (400 cfu / 100 mL Daily Max)	1.01	7.65E+09
IL0031704	WEST FRANKFORT STP	Yes, year-round	1.4	1.06E+10

The total WLA for the ten (10) point source dischargers in the IL_N-11 watershed is 3.02E+10 cfu/day. This does not include any dischargers in the areas upstream of Rend Lake. The significant retention time and settling capacity in the reservior are assumed to reduce fecal coliform loads from the upstream areas to be below the water quality standards.

The remainder of the loading capacity is given to the load allocation for nonpoint sources as an implicit MOS was used in this TMDL (Table 5-6). The load allocations are not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall fecal coliform load.

Table 5-6. Fecal Coliform TMDL for Segment IL_N-11 Upper Big Muddy River[1]

Upper Big Muddy River Flow (cfs)	Allowable Load (cfu/day)	Wasteload Allocation (WLA) (cfu/day)	Load Allocation (LA) (cfu/day)
12.6	6.16E+10	3.02E+10	3.14E+10
15.8	7.75E+10	3.02E+10	4.73E+10
21.9	1.07E+11	3.02E+10	7.71E+10
34.9	1.71E+11	3.02E+10	1.41E+11
56.9	2.78E+11	3.02E+10	2.48E+11
93.4	4.57E+11	3.02E+10	4.27E+11
154	7.55E+11	3.02E+10	7.25E+11
260	1.27E+12	3.02E+10	1.24E+12
609	2.98E+12	3.02E+10	2.95E+12
7226	3.54E+13	3.02E+10	3.53E+13

[1] This TMDL has an implicit Margin of Safety, so MOS is not included in this table.

5.3.3 Critical Condition

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Figure 4-5 provides a graphical depiction of the data compared to the load capacity, showing that exceedances of the TMDL target occur over the full range of flow conditions. TMDL development utilizing the load-duration approach applies to the full range of flow conditions; therefore critical conditions were addressed during TMDL development.

5.3.4 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The load capacity calculation approach used for the TMDL evaluated seasonal loads because only May through October water quality data were used in the analysis, consistent with the specification that the standard only applies during this period. The fecal coliform standard will be met regardless of flow conditions in the applicable season because the load capacity calculations specify target loads for the entire range of flow conditions that are possible to occur in any given point in the season where the standard applies.

5.3.5 Margin of Safety

Total maximum daily loads are required to contain a Margin of Safety (MOS) to account for any uncertainty concerning the relationship between pollutant loading and receiving water quality. The MOS can be either implicit (e.g., incorporated into the TMDL analysis through conservative assumptions), or explicit (e.g., expressed in the TMDL as a portion of the loading), or expressed as a combination of both. The fecal coliform TMDL contains an implicit margin of safety, through the use of multiple conservative assumptions. First, the TMDL target (no more than 200 cfu/100 mL at any point in time) is more conservative than the more restrictive portion of the fecal coliform water quality standard (geometric mean of 200 cfu/100 mL for all samples collected May through October). An additional implicit Margin of Safety is provided via the use of a conservative model to define load capacity. The model assumes no decay of bacteria that enter the river, and therefore represents an upper bound of expected concentrations for a given pollutant load. This margin of safety can be reviewed in the future as new data are developed.

5.4 Middle Fork Big Muddy (IL_NH-06) Fecal Coliform TMDL

A load capacity calculation approach was applied to support development of a fecal coliform TMDL for Middle Fork Big Muddy River segment IL_NH-06.

5.4.1 Calculation of Loading Capacity

The loading capacity is defined as the maximum pollutant load that a waterbody can receive and still maintain compliance with water quality standards.

The loading capacity for the Middle Fork Big Muddy River segment IL_NH-06 was defined over a range of specified flows based on expected flows at the outlet of the segment. The allowable loading capacity was computed by multiplying flow by the TMDL target (200 cfu/100 mL). The fecal coliform loading capacity for IL_NH-06 is presented in Table 5-7.

Table 5-7. Fecal Coliform Load Capacity (IL_NH-06)

Flow Exceedance Percentile from the LDC	Middle Fork Big Muddy River Flow (cfs)	Allowable Load (cfu/day)
99%	5.0	2.5E+10
95%	5.8	2.9E+10
90%	6.5	3.2E+10
80%	8.1	4.0E+10
70%	11	5.5E+10
60%	18	8.8E+10
50%	29	1.4E+11
40%	48	2.4E+11
30%	79	3.9E+11
20%	130	6.5E+11
10%	310	1.5E+12
5%	870	4.2E+12
1%	3700	1.8E+13

The maximum fecal coliform concentrations recorded between May and October were examined for each flow duration interval, as shown in Table 5-8, in order to estimate the percent reduction in existing loads required to meet the 200 cfu/100 mL target. As shown in Table 5-8, the greatest reduction is needed at normally encountered river flows to meet the target. During these higher flow periods, fecal coliform measurements were observed to exceed 200 cfu/100 mL more frequently (as a fraction of the samples taken).

Table 5-8. Required Reductions in Existing Loads under Different Flow Conditions (IL_NH-06)

Flow Percentile Interval	Upper Big Muddy River Flow (cfs)	# samples > 200/ # samples (May-Oct)	Maximum fecal coliform concentration (cfu/100 ml)	Percent Reduction to Meet Target
0 - 30	14,849 - 79	7 / 7	20,000	99.0%
30 - 70	79 - 11.3	10 / 18	63,600	99.7%
70 - 100	11.3 - 3.55	7 / 21	1,760	88.6%

5.4.2 Allocation

A TMDL consists of waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$TMDL = WLA + LA + MOS$$

The WLA for the 3 permitted sewage treatment plant discharges in the Middle Fork Big Muddy River segment IL_NH-06 watershed was calculated based on the permitted design average flow for these dischargers and a fecal coliform concentration that is consistent with meeting the TMDL target (200 cfu/100mL). All three of these NPDES-permitted dischargers have disinfection exemptions, therefore, the WLA is based on the dischargers meeting 200 cfu/100 mL at the downstream end of their exempted reach. WLAs are presented in Table 5-9.

Table 5-9. Segment IL_NH-06 Permitted Dischargers and WLAs

NPDES ID	Facility Name	Disinfection exemption?	Design average flow (MGD)	WLA (cfu/day)
ILG580221	HANAFORD STP	Yes, year-round	0.042	3.18E+08
IL0061760	HILL CITY APARTMENTS-BENTON	Yes, year-round	0.004	3.03E+07
IL0065111	REND LAKE CONS. DIST. STP	Yes, year-round	0.5	3.79E+09

The total WLA for the three (3) point source dischargers in the IL_NH-06 watershed is 4.13E+09 cfu/day.

The remainder of the loading capacity is given to the load allocation for nonpoint sources as an implicit MOS was used in this TMDL (Table 5-10). The load allocations are not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall fecal coliform load.

Table 5-10. Fecal Coliform TMDL for Segment IL_NH-06 Upper Big Muddy River[1]

Upper Big Muddy River Flow (cfs)	Allowable Load (cfu/day)	Wasteload Allocation (WLA) (cfu/day)	Load Allocation (LA) (cfu/day)
6.5	3.17E+10	4.13E+09	2.75E+10
8.1	3.99E+10	4.13E+09	3.57E+10
11.3	5.52E+10	4.13E+09	5.10E+10
18.0	8.79E+10	4.13E+09	8.38E+10
29.2	1.43E+11	4.13E+09	1.39E+11
48.0	2.35E+11	4.13E+09	2.31E+11
79.4	3.88E+11	4.13E+09	3.84E+11
134	6.54E+11	4.13E+09	6.50E+11
313	1.53E+12	4.13E+09	1.53E+12
3716	1.82E+13	4.13E+09	1.82E+13

[1] This TMDL has an implicit Margin of Safety, so MOS is not included in this table.

5.4.3 Critical Condition

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Figure 4-9 provides a graphical depiction of the data compared to the load capacity, showing that exceedances of the TMDL target occur over the full range of flow conditions. TMDL development utilizing the load-duration approach applies to the full range of flow conditions; therefore critical conditions were addressed during TMDL development.

5.4.4 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The load capacity calculation approach used for the TMDL evaluated seasonal loads because only May through October water quality data were used in the analysis, consistent with the specification that the standard only applies during this period. The fecal coliform standard will be met regardless of flow conditions in the applicable season because the load capacity calculations specify target loads for the entire range of flow conditions that are possible to occur in any given point in the season where the standard applies.

5.4.5 Margin of Safety

Total maximum daily loads are required to contain a Margin of Safety (MOS) to account for any uncertainty concerning the relationship between pollutant loading and receiving water quality. The MOS can be either implicit (e.g., incorporated into the TMDL analysis through conservative assumptions), or explicit (e.g., expressed in the TMDL as a portion of the loading), or expressed as a combination of both. The fecal coliform TMDL contains an implicit margin of safety, through the use of multiple conservative assumptions. First, the TMDL target (no more than 200 cfu/100 mL at any point in time) is more conservative than the more restrictive portion of the fecal coliform water quality standard (geometric mean of 200 cfu/100 mL for all samples collected May through October). An additional implicit Margin of Safety is provided via the use of a conservative model to define load capacity. The model assumes no decay of bacteria that enter the river, and therefore represents an upper bound of expected concentrations for a given pollutant load. This margin of safety can be reviewed in the future as new data are developed.

5.5 Andy Creek (IL_NZN-13) Iron TMDL

A load capacity calculation approach was applied to support development of dissolved iron TMDL for Andy Creek segment IL_NZN-13.

5.5.1 Calculation of Loading Capacity

The loading capacity is defined as the maximum pollutant load that a waterbody can receive and still maintain compliance with water quality standards. The loading capacity was defined over a range of specified flows based on expected flows. The allowable loading capacity was computed by multiplying the estimated flow in Andy Creek by the TMDL target concentration of 1 mg/l (Table 5-11).

Table 5-11. Iron Load Capacity (IL_NZN-13)

Flow Exceedance Percentile from the LDC	Stream Flow (cfs)	Allowable Load (lbs/day)
90%	0.1	0.27
80%	0.2	1.0
70%	0	2.5
60%	1	5.5
50%	2	1.3
40%	5	2.6
30%	9	4.8
20%	15	8.3
10%	40	2.1
5%	99	5.4

The maximum dissolved iron concentrations were examined for each flow duration interval, as shown in Table 5-12, in order to estimate the percent reduction in existing loads required to meet the 1 mg/l target. Reductions of up to 9.9% in current loads are needed at higher river flows to meet the target. No reductions are needed at lower flows.

Table 5-12. Required Reductions in Existing Loads under Different Flow Conditions (IL_NZN-13)

Flow Percentile Interval	Stream Flow (cfs)	# samples > 1 mg/L / # samples	Maximum Dissolved Iron concentration (mg/L)	Percent Reduction to Meet Target
0 - 30	3,572 - 9	1 / 1	1.11	9.9%
30 - 70	9 - 0.46	0 / 1	0.081	-
70 - 100	0.46 - 0	0 / 1	0.038	-

5.5.2 Allocation

A TMDL consists of a waste load allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

There are no permitted dischargers of iron in the Andy Creek segment IL_NZN-13 watershed, and therefore the wasteload allocation did not need to be calculated.

The remainder of the loading capacity is given to the load allocation for nonpoint sources and the MOS (Table 5-13). The load allocations are not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall iron load.

Table 5-13. Iron TMDL for Andy Creek (Segment IL_NZN-13)

Stream Flow (cfs)	Allowable Load (lbs/day)	MOS (10%) (lbs/day)	Wasteload Allocation (WLA) (lbs/day)	Load Allocation (LA) (lbs/day)
0.05	0.27	0.03	0	0.24
0.19	1.04	0.10	0	0.94
0.46	2.46	0.25	0	2.2
1.0	5.54	0.55	0	5.0
2.4	13.2	1.3	0	11.9
4.8	26.0	2.6	0	23.4
9.0	48.5	4.9	0	43.7
15	83.1	8.3	0	74.8
40	215	22	0	194
472	2541	254	0	2287

5.5.3 Critical Condition

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Figure 4-6 provides a graphical depiction of the data compared to the load capacity, showing that the TMDL target is exceeded during higher flow conditions. TMDL development utilizing the load-duration approach applies to the full range of flow conditions, including high flows; therefore critical conditions were addressed during TMDL development.

5.5.4 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The iron standard will be met regardless of flow conditions in any season because the load capacity calculations specify target loads for the entire range of flow conditions that are possible to occur in the stream.

5.5.5 Margin of Safety

Total maximum daily loads are required to contain a Margin of Safety (MOS) to account for any uncertainty concerning the relationship between pollutant loading and receiving water quality. The iron TMDL contains an explicit margin of safety of 10%. This 10% margin of safety was included to address potential uncertainty in the effectiveness of load reduction alternatives. This margin of safety can be reviewed in the future as new data are developed.

5.6 Beaver Creek (IL_NGAZ-JC-D1) Manganese TMDL

A load capacity calculation approach was applied to support development of a manganeseTMDL for Beaver Creek segment IL_NGAZ-JC-D1.

5.6.1 Calculation of Loading Capacity

The loading capacity is defined as the maximum pollutant load that a waterbody can receive and still maintain compliance with water quality standards. The loading capacity was defined over a range of specified flows based on expected flows. The allowable loading capacity was computed by multiplying the estimated Beaver Creek flow by the TMDL target concentration of 4.85 mg/l (Table 5-14).

Table 5-14. Manganese Load Capacity (IL_NGAZ-JC-D1)

Flow Exceedance Percentile from the LDC	Beaver Creek Flow (cfs)	Allowable Load (lbs/day)
80%	0.006	0.15
70%	0.01	0.36
60%	0.03	0.81
50%	0.07	1.93
40%	0.15	3.80
30%	0.27	7.10
20%	0.47	12.16
10%	1.2	31.42
5%	3.0	78.36
1%	14	371.98

The maximum manganese concentrations were examined for each flow duration interval, as shown in Table 5-15, in order to estimate the percent reduction in existing loads required to meet the 4.85 mg/L target. Reductions of 24.4% of current loads are needed based on the single water quality sample data point sampled in the normally occurring flows interval. No reductions are are able to be calculated at lower or higher flows based on the data available.

Table 5-15. Required Reductions in Existing Loads under Different Flow Conditions (IL_NGAZ-JC-D1)

Flow Percentile Interval	Beaver Creek Flow (cfs)	# samples > 4.85 mg/l samples	Maximum Manganese concentration (mg/L)	Percent Reduction to Meet Target
0 - 30	108 - 0.27	0 / 0	-	-
30 - 70	0.27 - 0.01	1 / 1	6.41	24.4%
70 - 100	0.01 - 0	0 / 0	-	-

5.6.2 Allocation

A TMDL consists of a waste load allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

There are no permitted dischargers of manganese in the Beaver Creer segment IL_NGAZ-JC-D1 watershed, and therefore the wasteload allocation did not need to be calculated.

The remainder of the loading capacity is given to the load allocation for nonpoint sources and the MOS (Table 5-16). The load allocations are not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall manganese load.

Table 5-16. Manganese TMDL for Beaver Creek (Segment IL_NGAZ-JC-D1)

Flow (cfs)	Allowable Load (lbs/day)	MOS (10%) (lbs/day)	Wasteload Allocation (WLA) (lbs/day)	Load Allocation (LA) (lbs/day)
0.01	0.36	0.04	0	0.32
0.03	0.81	0.08	0	0.73
0.07	1.9	0.2	0	1.7
0.15	3.8	0.4	0	3.4
0.27	7.1	0.7	0	6.4
0.5	12.2	1.2	0	11.0
1.2	31.3	3.1	0	28.2

5.6.3 Critical Condition

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Figure 4-8 provides a graphical depiction of the data compared to the load capacity, showing that the TMDL target is exceeded during higher flow conditions. TMDL development utilizing the load-duration approach applies to the full range of flow conditions, including high flows; therefore critical conditions were addressed during TMDL development.

5.6.4 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The manganese standard will be met regardless of flow conditions in any season because the load capacity calculations specify target loads for the entire range of flow conditions that are possible to occur in the river.

5.6.5 Margin of Safety

Total maximum daily loads are required to contain a Margin of Safety (MOS) to account for any uncertainty concerning the relationship between pollutant loading and receiving water quality. The manganese TMDL contains an explicit margin of safety of 10%. This 10% margin of safety was included to address potential uncertainty in the effectiveness of load reduction alternatives. This margin of safety can be reviewed in the future as new data are developed.

5.7 Herrin Old (IL_RNZD) Total Phosphorus TMDL

5.7.1 Calculation of the Loading Capacity

The loading capacity for Herrin Old Reservoir was determined by running the BATHTUB model repeatedly, reducing the tributary nutrient concentrations and/or internal phosphorus loadings for each simulation until model results demonstrated attainment of the water quality objective.

The maximum tributary concentration that results in compliance with water quality standards was used as the basis for determining the loading capacity. The tributary concentration was then converted into a loading rate through multiplication with the tributary flow.

The initial BATHTUB simulations and the sampling data from 2013 indicated that Herrin Old Reservoir phosphorus concentrations would meet the the water quality standards using the lake-averaged phosphorus concentrations. The sampling data indicated that the only exceedances of the water quality standard were at the deepest parts of the lake, which indicates that the internal phosphorus source needs to be reduced by either capping the sediments (e.g. alum treatment or similar), or by dredging any organic sediments from the lake. The resulting load, with calibrated tributary concentrations and no additional sediment phosphorus load yields an average phosphorus load of 0.23 kg/day (0.51 lbs/day) and a concentration of 0.029 mg/L. This is below the phosphorus target of 0.05 mg/L, so reductions in the tributary loads are not necessary.

5.7.2 Allocation

A TMDL consists of a waste load allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

There are no point sources in the watershed, and therefore there is no wasteload allocation given for Herrin Old Reservoir. The entire loading capacity is given to the load allocation for nonpoint sources and the margin of safety. The loading capacity is not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall phosphorus load. Given a loading capacity of 0.23 kg/day (0.51 lbs/day), and an explicit margin of safety of 10% (discussed below), the load allocation for Herrin Old Reservoir of 0.21 kg/day (0.46 lbs/day).

5.7.3 Critical Conditions

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Critical conditions were taken into account in the development of this TMDL. In terms of loading, spring runoff periods are considered critical because wet weather events can transport significant quantities of nonpoint source loads to lake. However, the water quality ramifications of these nutrient loads are most severe during middle or late summer. This TMDL is based upon an annual period that takes into account both spring loads and summer water quality in order to effectively consider these critical conditions.

5.7.4 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The BATHTUB model used for this TMDL is designed to evaluate loads over a seasonal to annual averaging period. The annual loading analysis that was used is appropriate due to the facts that:

1. The analysis demonstrated that the TMDL could only attain water quality targets if a significant reduction was achieved in sediment phosphorus release.
2. There is a long response time between phosphorus loading and sediment response, typically on the order of several years (e.g. Chapra and Canale, 1991).

5.7.5 Margin of Safety

The TMDL contains an explicit margin of safety of 10%. The 10% margin of safety is considered an appropriate value based upon the generally good agreement between the BATHTUB water quality model predicted values and the observed values. Since the model reasonably reflects the conditions in the watershed, a 10% margin of safety is considered to be adequate to address the uncertainty in the TMDL, based upon the data available. This margin of safety can be reviewed in the future as new data are developed. The resulting explicit total phosphorus load allocated to the margin of safety is 0.02 kg/day (0.04 lbs/day) for Herrin Old Reservoir.

5.7.6 Reserve Capacity

This watershed is located in Williamson County, the population of which has increased by 8.3% between 2000 and 2010 (Stage 1 Report Section 2.6). In 2010, the U.S. Census Bureau estimated the Franklin County population at 66,357.

The Illinois Department of Public Health population projections (Shahidullah 2015) for Williamson County shows a slight population increase to 69,246 in the year 2025. Further, the Greater Egypt Regional Planning and Development Commission, referencing US Census Bureau projections, states that the population in the Greater Egypt 5-county area which includes Williamson County will be relatively steady (or slightly declining) through 2030 (GERPDC 2010).

A reserve capacity is not needed, due to the slight projected increase in population, and because, at this time IEPA is not aware of any increases in discharges from the existing point sources, or the establishment of future municipal or industrial point sources.

5.7.7 TMDL Summary

The total phosphorus TMDL for Herrin Old Reservoir, segment IL_RNZD, is presented in Table 5-17.

Table 5-17. Herrin Old Reservior IL_RNZD TMDL Summary

Allocation	Total Phosphorus Load kg/day (lbs/day)
Load Capacity (LC)	0.23 (0.51)
Wasteload Allocation (WLA)	Not applicable. There are no permitted dischargers in this watershed
Load Allocation (LA)	0.21 (0.46)
Margin of safety (10% of LC)	0.02 (0.05)

5.8 Johnston City (IL_RNZE) Total Phosphorus TMDL

5.8.1 Calculation of the Loading Capacity

The loading capacity for Johnston City Reservoir was determined by running the BATHTUB model repeatedly, reducing the tributary nutrient concentrations for each simulation until model results demonstrated attainment of the water quality objective. The maximum tributary concentration that results in compliance with water quality standards was used as the basis for determining the loading capacity. The tributary concentration was then converted into a loading rate through multiplication with the tributary flow.

Initial BATHTUB load reduction simulations indicated that Johnston City Reservoir phosphorus concentrations would exceed the water quality standard regardless of the level of tributary load reduction, due to the elevated internal phosphorus loads from lake sediments. This internal phosphorus flux is expected to decrease in the future in response to external phosphorus load reductions, or in response to management actions to remove organic sediments from the lake, reverting back to more typical conditions. This reduction in future sediment phosphorus release was represented in the model by eliminating the additional internal sediment phosphorus source for future scenarios. The resulting load, with calibrated tributary concentrations and no additional sediment phosphorus load yields an average phosphorus load of 0.43 kg/day (0.95 lbs/day) and a concentration of 0.048 mg/L. This meets the phosphorus target of 0.05 mg/L, so reductions in the tributary loads are not necessary. Therefore, the loading capacity is equal to the current incoming loads of 0.43 kg/day (0.95 lbs/day).

5.8.2 Allocation

A TMDL consists of a waste load allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

There are no point sources in the watershed, and therefore there is no wasteload allocation given for Johnston City Reservoir. The entire loading capacity is given to the load allocation for nonpoint sources and the margin of safety. The loading capacity is not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall phosphorus load. Given a loading capacity of 0.2 kg/day (0.44 lbs/day), and an explicit margin of safety of 10% (discussed below), the load allocation for Johnston City Reservoir of 0.18 kg/day (0.40 lbs/day).

5.8.3 Critical Conditions

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Critical conditions were taken into account in the development of this TMDL. In terms of loading, spring runoff periods are considered critical because wet weather events can transport significant quantities of nonpoint source loads to lake. However, the water quality ramifications of these nutrient loads are most severe during middle or late summer. This TMDL is based upon an annual period that takes into account both spring loads and summer water quality in order to effectively consider these critical conditions.

5.8.4 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The BATHTUB model used for this TMDL is designed to evaluate loads over a seasonal to annual averaging period. The annual loading analysis that was used is appropriate due to the facts that:

1. The analysis demonstrated that the TMDL could only attain water quality targets if a significant reduction was achieved in sediment phosphorus release.
2. There is a long response time between phosphorus loading and sediment response, typically on the order of several years (e.g. Chapra and Canale, 1991).

5.8.5 Margin of Safety

The TMDL contains an explicit margin of safety of 10%. The 10% margin of safety is considered an appropriate value based upon the generally good agreement between the BATHTUB water quality model predicted values and the observed values. Since the model reasonably reflects the conditions in the watershed, a 10% margin of safety is considered to be adequate to address the uncertainty in the TMDL, based upon the data available. This margin of safety can be reviewed in the future as new data are developed. The resulting explicit total phosphorus load allocated to the margin of safety is 0.02 kg/day (0.04 lbs/day) for Johnston City Lake.

5.8.6 Reserve Capacity

This watershed is located in Williamson County, the population of which has increased by 8.3% between 2000 and 2010 (Stage 1 Report Section 2.6). In 2010, the U.S. Census Bureau estimated the Franklin County population at 66,357.

The Illinois Department of Public Health population projections (Shahidullah 2015) for Williamson County shows a slight population increase to 69,246 in the year 2025. Further, the Greater Egypt Regional Planning and Development Commission, referencing US Census Bureau projections, states that the population in the Greater Egypt 5-county area which includes Williamson County will be relatively steady (or slightly declining) through 2030 (GERPDC 2010).

A reserve capacity is not needed, due to the slight projected increase in population, and because, at this time IEPA is not aware of any increases in discharges from the existing point sources, or the establishment of future municipal or industrial point sources.

5.8.7 TMDL Summary

The total phosphorus TMDL for Johnston City Lake, segment IL_RNZE, is presented in Table 5-18.

Table 5-18. Johnston City Lake IL_RNZE TMDL Summary

Allocation	Total Phosphorus Load kg/day (lbs/day)
Load Capacity (LC)	0.48 (1.06)
Wasteload Allocation (WLA)	Not applicable. There are no permitted dischargers in this watershed
Load Allocation (LA)	0.43 (0.95)
Margin of safety (10% of LC)	0.05 (0.11)

5.9 Arrowhead (Williamson) (IL_RNZX) Total Phosphorus TMDL

5.9.1 Calculation of the Loading Capacity

The loading capacity for the Arrowhead (Williamson) Reservoir was determined by running the BATHTUB model repeatedly, reducing the tributary nutrient concentrations for each simulation until model results demonstrated attainment of the water quality objective. The maximum tributary concentration that results in compliance with water quality standards was used as the basis for determining the loading capacity. The tributary concentration was then converted into a loading rate through multiplication with the tributary flow.

Initial BATHTUB load reduction simulations indicated that Arrowhead (Williamson) Reservoir phosphorus concentrations would exceed the water quality standard regardless of the level of tributary load reduction, due to the elevated internal phosphorus loads from lake sediments. This internal phosphorus flux is expected to decrease in the future in response to external phosphorus load reductions and/or potential management actions (e.g. dredging organic sediments, alum treatment), reverting back to more typical conditions. This reduction in future sediment phosphorus release was represented in the model by eliminating the additional internal sediment phosphorus source for future scenarios. The resulting load, with calibrated tributary concentrations and no additional sediment phosphorus load yields an average phosphorus load of 0.11 kg/day (0.24 lbs/day) and a lake-wide average concentration of 0.049 mg/L. The predicted lake concentrations in the upstream model segments (Segment 2 and Segment 3) are 0.05 and 0.06 mg/l respectively. Therefore reductions in the tributary loads are necessary to meets the phosphorus target of 0.05 mg/L across the entire waterbody. The loading capacity was an average of 0.085 kg/day (0.19 lbs/day). This allowable load corresponds to an approximately 30% reduction from existing tributary loads.

5.9.2 Allocation

A TMDL consists of a waste load allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

There are no point sources in the watershed, and therefore there is no wasteload allocation given for Arrowhead (Williamson) Reservoir. The entire loading capacity is given to the load allocation for nonpoint sources and the margin of safety. The loading capacity is not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall phosphorus load. Given a loading capacity of 0.085 kg/day (0.19 lbs/day), and an explicit margin of safety of 10% (discussed below), the load allocation for Arrowhead (Williamson) Reservoir of 0.076 kg/day (0.17 lbs/day).

5.9.3 Critical Conditions

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Critical conditions were taken into account in the development of this TMDL. In terms of loading, spring runoff periods are considered critical because wet weather events can transport significant quantities of nonpoint source loads to lake. However, the water quality ramifications of these nutrient loads are most severe during middle or late summer. This TMDL is based upon an annual period that takes into account both spring loads and summer water quality in order to effectively consider these critical conditions.

5.9.4 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The BATHTUB model used for this TMDL is designed to evaluate loads over a seasonal to annual averaging period. The annual loading analysis that was used is appropriate due to the facts that:

3. The analysis demonstrated that the TMDL could only attain water quality targets if a significant reduction was achieved in sediment phosphorus release.
4. There is a long response time between phosphorus loading and sediment response, typically on the order of several years (e.g. Chapra and Canale, 1991).

5.9.5 Margin of Safety

The TMDL contains an explicit margin of safety of 10%. The 10% margin of safety is considered an appropriate value based upon the generally good agreement between the BATHTUB water quality model predicted values and the observed values. Since the model reasonably reflects the conditions in the watershed, a 10% margin of safety is considered to be adequate to address the uncertainty in the TMDL, based upon the data available. This margin of safety can be reviewed in the future as new data are developed. The resulting explicit total phosphorus load allocated to the margin of safety is 0.008 kg/day (0.02 lbs/day) for Arrowhead (Williamson) Reservoir.

5.9.6 Reserve Capacity

The Arrowhead (Williamson) Reservoir watershed is located in Williamson County, the population of which has increased by 8.3% between 2000 and 2010 (Stage 1 Report Section 2.6). In 2010, the U.S. Census Bureau estimated the Franklin County population at 66,357.

The Illinois Department of Public Health population projections (Shahidullah 2015) for Williamson County shows a slight population increase to 69,246 in the year 2025. Further, the Greater Egypt Regional Planning and Development Commission, referencing US Census Bureau projections, states that the population in the Greater Egypt 5-county area which includes Williamson County will be relatively steady (or slightly declining) through 2030 (GERPDC 2010).

A reserve capacity is not needed, due to the slight projected increase in population, and because, at this time IEPA is not aware of any increases in discharges from the existing point sources, or the establishment of future municipal or industrial point sources.

5.9.7 TMDL Summary

The total phosphorus TMDL for Arrowhead (Williamson) Reservoir, segment IL_RNZX, is presented in Table 5-19.

Table 5-19. Arrowhead (Williamson) IL_RNZX TMDL Summary

Allocation	Total Phosphorus Load kg/day (lbs/day)
Load Capacity (LC)	0.085 (0.19)
Wasteload Allocation (WLA)	Not applicable. There are no permitted dischargers in this watershed
Load Allocation (LA)	0.076 (0.17)
Margin of safety (10% of LC)	0.008 (0.02)

5.10 West Frankfort Old (IL_RNP) Total Phosphorus TMDL

Calculation of the Loading Capacity

The loading capacity for West Frankfort Old Reservoir was determined by running the BATHTUB model repeatedly, reducing the tributary nutrient concentrations for each simulation until model results demonstrated attainment of the water quality objective. The maximum tributary concentration that results in compliance with water quality standards was used as the basis for determining the loading capacity. The tributary concentration was then converted into a loading rate through multiplication with the tributary flow.

Initial BATHTUB load reduction simulations indicated that West Frankfort Old Reservoir phosphorus concentrations would exceed the water quality standard regardless of the level of tributary load reduction, due to the elevated internal phosphorus loads from lake sediments. This internal phosphorus flux is expected to decrease in the future in response to external phosphorus load reductions, reverting back to more typical conditions. This reduction in future sediment phosphorus release was represented in the model by eliminating the additional internal sediment phosphorus source for future scenarios. The resulting load, with calibrated tributary concentrations and no additional sediment phosphorus load yields an average phosphorus load of 1.99 kg/day (4.37 lbs/day) and a concentration of 0.11 mg/L. This exceeds the phosphorus target of 0.05 mg/L, so reductions in the tributary loads are necessary. The loading capacity was an average of 0.50 kg/day (1.09 lbs/day). This allowable load corresponds to an approximately 75% reduction from existing tributary loads.

5.10.1 Allocation

A TMDL consists of a waste load allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

There are no point sources in the watershed, and therefore there is no wasteload allocation given for West Frankfort Old Reservoir. The entire loading capacity is given to the load allocation for nonpoint sources and the margin of safety. The loading capacity is not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall phosphorus load. Given a loading capacity of 0.50 kg/day (1.09 lbs/day), and an explicit margin of safety of 10% (discussed below), the load allocation for West Frankfort Old Reservoir of 0.45 kg/day (0.98 lbs/day).

5.10.2 Critical Conditions

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Critical conditions were taken into account in the development of this TMDL. In terms of loading, spring runoff periods are considered critical because wet weather events can transport significant quantities of nonpoint source loads to lake. However, the water quality ramifications of these nutrient loads are most severe during middle or late summer. This TMDL is based upon an annual period that takes into account both spring loads and summer water quality in order to effectively consider these critical conditions.

5.10.3 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The BATHTUB model used for this TMDL is designed to evaluate loads over a seasonal to annual averaging period. The annual loading analysis that was used is appropriate due to the facts that:

1. The analysis demonstrated that the TMDL could only attain water quality targets if a significant reduction was achieved in sediment phosphorus release.
2. There is a long response time between phosphorus loading and sediment response, typically on the order of several years (e.g. Chapra and Canale, 1991).

5.10.4 Margin of Safety

The TMDL contains an explicit margin of safety of 10%. The 10% margin of safety is considered an appropriate value based upon the generally good agreement between the BATHTUB water quality model predicted values and the observed values. Since the model reasonably reflects the conditions in the watershed, a 10% margin of safety is considered to be adequate to address the uncertainty in the TMDL, based upon the data available. This margin of safety can be reviewed in the future as new data are developed. The resulting explicit total phosphorus load allocated to the margin of safety is 0.05 kg/day (0.11 lbs/day) for West Frankfort Old Reservoir.

5.10.5 Reserve Capacity

The West Frankfort Old Reservoir watershed is located in Franklin County, the population of which has increased by 1.4% between 2000 and 2010 (Stage 1 Report Section 2.6). In 2010, the U.S. Census Bureau estimated the Franklin County population at 39,570.

The Illinois Department of Public Health population projections (Shahidullah 2015) for Franklin County shows a slight population decline to 37,958 in the year 2025. Further, the Greater Egypt Regional Planning and Development Commission, referencing US Census Bureau projections, states that the population in the Greater Egypt 5-county area which includes Franklin County will be relatively steady (or slightly declining) through 2030 (GERPDC 2010).

A reserve capacity is not needed, due to the slight projected decrease in population, and because, at this time IEPA is not aware of any increases in discharges from the existing point sources, or the establishment of future municipal or industrial point sources.

5.10.6 TMDL Summary

The total phosphorus TMDL for West Frankfort Old Reservoir, segment IL_RNP, is presented in Table 5-20.

Table 5-20. West Frankfort Old IL_RNP TMDL Summary

Allocation	Total Phosphorus Load kg/day (lbs/day)
Load Capacity (LC)	0.50 (1.09)
Wasteload Allocation (WLA)	Not applicable. There are no permitted dischargers in this watershed
Load Allocation (LA)	0.45 (0.98)
Margin of safety (10% of LC)	0.05 (0.11)

5.11 West Frankfort New (IL_RNQ) Total Phosphorus TMDL

5.11.1 Calculation of the Loading Capacity

The loading capacity for West Frankfort New Reservoir was determined by running the BATHTUB model repeatedly, reducing the tributary nutrient concentrations for each simulation until model results demonstrated attainment of the water quality objective. The maximum tributary concentration that results in compliance with water quality standards was used as the basis for determining the loading capacity. The tributary concentration was then converted into a loading rate through multiplication with the tributary flow.

Initial BATHTUB load reduction simulations indicated that West Frankfort New Reservoir phosphorus concentrations would exceed the water quality standard regardless of the level of tributary load reduction, due to the elevated internal phosphorus loads from lake sediments. This internal phosphorus flux is expected to decrease in the future in response to external phosphorus load reductions or lake management actions, reverting back to more typical conditions. This reduction in future sediment phosphorus release was represented in the model by eliminating the additional internal sediment phosphorus source for future scenarios. The resulting load, with calibrated tributary and Thompsonville STP concentrations and no additional sediment phosphorus load yields an average phosphorus load of 3.63 kg/day (7.99 lbs/day) and a concentration of 0.104 mg/L. This exceeds the phosphorus target of 0.05 mg/L, so reductions in the tributary loads are necessary. The loading capacity calculated was an average of 0.91 kg/day (2.0 lbs/day). This allowable load corresponds to an approximately 75% reduction from existing loads, estimated as 3.68 kg/day (8.11 lbs/day).

5.11.2 Allocation

A TMDL consists of a waste load allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). This definition is typically illustrated by the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

There is a single point sources in the watershed from the Thompsonville STP (IL0072478). The current treatment at this facility consists of two cell aerated lagoon and a rock filter. These treatment processes are not capable of removing significant amount of total phosphorus from the effluent. The design average flow (DAF) for the facility is 0.08 million gallons per day (MGD) and the design maximum flow (DMF) for the facility is 0.20 MGD.

The average daily flows from this STP reported in the DMRs from 2008 through 2016 0.087 MGD. There is no water quality data for total phosphorus from this point source to use for model calibration. In estimating the existing phosphorus load from this facility, a total phosphorus concentration in the STP effluent was assumed to be 2.425 mg/L, as has been used in other TMDLs for similar facilities in Illinois. The resulting average load from the Thompsonville STP is 0.73 kg/day (1.60 lb/day). The WLA for this facility was developed based on the DAF, and a target effluent concentration of 2.425 mg/L. This results in an average WLA of 0.73 kg/day (1.60 lb/day).

The remaining loading capacity is given to the load allocation for nonpoint sources and the margin of safety. The load allocation for nonpoint sources is not divided into individual source categories for purposes of this TMDL, as it is the intent of the implementation plan to provide detail on the contributions of specific sources to the overall phosphorus load. Given a total loading capacity of 0.91 kg/day (2.01 lbs/day), a WLA for the Thompsonville STP of 0.73 kg/day (1.60 lb/day), and an explicit margin of safety of 10% (discussed below), the load allocation for West Frankfort New Reservoir is 0.09 kg/day (0.19 lbs/day). This represents a reduction of approximately 97% of the watershed nonpoint sources from the existing loads.

5.11.3 Critical Conditions

TMDLs must take into account critical environmental conditions to ensure that the water quality is protected during times when it is most vulnerable. Critical conditions were taken into account in the development of this TMDL. In terms of loading, spring runoff periods are considered critical because wet weather events can transport significant quantities of nonpoint source loads to lake. However, the water quality ramifications of these nutrient loads are most severe during middle or late summer. This TMDL is based upon an annual period that takes into account both spring loads and summer water quality in order to effectively consider these critical conditions.

5.11.4 Seasonality

This TMDL was conducted with an explicit consideration of seasonal variation. The BATHTUB model used for this TMDL is designed to evaluate loads over a seasonal to annual averaging period. The annual loading analysis that was used is appropriate due to the facts that:

1. The analysis demonstrated that the TMDL could only attain water quality targets if a significant reduction was achieved in sediment phosphorus release.
2. There is a long response time between phosphorus loading and sediment response, typically on the order of several years (e.g. Chapra and Canale, 1991).

5.11.5 Margin of Safety

The TMDL contains an explicit margin of safety of 10%. The 10% margin of safety is considered an appropriate value based upon the generally good agreement between the BATHTUB water quality model predicted values and the observed values. Since the model reasonably reflects the conditions in the watershed, a 10% margin of safety is considered to be adequate to address the uncertainty in the TMDL, based upon the data available. This margin of safety can be reviewed in the future as new data are developed. The resulting explicit total phosphorus load allocated to the margin of safety is 0.09 kg/day (0.2 lbs/day) for West Frankfort New Reservoir.

5.11.6 Reserve Capacity

This watershed is located in Franklin County, the population of which has increased by 1.4% between 2000 and 2010 (Stage 1 Report Section 2.6). In 2010, the U.S. Census Bureau estimated the Franklin County population at 39,570.

The Illinois Department of Public Health population projections (Shahidullah 2015) for Franklin County shows a slight population decline to 37,958 in the year 2025. Further, the Greater Egypt Regional Planning and Development Commission, referencing US Census Bureau projections, states that the population in the Greater Egypt 5-county area which includes Franklin County will be relatively steady (or slightly declining) through 2030 (GERPDC 2010).

A reserve capacity is not needed, due to the slight projected decrease in population, and because, at this time IEPA is not aware of any increases in discharges from the existing point sources, or the establishment of future municipal or industrial point sources.

5.11.7 TMDL Summary

The total phosphorus TMDL for West Frankfort New Reservoir, segment IL_RNQ, is presented in Table 5-21.

Table 5-21. West Frankfort New Reservoir IL_RNQ TMDL Summary

Allocation	Total Phosphorus Load kg/day (lbs/day)
Load Capacity (LC)	0.91 (2.0)
Wasteload Allocation (WLA)	0.73 (1.6)
Load Allocation (LA)	0.09 (0.2)
Margin of safety (10% of LC)	0.09 (0.2)

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LRS Development

This section presents the development of the total suspended solids Load Reduction Strategy for 5 streams in the Upper Big Muddy River watershed. IEPA requires a LRS to identify the load capacity, and the percentage reduction needed.

6.1 TSS Load Reduction Strategy - Streams

The load capacity was calculated by multiplying the total suspended solids concentration of 32.2 mg/L by the average annual 2015 Upper Big Muddy River flows estimated using a drainage area ratio approach and USGS measured flows for Upper Big Muddy River at Browns, IL (Gage 03378000). The percent reduction was calculated by comparing the average TSS concentrations for the monitoring stations located on the segment calculated from the full record of measured total suspended solids concentrations (Attachment 1 and Attachment 2) to the LRS target concentration.

Table 6-1 presents the TSS LRSs for all of the waterbodies in the Upper Big Muddy River watershed.

Table 6-1. Total Suspended Solids LRS

Stream (Segment ID)	Monitoring Station(s)	Target (mg/L)	Average Concentration (mg/L)	Current load (lbs/day)	Load capacity (lbs/day)	Percent Reduction
Big Muddy R. (IL_N-06)	N-06	32.2	43.7	16,148	11,910	26.2%
Big Muddy R. (IL_N-11)	N-11	32.2	53.0	31,932	19,395	39.3%
Big Muddy R. (IL_N-17)	N-17	32.2	110.3	27,108	7,911	70.8%
Pond Cr. (IL_NG-02)	NG-02	32.2	86.3	39,449	14,721	62.7%
M. Fk. Big Muddy (IL_NH-07)	NH-07, NH-08, NH-21	32.2	72.3	53,894	23,992	55.5%

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Reasonable Assurances

Documenting adequate reasonable assurance increases the probability that regulatory and voluntary mechanisms will achieve pollution reduction levels specified in the TMDL and that the applicable WQS are attained.

The Illinois EPA NPDES regulatory program and the issuance of an NPDES permit provide the reasonable assurance that the WLAs in the TMDL will be achieved. That is because federal regulations implementing the CWA require that effluent limits in permits be consistent with “the assumptions and requirements of any available [WLA]” in an approved TMDL [40 CFR 122.44(d)(1)(vii)(B)]. For point sources, Illinois EPA administers the NPDES permitting program for wastewater treatment plants, MS4s and CAFOs. Wasteload allocations in the TMDL report will be included in the appropriate NPDES permits when permits are renewed.

For TMDLs for waters impaired by both point and nonpoint sources, determinations of reasonable assurance that the TMDLs load allocations will be achieved include whether practices capable of reducing the specified pollutant load exist, are technically feasible, and have a high likelihood of implementation. The nonpoint source load reductions can and will be achieved when there are good management practices and programs (technical and funding mechanisms) to assist in achieving good management practices. The Watershed Implementation Plan for the TMDLs contained in this report identifies practices that are capable of reducing the pollutant loads to the TMDL endpoints, and potential funding mechanisms for implementation.

For nonpoint sources, the primary strategy for reduction for attaining water quality standards in the Upper Big Muddy River watershed is to implement BMPs to reduce and treat agricultural and urban stormwater runoff, along with the use of in-stream restoration practices. This strategy relies on voluntary actions that includes accountability. Educational efforts and cost sharing programs are intended to achieve participation levels sufficient to attain water quality standards and meet the designated uses. An important key to the success of a TMDL program, in terms of engaging the public, is building linkages to other programs, such as nonpoint source management practices.

In rural areas many homes, businesses, and schools do not have access to central sewage disposal systems. County and local health departments operate sewage and water programs to assure that sewage and water systems are designed according to code so that neither the public health nor the environment is jeopardized. The counties and local health departments issue licenses and provide training to contractors, inspect and license pumper trucks, review sewage system applications, issue construction permits, assist in the design of sewage disposal systems, inspect new sewage disposal systems, investigate complaints, and carry out enforcement activities based upon county ordinances. These activities help to eliminate the discharge of raw sewage and reduce the bacterial contamination within the Upper Big Muddy River watershed.

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Public Participation and Involvement

The draft Stage 3 public meeting was held on November 15, 2018, at 3:30 pm, at the West Frankfort Police/Fire Department on E. Nolen St. The public meeting was originally scheduled to be held at the Public Library in West Frankfort, Illinois, however, on this day the Library was closed early due to inclement weather, and the public meeting was re-located to the nearby Police/Fire Department. Approximately 10 people participated in the public meeting and the public comment period ended at midnight on December 15, 2018.

Illinois EPA provided public notice for all meetings by placing a display-ad in West Frankfort – Daily American (the local newspaper). In addition, a direct mailing was sent to several stakeholders/Permittees in the watershed. The notice gave the date, time, location, and purpose of the meeting. The notice also provided references on how to obtain additional information about this specific site, the TMDL program, and other related information. The draft TMDL report was available for review in hard copy at the West Frankfort Public Library, Herrin City Hall, Christopher City Hall, Ewing Village Hall, and electronically on the Agency's webpage: www2.illinois.gov/epa/public-notices/Pages/general-notices.aspx.

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Attachment 1:
Stage 1 Report

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Stage 1 Report

Upper Big Muddy River Watershed

Prepared for:
Illinois Environmental
Protection Agency

January 31, 2014

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Upper Big Muddy Watershed
Total Maximum Daily Load
Stage One Report

Prepared for:
Illinois EPA

January 31, 2014

Prepared by:
LimnoTech, Inc.
in association with
Baetis Environmental Services, Inc.

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ACRONYMS & ABREVIATIONS

ALMP	Ambient Lake Monitoring Program
AWQMN	Ambient Water Quality Monitoring Network
CAFO	Confined Animal Feeding Operation
CFR	Code of Federal Regulations
DO	Dissolved Oxygen
GIS	Geographic Information System
IAC	Illinois Administrative Code
IEPA	Illinois Environmental Protection Agency
LRS	Load Reduction Strategy
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
SWCD	Soil and Water Conservation District
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
UAL	Unit Area Load
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
µg/L	micrograms per liter
mg/L	milligrams per liter

Executive Summary

This Stage 1 report was developed for the impaired waterbody segments located within the Upper Big Muddy Creek watershed. It provides a characterization of watershed conditions, an analysis of water quality, an analysis of available data to confirm the sufficiency of the data to support both the listing decision and the sources of impairment that are included on the 2012 303(d) list, a review and recommendation of approaches for developing TMDLs and LRSs. This report also provides a plan for collecting additional field data, and summarizes public participation in this Stage 1 process.

Confirmation of Impairments

The Upper Big Muddy watershed was indicated in the 2012 303(d) list as having 16 waterbodies with impaired use support. For impaired waterbodies caused by pollutants that have numeric water quality standards, TMDLs are to be developed; other causes of impairment are to be addressed in LRSs. At the time the 303(d) list was prepared, this would suggest 23 TMDLs and 13 LRSs. Since development of the 2012 (and prior biennial 303(d) lists), some numeric water quality standards have been revised that affect whether or not a TMDL is prepared.

This review of available water quality data and current state water quality standards recommends that seventeen (17) TMDLs be developed for the 13 waterbodies with pollutants having numeric standards and 11 LRSs are recommended for development for 11 waterbodies. Further, we recommend that five TMDLs not be prepared for impairments in the Upper Big Muddy watershed:

- Manganese impairments of 2 segments of M. Fk. Big Muddy River (IL_NH-06 and IL_NH-07) and one segment of Andy Creek (IL_NZN-13)
- An impairment caused by lindane contamination of sediment in Hurricane Creek (IL_NF-01)
- Sulfate impairment in Prairie Creek (IL_NZM-01)

Below we summarize our conclusions:

Waterbody	Pollutant	Recommendation
Big Muddy R. / IL_N-06	Sedimentation/Siltation	Prepare LRS
Big Muddy R. / IL_N-11	Sulfates	Prepare TMDL
	Fecal Coliform	Prepare TMDL
	Sedimentation/Siltation, TSS	Prepare LRS
Big Muddy R. / IL_N-17	Dissolved Oxygen	Prepare TMDL
	Sedimentation/Siltation, TSS	Prepare LRS
Hurricane Creek / IL_NF-01	Lindane	Delist
	Sedimentation/Siltation	Prepare LRS
Prairie Cr. / IL_NZM-01	Sulfates	Delist
Andy Cr. / IL_NZN-13	Iron	Prepare TMDL
	Manganese	Delist
	Dissolved Oxygen	Prepare TMDL

Waterbody	Pollutant	Recommendation
Herrin Old / IL_RNZD	Phosphorus (Total)	Prepare TMDL
	Total Suspended Solids (TSS)	Prepare LRS
Pond Cr. / IL_NG-02	Chloride	Prepare TMDL
	Dissolved Oxygen	Prepare TMDL
	Sedimentation/Siltation	Prepare LRS
Lake Cr. / IL_NGA-02	Dissolved Oxygen	Prepare TMDL
	Phosphorus (Total)	Prepare LRS
Beaver Cr. / IL_NGAZ-JC-D1	Manganese	Prepare TMDL
Johnston City / IL_RNZE	Phosphorus (Total)	Prepare TMDL
	Total Suspended Solids (TSS)	Prepare LRS
Arrowhead (Williamson) / IL_RNZX	Phosphorus (Total)	Prepare TMDL
M. Fk. Big Muddy / IL_NH-06	Fecal Coliform	Prepare TMDL
	Dissolved Oxygen	Prepare TMDL
	Manganese	Delist
M. Fk. Big Muddy / IL_NH-07	Dissolved Oxygen	Prepare TMDL
	Manganese	Delist
	Sedimentation/Siltation	Prepare LRS
West Frankfort Old / IL_RNP	Phosphorus (Total)	Prepare TMDL
	Total Suspended Solids (TSS)	Prepare LRS
West Frankfort New/ IL_RNQ	Phosphorus (Total)	Prepare TMDL
	Total Suspended Solids (TSS)	Prepare LRS

Recommendations for TMDL Development

We are recommending simple approaches to all 17 TMDLs and 11 LRSs. All dissolved oxygen TMDLs will be developed using the QUAL2E/QUAL2K model, developed and supported by the US EPA. This approach has been used successfully for other TMDLs in Illinois. Fecal coliform bacteria, manganese, sulfate, iron, and chloride TMDLs will be developed using the load duration approach. Load duration analyses have also been used for development of other TMDLs in Illinois. Total phosphorus TMDLs for impaired lakes will be developed using a lake response model in a spreadsheet, similar to the EUTROMOD model used in many TMDLs. The load reduction strategies will be prepared using USLE-based methods, or, alternatively, a combination of the Simple Method and unit areal loading rates.

Recommendations for Field Data Collection

Additional data are required to support development of the TMDLs in the Upper Big Muddy watershed. Physical and chemical data are required for model development, calibration and verification.

Data on biochemical oxygen demand (BOD), sediment oxygen demand (SOD), water temperature, dissolved oxygen, manganese, iron, chloride, nitrogen, phosphorus, and fecal coliform bacteria are recommended to be collected.

Additional hydraulic and geomorphologic data collection is necessary to build and calibrate the QUAL2K models.

1

Introduction

Illinois EPA has developed a three-stage approach to TMDL development. This Stage 1 report describes initial activities related to the development of TMDLs for the Upper Big Muddy watershed, including: watershed characterization, data analysis to confirm the causes and sources of impairment, and methodology selection. Subsequent stages will include Stage 2 data collection (as needed) and Stage 3 model calibration, TMDL development and implementation plan development.

This section provides background information on the TMDL process, and Illinois assessment and listing procedures. The specific impairments in the Upper Big Muddy watershed are also described.

1.1 TMDL Process

Section 303(d) of the 1972 Clean Water Act requires States to define impaired waters and identify them on a list, which is called the 303(d) list. The State of Illinois recently issued the 2012 303(d) list (IEPA 2012), which is available on the web at: http://www.epa.state.il.us/water/tmdl/303d-list.html. Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for water bodies that are not meeting designated uses under technology-based controls. The TMDL process establishes the allowable loading of pollutants or other quantifiable parameters for a water body based on the relationship between pollution sources and instream conditions. This allowable loading represents the maximum quantity of the pollutant that the waterbody can receive without exceeding water quality standards. The TMDL also takes into account a margin of safety, which reflects scientific uncertainty, as well as the effects of seasonal variation. By following the TMDL process, States can establish water quality-based controls to reduce pollution from both point and nonpoint sources, and restore and maintain the quality of their water resources (USEPA, 1991).

As part of the TMDL process, the Illinois Environmental Protection Agency (IEPA) and a consultant team have compiled and reviewed data and information to determine the sufficiency of available data to support TMDL development. As part of this review, the data were used to confirm the impairments identified on the 303(d) list and to further identify potential sources causing these impairments. Additionally, this report recommends TMDL and LRS approaches, including an assessment of whether additional data are needed to develop a defensible TMDL.

In a subsequent stage of work the TMDLs and LRSs will be developed and IEPA will work with stakeholders to implement the necessary controls to improve water quality in the impaired waterbodies and meet water quality standards. It should be noted that the controls for nonpoint sources (e.g., agriculture) will be strictly voluntary.

1.2 Illinois Assessment and Listing Procedures

Surface water assessments in the 2012 Integrated Report are based primarily on biological, water, physical habitat, and fish-tissue information collected through 2010 from various monitoring programs (Illinois EPA 2007). These programs include: the Ambient Water Quality Monitoring Network, Intensive Basin Surveys, Facility-Related Stream Surveys, the Fish Contaminant Monitoring Program, the Ambient

Lake Monitoring Program, the Illinois Clean Lakes Monitoring Program, the Volunteer Lake Monitoring Program, the Lake Michigan Monitoring Program, TMDL monitoring and other outside sources (IEPA, 2012).

Illinois EPA conducts its assessment of water bodies using seven designated use categories: public and food processing water supplies, aquatic life, fish consumption, primary contact, secondary contact, indigenous aquatic life, and aesthetic quality (IEPA, 2012). For each water body, and for each designated use applicable to the water body, Illinois EPA's assessment concludes one of two possible "use-support" levels:

- Fully supporting (the water body attains the designated use); or
- Not supporting (the water body does not attain the designated use).

When sufficient data are available, each applicable designated use in each segment is assessed as Fully Supporting (good), Not Supporting (fair), or Not Supporting (poor). Waters in which at least one applicable use is not fully supported are called "impaired." Waters identified as impaired based on biological, physicochemical, physical habitat, and toxicity data are placed on the 303(d) list. Potential causes and sources of impairment are also identified for impaired waters.

1.3 Identified Waterbody Impairments

The impaired waterbody segments included in the project watershed are listed in Table 1, along with the parameters they are listed for, and the use impairments as identified in the 2012 303(d) list (IEPA, 2012). TMDLs are currently only being developed for pollutants that have numerical water quality criteria. Load Reduction Strategies (LRSs) are being developed for those pollutants that do not have numerical water quality criteria. The pollutants that are the focus of this study are indicated in Table 1 in boldface type. Table 1 provides information on the impaired waterbodies, including size, causes of impairment, and use support. Those impairments that are the focus of this report are shown in bold font.

The remaining sections of this report include:

- Watershed characterization: description of watershed features
- Public participation: description of active groups in the watershed, and public meetings related to this project
- Water quality standards and summary of impairment: discussion of relevant water quality standards, database development and summary of data for impaired segments
- Confirmation of causes and sources of impairment: assessment of sufficiency of data to support the listing and identification of potential sources contributing to the impairment
- Methodology: identification and selection of watershed and water quality models
- Data collection to support modeling: a general description of data needed to support modeling
- References

Table 1. Impaired Waterbodies in the Project Watershed

Waterbody/Segment Name	Use Support[2]	Size (acre, mile)	Impairment Cause	Potential Sources
Big Muddy R. / IL_N-06	Aquatic Life (N) Primary contact recreation (F)	15.13 mi	Sedimentation/Siltation	Natural Sources, Crop Production (crop land or dry land), Dam or Impoundment, Agriculture, Atmospheric Deposition - Toxics, Source Unknown
Big Muddy R. / IL_N-11	Aquatic Life (N) Primary contact recreation (N)	11.48 mi	Sulfates, Fecal Coliform, Sedimentation/Siltation, TSS	Non-irrigated Crop Production, Source Unknown, Atmospheric Deposition – Toxics
Big Muddy R. / IL_N-17	Aquatic Life (N)	21.48 mi	Dissolved Oxygen, Sedimentation/Siltation, TSS	Municipal Point Source Discharges, Non-irrigated crop production, Natural Sources, Crop Production (crop land or dry land), Atmospheric Deposition - Toxics, Source Unknown
Hurricane Cr. / IL_NF-01	Aquatic Life (N)	10.6 mi	Lindane, Sedimentation/Siltation	Crop Production (crop land or dry land), Agriculture
Prairie Cr. / IL_NZM-01	Aquatic Life (N)	9.06 mi	Sulfates	Surface mining
Andy Cr. / IL_NZN-13	Aquatic Life (N)	11.7 mi	Iron, Manganese, Dissolved Oxygen	Channelization, Loss of Riparian Habitat, Crop Production (crop land or dry land), Agriculture, Source Unknown
HERRIN OLD / IL_RNZD	Aesthetic Quality (N)	51.3 ac	Phosphorus (Total), Total Suspended Solids (TSS)	Atmospheric Deposition - Toxics, Source Unknown, Contaminated Sediments, Urban Runoff/Storm Sewers, Other Recreational Pollution Sources
Pond Cr. / IL_NG-02	Aquatic Life (N) Primary contact recreation (F)	23.53 mi	Chloride, Dissolved Oxygen, Sedimentation/Siltation	Channelization, Impacts from Abandoned Mines (Inactive), Loss of Riparian Habitat, Streambank Modifications/ destabilization, Crop production (crop land or dry land), Agriculture, Urban Runoff/Storm Sewers, Source Unknown

Waterbody/Segment Name	Use Support[2]	Size (acre, mile)	Impairment Cause	Potential Sources
Lake Cr. / IL_NGA-02	Aquatic Life (N)	12.33 mi	Dissolved Oxygen, Phosphorus (Total)	Source Unknown, Municipal Point Source Discharges, Crop Production (crop land or dry land), Agriculture, Urban Runoff/Storm Sewers
Beaver Cr. / IL_NGAZ-JC-D1	Aquatic Life (N)	1.7 mi	Manganese	Loss of Riparian Habitat, Municipal Point Source Discharges, Crop Production (crop land or dry land), Agriculture, Urban Runoff/Storm Sewers, Runoff from Forest/Grassland/Parkland
Johnston City / IL_RNZE	Aesthetic Quality (N)	64 ac	Phosphorus (Total), Total Suspended Solids (TSS)	Littoral/shore Area Modifications (Non-riverine), Runoff from Forest/Grassland/Parkland
Arrowhead (Williamson) / IL_RNZX	Aesthetic Quality (N)	30 ac	Phosphorus (Total)	Runoff from Forest/Grassland/Parkland
M. Fk. Big Muddy / IL_NH-06	Aquatic Life (N) Primary contact recreation (N)	12.52 mi	Manganese, Dissolved Oxygen, Fecal Coliform	Petroleum/Natural Gas Activities, Surface Mining, Animal Feeding Operations, Municipal Point Source Discharges, Channelization, Source Unknown
M. Fk. Big Muddy / IL_NH-07	Aquatic Life (N)	19.74 mi	Manganese, Dissolved Oxygen, Sedimentation/Siltation	Petroleum/Natural Gas Activities, Surface Mining, Animal Feeding Operations, Natural Sources, Crop Production (crop land or dry land)
West Frankfort Old / IL_RNP	Aesthetic Quality (N)	146 ac	Phosphorus (Total), Total Suspended Solids (TSS)	Littoral/shore Area Modifications (Non-riverine), Crop Production (crop land or dry land), Runoff from Forest/Grassland/Parkland

Waterbody/Segment Name	Use Support[2]	Size (acre, mile)	Impairment Cause	Potential Sources
West Frankfort New / IL_RNQ	Aesthetic Quality (N)	214 ac	**Phosphorus (Total)**, Total Suspended Solids (TSS)	Littoral/shore Area Modifications (Non-riverine), On-site Treatment Systems (Septic Systems and Similar Decentralized Systems), Site Clearance (land development of redevelopment), Crop Production (crop land or dry land), Urban Runoff/Storm Sewers, Runoff from Forest/Grassland/Parkland

[1] Bold font indicates cause will be addressed in this report. Other potential causes of impairment listed for these waterbodies do not have numeric Water Quality Standards and are not subject to TMDL development at this time.
[2] F = Fully supporting, N = Not supporting, Other uses were not assessed

2

Watershed Characterization

2.1 Methods

The project watershed was characterized by compiling and analyzing data and information from various sources. Where available, data were obtained in electronic or Geographic Information System (GIS) format to facilitate mapping and analysis. To develop a better understanding of land management practices in the watershed, local agencies are being contacted to obtain information on crops, pesticide and fertilizer application practices, tillage practices and best management practices employed.

After the watershed boundaries for the 16 impaired waterbodies in the project watershed were delineated from topographic and stream network (hydrography) information, other relevant information was obtained. This included land use and land cover, soils, point source dischargers, state, county and municipal boundaries, coal mines, dams, oil and gas wells, data collection locations and the location of 303(d) waterbodies.

2.2 Watershed Location

The impaired waterbodies addressed in this report are all in the Upper Big Muddy River watershed, which is located primarily in Franklin County, in southern Illinois, although there are also portions in Jackson, Williamson and Hamilton Counties. Figure 1 is a vicinity map. The watershed study area is approximately 313,435 acres (490 mi^2) in size, but this area does not include drainage areas upstream of Rend Lake Dam. The impaired reach of the main stem of the Upper Big Muddy begins at Rend Lake Dam and extends approximately 48 miles downstream (assessment units IL_N-06, IL_N-11, and IL_N-17). Major tributaries include: Middle Fork Big Muddy River (units IL_NH-06 and IL_NH-07) and Pond Creek (IL_NG-02). Figure 1 shows a map of the target watershed and includes some key features such as waterways, impaired waterbodies, and subwatersheds.

The sections that follow provide a broad overview of the characteristics of the Upper Big Muddy watershed.

2.3 Climate and Hydrology

The Upper Big Muddy watershed has a continental climate with cold winters and hot, humid summers. The National Weather Service (NWS) maintained a weather station in the watershed at Benton, Illinois that closed in February 2009. Benton is relatively near the center of the targeted watershed and is a reasonable approximation of climate in the watershed.

Precipitation data from 1912 through station closure were downloaded and summarized (Table 2). The 96 years of historical precipitation data for Station 110608 in Benton average 40.5 inches of precipitation each year. The highest monthly average is May, when about 4.2 inches can be expected. The lowest monthly average occurs in February (2.5 inches). The most intense storms, based upon the daily maximum precipitation, may come during spring, summer or fall; precipitation events are typically milder during winter.

Table 2. Long-term Precipitation Statistics for Benton, Illinois

Month/Season	Precipitation (in)	Days of Rain	Max Daily Precipitation (in)
1	3.1	8	1.2
2	2.5	7	1.0
3	3.8	9	1.3
4	4.0	9	1.4
5	4.2	9	1.4
6	3.9	8	1.4
7	3.0	7	1.3
8	3.4	6	1.4
9	3.2	6	1.4
10	3.2	7	1.3
11	3.5	7	1.4
12	3.2	8	1.2
Spring	12.0	26	2.0
Summer	10.3	21	2.1
Fall	9.8	20	2.0
Winter	8.8	22	1.8
Annual	40.5	89	3.1

Source: Downloaded from http://www.isws.illinois.edu/data/climatedb/choose.asp?stn=110608

There is an active USGS streamflow gage in the watershed, located on the Big Muddy River at Plumfield, Illinois where State Highway 149 crosses the river (gage 05597000). The gage is about 1.9 miles downstream from the confluence with the Middle Fork Big Muddy River. The drainage area at this gage is 792 square miles and daily discharge measurements are available from 1908 to present.

Hydrology of the river has been significantly altered since the construction and filling of the Rend Lake Dam in the early 1970s. Maximum recorded discharge before Rend Lake Dam construction is 42,900 ft^3/s on May 10, 1961. There was no flow at times in 1908-9, 1914, 1936, and 1940-41. Maximum recorded discharge since construction of Rend Lake is 14,200 ft^3/s on May 1, 1996. The minimum discharge since construction of Rend Lake is 6.8 ft^3/s on Oct. 13, 1970. Average daily flow over the past 42 years is 735 ft^3/s.

Flow durations represent the percentage of time that a specified streamflow is equaled or exceeded during a given period. Figure 2 is a flow duration curve for USGS gaging station 0559700. Such analyses are a summary of the past hydrologic events (in this case, daily discharge). And if the streamflow during the period for which the duration curve is based is a sufficiently long period of record, the statistics can be used as an indicator of probable future conditions. Figure 2 illustrates the tremendous effect that Rend Lake has had on the hydrology of the Big Muddy River.

2.4 Topography

The Upper Big Muddy watershed is generally flat, with gentle slopes in the headwaters. The highest elevations in the watershed (about 610 feet) are found west of Akin in Hamilton County. The lowest elevation (about 380 feet) in the watershed occurs at the outlet near De Soto in Jackson County.

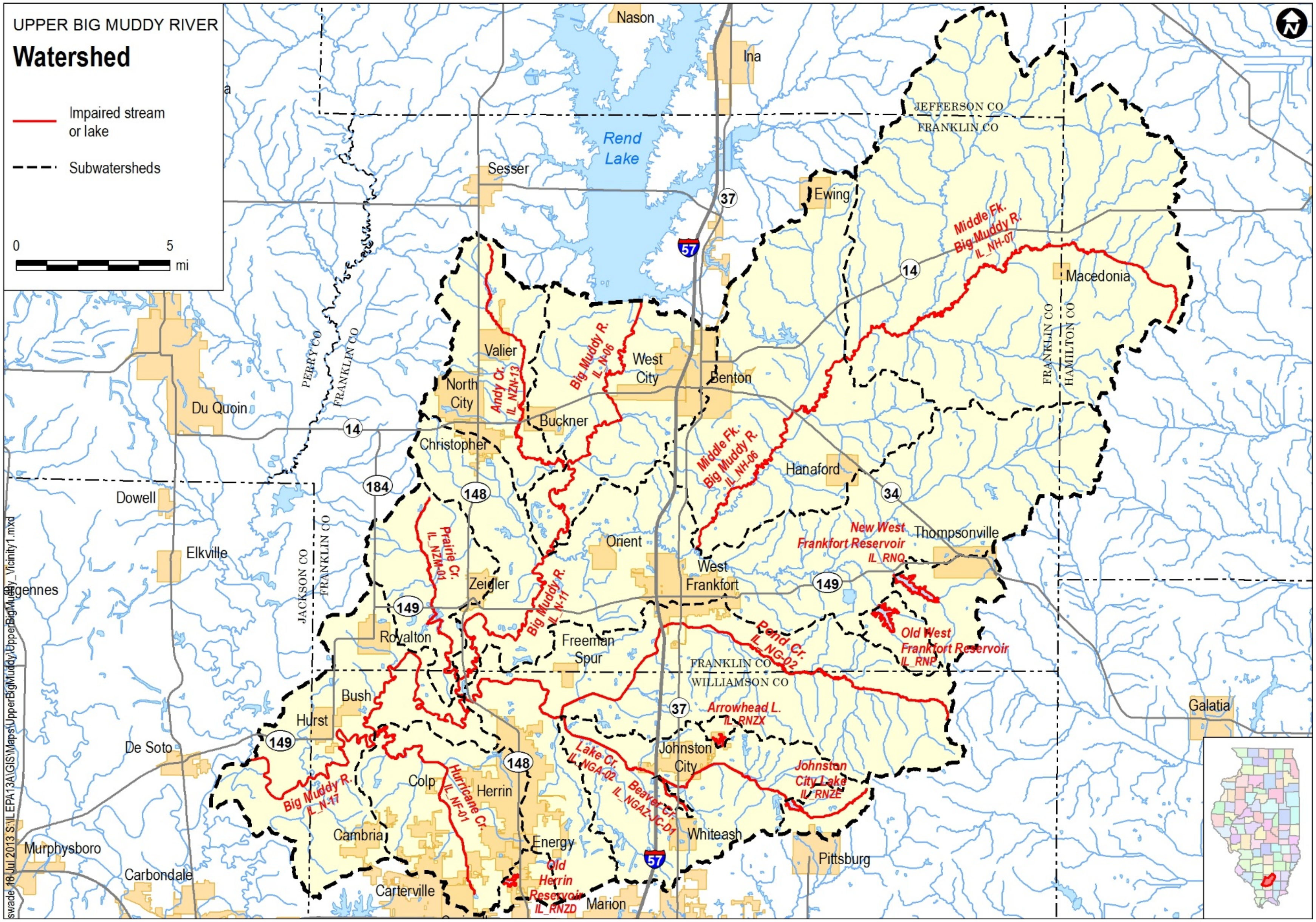

Figure 1. Study Area Map

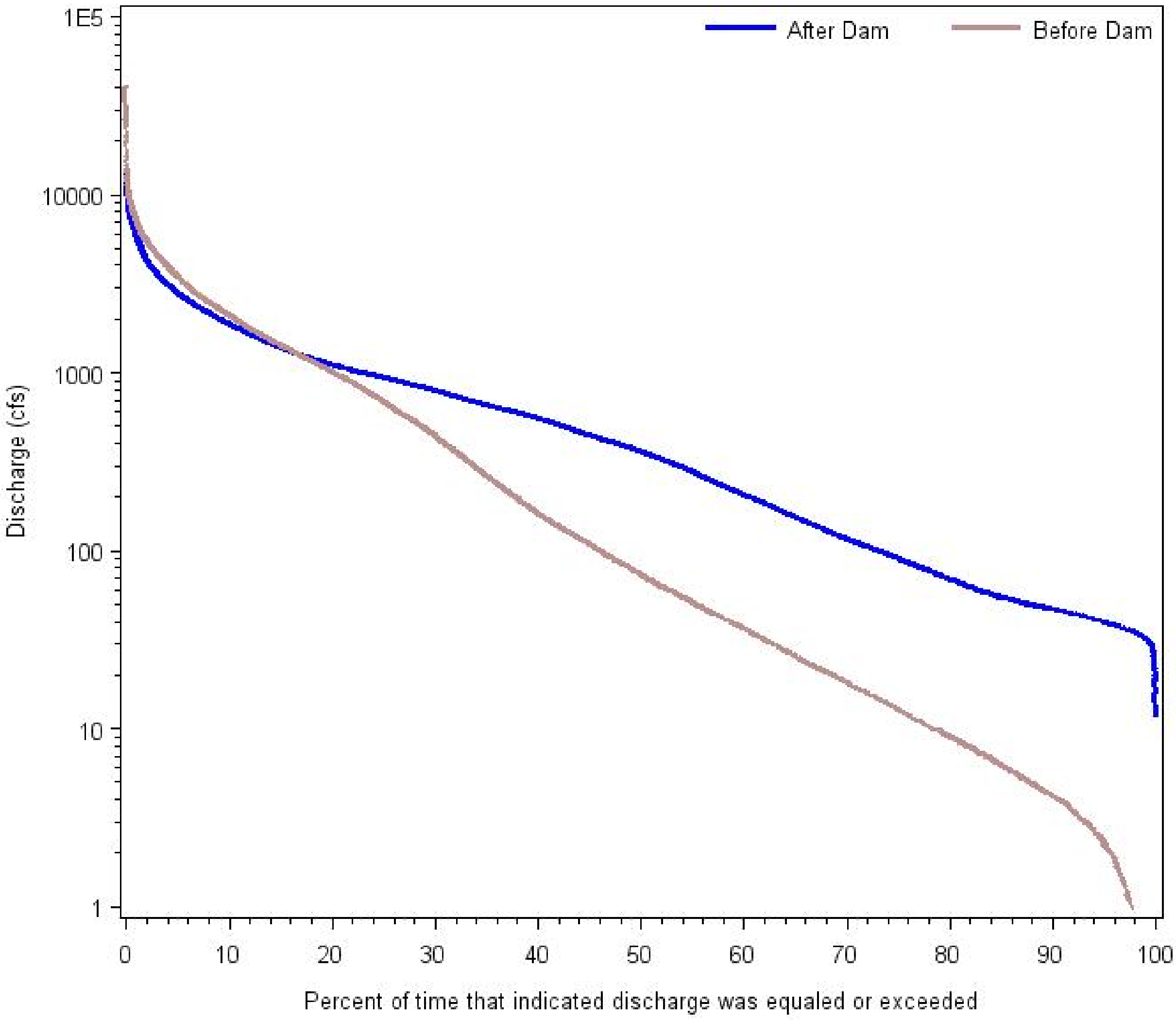

Figure 2. Flow Duration Curve, USGS Station 05597000, Big Muddy River at Plumfield, IL, Before and After Dam Construction

2.5 Soils

Together with topography, the nature of soils in a watershed play an important role in the amount of runoff generated and soil erosion. The Natural Resources Conservation Service's Soil Survey Geographic (SSURGO) database was reviewed to ascertain general information regarding soils in the study area (available at http://soildatamart.nrcs.usda.gov/). The target watershed has rich silt loam soils, lying predominately on slopes less than 2%. Based upon slope and other factors, the NRCS places soils into erodibility classes. The erodibility potential of soils in the study area is summarized for each subwatershed by area (Table 3) and percentage (Table 4). Areas that are included in the "No value' class include urban land, dumps (slurry) and dumps (mine). Land covered by water is excluded from this tally. Figure 2 maps these classes of erodibility of soils in the Upper Big Muddy watershed.

Table 3. Soil Erodibility in Target Watersheds, in acres

Waterbody	Watershed	High erodibility	Moderate erodibility	No value	Total
Big Muddy River	IL_N-06	22,363	10,491	320	33,174
Big Muddy River	IL_N-11	162,718	43,142	1,268	207,128
Big Muddy River	IL_N-17	240,240	65,384	2,529	308,153
Hurricane Creek	IL_NF-01	13,373	2,568	390	16,331
Prairie Creek	IL_NZM-01	8,395	1,481	311	10,188
Andy Creek	IL_NZN-13	9,743	3,075	79	12,897
Herrin Old	IL_RNZD	947	580	4.7	1,532
Pond Creek	IL_NG-02	50,393	11,689	618	62,700
Lake Creek	IL_NGA-02	17,052	3,670	383	21,105
Beaver Creek	IL_NGAZ-JC-D1	381	-	-	381
Johnson City	IL_RNZE	1,730	451	78	2,259
Arrowhead	IL_RNZX	403	43	0.4	447
M. Fk. Big Muddy R	IL_NH-06	85,976	16,053	105	102,133
M. Fk. Big Muddy R	IL_NH-07	58,759	9,687	-	68,446
West Frankfort Old	IL_RNP	1,964	317	-	2,281
West Frankfort New	IL_RNQ	3,140	1,570	-	4,710

Table 4. Soil Erodibility in Target Watersheds, by percentage

Waterbody	Subwatershed	High erodibility	Moderate erodibility	No value
Big Muddy River	IL_N-06	67%	32%	1%
Big Muddy River	IL_N-11	79%	21%	1%
Big Muddy River	IL_N-17	78%	21%	1%
Hurricane Creek	IL_NF-01	82%	16%	2%
Prairie Creek	IL_NZM-01	82%	15%	3%
Andy Creek	IL_NZN-13	76%	24%	1%
Herrin Old	IL_RNZD	62%	38%	0%
Pond Creek	IL_NG-02	80%	19%	1%
Lake Creek	IL_NGA-02	81%	17%	2%
Beaver Creek	IL_NGAZ-JC-D1	100%	0%	0%
Johnson City	IL_RNZE	77%	20%	3%
Arrowhead	IL_RNZX	90%	10%	0%
M. Fk. Big Muddy R	IL_NH-06	84%	16%	0%
M. Fk. Big Muddy R	IL_NH-07	86%	14%	0%
West Frankfort Old	IL_RNP	86%	14%	0%
West Frankfort New	IL_RNQ	67%	33%	0%

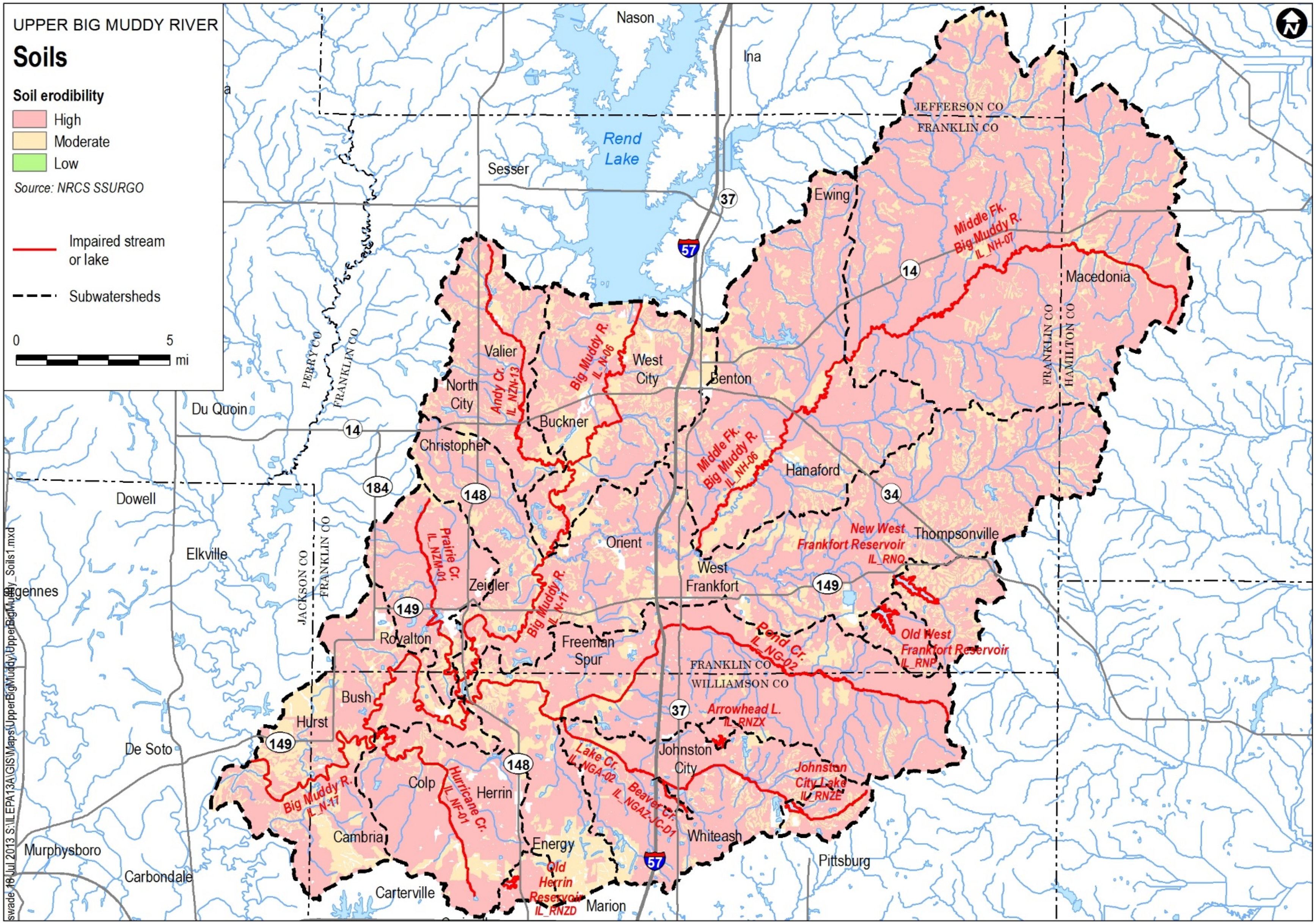

Figure 3. Upper Big Muddy Watershed Soil Erodibility

The Illinois Soil Conservation Transect Survey program provides a general overview of the current status of soil conservation efforts on agriculture land in the state. Survey results provide data on the presence of conservation practices in each county (IDOA 2011). The 2011 survey provided information on tillage systems used in planting corn and soybean crops in the spring and small grain crops in the fall. And, the surveyors also collect data on ephemeral or gully erosion in surveyed fields. Data are available by county rather than by watershed (Tables 5 through 8).

Table 5. Percent of Corn Fields in Each Tillage System in Illinois and in Target Watershed Counties

County	Conventional	Reduced	Mulch-Till	No-Till
Illinois	46%	25%	19%	11%
Franklin County	87%	3%	2%	8%
Hamilton County	57%	5%	3%	34%
Jackson County	No data			
Williamson County	54%	0%	0%	46%

Table 6. Percent of Soybean Fields in Each Tillage System in Illinois and in Target Watershed Counties

County	Conventional	Reduced	Mulch-Till	No-Till
Illinois	14%	20%	25%	41%
Franklin County	37%	16%	8%	38%
Hamilton County	27%	11%	10%	52%
Jackson County	No data			
Williamson County	39%	1%	8%	53%

Table 7. Percent of Small Grain Fields in Each Tillage System in Illinois and in Target Watershed Counties

County	Conventional	Reduced	Mulch-Till	No-Till
Illinois	24%	19%	17%	39%
Franklin County	0%	0%	0%	100%
Hamilton County	33%	14%	12%	41%
Jackson County	No data			
Williamson County	0%	0%	0%	0%

Table 8. Percent of Fields Indicating Ephemeral Erosion in Illinois and in Target Watershed Counties

County	Yes	No
Illinois	20%	80%
Franklin County	3%	97%
Hamilton County	6%	94%
Jackson County	No data	
Williamson County	26%	74%

2.6 Urbanization and Growth

Urbanization in the watershed is centered in the towns of Benton, West Frankfort, Herrin and Johnston City. The land cover data (see Section 2.8) indicates that the watershed is approximately 12% urbanized, but very little is considered heavily developed.

Population statistics and projections are available on a county basis. Most of this watershed is located in Franklin County, the population of which has increased 1.4% between 2000 and 2010 (Table 9), less than half the rate the state as a whole has grown.

Table 9. Population in Illinois and Target Watershed Counties

County	2000 Census [1] Total Population	2010 Census Total Population	2000-2010 Change	2000-2010 % Change
Illinois	12,419,293	12,830,632	411,339	3.3
Franklin County	39,018	39,561	543	1.4
Hamilton County	8,621	8,457	-164	-1.9
Jackson County	59,612	60,218	606	1.0
Williamson County	61,296	66,357	5,061	8.3

Source: Downloaded from http://www2.illinois.gov/census/Pages/Census2010Data.aspx on July 1, 2013

The Greater Egypt Regional Planning and Development Commission, referencing US Census Bureau projections, states that the population in the Greater Egypt 5-county area will be relatively steady (or slightly declining) through 2030 (GERPDC 2010).

2.7 Mining, Oil and Gas Activities

Coal, oil and gas have been extracted throughout this watershed. These activities peaked between 1940 and 1980. Figures 4 through 7 show the ubiquitous mined areas and wells in the watershed. Nearly all of the mining is underground. Nonetheless, mining and oil and gas drilling can affect the quality of surface waters.

2.8 Land Cover

Land cover in the study area is tabulated by subwatershed in Table 10 and mapped in Figure 8. These data are derived from 2011 Cropland Data Layer (CDL) for Illinois from the Natural Resources Conservation Service (NRCS). CDL is a variation on the National Land Cover Database (NLCD).

From these data it is apparent that the Upper Big Muddy River watershed is predominantly agricultural with roughly half of the land used for cultivated crops and pasture/hay. Roughly 25% of the watershed is forested and about 12% developed for urban uses.

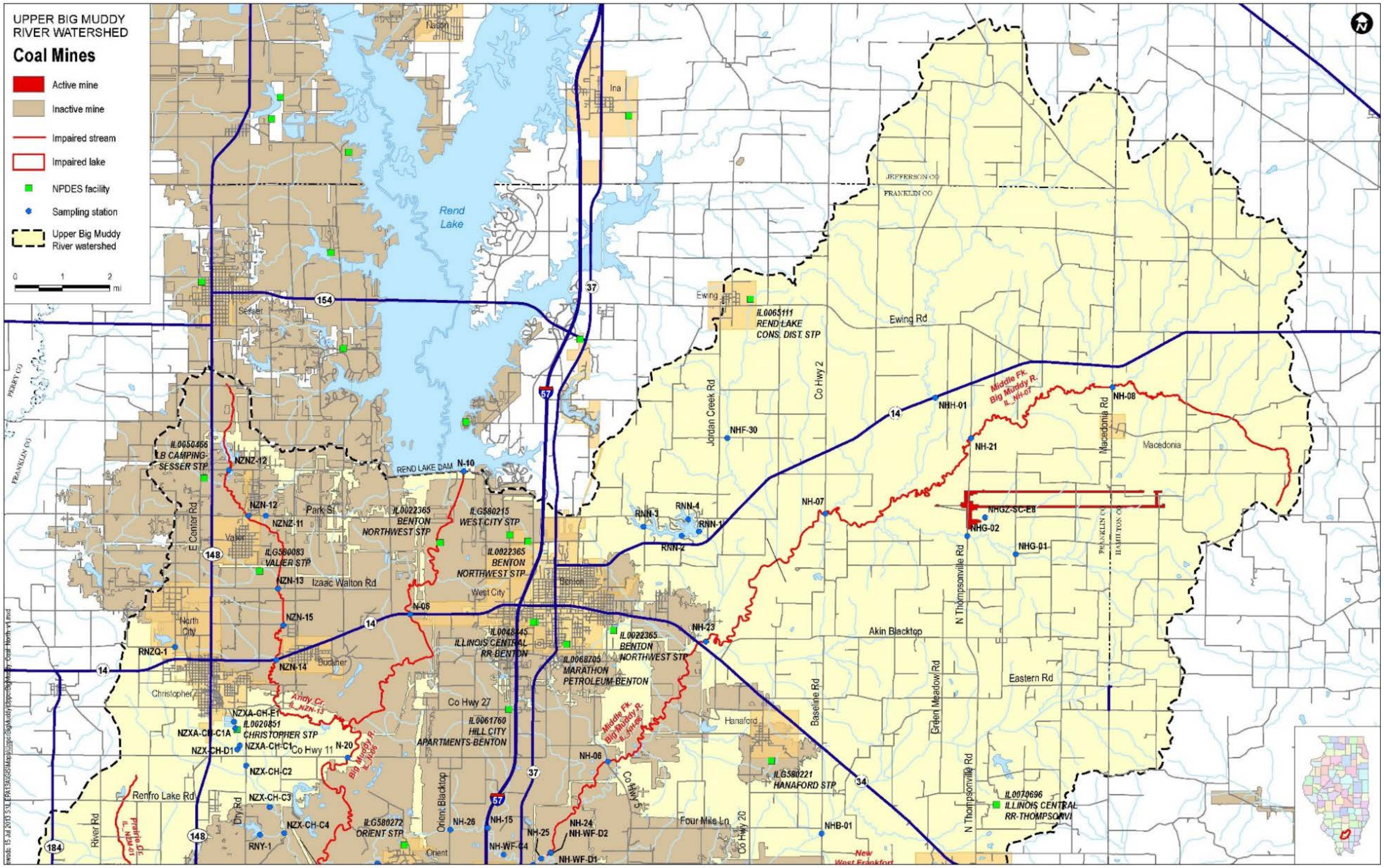

Figure 4. Coal Mined Areas in Upper Big Muddy Watershed (North)

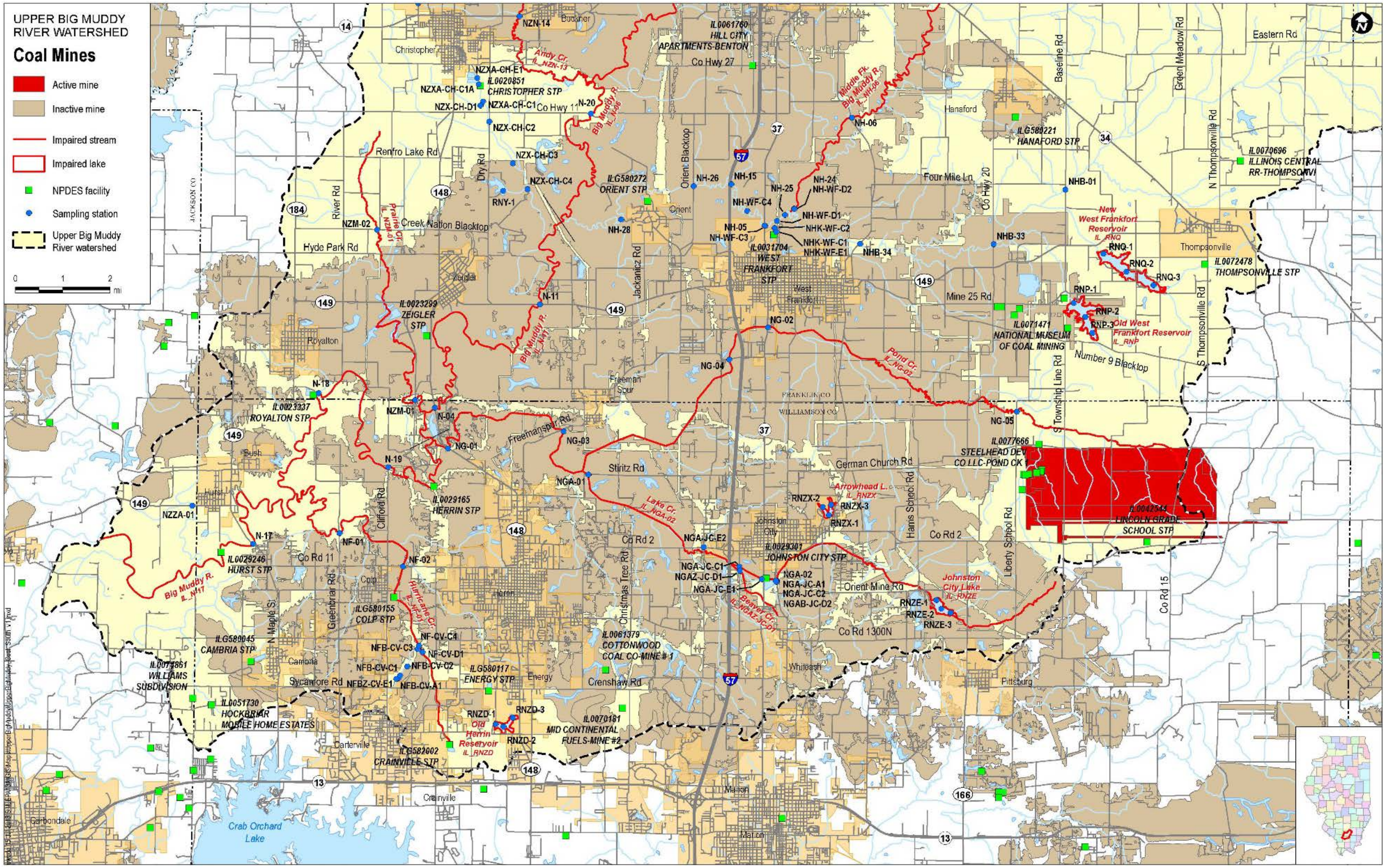

Figure 5. Coal Mined Areas in Upper Big Muddy Watershed (South)

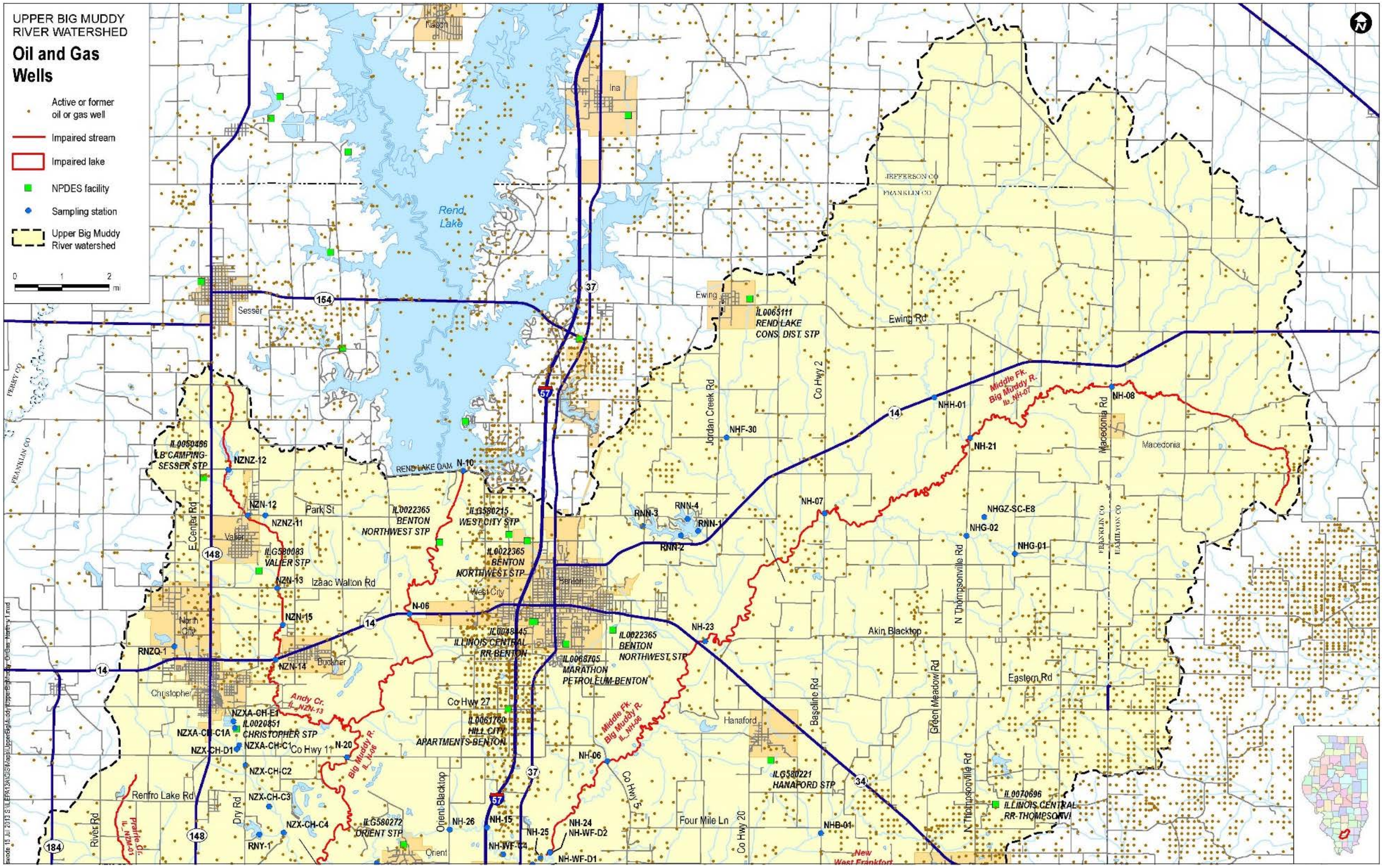

Figure 6. Oil and Gas Wells in Upper Big Muddy Watershed (North)

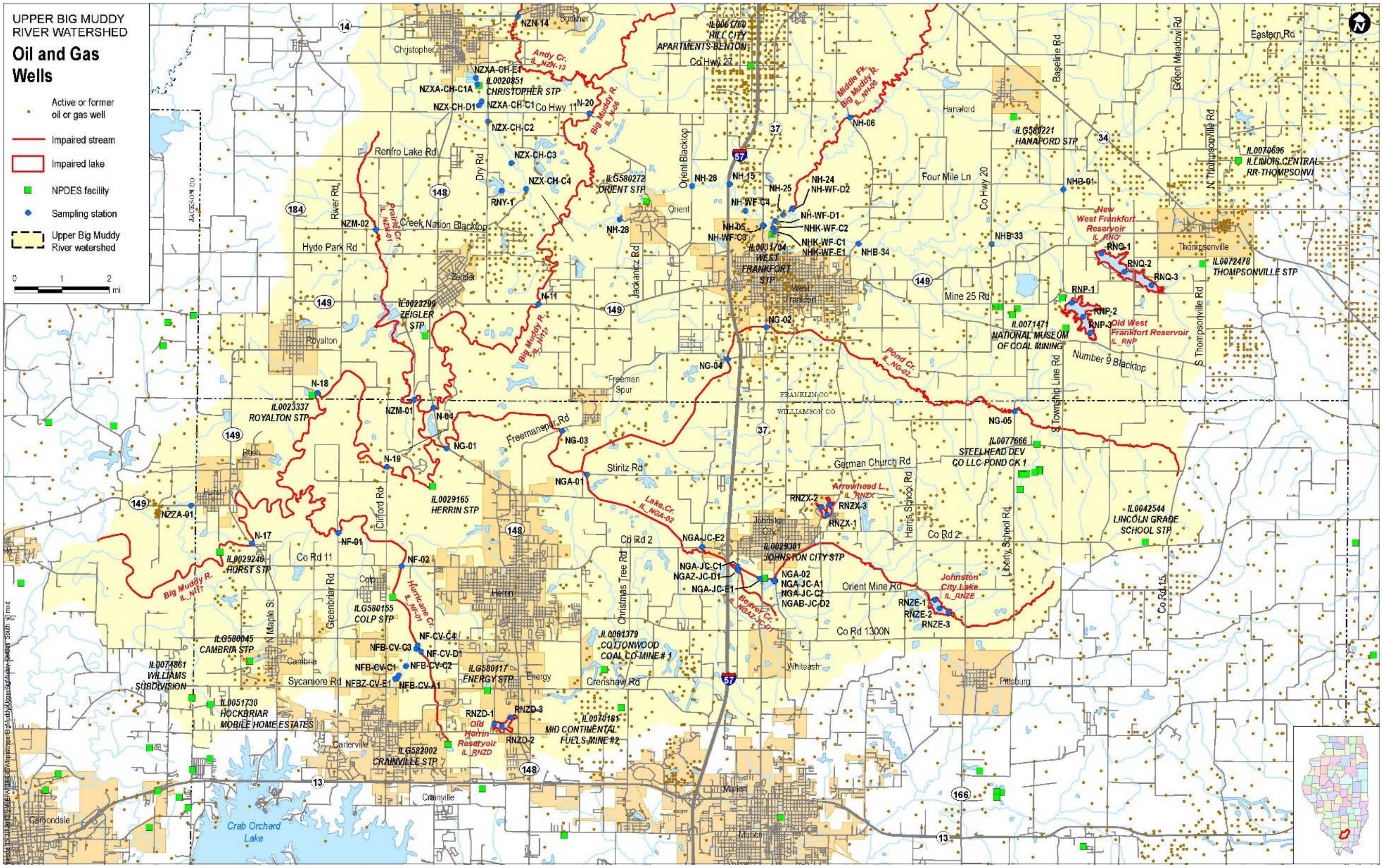

Figure 7. Oil and Gas Wells in Upper Big Muddy Watershed (South)

Table 10. Land Use Land Cover of Subwatersheds for the 16 Impaired Waterbodies in the Project Watershed, in acres

Land Cover Type	Big Muddy R IL_N-17	Hurricane Cr IL_NF-01	Herrin Old IL_RNZD	Pond Cr IL_NG-02	Lake Cr IL_NGA-02	Beaver Cr IL_NGAZ-JC-D1	Arrowhead IL_RNZX	Johnston City IL_RNZE
Barren	1	0	0	25	5	0	0	2
Cultivated crop	8,827	2,771	177	12,897	2,236	20	57	118
Developed, high intensity	1	82	4	57	18	0	0	0
Developed, low intensity	986	1,543	250	2,380	1,165	29	17	52
Developed, medium intensity	46	435	79	397	224	5	0	2
Developed, open	1,264	2,193	323	2,585	1,549	28	26	104
Forest	6,466	4,925	403	12,069	7,453	154	173	1,221
Grassland/pasture/hay	4,249	2,778	302	10,876	5,296	136	175	737
Water	588	191	66	724	483	16	33	170
Wetlands	222	64	3	137	73	4	0	2
Total	22,650	14,983	1,608	42,146	18,502	392	481	2,407

Land Cover Type	Big Muddy R ILN-11	Prairie Cr IL_NZM-01	W Frankfort Old IL_RNP	W Frankfort New IL_RNQ	M Fk B Muddy IL_NH-06	M Fk B Muddy IL_NH-07	B Muddy R IL_N-06	Andy Cr IL_NZN-13
Barren	1	0	0	0	3	71	3	0
Cultivated crop	19,578	5,238	601	552	14,184	31,209	4,700	4,182
Developed, high intensity	82	1	0	1	28	7	101	1
Developed, low intensity	2,702	474	37	163	1,389	776	1,451	740
Developed, medium intensity	526	32	4	19	206	36	395	32
Developed, open	3,528	438	106	503	2,003	2,709	1,699	1,591
Forest	14,810	1,970	848	1,799	6,538	15,155	8,015	2,923
Grassland/pasture/hay	12,869	2,000	696	1,696	8,447	18,155	3,885	3,438
Water	528	204	165	225	587	292	219	114
Wetlands	903	58	2	2	715	278	588	38
Total	55,528	10,414	2,460	4,959	34,100	68,689	21,056	13,059

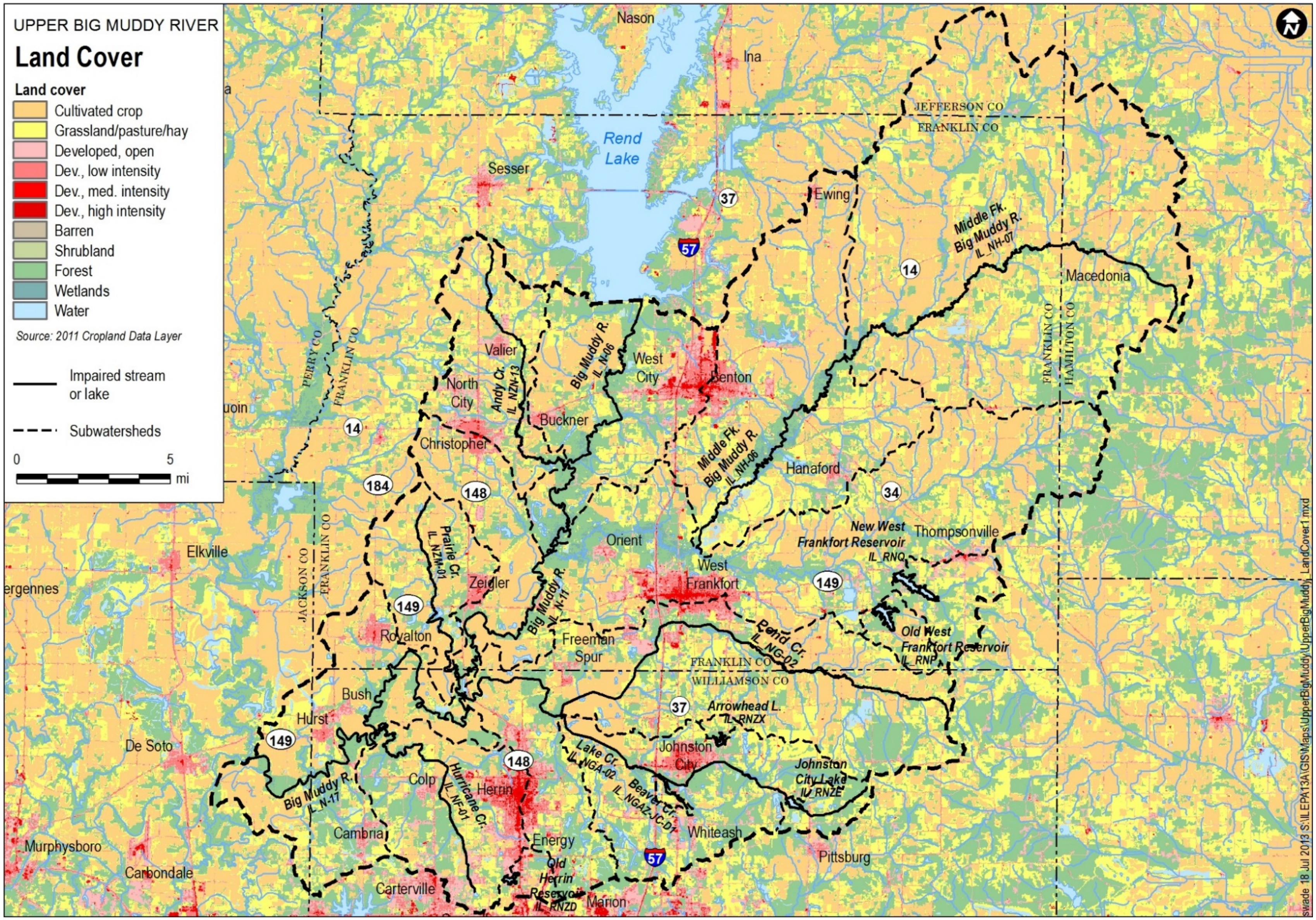

Figure 8. Land Cover in the Project Watershed

2.9 Livestock and Poultry

Illinois EPA has issued no permits in the Upper Big Muddy watershed for concentrated animal feeding operations (CAFO). CAFOs are agricultural operations where relatively large numbers of animals are kept and raised in confined situations; feed is brought to the animals rather than the animals grazing or browsing in pastures or fields.

The National Agricultural Statistics Service performs a census of livestock and poultry production every five years. The most recent census is from 2007 (Table 11). The data are not collected on a watershed basis, but are available by county. Tables from the census is relevant as these operations are a potential source of pollutants to area waterbodies. Livestock are a source of bacteria and nutrients while their grazing can increase erosion introducing sediments (that may contain manganese, iron, or other pollutants) to area streams and increasing sediment oxygen demand (SOD) within the segments which can deplete dissolved oxygen.

Table 11. Livestock and Poultry Census Data

County	Census Item	Value
Franklin County	Cattle, incl calves - inventory	6,668
	Hogs - inventory	25,120
	Sheep, incl lambs - inventory	(D)
	Poultry totals - hatched, measured in head	(D)
Hamilton County	Cattle, incl calves - inventory	2,540
	Hogs - inventory	21,988
	Sheep, incl lambs - inventory	532
	Poultry totals - hatched, measured in head	(D)
Jackson County	Cattle, incl calves - inventory	11,751
	Hogs - inventory	7,134
	Sheep, incl lambs - inventory	250
	Poultry totals - hatched, measured in head	746
Williamson County	Cattle, incl calves - inventory	4,875
	Hogs - inventory	(D)
	Sheep, incl lambs - inventory	110
	Poultry totals - hatched, measured in head	286

(D) Withheld to avoid disclosing data for individual operations.

2.10 Point Sources and Septic Systems

Sixty-six entities were identified that are permitted to discharge treated wastewater in the target watershed. Five of the twenty three (23) facilities that discharge treated sanitary wastewater, also have permitted wet weather overflow discharges. Fifteen of the permitted discharges are acid or alkaline mine drainage. The balance are generally stormwater-related outfalls (Tables 12 and 13 and Figure 9).

Septic systems are the dominate form of residential wastewater treatment in areas outside of towns.

Currently, there are no NPDES permitted CAFO facilities within the boundaries of the Upper Big Muddy River Watershed

Table 12. NPDES Discharges in the Target Watershed

NPID	Facility Name	TYPE	DSDG	Description	Subwatershed
IL0020851	CHRISTOPHER STP		0010	STP OUTFALL	IL_N-11
IL0022365	BENTON NORTHWEST STP	M	0020	EMERGENCY HIGH LEVEL BYPASS	IL_N-06
IL0022365	BENTON NORTHWEST STP	M	A010	EXCESS FLOW (OVER 2.52 MGD)	IL_N-06
IL0022365	BENTON NORTHWEST STP		0010	STP OUTFALL	IL_N-06
IL0022365	BENTON NORTHWEST STP	M	0030	EXCESS FLOW(OLD SOUTHEAST STP)	IL_N-06
IL0023299	ZEIGLER STP		0010	STP OUTFALL	IL_NZM-01
IL0023337	ROYALTON STP		0010	STP OUTFALL	IL_N-17
IL0029165	HERRIN STP		0010	STP OUTFALL	IL_N-17
IL0029246	HURST STP		0010	STP OUTFALL	IL_N-17
IL0029301	JOHNSTON CITY STP	M	A010	EXCESS FLOW OUTFALL	IL_NGA-02
IL0029301	JOHNSTON CITY STP		0010	STP OUTFALL	IL_NGA-02
IL0031704	WEST FRANKFORT STP	M	A010	EXCESS FLOW	IL_N-11
IL0031704	WEST FRANKFORT STP		0010	STP OUTFALL	IL_N-11
IL0042544	LINCOLN GRADE SCHOOL STP		0010	STP OUTFALL	IL_NG-02
IL0048445	ILLINOIS CENTRAL RR-BENTON	R	001A	YEARLY STORMWATER REPORTING	IL_N-06
IL0048445	ILLINOIS CENTRAL RR-BENTON	R	001Q	QUARTERLY STORMWATER RUNOFF	IL_N-06
IL0048445	ILLINOIS CENTRAL RR-BENTON	R	0010	STORMWATER RUNOFF	IL_N-06
IL0050466	LB CAMPING-SESSER STP		0010	STP OUTFALL	IL_NZN-13
IL0051730	HOCKBRIAR MOBILE HOME ESTATES		0010	EFFULENT REPORTING	IL_N-17
IL0061379	COTTONWOOD COAL CO-MINE # 1	M	001P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0061379	COTTONWOOD COAL CO-MINE # 1		0010	ALKALINE MINE DRAINAGE	IL_NG-02
IL0061379	COTTONWOOD COAL CO-MINE # 1	M	002P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0061379	COTTONWOOD COAL CO-MINE # 1		0020	ALKALINE MINE DRAINAGE	IL_NG-02
IL0061760	HILL CITY APARTMENTS-BENTON		0010	STP OUTFALL	IL_NH-06
IL0065111	REND LAKE CONS. DIST. STP		0010	STP OUTFALL	IL_NH-06
IL0068705	MARATHON PETROLEUM-BENTON	M	0010	SW RUNOFF&HYDROSTATIC TEST WTR	IL_NH-06
IL0068705	MARATHON PETROLEUM-BENTON	M	0011	HYDROSTATIC TEST WATER	IL_NH-06
IL0070181	MID CONTINENTAL FUELS-MINE #2	M	001P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0070181	MID CONTINENTAL FUELS-MINE #2		0010	ACID MINE DRAINAGE	IL_NG-02

NPID	Facility Name	TYPE	DSDG	Description	Subwatershed
IL0070696	ILLINOIS CENTRAL RR-THOMPSONVI		0010	TREATED STORMWATER & GROUNDWTR	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING		0020	ALKALINE MINE DRAINAGE	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING	M	002P	QUARTERLY PRECIPITATION EVENTS	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING		0250	ACID MINE DRAINAGE	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING	M	025P	QUARTERLY PRECIPITATION EVENTS	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING		0010	SANITARY WASTEWATER	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING		0050	ALKALINE MINE DRAINAGE	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING	M	005P	QUARTERLY PRECIPITATION EVENTS	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING		0060	ALKALINE MINE DRAINAGE	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING	M	006P	QUARTERLY PRECIPITATION EVENTS	IL_N-11
IL0071471	NATIONAL MUSEUM OF COAL MINING	M	007P	QUARTERLY PRECIPITATION EVENTS	IL_RNP
IL0071471	NATIONAL MUSEUM OF COAL MINING		0070	ALKALINE MINE DRAINAGE	IL_N-11
IL0072478	THOMPSONVILLE STP		0010	STP OUTFALL	IL_RNQ
IL0074861	WILLIAMS SUBDIVISION		0010	STP OUTFALL	IL_N-17
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	M	001P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1		0080	ACID MINE DRAINAGE	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	M	008P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	M	007P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1		0070	ACID MINE DRAINAGE	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1		0060	ACID MINE DRAINAGE	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	M	006P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1		0020	ALKALINE MINE DRAINAGE	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	M	002P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1		0030	ALKALINE MINE DRAINAGE	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	M	003P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	M	004P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1		0040	ALKALINE MINE DRAINAGE	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	M	005P	QUARTERLY PRECIPITATION EVENTS	IL_NG-02
IL0077666	STEELHEAD DEV CO LLC-POND CK 1		0050	ALKALINE MINE DRAINAGE	IL_NG-02
ILG580045	CAMBRIA STP		0010	STP OUTFALL	IL_N-17

NPID	Facility Name	TYPE	DSDG	Description	Subwatershed
ILG580083	VALIER STP		0010	STP OUTFALL	IL_NZN-13
ILG580117	ENERGY STP		0010	STP OUTFALL	IL_NF-01
ILG580155	COLP STP		0010	STP OUTFALL	IL_NF-01
ILG580215	WEST CITY STP		0010	STP OUTFALL	IL_N-06
ILG580221	HANAFORD STP		0010	STP OUTFALL	IL_NH-06
ILG580272	ORIENT STP		0010	STP OUTFALL	IL_N-11
ILG582002	CRAINVILLE STP		0010	STP OUTFALL	IL_NF-01

Table 13. NPDES Permit Expiration Dates

Permit ID	Facility Name	Permit Expiration
IL0020851	CHRISTOPHER STP	FEB-29-2016
IL0022365	BENTON NORTHWEST STP	MAY-31-2016
IL0023299	ZEIGLER STP	JUN-30-2010
IL0023337	ROYALTON STP	MAY-31-2017
IL0029165	HERRIN STP	SEP-30-2016
IL0029246	HURST STP	JAN-31-2018
IL0029301	JOHNSTON CITY STP	JUL-31-2011
IL0031704	WEST FRANKFORT STP	SEP-30-2016
IL0042544	LINCOLN GRADE SCHOOL STP	AUG-31-2017
IL0048445	ILLINOIS CENTRAL RR-BENTON	FEB-28-2014
IL0050466	LB CAMPING-SESSER STP	SEP-30-2017
IL0051730	HOCKBRIAR MOBILE HOME ESTATES	JUL-31-2014
IL0061379	COTTONWOOD COAL CO-MINE # 1	NOV-30-2003
IL0061760	HILL CITY APARTMENTS-BENTON	SEP-30-2017
IL0065111	REND LAKE CONS. DIST. STP	OCT-31-2017
IL0068705	MARATHON PETROLEUM-BENTON	NOV-30-2017
IL0070181	MID CONTINENTAL FUELS-MINE #2	OCT-31-2015
IL0070696	ILLINOIS CENTRAL RR-THOMPSONVI	NOV-30-2011

Permit ID	Facility Name	Permit Expiration
IL0071471	NATIONAL MUSEUM OF COAL MINING	AUG-31-2016
IL0072478	THOMPSONVILLE STP	JUN-30-2017
IL0074861	WILLIAMS SUBDIVISION	JUL-31-2016
IL0077666	STEELHEAD DEV CO LLC-POND CK 1	JUL-31-2010
ILG580045	CAMBRIA STP	DEC-31-2007
ILG580083	VALIER STP	DEC-31-2007
ILG580117	ENERGY STP	DEC-31-2007
ILG580155	COLP STP	DEC-31-2007
ILG580215	WEST CITY STP	DEC-31-2007
ILG580221	HANAFORD STP	DEC-31-2007
ILG580272	ORIENT STP	DEC-31-2007
ILG582002	CRAINVILLE STP	DEC-31-2007

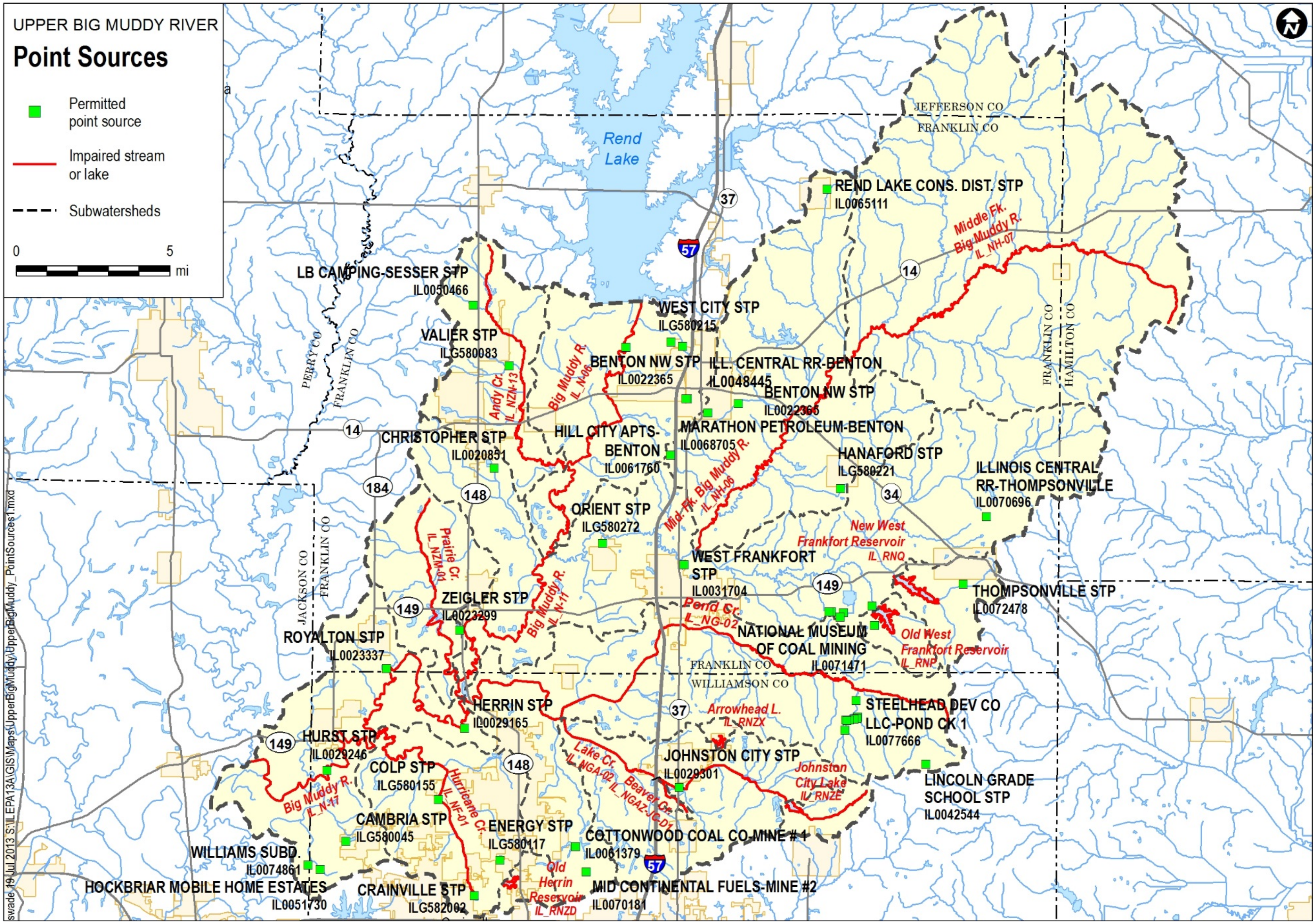

Figure 9. Point Source Outfalls in the Upper Big Muddy Watershed

3

Public Participation

This section summarizes the results of a December 17, 2013 public meeting, at which Illinois EPA Planning Unit TMDL project managers, along with their consultant presented the results of the Stage One Draft report for the Upper Big Muddy watershed.

On November 16, 2013, a public meeting was announced for presentation of the Stage One findings http://www.epa.state.il.us/public-notices/. The public meeting was held at 3:30 pm on Tuesday, December 17, 2013 in West Frankfort, Illinois at the public library. This meeting provided an opportunity for local agencies and the general public to provide input on work completed to date. Prior to the meeting, Illinois EPA posted the draft Stage 1 Report for the watershed to their website http://epa.state.il.us/water/tmdl/report/upper-big-muddy/stage-one-draft.pdf

In addition to the meeting's sponsors, 25 individuals attended the meeting. Attendees registered and listened to an introduction to the TMDL Program from Illinois EPA and a presentation on the Stage One findings by the Agency's consultant. This was followed by a general question and answer session.

A summary of questions and issues raised at the meeting, and responses, is provided below:

- Why is the upstream watershed (Rend Lake) being done separately and how will you accommodate those sources in this watershed?

  The Agency contracts watersheds separately, with large watersheds generally broken into smaller more manageable subareas for analysis. The Upper Big Muddy Watershed will prepare the TMDL under the assumption that the upstream Rend Lake TMDL is implemented and pollutant loads entering the Upper Big Muddy are within those limits.

- How do we factor in land treatment projects? Have we ever used FOIA to procure location-specific data on land treatment?

  The Agency nor the contractor have been successful obtaining specific data on BMPs from the Farm Service Agency due to confidentiality clauses in the FSA contracts.

- Do we consider weather conditions (drought, flood, etc) when sampling?

  Yes, and this is required for data that is intended to support load duration analysis. Water quality samples are ideally collected from high flow events, median flow conditions, and during times of low flow. Unfortunately flow conditions are difficult to predict.

- How does the TMDL affect individual farmers vs treatment plants?

  TMDL implementation on cropland is voluntary, with technical and financial assistance provided by the State. NPDES permit holders may be required to reduce their loadings.

The Agency entertained questions and concerns from the public through January 15, 2014. No additional questions, issues, or comments were received.

4

Water Quality Standards

Water quality standards are intended to protect the designated uses of water. In Illinois, the Illinois Pollution Control Board (IPCB) is authorized to establish designated uses and quality standards for water. The state's water quality standards are promulgated as the Illinois Administrative Rules Title 35, Environmental Protection; Subtitle C, Water Pollution; Chapter I, Pollution Control Board; Part 302, Water Quality Standards. These standards are updated every three years in accordance with federal regulations.

Water in the state is classified according to its designated uses. These are: General Use, Public and Food Processing Water Supplies, Lake Michigan, and Secondary Contact and Indigenous Aquatic Life Use. The designated use that is not being supported in the Upper Big Muddy River watershed, and hence is requiring this TMDL, is General Use.

The General Use classification is designed to protect aquatic life, wildlife, agricultural use, secondary contact use, most industrial uses, aesthetic qualities, and, primary contact use for those waters whose physical configuration permits such use. Below we paraphrase the water quality standards that are not being met in one or more waterbodies that are designated for General Use in the Upper Big Muddy River watershed.

4.1 Offensive Conditions

Water quality standards for offensive conditions are defined in a narrative form, rather than numeric, in Section 302.203 of Title 35 of the Illinois Administrative Code. That section states that waters of the State shall be free from sludge or bottom deposits, floating debris, visible oil, odor, plant or algal growth, color or turbidity of other than natural origin

4.2 Sulfate

The General Use standards for sulfate are in Section 302.208 of Title 35 of the Illinois Administrative Code. They are multifold, and in part, dependent on hardness and chloride concentrations:

1. At any point where water is used for livestock watering, the average of sulfate concentrations must not exceed 2,000 mg/L when measured at a representative frequency over a 30 day period.
2. The results of the following equations provide sulfate water quality standards in mg/L for the specified ranges of hardness (in mg/L as $CaCO_3$) and chloride (in mg/L) and must be met at all times:
    a. If the hardness concentration is greater than or equal to 100 mg/L but less than or equal to 500 mg/L, and if the chloride concentration is greater than or equal to 25 mg/L but less than or equal to 500 mg/L, then:

$$C = [1276.7 + 5.508\ (\text{hardness}) - 1.457\ (\text{chloride})] * 0.65$$

where: C = sulfate concentration

   b. If the hardness concentration is greater than or equal to 100 mg/L but less than or equal to 500 mg/L, and if the chloride concentration is greater than or equal to 5 mg/L but less than 25 mg/L, then:

$$C = [-57.478 + 5.79 (\text{hardness}) + 54.163 (\text{chloride})] * 0.65$$

3. The following sulfate standards must be met at all times when hardness and chloride concentrations other than specified above are present:
   a. If the hardness concentration is less than 100 mg/L or chloride concentration is less than 5 mg/L, the sulfate standard is 500 mg/L.
   b. If the hardness concentration is greater than 500 mg/L and the chloride concentration is 5 mg/L or greater, the sulfate standard is 2,000 mg/L.
   c. If the combination of hardness and chloride concentrations of existing waters are not reflected above, the sulfate standard may be determined in a site-specific rulemaking.

The sulfate standard was revised as above in 2008 through Illinois Pollution Control Board Rulemaking R2007-009 (In the Matter of: Triennial Review of Sulfate and Total Dissolved Solids Water Quality Standards: Proposed Amendments to 35 Ill. Adm. Code 302.102(b)(6), 302.102(b)(8), 302.102(b)(10), 302.208(g), 309.103(c)(3), 405.109(b)(2)(A), 409.109(b)(2)(B), 406.100(d); Repealer of 35 Ill. Adm. Code 406.203 and Part 407; and Proposed New 35 Ill. Adm. Code 302.208(h)).

4.3 Chloride

The General Use standard for chloride is in Section 302.208 of Title 35. The standard is 500 mg/L.

4.4 Fecal Coliform

The General Use standards for fecal coliform bacteria are in Section 302.209 of Title 35. During the months May through October (swimming season), based on a minimum of five samples taken over not more than a 30 day period, fecal coliform bacteria shall not exceed a geometric mean of 200 per 100 mL, nor shall more than 10% of the samples during any 30 day period exceed 400 per 100 mL.

4.5 Manganese and Iron

The General Use standards for aquatic life use support are in Section 302.208 of Title 35.The iron (dissolved) standard is 1 mg/L. Manganese has acute and chronic standards, and both are hardness based. The acute standard is:

$$\exp(4.9187 + 0.7467 * ln(H)) * \ 0.9812$$

where H is hardness (in mg/L as $CaCO_3$). The chronic standard is similar:

$$\exp(4.0635 + 0.7467 * ln(H)) * \ 0.9812$$

The manganese standard for Public Water Supply Intakes is 1.0 mg/L.

The manganese standard was revised in 2012 through Illinois Pollution Control Board Rulemaking R2011-018 (In the Matter of: Triennial Review of Water Quality Standards for Boron, Fluoride and Manganese: Amendments to 35 Ill. Adm. Code 301.106, 302.Subparts B, C, E, F and 303.312).

4.6 Phosphorus

The General Use standard for phosphorus is in Section 302.206 of Title 35. Phosphorus shall not exceed 0.05 mg/L in any reservoir or lake with a surface area of 20 acres or more, or in any stream at the point where it enters any such reservoir or lake.

4.7 Dissolved Oxygen

The General Use standards for dissolved oxygen (DO) are in Section 302.207 of Title 35. General Use waters must maintain sufficient DO concentrations to prevent offensive conditions as required in Section 302.203. Quiescent and isolated areas of General Use waters including but not limited to wetlands, sloughs, backwaters and waters below the thermocline in lakes and reservoirs must be maintained at sufficient dissolved oxygen concentrations to support their natural ecological functions and resident aquatic communities. Further, the DO concentration in the main body of all streams, in the water above the thermocline of thermally stratified lakes and reservoirs, and in the entire water column of unstratified lakes and reservoirs must not be less than:

1. During the period of March through July, 5.0 mg/L at any time, and, 6.0 mg/L as a daily mean averaged over 7 days.
2. During the period of August through February, 3.5 mg/L at any time, 4.0 mg/L as a daily minimum averaged over 7 days, and, 5.5 mg/L as a daily mean averaged over 30 days.

4.8 Lindane

Lindane, or gamma-BHC (hexachlorocyclohexane), is an insecticide used for agricultural and/or health care purposes. Agricultural-grade lindane products, limited in recent years to preplanting seed treatments for 6 crops (barley, corn, oats, rye, sorghum and wheat), have accounted for more than 99% of all lindane applications. Pharmaceutical-grade topical products containing lindane are available for the treatment of scabies and lice.

Illinois does not currently have a numeric water quality standard for lindane. However, the narrative water quality standards permit the Agency to derive numeric water quality criteria values for any substance that does not already have a numeric standard. These criteria serve to protect aquatic life, human health or wildlife, although wildlife based derived criteria have not yet been derived. To date, the IEPA has not derived criteria for lindane.

Hurricane Creek's listing as an impaired waterbody was based upon a no-longer-used sediment-based criterion.

5 Confirmation of Causes and Sources of Impairment

This section provides an analysis of available water quality data to verify the impairments identified in in the State's 2012 Integrated Water Quality Report and Section 303(D) List (IEPA, 2012). Only pollutants with numeric water quality standards are subjected to this analysis. Following that, potential pollutant sources in the subwatersheds are likewise verified.

5.1 Sufficiency of Data to Support Listing

For each listed water body, the available water quality data is analyzed to: 1) confirm the sufficiency of the data to support the listing decision, and 2) confirm the cause of the impairment according to the Illinois Integrated Water Quality Report and Section 303(d) List (IEPA, 2012). Data analysis involved compiling summary statistics for each parameter and comparing to numeric water quality standards.

Table 14. Data Summary for Impairments

Water body segment	Parameter	Sampling station	Period of record (# samples)	Minimum	Maximum	Average
Big Muddy River IL_N-11	Sulfate	N-11	4/04 – 11/11 (56 samples)	21.2 mg/L	814 mg/L	76 mg/L
	Fecal Coliform	N-11	5/09 – 10/10 (10 samples)	23 /100 mL	260 /100mL	86 /100mL
Big Muddy River IL_N-17	Dissolved Oxygen	N-17	6/03-11/03 (3 samples)	4.4 mg/L	8.1 mg/L	6.1 mg/L
Prairie Creek IL_NZM-01	Sulfate	NZM-01	7/88-8/88 (3 samples)	652 mg/L	808 mg/L	706 mg/L
Andy Creek IL_NZN-13	Iron	NZN-15	5/08-8/08 (3 samples)	38 µg/L	1,110 µg/L	410 µg/L
	Manganese	NZN-15	5/08-8/08 (1 sample)	224 µg/L	224 µg/L	224 µg/L
	Dissolved Oxygen	NZN-15	5/08-8/08 (3 samples)	2.5 mg/L	7.3 mg/L	4.2 mg/L
Herrin Old IL_RNZD	Phosphorus	RNZD-99	6/11 (1 sample)	0.085 mg/L	0.085 mg/L	0.085 mg/L

Water body segment	Parameter	Sampling station	Period of record (# samples)	Minimum	Maximum	Average
Pond Creek IL_NG-02	Chloride	NG-02	3/04-1/07 (27 samples)	8.07 mg/L	69.2 mg/L	32.8 mg/L
		NG-05	5/08-7/08 (3 samples)	43.8 mg/L	1420 mg/L	568 mg/L
	Dissolved Oxygen	NG-02	1/03-1/07 (37 samples)	0.0 mg/L	71 mg/L	5.9 mg/L
		NG-05	5/08-8/08 (7 samples)	5.5 mg/L	9.1 mg/L	7.2 mg/L
Lake Creek IL_NGA-02	Dissolved Oxygen	NGA-02	5/08-8/08 (7 samples)	3.6 mg/L	8.2 mg/L	5.4 mg/L
Beaver Creek IL_NGAZ-JC-D1	Manganese	NGAZ-JC-D1	8/08 (1 sample for total Mn only)	6,410 µg/L	6,410 µg/L	6,410 µg/L
Johnston City IL_RNZE	Phosphorus	RNZE-1	4/02-10/02 (10 samples)	0.035 mg/L	0.129 mg/L	0.070 mg/L
Arrowhead (Williamson) IL_RNZX	Phosphorus	RNZX-1	5/09-10/09 (10 samples)	0.05 mg/L	0.524 mg/L	0.152 mg/L
		RNZX-2	5/09-10/09 (5 samples)	0.034 mg/L	0.074 mg/L	0.055 mg/L
		RNZX-3	6/09-10/09 (4 samples)	0.049 mg/L	0.083 mg/L	0.064 mg/L
M. Fk. Big Muddy IL_NH-06	Fecal Coliform	NH-06	5/09-5/10 (5 samples)	105/100 mL	390/100 mL	250/100 mL
	Dissolved Oxygen	NH-06	1/09-11/11 (27 samples)	0.7 mg/L	16.4 mg/L	5.8 mg/L
	Manganese	NH-06	1/09-11/11 (27 samples)	43.8 µg/L	1,790 µg/L	686 µg/L
M. Fk. Big Muddy IL_NH-07	Dissolved Oxygen	NH-07	6/03-11/03 (3 samples)	2.5 mg/L	6.4 mg/L	4.0 mg/L
	Manganese	NH-07	6/03-11/03 (3 samples)	620 µg/L	1,700 µg/L	1,100 µg/L
West Frankfort Old IL_RNP	Phosphorus	RNP-1	7/11 (2 samples)	.034 mg/L	0.444 mg/L	0.239 mg/L

Water body segment	Parameter	Sampling station	Period of record (# samples)	Minimum	Maximum	Average
West Frankfort New IL_RNQ	Phosphorus	RNQ-1	7/11 (2 samples)	0.111 mg/L	0.221 mg/L	0.166 mg/L

Table 15. Confirmation of Use Impairment and Waterbody Listing

Waterbody/Cause of Impairment	Applicable Water Use Designation	Water Quality Criteria	Basis of Impairment
Big Muddy River (IL_N-11)			
Sulfate	General use (Aquatic life)	Dependent upon chloride and hardness	1 of 56 samples > criterion
Fecal coliform	Primary contact recreation	Geo mean of ≥5 samples in 30 days <200/100mL or fewer than 10% of samples be > 400/100mL	30-day sampling criterion not met; 1 out of 10 samples > 200/100mL
Big Muddy River (IL_N-17)			
Dissolved oxygen	General use (Aquatic life)	5.0 mg/L Mar-Jul 4.0 mg/L other months	1 of 3 samples < criterion
Prairie Creek (IL_NZM-01)			
Sulfate	General use (Aquatic life)	2,000 mg/L	0 out of 3 samples > criterion; recommend delisting
Andy Creek (IL_NZN-13)			
Iron	General use	1,000 µg/L	1 out of 3 samples > criterion
Manganese	General use (Aquatic life)	Dependent upon hardness	0 out of 1 sample > criterion; recommend delisting
Dissolved Oxygen	General use (Aquatic life)	5.0 mg/L Mar-Jul 4.0 mg/L other months	2 out of 3 samples < criterion
Herrin Old (IL_RNZD)			
Phosphorus	Aesthetics	0.05 mg/L	1 out of 1 sample > criterion
Pond Creek (IL_NG-02)			
Chloride	General use	500 mg/L	1 out of 30 samples > criterion
Dissolved oxygen	General use (Aquatic life)	5.0 mg/L Mar-Jul 4.0 mg/L other months	22 of 44 samples < criterion
Lake Creek (IL_NGA-02)			
Dissolved oxygen	General use (Aquatic life)	5.0 mg/L Mar-Jul 4.0 mg/L other months	2 out of 7 samples < criterion
Beaver Creek (IL_NGAZ-JC-D1)			
Manganese	General use (Aquatic life)	Chronic standard = 4,846 µg/L	1 out of 1 sample > criterion

Waterbody/Cause of Impairment	Applicable Water Use Designation	Water Quality Criteria	Basis of Impairment
Johnston City (IL_RNZE)			
Phosphorus	Aesthetics	0.05 mg/L	7 of 10 samples > criterion
Arrowhead (Williamson) (IL_RNZX)			
Phosphorus	Aesthetics	0.05 mg/L	16 of 19 samples > criterion
M. Fk. Big Muddy River (IL_NH-06)			
Fecal coliform	Primary contact recreation	Geo mean of ≥5 samples in 30 days <200/100mL or fewer than 10% of samples be > 400/100mL	30-day sampling criterion not met; 4 out of 5 samples > 200/100mL
Dissolved oxygen	General use (Aquatic life)	5.0 mg/L Mar-Jul 4.0 mg/L other months	12 out of 27 measurements < criterion
Manganese	General use (Aquatic life)	Dependent upon hardness	0 out of 27 samples > criterion; recommend delisting
M. Fk. Big Muddy River (IL_NH-07)			
Dissolved oxygen	General use (Aquatic life)	5.0 mg/L Mar-Jul 4.0 mg/L other months	2 out of 3 samples < criterion
Manganese	General use (Aquatic life)	Dependent upon hardness	0 out of 3 samples > criterion; recommend delisting
West Frankfort Old (IL_RNP)			
Phosphorus	Aesthetics	0.05 mg/L	1 out of 2 samples > criterion
West Frankfort New (IL_RNQ)			
Phosphorus	Aesthetics	0.05 mg/L	2 out of 2 samples > criterion

In summary, the Upper Big Muddy watershed has been indicated in the 2012 303(d) list as having 16 waterbodies with impaired use support. At the time the 303(d) list was prepared, this would suggest 23 TMDLs and 13 LRSs. Since development of the 2012 (and prior biennial 303(d) lists), some numeric water quality standards have been revised that affect whether or not a TMDL is prepared. TMDLs are only prepared for impairments caused by exceedance of a numeric water quality standard.

This review of available water quality data and current state water quality standards recommends that TMDLs not be prepared for impairments caused by manganese in 2 segments of the M. Fk. Big Muddy River (IL_NH-06 and IL_NH-07) and Andy Creek (IL_NZN-13).). Seventeen (17) TMDLs are recommended for the 13 waterbodies with pollutants having numeric standards and 11 LRSs are also recommended for 10 waterbodies to address pollutants with narrative standards.

The original listing of lindane (BHC- gamma) for Hurricane Creek , segment IL_NF-01, was from a sample of sediment taken in 1995 at station NF-01 which showed lindane at 2.5 ug/kg (personal communication, D. Muir, IEPA, in an email dated 9/10/2013). The aquatic life use support impairment of Hurricane Creek by lindane has been on the state's 303(d) list since 1996 and was identified using sediment criteria that are no longer in effect. In 2008, another sediment sample was analyzed from NF-01; lindane in that sample was less than the method detection limit of 0.16 µg/kg. The state has not yet derived numeric standards for lindane, and after consulting with Agency staff, it is not appropriate to retain it as an impaired waterbody nor to prepare an LRS for lindane.

5.2 Source Assessment

This section discusses potential sources of pollutants for the above water use impairments. Potential sources are known or suspected activities, facilities, or conditions that may be contributing to impairment of a designated use. The impairments identified by Illinois EPA in the 2012 Integrated Report are reprinted in Table 16.

Table 16. Waterbody Impairment Causes and Sources (from IEPA, 2012)

Waterbody/Cause of Impairment	Potential Sources
Big Muddy River (IL_N-06)	
Sedimentation/Siltation	Natural Sources Crop Production (crop land or dry land) Dam or Impoundment Agriculture Atmospheric Deposition – Toxics Source Unknown
Big Muddy River (IL_N-11)	
Sulfates Fecal Coliform Sedimentation/Siltation TSS	Non-irrigated Crop Production Source Unknown Atmospheric Deposition – Toxics
Big Muddy River (IL_N-17)	
Dissolved Oxygen Sedimentation/Siltation TSS	Municipal Point Source Discharges Non-irrigated crop production Natural Sources Crop Production (crop land or dry land) Atmospheric Deposition – Toxics Source Unknown
Hurricane Creek (IL_NF-01)	
Lindane Sedimentation/Siltation	Crop Production (crop land or dry land) Agriculture
Prairie Creek (IL_NZM-01)	
Sulfates	Surface mining
Andy Creek (IL_NZN-13)	
Iron Manganese Dissolved Oxygen	Channelization Loss of Riparian Habitat Crop Production (crop land or dry land) Agriculture Source Unknown
Herrin Old (IL_RNZD)	
Phosphorus (Total) Total Suspended Solids (TSS)	Atmospheric Deposition – Toxics Source Unknown Contaminated Sediments Urban Runoff/Storm Sewers Other Recreational Pollution Sources
Pond Creek (IL_NG-02)	

Waterbody/Cause of Impairment	Potential Sources
Chloride Dissolved Oxygen Sedimentation/Siltation	Channelization Impacts from Abandoned Mines (Inactive) Loss of Riparian Habitat Streambank Modifications/ destabilization Crop production (crop land or dry land) Agriculture Urban Runoff/Storm Sewers Source Unknown
Lake Creek (IL_NGA-02)	
Dissolved Oxygen Phosphorus (Total)	Source Unknown Municipal Point Source Discharges Crop Production (crop land or dry land) Agriculture Urban Runoff/Storm Sewers
Beaver Creek (IL_NGAZ-JC-D1)	
Manganese	Loss of Riparian Habitat Municipal Point Source Discharges Crop Production (crop land or dry land) Agriculture Urban Runoff/Storm Sewers Runoff from Forest/Grassland/Parkland
Johnston City (IL_RNZE)	
Phosphorus (Total) Total Suspended Solids (TSS)	Littoral/shore Area Modifications (Non-riverine) Runoff from Forest/Grassland/Parkland
M. Fk. Big Muddy River (IL_NH-06)	
Manganese Dissolved Oxygen Fecal Coliform	Petroleum/Natural Gas Activities Surface Mining Animal Feeding Operations Municipal Point Source Discharges Channelization Source Unknown
M. Fk. Big Muddy River (IL_NH-07)	
Manganese Dissolved Oxygen Sedimentation/Siltation	Petroleum/Natural Gas Activities Surface Mining Animal Feeding Operations Natural Sources Crop Production (crop land or dry land)
West Frankfort Old (IL_RNP)	
Phosphorus (Total) Total Suspended Solids (TSS)	Littoral/shore Area Modifications (Non-riverine) Crop Production (crop land or dry land) Runoff from Forest/Grassland/Parkland
West Frankfort New (IL_RNQ)	
Phosphorus (Total) Total Suspended Solids (TSS)	Littoral/shore Area Modifications (Non-riverine) On-site Treatment Systems (Septic Systems and Similar Decentralized Systems) Site Clearance (land development of redevelopment)

Waterbody/Cause of Impairment	Potential Sources
	Crop Production (crop land or dry land) Urban Runoff/Storm Sewers Runoff from Forest/Grassland/Parkland

Details for these and other point and nonpoint pollutant sources are presented in Section 2, Watershed Characterization.

One notable point is the possibility that hydrologic changes to downstream segments of the Big Muddy River due to flood storage at Rend Lake may be contributing to sedimentation/siltation and TSS (total suspended solids)-related impairments. The hydrologic changes are significant, particularly at low flows (<50 exceedance level). Those segments include IL_N-6, IL_N-11, and IL_N-17. Segment N-06 is the tailwater of Rend Lake.

6 Methodology

Development of TMDLs and LRSs requires: 1) a method to estimate the amount of pollutant load being delivered to the water body of interest from all contributing sources, and 2) a method to convert these pollutant loads into an in-stream (or in-lake) concentration for comparison to water quality targets. Both of these steps can be accomplished using a wide range of methodologies, ranging from simple calculations to complex computer models. This section recommends methodologies for the specific watersheds and waterbodies in the Upper Big Muddy watershed.

6.1 Applicable models and procedures to be used in TMDL and LRS development

Numerous methodologies exist to characterize watershed loads for TMDL and LRS development. These include:

- Empirical Approaches
- Simple Method/Unit Area Loads/Export Coefficients
- Universal Soil Loss Equation
- Generalized Watershed Loading Functions (AVGWLF)/MapShed Model
- Long Term Hydrologic Impact Analysis (L-THIA)
- Spreadsheet Tool for Estimating Pollutant Load (STEPL)
- Annualized Agricultural Nonpoint Source Pollution Model (AnnAGNPS)
- Hydrologic Simulation Program - Fortran (HSPF)
- Better Assessment Science Integrating point and Nonpoint Sources (BASINS)/ Nonpoint Source Model (NPSM)
- Storm Water Management Model (SWMM)
- Soil & Water Assessment Tool (SWAT)

This section describes each of the model frameworks listed above and their suitability for characterizing watershed loads for TMDL and LRS development. Table 17 summarizes some important characteristics of each of the models.

Table 17. Summary of Potentially Applicable Models for Estimating Watershed Loads

Model	Data Needs	Output Timescale	Potential Accuracy	Calibration	Applicability for TMDL or LRS
Empirical Approach	High	Any	High	N/A	Good for defining existing total load; less applicable for defining individual contributions or future loads
Simple Method/Unit Area Loads	Low	Annual average	Low	None	Acceptable when limited resources prevent development of more detailed model
USLE	Low	Annual average	Low	Requires data describing annual average load	Acceptable when limited resources prevent development of more detailed model
AVGWLF/ MapShed	Moderate	Monthly average	Moderate	Requires data describing flow and concentration	Good for mixed use watersheds; compromise between simple and more complex models
L-THIA	Moderate	Annual Average	Low	None	Good for screening-level assessments. Model focuses on the average impact, rather than an extreme year or storm.
STEPL	Moderate	Annual Total	Moderate	none	Suited for urban and rural watersheds. A simple model designed for TMDL support.
SWMM	Moderate	Continuous	Moderate	Requires data describing flow and concentration	Primarily suited for urban watersheds
AnnAGNPS	High	Continuous	High	Requires data describing flow and concentration	Primarily suited for rural watersheds; highly applicable if sufficient resources are available
HSPF	High	Continuous	High	Requires data describing flow and concentration	Good for mixed use watersheds; highly applicable if sufficient resources are available
SWAT	High	Continuous	High	Requires data describing flow and concentration	Primarily suited for rural watersheds; highly applicable if sufficient resources are available

6.1.1 Empirical Approaches

Empirical approaches estimate pollutant loading rates based upon site-specific measurements, without the use of a model to describe specific cause-effect relationships. Time series information is required for both stream flow and pollutant concentration. One advantage of empirical approaches is that direct measurement of pollutant loading will generally be far more accurate than any model-based estimate. The approach, however, has several disadvantages. The empirical approach provides information specific to the storms that are monitored, but does not provide direct information on conditions for events that were not monitored. To address this limitation, predictive methods can be used to integrate discrete measurements of suspended solids concentrations with continuous flow records to provide estimates of solids loads over a range of conditions.

The primary limitation of empirical techniques is their inability to separate individual contributions from multiple sources. This problem can be addressed by collecting samples from tributaries serving single land uses, but most tributary monitoring stations reflect multiple land uses. As a complement to empirical estimates of watershed loads, the EUTROMOD and BATHTUB water quality models described below contain routines that apply the empirical approach to estimate watershed loads.

6.1.2 Simple Method/Unit Area Loads/Export Coefficients

The EPA Simple Method is used to develop storm runoff volumes and associated pollutant loads. The method is discussed in the EPA guidance manual (USEPA 1992). In the Simple Method, annual pollutant loads are estimated as the product of storm runoff volume and event mean pollutant concentrations, summed over the course of one year.

A similar technique uses unit area loads or export coefficients, to develop estimates of pollutant loads in a watershed. A unit area load or export coefficient is a value expressing pollutant generation per unit area and unit time for a specific land use (Novotny and Olem, 1994).

The use of unit area loading or export coefficients has been used extensively in estimating loading contributions from different land uses (Beaulac 1980, Corsi et al. 1997, Reckhow et al. 1980, Reckhow and Simpson 1980, Uttormark et al. 1974). The concept is straightforward: different land use areas contribute different loads to receiving waters. By summing the amount of pollutant exported per unit area of land use in the watershed, the total pollutant load to the receiving water can be estimated.

The technique is usually based on average annual loads, and estimates existing load, as well as reductions in pollutant load for changing land uses or BMP installations necessary achieve a target TMDL or LRS pollutant load. The accuracy of the estimates is dependent on good land use data, and appropriate pollutant export coefficients for the region.

EUTROMOD is a spreadsheet-based modeling procedure for estimating phosphorus loading and associated lake trophic state variables. This watershed component of this tool can estimate phosphorus loads derived from watershed land uses or inflow data using approaches developed by Reckhow et al. (1980) and Reckhow and Simpson (1980). The FLUX module of the BATHTUB software program estimates watershed nutrient loads or fluxes to a lake/reservoir and provides five different algorithms for estimating these nutrient loads based on the correlation of concentration and flow. In addition, the potential errors in loading estimates are quantified.

6.1.3 Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE), and variations of the USLE, are the most widely used methods for predicting soil loss. When applied properly, the USLE can be used as a means to estimate loads of sediment and sediment-associated pollutants for TMDLs or LRSs. The USLE is empirical, meaning that it was developed from statistical regression analyses of a large database of runoff and soil loss data from numerous watersheds. It does not describe specific erosion processes. The USLE was designed to predict long-term average annual soil erosion for combinations of crop systems and management practices with specified soil types, rainfall patterns, and topography.

Required model inputs to the USLE consist of:

- Rainfall erosivity index factor
- Soil-erodibility factor
- Slope length factor reflecting local topography
- Cropping-management factor
- Conservation practice factor

Most of the required inputs for application of the USLE are tabulated by county Natural Resources Conservation Service (NRCS) offices.

There are also variants to the USLE: the Revised USLE (RUSLE) and the Modified USLE (MUSLE). The RUSLE is a computerized update of the USLE incorporating new data and making some improvements. The basic USLE equation is retained, but the technology for evaluating the factor values has been altered and new data introduced to evaluate the terms for specific conditions. The MUSLE is a modification of USLE, with the rainfall energy factor of the USLE replaced with a runoff energy factor. MUSLE allows for estimation of soil erosion on an event-specific basis.

While the USLE was originally designed to consider soil/sediment loading only, it is also commonly used to define loads from pollutants that are tightly bound to soils. In these situations, the USLE is used to define the sediment load, with the result multiplied by a pollutant concentration factor (mass of pollutant per mass of soil) to define pollutant load.

The USLE is among the simplest of the available models for estimating sediment and sediment-associated loads. It requires the least amount of input data for its application and consequently does not ensure a high level of accuracy. It is well suited for screening-level calculations, but is less suited for detailed applications. This is because it is an empirical model that does not explicitly represent site-specific physical processes. Furthermore, the annual average time scale of the USLE is poorly suited for model calibration purposes, as field data are rarely available to define erosion on an annual average basis. In addition, the USLE considers erosion only, and does not explicitly consider the amount of sediment that is delivered to stream locations of interest. It is best used in situations where data are available to define annual loading rates, which allows for site-specific determination of the fraction of eroded sediment that is delivered to the surface water.

6.1.4 Generalized Watershed Loading Functions Model (AVGWLF)/MapShed

The Generalized Watershed Loading Functions Model (AVGWLF) simulates runoff and sediment loadings from mixed-use watersheds. It is a continuous simulation model (i.e., predicts how concentrations change over time) that uses daily time steps for weather data and water balance calculations. Sediment loadings are provided on a monthly basis. AVGWLF requires the user to divide the watershed into any number of distinct groups, each of which is labeled as rural or urban. The model does not spatially distribute the source areas, but simply aggregates the loads from each area into a watershed total; in other words, there is no spatial routing. Erosion and sediment yield for rural areas are estimated using monthly erosion calculations based on the USLE (with monthly rainfall-runoff coefficients). A sediment delivery ratio based on watershed size and a transport capacity based on average daily runoff are then applied to the calculated erosion to determine how much of the sediment eroded from each source area is delivered to the watershed outlet. Erosion from urban areas is considered negligible.

GWLF provides more detailed temporal results than the USLE, but also requires more input data. Specifically, daily climate data are required as well as data on processes related to the hydrologic cycle (e.g., evapotranspiration rates, groundwater recession constants). By performing a water balance, it has the ability to predict concentrations at a watershed outlet as opposed to just loads. It lacks the ability to calculate the sediment delivery ratio; however, a delivery ratio can be specified by the user. Because the model performs on a continuous simulation basis, it is more amenable to site-specific calibration than USLE. Penn State University, developers of AVGWLF, is discontinuing support of the AVGWLF model in support of the MapShed model. MapShed essentially duplicates the functionality of AVGWLF model, but uses non-commercial GIS software.

6.1.5 Long Term Hydrologic Impact Analysis (L-THIA)

L-THIA is a web-based screening level model to evaluate the changes in runoff, recharge, nutrients and sediment loads due to proposed land use changes. L-THIA gives long-term average annual runoff for a land use configuration, based on actual long-term climate data for that area. By using many years of climate data in the analysis, L-THIA focuses on the average impact, rather than an extreme year or storm.

Data input requirements are minimal and include long-term precipitation, area of actual and proposed land use, and hydrologic soil groups. The user can choose basic or detailed input options depending on the choices of land use that need to be evaluated. An ArcView 3.x GIS version of L-THIA is available which allows the user to prepare input, conduct simulations and process results within the GIS environment.

L-THIA employs the curve number (CN) approach to estimate runoff. Antecedent moisture content (AMC) in the soil is estimated by precipitation data and CN is adjusted in accordance with the changes in AMC. Nonpoint source pollution masses are estimated based on Event Mean Concentration (EMC) data and estimated runoff. Built in EMC values can be replaced with site specific values. L-THIA will generate estimated runoff volumes and depths, and expected nonpoint source pollution loadings to water bodies. L-THIA's results can be used to analyze potential long-term problems and to support land use planning.

6.1.6 Spreadsheet Tool for Estimating Pollutant Load (STEPL)

Spreadsheet Tool for Estimating Pollutant Load (STEPL) employs simple algorithms to calculate nutrient and sediment loads from different land uses and the load reductions that would result from the implementation of various best management practices (BMPs). STEPL includes a Visual Basic (VB) interface in a spreadsheet-based model. It computes watershed surface runoff; nutrient loads, including nitrogen, phosphorus, and 5-day biological oxygen demand (BOD5); and sediment delivery based on various land uses and management practices.

Annual nutrient loading is calculated based on runoff volume and the pollutant concentrations in the runoff water as influenced by factors such as the land use distribution and management practices. The annual sediment load (sheet and rill erosion only) is calculated based on the Universal Soil Loss Equation (USLE) and the sediment delivery ratio. The sediment and pollutant load reductions that result from the implementation of BMPs are computed using BMP efficiencies.

6.1.7 Annualized Agricultural Nonpoint Source Pollution Model (AnnAGNPS)

The Agricultural Nonpoint Source Pollution Model (AGNPS) is a joint USDA-Agricultural Research Service and -Natural Resources Conservation Service system of computer models developed to predict nonpoint source pollutant loadings within agricultural watersheds. AnnAGNPS is one component (or module) of AGNPS and is a watershed-scale, continuous simulation model that operates on a daily time step and is designed to predict the impact of management on water, sediment, nutrients, and pesticides in agricultural watersheds. The sheet and rill erosion model internal to AnnAGNPS is based upon RUSLE, with additional routines added to allow for continuous simulation and more detailed consideration of sediment delivery.

AnnAGNPS was originally developed for use in agricultural watersheds, but has been adapted to allow consideration of construction sources. AnnAGNPS provides more spatial detail than GWLF and is therefore more rigorous in calculating the delivery of eroded sediment to the receiving water. This additional computational ability carries with it the cost of requiring more detailed information describing the topography of the watershed, as well as requiring more time to set up and apply the model.

6.1.8 Hydrologic Simulation Program – FORTRAN (HSPF)

The Hydrologic Simulation Program – FORTRAN (HSPF) uses continuous rainfall and other meteorologic records to compute stream flow hydrographs and pollutographs. HSPF is well suited for mixed-use (i.e., containing both urban and rural land uses) watersheds, as it contains separate sediment routines for pervious and impervious surfaces. HSPF is an integrated watershed/stream/reservoir model, and simulates sediment routing and deposition for different classes of particle size. HSPF was integrated with a geographical information system (GIS) environment with the development of Better Assessment Science Integrating point and Nonpoint Sources (BASINS). Although BASINS was designed as a multipurpose analysis tool to promote the integration of point and nonpoint sources in watershed and water quality-based applications, it also includes a suite of water quality models. One such model is Nonpoint Source Model (NPSM), a simplified version of HSPF that is linked with a graphical user interface within the GIS environment of BASINS.

HSPF provides a more detailed description of urban areas than AnnAGNPS and contains direct linkage to a receiving water model. This additional computational ability carries with it the cost of requiring more detailed model inputs, as well as requiring more time to set up and apply the model. The BASINS software can automatically incorporate existing environmental databases (e.g., land use, water quality data) into HSPF, although it is important to verify the accuracy of these sources before using them in the model.

6.1.9 Storm Water Management Model (SWMM)

The Storm Water Management Model (SWMM) is a comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. SWMM is designed to be able to describe both single events and continuous simulation over longer periods of time. SWMM is commonly used to simulate urban hydraulics, although its sediment transport capabilities are not as robust as some of the other models described here.

6.1.10 Soil & Water Assessment Tool (SWAT)

The Soil & Water Assessment Tool (SWAT) is a basin-scale, continuous-time model designed for agricultural watersheds. It operates on a daily time step. Sediment yield is calculated with the Modified Universal Soil Loss Equation. It contains a sediment routing model that considers deposition and channel erosion for various sediment particle sizes. SWAT is also contained as part of EPA’s BASINS software. SWAT is a continuous time model (i.e., a long-term yield model). The model is not designed to simulate detailed, single-event flood routing. SWAT was originally developed strictly for application to agricultural watersheds, but it has been modified to include consideration of urban areas and can be used in mixed-use watersheds.

6.2 Candidate Water Quality Methodologies and Modeling Frameworks

Watershed methods estimate pollutant loads that must be used to estimate water quality effects, or concentrations. Numerous methodologies exist to characterize the relationship between watershed loads and water quality for TMDL (or LRS) development. These include:

- Customized or Spreadsheet Approaches
- EUTROMOD
- BATHTUB
- QUAL-2E/QUAL-2K
- WASP7
- CE-QUAL-RIV1
- HSPF
- CE-QUAL-W2
- EFDC

This section describes each of the methodologies and their suitability for defining water quality for TMDL or LRS development. Table 18 summarizes some important characteristics of each of the models relative to TMDL and LRS application.

Table 18. Summary of Potentially Applicable Models for Estimating Water Quality

Model	Time scale	Water body type	Spatial scale	Data Needs	Pollutants Simulated	Applicability for TMDL or LRS
Spreadsheet approaches/ Load duration curve	Steady State	River or lake	0- or 1-D	Low	DO, nutrients, algae, metals	Screening-level assessments
EUTROMOD	Steady State	Lake	0-D	Low	DO, nutrients, algae	Screening-level assessments
BATHTUB	Steady State	Lake	1-D	Moderate	DO, nutrients, algae	Screening-level assessments; can provide more refined assessments if supporting data exist
QUAL2E/ QUAL2K	Steady State	River	1-D	Moderate/ High	DO, nutrients, algae, bacteria	Low flow assessments of conventional pollutants
WASP7	Dynamic	River or lake	1-D to 3-D	High	DO, nutrients, metals, organics	Excellent water quality capability; simple hydraulics
CE-QUAL-RIV1	Dynamic	River	1-D	High	DO, nutrients, algae	Conventional pollutants in hydraulically complex rivers
HSPF	Dynamic	River or lake	1-D	High	DO, nutrients, metals, organics, bacteria	Wide range of capabilities, directly linked to watershed model
CE-QUAL-W2	Dynamic	Lake	2-D vertical	High	DO, nutrients, algae, metals	Conventional pollutants in stratified lakes
EFDC	Dynamic	River or lake	3-D	High	DO, nutrients, metals, organics, bacteria	Potentially applicable to all sites, if sufficient data exist

6.2.1 Spreadsheet Approaches

A wide range of simple methods are available to describe the relationship between pollutant loads and receiving water quality, for a variety of situations including rivers and lakes. Many such methods are documented in Mills et al. (1985). These approaches do not require specific computer software, and are designed to be implemented on a spreadsheet. These approaches have the benefit of relatively low data requirements, as well as being easy to apply. Because of their simplistic nature, these approaches are best considered as screening procedures. They provide good initial estimates of the primary cause-effect relationships.

The load duration curve approach is foremost among the spreadsheet approaches and is widely used for TMDL development. The approach uses measurements of stream flow and pollutant concentrations for the period of record to gain insight into the flow conditions under which exceedances of the water quality standard occur. A load-duration curve is developed by: 1) ranking the daily flow data from lowest to highest, calculating the percent of days these flows were exceeded, and graphing the results in what is called a flow duration curve; 2) translating the flow duration curve into a load duration curve by multiplying the flows by the water quality standard; and 3) plotting observed pollutant loads (measured concentrations times stream flow) on the same graph. Observed loads that fall above the load duration curve exceed the maximum allowable load, while those that fall on or below the line do not exceed the maximum allowable load. An analysis of the observed loads relative to the load duration curve provides information on whether the pollutant source is point or nonpoint in nature.

6.2.2 EUTROMOD

EUTROMOD is a spreadsheet-based modeling procedure for estimating phosphorus loading and associated lake trophic state variables, distributed by the North American Lake Management Society (Reckhow 1990). The modeling system first estimates phosphorus loads derived from watershed land uses or inflow data using approaches developed by Reckhow et al. (1980) and Reckhow and Simpson (1980). The model accounts for both point and nonpoint source loads. Statistical algorithms are based on regression analyses performed on cross-sectional lake data. These algorithms predict in-lake phosphorus, nitrogen, hypolimnetic dissolved oxygen, chlorophyll, and trihalomethane precursor concentrations, and transparency (Secchi depth). The model also estimates the likelihood of blue-green bacteria dominance in the lake. Lake morphometry and hydrologic characteristics are incorporated in these algorithms. EUTROMOD also has algorithms for estimating uncertainty associated with the trophic state variables and hydrologic variability and estimating the confidence interval about the most likely values for the various trophic state indicators.

6.2.3 BATHTUB

BATHTUB is a software program for estimating nutrient loading to lakes and reservoirs, summarizing information on in-lake water quality data, and predicting the lake/reservoir response to nutrient loading (Walker 1986). It was developed and is distributed by the U.S. Army Corps of Engineers. BATHTUB consists of three modules: FLUX, PROFILE, and BATHTUB (Walker 1986). The FLUX module estimates nutrient loads or fluxes to the lake/reservoir and provides five different algorithms for estimating these nutrient loads based on the correlation of concentration and flow. In addition, the potential errors in loading estimates are quantified. PROFILE is an analysis module that permits the user to display lake water quality data. PROFILE algorithms can be used to estimate hypolimnetic oxygen depletion rates, area-weighted or mixed layer average constituent concentrations, and similar trophic state indicators. BATHTUB is the module that predicts lake/reservoir responses to nutrient fluxes. Because reservoir ecosystems typically have different characteristics than many natural lakes, BATHTUB was developed to specifically account for some of these differences, including the effects of non-algal turbidity on transparency and algae responses to phosphorus.

BATHTUB contains a number of regression equations that have been calibrated using a wide range of lake and reservoir data sets. It can treat the lake or reservoir as a continuously stirred, mixed reactor, or it can predict longitudinal gradients in trophic state variables in a reservoir or narrow lake. These trophic state variables include in-lake total and ortho-phosphorus, organic nitrogen, hypolimnetic dissolved oxygen, metalimnetic dissolved oxygen, chlorophyll concentrations, and Secchi depth (transparency). Uncertainty estimates are provided with predicted trophic state variables. There are several options for estimating uncertainty based on the distribution of the input and in-lake data. Both tabular and graphical displays are available from the program.

6.2.4 QUAL2E/QUAL2K

QUAL2K is a one-dimensional water quality model that assumes steady-state flow, but allows simulation of diurnal variations in dissolved oxygen and temperature. It is supported by the U.S. EPA and simulates many state variables, including temperature, dissolved oxygen, biochemical oxygen demand, ammonia, nitrate, organic nitrogen, inorganic phosphorus, organic phosphorus, algae, and conservative and non-conservative substances. The predecessor to QUAL2K, called QUAL2E, is also available and has been successfully applied in the development of many Illinois TMDLs, but is no longer officially supported by EPA.

The primary advantages of using QUAL2K (and QUAL2E) include its widespread use and acceptance, and ability to simulate all of the conventional pollutants of concern. Its disadvantage is that it is restricted to one-dimensional, steady-state analyses.

6.2.5 WASP7

WASP7 is EPA's general-purpose surface water quality modeling system. It is also supported by the U.S. EPA. The model can be applied in one, two, or three dimensions and is designed for linkage with the hydrodynamic model DYNHYD5. WASP7 has also been successfully linked with other one, two, and three dimensional hydrodynamic models such as RIVMOD, RMA-2V and EFDC. WASP7 can also accept user-specified advective and dispersive flows. WASP7 provides separate submodels for conventional and toxic pollutants. The EUTRO7 submodel describes up to eight state variables in the water column and bed sediments: dissolved oxygen, biochemical oxygen demand, ammonia, nitrate, organic nitrogen, orthophosphate, organic phosphorus, and phytoplankton. The TOXI7 submodel simulates the transformation of up to three different chemicals and three different solids classes.

The primary advantage of using WASP7 is that it provides the flexibility to describe almost any water quality constituent of concern, along with its widespread use and acceptance. Its primary disadvantage is that it contains limited hydrodynamic capabilities and must often obtain hydrodynamic results from other models.

6.2.6 CE-QUAL-RIV1

CE-QUAL-RIV1 is a linked hydrodynamic-water quality model, supported by the U.S. Army Corps of Engineers Waterways Experiment Station (WES) in Vicksburg, Mississippi. Water quality state variables consist of temperature, dissolved oxygen, carbonaceous biochemical oxygen demand, ammonia, nitrate, organic nitrogen, orthophosphate, coliform bacteria, dissolved iron, and dissolved manganese. The effects of algae and macrophytes can also be included as external forcing functions specified by the user.

The primary advantage of CE-QUAL-RIV1 is its direct link to an efficient hydrodynamic model. This makes it especially suitable to describe river systems affected by dams or experiencing extremely rapid changes in flow. Its primary disadvantage is that it simulates conventional pollutants only, and contains limited eutrophication kinetics. In addition, the effort and data required to support the CE-QUAL-RIV1 hydrodynamic routines may not be necessary in naturally flowing rivers.

6.2.7 HSPF

HSPF is a one-dimensional modeling system for simulation not only of watershed hydrology and pollutant source loadings, but receiving water quality. It is also supported by the U.S. EPA. The water quality component of HSPF allows dynamic simulation of both conventional pollutants (i.e., dissolved oxygen, nutrients, and phytoplankton) and toxics. The toxics routines combine organic chemical process kinetics with sediment balance algorithms to predict dissolved and sorbed chemical concentrations in the upper sediment bed and overlying water column. HSPF is also linked into EPA's BASINS modeling system.

The primary advantage of HSPF is that it exists as part of a linked watershed/receiving water modeling package. Nonpoint source loading and hydrodynamic results are automatically linked to the HSPF water quality submodel, such that no external linkages need be developed.

6.2.8 CE-QUAL-W2

CE-QUAL-W2 is a linked hydrodynamic-water quality model, supported by the U.S. Army Corps of Engineers Waterways Experiment Station (WES) in Vicksburg, Mississippi. CE-QUAL-W2 simulates variations in water quality in the longitudinal and lateral directions, and was developed to address water quality issues in long, narrow reservoirs. Water quality state variables consist of temperature, algae, dissolved oxygen, carbonaceous biochemical oxygen demand, ammonia, nitrate, organic nitrogen, orthophosphate, coliform bacteria, and dissolved iron.

The primary advantage of CE-QUAL-W2 is the ability to simulate the onset and breakdown of vertical temperature stratification and resulting water quality impacts. It will be the most appropriate model for those cases where these vertical variations are an important water quality consideration. In unstratified systems, the effort and data required to support the CE-QUAL-W2 hydrodynamic routines may not be necessary.

6.2.9 EFDC

EFDC (Environmental Fluid Dynamics Code) is a three-dimensional hydrodynamic and water quality model supported by the U. S. EPA Ecosystems Research Division. EFDC simulates variations in water quality in the longitudinal, lateral and vertical directions, and was developed to address water quality issues in rivers, lakes, reservoirs, wetland systems, estuaries, and the coastal ocean. EFDC transports salinity, heat, cohesive or non-cohesive sediments, and toxic contaminants that can be described by equilibrium partitioning between the aqueous and solid phases. Unique features of EFDC are its ability to simulate wetting and drying cycles, and that it includes a near field mixing zone model that is fully coupled with a far-field transport of salinity, temperature, sediment, contaminant, and eutrophication variables. It also contains hydraulic structure representation, vegetative resistance, and Lagrangian particle tracking. EFDC accepts radiation stress fields from wave refraction-diffraction models, thus allowing the simulation of longshore currents and sediment transport.

The primary advantage of EFDC is the ability to combine three-dimensional hydrodynamic simulation with a wide range of water quality modeling capabilities in a single model. The primary disadvantages are that data needs and computational requirements can be extremely high.

6.3 Model Recommendations

This section recommends model approaches to developing the TMDLs and LRSs in the Upper Big Muddy watershed. Three factors are being considered when selecting an appropriate model for TMDL or development:

Management objectives: Management objectives define the specific purpose of the model, including the pollutant of concern, the water quality objective, the space and time scales of interest, and required level or precision/accuracy.

Available resources: The resources available to support the modeling effort include data, time, and level of modeling effort.

Site-specific characteristics: Site-specific characteristics include the land use activity in the watershed, type of water body (e.g. lake vs. stream), important transport and transformation processes, and environmental conditions.

Model selection must be balanced between competing demands. Management objectives typically call for a high degree of model reliability, although available resources are generally insufficient to provide the degree of reliability desired. Decisions are often required regarding whether to proceed with a higher-than-desired level of uncertainty, or to postpone modeling until additional resources can be obtained. There are no simple answers to these questions, and the decisions are often made using best professional judgment.

The required level of reliability for this modeling effort is one able to “support development of a credible TMDL” and “support development of a reasonable, assurable LRS.” The amount of reliability required to develop a credible TMDL depends also on the degree of implementation to be included in the TMDL. The approach to be taken here also considers the models’ ability to provide recommendations which correspond to the level of detail required to be eligible for 319 funding.

6.3.1 Big Muddy R. / IL_N-06

This stream segment requires a LRS for sedimentation/siltation. Recent land use and soils data are available for the 33,174-acre watershed area located immediately downstream of Rend Lake Dam. It is mostly rural, but about half of the City of Benton drains into IL_N-06. We recommend that one of the USLE-based techniques be used for developing the LRS for sedimentation/siltation. As an alternative method, possibly one with diminished stakeholder acceptance, Simple Method/UAL techniques could be used.

6.3.2 Big Muddy R. / IL_N-11

This stream segment requires TMDLs for sulfates and fecal coliform bacteria, and a LRS for sedimentation/siltation and TSS. The drainage area is much larger at this point as the Middle Fork Big Muddy, Willis Creek and Ewing Creek join the Big Muddy in this segment. There is a realtime stream gaging station in this segment as well (05597000 Big Muddy River at Plumfield, IL). We recommend that one of the USLE-based techniques be used for developing the LRS for sedimentation/siltation and TSS. Alternatively, Simple Method/UAL techniques could be used but may be met with diminished stakeholder acceptance.

6.3.3 Big Muddy R. / IL_N-17

This stream segment requires a TMDL for dissolved oxygen and a LRS for sedimentation/siltation and TSS. This segment is at the downstream end of the Upper Big Muddy watershed and will require substantial effort to integrate all upstream point and nonpoint sources for oxygen demanding materials as well as sediment loads. We recommend a 1-dimensional fate and transport model such as QUAL2E/QUAL2K or WASP7 for modeling dissolved oxygen and development of the TMDL for DO. We recommend that one of the USLE-based techniques for developing the LRS for sedimentation/siltation and TSS. Alternatively, Simple Method/UAL techniques may be used, but as indicated earlier, may be met with diminished stakeholder acceptance.

6.3.4 Hurricane Creek / IL_NF-01

Hurricane Creek, IL_NF-01, requires a LRS for sedimentation/siltation. The town of Herrin is in this watershed, as are three NPDES point sources. We recommend that one of the USLE-based techniques for developing the LRS for sedimentation/siltation. Alternatively, Simple Method/UAL techniques may be used but possibly with diminished stakeholder acceptance.

6.3.5 Prairie Cr. / IL_NZM-01

Prairie Creek, segment IL_NZM-01, is recommended for delisting due to the sulfate concentrations not exceeding the standard of 2,000 mg/L.

6.3.6 Andy Cr. / IL_NZN-13

Andy Cr. / IL_NZN-13 requires TMDLs for iron and dissolved oxygen. Practically the entire subwatershed has been mined (subterranean) for coal. There is a scarcity of water quality data for Andy Creek and tributaries; no data more recent than 2008 are available. We recommend QUAL2E/QUAL2K or WASP7 for modeling dissolved oxygen and development of the TMDL for DO. The model can be modified to include iron for development of that TMDL.

6.3.7 Herrin Old / IL_RNZD

Herrin Old Lake requires a TMDL for total phosphorus and a LRS for TSS. Unfortunately, there is a single phosphorus measurement in our database. Additional water quality data will be required to confirm impairment and to prepare a TMDL. We recommend that a spreadsheet approach, exemplified by EUTROMOD, be taken for development of the TMDL. We recommend that one of the USLE-based techniques be used for developing the LRS for TSS. Alternatively, Simple Method/UAL techniques could be used but may be met with diminished stakeholder acceptance.

6.3.8 Pond Cr. / IL_NG-02

Pond Cr. / IL_NG-02 requires TMDLs for chloride and dissolved oxygen and a LRS for sedimentation/siltation. Surface (strip) mining and underground mining has occurred (and underground mining continues) in this watershed. There are numerous NPDES discharges in the watershed, some are sanitary treatment facilities, but most are mine-related discharges. The water quality dataset is somewhat dated, with no data more recent than 2007. We recommend QUAL2E/QUAL2K or WASP7 for modeling dissolved oxygen and development of the TMDL for DO. We recommend a load duration curve approach to the chloride TMDL, but if it is determined that the data do not vary sufficiently over the range of reasonable hydrologic events, the DO model can be modified to include chloride. We recommend that one of the USLE-based techniques be used for developing the LRS for sedimentation/siltation. Alternatively, Simple Method/UAL techniques could be used but may be met with diminished stakeholder acceptance.

6.3.9 Lake Cr. / IL_NGA-02

Lake Cr. / IL_NGA-02 requires a TMDL for dissolved oxygen and a LRS for total phosphorus. Johnston City is located in this drainage area, and the town's wastewater treatment facility discharges to Lake Creek by Route 37, just south of town. Two impaired lakes (Johnston City, IL_RNZE and Arrowhead, IL_RNZX) and one impaired stream segment (Beaver Creek, IL_NGAZ-JC-D1) are tributary to Lake Creek as well. The two lakes require TMDLs for phosphorus as well. The water quality dataset is somewhat old; there are no data more recent than 2008. As with other streams with DO-impairments, we recommend QUAL2E/QUAL2K or WASP7 for modeling dissolved oxygen and development of the TMDL. The phosphorus LRS can be developed using the Simple Method/UAL techniques.

6.3.10 Beaver Cr. / IL_NGAZ-JC-D1

Beaver Cr. / IL_NGAZ-JC-D1 is a short (1.7 miles) stream segment requiring a TMDL for manganese. The stream is located just south of Johnston City. We have a single measurement of manganese from 2008. In our opinion, this is insufficient information for confirming impairment or for development of a TMDL. Additional data will be required for construction of a load duration curve and development of the TMDL.

6.3.11 Johnston City / IL_RNZE

Johnston City Lake / IL_RNZE is an impoundment of Lake Creek; it is just east of Freeman No. 4 Mine. The lake requires a TMDL for total phosphorus and a LRS for TSS. The most recent water quality data is from 2002. We recommend that a spreadsheet approach, as exemplified by EUTROMOD, be taken for development of the TMDL. We recommend that one of the USLE-based techniques be used for developing the LRS for TSS. Alternatively, Simple Method/UAL techniques could be used but may be met with diminished stakeholder acceptance.

6.3.12 Arrowhead (Williamson) / IL_RNZX

Arrowhead Lake (Williamson) / IL_RNZX is located just northeast of Johnston City, near Shakerag, IL. Arrowhead requires a TMDL for total phosphorus. We recommend that a spreadsheet approach, as exemplified by EUTROMOD, be taken for development of the TMDL.

6.3.13 M. Fk. Big Muddy / IL_NH-06

Middle Fork Big Muddy River/ IL_NH-06 is an impaired stream that requires TMDLs for fecal coliform bacteria and dissolved oxygen. The City of Benton in the west central portion of this watershed, but the City's wastewater treatment facility drains to segment IL_N-06. We recommend QUAL2E/QUAL2K or WASP7 for modeling dissolved oxygen and development of the TMDL in this segment, in conjunction with the upstream segment, IL_NH-07.

6.3.14 M. Fk. Big Muddy / IL_NH-07

Segment IL_NH-07 is the headwater of the Middle Fork Big Muddy River. IL_NH-07 is an impaired stream that requires a TMDL for dissolved oxygen and a LRS for sedimentation/siltation. We recommend the TMDL be developed in conjunction with the downstream segment IL_NH-06 using QUAL2E/QUAL2K or WASP7. We recommend that one of the USLE-based techniques be used for developing the LRS for TSS. Alternatively, Simple Method/UAL techniques could be used but may be met with diminished stakeholder acceptance.

6.3.15 West Frankfort Old / IL_RNP

West Frankfort Old / IL_RNP requires a TMDL for total phosphorus and a LRS for TSS. The most recent water quality data is from 2011. We recommend that a spreadsheet approach, as exemplified by EUTROMOD, be taken for development of the TMDL. We recommend that one of the USLE-based techniques be used for developing the LRS for TSS. Alternatively, Simple Method/UAL techniques could be used but may be met with diminished stakeholder acceptance.

6.3.16 West Frankfort New/ IL_RNQ

West Frankfort New/ IL_RNQ requires a TMDL for total phosphorus and a LRS for TSS. The most recent water quality data is from 2011. We recommend that a spreadsheet approach, as exemplified by EUTROMOD, be taken for development of the TMDL. We recommend that one of the USLE-based techniques be used for developing the LRS for TSS. Alternatively, Simple Method/UAL techniques could be used but may be met with diminished stakeholder acceptance.

Table 19. Summary of Recommendations for Developing TMDLs in Upper Big Muddy Watershed

Waterbody	Cause of Impairment	Approach	Lake or Watershed Area/Stream Length
Big Muddy R. IL_N-06	Sedimentation/siltation	Simple Method/UAL	34,111 acre watershed
Big Muddy R. IL_N-11	Sulfates	Load duration curve	192,432 watershed acres
	Fecal coliform bacteria	Load duration curve	
	Sedimentation/siltation, TSS	Simple Method/UAL	
Big Muddy R. / IL_N-17	Dissolved oxygen	QUAL2E/QUAL2K or WASP7	21.47 stream miles
	Sedimentation/siltation, TSS	Simple Method/UAL	
Hurricane Creek / IL_NF-01	Sedimentation/siltation	Simple Method/UAL	14,981 watershed acres
Prairie Cr. / IL_NZM-01	Sufate	Delist	
Andy Cr. / IL_NZN-13	Iron	Load duration curve	13,054 watershed acres
	Dissolved oxygen	QUAL2E/QUAL2K or WASP7	11.68 stream miles
Herrin Old / IL_RNZD	Total phosphorus	Lake response model (spreadsheet approach)	51 lake acres
	TSS	Simple Method/UAL	1,609 watershed acres
Pond Cr. / IL_NG-02	Dissolved oxygen	QUAL2E/QUAL2K or WASP7	23.5 stream miles
	Chloride	Load duration curve	63,927 watershed acres
	Sedimentation/siltation	Simple Method/UAL	
Lake Cr. / IL_NGA-02	Total phosphorus	Simple Method/UAL	21,785 watershed acres
	Dissolved oxygen	QUAL2E/QUAL2K or WASP7	12.3 stream miles
Beaver Cr. / IL_NGAZ-JC-D1	Manganese	Load duration curve	394 watershed acres
Johnston City / IL_RNZE	Total phosphorus	Lake response model (spreadsheet approach)	64 lake acres
	TSS	Simple Method/UAL	2,408 watershed acres
Arrowhead (Williamson) / IL_RNZX	Total phosphorus	Lake response model (spreadsheet approach)	481 watershed acres
M. Fk. Big Muddy / IL_NH-06	Fecal coliform bacteria	Load duration curve	102,792 watershed acres
	Dissolved oxygen	QUAL2E/QUAL2K or WASP7	12.5 stream miles
M. Fk. Big Muddy / IL_NH-07	Dissolved oxygen	QUAL2E/QUAL2K or WASP7	19.7 stream miles
	Sedimentation/siltation	Simple Method/UAL	68,690 watershed acres
West Frankfort Old / IL_RNP	Total phosphorus	Lake response model (spreadsheet approach)	146 lake acres
	TSS	Simple Method/UAL	2,461 watershed acres
West Frankfort New/ IL_RNQ	Total phosphorus	Lake response model (spreadsheet approach)	214 lake acres
	TSS	Simple Method/UAL	4,959 watershed acres

7 Data Collection to Support Modeling

Additional data are required to support development of the TMDLs in the Upper Big Muddy watershed. Physical and chemical data are required for model development, calibration and verification.

7.1 Water Quality Data Collection

Table 20 provides the details for recommended Stage 2 water quality sampling for the Upper Big Muddy TMDLs. There are five types of sampling sites:

1. Legacy (IEPA) monitoring sites
2. Effluents of wastewater treatment plants
3. Stream quality sites intended to characterize other loads or pollutant assimilation
4. Discretionary sites that might be utilized in conjunction with, or, in lieu of one or more stream quality sites

Data on biochemical oxygen demand (BOD), sediment oxygen demand (SOD), water temperature, dissolved oxygen, manganese, iron, chloride, nitrogen, phosphorus, and fecal coliform bacteria are recommended to be collected during Stage 2.

7.1.1 BOD Data

Dissolved oxygen models require, among other parameters, estimates of biochemical oxygen demand (BOD). BOD is an indicator of the concentrations of organic waste and microorganisms in a sample of water. Because microorganisms require oxygen for respiration, their numbers, and thus the concentration of dead organic matter metabolized by the bacteria, can be gaged by measuring the consumption of oxygen. A standardized measure of BOD, performed in a controlled environment, is used in many water quality models to estimate removal of DO in the system.

The IEPA does not always collect BOD data during their stream assessment efforts. And hence, there are limited estimates of BOD in streams in the available dataset. BOD data are available for many of the wastewater treatment plant effluent loads and the Discharge Monitoring Reports containing those data are available.

Stream BOD measurements should be made during low flow periods, when the DO deficits typically occur.

7.1.2 SOD Data

SOD, or sediment oxygen demand, is the sum of biological and chemical processes in sediment that utilize oxygen, or that distinct portion of oxygen removal that occurs benthically, by sediment respiration. Field measurement of SOD involves confining sediment and overlying water and measuring the depletion of dissolved oxygen over time. A single measurement of SOD is recommended, and together with literature values of SOD and the QUAL2K SOD subroutine, we can develop reasonable estimates of SOD rates in the Big Muddy River system.

7.1.3 Dissolved Oxygen and Temperature

Dissolved oxygen (DO) and water temperature are also required for development and verification of the QUAL2K model. These measures can be collected fairly rapidly at numerous locations using field meters. These measurements should be made during summer, when low flow and high temperatures can lead to high DO deficits in streams. Depending on the specific flow and temperature conditions present during the actual field data collection, a diurnal DO survey can also be included in Stage 2. A diurnal, around the clock, DO survey would provide data on nighttime DO minima (worse-case conditions) and daytime maxima and insight into aquatic respiration and nutrient assimilation in the stream.

7.1.4 Nitrogen, Phosphorus

Ammonia oxidation can be a significant sink for DO in streams receiving treated wastewater effluent. Therefore, we have included measurements of ammonia nitrogen and nitrate+nitrite nitrogen in the field data collection plan. This information will improve the calibration of the QUAL2K model. However, collection of nitrate+nitrite nitrogen data is optional, and left to the discretion of the Agency.

Total phosphorus TMDLs are required for all five listed lakes; four of these lakes have insufficient data for development of the TMDLs.

7.1.5 Fecal Coliform Bacteria, Iron, Manganese, Chloride

Use of the load duration analysis for development of TMDLs requires additional concentration measurements of fecal coliform bacteria, iron, manganese and chloride. Multiple measurements should be made over a range of hydrologic conditions. For planning purposes, we recommend at least five sampling events at each station. Additional data on fecal coliform bacteria will also refine assumptions regarding source assessments and improve the confidence for the TMDL and the implementation plan.

7.2 Hydraulic Data Collection

Additional hydraulic and geomorphologic data collection is necessary to build and calibrate the QUAL2 models. Field data that need to be assembled include the following characteristics (at selected locations):

- Channel roughness
- Channel bottom width and side slopes
- Average depth
- Slope, velocity and/or time of travel
- Discharge

7.3 Summary of Stage 2 Activities

Table 20 summarizes our recommendations for filling data gaps necessary for development of the TMDLs and LRSs. A boat will be required for the lower portions of the Big Muddy River due to its depth.

Collecting data for prepare those TMDLs using the load duration approach are useful only if collected over a range of hydrologic conditions (low flow, base flow, high flow). This is not always possible during a field season because of the unpredictability of droughts and floods.

Table 20. Summary of Stage 2 Recommendations

Waterbody	Cause of Impairment	Data Collection Recommendation	Notes
Big Muddy R. IL_N-06	Sedimentation/siltation	none	
Big Muddy R. IL_N-11	Sulfates	none	Willis Creek (NZX-CH-C3), Big Muddy (N-11), Mid Fk Big Muddy (NH-28), Ewing Cr (NHB-34), other locations
	Fecal coliform bacteria	Fecal coliform concentration	
	Sedimentation/siltation, TSS	none	
Big Muddy R. / IL_N-17	Dissolved oxygen	Hydraulic data, DO, temp, BOD, SOD, NH3-N	21.47 stream miles, hydraulic survey, water quality at Big Muddy (N-17, N-18, N-19) plus tributaries and point sources
	Sedimentation/siltation, TSS	TSS	TSS in Big Muddy R (N-17, N-18, N-19) plus tributaries
Hurricane Creek / IL_NF-01	Sedimentation/siltation	none	14,981 watershed acres
Andy Cr. / IL_NZN-13	Iron	Iron concentrations	Andy Cr (NZN-13) over a range of hydrologic conditions
	Dissolved oxygen	Hydraulic data, DO, temp, BOD, SOD, NH3-N	11.68 stream miles, hydraulic survey, water quality at NZN-13, NZNZ-12, confl Andy Cr w/ Big Muddy R
Herrin Old / IL_RNZD	Total phosphorus	TP concentrations	RNZD-1, RNZD-2, RNZD-3 during summer stratification
	TSS	none	
Pond Cr. / IL_NG-02	Dissolved oxygen	Hydraulic data, DO, temp, BOD, SOD, NH3-N	23.5 stream miles, hydraulic survey, water quality at NG-01, NG-03, NG-02, NGA-01, NG-05
	Chloride	Cl concentrations	Water quality over a range of hydrologic conditions at NG-02, NG-05
	Sedimentation/siltation	none	
Lake Cr. / IL_NGA-02	Total phosphorus	none	
	Dissolved oxygen	Hydraulic data, DO, temp, BOD, SOD, NH3-N	12.3 stream miles, hydraulic survey, water quality at NGA_01, NGA-02, NGAZ-JC-D1, d/s STP outfall
Beaver Cr. / IL_NGAZ-JC-D1	Manganese	Mn concentrations	NGAZ-JC-D1 over a range of hydrologic conditions
Johnston City / IL_RNZE	Total phosphorus	TP concentrations	RNZE-1, RNZE-2, RNZE-3 during summer stratification
	TSS	none	
Arrowhead (Williamson) / IL_RNZX	Total phosphorus	none	
M. Fk. Big Muddy / IL_NH-06	Fecal coliform bacteria	Fecal coliform concentrations	NH-06 over a range of hydrologic conditions
	Dissolved oxygen	Hydraulic data, DO, temp, BOD, SOD, NH3-N	12.5 stream miles, hydraulic survey, water quality at NH-08, NH-21, NH-07
M. Fk. Big Muddy / IL_NH-07	Dissolved oxygen	Hydraulic data, DO, temp, BOD, SOD, NH3-N	19.7 stream miles, hydraulic survey, water quality at NH-23, NH-24, NH-06

Waterbody	Cause of Impairment	Data Collection Recommendation	Notes
	Sedimentation/siltation	none	
West Frankfort Old / IL_RNP	Total phosphorus	TP concentrations	RNP-1, RNP-2, RNP-3 during summer stratification
	TSS	none	
West Frankfort New/ IL_RNQ	Total phosphorus	TP concentrations	RNQ-1, RNQ-2, RNQ-3 during summer stratification
	TSS	none	

8 References

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Appendix A. Data Sources and Local Contacts

Table A-1. Data sources

Data description	Agency	Source
Climate summaries	Illinois State Water Survey	http://www.sws.uiuc.edu/atmos/statecli/index.htm
Daily hydrology data	US Geological Survey	http://waterdata.usgs.gov/nwis/
Soils data	USDA Natural Resources Conservation Service	http://soildatamart.nrcs.usda.gov/
Mines (shapefiles)	Illinois State Geological Survey	http://www.isgs.uiuc.edu/maps-data-pub/coal-maps/shapefiles/
Sample stations -- statewide	Illinois Environmental Protection Agency	Email from staff
Lake polygons -- statewide	Illinois Environmental Protection Agency	Email from staff
Location points from wells and borings database	Illinois Natural Resources Geospatial Data Clearinghouse	http://www.isgs.uiuc.edu/nsdihome/webdocs/st-geolb.html
Assessed streams and lakes (shapefiles)	Illinois Environmental Protection Agency	Email from staff
Revised cropland data layer (CDL)	Illinois Natural Resources Geospatial Data Clearinghouse	http://www.isgs.uiuc.edu/nsdihome/webdocs/landcover/nass07.html
Livestock census	National Agricultural Statistics Service, US Department of Agriculture	http://www.nass.usda.gov/Data_and_Statistics/index.asp
NPDES data	Illinois EPA	Provided to LTI via e-mail

Table A-2. State and Local Contacts

Contact	Agency/Organization	Phone/e-mail	Subject
Margaret Fertaly	Illinois EPA	(618) 993-7200	Introduction, watershed visit, project management
Diane Wallace, Chris Mitchell	NRCS - Benton	(618) 438-4021	Introduction, watershed discussions
Rhonda Cox, Scott Martin, Linda Presler	NRCS/SWCD - Murphysboro	(618) 684-3064	Introduction, watershed discussions
Mindy Scott	NRCS - Marion	(618) 993-5396	Introduction, watershed discussions
David Muir	Illinois EPA	(618) 993-7200	303(d) listing methodologies, pollutant data
Joe Stitely	Illinois EPA	(618) 993-7200	CAFOs
Sarah Seelbach	Illinois EPA		Public participation
Abel Haile	Illinois EPA		TMDL program management

Appendix B. Climate and Water Quality Data

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1913	1	8.17	14	1.56
1913	2	1.2	7	0.69
1913	3	9.7	12	5.22
1913	4	2.99	12	0.85
1913	5	2.42	6	0.87
1913	6	1.23	7	0.42
1913	7	1.79	4	0.9
1913	8	2.74	4	1.23
1913	9	3.88	8	1
1913	10	4.76	11	1.49
1913	11	3.35	10	1.2
1913	12	1.27	6	0.36
1913	Total	43.5	101	5.22
1913	Winter	10.04	27	1.56
1913	Spring	15.11	30	5.22
1913	Summer	5.76	15	1.23
1913	Fall	11.99	29	1.49
1914	1	2.46	5	0.6
1914	2	3.54	8	1.04
1914	3	3.37	8	1.41
1914	4	1.66	9	0.67
1914	5	0.47	3	0.22
1914	6	1.81	5	0.81
1914	7	0.22	2	0.12
1914	8	5.06	10	1.5
1914	9	4.47	9	1.55
1914	10	4.05	6	1.23
1914	11	0.55	2	0.3
1914	12	3.27	13	0.95
1914	Total	30.93	80	1.55
1914	Winter	7.27	19	1.04
1914	Spring	5.5	20	1.41
1914	Summer	7.09	17	1.5
1914	Fall	9.07	17	1.55
1915	1	4.74	9	1.8
1915	2	2.39	8	0.76
1915	3	0.31	5	0.24
1915	4	0.51	3	0.35
1915	5	8.03	12	2.68
1915	6	5.55	11	2.04
1915	7	4	13	0.95
1915	8	8.44	12	2.7
1915	9	2.79	7	1.04
1915	10	0.76	3	0.5
1915	11	2.21	3	1.06
1915	12	5.55	10	1.38
1915	Total	45.28	96	2.7

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1915	Winter	10.4	30	1.8
1915	Spring	8.85	20	2.68
1915	Summer	17.99	36	2.7
1915	Fall	5.76	13	1.06
1916	1	9.36	15	2.6
1916	2	1.38	7	0.56
1916	3	1.86	8	0.48
1916	4	1.28	6	0.64
1916	5	3.9	13	1.21
1916	6	6.97	11	1.87
1916	7	4.06	5	1.2
1916	8	7.02	9	2.17
1916	9	2.71	4	1.19
1916	10	2.6	7	0.62
1916	11	1.63	4	0.83
1916	12	2.63	8	1.35
1916	Total	45.4	97	2.6
1916	Winter	16.29	32	2.6
1916	Spring	7.04	27	1.21
1916	Summer	18.05	25	2.17
1916	Fall	6.94	15	1.19
1917	1	5.21	9	2.15
1917	2	0.51	5	0.15
1917	3	1.8	9	0.7
1917	4	5.83	9	2.24
1917	5	3.95	9	1
1917	6	3.17	8	1.12
1917	7	3.19	5	2.35
1917	8	2.38	5	1.55
1917	9	0.57	4	0.35
1917	10	2.28	6	1.2
1917	11	2.06	4	0.95
1917	12		9	0.99
1917	Total	30.95	73	2.35
1917	Winter	8.43	23	2.15
1917	Spring	11.58	27	2.24
1917	Summer	8.74	18	2.35
1917	Fall	4.91	14	1.2
1918	1	0.95	7	0.36
1918	2	0.75	3	0.6
1918	3	0.79	4	0.48
1918	4	6.63	8	1.5
1918	5	5.62	7	2.83
1918	6	1.3	5	0.6
1918	7	0.31	1	0.31
1918	8	4.9	8	1.27
1918	9	2.28	4	1.56

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1918	10	2.47	7	0.75
1918	11	3.03	5	0.86
1918	12	5.21	8	2.72
1918	Total	34.24	67	2.83
1918	Winter		10	0.6
1918	Spring	13.04	19	2.83
1918	Summer	6.51	14	1.27
1918	Fall	7.78	16	1.56
1919	1	0	0	0
1919	2	1.34	6	0.46
1919	3	3.62	8	1.13
1919	4	4.84	8	1.15
1919	5	4.93	12	1.09
1919	6	5.04	11	1.47
1919	7	0.6	3	0.45
1919	8	3.32	6	1.1
1919	9	1.43	5	0.77
1919	10	11.26	12	3.52
1919	11	4.53	6	1.47
1919	12	1.08	3	0.97
1919	Total	41.99	80	3.52
1919	Winter	6.55	14	2.72
1919	Spring	13.39	28	1.15
1919	Summer	8.96	20	1.47
1919	Fall	17.22	23	3.52
1920	1	2.82	8	1.4
1920	2	0	0	0
1920	3	4.63	10	0.81
1920	4	2.49	11	0.74
1920	5	6.62	14	1.22
1920	6	0.79	2	0.71
1920	7	2.82	6	1.12
1920	8	1.7	9	0.6
1920	9	1.57	4	0.97
1920	10	2.42	4	1.26
1920	11	1.36	6	0.45
1920	12	4.1	6	1.84
1920	Total	31.32	80	1.84
1920	Winter	3.9	11	1.4
1920	Spring	13.74	35	1.22
1920	Summer	5.31	17	1.12
1920	Fall	5.35	14	1.26
1921	1	1.98	10	0.66
1921	2	1.64	7	0.58
1921	3	4.35	10	1.76
1921	4	4.1	11	1.3
1921	5	1.87	6	0.69

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1921	6	1.92	8	0.46
1921	7	2.04	6	0.8
1921	8	5.95	9	1.19
1921	9	7.81	10	2
1921	10	1	8	0.24
1921	11	6.6	8	2.65
1921	12	3.55	8	0.88
1921	Total	42.81	101	2.65
1921	Winter	7.72	23	1.84
1921	Spring	10.32	27	1.76
1921	Summer	9.91	23	1.19
1921	Fall	15.41	26	2.65
1922	1	1.15	7	0.38
1922	2	1.98	4	1.09
1922	3	9.64	14	2.01
1922	4	4.53	8	0.88
1922	5	1.86	8	0.45
1922	6	1.09	4	0.69
1922	7	1.39	6	0.48
1922	8	1.96	6	1.2
1922	9	0.28	2	0.16
1922	10	2.88	8	1
1922	11	1.77	6	0.65
1922	12	7.76	8	4.7
1922	Total	36.29	81	4.7
1922	Winter	6.68	19	1.09
1922	Spring	16.03	30	2.01
1922	Summer	4.44	16	1.2
1922	Fall	4.93	16	1
1923	1	2.5	11	0.66
1923	2	3.61	6	1.05
1923	3	0	0	0
1923	4	2.28	5	0.98
1923	5	6.86	10	3.6
1923	6	3.37	10	1.79
1923	7	2.09	4	0.96
1923	8	7.2	7	2.2
1923	9	4.96	9	1.1
1923	10	3.64	6	2.3
1923	11	2.48	7	1.16
1923	12	5.31	15	1.18
1923	Total	44.3	90	3.6
1923	Winter	13.87	25	4.7
1923	Spring	0	15	3.6
1923	Summer	12.66	21	2.2
1923	Fall	11.08	22	2.3
1924	1	1.71	7	0.82

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1924	2	1.14	9	0.48
1924	3	2.08	8	0.6
1924	4	2.79	9	1.8
1924	5	4.55	12	0.86
1924	6	10.15	9	3.91
1924	7	2.81	9	0.68
1924	8	1.46	5	0.51
1924	9	2.94	9	1.52
1924	10	0.19	1	0.19
1924	11	1.41	5	0.61
1924	12	3.24	9	1.8
1924	Total	34.47	92	3.91
1924	Winter	8.16	31	1.18
1924	Spring	9.42	29	1.8
1924	Summer	14.42	23	3.91
1924	Fall	4.54	15	1.52
1925	1	1.26	5	0.56
1925	2	1.27	6	0.44
1925	3	2.14	6	0.76
1925	4	2.66	8	1.14
1925	5	2.48	4	1.05
1925	6	4.23	6	1.84
1925	7	0.75	4	0.39
1925	8	1.55	2	1.53
1925	9	7.07	12	1.24
1925	10	6.29	16	2.6
1925	11	4.23	7	1.74
1925	12	1.27	4	1.19
1925	Total	35.2	80	2.6
1925	Winter	5.91	21	1.8
1925	Spring	7.28	18	1.14
1925	Summer	6.53	12	1.84
1925	Fall	17.59	35	2.6
1926	1	1.87	6	0.7
1926	2	2.6	6	1
1926	3	2.74	7	0.82
1926	4	2.61	8	0.86
1926	5	0.86	3	0.56
1926	6	1.01	3	0.68
1926	7	1.32	7	0.56
1926	8	5.83	7	1.47
1926	9	4.77	10	2.15
1926	10	6.36	8	2.14
1926	11	3.96	8	1.7
1926	12	1.96	9	0.52
1926	Total	35.89	82	2.15
1926	Winter	5.74	16	1.19

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1926	Spring	6.21	18	0.86
1926	Summer	8.16	17	1.47
1926	Fall	15.09	26	2.15
1927	1	5.87	10	1.35
1927	2	0.74	5	0.22
1927	3	6.26	10	2.14
1927	4	10.44	17	2
1927	5	7.55	12	1.35
1927	6	4.29	8	2.9
1927	7	3.49	7	1.66
1927	8	2.06	2	1.68
1927	9	4.14	4	2.04
1927	10	2.33	4	1.66
1927	11	0	0	0
1927	12	5.38	8	3.44
1927	Total	52.55	87	3.44
1927	Winter	8.57	24	1.35
1927	Spring	24.25	39	2.14
1927	Summer	9.84	17	2.9
1927	Fall	0	8	2.04
1928	1	1.6	7	0.54
1928	2	2.35	8	1.08
1928	3	1.33	4	0.77
1928	4	2.87	4	1.5
1928	5	1.46	6	0.44
1928	6	9.79	14	2
1928	7	3.01	3	1.74
1928	8	5.97	7	1.97
1928	9	0.58	2	0.5
1928	10	5.64	5	1.8
1928	11	3.5	12	0.94
1928	12	2.58	6	0.98
1928	Total	40.68	78	2
1928	Winter	9.15	22	3.44
1928	Spring	5.66	14	1.5
1928	Summer	18.77	24	2
1928	Fall	9.72	19	1.8
1929	1	5.42	12	2
1929	2	2.45	8	1.46
1929	3	2.36	8	0.84
1929	4	3.43	12	1.5
1929	5	7.08	16	1.09
1929	6	5.02	9	1.13
1929	7	2.52	13	0.95
1929	8	2.49	6	1.02
1929	9	4.27	11	1.22
1929	10	1.88	9	0.48

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1929	11	2.44	11	1.4
1929	12	5.04	10	1.37
1929	Total	44.4	125	2
1929	Winter	10.45	26	2
1929	Spring	12.87	36	1.5
1929	Summer	10.03	28	1.13
1929	Fall	8.59	31	1.4
1930	1		12	2.13
1930	2	3.78	7	1.25
1930	3	1.89	8	0.58
1930	4	1.12	8	0.6
1930	5	1.4	10	0.72
1930	6	1.53	8	0.52
1930	7	0.49	4	0.29
1930	8	0.23	4	0.2
1930	9	6.3	10	1.74
1930	10	1.74	7	0.65
1930	11	1.64	10	0.52
1930	12	1.2	6	0.71
1930	Total	28.78	94	2.13
1930	Winter	16.28	29	2.13
1930	Spring	4.41	26	0.72
1930	Summer	2.25	16	0.52
1930	Fall	9.68	27	1.74
1931	1	0.77	6	0.3
1931	2	1.85	9	0.83
1931	3	2.88	7	1.73
1931	4	3.42	9	1.59
1931	5	4.28	13	1.04
1931	6	1.91	4	1.09
1931	7	2.27	7	0.79
1931	8	5.73	15	1.15
1931	9	6.26	6	4.57
1931	10	2.98	6	0.96
1931	11	6.31	11	2.24
1931	12	4.73	11	2.38
1931	Total	43.39	104	4.57
1931	Winter	3.82	21	0.83
1931	Spring	10.58	29	1.73
1931	Summer	9.91	26	1.15
1931	Fall	15.55	23	4.57
1932	1	4.92	11	1.22
1932	2	1.16	8	0.4
1932	3	2.78	10	1.24
1932	4	0	0	0
1932	5	1.74	5	0.82
1932	6	2.41	9	0.53

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1932	7	3.03	8	1.2
1932	8	4.39	11	1.14
1932	9	5.49	5	3.6
1932	10	4.37	7	2.26
1932	11	2.39	9	0.85
1932	12	6.12	8	2.3
1932	Total	38.8	91	3.6
1932	Winter	10.81	30	2.38
1932	Spring		15	1.24
1932	Summer	9.83	28	1.2
1932	Fall	12.25	21	3.6
1933	1	3.1	7	1.31
1933	2	1.52	10	0.4
1933	3	3.75	13	0.9
1933	4	3.18	7	1.04
1933	5	9.34	15	2
1933	6	0.54	6	0.16
1933	7	4.96	4	2.42
1933	8	2.13	6	0.91
1933	9	1.1	5	0.55
1933	10	2.91	8	1.03
1933	11	0.76	6	0.3
1933	12	1.98	8	0.78
1933	Total	35.27	95	2.42
1933	Winter	10.74	25	2.3
1933	Spring	16.27	35	2
1933	Summer	7.63	16	2.42
1933	Fall	4.77	19	1.03
1934	1	1.38	6	0.88
1934	2	0	0	0
1934	3	3.65	9	1.62
1934	4	3.07	9	1.34
1934	5	3.57	8	2.69
1934	6	1.92	9	1.12
1934	7	2.95	8	1.3
1934	8		4	2.53
1934	9	8.45	16	1.2
1934	10	1.28	4	0.96
1934	11	7.75	9	3.9
1934	12	2.04	9	0.9
1934	Total	39.23	91	3.9
1934	Winter	3.36	14	0.88
1934	Spring	10.29	26	2.69
1934	Summer	8.04	21	2.53
1934	Fall	17.48	29	3.9
1935	1	3.32	6	1.23
1935	2	0.75	4	0.31

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1935	3	8.23	15	3.9
1935	4	3.42	8	0.69
1935	5	5.46	9	1.2
1935	6	5.5	12	1.13
1935	7	1.03	7	0.49
1935	8	2.63	6	0.9
1935	9	1.87	4	0.7
1935	10	3.14	10	1.39
1935	11	3.98	11	1.25
1935	12	1.29	7	0.67
1935	Total	40.62	99	3.9
1935	Winter	6.11	19	1.23
1935	Spring	17.11	32	3.9
1935	Summer	9.16	25	1.13
1935	Fall	8.99	25	1.39
1936	1	0.9	4	0.62
1936	2	1.66	10	0.63
1936	3	1.63	7	0.85
1936	4	2.82	6	1.13
1936	5	1.08	5	0.34
1936	6	2.66	5	0.91
1936	7	0.27	3	0.2
1936	8	0.08	1	0.08
1936	9	2.89	8	1.66
1936	10	5.4	9	1.75
1936	11	3.77	2	3.75
1936	12	3.37	8	1.38
1936	Total	26.53	68	3.75
1936	Winter	3.85	21	0.67
1936	Spring	5.53	18	1.13
1936	Summer	3.01	9	0.91
1936	Fall	12.06	19	3.75
1937	1	11.91	14	4.2
1937	2	1.77	8	0.71
1937	3	1.03	4	0.46
1937	4	5.3	15	1.15
1937	5	3.13	9	1.33
1937	6	4.23	9	1.2
1937	7	1.77	5	0.77
1937	8	1	4	0.55
1937	9	4.12	5	1.93
1937	10	4.77	8	1.6
1937	11	1.63	5	0.58
1937	12	2.63	9	1.03
1937	Total	43.29	95	4.2
1937	Winter	17.05	30	4.2
1937	Spring	9.46	28	1.33

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1937	Summer	7	18	1.2
1937	Fall	10.52	18	1.93
1938	1	2.4	7	0.8
1938	2	3.16	9	1.03
1938	3	4.88	14	1.12
1938	4	1.83	4	0.79
1938	5	5.86	9	3.24
1938	6	4.22	12	2.27
1938	7	3.51	9	1.36
1938	8	2.75	7	0.95
1938	9	2.3	6	1.4
1938	10	0.67	3	0.54
1938	11	2.8	7	0.91
1938	12	1.73	6	0.95
1938	Total	36.11	93	3.24
1938	Winter	8.19	25	1.03
1938	Spring	12.57	27	3.24
1938	Summer	10.48	28	2.27
1938	Fall	5.77	16	1.4
1939	1	4.99	8	1.97
1939	2	3.73	13	0.8
1939	3	4.3	4	2.25
1939	4	5.94	10	1.67
1939	5	2.36	10	0.54
1939	6	5.15	10	1.48
1939	7	3.84	9	1.32
1939	8	2.92	7	1.27
1939	9	2.2	6	1.45
1939	10	1.14	5	0.5
1939	11	1.68	3	0.66
1939	12	2.03	5	0.68
1939	Total	40.28	90	2.25
1939	Winter	10.45	27	1.97
1939	Spring	12.6	24	2.25
1939	Summer	11.91	26	1.48
1939	Fall	5.02	14	1.45
1940	1	1.31	5	0.8
1940	2	4.21	10	1.16
1940	3	1.37	9	0.3
1940	4	6.03	9	2.03
1940	5	3.66	8	2.13
1940	6	0.93	6	0.4
1940	7	2.24	4	1.81
1940	8	1.45	6	0.45
1940	9	0.74	3	0.43
1940	10	0.26	2	0.14
1940	11	3.09	8	0.99

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1940	12	2.37	10	1
1940	Total	27.66	80	2.13
1940	Winter	7.55	20	1.16
1940	Spring	11.06	26	2.13
1940	Summer	4.62	16	1.81
1940	Fall	4.09	13	0.99
1941	1	2.33	9	0.98
1941	2	0.78	4	0.6
1941	3	1.15	4	0.49
1941	4			
1941	5	2.97	7	1.27
1941	6	4.03	10	2.2
1941	7	1.97	7	0.8
1941	8	2.59	6	1.51
1941	9	2.96	10	1.54
1941	10	10.11	12	2.8
1941	11	2.37	7	1.05
1941	12	2.9	5	1.44
1941	Total	34.16	81	2.8
1941	Winter	5.48	23	1
1941	Spring		11	1.27
1941	Summer	8.59	23	2.2
1941	Fall	15.44	29	2.8
1942	1	2.45	7	0.92
1942	2	3.64	12	0.91
1942	3	3.42	8	1.32
1942	4	2.18	6	1.3
1942	5	3.93	6	1.17
1942	6	4.77	13	1.47
1942	7	3.8	6	2.75
1942	8	3.88	8	1.51
1942	9	1.08	3	0.77
1942	10	2.23	3	1.79
1942	11	4.19	10	1.1
1942	12	1.74	6	0.5
1942	Total	37.31	88	2.75
1942	Winter	8.99	24	1.44
1942	Spring	9.53	20	1.32
1942	Summer	12.45	27	2.75
1942	Fall	7.5	16	1.79
1943	1	0.45	2	0.36
1943	2	0.97	4	0.58
1943	3	2.98	8	1.6
1943	4	3.23	8	1.17
1943	5	7.9	15	1.98
1943	6	5.25	11	1.16
1943	7	2.09	5	1.75

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1943	8	2.26	5	1.21
1943	9	6.24	9	2.92
1943	10	2.03	5	1.24
1943	11	1.78	5	1.15
1943	12	1.88	6	0.55
1943	Total	37.06	83	2.92
1943	Winter	3.16	12	0.58
1943	Spring	14.11	31	1.98
1943	Summer	9.6	21	1.75
1943	Fall	10.05	19	2.92
1944	1	0.48	4	0.19
1944	2	2.81	9	0.9
1944	3	3.26	12	0.62
1944	4	4.97	10	1.2
1944	5	3.45	14	0.67
1944	6	0.96	3	0.6
1944	7	1.99	4	0.97
1944	8	8.78	10	2.6
1944	9	1.09	7	0.63
1944	10	1.08	2	1.05
1944	11	1.26	7	0.34
1944	12	1.97	11	0.61
1944	Total	32.1	93	2.6
1944	Winter	4.99	18	0.9
1944	Spring	11.68	36	1.2
1944	Summer	11.73	17	2.6
1944	Fall	3.43	16	1.05
1945	1	1.39	13	0.35
1945	2	6.43	9	3.8
1945	3	11.36	15	1.83
1945	4	8.41	14	2.95
1945	5	4.67	17	1.22
1945	6	9.97	15	1.42
1945	7	1.21	6	0.61
1945	8	7.31	9	4.3
1945	9	7.81	14	2.3
1945	10	2.56	7	1.24
1945	11	3.14	6	1.14
1945	12	1.52	7	0.56
1945	Total	65.78	132	4.3
1945	Winter	9.79	33	3.8
1945	Spring	24.44	46	2.95
1945	Summer	18.49	30	4.3
1945	Fall	13.51	27	2.3
1946	1	2.63	7	1.06
1946	2	3.93	8	2.27
1946	3	1.03	8	0.38

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1946	4	3.11	7	0.73
1946	5	8.89	15	2.15
1946	6	1.77	7	0.6
1946	7	2.86	10	1.12
1946	8	15.8	9	5.08
1946	9	1.93	5	1.09
1946	10	2.21	5	0.75
1946	11	4	11	0.96
1946	12	2.53	7	0.85
1946	Total	50.69	99	5.08
1946	Winter	8.08	22	2.27
1946	Spring	13.03	30	2.15
1946	Summer	20.43	26	5.08
1946	Fall	8.14	21	1.09
1947	1	2.06	10	0.7
1947	2	0.21	6	0.09
1947	3	2.72	11	0.95
1947	4	7.66	13	2
1947	5	3.89	13	0.86
1947	6	3.7	10	0.66
1947	7	2.74	5	1.23
1947	8	2.77	7	0.63
1947	9	3.43	6	1.3
1947	10	4.55	7	1.9
1947	11	2.84	14	0.8
1947	12	3.9	5	2.67
1947	Total	40.47	107	2.67
1947	Winter	4.8	23	0.85
1947	Spring	14.27	37	2
1947	Summer	9.21	22	1.23
1947	Fall	10.82	27	1.9
1948	1	1.84	5	0.78
1948	2	2.92	13	0.54
1948	3	3.14	11	0.73
1948	4	2.08	3	0.75
1948	5	3.41	11	0.99
1948	6	3.25	10	0.98
1948	7	8.13	12	1.65
1948	8	2.16	7	1.2
1948	9	3.4	5	1.48
1948	10	3.03	7	1.9
1948	11	6.74	11	1.62
1948	12	2.52	7	0.65
1948	Total	42.62	102	1.9
1948	Winter	8.66	23	2.67
1948	Spring	8.63	25	0.99
1948	Summer	13.54	29	1.65

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1948	Fall	13.17	23	1.9
1949	1	11.24	13	3.88
1949	2	2.7	5	1.38
1949	3	7.65	12	2.34
1949	4	1.57	3	1.28
1949	5	2.73	6	1.72
1949	6	3.01	8	1.35
1949	7	1.2	9	0.65
1949	8	0.96	7	0.3
1949	9	5.35	5	2
1949	10	8.05	7	1.7
1949	11	0.57	2	0.55
1949	12	5.04	10	1.4
1949	Total	50.07	87	3.88
1949	Winter	16.46	25	3.88
1949	Spring	11.95	21	2.34
1949	Summer	5.17	24	1.35
1949	Fall	13.97	14	2
1950	1	12.69	10	2.52
1950	2	4.84	9	1.2
1950	3	3.97	9	2.15
1950	4	6.75	9	2.8
1950	5	4.07	9	2
1950	6	2.6	5	1.4
1950	7	2.96	8	1.34
1950	8	6.87	12	2
1950	9	3.99	10	1.25
1950	10	0.64	4	0.35
1950	11	3.68	10	0.95
1950	12	1.92	6	1.02
1950	Total	54.98	101	2.8
1950	Winter	22.57	29	2.52
1950	Spring	14.79	27	2.8
1950	Summer	12.43	25	2
1950	Fall	8.31	24	1.25
1951	1	5.33	10	1.55
1951	2	4.77	11	1.7
1951	3	3.5	9	1.4
1951	4	2.46	9	0.95
1951	5	1.14	7	0.4
1951	6	5.78	14	1.13
1951	7	3.33	9	0.98
1951	8	2.38	4	1.02
1951	9	4.22	8	2.03
1951	10	4.51	7	2.03
1951	11	4.02	8	1.6
1951	12	3.13	9	0.85

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1951	Total	44.57	105	2.03
1951	Winter	12.02	27	1.7
1951	Spring	7.1	25	1.4
1951	Summer	11.49	27	1.13
1951	Fall	12.75	23	2.03
1952	1	1.95	7	0.65
1952	2	2.26	9	0.65
1952	3	5.68	10	1.73
1952	4	4.12	9	1.45
1952	5	1.88	10	0.55
1952	6	4.82	5	1.9
1952	7	4.47	7	2.3
1952	8	1.71	5	0.82
1952	9	3.64	5	1.6
1952	10	1.3	3	0.8
1952	11	4.21	6	1.6
1952	12	2.31	7	1.2
1952	Total	38.35	83	2.3
1952	Winter	7.3	24	0.85
1952	Spring	11.68	29	1.73
1952	Summer	11	17	2.3
1952	Fall	9.15	14	1.6
1953	1	2.92	10	1.4
1953	2	0.91	5	0.43
1953	3	6	10	2.75
1953	4	4.01	11	0.73
1953	5	3.16	11	0.75
1953	6	1.26	6	0.65
1953	7	2.51	4	0.95
1953	8	1.17	4	0.45
1953	9	0.15	3	0.09
1953	10	1.4	3	0.8
1953	11	0.61	3	0.51
1953	12	0.72	4	0.35
1953	Total	24.82	74	2.75
1953	Winter	6.59	23	1.4
1953	Spring	13.17	32	2.75
1953	Summer	4.94	14	0.95
1953	Fall	2.16	9	0.8
1954	1	3.22	7	1.36
1954	2	2.41	5	1.8
1954	3	0.77	6	0.42
1954	4	1.84	8	0.6
1954	5	3.9	11	1.9
1954	6	2.47	6	0.6
1954	7	1.59	6	0.8
1954	8	4.17	11	0.72

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1954	9	3.41	7	2.24
1954	10	2.61	9	0.62
1954	11	1.15	5	0.7
1954	12	6	10	1.62
1954	Total	33.54	91	2.24
1954	Winter	6.35	16	1.8
1954	Spring	6.51	25	1.9
1954	Summer	8.23	23	0.8
1954	Fall	7.17	21	2.24
1955	1	0.84	6	0.36
1955	2	3.23	8	0.97
1955	3	4.96	12	2.38
1955	4	2.67	9	0.84
1955	5	4.88	10	1.35
1955	6	5.58	12	1.55
1955	7	2.37	6	0.82
1955	8	1.64	4	1.1
1955	9	2.97	6	1.57
1955	10	3.57	10	1.3
1955	11	3.01	6	1.2
1955	12	0.42	6	0.12
1955	Total	36.14	95	2.38
1955	Winter	10.07	24	1.62
1955	Spring	12.51	31	2.38
1955	Summer	9.59	22	1.55
1955	Fall	9.55	22	1.57
1956	1	1.74	7	0.67
1956	2	5.46	13	1.1
1956	3	2.52	7	1.43
1956	4	3.94	13	1.02
1956	5	3.06	7	1.11
1956	6	2.4	8	1.17
1956	7	4.83	10	1.17
1956	8	4.75	8	1.48
1956	9	1.8	6	0.54
1956	10	1.8	4	0.85
1956	11	2.73	6	1.02
1956	12	2.65	10	0.8
1956	Total	37.68	99	1.48
1956	Winter	7.62	26	1.1
1956	Spring	9.52	27	1.43
1956	Summer	11.98	26	1.48
1956	Fall	6.33	16	1.02
1957	1	3.04	10	1.57
1957	2	3.59	12	1.23
1957	3	3.1	8	1.5
1957	4	10.22	16	4

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1957	5	7.36	12	2
1957	6	3.95	15	1.32
1957	7	4.49	11	0.76
1957	8	2.47	7	1.3
1957	9	3.19	8	1.12
1957	10	1.92	5	0.8
1957	11	6.44	8	1.6
1957	12	6.96	15	2.2
1957	Total	56.73	127	4
1957	Winter	9.28	32	1.57
1957	Spring	20.68	36	4
1957	Summer	10.91	33	1.32
1957	Fall	11.55	21	1.6
1958	1	3.09	6	1.15
1958	2	0.79	6	0.37
1958	3	3.57	9	1.3
1958	4	3.99	11	0.98
1958	5	3.18	13	0.76
1958	6	5.44	10	1.25
1958	7	10.81	17	2.75
1958	8	2.65	8	1.2
1958	9	3.07	10	1.25
1958	10	0.46	4	0.28
1958	11	5.32	12	1.9
1958	12	0.84	6	0.47
1958	Total	43.21	112	2.75
1958	Winter	10.84	27	2.2
1958	Spring	10.74	33	1.3
1958	Summer	18.9	35	2.75
1958	Fall	8.85	26	1.9
1959	1	3.94	7	1.25
1959	2	2.43	9	0.74
1959	3	2.83	7	0.86
1959	4	1.56	7	0.55
1959	5	3.85	10	0.81
1959	6	0.85	6	0.3
1959	7	0.74	6	0.26
1959	8	10.99	6	8.19
1959	9	4.96	7	1.92
1959	10	2.43	9	0.85
1959	11	1.79	8	0.8
1959	12	4.31	10	1.57
1959	Total	40.68	92	8.19
1959	Winter	7.21	22	1.25
1959	Spring	8.24	24	0.86
1959	Summer	12.58	18	8.19
1959	Fall	9.18	24	1.92

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1960	1	2.46	9	1.47
1960	2	1.9	8	0.67
1960	3	2.48	10	1
1960	4	2.59	8	0.73
1960	5	3.44	12	0.88
1960	6	6.05	9	2.67
1960	7	2.02	7	1.44
1960	8	2.04	8	0.6
1960	9	0.17	2	0.14
1960	10	1.85	9	1.01
1960	11	4.26	9	1.17
1960	12	3.01	6	0.97
1960	Total	32.27	97	2.67
1960	Winter	8.67	27	1.57
1960	Spring	8.51	30	1
1960	Summer	10.11	24	2.67
1960	Fall	6.28	20	1.17
1961	1	1.13	7	0.3
1961	2	2.98	9	0.6
1961	3	6.58	15	2.63
1961	4	3.91	11	0.88
1961	5			
1961	6			
1961	7	3.72	13	0.88
1961	8	3.84	6	1.12
1961	9	2.73	4	2.06
1961	10	1.13	5	0.72
1961	11	5.47	9	2.05
1961	12	4.93	13	1.17
1961	Total	36.42	92	2.63
1961	Winter	7.12	22	0.97
1961	Spring		26	2.63
1961	Summer		19	1.12
1961	Fall	9.33	18	2.06
1962	1	4.94	11	2.36
1962	2	4.44	11	1.18
1962	3	4.31	10	1.2
1962	4	2.68	11	0.78
1962	5	5.23	10	1.25
1962	6	2.42	11	0.66
1962	7	2.54	7	1.1
1962	8	5.21	10	2.58
1962	9	2.99	9	0.95
1962	10	7.5	11	2.42
1962	11	1.06	5	0.35
1962	12	3.18	8	1.65
1962	Total	46.5	114	2.58

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1962	Winter	14.31	35	2.36
1962	Spring	12.22	31	1.25
1962	Summer	10.17	28	2.58
1962	Fall	11.55	25	2.42
1963	1	0.61	7	0.21
1963	2	0.32	3	0.21
1963	3	7.31	12	1.6
1963	4	1.26	6	0.57
1963	5	3.43	7	0.87
1963	6			
1963	7	2.74	5	1.15
1963	8	1.59	5	0.5
1963	9	0.36	3	0.16
1963	10	0.41	3	0.28
1963	11	3.28	8	1.25
1963	12			
1963	Total	21.31	59	1.6
1963	Winter	4.11	18	1.65
1963	Spring	12	25	1.6
1963	Summer		10	1.15
1963	Fall	4.05	14	1.25
1964	1	1.51	6	0.81
1964	2	2.48	7	1.04
1964	3	8.73	8	3.28
1964	4	5.86	16	1.28
1964	5	2.66	7	0.95
1964	6	2.06	10	0.76
1964	7	2.81	8	0.91
1964	8	2.15	4	1.5
1964	9	3.7	6	1.35
1964	10	0.04	1	0.04
1964	11	2.71	7	1.71
1964	12	2.47	8	1.01
1964	Total	37.18	88	3.28
1964	Winter		13	1.04
1964	Spring	17.25	31	3.28
1964	Summer	7.02	22	1.5
1964	Fall	6.45	14	1.71
1965	1	3.39	10	0.78
1965	2	4.89	7	1.8
1965	3	2.3	10	0.57
1965	4			
1965	5	1.77	6	0.75
1965	6	3.36	10	0.83
1965	7			
1965	8	4.2	8	1.19
1965	9	6.41	9	2.27

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1965	10	2.32	6	1.36
1965	11	0.5	4	0.35
1965	12	1.2	5	0.8
1965	Total	30.34	75	2.27
1965	Winter	10.75	25	1.8
1965	Spring		16	0.75
1965	Summer		18	1.19
1965	Fall	9.23	19	2.27
1966	1	3.13	7	2.03
1966	2	3.45	11	1.01
1966	3	1	8	0.3
1966	4	7.25	15	1.66
1966	5	5.73	10	1.53
1966	6	1.56	6	0.51
1966	7	0.91	5	0.47
1966	8	3.15	9	0.76
1966	9	3.48	5	1.69
1966	10	1.73	6	0.67
1966	11	3.06	6	1.75
1966	12	5.37	9	1.57
1966	Total	39.82	97	2.03
1966	Winter	7.78	23	2.03
1966	Spring	13.98	33	1.66
1966	Summer	5.62	20	0.76
1966	Fall	8.27	17	1.75
1967	1	1.49	3	0.63
1967	2	2.44	6	0.91
1967	3	2.47	7	1.03
1967	4	3.43	11	1.31
1967	5	3.34	9	1.36
1967	6	4.27	7	1.82
1967	7	4.53	8	1.01
1967	8	2.8	4	1.8
1967	9	2.27	8	0.77
1967	10	9.56	10	4.81
1967	11	2.83	8	1.52
1967	12	5.67	15	0.95
1967	Total	45.1	96	4.81
1967	Winter	9.3	18	1.57
1967	Spring	9.24	27	1.36
1967	Summer	11.6	19	1.82
1967	Fall	14.66	26	4.81
1968	1	2.67	8	1.15
1968	2	0.98	3	0.88
1968	3	5.04	8	1.51
1968	4	6.76	9	1.58
1968	5	5.02	11	1.7

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1968	6	2.26	6	1.05
1968	7	2.52	5	1.48
1968	8	3.55	6	1.2
1968	9	2.29	6	0.87
1968	10	1.27	4	0.65
1968	11	5.85	11	1.85
1968	12	4.65	10	1
1968	Total	42.86	87	1.85
1968	Winter	9.32	26	1.15
1968	Spring	16.82	28	1.7
1968	Summer	8.33	17	1.48
1968	Fall	9.41	21	1.85
1969	1	7.15	12	2.05
1969	2	1.67	7	0.8
1969	3	2.18	6	1.18
1969	4	4.64	8	1.45
1969	5	3.26	8	1.3
1969	6	9	9	2.25
1969	7	9.82	14	2.55
1969	8	0.18	3	0.08
1969	9	4.91	9	1.8
1969	10	4.31	7	1.57
1969	11	2.64	7	0.75
1969	12	3.67	10	1.1
1969	Total	53.43	100	2.55
1969	Winter	13.75	30	2.05
1969	Spring	10.08	22	1.45
1969	Summer	19	26	2.55
1969	Fall	11.86	23	1.8
1970	1	0.98	5	0.56
1970	2	2.02	6	0.49
1970	3	4.14	14	1.17
1970	4	4.96	8	1.54
1970	5	2.8	5	1.04
1970	6	11.07	11	3.18
1970	7	3.39	6	2.84
1970	8	1.68	7	0.68
1970	9	3.78	11	0.96
1970	10	3.55	11	0.9
1970	11	1.7	7	0.44
1970	12	2.18	10	0.73
1970	Total	42.25	101	3.18
1970	Winter	6.67	21	1.1
1970	Spring	11.9	27	1.54
1970	Summer	16.14	24	3.18
1970	Fall	9.03	29	0.96
1971	1	3.05	7	1.52

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1971	2	5.7	13	2.15
1971	3	1.35	7	0.39
1971	4	3.33	7	1.37
1971	5	5.6	10	1.62
1971	6	1.79	5	0.85
1971	7	2.07	5	0.72
1971	8	1.95	4	1.37
1971	9	1.3	4	0.68
1971	10	0.92	4	0.57
1971	11	1.32	8	0.35
1971	12	3.59	13	0.78
1971	Total	31.97	87	2.15
1971	Winter	10.93	30	2.15
1971	Spring	10.28	24	1.62
1971	Summer	5.81	14	1.37
1971	Fall	3.54	16	0.68
1972	1	1.8	9	0.52
1972	2	2.91	13	0.78
1972	3	3.98	9	0.89
1972	4	6.38	16	1.12
1972	5	0.91	4	0.55
1972	6	1.39	5	0.91
1972	7	4.5	9	1.93
1972	8	6.97	8	2.1
1972	9	2.31	10	0.42
1972	10	2.41	9	1.3
1972	11	6.91	15	1.74
1972	12	3.9	14	0.8
1972	Total	44.37	121	2.1
1972	Winter	8.3	35	0.78
1972	Spring	11.27	29	1.12
1972	Summer	12.86	22	2.1
1972	Fall	11.63	34	1.74
1973	1	3.23	8	0.86
1973	2	1.35	8	0.47
1973	3	7.44	18	2.25
1973	4	6.02	18	1.83
1973	5	5.23	15	1.23
1973	6	4.56	11	2
1973	7	3.94	9	1.76
1973	8	3.77	6	2.27
1973	9	1.92	8	0.52
1973	10	4.17	8	2.33
1973	11	7.72	12	2.36
1973	12	4.99	13	1.28
1973	Total	54.34	134	2.36
1973	Winter	8.48	30	0.86

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1973	Spring	18.69	51	2.25
1973	Summer	12.27	26	2.27
1973	Fall	13.81	28	2.36
1974	1	3.79	12	0.68
1974	2	1.95	9	0.77
1974	3	4.52	10	1
1974	4	4.24	9	1.33
1974	5	6.26	10	2.25
1974	6	3.38	12	0.82
1974	7	0.94	6	0.2
1974	8	4.59	10	2.07
1974	9	6.19	10	2.15
1974	10	1.65	5	1.09
1974	11	4.62	14	2.21
1974	12	3.3	13	0.66
1974	Total	45.43	120	2.25
1974	Winter	10.73	34	1.28
1974	Spring	15.02	29	2.25
1974	Summer	8.91	28	2.07
1974	Fall	12.46	29	2.21
1975	1	4.52	13	1.5
1975	2	4.06	13	1.93
1975	3	7.34	13	1.47
1975	4	6.42	11	2.26
1975	5	3.4	9	0.87
1975	6	3.14	11	0.68
1975	7	1.8	8	1.15
1975	8	7.53	13	2.31
1975	9	1.71	5	0.78
1975	10	2.32	7	0.86
1975	11	3.6	10	1.38
1975	12	6.17	10	1.3
1975	Total	52.01	123	2.31
1975	Winter	11.88	39	1.93
1975	Spring	17.16	33	2.26
1975	Summer	12.47	32	2.31
1975	Fall	7.63	22	1.38
1976	1	1.31	11	0.35
1976	2	1.92	5	0.79
1976	3	3.14	9	0.91
1976	4	1.65	8	1.05
1976	5	3.07	9	1.25
1976	6	4.67	12	1.45
1976	7	4.2	9	1.31
1976	8	0.26	2	0.2
1976	9	2.94	5	1.77
1976	10	3.46	7	1.54

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1976	11	0.57	1	0.57
1976	12	1.04	4	0.38
1976	Total	28.23	82	1.77
1976	Winter	9.4	26	1.3
1976	Spring	7.86	26	1.25
1976	Summer	9.13	23	1.45
1976	Fall	6.97	13	1.77
1977	1	1.16	7	0.51
1977	2	2.37	6	1.37
1977	3	7.61	10	3.37
1977	4	2.29	12	0.66
1977	5	1.33	8	0.52
1977	6	3.54	11	0.9
1977	7	2.28	9	0.73
1977	8	7.95	10	2.46
1977	9	4.92	7	2.8
1977	10	1.91	10	1
1977	11	2.96	13	1.32
1977	12	4.75	9	1.55
1977	Total	43.07	112	3.37
1977	Winter	4.69	18	1.37
1977	Spring	11.23	30	3.37
1977	Summer	13.77	30	2.46
1977	Fall	9.79	30	2.8
1978	1	1.85	9	0.82
1978	2	1	4	0.51
1978	3	5.03	12	1.51
1978	4	3.38	12	1.5
1978	5	4.01	13	1.17
1978	6	2.25	7	1.27
1978	7	2.35	8	0.98
1978	8	4.23	8	2.85
1978	9	0.84	2	0.72
1978	10	2.39	9	1.29
1978	11	4.93	8	1.31
1978	12	4.78	10	1.17
1978	Total	37.04	102	2.85
1978	Winter	7.6	22	1.55
1978	Spring	12.42	37	1.51
1978	Summer	8.83	23	2.85
1978	Fall	8.16	19	1.31
1979	1	3.59	14	1.18
1979	2			
1979	3	5.67	13	1.12
1979	4	7.68	16	1.39
1979	5	3.64	10	1.18
1979	6	3	7	1.08

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1979	7	3.84	10	1.84
1979	8	3.01	5	1.78
1979	9	0.8	2	0.57
1979	10	1.55	6	0.93
1979	11	5.79	6	1.96
1979	12	1.63	5	0.6
1979	Total	40.2	94	1.96
1979	Winter		24	1.18
1979	Spring	16.99	39	1.39
1979	Summer	9.85	22	1.84
1979	Fall	8.14	14	1.96
1980	1	1.45	7	0.85
1980	2	1.44	9	0.45
1980	3	4.91	15	1.2
1980	4	2.14	12	0.75
1980	5	3.05	8	1.15
1980	6	2.21	6	0.58
1980	7	5.8	6	2.63
1980	8	2.96	8	0.74
1980	9	4.04	4	1.56
1980	10	2.59	7	1.5
1980	11	3.1	5	1.5
1980	12	0.89	2	0.88
1980	Total	34.58	89	2.63
1980	Winter	4.52	21	0.85
1980	Spring	10.1	35	1.2
1980	Summer	10.97	20	2.63
1980	Fall	9.73	16	1.56
1981	1	0.33	4	0.24
1981	2	1.05	3	0.75
1981	3	1.88	7	0.7
1981	4	2.34	8	1.5
1981	5	10.16	14	1.33
1981	6	5.2	9	2.42
1981	7	7.01	14	1.16
1981	8	1.99	6	1.32
1981	9	2.08	4	1.3
1981	10	2.29	7	0.61
1981	11	1.77	7	0.43
1981	12	2.65	7	0.83
1981	Total	38.75	90	2.42
1981	Winter	2.37	10	0.88
1981	Spring	14.38	29	1.5
1981	Summer	14.2	29	2.42
1981	Fall	6.14	18	1.3
1982	1	7.07	8	2.95
1982	2	2.17	9	0.52

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1982	3	3.36	10	1.11
1982	4	2.44	9	1.16
1982	5	4.65	9	1.8
1982	6	3.61	11	1.27
1982	7	1.78	6	0.65
1982	8	1.2	6	0.72
1982	9	4.72	8	1.03
1982	10	1.85	6	0.58
1982	11	2.78	7	0.82
1982	12	11.94	10	3.95
1982	Total	47.57	99	3.95
1982	Winter	11.89	24	2.95
1982	Spring	10.45	28	1.8
1982	Summer	6.59	23	1.27
1982	Fall	9.35	21	1.03
1983	1	0.9	6	0.43
1983	2	1.36	5	1.15
1983	3	3.83	13	1
1983	4	10.18	16	3.7
1983	5	9.23	11	2.7
1983	6	4.49	6	2.22
1983	7	1.73	2	1.7
1983	8	2.68	3	2.57
1983	9	1.57	5	0.77
1983	10	8.44	10	1.95
1983	11	6.34	9	1.83
1983	12	3.57	8	1.05
1983	Total	54.32	94	3.7
1983	Winter	14.2	21	3.95
1983	Spring	23.24	40	3.7
1983	Summer	8.9	11	2.57
1983	Fall	16.35	24	1.95
1984	1	1.16	7	0.52
1984	2	2.87	10	1.11
1984	3	5.03	15	1.06
1984	4	4.31	11	1.65
1984	5	4.01	12	0.95
1984	6	2.07	4	1.07
1984	7	1.23	2	1.2
1984	8	2.73	6	1.81
1984	9	5.48	6	2.72
1984	10	8.4	18	2.42
1984	11	6.23	9	1.8
1984	12	4.67	11	1.1
1984	Total	48.19	111	2.72
1984	Winter	7.52	24	1.11
1984	Spring	13.35	38	1.65

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1984	Summer	6.03	12	1.81
1984	Fall	20.11	33	2.72
1985	1	1.59	7	0.68
1985	2	3.8	10	1.45
1985	3	6.32	14	2.3
1985	4			
1985	5	5.52	11	1.76
1985	6	4.76	14	1.17
1985	7	1.11	4	0.58
1985	8	6.7	12	1.5
1985	9	0.59	3	0.22
1985	10	6.66	12	2.35
1985	11	10.08	17	2.04
1985	12	1.31	4	0.9
1985	Total	48.44	108	2.35
1985	Winter	10.09	29	1.45
1985	Spring		25	2.3
1985	Summer	12.57	30	1.5
1985	Fall	17.33	32	2.35
1986	1	0.64	3	0.55
1986	2	3.56	13	0.75
1986	3	3.06	7	1.33
1986	4			
1986	5	5.03	8	1.62
1986	6	0.7	4	0.57
1986	7	7.35	7	2.65
1986	8	3.99	11	1.25
1986	9	5.01	9	2.75
1986	10	2.67	9	1.01
1986	11	2.67	7	1.23
1986	12	2.79	4	1.08
1986	Total	37.47	82	2.75
1986	Winter	5.51	20	0.9
1986	Spring		15	1.62
1986	Summer	12.04	22	2.65
1986	Fall	10.35	25	2.75
1987	1	1.09	7	0.45
1987	2	2.75	6	0.62
1987	3	2.13	9	0.85
1987	4	1.82	6	1.07
1987	5	1.2	5	0.52
1987	6	2.03	5	1.05
1987	7	5.76	7	1.95
1987	8	1.31	4	0.72
1987	9	1.2	2	0.6
1987	10	1.64	6	0.95
1987	11	4.45	9	0.91

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1987	12	6.14	10	1.8
1987	Total	31.52	76	1.95
1987	Winter	6.63	17	1.08
1987	Spring	5.15	20	1.07
1987	Summer	9.1	16	1.95
1987	Fall	7.29	17	0.95
1988	1	2.05	5	1.04
1988	2	2.6	9	1.1
1988	3	5.37	10	1.73
1988	4	1.69	5	0.87
1988	5	2.01	6	0.77
1988	6	1.31	3	0.82
1988	7	7.01	8	4.25
1988	8	0.53	3	0.4
1988	9	5.11	7	2.4
1988	10	3.18	9	0.97
1988	11	6.52	9	1.1
1988	12	1.99	4	1.6
1988	Total	39.37	78	4.25
1988	Winter	10.79	24	1.8
1988	Spring	9.07	21	1.73
1988	Summer	8.85	14	4.25
1988	Fall	14.81	25	2.4
1989	1	4.66	7	2.25
1989	2	6.59	7	2.35
1989	3	7.9	9	2.45
1989	4	1.73	6	0.55
1989	5	3.97	7	1.05
1989	6	6.99	9	2.05
1989	7	0.96	7	0.32
1989	8	2.91	9	0.82
1989	9	1.6	3	0.92
1989	10	1.19	4	0.4
1989	11	1.27	5	0.39
1989	12	1.17	3	0.68
1989	Total	40.94	76	2.45
1989	Winter	13.24	18	2.35
1989	Spring	13.6	22	2.45
1989	Summer	10.86	25	2.05
1989	Fall	4.06	12	0.92
1990	1	4.85	5	3.3
1990	2	4.72	10	1.52
1990	3	2.37	10	0.48
1990	4	4.36	10	1.48
1990	5	9.01	14	2.67
1990	6	3.68	9	1.31
1990	7	2.28	5	1.25

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1990	8	2.35	5	0.75
1990	9			
1990	10	4.51	7	1.82
1990	11	4.93	7	1.75
1990	12		3	0.83
1990	Total	44.44	85	3.3
1990	Winter	10.74	18	3.3
1990	Spring	15.74	34	2.67
1990	Summer	8.31	19	1.31
1990	Fall		14	1.82
1991	1	2.38	6	1.12
1991	2	2.37	8	0.97
1991	3	4.19	9	1.11
1991	4	3.84	11	1.27
1991	5	2.54	14	0.65
1991	6	1.32	4	0.75
1991	7	0.56	3	0.37
1991	8	2.1	8	0.72
1991	9	2.78	6	1.05
1991	10	5.08	11	1.3
1991	11	5.15	8	3.96
1991	12	3.47	9	1.11
1991	Total	35.78	97	3.96
1991	Winter	6.13	17	1.12
1991	Spring	10.57	34	1.27
1991	Summer	3.98	15	0.75
1991	Fall	13.01	25	3.96
1992	1	1.94	7	0.49
1992	2	1.25	4	0.65
1992	3	2.93	11	1.23
1992	4	1.65	5	0.62
1992	5	3.28	10	1.37
1992	6	2.79	6	2.35
1992	7	3.02	8	1.84
1992	8	1.87	3	1.08
1992	9	4.23	10	1.41
1992	10	0.91	3	0.71
1992	11	6.21	17	1.56
1992	12	1.69	10	0.43
1992	Total	31.77	94	2.35
1992	Winter	6.66	20	1.11
1992	Spring	7.86	26	1.37
1992	Summer	7.68	17	2.35
1992	Fall	11.35	30	1.56
1993	1	5.25	11	2.29
1993	2	1.29	3	0.62
1993	3	2.23	8	0.49

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1993	4	5.04	13	1.05
1993	5	4.72	12	1.59
1993	6	3.73	9	1.08
1993	7	4.9	9	1.35
1993	8	3.1	7	1.1
1993	9	8.85	8	2.04
1993	10	2.69	8	1.25
1993	11	12.46	4	9.3
1993	12	1.79	7	0.82
1993	Total	56.05	99	9.3
1993	Winter	8.23	24	2.29
1993	Spring	11.99	33	1.59
1993	Summer	11.73	25	1.35
1993	Fall	24	20	9.3
1994	1	4.59	6	1.88
1994	2		2	0.8
1994	3	2.09	8	0.89
1994	4	8.01	11	2.41
1994	5	1.76	3	0.66
1994	6	5.1	7	2.94
1994	7		2	1.17
1994	8	1.08	2	1.02
1994	9	1.83	2	1.03
1994	10	2.93	5	1.63
1994	11	6.91	8	2.17
1994	12		3	1.63
1994	Total	39.83	59	2.94
1994	Winter	7.74	15	1.88
1994	Spring	11.86	22	2.41
1994	Summer		11	2.94
1994	Fall	11.67	15	2.17
1995	1	3.1	4	1.5
1995	2	2.94	3	1.04
1995	3	4.25	5	2.87
1995	4	2.88	7	0.82
1995	5	12.26	13	4.37
1995	6	5.5	11	1.29
1995	7	0.92	6	0.26
1995	8	2.17	3	1.51
1995	9	1	4	0.41
1995	10	1.82	5	0.65
1995	11	2.7	3	2.14
1995	12	0.11	2	0.08
1995	Total	39.65	66	4.37
1995	Winter	7.93	10	1.63
1995	Spring	19.39	25	4.37
1995	Summer	8.59	20	1.51

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1995	Fall	5.52	12	2.14
1996	1		8	0.95
1996	2	0.73	4	0.42
1996	3	2.65	5	0.82
1996	4	13.94	6	8.77
1996	5	5.3	6	1.98
1996	6	9.08	8	2.72
1996	7	2.01	5	1.21
1996	8	0.12	1	0.12
1996	9	4.12	5	2.52
1996	10	2.16	3	0.82
1996	11	2.17	4	1.38
1996	12		4	1.27
1996	Total	48.3	59	8.77
1996	Winter	3.62	14	0.95
1996	Spring	21.89	17	8.77
1996	Summer	11.21	14	2.72
1996	Fall	8.45	12	2.52
1997	1	4.62	11	0.86
1997	2	2.7	5	1.29
1997	3	4.98	8	1.28
1997	4	3.31	4	1.69
1997	5		3	2.47
1997	6	9.68	9	3.05
1997	7	1.86	2	1.2
1997	8	3.21	5	1.57
1997	9	0.72	2	0.68
1997	10		2	1.16
1997	11	2.35	4	0.93
1997	12	3.52	3	1.87
1997	Total	43.24	58	3.05
1997	Winter	10.56	20	1.29
1997	Spring	12.4	15	2.47
1997	Summer	14.75	16	3.05
1997	Fall	5.25	8	1.16
1998	1	4	1	4
1998	2	4.09	7	1.14
1998	3	4.09	5	1.58
1998	4	8.55	9	3.95
1998	5	3.53	6	1.25
1998	6	9.46	8	3.22
1998	7	3.88	5	1.93
1998	8	1.2	3	0.65
1998	9	2.73	4	1.55
1998	10	3.77	3	2.44
1998	11	1.49	3	0.59
1998	12	2.93	3	1.82

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
1998	Total	49.72	57	4
1998	Winter	11.61	11	4
1998	Spring	16.17	20	3.95
1998	Summer	14.54	16	3.22
1998	Fall	7.99	10	2.44
1999	1	6.1	6	2.82
1999	2	5.14	5	1.85
1999	3	2.25	3	1.57
1999	4	6.29	8	3.17
1999	5	4.67	5	2.06
1999	6		5	0.71
1999	7	3.45	3	1.88
1999	8	1.58	2	1.56
1999	9	0.5	4	0.39
1999	10	2.01	3	1.22
1999	11	0.88	1	0.88
1999	12	4.15	4	2.43
1999	Total	38.54	49	3.17
1999	Winter	14.17	14	2.82
1999	Spring	13.21	16	3.17
1999	Summer	6.55	10	1.88
1999	Fall	3.39	8	1.22
2000	1	1.99	4	0.69
2000	2	4.32	4	1.76
2000	3	3.5	5	1.55
2000	4	2.89	5	1.19
2000	5	4.12	7	1.25
2000	6	8.79	7	5.95
2000	7	4.97	5	1.94
2000	8	5.15	8	1.65
2000	9	2.96	5	1.46
2000	10	0.42	2	0.21
2000	11	4.4	6	1.55
2000	12	3.01	5	1.21
2000	Total	46.52	63	5.95
2000	Winter	10.46	12	2.43
2000	Spring	10.51	17	1.55
2000	Summer	18.91	20	5.95
2000	Fall	7.78	13	1.55
2001	1	0.88	3	0.72
2001	2	3.15	6	1.08
2001	3	1.12	6	0.42
2001	4	1.79	2	1.68
2001	5	4.87	8	1.55
2001	6	3.26	9	0.99
2001	7	5.46	9	2.19
2001	8	2.22	4	1.02

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
2001	9	2.58	2	1.4
2001	10	9.58	8	3.34
2001	11	3.51	7	0.92
2001	12	5.27	6	2.93
2001	Total	43.69	70	3.34
2001	Winter	7.04	14	1.21
2001	Spring	7.78	16	1.68
2001	Summer	10.94	22	2.19
2001	Fall	15.67	17	3.34
2002	1	2.57	5	0.82
2002	2	2.63	5	1.38
2002	3	7.07	12	1.68
2002	4	6.23	9	2.25
2002	5	7.81	11	2.61
2002	6	5.29	6	2.05
2002	7	0.34	1	0.34
2002	8	0.97	6	0.38
2002	9	3.84	4	1.76
2002	10	3.63	10	1.13
2002	11	1.58	5	0.77
2002	12			
2002	Total	41.96	74	2.61
2002	Winter	10.47	16	2.93
2002	Spring	21.11	32	2.61
2002	Summer	6.6	13	2.05
2002	Fall	9.05	19	1.76
2003	1	2.75	2	2.25
2003	2	2.83	2	2.68
2003	3	2.11	2	1.56
2003	4	4.8	5	1.78
2003	5	5.53	6	1.57
2003	6	6.08	7	3.75
2003	7	0.92	3	0.83
2003	8	1.93	2	1.9
2003	9	3.07	4	2.13
2003	10	2.67	4	1.43
2003	11	2.9	7	1.01
2003	12	0.95	2	0.78
2003	Total	36.54	46	3.75
2003	Winter		4	2.68
2003	Spring	12.44	13	1.78
2003	Summer	8.93	12	3.75
2003	Fall	8.64	15	2.13
2004	1			
2004	2	1.75	1	1.75
2004	3	4.06	10	1.04
2004	4	1.66	4	0.82

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
2004	5		2	0.73
2004	6		1	1.26
2004	7	6.63	6	2
2004	8	4.58	7	1.43
2004	9	0.21	1	0.21
2004	10	6.34	10	2.01
2004	11	6.84	10	2.01
2004	12	2.03	3	0.82
2004	Total	36.47	55	2.01
2004	Winter		3	1.75
2004	Spring	6.83	16	1.04
2004	Summer		14	2
2004	Fall	13.39	21	2.01
2005	1	2.79	5	1.04
2005	2	2.37	7	0.81
2005	3	2.54	5	1.03
2005	4	2.71	7	0.71
2005	5	0.98	3	0.86
2005	6	3.93	3	2.48
2005	7	2.83	6	1.68
2005	8	6.25	9	1.9
2005	9	3.81	3	1.92
2005	10	1.28	3	0.79
2005	11	6.04	3	3.39
2005	12	0.88	5	0.37
2005	Total	36.41	59	3.39
2005	Winter	7.19	15	1.04
2005	Spring	6.23	15	1.03
2005	Summer	13.01	18	2.48
2005	Fall	11.13	9	3.39
2006	1	3.7	8	0.7
2006	2	0.37	2	0.25
2006	3	8.36	7	2.41
2006	4	1.78	7	0.5
2006	5	4.36	12	1.1
2006	6	3.77	5	1.77
2006	7	7.53	5	3.3
2006	8	2.59	7	1.18
2006	9	4.42	7	2.48
2006	10	6.66	8	2.61
2006	11	4.03	6	1.34
2006	12			
2006	Total	47.57	74	3.3
2006	Winter	4.95	15	0.7
2006	Spring	14.5	26	2.41
2006	Summer	13.89	17	3.3
2006	Fall	15.11	21	2.61

Appendix B.1 Precipitation

Year	Month	Precipitation	Rain Days	Daily Max Precipitation
2007	1	3.61	3	2.87
2007	2	2.48	1	2.48
2007	3	1.42	2	1.18
2007	4	3.09	6	1.1
2007	5	2.07	5	0.74
2007	6	4.13	7	2.34
2007	7	2.31	3	1.42
2007	8	2.79	5	1.37
2007	9	2.15	2	1.71
2007	10	5.84	3	3.61
2007	11			
2007	12			
2007	Total	29.89	37	3.61
2007	Winter	9.77	6	2.87
2007	Spring	6.58	13	1.18
2007	Summer	9.23	15	2.34
2007	Fall		5	3.61
2008	1			
2008	2			
2008	3			
2008	4			
2008	5	7.35	12	2.16
2008	6			
2008	7			
2008	8	1.05	3	0.71
2008	9	2.25	6	0.7
2008	10			
2008	11		2	
2008	12			
2008	Total			
2008	Winter		7	1.69
2008	Spring		12	2.16
2008	Summer		2	0.71
2008	Fall		6	0.7
2009	1	2.16	5	1.2
2009	2	1.49	5	0.9

StationCode	CollectionDate	CollectionTime	Matrix	MethodCode	Analyte	Result_TXT	Result_NUM	ResultUnits
N-17	24-Jun-03	10:00	Water	FIELD	Temperature, water	24	24	deg C
N-17	24-Jun-03	10:00	Water	FIELD	Dissolved oxygen (DO)	4.4	4.4	mg/l
N-17	16-Jul-03	11:45	Water	FIELD	Temperature, water	28.1	28.1	deg C
N-17	16-Jul-03	11:45	Water	FIELD	Dissolved oxygen (DO)	5.86	5.86	mg/l
N-17	19-Nov-03	12:00	Water	FIELD	Dissolved oxygen (DO)	8.1	8.1	mg/l
N-17	19-Nov-03	12:00	Water	FIELD	Temperature, water	12.5	12.5	deg C

StationCod	SampleDep	SampleDep	CollectionDat	SampleMe	Analyte	SampleFra	Result_NU	ResultUnit	Qualifier
RNZX-3	8	ft	8/26/2009	Sediment	Nitrogen, Kjeldahl	Total	3640	mg/kg	
RNZX-1	16	ft	8/26/2009	Sediment	Nitrogen, Kjeldahl	Total	6850	mg/kg	
RNZX-3	8	ft	8/26/2009	Sediment	Phosphorus as P	Total	321	mg/kg	
RNZX-1	16	ft	8/26/2009	Sediment	Phosphorus as P	Total	1020	mg/kg	
RNZX-3	8	ft	8/26/2009	Sediment	Temperature, sample		0	deg C	
RNZX-1	16	ft	8/26/2009	Sediment	Temperature, sample		0	deg C	
RNZX-3	8	ft	8/26/2009	Sediment	Total fixed solids		92.8	%	
RNZX-1	16	ft	8/26/2009	Sediment	Total fixed solids		87	%	
RNZX-3	8	ft	8/26/2009	Sediment	Total solids		44.2	%	
RNZX-1	16	ft	8/26/2009	Sediment	Total solids		37.5	%	
RNZX-3	8	ft	8/26/2009	Sediment	Total volatile solids		7.2	%	
RNZX-1	16	ft	8/26/2009	Sediment	Total volatile solids		13	%	
RNZX-2	1	ft	5/4/2009	Water	Alkalinity, total		46	mg/l	
RNZX-1	1	ft	5/4/2009	Water	Alkalinity, total		45	mg/l	
RNZX-3	1	ft	5/4/2009	Water	Alkalinity, total		46	mg/l	
RNZX-1	15	ft	5/4/2009	Water	Alkalinity, total		54	mg/l	
RNZX-3	1	ft	6/11/2009	Water	Alkalinity, total		52	mg/l	
RNZX-2	1	ft	6/11/2009	Water	Alkalinity, total		52	mg/l	
RNZX-1	1	ft	6/11/2009	Water	Alkalinity, total		52	mg/l	
RNZX-1	15	ft	6/11/2009	Water	Alkalinity, total		84	mg/l	
RNZX-2	1	ft	7/13/2009	Water	Alkalinity, total		54	mg/l	
RNZX-3	1	ft	7/13/2009	Water	Alkalinity, total		55	mg/l	
RNZX-1	1	ft	7/13/2009	Water	Alkalinity, total		53	mg/l	
RNZX-1	14	ft	7/13/2009	Water	Alkalinity, total		88	mg/l	
RNZX-2	1	ft	8/26/2009	Water	Alkalinity, total		58	mg/l	
RNZX-3	1	ft	8/26/2009	Water	Alkalinity, total		57	mg/l	
RNZX-1	1	ft	8/26/2009	Water	Alkalinity, total		58	mg/l	
RNZX-1	14	ft	8/26/2009	Water	Alkalinity, total		135	mg/l	
RNZX-1	1	ft	10/14/2009	Water	Alkalinity, total		56	mg/l	
RNZX-3	1	ft	10/14/2009	Water	Alkalinity, total		56	mg/l	
RNZX-2	1	ft	10/14/2009	Water	Alkalinity, total		54	mg/l	
RNZX-1	14	ft	10/14/2009	Water	Alkalinity, total		57	mg/l	
RNZX-2	5	ft	5/4/2009	Water	Chlorophyll a, corrected	Total	17.6	ug/l	
RNZX-1	6	ft	5/4/2009	Water	Chlorophyll a, corrected	Total	16.1	ug/l	
RNZX-3	6	ft	5/4/2009	Water	Chlorophyll a, corrected	Total	16.8	ug/l	
RNZX-2	4	ft	6/11/2009	Water	Chlorophyll a, corrected	Total	31.7	ug/l	
RNZX-1	4	ft	6/11/2009	Water	Chlorophyll a, corrected	Total	53.5	ug/l	
RNZX-3	4	ft	6/11/2009	Water	Chlorophyll a, corrected	Total	22.9	ug/l	
RNZX-1	3	ft	7/13/2009	Water	Chlorophyll a, corrected	Total	43.4	ug/l	
RNZX-3	3	ft	7/13/2009	Water	Chlorophyll a, corrected	Total	52.1	ug/l	
RNZX-2	3	ft	7/13/2009	Water	Chlorophyll a, corrected	Total	45.3	ug/l	
RNZX-2	3	ft	8/26/2009	Water	Chlorophyll a, corrected	Total	49.7	ug/l	
RNZX-3	3	ft	8/26/2009	Water	Chlorophyll a, corrected	Total	54.5	ug/l	
RNZX-1	3	ft	8/26/2009	Water	Chlorophyll a, corrected	Total	83.8	ug/l	
RNZX-2	4	ft	10/14/2009	Water	Chlorophyll a, corrected	Total	44.8	ug/l	
RNZX-1	4	ft	10/14/2009	Water	Chlorophyll a, corrected	Total	23.4	ug/l	
RNZX-3	4	ft	10/14/2009	Water	Chlorophyll a, corrected	Total	5.4	ug/l	
RNZX-2	5	ft	5/4/2009	Water	Chlorophyll a, uncorrect	Total	17.8	ug/l	
RNZX-1	6	ft	5/4/2009	Water	Chlorophyll a, uncorrect	Total	16.4	ug/l	
RNZX-3	6	ft	5/4/2009	Water	Chlorophyll a, uncorrect	Total	17	ug/l	
RNZX-2	4	ft	6/11/2009	Water	Chlorophyll a, uncorrect	Total	33	ug/l	
RNZX-1	4	ft	6/11/2009	Water	Chlorophyll a, uncorrect	Total	56.8	ug/l	

StationCod	SampleDe	SampleDe	CollectionDa	SampleMe	Analyte	SampleFra	Result_NU	ResultUnit	Qualifier
RNZX-3	4	ft	6/11/2009	Water	Chlorophyll a, uncorrect	Total	24.5	ug/l	
RNZX-1	3	ft	7/13/2009	Water	Chlorophyll a, uncorrect	Total	48.2	ug/l	
RNZX-3	3	ft	7/13/2009	Water	Chlorophyll a, uncorrect	Total	55.2	ug/l	
RNZX-2	3	ft	7/13/2009	Water	Chlorophyll a, uncorrect	Total	46.2	ug/l	
RNZX-1	3	ft	8/26/2009	Water	Chlorophyll a, uncorrect	Total	84.2	ug/l	
RNZX-3	3	ft	8/26/2009	Water	Chlorophyll a, uncorrect	Total	52.8	ug/l	
RNZX-2	3	ft	8/26/2009	Water	Chlorophyll a, uncorrect	Total	49.4	ug/l	
RNZX-3	4	ft	10/14/2009	Water	Chlorophyll a, uncorrect	Total	6.49	ug/l	
RNZX-2	4	ft	10/14/2009	Water	Chlorophyll a, uncorrect	Total	46.9	ug/l	
RNZX-1	4	ft	10/14/2009	Water	Chlorophyll a, uncorrect	Total	25.2	ug/l	
RNZX-2	5	ft	5/4/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-3	6	ft	5/4/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-1	6	ft	5/4/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-1	4	ft	6/11/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-2	4	ft	6/11/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-3	4	ft	6/11/2009	Water	Chlorophyll-b	Total	0.64	ug/l	
RNZX-3	3	ft	7/13/2009	Water	Chlorophyll-b	Total	0.71	ug/l	
RNZX-1	3	ft	7/13/2009	Water	Chlorophyll-b	Total	0.6	ug/l	
RNZX-2	3	ft	7/13/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-1	3	ft	8/26/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-2	3	ft	8/26/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-3	3	ft	8/26/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-2	4	ft	10/14/2009	Water	Chlorophyll-b	Total		ug/l	ND
RNZX-3	4	ft	10/14/2009	Water	Chlorophyll-b	Total	3.11	ug/l	
RNZX-1	4	ft	10/14/2009	Water	Chlorophyll-b	Total	0.58	ug/l	
RNZX-2	5	ft	5/4/2009	Water	Chlorophyll-c	Total	2.1	ug/l	
RNZX-3	6	ft	5/4/2009	Water	Chlorophyll-c	Total	1.88	ug/l	
RNZX-1	6	ft	5/4/2009	Water	Chlorophyll-c	Total	2.13	ug/l	
RNZX-1	4	ft	6/11/2009	Water	Chlorophyll-c	Total	8.08	ug/l	
RNZX-3	4	ft	6/11/2009	Water	Chlorophyll-c	Total	3.14	ug/l	
RNZX-2	4	ft	6/11/2009	Water	Chlorophyll-c	Total	3.88	ug/l	
RNZX-1	3	ft	7/13/2009	Water	Chlorophyll-c	Total	2.94	ug/l	
RNZX-3	3	ft	7/13/2009	Water	Chlorophyll-c	Total	3.33	ug/l	
RNZX-2	3	ft	7/13/2009	Water	Chlorophyll-c	Total	2.53	ug/l	
RNZX-2	3	ft	8/26/2009	Water	Chlorophyll-c	Total	2.91	ug/l	
RNZX-1	3	ft	8/26/2009	Water	Chlorophyll-c	Total	6.5	ug/l	
RNZX-3	3	ft	8/26/2009	Water	Chlorophyll-c	Total	3.27	ug/l	
RNZX-2	4	ft	10/14/2009	Water	Chlorophyll-c	Total	4.64	ug/l	
RNZX-1	4	ft	10/14/2009	Water	Chlorophyll-c	Total	2.24	ug/l	
RNZX-3	4	ft	10/14/2009	Water	Chlorophyll-c	Total	4.84	ug/l	
RNZX-1	1	ft	5/4/2009	Water	Nitrogen, ammonia as N	Total	0.0753	mg/l	J
RNZX-2	1	ft	5/4/2009	Water	Nitrogen, ammonia as N	Total	0.0596	mg/l	J
RNZX-1	15	ft	5/4/2009	Water	Nitrogen, ammonia as N	Total	0.417	mg/l	
RNZX-2	1	ft	6/11/2009	Water	Nitrogen, ammonia as N	Total		mg/l	ND
RNZX-1	1	ft	6/11/2009	Water	Nitrogen, ammonia as N	Total		mg/l	ND
RNZX-3	1	ft	6/11/2009	Water	Nitrogen, ammonia as N	Total	0.0318	mg/l	J
RNZX-1	15	ft	6/11/2009	Water	Nitrogen, ammonia as N	Total	1.65	mg/l	
RNZX-1	1	ft	7/13/2009	Water	Nitrogen, ammonia as N	Total		mg/l	ND
RNZX-3	1	ft	7/13/2009	Water	Nitrogen, ammonia as N	Total	0.0247	mg/l	J
RNZX-2	1	ft	7/13/2009	Water	Nitrogen, ammonia as N	Total	0.937	mg/l	
RNZX-1	14	ft	7/13/2009	Water	Nitrogen, ammonia as N	Total	0.0697	mg/l	J
RNZX-3	1	ft	8/26/2009	Water	Nitrogen, ammonia as N	Total	0.137	mg/l	

StationCod	SampleDe	SampleDe	CollectionDa	SampleMe	Analyte	SampleFra	Result_NU	ResultUnit	Qualifier
RNZX-1	1	ft	8/26/2009	Water	Nitrogen, ammonia as N	Total	0.0729	mg/l	J
RNZX-2	1	ft	8/26/2009	Water	Nitrogen, ammonia as N	Total	0.0352	mg/l	J
RNZX-1	14	ft	8/26/2009	Water	Nitrogen, ammonia as N	Total	4.66	mg/l	
RNZX-3	1	ft	10/14/2009	Water	Nitrogen, ammonia as N	Total	0.369	mg/l	
RNZX-2	1	ft	10/14/2009	Water	Nitrogen, ammonia as N	Total		mg/l	ND
RNZX-1	1	ft	10/14/2009	Water	Nitrogen, ammonia as N	Total	0.33	mg/l	
RNZX-1	14	ft	10/14/2009	Water	Nitrogen, ammonia as N	Total	0.36	mg/l	
RNZX-2	1	ft	5/4/2009	Water	Nitrogen, Kjeldahl	Total	0.527	mg/l	
RNZX-1	1	ft	5/4/2009	Water	Nitrogen, Kjeldahl	Total	0.608	mg/l	
RNZX-1	15	ft	5/4/2009	Water	Nitrogen, Kjeldahl	Total	0.883	mg/l	
RNZX-1	1	ft	6/11/2009	Water	Nitrogen, Kjeldahl	Total	0.916	mg/l	
RNZX-2	1	ft	6/11/2009	Water	Nitrogen, Kjeldahl	Total	0.992	mg/l	
RNZX-3	1	ft	6/11/2009	Water	Nitrogen, Kjeldahl	Total	0.959	mg/l	
RNZX-1	15	ft	6/11/2009	Water	Nitrogen, Kjeldahl	Total	2.82	mg/l	
RNZX-1	1	ft	7/13/2009	Water	Nitrogen, Kjeldahl	Total	0.908	mg/l	
RNZX-2	1	ft	7/13/2009	Water	Nitrogen, Kjeldahl	Total	0.914	mg/l	
RNZX-3	1	ft	7/13/2009	Water	Nitrogen, Kjeldahl	Total	1.13	mg/l	
RNZX-1	14	ft	7/13/2009	Water	Nitrogen, Kjeldahl	Total	1.9	mg/l	
RNZX-1	1	ft	8/26/2009	Water	Nitrogen, Kjeldahl	Total	1.8	mg/l	
RNZX-3	1	ft	8/26/2009	Water	Nitrogen, Kjeldahl	Total	1.41	mg/l	
RNZX-2	1	ft	8/26/2009	Water	Nitrogen, Kjeldahl	Total	1.16	mg/l	
RNZX-1	14	ft	8/26/2009	Water	Nitrogen, Kjeldahl	Total	4.92	mg/l	
RNZX-2	1	ft	10/14/2009	Water	Nitrogen, Kjeldahl	Total	4.92	mg/l	
RNZX-3	1	ft	10/14/2009	Water	Nitrogen, Kjeldahl	Total	1.21	mg/l	
RNZX-1	1	ft	10/14/2009	Water	Nitrogen, Kjeldahl	Total	1.21	mg/l	
RNZX-1	14	ft	10/14/2009	Water	Nitrogen, Kjeldahl	Total	1.04	mg/l	
RNZX-1	1	ft	5/4/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-2	1	ft	5/4/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-1	15	ft	5/4/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-2	1	ft	6/11/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-3	1	ft	6/11/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-1	1	ft	6/11/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-1	15	ft	6/11/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-2	1	ft	7/13/2009	Water	Nitrogen, Nitrite (NO2)	Total	0.101	mg/l	
RNZX-3	1	ft	7/13/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-1	1	ft	7/13/2009	Water	Nitrogen, Nitrite (NO2)	Total	0.031	mg/l	J
RNZX-1	14	ft	7/13/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-2	1	ft	8/26/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-3	1	ft	8/26/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-1	1	ft	8/26/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-1	14	ft	8/26/2009	Water	Nitrogen, Nitrite (NO2)	Total		mg/l	ND
RNZX-2	1	ft	10/14/2009	Water	Nitrogen, Nitrite (NO2)	Total	0.104	mg/l	
RNZX-1	1	ft	10/14/2009	Water	Nitrogen, Nitrite (NO2)	Total	0.11	mg/l	
RNZX-3	1	ft	10/14/2009	Water	Nitrogen, Nitrite (NO2)	Total	0.111	mg/l	
RNZX-1	14	ft	10/14/2009	Water	Nitrogen, Nitrite (NO2)	Total	0.113	mg/l	
RNZX-2	5	ft	5/4/2009	Water	Pheophytin-a	Total		ug/l	ND
RNZX-3	6	ft	5/4/2009	Water	Pheophytin-a	Total		ug/l	ND
RNZX-1	6	ft	5/4/2009	Water	Pheophytin-a	Total		ug/l	ND
RNZX-3	4	ft	6/11/2009	Water	Pheophytin-a	Total	1.47	ug/l	
RNZX-2	4	ft	6/11/2009	Water	Pheophytin-a	Total		ug/l	ND
RNZX-1	4	ft	6/11/2009	Water	Pheophytin-a	Total	2.35	ug/l	
RNZX-3	3	ft	7/13/2009	Water	Pheophytin-a	Total	2.14	ug/l	

StationCod	SampleDe	SampleDe	CollectionDa	SampleMe	Analyte	SampleFra	Result_NU	ResultUnit	Qualifier
RNZX-2	3	ft	7/13/2009	Water	Pheophytin-a	Total		ug/l	ND
RNZX-1	3	ft	7/13/2009	Water	Pheophytin-a	Total	5.21	ug/l	
RNZX-2	3	ft	8/26/2009	Water	Pheophytin-a	Total		ug/l	ND
RNZX-3	3	ft	8/26/2009	Water	Pheophytin-a	Total		ug/l	ND
RNZX-1	3	ft	8/26/2009	Water	Pheophytin-a	Total		ug/l	ND
RNZX-3	4	ft	10/14/2009	Water	Pheophytin-a	Total	1.94	ug/l	
RNZX-2	4	ft	10/14/2009	Water	Pheophytin-a	Total	0.71	ug/l	
RNZX-1	4	ft	10/14/2009	Water	Pheophytin-a	Total	1.52	ug/l	
RNZX-3	1	ft	5/4/2009	Water	Phosphorus as P	Dissolved	0.012	mg/l	
RNZX-2	1	ft	5/4/2009	Water	Phosphorus as P	Dissolved	0.013	mg/l	
RNZX-1	1	ft	5/4/2009	Water	Phosphorus as P	Dissolved	0.014	mg/l	
RNZX-1	15	ft	5/4/2009	Water	Phosphorus as P	Dissolved	0.026	mg/l	
RNZX-3	1	ft	6/11/2009	Water	Phosphorus as P	Dissolved	0.007	mg/l	
RNZX-1	1	ft	6/11/2009	Water	Phosphorus as P	Dissolved	0.009	mg/l	
RNZX-1	15	ft	6/11/2009	Water	Phosphorus as P	Dissolved	0.307	mg/l	
RNZX-3	1	ft	7/13/2009	Water	Phosphorus as P	Dissolved	0.007	mg/l	
RNZX-1	1	ft	7/13/2009	Water	Phosphorus as P	Dissolved	0.008	mg/l	
RNZX-2	1	ft	7/13/2009	Water	Phosphorus as P	Dissolved	0.009	mg/l	
RNZX-1	14	ft	7/13/2009	Water	Phosphorus as P	Dissolved	0.079	mg/l	
RNZX-2	1	ft	8/26/2009	Water	Phosphorus as P	Dissolved		mg/l	ND
RNZX-3	1	ft	8/26/2009	Water	Phosphorus as P	Dissolved	0.029	mg/l	
RNZX-1	1	ft	8/26/2009	Water	Phosphorus as P	Dissolved	0.029	mg/l	
RNZX-1	14	ft	8/26/2009	Water	Phosphorus as P	Dissolved	0.399	mg/l	
RNZX-2	1	ft	10/14/2009	Water	Phosphorus as P	Dissolved	0.013	mg/l	
RNZX-3	1	ft	10/14/2009	Water	Phosphorus as P	Dissolved	0.013	mg/l	
RNZX-1	1	ft	10/14/2009	Water	Phosphorus as P	Dissolved	0.019	mg/l	
RNZX-1	14	ft	10/14/2009	Water	Phosphorus as P	Dissolved	0.011	mg/l	
RNZX-2	1	ft	5/4/2009	Water	Phosphorus as P	Total	0.034	mg/l	
RNZX-1	1	ft	5/4/2009	Water	Phosphorus as P	Total	0.05	mg/l	
RNZX-1	15	ft	5/4/2009	Water	Phosphorus as P	Total	0.067	mg/l	
RNZX-2	1	ft	6/11/2009	Water	Phosphorus as P	Total	0.056	mg/l	
RNZX-1	1	ft	6/11/2009	Water	Phosphorus as P	Total	0.055	mg/l	
RNZX-3	1	ft	6/11/2009	Water	Phosphorus as P	Total	0.057	mg/l	
RNZX-1	15	ft	6/11/2009	Water	Phosphorus as P	Total	0.38	mg/l	
RNZX-3	1	ft	7/13/2009	Water	Phosphorus as P	Total	0.065	mg/l	
RNZX-2	1	ft	7/13/2009	Water	Phosphorus as P	Total	0.062	mg/l	
RNZX-1	1	ft	7/13/2009	Water	Phosphorus as P	Total	0.06	mg/l	
RNZX-1	14	ft	7/13/2009	Water	Phosphorus as P	Total	0.144	mg/l	
RNZX-2	1	ft	8/26/2009	Water	Phosphorus as P	Total	0.051	mg/l	
RNZX-3	1	ft	8/26/2009	Water	Phosphorus as P	Total	0.049	mg/l	
RNZX-1	1	ft	8/26/2009	Water	Phosphorus as P	Total	0.081	mg/l	
RNZX-1	14	ft	8/26/2009	Water	Phosphorus as P	Total	0.524	mg/l	
RNZX-2	1	ft	10/14/2009	Water	Phosphorus as P	Total	0.074	mg/l	
RNZX-3	1	ft	10/14/2009	Water	Phosphorus as P	Total	0.083	mg/l	
RNZX-1	1	ft	10/14/2009	Water	Phosphorus as P	Total	0.083	mg/l	
RNZX-1	14	ft	10/14/2009	Water	Phosphorus as P	Total	0.077	mg/l	
RNZX-1	1	ft	5/4/2009	Water	Solids, suspended, volatile		6	mg/l	
RNZX-2	1	ft	5/4/2009	Water	Solids, suspended, volatile		4	mg/l	
RNZX-3	1	ft	5/4/2009	Water	Solids, suspended, volatile		5	mg/l	
RNZX-1	15	ft	5/4/2009	Water	Solids, suspended, volatile		5	mg/l	
RNZX-3	1	ft	6/11/2009	Water	Solids, suspended, volatile		8	mg/l	
RNZX-2	1	ft	6/11/2009	Water	Solids, suspended, volatile		7	mg/l	

StationCod	SampleDep	SampleDep	CollectionDat	SampleMe	Analyte	SampleFra	Result_NU	ResultUnit	Qualifier
RNZX-1	1	ft	6/11/2009	Water	Solids, suspended, volatile		8	mg/l	
RNZX-1	15	ft	6/11/2009	Water	Solids, suspended, volatile		8	mg/l	
RNZX-2	1	ft	7/13/2009	Water	Solids, suspended, volatile		9	mg/l	
RNZX-3	1	ft	7/13/2009	Water	Solids, suspended, volatile		8	mg/l	
RNZX-1	1	ft	7/13/2009	Water	Solids, suspended, volatile		10	mg/l	
RNZX-1	14	ft	7/13/2009	Water	Solids, suspended, volatile		9	mg/l	
RNZX-2	1	ft	8/26/2009	Water	Solids, suspended, volatile		8	mg/l	
RNZX-1	1	ft	8/26/2009	Water	Solids, suspended, volatile		11	mg/l	
RNZX-3	1	ft	8/26/2009	Water	Solids, suspended, volatile		8	mg/l	
RNZX-1	14	ft	8/26/2009	Water	Solids, suspended, volatile		10	mg/l	
RNZX-3	1	ft	10/14/2009	Water	Solids, suspended, volatile		7	mg/l	
RNZX-2	1	ft	10/14/2009	Water	Solids, suspended, volatile		7	mg/l	
RNZX-1	1	ft	10/14/2009	Water	Solids, suspended, volatile		6	mg/l	
RNZX-1	14	ft	10/14/2009	Water	Solids, suspended, volatile		7	mg/l	
RNZX-3	1	ft	5/4/2009	Water	Solids, Total Suspended (TSS)		5	mg/l	
RNZX-1	1	ft	5/4/2009	Water	Solids, Total Suspended (TSS)		6	mg/l	
RNZX-2	1	ft	5/4/2009	Water	Solids, Total Suspended (TSS)		7	mg/l	
RNZX-1	15	ft	5/4/2009	Water	Solids, Total Suspended (TSS)			mg/l	ND
RNZX-2	1	ft	6/11/2009	Water	Solids, Total Suspended (TSS)		7	mg/l	
RNZX-3	1	ft	6/11/2009	Water	Solids, Total Suspended (TSS)		7	mg/l	
RNZX-1	1	ft	6/11/2009	Water	Solids, Total Suspended (TSS)		9	mg/l	
RNZX-1	15	ft	6/11/2009	Water	Solids, Total Suspended (TSS)		9	mg/l	
RNZX-2	1	ft	7/13/2009	Water	Solids, Total Suspended (TSS)		11	mg/l	
RNZX-3	1	ft	7/13/2009	Water	Solids, Total Suspended (TSS)		9	mg/l	
RNZX-1	1	ft	7/13/2009	Water	Solids, Total Suspended (TSS)		12	mg/l	
RNZX-1	14	ft	7/13/2009	Water	Solids, Total Suspended (TSS)		9	mg/l	
RNZX-2	1	ft	8/26/2009	Water	Solids, Total Suspended (TSS)		8	mg/l	
RNZX-1	1	ft	8/26/2009	Water	Solids, Total Suspended (TSS)		8	mg/l	
RNZX-3	1	ft	8/26/2009	Water	Solids, Total Suspended (TSS)		8	mg/l	
RNZX-1	14	ft	8/26/2009	Water	Solids, Total Suspended (TSS)		14	mg/l	
RNZX-2	1	ft	10/14/2009	Water	Solids, Total Suspended (TSS)		10	mg/l	
RNZX-3	1	ft	10/14/2009	Water	Solids, Total Suspended (TSS)		10	mg/l	
RNZX-1	1	ft	10/14/2009	Water	Solids, Total Suspended (TSS)		10	mg/l	
RNZX-1	14	ft	10/14/2009	Water	Solids, Total Suspended (TSS)		9	mg/l	
RNZX-1	1	ft	5/4/2009	Water	Temperature, sample		5	deg C	
RNZX-3	1	ft	5/4/2009	Water	Temperature, sample		5	deg C	
RNZX-2	1	ft	5/4/2009	Water	Temperature, sample		5	deg C	
RNZX-2	5	ft	5/4/2009	Water	Temperature, sample		0	deg C	
RNZX-1	6	ft	5/4/2009	Water	Temperature, sample		0	deg C	
RNZX-3	6	ft	5/4/2009	Water	Temperature, sample		0	deg C	
RNZX-1	15	ft	5/4/2009	Water	Temperature, sample		5	deg C	
RNZX-3	1	ft	6/11/2009	Water	Temperature, sample		1	deg C	
RNZX-2	1	ft	6/11/2009	Water	Temperature, sample		1	deg C	
RNZX-1	1	ft	6/11/2009	Water	Temperature, sample		1	deg C	
RNZX-1	15	ft	6/11/2009	Water	Temperature, sample		1	deg C	
RNZX-3	1	ft	7/13/2009	Water	Temperature, sample		2	deg C	
RNZX-2	1	ft	7/13/2009	Water	Temperature, sample		2	deg C	
RNZX-1	1	ft	7/13/2009	Water	Temperature, sample		2	deg C	
RNZX-1	14	ft	7/13/2009	Water	Temperature, sample		2	deg C	
RNZX-3	1	ft	8/26/2009	Water	Temperature, sample		4	deg C	
RNZX-1	1	ft	8/26/2009	Water	Temperature, sample		4	deg C	
RNZX-2	1	ft	8/26/2009	Water	Temperature, sample		4	deg C	

StationCod	SampleDep	SampleDep	CollectionDat	SampleMe	Analyte	SampleFra	Result_NU	ResultUnits	Qualifier
RNZX-1	14	ft	8/26/2009	Water	Temperature, sample		4	deg C	
RNZX-2	1	ft	10/14/2009	Water	Temperature, sample		3	deg C	
RNZX-1	1	ft	10/14/2009	Water	Temperature, sample		3	deg C	
RNZX-3	1	ft	10/14/2009	Water	Temperature, sample		3	deg C	
RNZX-1	14	ft	10/14/2009	Water	Temperature, sample		3	deg C	

StationCod	SampleDep	SampleDep	CollectionDate	Analyte	SampleFra	Result_NU	ResultUnit	Qualifier
RNZD-99	1	ft	6/16/2011	Alkalinity, total		57	mg/l	
RNZD-99	1	ft	6/16/2011	Chloride	Total	4.57	mg/l	
RNZD-99	4	ft	6/16/2011	Chlorophyll a, corrected for pheophytin	Total	42.2	ug/l	
RNZD-99	4	ft	6/16/2011	Chlorophyll a, uncorrected for pheophytin	Total	43.8	ug/l	
RNZD-99	4	ft	6/16/2011	Chlorophyll-b	Total	4.05	ug/l	
RNZD-99	4	ft	6/16/2011	Chlorophyll-c	Total	3.69	ug/l	
RNZD-99	1	ft	6/16/2011	Nitrogen, ammonia as N	Total		mg/l	ND
RNZD-99	4	ft	6/16/2011	Pheophytin-a	Total		ug/l	ND
RNZD-99	1	ft	6/16/2011	Phosphorus as P	Total	0.085	mg/l	
RNZD-99	1	ft	6/16/2011	Phosphorus as P	Dissolved	0.025	mg/l	
RNZD-99	1	ft	6/16/2011	Solids, suspended, volatile		9	mg/l	
RNZD-99	1	ft	6/16/2011	Solids, Total Suspended (TSS)		10	mg/l	
RNZD-99	1	ft	6/16/2011	Temperature, sample		3	deg C	

StationCo	SampleDe	SampleDe	CollectionDat	SampleMe	Analyte	SampleFra	Result_NU	ResultUnit	Qualifier
RNQ-1	13	ft	7/12/2011	Sediment	Nitrogen, Kjeldahl	Total	4990	mg/kg	
RNQ-1	13	ft	7/12/2011	Sediment	Phosphorus as P	Total	1430	mg/kg	
RNQ-1	13	ft	7/12/2011	Sediment	Total fixed solids		88.1	%	
RNQ-1	13	ft	7/12/2011	Sediment	Total solids		35.3	%	
RNQ-1	13	ft	7/12/2011	Sediment	Total volatile solids		11.9	%	
RNQ-1	1	ft	7/29/2011	Water	Alkalinity, total		55	mg/l	
RNQ-1	11	ft	7/29/2011	Water	Alkalinity, total		71	mg/l	
RNQ-1	3	ft	7/12/2011	Water	Chlorophyll a, corrected for pheophytin	Total	132	ug/l	
RNQ-1	3	ft	7/12/2011	Water	Chlorophyll a, uncorrected for pheophytin	Total	153	ug/l	
RNQ-1	3	ft	7/12/2011	Water	Chlorophyll-b	Total		ug/l	ND
RNQ-1	3	ft	7/12/2011	Water	Chlorophyll-c	Total	7.47	ug/l	
RNQ-1	1	ft	7/29/2011	Water	Nitrogen, ammonia as N	Total		mg/l	ND
RNQ-1	11	ft	7/29/2011	Water	Nitrogen, ammonia as N	Total	1.59	mg/l	
RNQ-1	1	ft	7/29/2011	Water	Nitrogen, Kjeldahl	Total	1.32	mg/l	
RNQ-1	11	ft	7/29/2011	Water	Nitrogen, Kjeldahl	Total	2.47	mg/l	
RNQ-1	1	ft	7/29/2011	Water	Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	Total		mg/l	ND
RNQ-1	11	ft	7/29/2011	Water	Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	Total		mg/l	ND
RNQ-1	3	ft	7/12/2011	Water	Pheophytin-a	Total	25.3	ug/l	
RNQ-1	1	ft	7/29/2011	Water	Phosphorus as P	Total	0.111	mg/l	
RNQ-1	11	ft	7/29/2011	Water	Phosphorus as P	Total	0.221	mg/l	
RNQ-1	1	ft	7/29/2011	Water	Solids, suspended, volatile		17	mg/l	
RNQ-1	11	ft	7/29/2011	Water	Solids, suspended, volatile		9	mg/l	
RNQ-1	1	ft	7/29/2011	Water	Solids, Total Suspended (TSS)		19	mg/l	
RNQ-1	11	ft	7/29/2011	Water	Solids, Total Suspended (TSS)		11	mg/l	
RNQ-1	1	ft	7/29/2011	Water	Temperature, sample		5	deg C	
RNQ-1	11	ft	7/29/2011	Water	Temperature, sample		5	deg C	

StationCoc	SampleDe	SampleDe	CollectionDate	SampleMe	Analyte	SampleFra	Result_NU	ResultUnit	Qualifier
RNP-1	3	ft	7/12/2011	Water	Chlorophyll a, corrected for pheophytin	Total	76.5	ug/l	
RNP-1	3	ft	7/12/2011	Water	Chlorophyll a, uncorrected for pheophytin	Total	81.7	ug/l	
RNP-1	3	ft	7/12/2011	Water	Chlorophyll-b	Total		ug/l	ND
RNP-1	16	ft	7/12/2011	Sediment	Nitrogen, Kjeldahl	Total	6870	mg/kg	
RNP-1	16	ft	7/12/2011	Sediment	Phosphorus as P	Total	1020	mg/kg	
RNP-1	16	ft	7/12/2011	Sediment	Total fixed solids		87.9	%	
RNP-1	16	ft	7/12/2011	Sediment	Total solids		31.8	%	
RNP-1	16	ft	7/12/2011	Sediment	Total volatile solids		12.1	%	
RNP-1	1	ft	7/29/2011	Water	Alkalinity, total		45	mg/l	
RNP-1	1	ft	7/29/2011	Water	Nitrogen, ammonia as N	Total		mg/l	ND
RNP-1	14	ft	7/29/2011	Water	Nitrogen, ammonia as N	Total	3.46	mg/l	
RNP-1	1	ft	7/29/2011	Water	Nitrogen, Kjeldahl	Total	1.14	mg/l	
RNP-1	14	ft	7/29/2011	Water	Nitrogen, Kjeldahl	Total	4.07	mg/l	
RNP-1	14	ft	7/29/2011	Water	Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	Total	0.02	mg/l	J
RNP-1	1	ft	7/29/2011	Water	Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N	Total		mg/l	ND
RNP-1	1	ft	7/29/2011	Water	Phosphorus as P	Total	0.034	mg/l	
RNP-1	14	ft	7/29/2011	Water	Phosphorus as P	Total	0.444	mg/l	
RNP-1	1	ft	7/29/2011	Water	Solids, suspended, volatile		7	mg/l	
RNP-1	1	ft	7/29/2011	Water	Solids, Total Suspended (TSS)		9	mg/l	
RNP-1	14	ft	7/29/2011	Water	Temperature, sample		5	deg C	
RNP-1	1	ft	7/29/2011	Water	Temperature, sample		5	deg C	

StationCode	CollectionDate	SampleMedium	Analyte	SampleFraction	Result_NUM	ResultUnits	Qualifier
NZN-15	5/13/2008	Water	Dissolved oxygen (DO)		7.300000191	mg/l	
NZN-15	6/11/2008	Water	Dissolved oxygen (DO)		2.5	mg/l	
NZN-15	8/15/2008	Water	Dissolved oxygen (DO)		2.799999952	mg/l	
NZN-15	8/15/2008	Water	Hardness, Ca + Mg	Total	237000	ug/l	C
NZN-15	5/13/2008	Water	Iron	Dissolved	1110	ug/l	
NZN-15	6/11/2008	Water	Iron	Dissolved	81	ug/l	
NZN-15	8/15/2008	Water	Iron	Dissolved	38.40000153	ug/l	J
NZN-15	6/11/2008	Water	Manganese	Dissolved	1590	ug/l	
NZN-15	8/15/2008	Water	Manganese	Dissolved	224	ug/l	
NZN-15	5/13/2008	Water	Temperature, water		14.30000019	deg C	
NZN-15	6/11/2008	Water	Temperature, water		23.10000038	deg C	
NZN-15	8/15/2008	Water	Temperature, water		20.70000076	deg C	

StationCode	CollectionDate	Matrix	Analyte	SmplFrac_Corrected	Result_NUM	ResultUnits	Qualifier2
NH-07	7/9/2003	Sediment	Manganese		300	mg/kg	
NHH-01	7/21/2003	Sediment	Manganese		480	mg/kg	
NH-07	6/25/2003	Water	Dissolved oxygen (DO)		3	mg/l	
NH-07	7/9/2003	Water	Dissolved oxygen (DO)		2.5	mg/l	
NH-07	11/24/2003	Water	Dissolved oxygen (DO)		6.4	mg/l	
NH-07	6/25/2003	Water	Hardness, Ca + Mg		226	mg/l	C
NH-07	7/9/2003	Water	Hardness, Ca + Mg		222	mg/l	C
NH-07	11/24/2003	Water	Hardness, Ca + Mg		148	mg/l	C
NH-07	6/25/2003	Water	Manganese	Dissolved	980	ug/l	
NH-07	7/9/2003	Water	Manganese	Dissolved	1700	ug/l	
NH-07	11/24/2003	Water	Manganese	Dissolved	620	ug/l	
NH-07	6/25/2003	Water	Manganese	Total	1000	ug/l	
NH-07	7/9/2003	Water	Manganese	Total	1700	ug/l	
NH-07	11/24/2003	Water	Manganese	Total	720	ug/l	
NH-07	6/25/2003	Water	Temperature, water		24.2	deg C	
NH-07	7/9/2003	Water	Temperature, water		28.5	deg C	
NH-07	11/24/2003	Water	Temperature, water		8.5	deg C	
NHH-01	6/25/2003	Water	Dissolved oxygen (DO)		5.2	mg/l	
NHH-01	7/21/2003	Water	Dissolved oxygen (DO)		5	mg/l	
NHH-01	11/19/2003	Water	Dissolved oxygen (DO)		0.6	mg/l	
NHH-01	6/25/2003	Water	Hardness, Ca + Mg		249	mg/l	C
NHH-01	7/21/2003	Water	Hardness, Ca + Mg		251	mg/l	C
NHH-01	11/19/2003	Water	Hardness, Ca + Mg		125	mg/l	C
NHH-01	6/25/2003	Water	Manganese	Dissolved	250	ug/l	
NHH-01	7/21/2003	Water	Manganese	Dissolved	200	ug/l	
NHH-01	11/19/2003	Water	Manganese	Dissolved	2800	ug/l	
NHH-01	6/25/2003	Water	Manganese	Total	280	ug/l	
NHH-01	7/21/2003	Water	Manganese	Total	260	ug/l	
NHH-01	11/19/2003	Water	Manganese	Total	3700	ug/l	
NHH-01	6/25/2003	Water	Temperature, water		22.6	deg C	
NHH-01	7/21/2003	Water	Temperature, water		24.5	deg C	
NHH-01	11/19/2003	Water	Temperature, water		10.9	deg C	

StationCode	CollectionDate	SampleMedium	Analyte	SampleFraction	Result_NUM	ResultUnits	Qualifier
NH-06	17-Jan-06	Water	Dissolved oxygen (DO)		10.4	mg/l	
NH-06	28-Feb-06	Water	Dissolved oxygen (DO)		11.2	mg/l	
NH-06	03-Apr-06	Water	Dissolved oxygen (DO)		6.5	mg/l	
NH-06	02-May-06	Water	Dissolved oxygen (DO)		6.6	mg/l	
NH-06	28-Jun-06	Water	Dissolved oxygen (DO)		2.68	mg/l	
NH-06	22-Aug-06	Water	Dissolved oxygen (DO)		1.5	mg/l	
NH-06	20-Sep-06	Water	Dissolved oxygen (DO)		3.5	mg/l	
NH-06	25-Oct-06	Water	Dissolved oxygen (DO)		2.7	mg/l	
NH-06	11-Dec-06	Water	Dissolved oxygen (DO)		11.6	mg/l	
NH-06	22-Jan-07	Water	Dissolved oxygen (DO)		12.1	mg/l	
NH-06	13-May-08	Water	Dissolved oxygen (DO)		6.8	mg/l	
NH-06	20-Aug-08	Water	Dissolved oxygen (DO)		5.3	mg/l	
NH-06	03-Sep-08	Water	Dissolved oxygen (DO)		2.3	mg/l	
NH-06	01-Oct-08	Water	Dissolved oxygen (DO)		5.4	mg/l	
NH-06	03-Dec-08	Water	Dissolved oxygen (DO)		5.1	mg/l	
NH-06	17-Jan-06	Water	Manganese	Dissolved	180	ug/l	
NH-06	17-Jan-06	Water	Manganese	Total	220	ug/l	
NH-06	28-Feb-06	Water	Manganese	Dissolved	510	ug/l	
NH-06	28-Feb-06	Water	Manganese	Total	570	ug/l	
NH-06	03-Apr-06	Water	Manganese	Dissolved	400	ug/l	
NH-06	03-Apr-06	Water	Manganese	Total	480	ug/l	
NH-06	02-May-06	Water	Manganese	Dissolved	500	ug/l	
NH-06	02-May-06	Water	Manganese	Total	730	ug/l	
NH-06	28-Jun-06	Water	Manganese	Dissolved	590	ug/l	
NH-06	28-Jun-06	Water	Manganese	Total	680	ug/l	
NH-06	22-Aug-06	Water	Manganese	Dissolved	1000	ug/l	
NH-06	22-Aug-06	Water	Manganese	Total	1000	ug/l	
NH-06	20-Sep-06	Water	Manganese	Dissolved	1200	ug/l	J6
NH-06	20-Sep-06	Water	Manganese	Total	1200	ug/l	
NH-06	25-Oct-06	Water	Manganese	Dissolved	490	ug/l	
NH-06	25-Oct-06	Water	Manganese	Total	530	ug/l	
NH-06	11-Dec-06	Water	Manganese	Dissolved	370	ug/l	
NH-06	11-Dec-06	Water	Manganese	Total	380	ug/l	
NH-06	22-Jan-07	Water	Manganese	Dissolved	110	ug/l	
NH-06	22-Jan-07	Water	Manganese	Total	150	ug/l	
NH-06	13-May-08	Water	Manganese	Dissolved	43	ug/l	
NH-06	13-May-08	Water	Manganese	Total	72.5	ug/l	
NH-06	20-Aug-08	Water	Manganese	Dissolved	837	ug/l	
NH-06	20-Aug-08	Water	Manganese	Total	910	ug/l	
NH-06	03-Sep-08	Water	Manganese	Dissolved	1000	ug/l	
NH-06	03-Sep-08	Water	Manganese	Total	1100	ug/l	
NH-06	01-Oct-08	Water	Manganese	Dissolved	846	ug/l	
NH-06	01-Oct-08	Water	Manganese	Total	935	ug/l	
NH-06	03-Dec-08	Water	Manganese	Dissolved	696	ug/l	
NH-06	03-Dec-08	Water	Manganese	Total	699	ug/l	

StationCoc	CollectionDate	SampleMe	Analyte	SampleFraction	Result_NUM	ResultUnit	Qualifier
NH-06	1/14/2009	Water	Dissolved oxygen (DO)		11.69999981	mg/l	
NH-06	2/26/2009	Water	Dissolved oxygen (DO)		11.89999962	mg/l	
NH-06	4/9/2009	Water	Dissolved oxygen (DO)		7.699999809	mg/l	
NH-06	5/21/2009	Water	Dissolved oxygen (DO)		3.799999952	mg/l	
NH-06	6/24/2009	Water	Dissolved oxygen (DO)		0.699999988	mg/l	
NH-06	7/28/2009	Water	Dissolved oxygen (DO)		2.539999962	mg/l	
NH-06	9/2/2009	Water	Dissolved oxygen (DO)		3.799999952	mg/l	
NH-06	10/13/2009	Water	Dissolved oxygen (DO)		6	mg/l	
NH-06	11/18/2009	Water	Dissolved oxygen (DO)		6.699999809	mg/l	
NH-06	1/25/2010	Water	Dissolved oxygen (DO)		9.100000381	mg/l	
NH-06	3/8/2010	Water	Dissolved oxygen (DO)		8.899999619	mg/l	
NH-06	4/15/2010	Water	Dissolved oxygen (DO)		4.599999905	mg/l	
NH-06	5/5/2010	Water	Dissolved oxygen (DO)		4.699999809	mg/l	
NH-06	7/1/2010	Water	Dissolved oxygen (DO)		2.640000105	mg/l	
NH-06	8/24/2010	Water	Dissolved oxygen (DO)		1.399999976	mg/l	
NH-06	9/13/2010	Water	Dissolved oxygen (DO)		2.299999952	mg/l	
NH-06	10/6/2010	Water	Dissolved oxygen (DO)		5.5	mg/l	
NH-06	12/20/2010	Water	Dissolved oxygen (DO)		6.199999809	mg/l	
NH-06	1/27/2011	Water	Dissolved oxygen (DO)		16.39999962	mg/l	
NH-06	3/8/2011	Water	Dissolved oxygen (DO)		8.699999809	mg/l	
NH-06	4/12/2011	Water	Dissolved oxygen (DO)		5.199999809	mg/l	
NH-06	5/24/2011	Water	Dissolved oxygen (DO)		5.800000191	mg/l	
NH-06	6/9/2011	Water	Dissolved oxygen (DO)		1.75999999	mg/l	
NH-06	8/15/2011	Water	Dissolved oxygen (DO)		2.299999952	mg/l	
NH-06	8/31/2011	Water	Dissolved oxygen (DO)		1.700000048	mg/l	
NH-06	10/19/2011	Water	Dissolved oxygen (DO)		4.400000095	mg/l	
NH-06	11/30/2011	Water	Dissolved oxygen (DO)		10.19999981	mg/l	
NH-06	1/14/2009	Water	Dissolved oxygen saturation		82	%	
NH-06	2/26/2009	Water	Dissolved oxygen saturation		96	%	
NH-06	4/9/2009	Water	Dissolved oxygen saturation		72	%	
NH-06	5/21/2009	Water	Dissolved oxygen saturation		40	%	
NH-06	6/24/2009	Water	Dissolved oxygen saturation		9	%	
NH-06	7/28/2009	Water	Dissolved oxygen saturation		30	%	
NH-06	9/2/2009	Water	Dissolved oxygen saturation		42	%	
NH-06	10/13/2009	Water	Dissolved oxygen saturation		56	%	
NH-06	11/18/2009	Water	Dissolved oxygen saturation		61	%	
NH-06	1/25/2010	Water	Dissolved oxygen saturation		74	%	
NH-06	3/8/2010	Water	Dissolved oxygen saturation		103	%	
NH-06	4/15/2010	Water	Dissolved oxygen saturation		50	%	
NH-06	5/5/2010	Water	Dissolved oxygen saturation		52	%	
NH-06	7/1/2010	Water	Dissolved oxygen saturation		31	%	
NH-06	8/24/2010	Water	Dissolved oxygen saturation		17	%	
NH-06	9/13/2010	Water	Dissolved oxygen saturation		28	%	
NH-06	10/6/2010	Water	Dissolved oxygen saturation		52	%	
NH-06	12/20/2010	Water	Dissolved oxygen saturation		45	%	
NH-06	1/27/2011	Water	Dissolved oxygen saturation		115	%	
NH-06	3/8/2011	Water	Dissolved oxygen saturation		70	%	
NH-06	4/12/2011	Water	Dissolved oxygen saturation		54	%	
NH-06	5/24/2011	Water	Dissolved oxygen saturation		63	%	
NH-06	6/9/2011	Water	Dissolved oxygen saturation		21	%	

StationCoc	CollectionDate	SampleMe	Analyte	SampleFraction	Result_NUM	ResultUnit	Qualifier
NH-06	8/15/2011	Water	Dissolved oxygen saturation		27	%	
NH-06	8/31/2011	Water	Dissolved oxygen saturation		20	%	
NH-06	10/19/2011	Water	Dissolved oxygen saturation		41	%	
NH-06	11/30/2011	Water	Dissolved oxygen saturation		79	%	
NH-06	1/14/2009	Water	Hardness, Ca + Mg	Total	299000	ug/l	C
NH-06	2/26/2009	Water	Hardness, Ca + Mg	Total	268000	ug/l	C
NH-06	4/9/2009	Water	Hardness, Ca + Mg	Total	166000	ug/l	C
NH-06	5/21/2009	Water	Hardness, Ca + Mg	Total	146000	ug/l	
NH-06	6/24/2009	Water	Hardness, Ca + Mg	Total	173000	ug/l	C
NH-06	7/28/2009	Water	Hardness, Ca + Mg	Total	121000	ug/l	C
NH-06	9/2/2009	Water	Hardness, Ca + Mg	Total	181000	ug/l	C
NH-06	10/13/2009	Water	Hardness, Ca + Mg	Total	74600	ug/l	C
NH-06	11/18/2009	Water	Hardness, Ca + Mg	Total	279000	ug/l	
NH-06	1/25/2010	Water	Hardness, Ca + Mg	Total	176000	ug/l	
NH-06	3/8/2010	Water	Hardness, Ca + Mg	Total	266000	ug/l	
NH-06	4/15/2010	Water	Hardness, Ca + Mg	Total	240000	ug/l	
NH-06	5/5/2010	Water	Hardness, Ca + Mg	Total	119000	ug/l	
NH-06	7/1/2010	Water	Hardness, Ca + Mg	Total	145000	ug/l	
NH-06	8/24/2010	Water	Hardness, Ca + Mg	Total	135000	ug/l	
NH-06	9/13/2010	Water	Hardness, Ca + Mg	Total	157000	ug/l	
NH-06	10/6/2010	Water	Hardness, Ca + Mg	Total	167000	ug/l	
NH-06	12/20/2010	Water	Hardness, Ca + Mg	Total	194000	ug/l	
NH-06	1/27/2011	Water	Hardness, Ca + Mg		281000	ug/l	C
NH-06	3/8/2011	Water	Hardness, Ca + Mg		85500	ug/l	C
NH-06	4/12/2011	Water	Hardness, Ca + Mg		178000	ug/l	C
NH-06	5/24/2011	Water	Hardness, Ca + Mg		114000	ug/l	C
NH-06	6/9/2011	Water	Hardness, Ca + Mg		184000	ug/l	C
NH-06	8/15/2011	Water	Hardness, Ca + Mg		131000	ug/l	C
NH-06	8/31/2011	Water	Hardness, Ca + Mg		149000	ug/l	C
NH-06	10/19/2011	Water	Hardness, Ca + Mg		114000	ug/l	C
NH-06	11/30/2011	Water	Hardness, Ca + Mg		70000	ug/l	C
NH-06	1/14/2009	Water	Manganese	Dissolved	294	ug/l	
NH-06	2/26/2009	Water	Manganese	Dissolved	423	ug/l	
NH-06	4/9/2009	Water	Manganese	Dissolved	326	ug/l	
NH-06	5/21/2009	Water	Manganese	Dissolved	824	ug/l	
NH-06	6/24/2009	Water	Manganese	Dissolved	1600	ug/l	
NH-06	7/28/2009	Water	Manganese	Dissolved	629	ug/l	
NH-06	9/2/2009	Water	Manganese	Dissolved	1380	ug/l	
NH-06	10/13/2009	Water	Manganese	Dissolved	49	ug/l	
NH-06	11/18/2009	Water	Manganese	Dissolved	491	ug/l	
NH-06	1/25/2010	Water	Manganese	Dissolved	171	ug/l	
NH-06	3/8/2010	Water	Manganese	Dissolved	513	ug/l	
NH-06	4/15/2010	Water	Manganese	Dissolved	1110	ug/l	
NH-06	5/5/2010	Water	Manganese	Dissolved	95.19999695	ug/l	
NH-06	7/1/2010	Water	Manganese	Dissolved	700	ug/l	
NH-06	8/24/2010	Water	Manganese	Dissolved	1090	ug/l	
NH-06	9/13/2010	Water	Manganese	Dissolved	1320	ug/l	
NH-06	10/6/2010	Water	Manganese	Dissolved	1070	ug/l	
NH-06	12/20/2010	Water	Manganese	Dissolved	511	ug/l	
NH-06	1/27/2011	Water	Manganese	Dissolved	369	ug/l	

StationCoc	CollectionDate	SampleMe	Analyte	SampleFraction	Result_NUM	ResultUnit	Qualifier
NH-06	3/8/2011	Water	Manganese	Dissolved	45.70000076	ug/l	
NH-06	4/12/2011	Water	Manganese	Dissolved	716	ug/l	
NH-06	5/24/2011	Water	Manganese	Dissolved	199	ug/l	
NH-06	6/9/2011	Water	Manganese	Dissolved	1790	ug/l	
NH-06	8/15/2011	Water	Manganese	Dissolved	1160	ug/l	
NH-06	8/31/2011	Water	Manganese	Dissolved	1150	ug/l	
NH-06	10/19/2011	Water	Manganese	Dissolved	460	ug/l	
NH-06	11/30/2011	Water	Manganese	Dissolved	43.79999924	ug/l	
NH-06	1/14/2009	Water	Solids, Total Suspended (TSS)		10	mg/l	
NH-06	2/26/2009	Water	Solids, Total Suspended (TSS)		13	mg/l	
NH-06	4/9/2009	Water	Solids, Total Suspended (TSS)		37	mg/l	
NH-06	5/21/2009	Water	Solids, Total Suspended (TSS)		57	mg/l	
NH-06	6/24/2009	Water	Solids, Total Suspended (TSS)		20	mg/l	
NH-06	7/28/2009	Water	Solids, Total Suspended (TSS)		78	mg/l	
NH-06	9/2/2009	Water	Solids, Total Suspended (TSS)		81	mg/l	
NH-06	10/13/2009	Water	Solids, Total Suspended (TSS)		18	mg/l	
NH-06	11/18/2009	Water	Solids, Total Suspended (TSS)		10	mg/l	
NH-06	1/25/2010	Water	Solids, Total Suspended (TSS)		60	mg/l	
NH-06	3/8/2010	Water	Solids, Total Suspended (TSS)		8	mg/l	
NH-06	4/15/2010	Water	Solids, Total Suspended (TSS)		92	mg/l	
NH-06	5/5/2010	Water	Solids, Total Suspended (TSS)		23	mg/l	
NH-06	7/1/2010	Water	Solids, Total Suspended (TSS)		56	mg/l	
NH-06	9/13/2010	Water	Solids, Total Suspended (TSS)		79	mg/l	
NH-06	12/20/2010	Water	Solids, Total Suspended (TSS)		8	mg/l	
NH-06	1/27/2011	Water	Solids, Total Suspended (TSS)		19	mg/l	
NH-06	3/8/2011	Water	Solids, Total Suspended (TSS)		20	mg/l	
NH-06	4/12/2011	Water	Solids, Total Suspended (TSS)		72	mg/l	
NH-06	5/24/2011	Water	Solids, Total Suspended (TSS)		220	mg/l	
NH-06	6/9/2011	Water	Solids, Total Suspended (TSS)		39	mg/l	
NH-06	8/15/2011	Water	Solids, Total Suspended (TSS)		75	mg/l	
NH-06	8/31/2011	Water	Solids, Total Suspended (TSS)		9	mg/l	
NH-06	10/19/2011	Water	Solids, Total Suspended (TSS)		12	mg/l	
NH-06	11/30/2011	Water	Solids, Total Suspended (TSS)		37	mg/l	

StationCode	CollectionDate	SampleMedium	Analyte	Result_NUM	Qualifier	ResultUnits
NH-06	05/21/09	Water	Fecal coliform	260		cfu/100ml
NH-06	06/24/09	Water	Fecal coliform	225		cfu/100ml
NH-06	07/28/09	Water	Fecal coliform	390		cfu/100ml
NH-06	09/02/09	Water	Fecal coliform	6	B	cfu/100ml
NH-06	10/13/09	Water	Fecal coliform	105		cfu/100ml
NH-06	05/05/10	Water	Fecal coliform	270		cfu/100ml
NH-06	07/01/10	Water	Fecal coliform	760	B	cfu/100ml
NH-06	08/24/10	Water	Fecal coliform	1100	B	cfu/100ml
NH-06	09/13/10	Water	Fecal coliform	180	B	cfu/100ml
NH-06	10/06/10	Water	Fecal coliform	35	B	cfu/100ml

StationCode	CollectionDate	SampleMedium	Analyte	SampleFraction	Result_NUM	ResultUnits	Qualifier
NGA-02	23-Jun-08	Water	BOD, carbonaceous	Total		mg/l	ND
NGA-02	11-Aug-08	Water	BOD, carbonaceous	Total	2.1	mg/l	
NGA-02	06-Aug-08	Water	BOD, carbonaceous	Total		mg/l	ND
NGA-02	04-Aug-08	Water	BOD, carbonaceous	Total		mg/l	ND
NGA-02	04-Aug-08	Water	Dissolved oxygen (DO)		3.6	mg/l	
NGA-02	15-May-08	Water	Dissolved oxygen (DO)		8.2	mg/l	
NGA-02	06-Aug-08	Water	Dissolved oxygen (DO)		3.6	mg/l	
NGA-02	23-Jun-08	Water	Dissolved oxygen (DO)		5.3	mg/l	
NGA-02	16-Jun-08	Water	Dissolved oxygen (DO)		7.3	mg/l	
NGA-02	12-Jun-08	Water	Dissolved oxygen (DO)		5.5	mg/l	
NGA-02	11-Aug-08	Water	Dissolved oxygen (DO)		4.5	mg/l	
NGA-02	06-Aug-08	Water	Phosphorus as P	Total	0.057	mg/l	
NGA-02	15-May-08	Water	Phosphorus as P	Dissolved	0.031	mg/l	
NGA-02	15-May-08	Water	Phosphorus as P	Total	0.078	mg/l	
NGA-02	12-Jun-08	Water	Phosphorus as P	Dissolved	0.039	mg/l	
NGA-02	12-Jun-08	Water	Phosphorus as P	Total	0.093	mg/l	
NGA-02	06-Aug-08	Water	Phosphorus as P	Dissolved	0.029	mg/l	
NGA-02	16-Jun-08	Water	Phosphorus as P	Total	0.022	mg/l	
NGA-02	23-Jun-08	Water	Phosphorus as P	Total	0.021	mg/l	
NGA-02	17-Jun-08	Sediment	Phosphorus as P	Total	190	mg/kg	
NGA-02	04-Aug-08	Water	Phosphorus as P	Total	0.052	mg/l	
NGA-02	11-Aug-08	Water	Phosphorus as P	Total	0.041	mg/l	
NGA-02	12-Jun-08	Water	Solids, Total Suspended (TSS)		23.5	mg/l	
NGA-02	11-Aug-08	Water	Solids, Total Suspended (TSS)		8	mg/l	
NGA-02	15-May-08	Water	Solids, Total Suspended (TSS)		4	mg/l	
NGA-02	16-Jun-08	Water	Solids, Total Suspended (TSS)		21	mg/l	
NGA-02	23-Jun-08	Water	Solids, Total Suspended (TSS)		7	mg/l	
NGA-02	04-Aug-08	Water	Solids, Total Suspended (TSS)		8	mg/l	
NGA-02	06-Aug-08	Water	Solids, Total Suspended (TSS)		9.5	mg/l	

StationCode	CollectionDate	SampleMedium	Analyte	SampleFraction	Result_NUM	ResultUnits	Qualifier
NG-02	3/2/2004	Water	Chloride	Total	18.2	mg/l	
NG-02	4/13/2004	Water	Chloride	Total	42.8	mg/l	
NG-02	5/18/2004	Water	Chloride	Total	22.1	mg/l	
NG-02	6/7/2004	Water	Chloride	Total	18.8	mg/l	
NG-02	6/7/2004	Water	Chloride	Total	28.9	mg/l	
NG-02	8/4/2004	Water	Chloride	Total	29.6	mg/l	
NG-02	10/21/2004	Water	Chloride	Total	25.1	mg/l	
NG-02	11/3/2004	Water	Chloride	Total	12.5	mg/l	
NG-02	12/7/2004	Water	Chloride	Total	9.22	mg/l	
NG-02	1/26/2005	Water	Chloride	Total	29.3	mg/l	
NG-02	3/2/2005	Water	Chloride	Total	27	mg/l	
NG-02	3/29/2005	Water	Chloride	Total	10.9	mg/l	
NG-02	5/5/2005	Water	Chloride	Total	29.6	mg/l	
NG-02	6/21/2005	Water	Chloride	Total	69.2	mg/l	Y
NG-02	8/16/2005	Water	Chloride	Total	66	mg/l	
NG-02	9/13/2005	Water	Chloride	Total	52	mg/l	
NG-02	10/26/2005	Water	Chloride	Total	44	mg/l	
NG-02	11/28/2005	Water	Chloride	Total	44.8	mg/l	
NG-02	1/17/2006	Water	Chloride	Total	18.5	mg/l	
NG-02	2/28/2006	Water	Chloride	Total	44.5	mg/l	
NG-02	4/3/2006	Water	Chloride	Total	16.20000076	mg/l	
NG-02	6/28/2006	Water	Chloride	Total	51.29999924	mg/l	
NG-02	8/22/2006	Water	Chloride	Total	43.09999847	mg/l	
NG-02	9/20/2006	Water	Chloride	Total	59	mg/l	
NG-02	10/25/2006	Water	Chloride	Total	29.20000076	mg/l	
NG-02	12/11/2006	Water	Chloride	Total	35	mg/l	
NG-02	1/22/2007	Water	Chloride	Total	8.069999695	mg/l	
NG-02	1/8/2003	Water	Dissolved oxygen (DO)		12.2	mg/l	
NG-02	3/3/2003	Water	Dissolved oxygen (DO)		10.8	mg/l	
NG-02	4/28/2003	Water	Dissolved oxygen (DO)		4.5	mg/l	
NG-02	5/29/2003	Water	Dissolved oxygen (DO)		71	mg/l	
NG-02	6/11/2003	Water	Dissolved oxygen (DO)		3	mg/l	
NG-02	7/21/2003	Water	Dissolved oxygen (DO)		4.5	mg/l	
NG-02	10/29/2003	Water	Dissolved oxygen (DO)		0	mg/l	
NG-02	12/2/2003	Water	Dissolved oxygen (DO)		0	mg/l	
NG-02	1/27/2004	Water	Dissolved oxygen (DO)		1.7	mg/l	
NG-02	3/2/2004	Water	Dissolved oxygen (DO)		11.5	mg/l	
NG-02	4/13/2004	Water	Dissolved oxygen (DO)		2.5	mg/l	
NG-02	5/18/2004	Water	Dissolved oxygen (DO)		6.1	mg/l	
NG-02	6/7/2004	Water	Dissolved oxygen (DO)		3.8	mg/l	
NG-02	6/7/2004	Water	Dissolved oxygen (DO)		6.1	mg/l	
NG-02	8/4/2004	Water	Dissolved oxygen (DO)		2.6	mg/l	
NG-02	10/21/2004	Water	Dissolved oxygen (DO)		1	mg/l	
NG-02	11/3/2004	Water	Dissolved oxygen (DO)		5.9	mg/l	
NG-02	12/7/2004	Water	Dissolved oxygen (DO)		6.7	mg/l	
NG-02	1/26/2005	Water	Dissolved oxygen (DO)		6.7	mg/l	
NG-02	3/2/2005	Water	Dissolved oxygen (DO)		6.7	mg/l	
NG-02	3/29/2005	Water	Dissolved oxygen (DO)		7.7	mg/l	
NG-02	5/5/2005	Water	Dissolved oxygen (DO)		0	mg/l	
NG-02	6/21/2005	Water	Dissolved oxygen (DO)		1.3	mg/l	
NG-02	8/16/2005	Water	Dissolved oxygen (DO)		0.4	mg/l	
NG-02	9/13/2005	Water	Dissolved oxygen (DO)		0	mg/l	
NG-02	10/26/2005	Water	Dissolved oxygen (DO)		0	mg/l	

StationCode	CollectionDate	SampleMedium	Analyte	SampleFraction	Result_NUM	ResultUnits	Qualifier
NG-02	11/28/2005	Water	Dissolved oxygen (DO)		4.4	mg/l	
NG-02	1/17/2006	Water	Dissolved oxygen (DO)		0	mg/l	
NG-02	2/28/2006	Water	Dissolved oxygen (DO)		2.900000095	mg/l	
NG-02	4/3/2006	Water	Dissolved oxygen (DO)		7.800000191	mg/l	
NG-02	5/2/2006	Water	Dissolved oxygen (DO)		0	mg/l	
NG-02	6/28/2006	Water	Dissolved oxygen (DO)		0	mg/l	
NG-02	8/22/2006	Water	Dissolved oxygen (DO)		2.099999905	mg/l	
NG-02	9/20/2006	Water	Dissolved oxygen (DO)		0.899999976	mg/l	
NG-02	10/25/2006	Water	Dissolved oxygen (DO)		0	mg/l	
NG-02	12/11/2006	Water	Dissolved oxygen (DO)		11	mg/l	
NG-02	1/22/2007	Water	Dissolved oxygen (DO)		11.89999962	mg/l	
NG-02	3/2/2004	Water	Solids, Total Suspended (TSS)		74	mg/l	
NG-02	4/13/2004	Water	Solids, Total Suspended (TSS)		6	mg/l	
NG-02	5/18/2004	Water	Solids, Total Suspended (TSS)		25	mg/l	
NG-02	6/7/2004	Water	Solids, Total Suspended (TSS)		11	mg/l	
NG-02	6/7/2004	Water	Solids, Total Suspended (TSS)		52	mg/l	
NG-02	8/4/2004	Water	Solids, Total Suspended (TSS)		23	mg/l	
NG-02	10/21/2004	Water	Solids, Total Suspended (TSS)		21	mg/l	
NG-02	12/7/2004	Water	Solids, Total Suspended (TSS)		1220	mg/l	
NG-02	1/26/2005	Water	Solids, Total Suspended (TSS)		12	mg/l	
NG-02	3/2/2005	Water	Solids, Total Suspended (TSS)		10	mg/l	
NG-02	3/29/2005	Water	Solids, Total Suspended (TSS)		56	mg/l	
NG-02	5/5/2005	Water	Solids, Total Suspended (TSS)		10	mg/l	
NG-02	9/13/2005	Water	Solids, Total Suspended (TSS)		5	mg/l	J
NG-02	10/26/2005	Water	Solids, Total Suspended (TSS)			mg/l	ND
NG-02	8/22/2006	Water	Solids, Total Suspended (TSS)		21	mg/l	
NG-02	9/20/2006	Water	Solids, Total Suspended (TSS)		16	mg/l	
NG-02	10/25/2006	Water	Solids, Total Suspended (TSS)		27	mg/l	
NG-02	12/11/2006	Water	Solids, Total Suspended (TSS)		5	mg/l	
NG-02	1/22/2007	Water	Solids, Total Suspended (TSS)		43	mg/l	
NG-02	1/8/2003	Water	Temperature, water		1.9	deg C	
NG-02	3/3/2003	Water	Temperature, water		1.2	deg C	
NG-02	4/28/2003	Water	Temperature, water		16.1	deg C	
NG-02	5/29/2003	Water	Temperature, water		16.5	deg C	
NG-02	6/11/2003	Water	Temperature, water		18.5	deg C	
NG-02	7/21/2003	Water	Temperature, water		24.8	deg C	
NG-02	10/29/2003	Water	Temperature, water		9.3	deg C	
NG-02	12/2/2003	Water	Temperature, water		4.1	deg C	
NG-02	1/27/2004	Water	Temperature, water		-0.12	deg C	
NG-02	3/2/2004	Water	Temperature, water		11	deg C	
NG-02	4/13/2004	Water	Temperature, water		8.7	deg C	
NG-02	5/18/2004	Water	Temperature, water		18.8	deg C	
NG-02	6/7/2004	Water	Temperature, water		20	deg C	
NG-02	6/7/2004	Water	Temperature, water		21.5	deg C	
NG-02	8/4/2004	Water	Temperature, water		25	deg C	
NG-02	10/21/2004	Water	Temperature, water		14	deg C	
NG-02	11/3/2004	Water	Temperature, water		13.7	deg C	
NG-02	12/7/2004	Water	Temperature, water		12.4	deg C	
NG-02	1/26/2005	Water	Temperature, water		3.2	deg C	
NG-02	3/2/2005	Water	Temperature, water		2.1	deg C	
NG-02	3/29/2005	Water	Temperature, water		10.8	deg C	
NG-02	5/5/2005	Water	Temperature, water		12.2	deg C	
NG-02	6/21/2005	Water	Temperature, water		20.5	deg C	

StationCode	CollectionDate	SampleMedium	Analyte	SampleFraction	Result_NUM	ResultUnits	Qualifier
NG-02	8/16/2005	Water	Temperature, water		24.2	deg C	
NG-02	9/13/2005	Water	Temperature, water		22.2	deg C	
NG-02	10/26/2005	Water	Temperature, water		8.3	deg C	
NG-02	11/28/2005	Water	Temperature, water		11.1	deg C	
NG-02	1/17/2006	Water	Temperature, water		6.099999905	deg C	
NG-02	2/28/2006	Water	Temperature, water		8.300000191	deg C	
NG-02	4/3/2006	Water	Temperature, water		13.69999981	deg C	
NG-02	5/2/2006	Water	Temperature, water		15.5	deg C	
NG-02	6/28/2006	Water	Temperature, water		21.44000053	deg C	
NG-02	8/22/2006	Water	Temperature, water		22.79999924	deg C	
NG-02	9/20/2006	Water	Temperature, water		14.89999962	deg C	
NG-02	10/25/2006	Water	Temperature, water		6.900000095	deg C	
NG-02	12/11/2006	Water	Temperature, water		3.900000095	deg C	
NG-02	1/22/2007	Water	Temperature, water		3.200000048	deg C	
NG-05	6/16/2008	Water	BOD, Biochemical oxygen demand	Total		mg/l	ND
NG-05	6/23/2008	Water	BOD, Biochemical oxygen demand	Total		mg/l	J7,ND
NG-05	8/4/2008	Water	BOD, Biochemical oxygen demand	Total	3	mg/l	
NG-05	8/11/2008	Water	BOD, Biochemical oxygen demand	Total		mg/l	J7,ND
NG-05	6/23/2008	Water	BOD, carbonaceous	Total		mg/l	ND
NG-05	8/11/2008	Water	BOD, carbonaceous	Total		mg/l	ND
NG-05	5/15/2008	Water	Chloride	Total	43.79999924	mg/l	
NG-05	6/12/2008	Water	Chloride	Total	240	mg/l	
NG-05	7/24/2008	Water	Chloride	Total	1420	mg/l	
NG-05	5/15/2008	Water	Dissolved oxygen (DO)		9.100000381	mg/l	
NG-05	6/12/2008	Water	Dissolved oxygen (DO)		5.5	mg/l	
NG-05	6/16/2008	Water	Dissolved oxygen (DO)		7	mg/l	
NG-05	6/23/2008	Water	Dissolved oxygen (DO)		7.099999905	mg/l	
NG-05	7/24/2008	Water	Dissolved oxygen (DO)		8	mg/l	
NG-05	8/4/2008	Water	Dissolved oxygen (DO)		7.699999809	mg/l	
NG-05	8/11/2008	Water	Dissolved oxygen (DO)		6	mg/l	
NG-05	5/15/2008	Water	Solids, Total Suspended (TSS)		5	mg/l	
NG-05	6/12/2008	Water	Solids, Total Suspended (TSS)		4.5	mg/l	
NG-05	6/16/2008	Water	Solids, Total Suspended (TSS)		7	mg/l	
NG-05	6/23/2008	Water	Solids, Total Suspended (TSS)		5	mg/l	
NG-05	7/24/2008	Water	Solids, Total Suspended (TSS)		10	mg/l	
NG-05	8/4/2008	Water	Solids, Total Suspended (TSS)		25	mg/l	
NG-05	8/11/2008	Water	Solids, Total Suspended (TSS)		7	mg/l	
NG-05	5/15/2008	Water	Temperature, water		14.80000019	deg C	
NG-05	6/12/2008	Water	Temperature, water		23.20000076	deg C	
NG-05	6/16/2008	Water	Temperature, water		23.89999962	deg C	
NG-05	6/23/2008	Water	Temperature, water		22.10000038	deg C	
NG-05	7/24/2008	Water	Temperature, water		23.5	deg C	
NG-05	8/4/2008	Water	Temperature, water		23.60000038	deg C	
NG-05	8/11/2008	Water	Temperature, water		20.70000076	deg C	

StationCode	WaterbodyName	CollectionDate	SampleMedium	Analyte	Result_NUM	ResultUnits	Qualifier
NF-01	HURRICANE CREEK	14-May-08	Water	Solids, Total Suspended (TSS)	29.5	mg/l	
NF-01	HURRICANE CREEK	10-Jun-08	Water	Solids, Total Suspended (TSS)	20.5	mg/l	
NF-01	HURRICANE CREEK	29-Jul-08	Water	Solids, Total Suspended (TSS)	10.5	mg/l	
NF-01	HURRICANE CREEK	10-Jun-08	Sediment	BHC-gamma (Lindane)		ug/kg	ND

StationCode	CollectionDat	SampleMe	Analyte_Type	Analyte	Result_NU	ResultUnit	Qualifier
N-11	1/9/2006	Water		Sulfate	162	mg/l	
N-11	2/16/2006	Water		Sulfate	113	mg/l	
N-11	6/29/2006	Water		Sulfate	48.9	mg/l	
N-11	8/15/2006	Water		Sulfate	45.6	mg/l	
N-11	9/19/2006	Water		Sulfate	49.9	mg/l	
N-11	12/5/2006	Water		Sulfate	51.4	mg/l	
N-11	1/24/2007	Water		Sulfate	814	mg/l	
N-11	5/14/2008	Water		Sulfate	56.1	mg/l	
N-11	8/21/2008	Water		Sulfate	68.3	mg/l	
N-11	10/1/2008	Water		Sulfate	26.9	mg/l	
N-11	12/3/2008	Water		Sulfate	40.8	mg/l	
N-11	1/14/2009	Water	Misc_Inorganic	Sulfate	112	mg/l	
N-11	2/26/2009	Water	Misc_Inorganic	Sulfate	75.5	mg/l	
N-11	4/9/2009	Water	Misc_Inorganic	Sulfate	79.3	mg/l	
N-11	5/21/2009	Water	Misc_Inorganic	Sulfate	48.2	mg/l	
N-11	6/24/2009	Water	Misc_Inorganic	Sulfate	54.3	mg/l	
N-11	7/28/2009	Water	Misc_Inorganic	Sulfate	41.6	mg/l	
N-11	9/2/2009	Water	Misc_Inorganic	Sulfate	36	mg/l	
N-11	10/13/2009	Water	Misc_Inorganic	Sulfate	35.8	mg/l	
N-11	11/18/2009	Water	Misc_Inorganic	Sulfate	68.2	mg/l	
N-11	1/25/2010	Water	Misc_Inorganic	Sulfate	94.7	mg/l	
N-11	3/8/2010	Water	Misc_Inorganic	Sulfate	63	mg/l	
N-11	4/15/2010	Water	Misc_Inorganic	Sulfate	65.2	mg/l	
N-11	5/5/2010	Water	Misc_Inorganic	Sulfate	78.2	mg/l	
N-11	7/1/2010	Water	Misc_Inorganic	Sulfate	64.6	mg/l	
N-11	9/13/2010	Water	Misc_Inorganic	Sulfate	61	mg/l	
N-11	10/6/2010	Water	Misc_Inorganic	Sulfate	52.8	mg/l	
N-11	12/20/2010	Water	Misc_Inorganic	Sulfate	58	mg/l	
N-11	1/27/2011	Water	Misc_Inorganic	Sulfate	86.9	mg/l	
N-11	3/8/2011	Water	Misc_Inorganic	Sulfate	67.7	mg/l	
N-11	4/12/2011	Water	Misc_Inorganic	Sulfate	88.1	mg/l	
N-11	5/24/2011	Water	Misc_Inorganic	Sulfate	37.4	mg/l	
N-11	6/9/2011	Water	Misc_Inorganic	Sulfate	35	mg/l	
N-11	8/15/2011	Water	Misc_Inorganic	Sulfate	21.2	mg/l	
N-11	10/19/2011	Water	Misc_Inorganic	Sulfate	38.9	mg/l	

StationCod	CollectionDate	SampleMe	Analyte	Result_NU	ResultUnit	Qualifier
N-11	8/15/2006	Water	Solids, Total Suspended (TSS)	14	mg/l	
N-11	9/19/2006	Water	Solids, Total Suspended (TSS)	179	mg/l	
N-11	10/26/2006	Water	Solids, Total Suspended (TSS)	4	mg/l	
N-11	12/5/2006	Water	Solids, Total Suspended (TSS)	15	mg/l	
N-11	1/24/2007	Water	Solids, Total Suspended (TSS)	18	mg/l	
N-11	5/14/2008	Water	Solids, Total Suspended (TSS)	29.5	mg/l	
N-11	8/21/2008	Water	Solids, Total Suspended (TSS)	100	mg/l	
N-11	10/1/2008	Water	Solids, Total Suspended (TSS)	73	mg/l	
N-11	12/3/2008	Water	Solids, Total Suspended (TSS)	24	mg/l	
N-11	1/14/2009	Water	Solids, Total Suspended (TSS)	17	mg/l	
N-11	2/26/2009	Water	Solids, Total Suspended (TSS)	53	mg/l	
N-11	4/9/2009	Water	Solids, Total Suspended (TSS)	57	mg/l	
N-11	5/21/2009	Water	Solids, Total Suspended (TSS)	8	mg/l	
N-11	6/24/2009	Water	Solids, Total Suspended (TSS)	66	mg/l	
N-11	7/28/2009	Water	Solids, Total Suspended (TSS)	87	mg/l	
N-11	9/2/2009	Water	Solids, Total Suspended (TSS)	106	mg/l	
N-11	10/13/2009	Water	Solids, Total Suspended (TSS)	14	mg/l	
N-11	11/18/2009	Water	Solids, Total Suspended (TSS)	45	mg/l	
N-11	1/25/2010	Water	Solids, Total Suspended (TSS)	31	mg/l	
N-11	3/8/2010	Water	Solids, Total Suspended (TSS)	30	mg/l	
N-11	4/15/2010	Water	Solids, Total Suspended (TSS)	59	mg/l	
N-11	5/5/2010	Water	Solids, Total Suspended (TSS)	4	mg/l	
N-11	7/1/2010	Water	Solids, Total Suspended (TSS)	83	mg/l	
N-11	9/13/2010	Water	Solids, Total Suspended (TSS)	116	mg/l	
N-11	10/6/2010	Water	Solids, Total Suspended (TSS)	98	mg/l	
N-11	12/20/2010	Water	Solids, Total Suspended (TSS)	26	mg/l	
N-11	1/27/2011	Water	Solids, Total Suspended (TSS)	14	mg/l	
N-11	3/8/2011	Water	Solids, Total Suspended (TSS)	27	mg/l	
N-11	4/12/2011	Water	Solids, Total Suspended (TSS)	97	mg/l	
N-11	5/24/2011	Water	Solids, Total Suspended (TSS)	42	mg/l	
N-11	6/9/2011	Water	Solids, Total Suspended (TSS)	107	mg/l	
N-11	8/15/2011	Water	Solids, Total Suspended (TSS)	118	mg/l	
N-11	8/31/2011	Water	Solids, Total Suspended (TSS)	7	mg/l	
N-11	10/19/2011	Water	Solids, Total Suspended (TSS)	62	mg/l	
N-11	11/30/2011	Water	Solids, Total Suspended (TSS)	25	mg/l	

StationCode	CollectionDate	Matrix	Analyte	Result_NUM	ResultUnits
N-06	23-Feb-04	Water	Solids, Total Suspended (TSS)	10	mg/l
N-06	22-Apr-04	Water	Solids, Total Suspended (TSS)	14	mg/l
N-06	17-May-04	Water	Solids, Total Suspended (TSS)	39	mg/l
N-06	29-Jun-04	Water	Solids, Total Suspended (TSS)	43	mg/l
N-06	09-Aug-04	Water	Solids, Total Suspended (TSS)	55	mg/l
N-06	07-Sep-04	Water	Solids, Total Suspended (TSS)	85	mg/l
N-06	21-Oct-04	Water	Solids, Total Suspended (TSS)	27	mg/l
N-06	13-Dec-04	Water	Solids, Total Suspended (TSS)	24	mg/l
N-06	02-Feb-05	Water	Solids, Total Suspended (TSS)	14	mg/l
N-06	02-Mar-05	Water	Solids, Total Suspended (TSS)	26	mg/l
N-06	29-Mar-05	Water	Solids, Total Suspended (TSS)	14	mg/l
N-06	04-May-05	Water	Solids, Total Suspended (TSS)	40	mg/l
N-06	15-Jun-05	Water	Solids, Total Suspended (TSS)	62	mg/l
N-06	31-Aug-05	Water	Solids, Total Suspended (TSS)	69	mg/l
N-06	17-Oct-05	Water	Solids, Total Suspended (TSS)	35	mg/l
N-06	5/13/2008	Water	Solids, Total Suspended (TSS)	7.5	mg/l
N-06	8/20/2008	Water	Solids, Total Suspended (TSS)	50.5	mg/l
N-06	9/3/2008	Water	Solids, Total Suspended (TSS)	62	mg/l
N-06	8/15/2006	Water	Solids, Total Suspended (TSS)	45	mg/l
N-06	9/19/2006	Water	Solids, Total Suspended (TSS)	58	mg/l
N-06	10/26/2006	Water	Solids, Total Suspended (TSS)	1	mg/l
N-06	12/11/2006	Water	Solids, Total Suspended (TSS)	11	mg/l
N-06	1/22/2007	Water	Solids, Total Suspended (TSS)	13	mg/l
N-06	6/16/2008	Water	Solids, Total Suspended (TSS)	65	mg/l
N-06	6/23/2008	Water	Solids, Total Suspended (TSS)	75	mg/l
N-06	7/22/2008	Water	Solids, Total Suspended (TSS)	101	mg/l
N-06	7/29/2008	Water	Solids, Total Suspended (TSS)	72	mg/l
N-06	8/4/2008	Water	Solids, Total Suspended (TSS)	63	mg/l
N-06	8/11/2008	Water	Solids, Total Suspended (TSS)	85	mg/l

STORET_Station	StartDate	USEPA STORET Name	Result Value	RemarkCode
NZM 01	1988-07-19	SULFATE, TOTAL (MG/L AS SO4)	808	
NZM 01	1988-08-09	SULFATE, TOTAL (MG/L AS SO4)	652	
NZM 01	1988-08-30	SULFATE, TOTAL (MG/L AS SO4)	658	
NZM 01	1988-07-19	HARDNESS, TOTAL (MG/L AS CACO3)	854	C
NZM 01	1988-08-09	HARDNESS, TOTAL (MG/L AS CACO3)	704	C
NZM 01	1988-08-30	HARDNESS, TOTAL (MG/L AS CACO3)	741	C
NZM 01	1988-07-19	CHLORIDE,TOTAL IN WATER MG/L	130	
NZM 01	1988-08-09	CHLORIDE,TOTAL IN WATER MG/L	100.4	
NZM 01	1988-08-30	CHLORIDE,TOTAL IN WATER MG/L	118	

STATION_I	ACTIVITY_START_DATE	ACTIVITY_I	CHARACTERISTIC_	SAMPLE_F	RESULT_V	ACTIVITY_DEPTH	ACTIVITY_I	DESCRIPTION_TEXT
RNZE-1	08/09/2002	Sediment	Phosphorus as P	Total	824	500.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	10/23/2002	Water	Phosphorus as P	Total	0.06	500.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	10/23/2002	Water	Phosphorus as P	Dissolved	0.013	500.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	10/23/2002	Water	Phosphorus as P	Dissolved	0.017	500.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	10/23/2002	Water	Phosphorus as P	Total	0.061	500.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	08/09/2002	Water	Phosphorus as P	Dissolved	0.011	406.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	08/09/2002	Water	Phosphorus as P	Total	0.09	406.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	07/16/2002	Water	Phosphorus as P	Dissolved	0.009	300.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	07/16/2002	Water	Phosphorus as P	Total	0.084	300.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	07/16/2002	Water	Phosphorus as P	Dissolved	0.008	300.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	07/16/2002	Water	Phosphorus as P	Total	0.083	300.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	06/07/2002	Water	Phosphorus as P	Dissolved	0.008	6.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	06/07/2002	Water	Phosphorus as P	Total	0.046	6.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	06/07/2002	Water	Phosphorus as P	Dissolved	0.011	6.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	06/07/2002	Water	Phosphorus as P	Total	0.047	6.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	04/02/2002	Water	Phosphorus as P	Dissolved	0.005	10.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	04/02/2002	Water	Phosphorus as P	Total	0.035	10.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	04/02/2002	Water	Phosphorus as P	Total	0.061	1.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	04/02/2002	Water	Phosphorus as P	Dissolved	0.021	1.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	08/09/2002	Water	Phosphorus as P	Dissolved	0.015	406.0	ft	SITE 1 T8SR3ENE27 NEAR DAM
RNZE-1	08/09/2002	Water	Phosphorus as P	Total	0.129	406.0	ft	SITE 1 T8SR3ENE27 NEAR DAM

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Attachment 2. 2015 IEPA Stage 2 Monitoring Data
2015 Upper Big Muddy River Watershed Data

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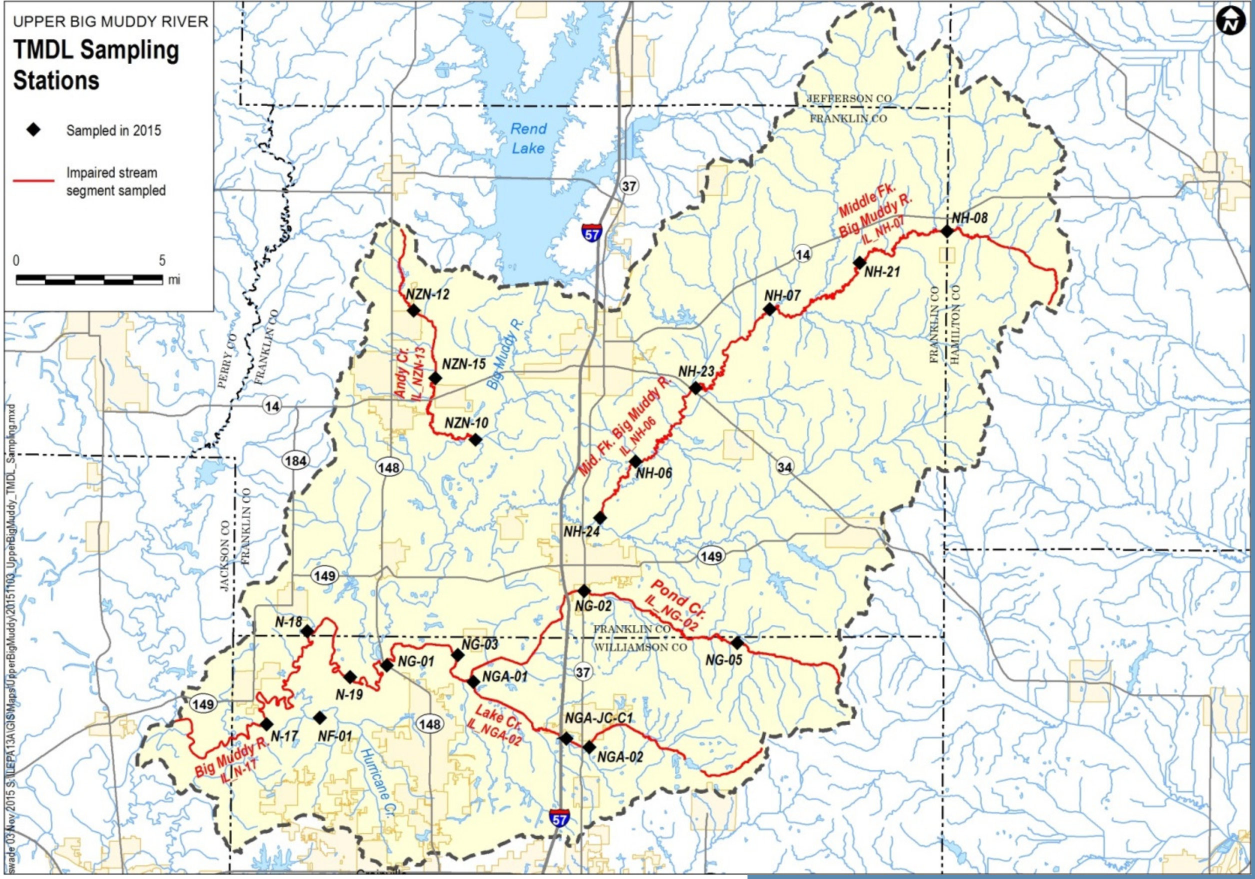

Stage 2 Report

for TMDL Sampling Activities in the Upper Big Muddy River Watershed, Illinois

Prepared for:
Illinois Environmental Protection Agency

March 2016

LimnoTech
Water Environment | Scientists Engineers

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Introduction

LimnoTech completed surface water sampling in September and October, 2015 to support Total Maximum Daily Load (TMDL) development for impaired waterbodies in the Upper Big Muddy River watershed. This report describes the field investigations and results of the sampling program. This report is divided into sections describing:

- Field investigation overview
- Water sample collection and field measurements
- Sediment oxygen demand and dissolved oxygen monitoring
- Quality assurance review

2

Field Investigation Overview

Monitoring was conducted within the Upper Big Muddy watershed in southern Illinois during summer 2015, in accordance with an Illinois EPA-approved Quality Assurance Project Plan (QAPP) (LimnoTech, 2014). Sampling was initially planned for summer/fall of 2014, but was delayed until 2015 due to wet conditions. Survey deployment in 2015 was based on real-time streamflow at United States Geological Survey (USGS) gages in and near the watershed.

The sampling and analysis activities included:

- collection of water samples for laboratory analysis;
- measurement of in-stream water quality and channel morphology parameters;
- stream discharge measurements;
- dissolved oxygen (DO) monitoring in the morning and afternoon; and
- sediment oxygen demand (SOD) measurements.

Water samples, stream and discharge measurements were collected from the selected locations during both events. SOD and morning/afternoon DO measurements were conducted at a subset of locations in each watershed.

Following the completion of field investigation and laboratory analysis activities, the generated data were compiled and a quality assurance review was conducted to assess data quality and usability.

Table 2-1 describes the sampling stations and presents field notes. One of the locations (NH-24) was inaccessible due to the presence of a locked access road gate with a no trespassing sign and was not sampled. Sampling locations are mapped in Figure 2-1.

Tables 2-2 and 2-3 present a summary of sampling conducted at each location during round 1 and round 2, respectively

Table 2-1. Sampling Locations in the Upper Big Muddy River Watershed

Stream	Access	TMDL Station ID	Notes regarding flow conditions and accessibility
Middle Fork Big Muddy	Deering Road/Co. Hwy. 5	NH-06	
Middle Fork Big Muddy	Illinois State Hwy. 34	NH-23	
Middle Fork Big Muddy	Unnamed lane west of Deering Road/Co. Hwy. 5 at W. Neal Rd	NH-24	Not accessible; locked access road gate/no trespassing sign
Middle Fork Big Muddy	Macedonia Road/Co. Hwy. 18/Co. Hwy 34	NH-08	
Middle Fork Big Muddy	N. Thompsonville Road/Co. Hwy. 17	NH-21	
Middle Fork Big Muddy	Bessie Road/Co. Hwy. 2	NH-07	
Andy Creek	Satch Road	NZN-15	
Andy Creek	Park Street Rd/Co. Hwy. 37	NZN-12	
Andy Creek	Forest cut/path north of Yellow Banks Road/Co. Hwy. 11 and west of Big Muddy River	NZN-10	
Big Muddy River	Cambria Road/Co. Hwy. 9	N-17	Higher than desirable flows
Big Muddy River	Pump Station Road/Lane	N-18	Higher than desirable flows; Not accessible during round 1 sampling.
Big Muddy River	Unnamed lane north of Clifford Road at Big Muddy Road	N-19	Higher than desirable flows
Hurricane Creek	N. Bend Road	NF-01	
Pond Creek	Illinois State Hwy. 148	NG-01	
Pond Creek	Freeman Spur Road	NG-03	
Pond Creek	Illinois State Hwy. 37	NG-02	
Pond Creek	Liberty School Road	NG-05	
Lake Creek	Stiritz Road	NGA-01	
Lake Creek	Binkley Road	NGA-02	
Lake Creek	Prosperity Road/Co. Hwy. 1	NGA-JC-C1	

Table 2-2. Round 1 Sampling Summary

Stream	Station ID	NH3, TKN, TP, oP, CBOD5, Chla, DO, water temp.	Flow (depth, velocity, channel morphometry)	SOD, DO (am and pm)
Middle Fork Big Muddy	NH-06	X	X	DO (am, pm) [no access for SOD measurement]
Middle Fork Big Muddy	NH-23	X	X	SOD, DO (2 am)
Middle Fork Big Muddy	NH-24	No access, locked gate/no trespassing sign		
Middle Fork Big Muddy	NH-08	X	X	
Middle Fork Big Muddy	NH-21	X	X	
Middle Fork Big Muddy	NH-07	X	X	SOD (alt. for NH-06)
Andy Creek	NZN-15	X	X	SOD, DO (am, pm)
Andy Creek	NZN-12	X	X	
Andy Creek	NZN-10	X	X	
Big Muddy River	N-17	X	No - Equipment failure	DO (am, pm) [no SOD-unsuitable substrate]
Big Muddy River	N-18	No access, locked gate/no trespassing sign		
Big Muddy River	N-19	X	No bridge access, unsafe to wade	SOD (alt. for N-17)
Hurricane Creek	NF-01	X	X	
Pond Creek	NG-01	X	X	
Pond Creek	NG-03	X	X	
Pond Creek	NG-02	X	X	SOD, DO (am, pm)
Pond Creek	NG-05	X	X	
Lake Creek	NGA-01	X	X	
Lake Creek	NGA-02	X	X	SOD, DO (am, pm)
Lake Creek	NGA-JC-C1	X	X	

Notes:

- NH3 (ammonia), TKN (Total Kjeldahl Nitrogen), TP (Total Phosphorus), op (ortho phosphorus), CBOD5 (5-day carbonaceous biochemical oxygen demand), Chla (chloropyll a), DO (Dissolved oxygen), SOD (sediment oxygen demand)
- Alternate locations were used for SOD as follows (NH-07 in place of NH-06; N-19 in place of N-17) for reasons described above.

Table 2-3. Round 2 Sampling Summary

Stream	Station ID	NH3, NO3, TKN, TP, oP, CBOD5, DO, water temp.	Flow (depth, velocity, channel morphometry)
Middle Fork Big Muddy	NH-06	X + Chla	X
Middle Fork Big Muddy	NH-23	X + Chla	X
Middle Fork Big Muddy	NH-24	No access, locked gate/no tresspassing sign	
Andy Creek	NZN-15	X	X
Andy Creek	NZN-12	X	X
Andy Creek	NZN-10	X	X
Big Muddy River	N-17	DO/water temp. only	X
Big Muddy River	N-18	X + Chla	
Big Muddy River	N-19	DO/water temp. only	

Notes:

- NH3 (ammonia), NO3 (nitrate), TKN (Total Kjeldahl Nitrogen), TP (Total Phosphorus), oP (ortho phosphorus), CBOD5 (5-day carbonaceous biochemical oxygen demand), Chla (chloropyll a), DO (Dissolved oxygen), SOD (sediment oxygen demand)

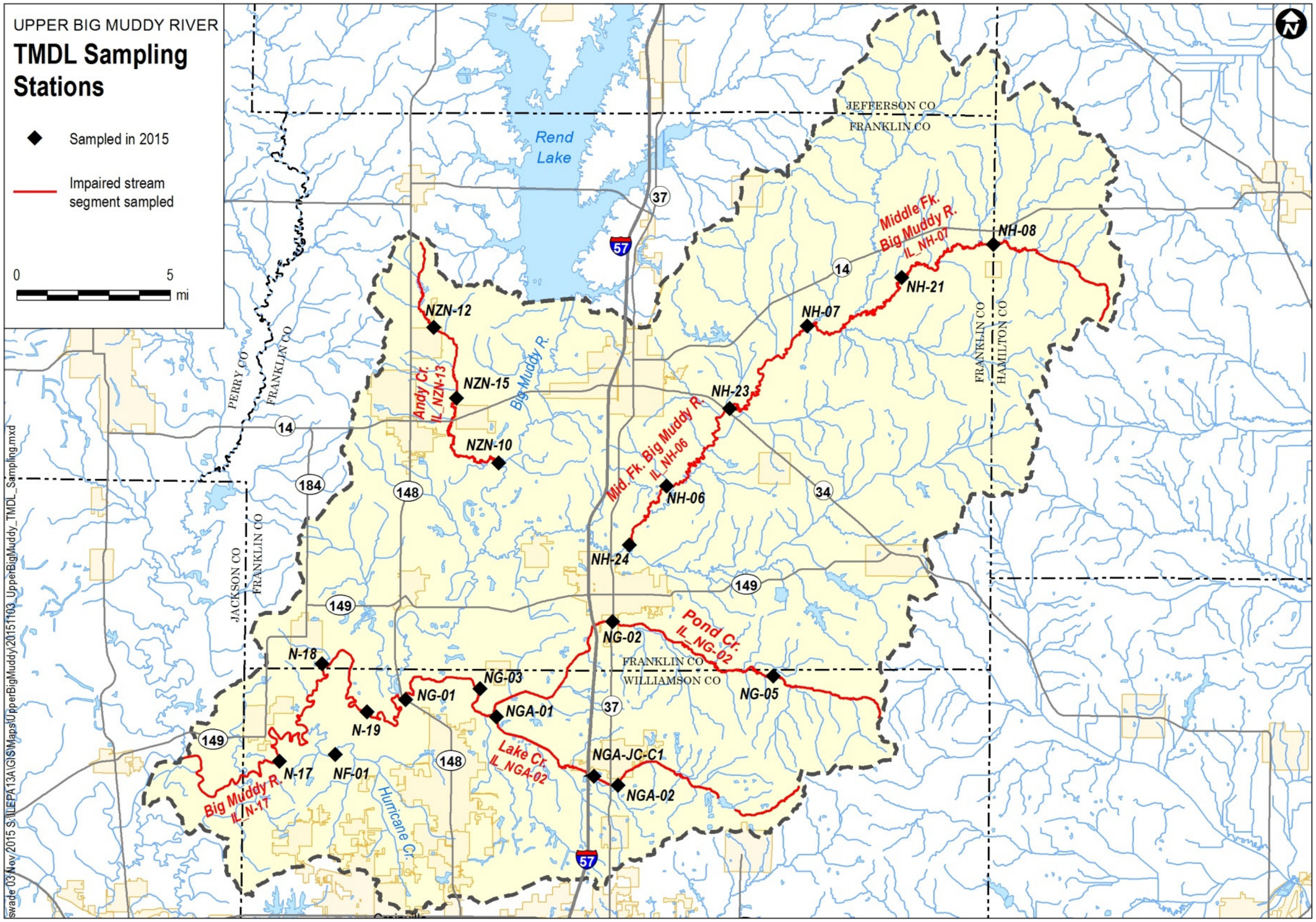

Figure 2-1 Upper Big Muddy River Watershed Sampling Locations

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Water Sample Collection and Field Measurements

Sampling activities were conducted in accordance with the QAPP during low flow conditions on two separate occasions (Round 1 and Round 2), with the exception of the Big Muddy River segment sampling locations which were at higher than median flows for both rounds of sampling. Stream segments impaired due to low dissolved oxygen were sampled twice if a permitted point source discharge was being considered as a potential source contributing to low dissolved oxygen. This assessment was based on an evaluation of point source discharge locations compared to IEPA sampling locations that the impairment assessments were based on. For example, if a stream segment is impaired due to low dissolved oxygen, but the impairment determination was based on data collected upstream of all point sources to that segment, then the stream was only sampled once.

Surface water samples and field measurements were collected at 19 stream locations (out of a possible 20 planned locations); Two locations (N-18, NH-24) were not sampled due to lack of access during the first round of sampling and one location (NH-24) was not sampled due to lack of access during the second round of sampling. The Big Muddy River was flowing above median levels for both sampling rounds, though at lower flows during the second round. All other stream locations were at low flows; generally flowing during the first round of sampling and generally not flowing during the second round of sampling. Water level conditions observed in the field are noted in Table 2-1.

Field instruments were used to measure in-situ water quality parameters, and TriMatrix Laboratories in Grand Rapids, Michigan, conducted all laboratory analyses except those for Chlorophyll a, which were conducted by the Great Lakes Environmental Center (GLEC) in Traverse City, Michigan under subcontract to TriMatrix. At all locations, water samples were collected for laboratory analysis of ammonia ($NH3$), total kjeldahl nitrogen (TKN), total phosphorus (TP), ortho phosphorus (oP), 5-day carbonaceous biochemical oxygen demand ($CBOD_5$) and chlorophyll a (Chla). During the second round of sampling, nitrate ($NO3$) analysis was added and Chla was only sampled at the Big Muddy and Middle Fork Big Muddy locations. Field measurements included dissolved oxygen (DO), water temperature (T), channel morphometry (water depth and width) and discharge measurements. Discharge was recorded using standard USGS techniques employing an electromagnetic point velocity meter (Marsh–McBirney Flo-Mate 2000) and a bridgeboard or a wading rod. Information supporting flow calculation was recorded in field notebooks and included:

- Site location,
- Date and time,
- Measurement monitoring point,
- Distance between measurement points,
- Depth at each measurement point,
- Velocities at each measurement point, and
- Any significant observations of monitoring procedures or river conditions.

Round 1 laboratory analytical and field measurement results are presented in Tables 3-1 and 3-2, respectively. Round 1 channel morphometry and discharge measurement results are presented in Table 3-3.

Round 2 laboratory analytical and field measurement results are presented in Tables 3-4 and 3-5, respectively. Round 2 channel morphometry and discharge measurement results are presented in Table 3-6.

Table 3-1. Round 1 Laboratory Analytical Results

Sample ID	Sample Collection Date Time	CBOD5 (mg/L)	Chla (mg/L)	NH3 (mg/L)	TKN (mg/L)	oP (mg/L)	TP (mg/L)
Middle Fork Big Muddy River							
NH-06	9/22/2015 13:20	8.9	0.04571	<0.050	1.1	0.03	0.122
NH-07	9/22/2015 11:20	<2.0	0.03011	<0.050	0.68	0.044	0.124
NH-08	9/22/2015 16:20	<2.0	0.01157	0.27	1.1	0.033	0.102
NH-21	9/22/2015 15:30	3.5	0.01669	<0.050	1.1	0.018	0.112
NH-23	9/22/2015 14:30	2.1	0.01375	<0.050	0.71	0.042	0.103
Big Muddy River							
N-17	9/23/2015 14:20	2.3	0.02903	0.068	0.73	0.111	0.252
N-19	9/23/2015 16:30	2.5	0.02954	0.069	0.94	0.128	0.228
Andy Creek							
NZN-10	9/23/2015 11:05	<2.0	0.00486	0.26	1.1	0.457	0.582
NZN-12	9/23/2015 10:15	<2.0	0.00467	0.061	0.63	0.047	0.0807
NZN-15	9/23/2015 9:30	<2.0	0.00352	0.47	1.2	0.214	0.245
DUP-1 (NZN-15)	9/23/2015 9:30	<2.0	0.0046	0.45	1.1	0.187	0.229
Hurricane Creek							
NF-01	9/23/2015 18:00	<2.0	0.00173	0.056	<0.50	0.125	0.161
Pond Creek							
NG-01	9/24/2015 11:30	<2.0	0.00166	0.06	0.66	0.109	0.174
NG-02	9/24/2015 9:20	5	0.03452	<0.050	0.84	<0.0100	0.132
DUP-2 (NG-02)	9/24/2015 9:20	5.4	0.03874	<0.050	1.1	<0.0100	0.132
NG-03	9/24/2015 10:00	<2.0	0.00806	0.051	0.66	0.091	0.135
NG-05	9/24/2015 16:40	2.6	0.02832	1.4	2	<0.0100	0.0565
Lake Creek							
NGA-01	9/24/2015 12:30	<2.0	0.02161	<0.050	0.53	0.133	0.151
NGA-02	9/24/2015 15:10	<2.0	0.00332	<0.050	<0.50	<0.0100	0.0218
NGA-JC-C1	9/24/2015 16:00	<2.0	0.00511	8.9	9.9	2.43	2.41
Field Blank Samples							
FB-1	9/22/2015 11:15	<2.0	<0.0003	0.2	<0.50	<0.0100	<0.0100
FB-2	9/24/2015 7:15	<2.0	<0.0003	<0.050	<0.50	<0.0100	<0.0200

Analyte Codes:
CBOD5 – Carbonaceous Biochemical Oxygen Demand
Chla – Chlorophyll a
NH3 – Ammonia Nitrogen
TKN – Total Kjeldahl Nitrogen
oP – ortho phosphorus
TP – Total Phosphorus

Table 3-2. Round 1 Field Measurement Results

Station	Collection Date Time	Dissolved Oxygen (mg/L)	Water Temperature (degC)
Middle Fork Big Muddy River			
NH-06	9/22/2015 12:18	12.03	19.72
NH-06	9/22/2015 18:15	13.32	20.36
NH-07	9/22/2015 10:11	6.06	19.1
NH-07	9/22/2015 10:16	6.31	19.1
NH-07	9/22/2015 11:20	6.86	19.64
NH-08	9/22/2015 16:20	3.04	19.11
NH-21	9/22/2015 15:30	4.87	21.18
NH-23	9/22/2015 14:30	7.91	19.31
NH-23	9/22/2015 17:53	9.75	21.6
Big Muddy River			
N-17	9/23/2015 7:32	7.43	21.19
N-17	9/23/2015 14:20	8.58	24.44
N-19	9/23/2015 16:47	8.36	22.6
N-19	9/23/2015 17:23	8.04	23.3
N-19	9/23/2015 17:30	8.05	23
Andy Creek			
NZN-10	9/23/2015 11:19	1.9	20.53
NZN-12	9/23/2015 10:15	4.47	17.6
NZN-15	9/23/2015 8:40	1.88	16.8
NZN-15	9/23/2015 8:49	1.6	16.7
NZN-15	9/23/2015 9:36	2.15	17.04
NZN-15	9/23/2015 12:20	1.94	18.5
Hurricane Creek			
NF-01	9/23/2015 18:01	7.84	20.97
Pond Creek			
NG-01	9/24/2015 11:30	9.12	19.47
NG-02	9/24/2015 8:44	7.54	17.7
NG-02	9/24/2015 8:45	7.35	17.7
NG-02	9/24/2015 9:27	7.08	17.65
NG-02	9/24/2015 14:19	14.77	25.97
NG-03	9/24/2015 10:03	6.52	19.01
NG-05	9/24/2015 16:47	15.33	20.65
Lake Creek			
NGA-01	9/24/2015 12:30	8.9	19.74
NGA-02	9/24/2015 7:52	7.01	17.14
NGA-02	9/24/2015 14:54	6.75	20.1
NGA-02	9/24/2015 15:00	7.49	21.3
NGA-02	9/24/2015 15:27	8.83	25.33
NGA-JC-C1	9/24/2015 16:03	3.5	20.76

Table 3-3. Round 1 Channel Morphometry and Flow

Station	Date	Stream Width (ft)	Average Water Depth (ft)	Average Velocity (ft/s)	Water Area (ft2)	Discharge (ft3/s)
Middle Fork Big Muddy River						
NH-08	9/22/2015 16:30	34	1.99	0.04	67.5	2.68
NH-21	9/22/2015 15:40	77	1.53	0.04	117.5	3.64
NH-07	9/22/2015 10:30	68	4.09	0.05	278.0	13.04
NH-23	9/22/2015 14:45	70	3.91	0.03	274.0	8.13
NH-06	9/22/2015 12:30	318	1.30	0.03	412.0	15.42
Andy Creek						
NZN-12	9/23/2015 10:20	20	0.24	0.00	4.8	0.01
NZN-15	9/23/2015 9:10	18	0.60	0.03	10.8	0.32
NZN-10	9/23/2015 11:10	14	0.43	0.03	6.0	0.21
Lake Creek						
NGA-02	9/24/2015 15:35	16	1.15	0.04	18.4	0.75
NGA-JC-C1	9/24/2015 16:00	17	1.04	0.03	17.6	0.68
NGA-01	9/24/2015 12:40	25	0.40	0.45	10.0	5.54
Pond Creek						
NG-05	9/24/2015 16:50	25	1.10	0.06	27.6	1.90
NG-02	9/24/2015 8:55	29	0.87	0.08	25.2	2.24
NG-03	9/24/2015 10:15	44	2.48	0.07	109.2	7.23
NG-01	9/24/2015 11:45	32	1.86	0.05	59.6	3.43
Hurricane Creek						
NF-01	9/23/2015 18:10	18	0.31	0.37	5.6	1.88
Big Muddy River						
N-17	9/23/2015 14:50	70	Not measured - equipment failure			

Table 3-4. Round 2 Laboratory Analytical Results

Sample ID	Sample Collection Date Time	CBOD5 (mg/L)	Chla (mg/L)	NO3 (mg/L)	NH3 (mg/L)	TKN (mg/L)	oP (mg/L)	TP (mg/L)
Andy Creek								
NZN-10	10/14/2015 13:15	<2.0	n/a	<0.050	0.39	1.1	0.449	0.479
NZN-12	10/14/2015 11:45	<2.0	n/a	<0.050	<0.050	0.51	0.115	0.154
DUP-3 (NZN-12)	10/14/2015 11:45	<2.0	n/a	<0.050	<0.050	0.52	0.114	0.162
NZN-15	10/14/2015 12:20	<2.0	n/a	0.065	1.7	2.9	0.276	0.33
Big Muddy River								
N-18	10/14/2015 9:00	2.5	0.032	0.56	<0.050	0.86	0.119	0.189
Middle Fork Big Muddy River								
NH-06	10/14/2015 15:40	2.5	0.0094	0.29	<0.050	0.66	0.072	0.113
NH-23	10/14/2015 14:00	2.4	0.02	0.49	<0.050	0.84	0.049	0.108
Field Blank								
FB-3	10/14/2015 11:30	<2.0	<0.0003	<0.050	<0.050	<0.50	<0.0100	<0.0100

Analyte Codes:

CBOD5 – Carbonaceous Biochemical Oxygen Demand
Chla – Chlorophyll a
NO3 – Nitrate Nitrogen
NH3 – Ammonia Nitrogen
TKN – Total Kjeldahl Nitrogen
oP – ortho phosphorus
TP – Total Phosphorus
n/a – not analyzed

Table 3-5. Round 2 Field Measurement Results

Station	Collection Date Time	Dissolved Oxygen (mg/L)	Water Temperature (degC)
Middle Fork Big Muddy River			
NH-06	10/14/2015 15:45	4.81	16.4
NH-23	10/14/2015 14:00	6.56	15.2
Big Muddy River			
N-17	10/14/2015 10:00	8.36	16.6
N-18	10/14/2015 9:00	7.64	16.9
N-19	10/14/2015 8:00	7.76	16.8
Andy Creek			
NZN-10	10/14/2015 13:15	2.45	16.2
NZN-12	10/14/2015 11:30	6.79	13
NZN-15	10/14/2015 12:20	1.49	14

Table 3-6. Round 2 Channel Morphometry and Flow

Station	Date	Stream Width (ft)	Average Water Depth (ft)	Average Velocity (ft/s)	Water Area (ft2)	Discharge (ft3/s)
Middle Fork Big Muddy River						
NH-23	10/14/2015 14:30	73	4.38	0.01	320.10	5.97
NH-06	10/14/2015 14:30	80	2.78	0.00	222.00	0.00
Andy Creek						
NZN-12	10/14/2015 11:50	21	0.42	0.00	8.80	0.00
NZN-15	10/14/2015 12:25	28	0.89	0.03	25.00	0.69
NZN-10	10/14/2015 13:20	18	0.67	0.01	12.00	0.16
Big Muddy River						
N-17	10/14/2015 10:19	52	1.37	1.89	71.40	146.06

4

Sediment Oxygen Demand and Dissolved Oxygen Monitoring

Sediment oxygen demand and dissolved oxygen were measured at select locations representative of river conditions in each watershed during the first round of sampling. SOD respirometer chambers were installed in accordance with the QAPP, and DO measurements during SOD testing were manually recorded in the field notes for a period of 2 hours or until DO dropped by 2 mg/L or to zero mg/L. The data were used to calculate SOD rates for use in the DO modeling activities. The SOD rate results are presented in Table 4-1.

Dissolved oxygen (DO) readings were recorded in the morning and the afternoon at select locations using optical dissolved oxygen sensors. The DO sensors were calibrated every morning on the days of sampling using the percent air saturation method in accordance with the manufacturer's operation manual.

The diurnal DO data are presented in Table 4-2.

Table 4-1. Sediment Oxygen Demand

Date	Site ID	Location	SOD, g/m2/day @ 20c (2)
9/22/2015	NH-07	Middle Fork Big Muddy River	-0.3789
9/22/2015	NH-23	Middle Fork Big Muddy River	-1.8326
9/23/2015	NZN-15	Andy Creek	-0.6979
9/24/2015	NG-02	Lake Creek	-1.4260
9/24/2015	NGA-02	Pond Creek	-0.8503
9/23/2015	N-19	Big Muddy River	-2.3607

Table 4-2. Diurnal Dissolved Oxygen Measurements

Station	Collection Date Time	Dissolved Oxygen (mg/L)
Middle Fork Big Muddy River		
NH-06	9/22/2015 12:18	12.03
NH-06	9/22/2015 18:15	13.32
NH-23	9/22/2015 14:30	7.91
NH-23	9/22/2015 17:53	9.75
Big Muddy River		
N-17	9/23/2015 7:32	7.43
N-17	9/23/2015 14:20	8.58
N-19	9/23/2015 17:30	8.05
Andy Creek		
NZN-15	9/23/2015 9:36	2.15
NZN-15	9/23/2015 12:20	1.94
Pond Creek		
NG-02	9/24/2015 8:44	7.54
NG-02	9/24/2015 8:45	7.35
NG-02	9/24/2015 9:27	7.08
NG-02	9/24/2015 14:19	14.77
Lake Creek		
NGA-02	9/24/2015 7:52	7.01
NGA-02	9/24/2015 14:54	6.75
NGA-02	9/24/2015 15:00	7.49
NGA-02	9/24/2015 15:27	8.83

5

Quality Assurance Review

A review was conducted to assess the quality and usability of data generated from implementation of the work activities and to assess adherence to protocols specified in the QAPP. Field and laboratory methods were reviewed and found to be in accordance with the QAPP; however, certain changes to sampling and analysis activities were implemented that deviated from the sampling plan presented in the QAPP and are documented in this section. Field measurement data and laboratory analytical data were verified and validated in accordance with the QAPP.

Overall, the data generated are of satisfactory quality and suitable for the intended uses, which include stream characterization and modeling for TMDL development. Some of the data, though acceptable for use, are qualified because of deficiencies in field or laboratory quality control procedures or conditions. Other data, though not specifically flagged with a data qualifier, are associated with uncertainties that prompt caution in their use. These are discussed in this section.

The following subsections of this document present the deviations, deficiencies and cautions associated with the data generated during the investigations. These subsections include the sampling plan changes implemented during the course of the investigation and the results of the data verification and data validation activities.

5.1 Changes from Sampling Plan (QAPP)

The QAPP was approved in September 2014 and contains the sampling plan for the investigations described in this report. Sampling was originally scheduled to occur during 2014 but was delayed a year because of unsuitably high flow conditions in the Upper Big Muddy River system. During this period of delay and prior to the sampling and analysis activities conducted in 2015, certain changes were made to the sampling plan or sampling protocols specified in the QAPP as noted in the following list. The QAPP was not updated to reflect these changes which are instead documented in this section of this report.

- The laboratory was changed to TriMatrix (and GLEC) from Brighton Analytical. The change in laboratories resulted in a change in reporting limits for ammonia (from 0.01 to 0.05 mg/L) and total Kjeldahl nitrogen (from 0.1 to 0.5 mg/L). The reporting limits used for data validation are included in Table 5-2 of this report. These reporting limit changes did not affect the usability of the data for the Stage 3 modeling activities.
- Chlorophyll a analyses were added to evaluate possible effects of phytoplankton on dissolved oxygen levels.
- It was planned that nitrate be dropped from the analytical list as it is not essential for the Stage 3 modeling activities; however, it was analyzed for the second sampling event conducted in October 2015. The omission of nitrate analysis for the first sampling event in September 2015 does not affect the usability or completeness of the data.

- Changes in sampling locations occurred as NH-24 and N-18 were not accessible during Round 1 and NH-24 was not accessible during round 2, but N-18 was. Inaccessibility was caused by locked access gates with no trespassing signs and unavailability of contact personnel to gain access.
- The low flow condition threshold was exceeded for the Big Muddy River during both sampling rounds but sampled tributaries to the Big Muddy River were at acceptable low flow conditions.
- SOD measurements were moved from the planned location of NH-06 to the alternate location of NH-07 because there was no safe access to the main channel river banks at NH-06. In addition, SOD measurements were moved from the planned location of N-17 to the alternate location of N-19 because of inability to properly seat the respirometers at the N-17 location related to the presence of cobbles in the river bottom sediments that were at accessible wading depths.

5.2 Data Verification and Validation

The data generated are of overall good quality and acceptable for use with some qualifications as discussed below.

Completeness. The completeness criterion of 90% in the QAPP was met. One station (NH-24) out of 20 (26 stations total, if repeat visits counted) was not sampled during both events because of lack of access. All other locations were sampled with 100% analysis of samples submitted to the laboratory.

Accuracy and Precision. All quality control results for accuracy (method blank, lab control samples) and precision (lab and field duplicates) were within the control limits stated in the QAPP.

Representativeness. Representativeness was achieved through the use of standard operating procedures for sample collection and handling activities and laboratory analysis and reporting activities.

Discharge data. All stream discharge results are acceptable for use. Discharge was not measured at locations that were unsafe to wade or had no bridge access. These included N-17, N-18 and N-19 during the first sampling event. N-17 flows could not be measured from the bridge because of an equipment failure, while wading techniques at all three stations couldn't be employed because of unsafe water velocities, depths and/or mucky bottoms. N-17 flow measurements were successfully obtained during the second sampling event.

Laboratory QC data. All sample analytical results are acceptable for use.

- The holding time of 24 hours from sample collection to sample filtration was slightly exceeded for event 1 chlorophyll a analyses of NZN-15 (and DUP-1), FB-2, and NG-02 (and DUP-2) and for event 2 chlorophyll a analyses of N-18; however, the results for these samples are considered acceptable for their planned use.
- The matrix spike (MS) or matrix spike duplicate (MSD) recovery, but not both, was outside the control limits for the round 1 event ortho phosphorus analysis of NZN-15 and the round 2 event total kjeldahl nitrogen analysis in N-18. In both cases, the MS/MSD relative percent difference (RPD) was within the control limit. No action is required for deficient MS results and the sample results are considered acceptable for the planned use.
- The calibration reporting limit standard (CRL) recovery was outside control limits for the 10/14/2015 samples analyzed for nitrate, ammonia and total phosphorus. The method QC was within the limits. CRL recovery issues are not a cause for qualification per the method.

Field QC data. Field quality control (QC) samples were collected to assess bias associated with field and laboratory methods. The field QC samples included three rinse blank samples and three field duplicate sample pairs. The results of these analyses are presented below.

- **Rinse Blanks.** All field rinse blank sample results were below the detection limit with the exception of ammonia at 0.2 mg/L in the FB-1 sample collected at 9/22/2015 at 11:15. This ammonia result most likely did not impact the NH-07 sample collected at 9/22/2015 at 11:20. All samples were collected after cleaning the sample collection bucket by employing a detergent wash followed by a distilled water triple rinse, followed by a sample water rinse immediately prior to collection of the stream water sample. Based on the sample equipment cleaning procedures, it is unlikely that cross-contamination occurred in any environmental sample.
- **Duplicates.** The duplicate results were all acceptable with relative percent differences below the precision criterion (20%) specified in the QAPP. The duplicate sample quality assurance results are presented in Table 5-1. For the purposes of submitting field duplicate results in accordance with IEPA-formatting requirements for the Station Code field, one minute was added to the sample collection time to distinguish between duplicate samples, as approved by the IEPA project manager.

Table 5-1. Field Duplicate Pair Sample Results

Sample ID	$CBOD_5$ (mg/L)	Chl a	NH3 (mg/L)	NO3 (mg/L)	TKN (mg/L)	oP (mg/L)	TP (mg/L)
Round 1 Results							
NZN-15	<2	0.00352	0.47	n/a	1.2	0.214	0.245
DUP-1 (NZN-15)	<2	0.0046	0.45	n/a	1.1	0.187	0.229
RPD (%)		6.7	1.1	n/a	2.2	3.4	1.7
NG-02	5	0.03452	<0.05	n/a	0.84	<0.01	0.132
DUP-2 (NG-02)	5.4	0.03874	<0.05	n/a	1.1	<0.01	0.132
RPD (%)	1.9	2.9			6.7		0.0
Round 2 Results							
NZN-12	<2.0	n/a	<0.050	<0.050	0.51	0.115	0.154
DUP-3 (NZN-12)	<2.0	n/a	<0.050	<0.050	0.52	0.114	0.162
RPD (%)					0.5	0.2	1.3

*RPD= |S-D| x100 / (S+D)/2 where S: original sample; D: Duplicate sample

n/a – not analyzed

Conformance to Data Quality Objectives. Overall, the data generated during the investigation conformed to the project data quality objectives (DQOs) and are suitable for their intended uses. The monitored parameters were evaluated in terms of minimum measurement criteria, minimum measurement objectives, required detection limits, accuracy, precision and completeness using the DQOs presented in the project QAPP. Table 5-2 summarizes the results of the DQO quality assurance (QA) check.

The QA check shows apparent deficiencies with reporting limits for NH3, TKN and TP results; however, the values reported are subject to laboratory capabilities and also are deemed satisfactory for the intended use of the data. The completeness criteria reflect the number of samples and measurements that were originally planned; however, as noted previously, one location (NH-24) on private property was unable to be accessed and an alternate location is not available.

November 2015

Table 5-2. Measurement Objectives and Criteria Check

					Matrix Spike/Matrix Spike Duplicate *				Lab Control Sample *			
Parameter	**Minimum Measurement Criteria**	**Minimum Measurement Objectives**	**Method *; MDL/Reporting Limit[1]**	**QA Check ****	**Accuracy (% recovery)**	**QA Check ****	**Precision (RPD)**	**QA Check ****	**Accuracy (% recovery)**	**QA Check ****	**Completeness**	**QA Check ****
Dissolved Oxygen	NA	0.1 mg/L[S]	Optical sensor; 0.1 mg/l [S]	Sat	NA	NA	NA	NA	NA	NA	90%	92.3%
Water Temperature	NA	0.1 degree C[S]	Thermometer; 0.1 degree C [S]	Sat	NA	NA	NA	NA	NA	NA	90%	92.3%
Ammonia	15.0 mg/L[G]	3.0 mg/L	SM4500NH3G; 0.009 mg/l / 0.01 mg/l	Sat (RL=0.05 mg/l)	80-120%	Sat	20%	Sat	80-120%	Sat	90%	92.3%
Total Kjeldahl Nitrogen	No Standard		EPA 351.2; 0.09 mg/l / 0.1 mg/l	Sat (RL=0.5 mg/l)	80-120%	Sat	20%	Sat	80-120%	Sat	90%	92.3%
Nitrate	No Standard		EPA 300.0 0.005 mg/l / 0.05 mg/l	Sat	80-120%	Sat	20%	Sat	80-120%	Sat	90%	NA***
Total Phosphorus	0.05 mg/L[G]	0.01 mg/L	SM4500PE; 0.008 mg/l / 0.01 mg/l	Sat (RL=0.01 to 0.02 mg/l)	80-120%	Sat	20%	Sat	80-120%	Sat	90%	92.3%
Ortho phosphorus	No Standard		SM4500PE; 0.008 mg/l / 0.01 mg/l	Sat	80-120%	Sat	20%	Sat	80-120%	Sat	90%	92.3%
cBOD$_5$	No Standard		SM5210B; NA / 2 mg/l	Sat	NA	NA	20%[a]	Sat	N/A	Sat	90%	92.3%
Chlorophyll a	No Standard		SM10200H 0.0003 mg/l / 0.0007 mg/l	Sat	80-120%	Sat	20%	Sat	80-120%	Sat	90%	92.3%

NA = Not Applicable   SM - Standard Methods of the Examination of Water and Wastewater, 20th Edition
S = Required sensitivity   EPA - EPA Methods for Chemical Analysis of Water and Wastes, March 1983
* = Limits reported in the QAPP are subject to change based upon capabilities of the contract lab
1 = Method Detection Limit (MDL) from SM and EPA.
G = State of Illinois General Use Water Quality Standard
a = Precision will be evaluated using laboratory replicates rather than MS/MSD

** = These columns document the results of the QA review and changes in the laboratory reporting limits (RL)

Sat = QA check is satisfactory, criterion met

***Nitrate is not an essential analyte for the Stage 3 modeling

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References

Illinois Environmental Protection Agency (IEPA). 2012. *Illinois Integrated Water Quality Report and Section 303(D) List, 2012*. Clean Water Act Sections 303(d), 305(b) and 314 Water Resource Assessment Information and List of Impaired Waters Volume I: Surface Water. Bureau of Water, Division of Water Pollution Control. Springfield, Illinois.

LimnoTech, 2014. Quality Assurance Project Plan for TMDL Sampling Activities in the Upper Big Muddy River Watershed, Illinois. Prepared by LimnoTech for Illinois EPA. September 2014; Revised November 2015.

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Attachment 3:

QUAL2E Model Files

Calibration input

Calibration output

```
TITLE01             Andy Creek DO TMDL ILEPA13A
TITLE02             Setup run for 9/23/2015
TITLE03   NO        CONSERVATIVE MINERAL   I
TITLE04   NO        CONSERVATIVE MINERAL  II
TITLE05   NO        CONSERVATIVE MINERAL III
TITLE06  YES        TEMPERATURE
TITLE07  YES        5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES        ALGAE AS CHL-A IN UG/L
TITLE09  YES        PHOSPHORUS CYCLE AS P IN MG/L
TITLE10               (ORGANIC-P; DISSOLVED-P)
TITLE11  YES        NITROGEN CYCLE AS N IN MG/L
TITLE12               (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES        DISSOLVED OXYGEN IN MG/L
TITLE14   NO        FECAL COLIFORM IN NO./100 ML
TITLE15   NO        ARBITRARY NON-CONSERVATIVE
ENDTITLE
LIST DATA INPUT
NOWRITE OPTIONAL SUMMARY
NO FLOW AUGMENTATION
STEADY STATE
NO TRAPEZOIDAL CHANNELS
NO PRINT LCD/SOLAR DATA
NO PLOT DO AND BOD
FIXED DNSTM CONC (YES=1)=         0         5D-ULT BOD CONV K COEF  =      0.230
INPUT METRIC            =         0         OUTPUT METRIC           =          0
NUMBER OF REACHES       =         2         NUMBER OF JUNCTIONS     =          0
NUM OF HEADWATERS       =         1         NUMBER OF POINT LOADS   =          1
TIME STEP (HOURS)       =         1         LNTH. COMP. ELEMENT (MI)=       0.25
MAXIMUM ROUTE TIME (HRS)=        60         TIME INC. FOR RPT2 (HRS)=        1.0
LATITUDE OF BASIN (DEG) =     38.02         LONGITUDE OF BASIN (DEG)=     -89.04
STANDARD MERIDIAN (DEG) =         0         DAY OF YEAR START TIME  =        266
EVAP. COEF.,(AE)        =   0.00068         EVAP. COEF.,(BE)        =    0.00027
ELEV. OF BASIN (ELEV)   =       373         DUST ATTENUATION COEF.  =       0.06
ENDATA1
O UPTAKE BY NH3 OXID(MG O/MG N)=   3.43  O UPTAKE BY NO2 OXID(MG O/MG N)=   1.14
O PROD  BY ALGAE (MG O/MG A)   =    1.8  O UPTAKE BY ALGAE (MG O/MG A)  =   1.90
N CONTENT OF ALGAE (MG N/MG A) =   0.09  P CONTENT OF ALGAE (MG P/MG A) =  0.014
ALG MAX SPEC GROWTH RATE(1/DAY)=    2.0  ALGAE RESPIRATION RATE (1/DAY)=   0.105
N HALF SATURATION CONST (MG/L) =   0.03  P HALF SATURATION CONST  (MG/L)=  0.005
LIN ALG SHADE CO (1/H-UGCHA/L) =  0.003  NLIN SHADE (1/H-(UGCHA/L)**2/3)=  0.000
LIGHT FUNCTION OPTION (LFNOPT) =    2.0  LIGHT SATURATION COEF (INT/MIN)=   0.66
DAILY AVERAGING OPTION (LAVOPT)=    3.0  LIGHT AVERAGING FACTOR  (INT)  =    0.9
NUMBER OF DAYLIGHT HOURS (DLH) =   13.3  TOTAL DAILY SOLAR RADTN (INT)  =  1500.
ALGY GROWTH CALC OPTION(LGROPT)=    2.0  ALGAL PREF FOR NH3-N (PREFN)   =    0.1
ALG/TEMP SOLR RAD FACTOR(TFACT)=   0.45  NITRIFICATION INHIBITION COEF  =    0.6
ENDATA1A
         SOD RATE  1.0
ENDATA1B
STREAM REACH      1. RCH= Hdwtr, RM 5-8.25  FROM       8.25    TO           5.0
STREAM REACH      2. RCH= RM 0.0 to 5.0     FROM        5.0    TO           0.0
ENDATA2
ENDATA3
FLAG FIELD RCH=   1.        13          1.2.2.2.2.2.2.6.2.2.2.2.2.
FLAG FIELD RCH=   2.        20          2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.5.
ENDATA4
HYDRAULICS RCH=   1.     100.0     0.020      0.00      0.42     0.000     0.020
HYDRAULICS RCH=   2.     100.0     0.030      0.00      0.51     0.000     0.020
ENDATA5
TEMP/LCD          1.     399.00   0.06   0.90   79.0   53.0  29.23    5.4
TEMP/LCD          2.     379.00   0.06   0.90   79.0   53.0  29.23    5.4
ENDATA5A
REACT COEF RCH=   1.   0.050    0.00  0.0540  1.     .65  0.0000  0.0000
REACT COEF RCH=   2.   0.050    0.00  0.0650  1.     .67  0.0000  0.0000
ENDATA6
N AND P COEF   RCH=   1.   0.00   0.00   0.01   0.00   2.00   0.00   0.00   0.00
N AND P COEF   RCH=   2.   0.00   0.00   0.01   0.00   2.00   0.00   0.00   0.00
ENDATA6A
ALGAE/OTHER    RCH=   1.   50.0   0.10   0.01   0.00   0.00   0.00   0.00
ALGAE/OTHER    RCH=   2.   50.0   0.20   0.01   0.00   0.00   0.00   0.00
ENDATA6B
INITIAL COND-1 RCH=   1.  63.00   4.80   1.00   0.00   0.00   0.00  0.000    0.0
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INITIAL COND-1 RCH=   2.  63.00   1.85   1.00   0.00   0.00   0.00  0.000    0.0
ENDATA7
INITIAL COND-2 RCH=   1.   4.60   0.43   0.05   0.00   0.10   0.00  0.030    0.0
INITIAL COND-2 RCH=   2.   4.60   0.43   0.05   0.00   0.10   0.00  0.030
ENDATA7A
INCR INFLOW-1  RCH=   1.  0.145  65.00   4.5   1.0   0.0   0.0   0.0   0.0   0.0
INCR INFLOW-1  RCH=   2.  0.000  65.00   4.5   1.0   0.0   0.0   0.0   0.0   0.0
ENDATA8
INCR INFLOW-2  RCH=   1.   0.00   0.00   0.00   0.00   0.00   0.00   0.00
INCR INFLOW-2  RCH=   2.   0.08   0.00   0.00   0.00   0.00   0.00   0.00
ENDATA8A
ENDATA9
HDWTR-NFK HDW=  1.         ANDY_CK    0.100 63.70  4.47  1.00   0.0   0.0   0.0
ENDATA10
HEADWTR-2 HDW=    1.  0.00  0.00   4.6  0.43  0.05  0.00  0.10  0.00  0.04
ENDATA10A
POINTLD-1 PTL=   1.   VALIER 0.00   0.065   70.00   8.7   10.9   0.0   0.0   0.0
ENDATA11
POINTLD-2 PTL=    1.  0.00   0.0  0.00  0.00  5.80  0.00  0.00  0.60  1.0
ENDATA11A
ENDATA12
ENDATA13
ENDATA13A
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                                       * * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
                                                  Version 3.22  --  May 1996

 $$$ (PROBLEM TITLES) $$$

CARD TYPE                             QUAL-2E PROGRAM TITLES
TITLE01              Andy Creek DO TMDL ILEPA13A
TITLE02              Setup run for 9/23/2015
TITLE03   NO         CONSERVATIVE MINERAL   I
TITLE04   NO         CONSERVATIVE MINERAL  II
TITLE05   NO         CONSERVATIVE MINERAL III
TITLE06  YES         TEMPERATURE
TITLE07  YES         5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES         ALGAE AS CHL-A IN UG/L
TITLE09  YES         PHOSPHORUS CYCLE AS P IN MG/L
TITLE10                (ORGANIC-P; DISSOLVED-P)
TITLE11  YES         NITROGEN CYCLE AS N IN MG/L
TITLE12                (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES         DISSOLVED OXYGEN IN MG/L
TITLE14   NO         FECAL COLIFORM IN NO./100 ML
TITLE15   NO         ARBITRARY NON-CONSERVATIVE
ENDTITLE

 $$$ DATA TYPE 1 (CONTROL DATA) $$$

CARD TYPE                                    CARD TYPE
LIST DATA INPUT             0.00000                                       0.00000
NOWRITE OPTIONAL SUMMARY    0.00000                                       0.00000
NO FLOW AUGMENTATION        0.00000                                       0.00000
STEADY STATE                0.00000                                       0.00000
NO TRAPEZOIDAL CHANNELS     0.00000                                       0.00000
NO PRINT LCD/SOLAR DATA     0.00000                                       0.00000
NO PLOT DO AND BOD          0.00000                                       0.00000
FIXED DNSTM CONC (YES=1)=   0.00000          D-ULT BOD CONV K COEF  =    0.23000
INPUT METRIC           =    0.00000          UTPUT METRIC           =    0.00000
NUMBER OF REACHES      =    2.00000          UMBER OF JUNCTIONS     =    0.00000
NUM OF HEADWATERS      =    1.00000          UMBER OF POINT LOADS   =    1.00000
TIME STEP (HOURS)      =    1.00000          NTH. COMP. ELEMENT (MI)=    0.25000
MAXIMUM ROUTE TIME (HRS)=  60.00000          IME INC. FOR RPT2 (HRS)=    1.00000
LATITUDE OF BASIN (DEG) =  38.02000          ONGITUDE OF BASIN (DEG)=  -89.04000
STANDARD MERIDIAN (DEG) =   0.00000          AY OF YEAR START TIME  =  266.00000
EVAP. COEF.,(AE)       =    0.00068          VAP. COEF.,(BE)        =    0.00027
ELEV. OF BASIN (ELEV)   = 373.00000          UST ATTENUATION COEF.  =    0.06000
ENDATA1                     0.00000                                       0.00000

 $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

CARD TYPE                                           CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=    3.4300          O UPTAKE BY NO2 OXID(MG O/MG N)=    1.1400
O PROD  BY ALGAE (MG O/MG A)   =    1.8000          O UPTAKE BY ALGAE (MG O/MG A)  =    1.9000
N CONTENT OF ALGAE (MG N/MG A) =    0.0900          P CONTENT OF ALGAE (MG P/MG A) =    0.0140
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ALG MAX SPEC GROWTH RATE(1/DAY)=    2.0000          ALGAE RESPIRATION RATE (1/DAY)=     0.1050
N HALF SATURATION CONST (MG/L) =    0.0300          P HALF SATURATION CONST  (MG/L)=    0.0050
LIN ALG SHADE CO (1/FT-UGCHA/L=)    0.0030          NLIN SHADE(1/FT-(UGCHA/L)**2/3)=    0.0000
LIGHT FUNCTION OPTION (LFNOPT) =    2.0000          LIGHT SAT'N COEF (BTU/FT2-MIN) =    0.6600
DAILY AVERAGING OPTION (LAVOPT)=    3.0000          LIGHT AVERAGING FACTOR  (INT)  =    0.9000
NUMBER OF DAYLIGHT HOURS (DLH) =   13.3000          TOTAL DAILY SOLR RAD (BTU/FT-2)= 1500.0000
ALGY GROWTH CALC OPTION(LGROPT)=    2.0000          ALGAL PREF FOR NH3-N (PREFN)   =    0.1000
ALG/TEMP SOLR RAD FACTOR(TFACT)=    0.4500          NITRIFICATION INHIBITION COEF  =    0.6000
ENDATA1A                            0.0000                                              0.0000

 $$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE     RATE CODE     THETA VALUE

THETA( 1)      BOD DECA        1.047     DFLT
THETA( 2)      BOD SETT        1.024     DFLT
THETA( 3)      OXY TRAN        1.024     DFLT
THETA( 4)      SOD RATE        1.000     USER
THETA( 5)      ORGN DEC        1.047     DFLT
THETA( 6)      ORGN SET        1.024     DFLT
THETA( 7)      NH3 DECA        1.083     DFLT
THETA( 8)      NH3 SRCE        1.074     DFLT
THETA( 9)      NO2 DECA        1.047     DFLT
THETA(10)      PORG DEC        1.047     DFLT
THETA(11)      PORG SET        1.024     DFLT
THETA(12)      DISP SRC        1.074     DFLT
THETA(13)      ALG GROW        1.047     DFLT
THETA(14)      ALG RESP        1.047     DFLT
THETA(15)      ALG SETT        1.024     DFLT
THETA(16)      COLI DEC        1.047     DFLT
THETA(17)      ANC DECA        1.000     DFLT
THETA(18)      ANC SETT        1.024     DFLT
THETA(19)      ANC SRCE        1.000     DFLT
ENDATA1B

 $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE           REACH ORDER AND IDENT               R. MI/KM            R. MI/KM
STREAM REACH     1.0   RCH= Hdwtr, RM 5-8.    FRO          8.2    O            5.0
STREAM REACH     2.0   RCH= RM 0.0 to 5.0     FRO          5.0    O            0.0
ENDATA2          0.0                                       0.0                 0.0

 $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE                  REACH  AVAIL HDWS TARGET     ORDER OF AVAIL SOURCES
ENDATA3                     0.        0.       0.0   0.   0.   0.   0.   0.   0.

 $$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE        REACH ELEMENTS/REACH             COMPUTATIONAL FLAGS
FLAG FIELD        1.       13.          1.2.2.2.2.2.2.6.2.2.2.2.2.0.0.0.0.0.0.0.
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FLAG FIELD        2.       20.          2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.5.
ENDATA4           0.        0.          0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

 $$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE        REACH  COEF-DSPN  COEFQV    EXPOQV    COEFQH   EXPOQH     CMANN
HYDRAULICS        1.    100.00     0.020     0.000     0.420     0.000     0.020
HYDRAULICS        2.    100.00     0.030     0.000     0.510     0.000     0.020
ENDATA5           0.      0.00     0.000     0.000     0.000     0.000     0.000

 $$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE                             DUST     CLOUD   DRY BULB  WET BULB    ATM                SOLAR RAD
                REACH   ELEVATION     COEF     COVER     TEMP      TEMP    PRESSURE     WIND   ATTENUATION
TEMP/LCD          1.      399.00      0.06      0.90     79.00     53.00     29.23      5.40      1.00
TEMP/LCD          2.      379.00      0.06      0.90     79.00     53.00     29.23      5.40      1.00
ENDATA5A          0.        0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE        REACH     K1        K3       SOD         K2OPT     K2      COEQK2    OR   EXPQK2
                                              RATE                         TSIV COEF  OR    SLOPE
                                                                           FOR OPT 8      FOR OPT 8
REACT COEF        1.      0.05      0.00      0.054        1.      0.65      0.000        0.00000
REACT COEF        2.      0.05      0.00      0.065        1.      0.67      0.000        0.00000
ENDATA6           0.      0.00      0.00      0.000        0.      0.00      0.000        0.00000

  $$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE           REACH    CKNH2    SETNH2     CKNH3      SNH3     CKNO2     CKPORG   SETPORG     SPO4
N AND P COEF          1.      0.00      0.00      0.01      0.00      2.00      0.00      0.00      0.00
N AND P COEF          2.      0.00      0.00      0.01      0.00      2.00      0.00      0.00      0.00
ENDATA6A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE           REACH    ALPHAO    ALGSET    EXCOEF      CK5     CKANC    SETANC    SRCANC
                                                           CKCOLI
ALGAE/OTHER           1.     50.00      0.10      0.01      0.00      0.00      0.00      0.00
ALGAE/OTHER           2.     50.00      0.20      0.01      0.00      0.00      0.00      0.00
ENDATA6B              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE           REACH    TEMP       D.O.      BOD       CM-1      CM-2      CM-3       ANC      COLI
INITIAL COND-1        1.     63.00      4.80      1.00      0.00      0.00      0.00      0.00      0.00
INITIAL COND-1        2.     63.00      1.85      1.00      0.00      0.00      0.00      0.00      0.00
ENDATA7               0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$
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CARD TYPE           REACH    CHL-A     ORG-N     NH3-N     NO2-N     NO3-N     ORG-P     DIS-P
INITIAL COND-2        1.      4.60      0.43      0.05      0.00      0.10      0.00      0.03
INITIAL COND-2        2.      4.60      0.43      0.05      0.00      0.10      0.00      0.03
ENDATA7A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE           REACH     FLOW      TEMP     D.O.        BOD      CM-1      CM-2      CM-3       ANC      COLI
INCR INFLOW-1         1.     0.145     65.00      4.50      1.00      0.00      0.00      0.00      0.00      0.00
INCR INFLOW-1         2.     0.000     65.00      4.50      1.00      0.00      0.00      0.00      0.00      0.00
ENDATA8               0.     0.000      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE           REACH    CHL-A     ORG-N     NH3-N     NO2-N     NO3-N     ORG-P     DIS-P
INCR INFLOW-2         1.      0.00      0.00      0.00      0.00      0.00      0.00      0.00
INCR INFLOW-2         2.      0.08      0.00      0.00      0.00      0.00      0.00      0.00
ENDATA8A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE              JUNCTION ORDER AND IDENT         UPSTRM   JUNCTION    TRIB
ENDATA9                0.                                 0.        0.        0.

 $$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE    HDWTR     NAME              FLOW      TEMP      D.O.       BOD      CM-1      CM-2      CM-3
             ORDER
HDWTR-NFK      1.          ANDY_CK       0.10     63.70      4.47      1.00      0.00      0.00      0.00
ENDATA10       0.                        0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS,
                    COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE     HDWTR     ANC     COLI    CHL-A    ORG-N    NH3-N    NO2-N    NO3-N    ORG-P    DIS-P
              ORDER
HEADWTR-2       1.     0.00 0.00E+00     4.60     0.43     0.05     0.00     0.10     0.00     0.04
ENDATA10A       0.     0.00 0.00E+00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

              POINT
CARD TYPE      LOAD    NAME              EFF     FLOW     TEMP     D.O.      BOD     CM-1     CM-2     CM-3
              ORDER
POINTLD-1      1.     VALIER 0.         0.00     0.06    70.00     8.70    10.90     0.00     0.00     0.00
ENDATA11       0.                       0.00     0.00      0.00    0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS,
                    COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

              POINT
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CARD TYPE      LOAD     ANC     COLI    CHL-A    ORG-N    NH3-N    NO2-N    N03-N    ORG-P    DIS-P
              ORDER
POINTLD-2       1.     0.00 0.00E+00     0.00     0.00     5.80     0.00     0.00     0.60     1.00
ENDATA11A       0.     0.00 0.00E+00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

                      DAM   RCH   ELE    ADAM    BDAM    FDAM    HDAM

ENDATA12                 0.    0.    0.    0.00    0.00    0.00    0.00

 $$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$

     CARD TYPE               TEMP       D.O.      BOD       CM-1      CM-2      CM-3       ANC      COLI

ENDATA13                     DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED

 $$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

     CARD TYPE               CHL-A     ORG-N     NH3-N     NO2-N     NH3-N     ORG-P     DIS-P

ENDATA13A                    DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
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STEADY STATE TEMPERATURE SIMULATION; CONVERGENCE SUMMARY:
---------------------------------------------------------

                      NUMBER OF
        ITERATION   NONCONVERGENT
                      ELEMENTS

             1             33
             2              0


SUMMARY OF VALUES FOR STEADY STATE TEMPERATURE CALCULATIONS (SUBROUTINE HEATER):
--------------------------------------------------------------------------------

      DAILY NET SOLAR RADIATION =     934.868 BTU/FT-2   (  253.695 LANGLEYS)
      NUMBER OF DAYLIGHT HOURS =  11.9


      HOURLY VALUES OF SOLAR RADIATION (BTU/FT-2)

            1    11.65         9    97.24        17     0.00
            2    43.95        10    71.03        18     0.00
            3    74.33        11    40.26        19     0.00
            4    99.85        12     7.78        20     0.00
            5   118.11        13     0.00        21     0.00
            6   127.39        14     0.00        22     0.00
            7   126.82        15     0.00        23     0.00
            8   116.44        16     0.00        24     0.00
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STEADY STATE ALGAE/NUTRIENT/DISSOLVED OXYGEN SIMULATION; CONVERGENCE SUMMARY:
------------------------------------------------------------------------------

                                                   NUMBER OF
           VARIABLE              ITERATION      NONCONVERGENT
                                                   ELEMENTS

 ALGAE GROWTH RATE                 1               33
 ALGAE GROWTH RATE                 2               33
 ALGAE GROWTH RATE                 3               33
 ALGAE GROWTH RATE                 4               32
 ALGAE GROWTH RATE                 5               14
 ALGAE GROWTH RATE                 6                0
   NITRIFICATION INHIBITION           1                 0
 ALGAE GROWTH RATE                 7                0
   NITRIFICATION INHIBITION           2                 0



SUMMARY OF CONDITIONS FOR ALGAL GROWTH RATE SIMULATION:
--------------------------------------------------------

      1. LIGHT AVERAGING OPTION.   LAVOPT= 3

          METHOD: AVERAGE OF HOURLY SOLAR VALUES

          SOURCE OF SOLAR VALUES: SUBROUTINE HEATER (SS TEMP)
              DAILY NET SOLAR RADIATION:   934.868 BTU/FT-2 (  253.695 LANGLEYS)
              NUMBER OF DAYLIGHT HOURS: 11.9
              PHOTOSYNTHETIC ACTIVE FRACTION OF SOLAR RADIATION (TFACT):  0.45
              MEAN SOLAR RADIATION ADJUSTMENT FACTOR (AFACT): N/A

          HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

            1     3.16         9    26.39        17     0.00
            2    11.93        10    19.28        18     0.00
            3    20.17        11    10.92        19     0.00
            4    27.10        12     2.11        20     0.00
            5    32.05        13     0.00        21     0.00
            6    34.57        14     0.00        22     0.00
            7    34.41        15     0.00        23     0.00
            8    31.60        16     0.00        24     0.00


      2. LIGHT FUNCTION OPTION:   LFNOPT= 2

          SMITH FUNCTION, WITH 71% IMAX =  0.179 LANGLEYS/MIN


      3. GROWTH ATTENUATION OPTION FOR NUTRIENTS.   LGROPT= 2
```

MINIMUM OF NITROGEN, PHOSPHORUS: FL*MIN(FN,FP)

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          STREAM QUALITY SIMULATION                                                                 OUTPUT PAGE NUMBER     1
          QUAL-2E STREAM QUALITY ROUTING MODEL                                                   Version 3.22  --  May 1996
                                                      ***** STEADY STATE SIMULATION *****

                                                           ** HYDRAULICS SUMMARY **

ELE RCH ELE   BEGIN    END           POINT    INCR            TRVL                                     BOTTOM      X-SECT    DSPRSN
ORD NUM NUM     LOC     LOC    FLOW   SRCE    FLOW      VEL   TIME    DEPTH    WIDTH      VOLUME        AREA        AREA      COEF
               MILE    MILE     CFS    CFS     CFS      FPS    DAY       FT       FT      K-FT-3      K-FT-2        FT-2    FT-2/S

  1   1   1    8.25    8.00    0.11   0.00    0.01    0.020  0.764    0.420   13.233        7.34       18.58        5.56      0.07
  2   1   2    8.00    7.75    0.12   0.00    0.01    0.020  0.764    0.420   14.560        8.07       20.33        6.12      0.07
  3   1   3    7.75    7.50    0.13   0.00    0.01    0.020  0.764    0.420   15.888        8.81       22.08        6.67      0.07
  4   1   4    7.50    7.25    0.14   0.00    0.01    0.020  0.764    0.420   17.216        9.54       23.83        7.23      0.07
  5   1   5    7.25    7.00    0.16   0.00    0.01    0.020  0.764    0.420   18.544       10.28       25.59        7.79      0.07
  6   1   6    7.00    6.75    0.17   0.00    0.01    0.020  0.764    0.420   19.872       11.02       27.34        8.35      0.07
  7   1   7    6.75    6.50    0.18   0.00    0.01    0.020  0.764    0.420   21.200       11.75       29.09        8.90      0.07
  8   1   8    6.50    6.25    0.25   0.06    0.01    0.020  0.764    0.420   30.266       16.78       41.06       12.71      0.07
  9   1   9    6.25    6.00    0.27   0.00    0.01    0.020  0.764    0.420   31.593       17.52       42.81       13.27      0.07
 10   1  10    6.00    5.75    0.28   0.00    0.01    0.020  0.764    0.420   32.921       18.25       44.56       13.83      0.07
 11   1  11    5.75    5.50    0.29   0.00    0.01    0.020  0.764    0.420   34.249       18.99       46.32       14.38      0.07
 12   1  12    5.50    5.25    0.30   0.00    0.01    0.020  0.764    0.420   35.577       19.72       48.07       14.94      0.07
 13   1  13    5.25    5.00    0.31   0.00    0.01    0.020  0.764    0.420   36.905       20.46       49.82       15.50      0.07


 14   2   1    5.00    4.75    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 15   2   2    4.75    4.50    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 16   2   3    4.50    4.25    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 17   2   4    4.25    4.00    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 18   2   5    4.00    3.75    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 19   2   6    3.75    3.50    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 20   2   7    3.50    3.25    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 21   2   8    3.25    3.00    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 22   2   9    3.00    2.75    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 23   2  10    2.75    2.50    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 24   2  11    2.50    2.25    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 25   2  12    2.25    2.00    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 26   2  13    2.00    1.75    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 27   2  14    1.75    1.50    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 28   2  15    1.50    1.25    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 29   2  16    1.25    1.00    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 30   2  17    1.00    0.75    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 31   2  18    0.75    0.50    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 32   2  19    0.50    0.25    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
 33   2  20    0.25    0.00    0.31   0.00    0.00    0.030  0.509    0.510   20.261       13.64       28.09       10.33      0.13
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                                                 ***** STEADY STATE SIMULATION *****

                                                 ** REACTION COEFFICIENT SUMMARY **

RCH ELE      DO  K2  OXYGN    BOD    BOD    SOD   ORGN   ORGN    NH3    NH3    NO2   ORGP   ORGP   DISP   COLI    ANC    ANC    ANC
NUM NUM     SAT OPT  REAIR  DECAY   SETT   RATE  DECAY   SETT  DECAY   SRCE  DECAY  DECAY   SETT   SRCE  DECAY  DECAY   SETT   SRCE
           MG/L      1/DAY  1/DAY  1/DAY  G/F2D  1/DAY  1/DAY  1/DAY MG/F2D  1/DAY  1/DAY  1/DAY MG/F2D  1/DAY  1/DAY  1/DAY MG/F2D

  1   1    9.08   1   0.63   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.65   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   2    9.03   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.56   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   3    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.46   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   4    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.39   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   5    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.34   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   6    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.31   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   7    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.29   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   8    8.99   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.55   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   9    9.00   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.43   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1  10    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.35   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1  11    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.30   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1  12    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.27   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1  13    9.01   1   0.64   0.05   0.00   0.05   0.00   0.00   0.01   0.00   1.26   0.00   0.00   0.00   0.00   0.00   0.00   0.00


  2   1    9.01   1   0.65   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.40   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   2    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.36   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   3    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.34   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   4    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.32   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   5    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.31   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   6    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.30   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   7    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.29   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   8    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.29   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   9    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.29   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  10    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.29   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  11    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.29   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  12    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.30   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  13    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.30   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  14    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.30   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  15    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.31   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  16    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.31   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  17    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.32   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  18    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.32   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  19    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.33   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  20    9.01   1   0.66   0.05   0.00   0.06   0.00   0.00   0.01   0.00   1.33   0.00   0.00   0.00   0.00   0.00   0.00   0.00
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         STREAM QUALITY SIMULATION                                                                      OUTPUT PAGE NUMBER     3
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                   Version 3.22  --  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                    ** WATER QUALITY VARIABLES **

RCH ELE              CM-1   CM-2   CM-3                                                                                 ANC
NUM NUM       TEMP                          DO    BOD   ORGN   NH3N   NO2N   NO3N  SUM-N   ORGP  DIS-P  SUM-P   COLI          CHLA
             DEG-F                        MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L #/100ML         UG/L

  1   1      66.05   0.00   0.00   0.00   3.39   0.97   0.39   0.04   0.00   0.09   0.52   0.00   0.04   0.04.00E+00   0.00   4.55
  1   2      66.57   0.00   0.00   0.00   2.74   0.94   0.35   0.04   0.00   0.08   0.47   0.00   0.03   0.03.00E+00   0.00   4.53
  1   3      66.69   0.00   0.00   0.00   2.34   0.91   0.32   0.04   0.00   0.07   0.43   0.00   0.03   0.03.00E+00   0.00   4.50
  1   4      66.72   0.00   0.00   0.00   2.10   0.89   0.30   0.03   0.00   0.06   0.39   0.00   0.03   0.03.00E+00   0.00   4.47
  1   5      66.73   0.00   0.00   0.00   1.96   0.86   0.28   0.03   0.00   0.05   0.36   0.00   0.02   0.02.00E+00   0.00   4.43
  1   6      66.74   0.00   0.00   0.00   1.87   0.84   0.26   0.03   0.00   0.05   0.34   0.00   0.02   0.02.00E+00   0.00   4.38
  1   7      66.74   0.00   0.00   0.00   1.82   0.83   0.24   0.03   0.00   0.04   0.32   0.00   0.02   0.02.00E+00   0.00   4.33
  1   8      66.97   0.00   0.00   0.00   2.63   3.30   0.17   1.49   0.00   0.03   1.70   0.15   0.27   0.42.00E+00   0.00   3.56
  1   9      66.80   0.00   0.00   0.00   2.24   3.09   0.17   1.42   0.01   0.04   1.63   0.15   0.26   0.40.00E+00   0.00   4.09
  1  10      66.76   0.00   0.00   0.00   2.00   2.90   0.16   1.35   0.01   0.04   1.56   0.14   0.25   0.39.00E+00   0.00   4.72
  1  11      66.76   0.00   0.00   0.00   1.86   2.73   0.15   1.29   0.01   0.04   1.49   0.14   0.24   0.37.00E+00   0.00   5.44
  1  12      66.75   0.00   0.00   0.00   1.78   2.57   0.15   1.23   0.01   0.05   1.43   0.13   0.23   0.36.00E+00   0.00   6.28
  1  13      66.75   0.00   0.00   0.00   1.75   2.43   0.14   1.18   0.01   0.05   1.38   0.13   0.22   0.34.00E+00   0.00   7.26


  2   1      66.77   0.00   0.00   0.00   2.13   2.35   0.15   1.17   0.01   0.05   1.37   0.13   0.22   0.34.00E+00   0.00   7.59
  2   2      66.77   0.00   0.00   0.00   2.03   2.30   0.15   1.16   0.01   0.06   1.37   0.13   0.22   0.34.00E+00   0.00   7.87
  2   3      66.77   0.00   0.00   0.00   1.95   2.24   0.15   1.16   0.01   0.06   1.37   0.13   0.22   0.34.00E+00   0.00   8.15
  2   4      66.77   0.00   0.00   0.00   1.90   2.19   0.15   1.15   0.01   0.06   1.36   0.13   0.22   0.34.00E+00   0.00   8.45
  2   5      66.77   0.00   0.00   0.00   1.87   2.14   0.15   1.14   0.01   0.06   1.36   0.13   0.21   0.34.00E+00   0.00   8.75
  2   6      66.77   0.00   0.00   0.00   1.85   2.08   0.15   1.14   0.01   0.07   1.36   0.13   0.21   0.34.00E+00   0.00   9.07
  2   7      66.77   0.00   0.00   0.00   1.83   2.03   0.15   1.13   0.01   0.07   1.35   0.13   0.21   0.34.00E+00   0.00   9.40
  2   8      66.77   0.00   0.00   0.00   1.83   1.99   0.15   1.12   0.01   0.07   1.35   0.13   0.21   0.34.00E+00   0.00   9.74
  2   9      66.77   0.00   0.00   0.00   1.82   1.94   0.15   1.12   0.01   0.07   1.35   0.13   0.21   0.34.00E+00   0.00  10.09
  2  10      66.77   0.00   0.00   0.00   1.83   1.89   0.15   1.11   0.01   0.07   1.34   0.13   0.21   0.34.00E+00   0.00  10.45
  2  11      66.77   0.00   0.00   0.00   1.83   1.85   0.15   1.10   0.01   0.07   1.34   0.13   0.21   0.34.00E+00   0.00  10.82
  2  12      66.77   0.00   0.00   0.00   1.84   1.80   0.16   1.10   0.01   0.08   1.33   0.13   0.21   0.34.00E+00   0.00  11.21
  2  13      66.77   0.00   0.00   0.00   1.85   1.76   0.16   1.09   0.01   0.08   1.33   0.13   0.21   0.34.00E+00   0.00  11.61
  2  14      66.77   0.00   0.00   0.00   1.86   1.71   0.16   1.08   0.01   0.08   1.32   0.13   0.21   0.34.00E+00   0.00  12.02
  2  15      66.77   0.00   0.00   0.00   1.87   1.67   0.16   1.07   0.01   0.08   1.32   0.13   0.21   0.33.00E+00   0.00  12.45
  2  16      66.77   0.00   0.00   0.00   1.88   1.63   0.16   1.07   0.01   0.08   1.31   0.13   0.20   0.33.00E+00   0.00  12.89
  2  17      66.77   0.00   0.00   0.00   1.90   1.59   0.16   1.06   0.01   0.08   1.31   0.13   0.20   0.33.00E+00   0.00  13.34
  2  18      66.77   0.00   0.00   0.00   1.91   1.56   0.16   1.05   0.01   0.08   1.30   0.13   0.20   0.33.00E+00   0.00  13.81
  2  19      66.77   0.00   0.00   0.00   1.93   1.52   0.16   1.04   0.01   0.08   1.29   0.13   0.20   0.33.00E+00   0.00  14.30
  2  20      66.77   0.00   0.00   0.00   1.94   1.48   0.17   1.04   0.01   0.08   1.29   0.13   0.20   0.33.00E+00   0.00  14.79
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                                                        ***** STEADY STATE SIMULATION *****

                                                               ** ALGAE DATA **

                                                                                    NH3-N           ALGAE GROWTH RATE ATTEN FACTORS
 ELE RCH ELE                    ALGY    ALGY    ALGY   A P/R     NET           NH3  FRACT   LIGHT
 ORD NUM NUM           CHLA    GRWTH    RESP    SETT   RATIO     P-R          PREF N-UPTKE  EXTCO          LIGHT   NITRGN   PHSPRS
                       UG/L    1/DAY   1/DAY   FT/DA     *    MG/L-D            *      *     1/FT            *        *        *

   1   1   1           4.55     0.46    0.10    0.10    4.33    0.06          0.10    0.05    0.02           0.29     0.81     0.88
   2   1   2           4.53     0.45    0.10    0.10    4.24    0.06          0.10    0.05    0.02           0.29     0.80     0.86
   3   1   3           4.50     0.44    0.10    0.10    4.14    0.05          0.10    0.06    0.02           0.29     0.78     0.85
   4   1   4           4.47     0.43    0.10    0.10    4.03    0.05          0.10    0.06    0.02           0.29     0.76     0.84
   5   1   5           4.43     0.42    0.10    0.10    3.93    0.05          0.10    0.06    0.02           0.29     0.74     0.83
   6   1   6           4.38     0.41    0.10    0.10    3.83    0.05          0.10    0.06    0.02           0.29     0.72     0.81
   7   1   7           4.33     0.41    0.10    0.10    3.78    0.05          0.10    0.07    0.02           0.29     0.71     0.81
   8   1   8           3.56     0.56    0.10    0.10    5.22    0.06          0.10    0.83    0.02           0.29     0.98     0.98
   9   1   9           4.09     0.56    0.10    0.10    5.21    0.07          0.10    0.81    0.02           0.29     0.98     0.98
  10   1  10           4.72     0.56    0.10    0.10    5.21    0.08          0.10    0.78    0.02           0.29     0.98     0.98
  11   1  11           5.44     0.56    0.10    0.10    5.20    0.09          0.10    0.76    0.03           0.29     0.98     0.98
  12   1  12           6.28     0.56    0.10    0.10    5.19    0.10          0.10    0.74    0.03           0.29     0.98     0.98
  13   1  13           7.26     0.56    0.10    0.10    5.19    0.12          0.10    0.73    0.03           0.29     0.98     0.98


  14   2   1           7.59     0.56    0.10    0.20    5.18    0.12          0.10    0.71    0.03           0.29     0.98     0.98
  15   2   2           7.87     0.56    0.10    0.20    5.18    0.13          0.10    0.70    0.03           0.29     0.98     0.98
  16   2   3           8.15     0.56    0.10    0.20    5.18    0.13          0.10    0.69    0.03           0.29     0.98     0.98
  17   2   4           8.45     0.56    0.10    0.20    5.18    0.14          0.10    0.68    0.04           0.29     0.98     0.98
  18   2   5           8.75     0.56    0.10    0.20    5.18    0.14          0.10    0.67    0.04           0.29     0.98     0.98
  19   2   6           9.07     0.56    0.10    0.20    5.18    0.15          0.10    0.66    0.04           0.29     0.98     0.98
  20   2   7           9.40     0.56    0.10    0.20    5.18    0.15          0.10    0.65    0.04           0.29     0.98     0.98
  21   2   8           9.74     0.56    0.10    0.20    5.18    0.16          0.10    0.64    0.04           0.29     0.98     0.98
  22   2   9          10.09     0.56    0.10    0.20    5.17    0.16          0.10    0.64    0.04           0.29     0.98     0.98
  23   2  10          10.45     0.56    0.10    0.20    5.17    0.17          0.10    0.63    0.04           0.29     0.98     0.98
  24   2  11          10.82     0.56    0.10    0.20    5.17    0.17          0.10    0.62    0.04           0.29     0.98     0.98
  25   2  12          11.21     0.56    0.10    0.20    5.17    0.18          0.10    0.62    0.04           0.29     0.98     0.98
  26   2  13          11.61     0.56    0.10    0.20    5.17    0.19          0.10    0.61    0.04           0.29     0.97     0.98
  27   2  14          12.02     0.56    0.10    0.20    5.17    0.19          0.10    0.61    0.05           0.29     0.97     0.98
  28   2  15          12.45     0.55    0.10    0.20    5.17    0.20          0.10    0.60    0.05           0.29     0.97     0.98
  29   2  16          12.89     0.55    0.10    0.20    5.16    0.21          0.10    0.60    0.05           0.29     0.97     0.98
  30   2  17          13.34     0.55    0.10    0.20    5.16    0.21          0.10    0.59    0.05           0.29     0.97     0.98
  31   2  18          13.81     0.55    0.10    0.20    5.16    0.22          0.10    0.59    0.05           0.29     0.97     0.98
  32   2  19          14.30     0.55    0.10    0.20    5.16    0.23          0.10    0.59    0.05           0.29     0.97     0.98
  33   2  20          14.79     0.55    0.10    0.20    5.16    0.24          0.10    0.58    0.05           0.29     0.97     0.98
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                                                 ***** STEADY STATE SIMULATION *****

                                                     ** DISSOLVED OXYGEN DATA **

                                                                  COMPONENTS OF DISSOLVED OXYGEN MASS BALANCE (MG/L-DAY)
ELE RCH ELE              DO              DO     DAM     NIT
ORD NUM NUM    TEMP     SAT      DO     DEF   INPUT   INHIB      F-FNCTN   OXYGN                     NET
              DEG-F    MG/L    MG/L    MG/L    MG/L    FACT        INPUT   REAIR   C-BOD     SOD     P-R   NH3-N   NO2-N

  1   1   1   66.05    9.08    3.39    5.69    0.00    0.87         5.86    3.60   -0.05   -4.54    0.06    0.00    0.00
  2   1   2   66.57    9.03    2.74    6.29    0.00    0.81         0.54    4.01   -0.05   -4.54    0.06    0.00    0.00
  3   1   3   66.69    9.01    2.34    6.67    0.00    0.75         0.49    4.26   -0.04   -4.54    0.05    0.00    0.00
  4   1   4   66.72    9.01    2.10    6.91    0.00    0.72         0.45    4.41   -0.04   -4.54    0.05    0.00    0.00
  5   1   5   66.73    9.01    1.96    7.05    0.00    0.69         0.42    4.51   -0.04   -4.54    0.05    0.00    0.00
  6   1   6   66.74    9.01    1.87    7.14    0.00    0.67         0.39    4.56   -0.04   -4.54    0.05    0.00    0.00
  7   1   7   66.74    9.01    1.82    7.19    0.00    0.66         0.37    4.60   -0.04   -4.54    0.05    0.00    0.00
  8   1   8   66.97    8.99    2.63    6.36    0.00    0.79         3.17    4.08   -0.16   -4.54    0.06   -0.04   -0.01
  9   1   9   66.80    9.00    2.24    6.77    0.00    0.74         0.25    4.33   -0.15   -4.54    0.07   -0.03   -0.01
 10   1  10   66.76    9.01    2.00    7.01    0.00    0.70         0.24    4.48   -0.14   -4.54    0.08   -0.03   -0.01
 11   1  11   66.76    9.01    1.86    7.15    0.00    0.67         0.23    4.57   -0.13   -4.54    0.09   -0.03   -0.01
 12   1  12   66.75    9.01    1.78    7.23    0.00    0.66         0.22    4.62   -0.12   -4.54    0.10   -0.03   -0.01
 13   1  13   66.75    9.01    1.75    7.26    0.00    0.65         0.21    4.64   -0.12   -4.54    0.12   -0.02   -0.01


 14   2   1   66.77    9.01    2.13    6.88    0.00    0.72         0.00    4.47   -0.11   -4.50    0.12   -0.03   -0.01
 15   2   2   66.77    9.01    2.03    6.98    0.00    0.70         0.00    4.60   -0.11   -4.50    0.13   -0.03   -0.01
 16   2   3   66.77    9.01    1.95    7.05    0.00    0.69         0.00    4.65   -0.11   -4.50    0.13   -0.03   -0.01
 17   2   4   66.77    9.01    1.90    7.10    0.00    0.68         0.00    4.68   -0.11   -4.50    0.14   -0.03   -0.01
 18   2   5   66.77    9.01    1.87    7.14    0.00    0.67         0.00    4.71   -0.10   -4.50    0.14   -0.03   -0.01
 19   2   6   66.77    9.01    1.85    7.16    0.00    0.67         0.00    4.72   -0.10   -4.50    0.15   -0.02   -0.01
 20   2   7   66.77    9.01    1.83    7.17    0.00    0.67         0.00    4.73   -0.10   -4.50    0.15   -0.02   -0.01
 21   2   8   66.77    9.01    1.83    7.18    0.00    0.67         0.00    4.73   -0.10   -4.50    0.16   -0.02   -0.01
 22   2   9   66.77    9.01    1.82    7.18    0.00    0.67         0.00    4.73   -0.09   -4.50    0.16   -0.02   -0.01
 23   2  10   66.77    9.01    1.83    7.18    0.00    0.67         0.00    4.73   -0.09   -4.50    0.17   -0.02   -0.01
 24   2  11   66.77    9.01    1.83    7.17    0.00    0.67         0.00    4.73   -0.09   -4.50    0.17   -0.02   -0.01
 25   2  12   66.77    9.01    1.84    7.17    0.00    0.67         0.00    4.72   -0.09   -4.50    0.18   -0.02   -0.01
 26   2  13   66.77    9.01    1.85    7.16    0.00    0.67         0.00    4.72   -0.09   -4.50    0.19   -0.02   -0.01
 27   2  14   66.77    9.01    1.86    7.15    0.00    0.67         0.00    4.71   -0.08   -4.50    0.19   -0.02   -0.01
 28   2  15   66.77    9.01    1.87    7.13    0.00    0.67         0.00    4.70   -0.08   -4.50    0.20   -0.02   -0.01
 29   2  16   66.77    9.01    1.88    7.12    0.00    0.68         0.00    4.69   -0.08   -4.50    0.21   -0.02   -0.01
 30   2  17   66.77    9.01    1.90    7.11    0.00    0.68         0.00    4.69   -0.08   -4.50    0.21   -0.02   -0.01
 31   2  18   66.77    9.01    1.91    7.09    0.00    0.68         0.00    4.68   -0.08   -4.50    0.22   -0.02   -0.01
 32   2  19   66.77    9.01    1.93    7.08    0.00    0.69         0.00    4.67   -0.07   -4.50    0.23   -0.02   -0.01
 33   2  20   66.77    9.01    1.94    7.07    0.00    0.69         0.00    4.66   -0.07   -4.50    0.24   -0.02   -0.01
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TITLE01               Lake Creek DO TMDL ILEPA13A
TITLE02               Calibration run for 9/24/2015
TITLE03   NO          CONSERVATIVE MINERAL   I
TITLE04   NO          CONSERVATIVE MINERAL  II
TITLE05   NO          CONSERVATIVE MINERAL III
TITLE06  YES          TEMPERATURE
TITLE07  YES          5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES          ALGAE AS CHL-A IN UG/L
TITLE09  YES          PHOSPHORUS CYCLE AS P IN MG/L
TITLE10                 (ORGANIC-P; DISSOLVED-P)
TITLE11  YES          NITROGEN CYCLE AS N IN MG/L
TITLE12                 (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES          DISSOLVED OXYGEN IN MG/L
TITLE14   NO          FECAL COLIFORM IN NO./100 ML
TITLE15   NO          ARBITRARY NON-CONSERVATIVE
ENDTITLE
LIST DATA INPUT
NOWRITE OPTIONAL SUMMARY
NO FLOW AUGMENTATION
STEADY STATE
NO TRAPEZOIDAL CHANNELS
NO PRINT LCD/SOLAR DATA
NO PLOT DO AND BOD
FIXED DNSTM CONC (YES=1)=         0         5D-ULT BOD CONV K COEF  =      0.230
INPUT METRIC            =         0         OUTPUT METRIC           =          0
NUMBER OF REACHES       =         2         NUMBER OF JUNCTIONS     =          0
NUM OF HEADWATERS       =         1         NUMBER OF POINT LOADS   =          1
TIME STEP (HOURS)       =         1         LNTH. COMP. ELEMENT (MI)=       0.25
MAXIMUM ROUTE TIME (HRS)=        60         TIME INC. FOR RPT2 (HRS)=        1.0
LATITUDE OF BASIN (DEG) =     38.02         LONGITUDE OF BASIN (DEG)=     -89.04
STANDARD MERIDIAN (DEG) =         0         DAY OF YEAR START TIME  =        266
EVAP. COEF.,(AE)        =   0.00068         EVAP. COEF.,(BE)        =    0.00027
ELEV. OF BASIN (ELEV)   =       373         DUST ATTENUATION COEF.  =       0.06
ENDATA1
O UPTAKE BY NH3 OXID(MG O/MG N)=   3.43  O UPTAKE BY NO2 OXID(MG O/MG N)=   1.14
O PROD  BY ALGAE (MG O/MG A)   =    1.8  O UPTAKE BY ALGAE (MG O/MG A)  =   1.90
N CONTENT OF ALGAE (MG N/MG A) =   0.09  P CONTENT OF ALGAE (MG P/MG A) =  0.014
ALG MAX SPEC GROWTH RATE(1/DAY)=    2.0  ALGAE RESPIRATION RATE (1/DAY)=   0.105
N HALF SATURATION CONST (MG/L) =   0.03  P HALF SATURATION CONST  (MG/L)=  0.005
LIN ALG SHADE CO (1/H-UGCHA/L) =  0.003  NLIN SHADE (1/H-(UGCHA/L)**2/3)=  0.000
LIGHT FUNCTION OPTION (LFNOPT) =    2.0  LIGHT SATURATION COEF (INT/MIN)=   0.66
DAILY AVERAGING OPTION (LAVOPT)=    3.0  LIGHT AVERAGING FACTOR  (INT)  =    0.9
NUMBER OF DAYLIGHT HOURS (DLH) =   13.3  TOTAL DAILY SOLAR RADTN (INT)  =  1500.
ALGY GROWTH CALC OPTION(LGROPT)=    2.0  ALGAL PREF FOR NH3-N (PREFN)   =    0.1
ALG/TEMP SOLR RAD FACTOR(TFACT)=   0.45  NITRIFICATION INHIBITION COEF  =    0.6
ENDATA1A
         SOD RATE  1.0
ENDATA1B
STREAM REACH      1. RCH= Hdwtr, RM 3.5-5.5 FROM        5.5    TO           3.5
STREAM REACH      2. RCH= RM 0.0 to 3.5     FROM        3.5    TO           0.0
ENDATA2
ENDATA3
FLAG FIELD RCH=   1.         8          1.2.6.2.2.2.2.2.
FLAG FIELD RCH=   2.        14          2.2.2.2.2.2.2.2.2.2.2.2.2.5.
ENDATA4
HYDRAULICS RCH=   1.     100.0     0.040      0.00      1.10     0.000     0.020
HYDRAULICS RCH=   2.     100.0     0.450      0.00      0.40     0.000     0.020
ENDATA5
TEMP/LCD          1.     399.00   0.06   0.90   79.0   53.0  29.23    5.4
TEMP/LCD          2.     379.00   0.06   0.90   79.0   53.0  29.23    5.4
ENDATA5A
REACT COEF RCH=   1.   0.050    0.00  0.0790  1.     1.3  0.0000  0.0000
REACT COEF RCH=   2.   0.050    0.00  0.0600  1.     5.5  0.0000  0.0000
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ENDATA6
N AND P COEF   RCH=   1.   0.00   0.00   0.30   0.00   2.00   0.00   0.00   0.00
N AND P COEF   RCH=   2.   0.00   0.00   0.30   0.00   2.00   0.00   0.00   0.00
ENDATA6A
ALGAE/OTHER    RCH=   1.   50.0   0.10   0.01   0.00   0.00   0.00   0.00
ALGAE/OTHER    RCH=   2.   50.0   0.10   0.01   0.00   0.00   0.00   0.00
ENDATA6B
INITIAL COND-1 RCH=   1.  63.00   4.80   1.00   0.00   0.00   0.00  0.000    0.0
INITIAL COND-1 RCH=   2.  63.00   1.85   1.00   0.00   0.00   0.00  0.000    0.0
ENDATA7
INITIAL COND-2 RCH=   1.   7.00   0.43   0.05   0.00   0.10   0.00  0.030    0.0
INITIAL COND-2 RCH=   2.   4.60   0.43   0.05   0.00   0.10   0.00  0.030
ENDATA7A
INCR INFLOW-1  RCH=   1.  0.000   0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0
INCR INFLOW-1  RCH=   2.  4.690  65.00   9.0   1.0   0.0   0.0   0.0   0.0   0.0
ENDATA8
INCR INFLOW-2  RCH=   1.   0.00   0.00   0.00   0.00   0.00   0.00   0.00
INCR INFLOW-2  RCH=   2.  21.00   0.00   0.00   0.00   0.00   0.00   0.00
ENDATA8A
ENDATA9
HDWTR-NFK HDW=  1.         LAKE_CK    0.100 68.20  7.01  1.00   0.0   0.0   0.0
ENDATA10
HEADWTR-2 HDW=    1.  0.00  0.00   3.3  0.25  0.05  0.00  0.00 0.005  0.01
ENDATA10A
POINTLD-1 PTL=   1.   JC_STP 0.00   0.750   70.00   7.6   14.2   0.0   0.0   0.0
ENDATA11
POINTLD-2 PTL=    1.  0.00   0.0  4.00  0.00  8.90  0.00  0.00  0.00  2.6
ENDATA11A
ENDATA12
ENDATA13
ENDATA13A
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                              * * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
                                          Version 3.22  --  May 1996

 $$$ (PROBLEM TITLES) $$$

CARD TYPE                             QUAL-2E PROGRAM TITLES
TITLE01             Lake Creek DO TMDL ILEPA13A
TITLE02             Calibration run for 9/24/2015
TITLE03   NO        CONSERVATIVE MINERAL   I
TITLE04   NO        CONSERVATIVE MINERAL  II
TITLE05   NO        CONSERVATIVE MINERAL III
TITLE06  YES        TEMPERATURE
TITLE07  YES        5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES        ALGAE AS CHL-A IN UG/L
TITLE09  YES        PHOSPHORUS CYCLE AS P IN MG/L
TITLE10               (ORGANIC-P; DISSOLVED-P)
TITLE11  YES        NITROGEN CYCLE AS N IN MG/L
TITLE12               (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES        DISSOLVED OXYGEN IN MG/L
TITLE14   NO        FECAL COLIFORM IN NO./100 ML
TITLE15   NO        ARBITRARY NON-CONSERVATIVE
ENDTITLE

 $$$ DATA TYPE 1 (CONTROL DATA) $$$

CARD TYPE                                    CARD TYPE
LIST DATA INPUT             0.00000                                     0.00000
NOWRITE OPTIONAL SUMMARY    0.00000                                     0.00000
NO FLOW AUGMENTATION        0.00000                                     0.00000
STEADY STATE                0.00000                                     0.00000
NO TRAPEZOIDAL CHANNELS     0.00000                                     0.00000
NO PRINT LCD/SOLAR DATA     0.00000                                     0.00000
NO PLOT DO AND BOD          0.00000                                     0.00000
FIXED DNSTM CONC (YES=1)=   0.00000          D-ULT BOD CONV K COEF  =    0.23000
INPUT METRIC          =     0.00000          UTPUT METRIC           =    0.00000
NUMBER OF REACHES     =     2.00000          UMBER OF JUNCTIONS     =    0.00000
NUM OF HEADWATERS     =     1.00000          UMBER OF POINT LOADS   =    1.00000
TIME STEP (HOURS)     =     1.00000          NTH. COMP. ELEMENT (MI)=    0.25000
MAXIMUM ROUTE TIME (HRS)=  60.00000          IME INC. FOR RPT2 (HRS)=    1.00000
LATITUDE OF BASIN (DEG) =  38.02000          ONGITUDE OF BASIN (DEG)=  -89.04000
STANDARD MERIDIAN (DEG) =   0.00000          AY OF YEAR START TIME  =  266.00000
EVAP. COEF.,(AE)      =     0.00068          VAP. COEF.,(BE)        =    0.00027
ELEV. OF BASIN (ELEV)  = 373.00000           UST ATTENUATION COEF.  =    0.06000
ENDATA1                     0.00000                                     0.00000

 $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

CARD TYPE                                           CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=    3.4300          O UPTAKE BY NO2 OXID(MG O/MG N)=    1.1400
O PROD  BY ALGAE (MG O/MG A)   =    1.8000          O UPTAKE BY ALGAE (MG O/MG A)  =    1.9000
N CONTENT OF ALGAE (MG N/MG A) =    0.0900          P CONTENT OF ALGAE (MG P/MG A) =    0.0140
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ALG MAX SPEC GROWTH RATE(1/DAY)=    2.0000          ALGAE RESPIRATION RATE (1/DAY)=     0.1050
N HALF SATURATION CONST (MG/L) =    0.0300          P HALF SATURATION CONST  (MG/L)=    0.0050
LIN ALG SHADE CO (1/FT-UGCHA/L=)    0.0030          NLIN SHADE(1/FT-(UGCHA/L)**2/3)=    0.0000
LIGHT FUNCTION OPTION (LFNOPT) =    2.0000          LIGHT SAT'N COEF (BTU/FT2-MIN) =    0.6600
DAILY AVERAGING OPTION (LAVOPT)=    3.0000          LIGHT AVERAGING FACTOR  (INT)  =    0.9000
NUMBER OF DAYLIGHT HOURS (DLH) =   13.3000          TOTAL DAILY SOLR RAD (BTU/FT-2)= 1500.0000
ALGY GROWTH CALC OPTION(LGROPT)=    2.0000          ALGAL PREF FOR NH3-N (PREFN)   =    0.1000
ALG/TEMP SOLR RAD FACTOR(TFACT)=    0.4500          NITRIFICATION INHIBITION COEF  =    0.6000
ENDATA1A                            0.0000                                              0.0000

 $$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE     RATE CODE     THETA VALUE

THETA( 1)      BOD DECA        1.047     DFLT
THETA( 2)      BOD SETT        1.024     DFLT
THETA( 3)      OXY TRAN        1.024     DFLT
THETA( 4)      SOD RATE        1.000     USER
THETA( 5)      ORGN DEC        1.047     DFLT
THETA( 6)      ORGN SET        1.024     DFLT
THETA( 7)      NH3 DECA        1.083     DFLT
THETA( 8)      NH3 SRCE        1.074     DFLT
THETA( 9)      NO2 DECA        1.047     DFLT
THETA(10)      PORG DEC        1.047     DFLT
THETA(11)      PORG SET        1.024     DFLT
THETA(12)      DISP SRC        1.074     DFLT
THETA(13)      ALG GROW        1.047     DFLT
THETA(14)      ALG RESP        1.047     DFLT
THETA(15)      ALG SETT        1.024     DFLT
THETA(16)      COLI DEC        1.047     DFLT
THETA(17)      ANC DECA        1.000     DFLT
THETA(18)      ANC SETT        1.024     DFLT
THETA(19)      ANC SRCE        1.000     DFLT
ENDATA1B

 $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

CARD TYPE           REACH ORDER AND IDENT               R. MI/KM            R. MI/KM
STREAM REACH     1.0   RCH= Hdwtr, RM 3.5-    FRO          5.5    O            3.5
STREAM REACH     2.0   RCH= RM 0.0 to 3.5     FRO          3.5    O            0.0
ENDATA2          0.0                                       0.0                 0.0

 $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

CARD TYPE                  REACH  AVAIL HDWS TARGET     ORDER OF AVAIL SOURCES
ENDATA3                     0.        0.       0.0   0.   0.   0.   0.   0.   0.

 $$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

CARD TYPE        REACH ELEMENTS/REACH             COMPUTATIONAL FLAGS
FLAG FIELD        1.        8.          1.2.6.2.2.2.2.2.2.0.0.0.0.0.0.0.0.0.0.0.
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FLAG FIELD        2.       14.          2.2.2.2.2.2.2.2.2.2.2.2.2.2.5.0.0.0.0.0.0.
ENDATA4           0.        0.          0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

 $$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

CARD TYPE        REACH  COEF-DSPN  COEFQV    EXPOQV    COEFQH   EXPOQH     CMANN
HYDRAULICS        1.    100.00     0.040     0.000     1.100     0.000     0.020
HYDRAULICS        2.    100.00     0.450     0.000     0.400     0.000     0.020
ENDATA5           0.      0.00     0.000     0.000     0.000     0.000     0.000

 $$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

CARD TYPE                             DUST     CLOUD   DRY BULB  WET BULB    ATM                SOLAR RAD
                REACH   ELEVATION     COEF     COVER     TEMP      TEMP    PRESSURE     WIND   ATTENUATION
TEMP/LCD          1.      399.00      0.06      0.90     79.00     53.00     29.23      5.40      1.00
TEMP/LCD          2.      379.00      0.06      0.90     79.00     53.00     29.23      5.40      1.00
ENDATA5A          0.        0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

CARD TYPE        REACH     K1        K3       SOD         K2OPT     K2      COEQK2    OR   EXPQK2
                                              RATE                         TSIV COEF  OR    SLOPE
                                                                           FOR OPT 8      FOR OPT 8
REACT COEF        1.      0.05      0.00      0.079        1.      1.30      0.000        0.00000
REACT COEF        2.      0.05      0.00      0.060        1.      5.50      0.000        0.00000
ENDATA6           0.      0.00      0.00      0.000        0.      0.00      0.000        0.00000

  $$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

CARD TYPE           REACH    CKNH2    SETNH2     CKNH3      SNH3     CKNO2     CKPORG   SETPORG     SPO4
N AND P COEF          1.      0.00      0.00      0.30      0.00      2.00      0.00      0.00      0.00
N AND P COEF          2.      0.00      0.00      0.30      0.00      2.00      0.00      0.00      0.00
ENDATA6A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

CARD TYPE           REACH    ALPHAO    ALGSET    EXCOEF      CK5     CKANC    SETANC    SRCANC
                                                           CKCOLI
ALGAE/OTHER           1.     50.00      0.10      0.01      0.00      0.00      0.00      0.00
ALGAE/OTHER           2.     50.00      0.10      0.01      0.00      0.00      0.00      0.00
ENDATA6B              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

CARD TYPE           REACH    TEMP       D.O.      BOD       CM-1      CM-2      CM-3       ANC      COLI
INITIAL COND-1        1.     63.00      4.80      1.00      0.00      0.00      0.00      0.00      0.00
INITIAL COND-1        2.     63.00      1.85      1.00      0.00      0.00      0.00      0.00      0.00
ENDATA7               0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$
```

```
CARD TYPE           REACH    CHL-A     ORG-N     NH3-N     NO2-N     NO3-N     ORG-P     DIS-P
INITIAL COND-2        1.      7.00      0.43      0.05      0.00      0.10      0.00      0.03
INITIAL COND-2        2.      4.60      0.43      0.05      0.00      0.10      0.00      0.03
ENDATA7A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

CARD TYPE           REACH     FLOW      TEMP      D.O.       BOD      CM-1      CM-2      CM-3       ANC      COLI
INCR INFLOW-1         1.     0.000      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
INCR INFLOW-1         2.     4.690     65.00      9.00      1.00      0.00      0.00      0.00      0.00      0.00
ENDATA8               0.     0.000      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

CARD TYPE           REACH    CHL-A     ORG-N     NH3-N     NO2-N     NO3-N     ORG-P     DIS-P
INCR INFLOW-2         1.      0.00      0.00      0.00      0.00      0.00      0.00      0.00
INCR INFLOW-2         2.     21.00      0.00      0.00      0.00      0.00      0.00      0.00
ENDATA8A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

CARD TYPE              JUNCTION ORDER AND IDENT         UPSTRM   JUNCTION    TRIB
ENDATA9                0.                                 0.        0.        0.

 $$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

CARD TYPE    HDWTR     NAME              FLOW      TEMP      D.O.       BOD      CM-1      CM-2      CM-3
             ORDER
HDWTR-NFK      1.          LAKE_CK       0.10     68.20      7.01      1.00      0.00      0.00      0.00
ENDATA10       0.                        0.00      0.00      0.00      0.00      0.00      0.00      0.00

 $$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS,
                    COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

CARD TYPE     HDWTR     ANC     COLI    CHL-A    ORG-N    NH3-N    NO2-N    NO3-N    ORG-P    DIS-P
              ORDER
HEADWTR-2       1.     0.00 0.00E+00     3.30     0.25     0.05     0.00     0.00     0.00     0.01
ENDATA10A       0.     0.00 0.00E+00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

              POINT
CARD TYPE      LOAD    NAME              EFF     FLOW     TEMP     D.O.      BOD     CM-1     CM-2     CM-3
              ORDER
POINTLD-1      1.     JC_STP 0.         0.00     0.75    70.00     7.60    14.20     0.00     0.00     0.00
ENDATA11       0.                       0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS,
                    COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

              POINT
```

```
CARD TYPE      LOAD     ANC     COLI    CHL-A    ORG-N    NH3-N    NO2-N    N03-N    ORG-P    DIS-P
              ORDER
POINTLD-2       1.     0.00 0.00E+00     4.00     0.00     8.90     0.00     0.00     0.00     2.60
ENDATA11A       0.     0.00 0.00E+00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 $$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

                      DAM   RCH   ELE    ADAM    BDAM    FDAM    HDAM

ENDATA12                 0.    0.    0.    0.00    0.00    0.00    0.00

 $$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$

     CARD TYPE               TEMP       D.O.      BOD       CM-1      CM-2      CM-3       ANC      COLI

ENDATA13                     DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED

 $$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

     CARD TYPE               CHL-A     ORG-N     NH3-N     NO2-N     NH3-N     ORG-P     DIS-P

ENDATA13A                    DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
```

```
STEADY STATE TEMPERATURE SIMULATION; CONVERGENCE SUMMARY:
---------------------------------------------------------

                      NUMBER OF
        ITERATION   NONCONVERGENT
                      ELEMENTS

             1             22
             2              0


SUMMARY OF VALUES FOR STEADY STATE TEMPERATURE CALCULATIONS (SUBROUTINE HEATER):
--------------------------------------------------------------------------------

      DAILY NET SOLAR RADIATION =     934.851 BTU/FT-2   (  253.691 LANGLEYS)
      NUMBER OF DAYLIGHT HOURS =  11.9


      HOURLY VALUES OF SOLAR RADIATION (BTU/FT-2)

            1    11.65         9    97.24        17     0.00
            2    43.95        10    71.03        18     0.00
            3    74.33        11    40.26        19     0.00
            4    99.85        12     7.78        20     0.00
            5   118.11        13     0.00        21     0.00
            6   127.39        14     0.00        22     0.00
            7   126.82        15     0.00        23     0.00
            8   116.44        16     0.00        24     0.00
```

```
STEADY STATE ALGAE/NUTRIENT/DISSOLVED OXYGEN SIMULATION; CONVERGENCE SUMMARY:
-----------------------------------------------------------------------------

                                                  NUMBER OF
           VARIABLE              ITERATION      NONCONVERGENT
                                                  ELEMENTS

 ALGAE GROWTH RATE                 1               22
 ALGAE GROWTH RATE                 2               22
 ALGAE GROWTH RATE                 3               22
 ALGAE GROWTH RATE                 4               22
 ALGAE GROWTH RATE                 5               21
 ALGAE GROWTH RATE                 6                0
   NITRIFICATION INHIBITION           1                 2
 ALGAE GROWTH RATE                 7                0
   NITRIFICATION INHIBITION           2                 0
 ALGAE GROWTH RATE                 8                0
   NITRIFICATION INHIBITION           3                 0



SUMMARY OF CONDITIONS FOR ALGAL GROWTH RATE SIMULATION:
-------------------------------------------------------

      1. LIGHT AVERAGING OPTION.   LAVOPT= 3

          METHOD: AVERAGE OF HOURLY SOLAR VALUES

          SOURCE OF SOLAR VALUES: SUBROUTINE HEATER (SS TEMP)
              DAILY NET SOLAR RADIATION:   934.851 BTU/FT-2 (  253.691 LANGLEYS)
              NUMBER OF DAYLIGHT HOURS: 11.9
              PHOTOSYNTHETIC ACTIVE FRACTION OF SOLAR RADIATION (TFACT):  0.45
              MEAN SOLAR RADIATION ADJUSTMENT FACTOR (AFACT): N/A

          HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

            1     3.16         9    26.39        17     0.00
            2    11.93        10    19.27        18     0.00
            3    20.17        11    10.92        19     0.00
            4    27.10        12     2.11        20     0.00
            5    32.05        13     0.00        21     0.00
            6    34.57        14     0.00        22     0.00
            7    34.41        15     0.00        23     0.00
            8    31.60        16     0.00        24     0.00


      2. LIGHT FUNCTION OPTION:   LFNOPT= 2

          SMITH FUNCTION, WITH 71% IMAX =  0.179 LANGLEYS/MIN
```

```
3. GROWTH ATTENUATION OPTION FOR NUTRIENTS.   LGROPT= 2

    MINIMUM OF NITROGEN, PHOSPHORUS:   FL*MIN(FN,FP)
```

```
         STREAM QUALITY SIMULATION                                                                       OUTPUT PAGE NUMBER     1
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                    Version 3.22  --  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                      ** HYDRAULICS SUMMARY **

ELE RCH ELE   BEGIN     END            POINT    INCR            TRVL                                  BOTTOM      X-SECT   DSPRSN
ORD NUM NUM     LOC     LOC    FLOW    SRCE    FLOW     VEL    TIME    DEPTH    WIDTH      VOLUME        AREA        AREA     COEF
               MILE    MILE     CFS     CFS     CFS     FPS     DAY       FT       FT      K-FT-3      K-FT-2        FT-2   FT-2/S

  1   1   1    5.50    5.25    0.10    0.00    0.00   0.040   0.382    1.100    2.273        3.30        5.90        2.50     0.33
  2   1   2    5.25    5.00    0.10    0.00    0.00   0.040   0.382    1.100    2.273        3.30        5.90        2.50     0.33
  3   1   3    5.00    4.75    0.85    0.75    0.00   0.040   0.382    1.100   19.318       28.05       28.40       21.25     0.33
  4   1   4    4.75    4.50    0.85    0.00    0.00   0.040   0.382    1.100   19.318       28.05       28.40       21.25     0.33
  5   1   5    4.50    4.25    0.85    0.00    0.00   0.040   0.382    1.100   19.318       28.05       28.40       21.25     0.33
  6   1   6    4.25    4.00    0.85    0.00    0.00   0.040   0.382    1.100   19.318       28.05       28.40       21.25     0.33
  7   1   7    4.00    3.75    0.85    0.00    0.00   0.040   0.382    1.100   19.318       28.05       28.40       21.25     0.33
  8   1   8    3.75    3.50    0.85    0.00    0.00   0.040   0.382    1.100   19.318       28.05       28.40       21.25     0.33


  9   2   1    3.50    3.25    1.19    0.00    0.34   0.450   0.034    0.400    6.583        3.48        9.75        2.63     1.60
 10   2   2    3.25    3.00    1.52    0.00    0.34   0.450   0.034    0.400    8.444        4.46       12.20        3.38     1.60
 11   2   3    3.00    2.75    1.86    0.00    0.34   0.450   0.034    0.400   10.306        5.44       14.66        4.12     1.60
 12   2   4    2.75    2.50    2.19    0.00    0.34   0.450   0.034    0.400   12.167        6.42       17.12        4.87     1.60
 13   2   5    2.50    2.25    2.53    0.00    0.34   0.450   0.034    0.400   14.028        7.41       19.57        5.61     1.60
 14   2   6    2.25    2.00    2.86    0.00    0.34   0.450   0.034    0.400   15.889        8.39       22.03        6.36     1.60
 15   2   7    2.00    1.75    3.20    0.00    0.34   0.450   0.034    0.400   17.750        9.37       24.49        7.10     1.60
 16   2   8    1.75    1.50    3.53    0.00    0.34   0.450   0.034    0.400   19.611       10.35       26.94        7.84     1.60
 17   2   9    1.50    1.25    3.87    0.00    0.34   0.450   0.034    0.400   21.472       11.34       29.40        8.59     1.60
 18   2  10    1.25    1.00    4.20    0.00    0.34   0.450   0.034    0.400   23.333       12.32       31.86        9.33     1.60
 19   2  11    1.00    0.75    4.54    0.00    0.34   0.450   0.034    0.400   25.194       13.30       34.31       10.08     1.60
 20   2  12    0.75    0.50    4.87    0.00    0.34   0.450   0.034    0.400   27.056       14.29       36.77       10.82     1.60
 21   2  13    0.50    0.25    5.21    0.00    0.34   0.450   0.034    0.400   28.917       15.27       39.23       11.57     1.60
 22   2  14    0.25    0.00    5.54    0.00    0.34   0.450   0.034    0.400   30.778       16.25       41.68       12.31     1.60
```

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         STREAM QUALITY SIMULATION                                                                                OUTPUT PAGE NUMBER     2
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                             Version 3.22  --  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                 ** REACTION COEFFICIENT SUMMARY **

RCH ELE     DO  K2  OXYGN    BOD    BOD    SOD   ORGN   ORGN    NH3    NH3    NO2   ORGP   ORGP   DISP   COLI    ANC    ANC    ANC
NUM NUM    SAT OPT  REAIR  DECAY   SETT   RATE  DECAY   SETT  DECAY   SRCE  DECAY  DECAY   SETT   SRCE  DECAY  DECAY   SETT   SRCE
          MG/L      1/DAY  1/DAY  1/DAY  G/F2D  1/DAY  1/DAY  1/DAY MG/F2D  1/DAY  1/DAY  1/DAY MG/F2D  1/DAY  1/DAY  1/DAY MG/F2D

  1   1   8.92   1   1.29   0.05   0.00   0.08   0.00   0.00   0.29   0.00   1.94   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   2   8.95   1   1.29   0.05   0.00   0.08   0.00   0.00   0.28   0.00   1.91   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   3   8.79   1   1.32   0.05   0.00   0.08   0.00   0.00   0.30   0.00   1.96   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   4   8.87   1   1.30   0.05   0.00   0.08   0.00   0.00   0.27   0.00   1.79   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   5   8.92   1   1.29   0.05   0.00   0.08   0.00   0.00   0.24   0.00   1.63   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   6   8.95   1   1.29   0.05   0.00   0.08   0.00   0.00   0.23   0.00   1.53   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   7   8.97   1   1.28   0.05   0.00   0.08   0.00   0.00   0.22   0.00   1.49   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  1   8   8.99   1   1.28   0.05   0.00   0.08   0.00   0.00   0.22   0.00   1.50   0.00   0.00   0.00   0.00   0.00   0.00   0.00


  2   1   9.03   1   3.33   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.85   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   2   9.06   1   5.37   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.87   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   3   9.07   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.87   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   4   9.08   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.88   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   5   9.08   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.88   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   6   9.08   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.88   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   7   9.08   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.88   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   8   9.08   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.88   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2   9   9.08   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.89   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  10   9.08   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.89   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  11   9.08   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.89   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  12   9.07   1   5.36   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.89   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  13   9.07   1   5.37   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.89   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  2  14   9.07   1   5.37   0.05   0.00   0.06   0.00   0.00   0.27   0.00   1.89   0.00   0.00   0.00   0.00   0.00   0.00   0.00
```

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         STREAM QUALITY SIMULATION                                                               OUTPUT PAGE NUMBER     3
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                   Version 3.22  --  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                    ** WATER QUALITY VARIABLES **

RCH ELE              CM-1   CM-2   CM-3                                                                                 ANC
NUM NUM       TEMP                          DO    BOD   ORGN   NH3N   NO2N   NO3N  SUM-N   ORGP  DIS-P  SUM-P   COLI          CHLA
             DEG-F                        MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L #/100ML         UG/L

  1   1      67.66   0.00   0.00   0.00   6.34   0.98   0.25   0.04   0.00   0.00   0.30   0.01   0.01   0.01.00E+00   0.00   3.52
  1   2      67.33   0.00   0.00   0.00   5.89   1.03   0.25   0.08   0.01   0.01   0.35   0.01   0.02   0.03.00E+00   0.00   3.87
  1   3      68.93   0.00   0.00   0.00   5.33  12.47   0.03   7.36   0.33   0.14   7.87   0.00   2.29   2.29.00E+00   0.00   4.36
  1   4      68.11   0.00   0.00   0.00   3.70  12.24   0.03   6.68   0.60   0.55   7.86   0.00   2.29   2.29.00E+00   0.00   5.12
  1   5      67.60   0.00   0.00   0.00   2.87  12.01   0.03   6.11   0.72   1.00   7.86   0.00   2.29   2.29.00E+00   0.00   6.00
  1   6      67.29   0.00   0.00   0.00   2.51  11.79   0.03   5.62   0.76   1.44   7.86   0.00   2.29   2.29.00E+00   0.00   7.02
  1   7      67.09   0.00   0.00   0.00   2.40  11.58   0.03   5.19   0.76   1.87   7.86   0.00   2.29   2.29.00E+00   0.00   8.20
  1   8      66.97   0.00   0.00   0.00   2.44  11.35   0.03   4.78   0.74   2.29   7.84   0.00   2.28   2.28.00E+00   0.00   9.59


  2   1      66.51   0.00   0.00   0.00   5.31   8.35   0.02   3.29   0.52   1.78   5.61   0.00   1.63   1.63.00E+00   0.00  13.27
  2   2      66.25   0.00   0.00   0.00   6.28   6.72   0.02   2.54   0.40   1.41   4.38   0.00   1.27   1.27.00E+00   0.00  15.07
  2   3      66.11   0.00   0.00   0.00   6.86   5.68   0.02   2.07   0.33   1.18   3.59   0.00   1.04   1.04.00E+00   0.00  16.25
  2   4      66.04   0.00   0.00   0.00   7.23   4.96   0.01   1.73   0.28   1.01   3.04   0.00   0.88   0.88.00E+00   0.00  17.09
  2   5      66.01   0.00   0.00   0.00   7.49   4.43   0.01   1.49   0.24   0.89   2.63   0.00   0.77   0.77.00E+00   0.00  17.72
  2   6      66.00   0.00   0.00   0.00   7.66   4.02   0.01   1.31   0.21   0.80   2.33   0.00   0.68   0.68.00E+00   0.00  18.23
  2   7      66.01   0.00   0.00   0.00   7.79   3.70   0.01   1.16   0.19   0.73   2.08   0.00   0.61   0.61.00E+00   0.00  18.64
  2   8      66.02   0.00   0.00   0.00   7.89   3.44   0.01   1.04   0.17   0.67   1.88   0.00   0.55   0.55.00E+00   0.00  18.99
  2   9      66.04   0.00   0.00   0.00   7.95   3.22   0.01   0.94   0.15   0.62   1.72   0.00   0.50   0.50.00E+00   0.00  19.29
  2  10      66.06   0.00   0.00   0.00   8.01   3.04   0.01   0.86   0.14   0.58   1.58   0.00   0.46   0.46.00E+00   0.00  19.56
  2  11      66.08   0.00   0.00   0.00   8.05   2.88   0.01   0.79   0.13   0.54   1.46   0.00   0.43   0.43.00E+00   0.00  19.80
  2  12      66.10   0.00   0.00   0.00   8.08   2.75   0.01   0.73   0.12   0.51   1.36   0.00   0.40   0.40.00E+00   0.00  20.01
  2  13      66.12   0.00   0.00   0.00   8.10   2.63   0.01   0.67   0.11   0.48   1.28   0.00   0.37   0.37.00E+00   0.00  20.21
  2  14      66.15   0.00   0.00   0.00   8.11   2.53   0.01   0.63   0.10   0.46   1.20   0.00   0.35   0.35.00E+00   0.00  20.39
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         STREAM QUALITY SIMULATION                                                      OUTPUT PAGE NUMBER     4
         QUAL-2E STREAM QUALITY ROUTING MODEL                                   Version 3.22  --  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                          ** ALGAE DATA **

                                                                             NH3-N            ALGAE GROWTH RATE ATTEN FACTORS
ELE RCH ELE               ALGY    ALGY    ALGY   A P/R     NET         NH3   FRACT   LIGHT
ORD NUM NUM       CHLA   GRWTH    RESP    SETT   RATIO     P-R        PREF N-UPTKE   EXTCO        LIGHT   NITRGN   PHSPRS
                  UG/L   1/DAY   1/DAY   FT/DA      *   MG/L-D          *       *     1/FT           *        *        *

  1   1   1       3.52    0.35    0.10    0.10    3.23    0.03        0.10    0.72    0.02         0.29     0.61     0.67
  2   1   2       3.87    0.43    0.10    0.10    3.96    0.04        0.10    0.53    0.02         0.29     0.75     0.83
  3   1   3       4.36    0.60    0.11    0.10    5.28    0.08        0.10    0.85    0.02         0.29     1.00     1.00
  4   1   4       5.12    0.59    0.11    0.10    5.27    0.09        0.10    0.57    0.03         0.29     1.00     1.00
  5   1   5       6.00    0.58    0.10    0.10    5.27    0.10        0.10    0.40    0.03         0.29     1.00     1.00
  6   1   6       7.02    0.57    0.10    0.10    5.26    0.12        0.10    0.30    0.03         0.29     1.00     1.00
  7   1   7       8.20    0.57    0.10    0.10    5.26    0.14        0.10    0.24    0.03         0.29     1.00     1.00
  8   1   8       9.59    0.57    0.10    0.10    5.25    0.16        0.10    0.19    0.04         0.29     1.00     1.00


  9   2   1      13.27    0.56    0.10    0.10    5.27    0.22        0.10    0.17    0.05         0.29     0.99     1.00
 10   2   2      15.07    0.56    0.10    0.10    5.26    0.25        0.10    0.17    0.06         0.29     0.99     1.00
 11   2   3      16.25    0.55    0.10    0.10    5.25    0.26        0.10    0.16    0.06         0.29     0.99     1.00
 12   2   4      17.09    0.55    0.10    0.10    5.24    0.28        0.10    0.16    0.06         0.29     0.99     0.99
 13   2   5      17.72    0.55    0.10    0.10    5.23    0.28        0.10    0.16    0.06         0.29     0.99     0.99
 14   2   6      18.23    0.55    0.10    0.10    5.22    0.29        0.10    0.15    0.06         0.29     0.99     0.99
 15   2   7      18.64    0.55    0.10    0.10    5.21    0.30        0.10    0.15    0.07         0.29     0.98     0.99
 16   2   8      18.99    0.55    0.10    0.10    5.21    0.30        0.10    0.15    0.07         0.29     0.98     0.99
 17   2   9      19.29    0.55    0.10    0.10    5.20    0.31        0.10    0.14    0.07         0.29     0.98     0.99
 18   2  10      19.56    0.55    0.10    0.10    5.19    0.31        0.10    0.14    0.07         0.29     0.98     0.99
 19   2  11      19.80    0.55    0.10    0.10    5.18    0.31        0.10    0.14    0.07         0.29     0.98     0.99
 20   2  12      20.01    0.55    0.10    0.10    5.17    0.32        0.10    0.14    0.07         0.29     0.98     0.99
 21   2  13      20.21    0.55    0.10    0.10    5.16    0.32        0.10    0.13    0.07         0.29     0.97     0.99
 22   2  14      20.39    0.54    0.10    0.10    5.15    0.32        0.10    0.13    0.07         0.29     0.97     0.99
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                                         ***** STEADY STATE SIMULATION *****

                                            ** DISSOLVED OXYGEN DATA **

                                                                COMPONENTS OF DISSOLVED OXYGEN MASS BALANCE (MG/L-DAY)
ELE RCH ELE                 DO              DO     DAM     NIT
ORD NUM NUM    TEMP        SAT       DO     DEF   INPUT   INHIB       F-FNCTN   OXYGN                        NET
               DEG-F       MG/L     MG/L    MG/L    MG/L    FACT         INPUT   REAIR   C-BOD     SOD      P-R   NH3-N   NO2-N

  1   1   1    67.66       8.92     6.34    2.58    0.00    0.98         18.35    3.33   -0.05   -2.54     0.03   -0.04   -0.01
  2   1   2    67.33       8.95     5.89    3.06    0.00    0.97          0.00    3.94   -0.05   -2.54     0.04   -0.08   -0.02
  3   1   3    68.93       8.79     5.33    3.46    0.00    0.96         17.56    4.56   -0.64   -2.54     0.08   -7.57   -0.74
  4   1   4    68.11       8.87     3.70    5.17    0.00    0.89          0.00    6.74   -0.61   -2.54     0.09   -6.15   -1.23
  5   1   5    67.60       8.92     2.87    6.05    0.00    0.82          0.00    7.83   -0.59   -2.54     0.10   -5.07   -1.34
  6   1   6    67.29       8.95     2.51    6.45    0.00    0.78          0.00    8.30   -0.58   -2.54     0.12   -4.36   -1.33
  7   1   7    67.09       8.97     2.40    6.57    0.00    0.76          0.00    8.44   -0.57   -2.54     0.14   -3.91   -1.30
  8   1   8    66.97       8.99     2.44    6.55    0.00    0.77          0.00    8.40   -0.55   -2.54     0.16   -3.61   -1.26


  9   2   1    66.51       9.03     5.31    3.72    0.00    0.96         74.94   12.40   -0.40   -5.30     0.22   -3.03   -1.09
 10   2   2    66.25       9.06     6.28    2.78    0.00    0.98         58.42   14.96   -0.32   -5.30     0.25   -2.36   -0.86
 11   2   3    66.11       9.07     6.86    2.22    0.00    0.98         47.87   11.90   -0.27   -5.30     0.26   -1.92   -0.70
 12   2   4    66.04       9.08     7.23    1.85    0.00    0.99         40.55    9.91   -0.24   -5.30     0.28   -1.62   -0.59
 13   2   5    66.01       9.08     7.49    1.60    0.00    0.99         35.17    8.56   -0.21   -5.30     0.28   -1.39   -0.51
 14   2   6    66.00       9.08     7.66    1.42    0.00    0.99         31.05    7.61   -0.19   -5.30     0.29   -1.22   -0.45
 15   2   7    66.01       9.08     7.79    1.29    0.00    0.99         27.80    6.92   -0.18   -5.30     0.30   -1.08   -0.40
 16   2   8    66.02       9.08     7.89    1.20    0.00    0.99         25.16    6.41   -0.16   -5.30     0.30   -0.97   -0.36
 17   2   9    66.04       9.08     7.95    1.13    0.00    0.99         22.98    6.03   -0.15   -5.30     0.31   -0.88   -0.33
 18   2  10    66.06       9.08     8.01    1.07    0.00    0.99         21.14    5.75   -0.14   -5.30     0.31   -0.80   -0.30
 19   2  11    66.08       9.08     8.05    1.03    0.00    0.99         19.58    5.53   -0.14   -5.30     0.31   -0.74   -0.28
 20   2  12    66.10       9.07     8.08    1.00    0.00    0.99         18.24    5.36   -0.13   -5.30     0.32   -0.68   -0.25
 21   2  13    66.12       9.07     8.10    0.97    0.00    0.99         17.06    5.23   -0.13   -5.30     0.32   -0.63   -0.24
 22   2  14    66.15       9.07     8.11    0.96    0.00    0.99         16.03    5.13   -0.12   -5.30     0.32   -0.59   -0.22
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TITLE01               Pond Creek DO TMDL ILEPA13A
TITLE02               Setup run for 9/24/2015
TITLE03   NO          CONSERVATIVE MINERAL   I
TITLE04   NO          CONSERVATIVE MINERAL  II
TITLE05   NO          CONSERVATIVE MINERAL III
TITLE06  YES          TEMPERATURE
TITLE07  YES          5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES          ALGAE AS CHL-A IN UG/L
TITLE09  YES          PHOSPHORUS CYCLE AS P IN MG/L
TITLE10                 (ORGANIC-P; DISSOLVED-P)
TITLE11  YES          NITROGEN CYCLE AS N IN MG/L
TITLE12                 (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES          DISSOLVED OXYGEN IN MG/L
TITLE14   NO          FECAL COLIFORM IN NO./100 ML
TITLE15   NO          ARBITRARY NON-CONSERVATIVE
ENDTITLE
LIST DATA INPUT
NOWRITE OPTIONAL SUMMARY
NO FLOW AUGMENTATION
STEADY STATE
NO TRAPEZOIDAL CHANNELS
NO PRINT LCD/SOLAR DATA
NO PLOT DO AND BOD
FIXED DNSTM CONC (YES=1)=         0        5D-ULT BOD CONV K COEF  =      0.230
INPUT METRIC            =         0        OUTPUT METRIC           =          0
NUMBER OF REACHES       =         3        NUMBER OF JUNCTIONS     =          0
NUM OF HEADWATERS       =         1        NUMBER OF POINT LOADS   =          2
TIME STEP (HOURS)       =         1        LNTH. COMP. ELEMENT (MI)=        0.5
MAXIMUM ROUTE TIME (HRS)=        60        TIME INC. FOR RPT2 (HRS)=        1.0
LATITUDE OF BASIN (DEG) =     37.86        LONGITUDE OF BASIN (DEG)=     -88.96
STANDARD MERIDIAN (DEG) =         0        DAY OF YEAR START TIME  =        267
EVAP. COEF.,(AE)        =   0.00068        EVAP. COEF.,(BE)        =    0.00027
ELEV. OF BASIN (ELEV)   =       373        DUST ATTENUATION COEF.  =       0.06
ENDATA1
O UPTAKE BY NH3 OXID(MG O/MG N)=   3.43  O UPTAKE BY NO2 OXID(MG O/MG N)=   1.14
O PROD  BY ALGAE (MG O/MG A)   =    1.8  O UPTAKE BY ALGAE (MG O/MG A)  =   1.90
N CONTENT OF ALGAE (MG N/MG A) =   0.09  P CONTENT OF ALGAE (MG P/MG A) =  0.014
ALG MAX SPEC GROWTH RATE(1/DAY)=    2.0  ALGAE RESPIRATION RATE (1/DAY)=   0.105
N HALF SATURATION CONST (MG/L) =   0.03  P HALF SATURATION CONST  (MG/L)=  0.005
LIN ALG SHADE CO (1/H-UGCHA/L) =  0.003  NLIN SHADE (1/H-(UGCHA/L)**2/3)=  0.000
LIGHT FUNCTION OPTION (LFNOPT) =    2.0  LIGHT SATURATION COEF (INT/MIN)=   0.66
DAILY AVERAGING OPTION (LAVOPT)=    3.0  LIGHT AVERAGING FACTOR  (INT)  =    0.9
NUMBER OF DAYLIGHT HOURS (DLH) =   13.3  TOTAL DAILY SOLAR RADTN (INT)  =  1500.
ALGY GROWTH CALC OPTION(LGROPT)=    2.0  ALGAL PREF FOR NH3-N (PREFN)   =    0.1
ALG/TEMP SOLR RAD FACTOR(TFACT)=   0.45  NITRIFICATION INHIBITION COEF  =    0.6
ENDATA1A
         SOD RATE  1.0
ENDATA1B
STREAM REACH      1. RCH= Hdwtr, RM 21.1-15.6FROM      21.1    TO          15.6
STREAM REACH      2. RCH= RM 5.6 to 15.6    FROM      15.6    TO           5.6
STREAM REACH      3. RCH= RM 0.1 to 5.6     FROM       5.6    TO           0.1
ENDATA2
ENDATA3
FLAG FIELD RCH=   1.        11          1.6.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=   2.        20          2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
FLAG FIELD RCH=   3.        11          6.2.2.2.2.2.2.2.2.2.5.
ENDATA4
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HYDRAULICS RCH=   1.     100.0     0.060      0.00      1.10     0.000     0.020
HYDRAULICS RCH=   2.     100.0     0.080      0.00      0.87     0.000     0.020
HYDRAULICS RCH=   3.     100.0     0.060      0.00      2.48     0.000     0.020
ENDATA5
TEMP/LCD          1.     399.00   0.06   0.90   79.0   53.0  29.23    5.4
TEMP/LCD          2.     379.00   0.06   0.90   79.0   53.0  29.23    5.4
TEMP/LCD          3.     379.00   0.06   0.90   79.0   53.0  29.23    5.4
ENDATA5A
REACT COEF RCH=   1.   0.050    0.00  0.1330  1.     .65  0.0000  0.0000
REACT COEF RCH=   2.   0.050    0.00  0.1330  1.     .65  0.0000  0.0000
REACT COEF RCH=   3.   0.050    0.00  0.1330  1.     .65  0.0000  0.0000
ENDATA6
N AND P COEF   RCH=   1.   0.00   0.00   0.01   0.00   2.00   0.00   0.00   0.00
N AND P COEF   RCH=   2.   0.00   0.00   0.01   0.00   2.00   0.00   0.00   0.00
N AND P COEF   RCH=   3.   0.00   0.00   0.01   0.00   2.00   0.00   0.00   0.00
ENDATA6A
ALGAE/OTHER    RCH=   1.   50.0   0.10   0.01   0.00   0.00   0.00   0.00
ALGAE/OTHER    RCH=   2.   50.0   0.10   0.01   0.00   0.00   0.00   0.00
ALGAE/OTHER    RCH=   3.   50.0   0.10   0.01   0.00   0.00   0.00   0.00
ENDATA6B
INITIAL COND-1 RCH=   1.  69.00   15.3   5.00   0.00   0.00   0.00  0.000    0.0
INITIAL COND-1 RCH=   2.  66.00   7.08   5.00   0.00   0.00   0.00  0.000    0.0
INITIAL COND-1 RCH=   3.  66.00   6.52   2.60   0.00   0.00   0.00  0.000    0.0
ENDATA7
INITIAL COND-2 RCH=   1.   28.3   0.43   0.05   0.00   0.10   0.00  0.030    0.0
INITIAL COND-2 RCH=   2.   36.6   0.43   0.05   0.00   0.10   0.00  0.030
INITIAL COND-2 RCH=   3.   7.96   0.43   0.05   0.00   0.10   0.00  0.030
ENDATA7A
INCR INFLOW-1  RCH=   1.  0.000  65.00   4.5   1.0   0.0   0.0   0.0   0.0   0.0
INCR INFLOW-1  RCH=   2.  0.000  65.00   4.5   1.0   0.0   0.0   0.0   0.0   0.0
INCR INFLOW-1  RCH=   2.  0.000  65.00   4.5   1.0   0.0   0.0   0.0   0.0   0.0
ENDATA8
INCR INFLOW-2  RCH=   1.   0.00   0.00   0.00   0.00   0.00   0.00   0.00
INCR INFLOW-2  RCH=   2.   0.08   0.00   0.00   0.00   0.00   0.00   0.00
INCR INFLOW-2  RCH=   2.   0.08   0.00   0.00   0.00   0.00   0.00   0.00
ENDATA8A
ENDATA9
HDWTR-NFK HDW=  1.         POND_CK    1.90  69.00  15.33  2.60   0.0   0.0   0.0
ENDATA10
HEADWTR-2 HDW=    1.  0.00  0.00  28.3  0.60  1.40  0.00  0.10  0.06  0.005
ENDATA10A
POINTLD-1 PTL=   1.STEELHEAD 0.00   0.000   70.00   8.7   10.9   0.0   0.0   0.0
POINTLD-1 PTL=   2.   LAKECR 0.00   5.540   67.50   8.9    1.0   0.0   0.0   0.0
ENDATA11
POINTLD-2 PTL=    1.  0.00   0.0  0.00  0.00  1.80  0.00  0.00  0.60  1.0
POINTLD-2 PTL=    2.  0.00   0.0  21.6  0.53  0.02  0.00  0.10  0.02  0.133
ENDATA11A
ENDATA12
ENDATA13
ENDATA13A
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                                         * * * QUAL-2E  STREAM QUALITY ROUTING MODEL * * *
                                                       Version 3.22  --  May 1996

 $$$ (PROBLEM TITLES) $$$

CARD TYPE                             QUAL-2E PROGRAM TITLES
TITLE01              Pond Creek DO TMDL ILEPA13A
TITLE02              Setup run for 9/24/2015
TITLE03   NO         CONSERVATIVE MINERAL   I
TITLE04   NO         CONSERVATIVE MINERAL  II
TITLE05   NO         CONSERVATIVE MINERAL III
TITLE06  YES         TEMPERATURE
TITLE07  YES         5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  YES         ALGAE AS CHL-A IN UG/L
TITLE09  YES         PHOSPHORUS CYCLE AS P IN MG/L
TITLE10                (ORGANIC-P; DISSOLVED-P)
TITLE11  YES         NITROGEN CYCLE AS N IN MG/L
TITLE12                (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES         DISSOLVED OXYGEN IN MG/L
TITLE14   NO         FECAL COLIFORM IN NO./100 ML
TITLE15   NO         ARBITRARY NON-CONSERVATIVE
ENDTITLE

 $$$ DATA TYPE 1 (CONTROL DATA) $$$

CARD TYPE                                      CARD TYPE
LIST DATA INPUT              0.00000                                       0.00000
NOWRITE OPTIONAL SUMMARY     0.00000                                       0.00000
NO FLOW AUGMENTATION         0.00000                                       0.00000
STEADY STATE                 0.00000                                       0.00000
NO TRAPEZOIDAL CHANNELS      0.00000                                       0.00000
NO PRINT LCD/SOLAR DATA      0.00000                                       0.00000
NO PLOT DO AND BOD           0.00000                                       0.00000
FIXED DNSTM CONC (YES=1)=    0.00000          D-ULT BOD CONV K COEF  =    0.23000
INPUT METRIC            =    0.00000          UTPUT METRIC           =    0.00000
NUMBER OF REACHES       =    3.00000          UMBER OF JUNCTIONS     =    0.00000
NUM OF HEADWATERS       =    1.00000          UMBER OF POINT LOADS   =    2.00000
TIME STEP (HOURS)       =    1.00000          NTH. COMP. ELEMENT (MI)=    0.50000
MAXIMUM ROUTE TIME (HRS)=   60.00000          IME INC. FOR RPT2 (HRS)=    1.00000
LATITUDE OF BASIN (DEG) =   37.86000          ONGITUDE OF BASIN (DEG)=  -88.96000
STANDARD MERIDIAN (DEG) =    0.00000          AY OF YEAR START TIME  =  267.00000
EVAP. COEF.,(AE)        =    0.00068          VAP. COEF.,(BE)        =    0.00027
ELEV. OF BASIN (ELEV)   =  373.00000          UST ATTENUATION COEF.  =    0.06000
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ENDATA1                     0.00000                                      0.00000

 $$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN OXIDATION CONSTANTS) $$$

CARD TYPE                                          CARD TYPE
O UPTAKE BY NH3 OXID(MG O/MG N)=    3.4300         O UPTAKE BY NO2 OXID(MG O/MG N)=    1.1400
O PROD  BY ALGAE (MG O/MG A)   =    1.8000         O UPTAKE BY ALGAE (MG O/MG A)  =    1.9000
N CONTENT OF ALGAE (MG N/MG A) =    0.0900         P CONTENT OF ALGAE (MG P/MG A) =    0.0140
ALG MAX SPEC GROWTH RATE(1/DAY)=    2.0000         ALGAE RESPIRATION RATE (1/DAY)=     0.1050
N HALF SATURATION CONST (MG/L) =    0.0300         P HALF SATURATION CONST  (MG/L)=    0.0050
LIN ALG SHADE CO (1/FT-UGCHA/L=)    0.0030         NLIN SHADE(1/FT-(UGCHA/L)**2/3)=    0.0000
LIGHT FUNCTION OPTION (LFNOPT) =    2.0000         LIGHT SAT'N COEF (BTU/FT2-MIN) =    0.6600
DAILY AVERAGING OPTION (LAVOPT)=    3.0000         LIGHT AVERAGING FACTOR  (INT)  =    0.9000
NUMBER OF DAYLIGHT HOURS (DLH) =   13.3000         TOTAL DAILY SOLR RAD (BTU/FT-2)= 1500.0000
ALGY GROWTH CALC OPTION(LGROPT)=    2.0000         ALGAL PREF FOR NH3-N (PREFN)   =    0.1000
ALG/TEMP SOLR RAD FACTOR(TFACT)=    0.4500         NITRIFICATION INHIBITION COEF  =    0.6000
ENDATA1A                            0.0000                                             0.0000

 $$$ DATA TYPE 1B (TEMPERATURE CORRECTION CONSTANTS FOR RATE COEFFICIENTS) $$$

CARD TYPE     RATE CODE     THETA VALUE

THETA( 1)      BOD DECA        1.047     DFLT
THETA( 2)      BOD SETT        1.024     DFLT
THETA( 3)      OXY TRAN        1.024     DFLT
THETA( 4)      SOD RATE        1.000     USER
THETA( 5)      ORGN DEC        1.047     DFLT
THETA( 6)      ORGN SET        1.024     DFLT
THETA( 7)      NH3 DECA        1.083     DFLT
THETA( 8)      NH3 SRCE        1.074     DFLT
THETA( 9)      NO2 DECA        1.047     DFLT
THETA(10)      PORG DEC        1.047     DFLT
THETA(11)      PORG SET        1.024     DFLT
THETA(12)      DISP SRC        1.074     DFLT
THETA(13)      ALG GROW        1.047     DFLT
THETA(14)      ALG RESP        1.047     DFLT
THETA(15)      ALG SETT        1.024     DFLT
THETA(16)      COLI DEC        1.047     DFLT
THETA(17)      ANC DECA        1.000     DFLT
THETA(18)      ANC SETT        1.024     DFLT
THETA(19)      ANC SRCE        1.000     DFLT
ENDATA1B
```

```
           $$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$

          CARD TYPE           REACH ORDER AND IDENT               R. MI/KM            R. MI/KM
          STREAM REACH     1.0   RCH= Hdwtr, RM 21.1   .6FR         21.1    O           15.6
          STREAM REACH     2.0   RCH= RM 5.6 to 15.6    FRO         15.6    O            5.6
          STREAM REACH     3.0   RCH= RM 0.1 to 5.6     FRO          5.6    O            0.1
          ENDATA2          0.0                                     0.0                 0.0

           $$$ DATA TYPE 3 (TARGET LEVEL DO AND FLOW AUGMENTATION SOURCES) $$$

          CARD TYPE                  REACH  AVAIL HDWS TARGET     ORDER OF AVAIL SOURCES
          ENDATA3                     0.         0.       0.0   0.   0.   0.   0.   0.   0.

           $$$ DATA TYPE 4 (COMPUTATIONAL REACH FLAG FIELD) $$$

          CARD TYPE        REACH ELEMENTS/REACH             COMPUTATIONAL FLAGS
          FLAG FIELD        1.       11.          1.6.2.2.2.2.2.2.2.2.2.0.0.0.0.0.0.0.0.0.
          FLAG FIELD        2.       20.          2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.
          FLAG FIELD        3.       11.          6.2.2.2.2.2.2.2.2.2.5.0.0.0.0.0.0.0.0.0.
          ENDATA4           0.        0.          0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.

           $$$ DATA TYPE 5 (HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH) $$$

          CARD TYPE        REACH  COEF-DSPN  COEFQV    EXPOQV    COEFQH   EXPOQH     CMANN
          HYDRAULICS        1.    100.00     0.060     0.000     1.100     0.000     0.020
          HYDRAULICS        2.    100.00     0.080     0.000     0.870     0.000     0.020
          HYDRAULICS        3.    100.00     0.060     0.000     2.480     0.000     0.020
          ENDATA5           0.      0.00     0.000     0.000     0.000     0.000     0.000

           $$$ DATA TYPE 5A (STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA) $$$

          CARD TYPE                             DUST     CLOUD   DRY BULB  WET BULB     ATM
 SOLAR RAD
                          REACH   ELEVATION     COEF     COVER     TEMP      TEMP    PRESSURE     WIND
 ATTENUATION
          TEMP/LCD          1.      399.00      0.06      0.90     79.00     53.00     29.23      5.40
 1.00
          TEMP/LCD          2.      379.00      0.06      0.90     79.00     53.00     29.23      5.40
 1.00
          TEMP/LCD          3.      379.00      0.06      0.90     79.00     53.00     29.23      5.40
 1.00
          ENDATA5A          0.        0.00      0.00      0.00      0.00      0.00      0.00      0.00
 0.00
```

```
          $$$ DATA TYPE 6 (REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION) $$$

         CARD TYPE        REACH     K1        K3       SOD         K2OPT     K2      COEQK2    OR   EXPQK2
                                                       RATE                         TSIV COEF  OR    SLOPE
                                                                                    FOR OPT 8      FOR OPT 8
         REACT COEF        1.      0.05      0.00      0.023        1.      0.65      0.000        0.00000
         REACT COEF        2.      0.05      0.00      0.023        1.      0.65      0.000        0.00000
         REACT COEF        3.      0.05      0.00      0.023        1.      0.65      0.000        0.00000
         ENDATA6           0.      0.00      0.00      0.000        0.      0.00      0.000        0.00000

           $$$ DATA TYPE 6A (NITROGEN AND PHOSPHORUS CONSTANTS) $$$

         CARD TYPE           REACH    CKNH2    SETNH2     CKNH3      SNH3     CKNO2      CKPORG   SETPORG
SPO4
         N AND P COEF          1.      0.00      0.00      0.20      0.00      2.00      0.00      0.00
0.00
         N AND P COEF          2.      0.00      0.00      0.20      0.00      2.00      0.00      0.00
0.00
         N AND P COEF          3.      0.00      0.00      0.20      0.00      2.00      0.00      0.00
0.00
         ENDATA6A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00

          $$$ DATA TYPE 6B (ALGAE/OTHER COEFFICIENTS) $$$

         CARD TYPE           REACH    ALPHAO    ALGSET    EXCOEF      CK5     CKANC     SETANC    SRCANC
                                                                   CKCOLI
         ALGAE/OTHER           1.     50.00      0.10      0.01      0.00      0.00      0.00      0.00
         ALGAE/OTHER           2.     50.00      0.10      0.01      0.00      0.00      0.00      0.00
         ALGAE/OTHER           3.     50.00      0.75      0.60      0.00      0.00      0.00      0.00
         ENDATA6B              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

          $$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$

         CARD TYPE           REACH    TEMP       D.O.      BOD       CM-1      CM-2      CM-3       ANC
COLI
         INITIAL COND-1        1.     69.00     15.30      5.00      0.00      0.00      0.00      0.00
0.00
         INITIAL COND-1        2.     66.00      7.08      5.00      0.00      0.00      0.00      0.00
0.00
         INITIAL COND-1        3.     66.00      6.52      2.60      0.00      0.00      0.00      0.00
0.00
```

```
         ENDATA7               0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00

          $$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

         CARD TYPE           REACH     CHL-A     ORG-N     NH3-N     NO2-N     NO3-N     ORG-P     DIS-P
         INITIAL COND-2        1.     28.30      0.43      0.05      0.00      0.10      0.00      0.03
         INITIAL COND-2        2.     36.60      0.43      0.05      0.00      0.10      0.00      0.03
         INITIAL COND-2        3.      7.96      0.43      0.05      0.00      0.10      0.00      0.03
         ENDATA7A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

          $$$ DATA TYPE 8 (INCREMENTAL INFLOW CONDITIONS) $$$

         CARD TYPE           REACH      FLOW      TEMP      D.O.       BOD      CM-1      CM-2      CM-3
ANC      COLI
         INCR INFLOW-1         1.     0.000     65.00      4.50      1.00      0.00      0.00      0.00
0.00      0.00
         INCR INFLOW-1         2.     0.000     65.00      4.50      1.00      0.00      0.00      0.00
0.00      0.00
         INCR INFLOW-1         2.     0.000     65.00      4.50      1.00      0.00      0.00      0.00
0.00      0.00
         ENDATA8               0.     0.000      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00

          $$$ DATA TYPE 8A (INCREMENTAL INFLOW CONDITIONS FOR CHLOROPHYLL A, NITROGEN, AND PHOSPHORUS) $$$

         CARD TYPE           REACH     CHL-A     ORG-N     NH3-N     NO2-N     NO3-N     ORG-P     DIS-P
         INCR INFLOW-2         1.      0.00      0.00      0.00      0.00      0.00      0.00      0.00
         INCR INFLOW-2         2.      0.08      0.00      0.00      0.00      0.00      0.00      0.00
         INCR INFLOW-2         2.      0.08      0.00      0.00      0.00      0.00      0.00      0.00
         ENDATA8A              0.      0.00      0.00      0.00      0.00      0.00      0.00      0.00

          $$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$

         CARD TYPE              JUNCTION ORDER AND IDENT         UPSTRM   JUNCTION    TRIB
         ENDATA9                0.                                 0.        0.        0.

          $$$ DATA TYPE 10 (HEADWATER SOURCES) $$$

         CARD TYPE    HDWTR     NAME              FLOW      TEMP      D.O.       BOD      CM-1      CM-2
CM-3
                      ORDER
```

```
         HDWTR-NFK      1.          POND_CK       1.90     69.00     15.33      2.60      0.00      0.00
0.00
         ENDATA10       0.                        0.00      0.00      0.00      0.00      0.00      0.00
0.00

          $$$ DATA TYPE 10A (HEADWATER CONDITIONS FOR CHLOROPHYLL, NITROGEN, PHOSPHORUS,
                            COLIFORM AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

         CARD TYPE     HDWTR     ANC     COLI     CHL-A    ORG-N    NH3-N    NO2-N    NO3-N    ORG-P    DIS-P
                       ORDER
         HEADWTR-2       1.     0.00 0.00E+00    28.30     0.60     1.40     0.00     0.10     0.04     0.02
         ENDATA10A       0.     0.00 0.00E+00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

          $$$ DATA TYPE 11 (POINT SOURCE / POINT SOURCE CHARACTERISTICS) $$$

                       POINT
         CARD TYPE      LOAD    NAME                EFF      FLOW      TEMP      D.O.       BOD      CM-1      CM-2
CM-3
                       ORDER
         POINTLD-1      1.  STEELHEAD 0.         0.00      0.00     70.00      8.70     10.90      0.00      0.00
0.00
         POINTLD-1      2.     LAKECR 0.         0.00      5.54     67.50      8.90      1.00      0.00      0.00
0.00
         ENDATA11       0.                       0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00

          $$$ DATA TYPE 11A (POINT SOURCE CHARACTERISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS,
                            COLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT) $$$

                       POINT
         CARD TYPE      LOAD     ANC     COLI     CHL-A    ORG-N    NH3-N    NO2-N    N03-N    ORG-P    DIS-P
                       ORDER
         POINTLD-2       1.     0.00 0.00E+00     0.00     0.00     1.80     0.00     0.00     0.60     1.00
         POINTLD-2       2.     0.00 0.00E+00    21.60     0.53     0.02     0.00     0.10     0.02     0.13
         ENDATA11A       0.     0.00 0.00E+00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

          $$$ DATA TYPE 12 (DAM CHARACTERISTICS) $$$

                                DAM   RCH   ELE    ADAM     BDAM     FDAM     HDAM

         ENDATA12                  0.    0.    0.     0.00     0.00     0.00     0.00

          $$$ DATA TYPE 13 (DOWNSTREAM BOUNDARY CONDITIONS-1) $$$
```

```
              CARD TYPE               TEMP       D.O.      BOD       CM-1      CM-2      CM-3       ANC
COLI

         ENDATA13                     DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED

          $$$ DATA TYPE 13A (DOWNSTREAM BOUNDARY CONDITIONS-2) $$$

              CARD TYPE               CHL-A     ORG-N     NH3-N     NO2-N     NH3-N     ORG-P     DIS-P

         ENDATA13A                    DOWNSTREAM BOUNDARY CONCENTRATIONS ARE UNCONSTRAINED
```

```
STEADY STATE TEMPERATURE SIMULATION; CONVERGENCE SUMMARY:
---------------------------------------------------------

                      NUMBER OF
        ITERATION   NONCONVERGENT
                      ELEMENTS

             1              0


SUMMARY OF VALUES FOR STEADY STATE TEMPERATURE CALCULATIONS (SUBROUTINE HEATER):
--------------------------------------------------------------------------------

      DAILY NET SOLAR RADIATION =     928.745 BTU/FT-2   (  252.034 LANGLEYS)
      NUMBER OF DAYLIGHT HOURS =  11.8


      HOURLY VALUES OF SOLAR RADIATION (BTU/FT-2)

            1    11.15         9    96.72        17     0.00
            2    43.38        10    70.46        18     0.00
            3    73.81        11    39.63        19     0.00
            4    99.38        12     7.24        20     0.00
            5   117.67        13     0.00        21     0.00
            6   126.96        14     0.00        22     0.00
            7   126.37        15     0.00        23     0.00
            8   115.97        16     0.00        24     0.00
```

```
STEADY STATE ALGAE/NUTRIENT/DISSOLVED OXYGEN SIMULATION; CONVERGENCE SUMMARY:
-----------------------------------------------------------------------------

                                                  NUMBER OF
           VARIABLE              ITERATION      NONCONVERGENT
                                                  ELEMENTS

 ALGAE GROWTH RATE                 1               42
 ALGAE GROWTH RATE                 2               42
 ALGAE GROWTH RATE                 3               41
 ALGAE GROWTH RATE                 4               41
 ALGAE GROWTH RATE                 5               38
 ALGAE GROWTH RATE                 6               36
 ALGAE GROWTH RATE                 7               23
 ALGAE GROWTH RATE                 8               22
 ALGAE GROWTH RATE                 9               19
 ALGAE GROWTH RATE                10               17
 ALGAE GROWTH RATE                11               15
 ALGAE GROWTH RATE                12               12
 ALGAE GROWTH RATE                13                8
 ALGAE GROWTH RATE                14                4
 ALGAE GROWTH RATE                15                0
   NITRIFICATION INHIBITION           1                 0
 ALGAE GROWTH RATE                16                0
   NITRIFICATION INHIBITION           2                 0


SUMMARY OF CONDITIONS FOR ALGAL GROWTH RATE SIMULATION:
-------------------------------------------------------

      1. LIGHT AVERAGING OPTION.   LAVOPT= 3

          METHOD: AVERAGE OF HOURLY SOLAR VALUES

          SOURCE OF SOLAR VALUES: SUBROUTINE HEATER (SS TEMP)
              DAILY NET SOLAR RADIATION:   928.745 BTU/FT-2 (  252.034 LANGLEYS)
              NUMBER OF DAYLIGHT HOURS: 11.8
              PHOTOSYNTHETIC ACTIVE FRACTION OF SOLAR RADIATION (TFACT):  0.45
              MEAN SOLAR RADIATION ADJUSTMENT FACTOR (AFACT): N/A

          HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)
```

```
      1     3.03         9    26.25        17     0.00
      2    11.77        10    19.12        18     0.00
      3    20.03        11    10.75        19     0.00
      4    26.97        12     1.96        20     0.00
      5    31.93        13     0.00        21     0.00
      6    34.45        14     0.00        22     0.00
      7    34.29        15     0.00        23     0.00
      8    31.47        16     0.00        24     0.00

2. LIGHT FUNCTION OPTION:   LFNOPT= 2

    SMITH FUNCTION, WITH 71% IMAX =  0.179 LANGLEYS/MIN


3. GROWTH ATTENUATION OPTION FOR NUTRIENTS.   LGROPT= 2

    MINIMUM OF NITROGEN, PHOSPHORUS:   FL*MIN(FN,FP)
```

```
         STREAM QUALITY SIMULATION
OUTPUT PAGE NUMBER     1
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                   Version 3.22
--  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                      ** HYDRAULICS SUMMARY **

ELE RCH ELE   BEGIN     END           POINT    INCR            TRVL                                    BOTTOM
X-SECT   DSPRSN
ORD NUM NUM     LOC     LOC    FLOW    SRCE    FLOW     VEL    TIME    DEPTH    WIDTH      VOLUME        AREA
AREA     COEF
               MILE    MILE     CFS     CFS     CFS     FPS     DAY       FT       FT      K-FT-3      K-FT-2
FT-2   FT-2/S

  1   1   1   21.10   20.60    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
  2   1   2   20.60   20.10    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
  3   1   3   20.10   19.60    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
  4   1   4   19.60   19.10    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
  5   1   5   19.10   18.60    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
  6   1   6   18.60   18.10    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
  7   1   7   18.10   17.60    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
  8   1   8   17.60   17.10    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
  9   1   9   17.10   16.60    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
 10   1  10   16.60   16.10    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50
 11   1  11   16.10   15.60    1.90    0.00    0.00   0.060   0.509    1.100   28.788       83.60       81.81
31.67     0.50


 12   2   1   15.60   15.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299       62.70       76.66
23.75     0.54
 13   2   2   15.10   14.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299       62.70       76.66
23.75     0.54
```

```
 14   2   3  14.60   14.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 15   2   4  14.10   13.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 16   2   5  13.60   13.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 17   2   6  13.10   12.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 18   2   7  12.60   12.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 19   2   8  12.10   11.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 20   2   9  11.60   11.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 21   2  10  11.10   10.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 22   2  11  10.60   10.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 23   2  12  10.10    9.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 24   2  13   9.60    9.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 25   2  14   9.10    8.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 26   2  15   8.60    8.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 27   2  16   8.10    7.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 28   2  17   7.60    7.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 29   2  18   7.10    6.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 30   2  19   6.60    6.10    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54
 31   2  20   6.10    5.60    1.90    0.00    0.00   0.080   0.382    0.870   27.299        62.70        76.66
23.75     0.54


 32   3   1   5.60    5.10    7.44    5.54    0.00   0.060   0.509    2.480   50.000       327.36       145.09
124.00     0.98
 33   3   2   5.10    4.60    7.44    0.00    0.00   0.060   0.509    2.480   50.000       327.36       145.09
124.00     0.98
```

```
 34   3   3    4.60    4.10    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
 35   3   4    4.10    3.60    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
 36   3   5    3.60    3.10    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
 37   3   6    3.10    2.60    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
 38   3   7    2.60    2.10    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
 39   3   8    2.10    1.60    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
 40   3   9    1.60    1.10    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
 41   3  10    1.10    0.60    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
 42   3  11    0.60    0.10    7.44    0.00    0.00   0.060   0.509    2.480   50.000      327.36      145.09
124.00     0.98
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         STREAM QUALITY SIMULATION
OUTPUT PAGE NUMBER     2
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                   Version 3.22
--  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                 ** REACTION COEFFICIENT SUMMARY **

RCH ELE     DO  K2  OXYGN    BOD    BOD    SOD   ORGN   ORGN    NH3    NH3    NO2   ORGP   ORGP   DISP   COLI
ANC    ANC    ANC
NUM NUM    SAT OPT  REAIR  DECAY   SETT   RATE  DECAY   SETT  DECAY   SRCE  DECAY  DECAY   SETT   SRCE  DECAY
DECAY   SETT   SRCE
          MG/L      1/DAY  1/DAY  1/DAY  G/F2D  1/DAY  1/DAY  1/DAY MG/F2D  1/DAY  1/DAY  1/DAY MG/F2D  1/DAY
1/DAY  1/DAY MG/F2D

  1   1   8.89   1   0.65   0.05   0.00   0.02   0.00   0.00   0.20   0.00   2.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1   2   8.94   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.97   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1   3   8.97   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.95   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1   4   8.99   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.94   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1   5   9.00   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1   6   9.00   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1   7   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.92   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1   8   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.92   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1   9   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.92   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1  10   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.91   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  1  11   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.91   0.00   0.00   0.00   0.00
0.00   0.00   0.00


  2   1   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.91   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2   2   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.91   0.00   0.00   0.00   0.00
0.00   0.00   0.00
```

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  2   3   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2   4   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2   5   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2   6   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2   7   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2   8   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2   9   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  10   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  11   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  12   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  13   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  14   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  15   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  16   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  17   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.90   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  18   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.91   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  19   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.91   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  2  20   9.01   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.91   0.00   0.00   0.00   0.00
0.00   0.00   0.00


  3   1   8.97   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.94   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3   2   8.98   1   0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.94   0.00   0.00   0.00   0.00
0.00   0.00   0.00
```

```
  3   3   8.99   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3   4   8.99   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3   5   9.00   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3   6   9.00   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3   7   9.01   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3   8   9.01   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3   9   9.01   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.93   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3  10   9.01   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.92   0.00   0.00   0.00   0.00
0.00   0.00   0.00
  3  11   9.01   1    0.64   0.05   0.00   0.02   0.00   0.00   0.19   0.00   1.92   0.00   0.00   0.00   0.00
0.00   0.00   0.00
```

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         STREAM QUALITY SIMULATION
OUTPUT PAGE NUMBER     3
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                   Version 3.22
--  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                    ** WATER QUALITY VARIABLES **

RCH ELE              CM-1   CM-2   CM-3
ANC
NUM NUM       TEMP                                    DO    BOD   ORGN   NH3N   NO2N   NO3N  SUM-N   ORGP  DIS-P  SUM-P
COLI          CHLA
             DEG-F                                  MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L   MG/L
#/100ML         UG/L

  1   1      67.98   0.00    0.00    0.00  13.12    2.54   0.60   1.27   0.06   0.16   2.09   0.04   0.02
0.06.00E+00   0.00  32.44
  1   2      67.41   0.00    0.00    0.00  11.50    2.47   0.61   1.15   0.09   0.24   2.08   0.04   0.02
0.06.00E+00   0.00  36.77
  1   3      67.10   0.00    0.00    0.00  10.33    2.41   0.61   1.04   0.10   0.32   2.07   0.04   0.01
0.05.00E+00   0.00  41.18
  1   4      66.94   0.00    0.00    0.00   9.48    2.36   0.61   0.95   0.09   0.40   2.06   0.04   0.01
0.05.00E+00   0.00  45.46
  1   5      66.84   0.00    0.00    0.00   8.87    2.30   0.62   0.86   0.09   0.48   2.05   0.04   0.01
0.05.00E+00   0.00  49.28
  1   6      66.79   0.00    0.00    0.00   8.41    2.24   0.62   0.78   0.08   0.55   2.04   0.04   0.01
0.05.00E+00   0.00  52.22
  1   7      66.76   0.00    0.00    0.00   8.06    2.19   0.63   0.71   0.08   0.61   2.03   0.04   0.00
0.05.00E+00   0.00  53.87
  1   8      66.75   0.00    0.00    0.00   7.77    2.14   0.63   0.65   0.07   0.67   2.02   0.05   0.00
0.05.00E+00   0.00  53.97
  1   9      66.74   0.00    0.00    0.00   7.54    2.08   0.64   0.59   0.06   0.72   2.02   0.05   0.00
0.05.00E+00   0.00  52.62
  1  10      66.74   0.00    0.00    0.00   7.35    2.03   0.64   0.54   0.06   0.78   2.02   0.05   0.00
0.05.00E+00   0.00  50.18
  1  11      66.73   0.00    0.00    0.00   7.20    1.99   0.65   0.49   0.05   0.83   2.02   0.05   0.00
0.05.00E+00   0.00  47.10


  2   1      66.72   0.00    0.00    0.00   7.09    1.94   0.65   0.46   0.05   0.87   2.03   0.05   0.00
0.05.00E+00   0.00  43.74
  2   2      66.72   0.00    0.00    0.00   6.97    1.91   0.65   0.43   0.05   0.90   2.03   0.05   0.00
0.05.00E+00   0.00  40.86
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  2   3      66.72   0.00   0.00   0.00   6.88   1.87   0.66   0.40   0.04   0.93   2.03   0.05   0.00
0.05.00E+00   0.00  38.05
  2   4      66.71   0.00   0.00   0.00   6.82   1.84   0.66   0.37   0.04   0.96   2.03   0.05   0.00
0.05.00E+00   0.00  35.36
  2   5      66.71   0.00   0.00   0.00   6.78   1.81   0.66   0.35   0.04   0.99   2.03   0.05   0.00
0.05.00E+00   0.00  32.81
  2   6      66.71   0.00   0.00   0.00   6.75   1.77   0.66   0.32   0.04   1.01   2.04   0.05   0.00
0.05.00E+00   0.00  30.41
  2   7      66.71   0.00   0.00   0.00   6.74   1.74   0.67   0.30   0.03   1.04   2.04   0.05   0.00
0.05.00E+00   0.00  28.17
  2   8      66.71   0.00   0.00   0.00   6.74   1.71   0.67   0.28   0.03   1.06   2.04   0.05   0.00
0.05.00E+00   0.00  26.08
  2   9      66.71   0.00   0.00   0.00   6.74   1.68   0.67   0.26   0.03   1.08   2.04   0.05   0.00
0.05.00E+00   0.00  24.14
  2  10      66.71   0.00   0.00   0.00   6.76   1.65   0.67   0.25   0.03   1.10   2.04   0.05   0.00
0.05.00E+00   0.00  22.33
  2  11      66.71   0.00   0.00   0.00   6.77   1.62   0.67   0.23   0.02   1.12   2.04   0.05   0.00
0.05.00E+00   0.00  20.66
  2  12      66.71   0.00   0.00   0.00   6.79   1.59   0.67   0.21   0.02   1.13   2.05   0.05   0.00
0.05.00E+00   0.00  19.11
  2  13      66.71   0.00   0.00   0.00   6.82   1.56   0.68   0.20   0.02   1.15   2.05   0.05   0.00
0.05.00E+00   0.00  17.67
  2  14      66.71   0.00   0.00   0.00   6.84   1.53   0.68   0.19   0.02   1.16   2.05   0.05   0.00
0.05.00E+00   0.00  16.34
  2  15      66.71   0.00   0.00   0.00   6.86   1.50   0.68   0.17   0.02   1.18   2.05   0.05   0.00
0.05.00E+00   0.00  15.11
  2  16      66.71   0.00   0.00   0.00   6.89   1.48   0.68   0.16   0.02   1.19   2.05   0.05   0.00
0.05.00E+00   0.00  13.97
  2  17      66.71   0.00   0.00   0.00   6.91   1.45   0.68   0.15   0.02   1.20   2.05   0.05   0.00
0.05.00E+00   0.00  12.91
  2  18      66.71   0.00   0.00   0.00   6.94   1.42   0.68   0.14   0.02   1.21   2.05   0.05   0.00
0.05.00E+00   0.00  11.94
  2  19      66.71   0.00   0.00   0.00   6.96   1.40   0.68   0.13   0.01   1.22   2.05   0.05   0.00
0.05.00E+00   0.00  11.04
  2  20      66.71   0.00   0.00   0.00   6.99   1.37   0.68   0.12   0.01   1.23   2.05   0.05   0.00
0.05.00E+00   0.00  10.31


  3   1      67.15   0.00   0.00   0.00   8.35   1.08   0.57   0.04   0.00   0.39   1.01   0.03   0.10
0.12.00E+00   0.00  18.29
  3   2      67.04   0.00   0.00   0.00   8.38   1.05   0.57   0.04   0.00   0.39   1.00   0.03   0.10
0.12.00E+00   0.00  17.63
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  3   3      66.95   0.00   0.00   0.00   8.40   1.03   0.57   0.04   0.00   0.39   1.00   0.03   0.09
0.12.00E+00   0.00  16.99
  3   4      66.89   0.00   0.00   0.00   8.42   1.00   0.57   0.03   0.00   0.39   1.00   0.03   0.09
0.12.00E+00   0.00  16.38
  3   5      66.84   0.00   0.00   0.00   8.44   0.98   0.58   0.03   0.00   0.38   0.99   0.03   0.09
0.12.00E+00   0.00  15.79
  3   6      66.80   0.00   0.00   0.00   8.45   0.96   0.58   0.03   0.00   0.38   0.99   0.03   0.09
0.12.00E+00   0.00  15.22
  3   7      66.78   0.00   0.00   0.00   8.46   0.93   0.58   0.03   0.00   0.38   0.99   0.03   0.09
0.12.00E+00   0.00  14.68
  3   8      66.76   0.00   0.00   0.00   8.46   0.91   0.58   0.02   0.00   0.38   0.98   0.03   0.09
0.12.00E+00   0.00  14.15
  3   9      66.75   0.00   0.00   0.00   8.47   0.89   0.58   0.02   0.00   0.38   0.98   0.03   0.09
0.12.00E+00   0.00  13.65
  3  10      66.74   0.00   0.00   0.00   8.47   0.87   0.58   0.02   0.00   0.38   0.98   0.03   0.09
0.12.00E+00   0.00  13.16
  3  11      66.73   0.00   0.00   0.00   8.48   0.85   0.58   0.02   0.00   0.37   0.98   0.03   0.09
0.12.00E+00   0.00  12.70
```

```
         STREAM QUALITY SIMULATION
OUTPUT PAGE NUMBER     4
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                   Version 3.22
--  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                          ** ALGAE DATA **

                                                                             NH3-N            ALGAE GROWTH
RATE ATTEN FACTORS
ELE RCH ELE               ALGY    ALGY    ALGY   A P/R     NET         NH3   FRACT   LIGHT
ORD NUM NUM       CHLA   GRWTH    RESP    SETT   RATIO     P-R        PREF  N-UPTKE  EXTCO         LIGHT
NITRGN   PHSPRS
                  UG/L   1/DAY   1/DAY   FT/DA       *  MG/L-D           *       *    1/FT             *
*        *

  1   1   1      32.44    0.45    0.10    0.10    4.03    0.39        0.10    0.47    0.11          0.29
0.98     0.78
  2   1   2      36.77    0.43    0.10    0.10    3.89    0.42        0.10    0.35    0.12          0.28
0.98     0.76
  3   1   3      41.18    0.40    0.10    0.10    3.72    0.44        0.10    0.26    0.13          0.28
0.98     0.73
  4   1   4      45.46    0.38    0.10    0.10    3.49    0.44        0.10    0.21    0.15          0.28
0.98     0.69
  5   1   5      49.28    0.34    0.10    0.10    3.19    0.42        0.10    0.17    0.16          0.28
0.98     0.63
  6   1   6      52.22    0.30    0.10    0.10    2.81    0.37        0.10    0.14    0.17          0.28
0.98     0.56
  7   1   7      53.87    0.25    0.10    0.10    2.34    0.28        0.10    0.12    0.17          0.28
0.98     0.46
  8   1   8      53.97    0.20    0.10    0.10    1.82    0.17        0.10    0.10    0.17          0.28
0.98     0.36
  9   1   9      52.62    0.14    0.10    0.10    1.31    0.06        0.10    0.08    0.17          0.28
0.98     0.26
 10   1  10      50.18    0.10    0.10    0.10    0.89   -0.02        0.10    0.07    0.16          0.28
0.98     0.18
 11   1  11      47.10    0.06    0.10    0.10    0.58   -0.08        0.10    0.06    0.15          0.28
0.98     0.11


 12   2   1      43.74    0.04    0.10    0.10    0.40   -0.10        0.10    0.06    0.14          0.29
0.98     0.08
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 13   2   2      40.86    0.03    0.10    0.10    0.28   -0.11        0.10    0.05    0.13         0.29
0.98     0.05
 14   2   3      38.05    0.02    0.10    0.10    0.20   -0.12        0.10    0.05    0.12         0.29
0.98     0.04
 15   2   4      35.36    0.02    0.10    0.10    0.14   -0.12        0.10    0.04    0.12         0.29
0.98     0.03
 16   2   5      32.81    0.01    0.10    0.10    0.10   -0.11        0.10    0.04    0.11         0.29
0.98     0.02
 17   2   6      30.41    0.01    0.10    0.10    0.08   -0.11        0.10    0.03    0.10         0.29
0.98     0.01
 18   2   7      28.17    0.01    0.10    0.10    0.06   -0.10        0.10    0.03    0.09         0.29
0.98     0.01
 19   2   8      26.08    0.00    0.10    0.10    0.04   -0.10        0.10    0.03    0.09         0.29
0.98     0.01
 20   2   9      24.14    0.00    0.10    0.10    0.03   -0.09        0.10    0.03    0.08         0.29
0.98     0.01
 21   2  10      22.33    0.00    0.10    0.10    0.03   -0.08        0.10    0.02    0.08         0.29
0.98     0.01
 22   2  11      20.66    0.00    0.10    0.10    0.02   -0.08        0.10    0.02    0.07         0.29
0.98     0.00
 23   2  12      19.11    0.00    0.10    0.10    0.02   -0.07        0.10    0.02    0.07         0.29
0.98     0.00
 24   2  13      17.67    0.00    0.10    0.10    0.01   -0.07        0.10    0.02    0.06         0.29
0.98     0.00
 25   2  14      16.34    0.00    0.10    0.10    0.01   -0.06        0.10    0.02    0.06         0.29
0.98     0.00
 26   2  15      15.11    0.00    0.10    0.10    0.01   -0.06        0.10    0.02    0.06         0.29
0.98     0.00
 27   2  16      13.97    0.00    0.10    0.10    0.01   -0.05        0.10    0.02    0.05         0.29
0.98     0.00
 28   2  17      12.91    0.00    0.10    0.10    0.01   -0.05        0.10    0.01    0.05         0.29
0.98     0.00
 29   2  18      11.94    0.00    0.10    0.10    0.01   -0.05        0.10    0.01    0.05         0.29
0.98     0.00
 30   2  19      11.04    0.00    0.10    0.10    0.01   -0.04        0.10    0.01    0.04         0.29
0.98     0.00
 31   2  20      10.31    0.02    0.10    0.10    0.23   -0.03        0.10    0.01    0.04         0.29
0.98     0.04


 32   3   1      18.29    0.33    0.10    0.74    3.02    0.14        0.10    0.01    0.65         0.18
0.94     0.95
```

```
 33   3   2      17.63    0.33    0.10    0.74    3.03    0.14        0.10    0.01    0.65         0.18
0.93     0.95
 34   3   3      16.99    0.33    0.10    0.74    3.03    0.13        0.10    0.01    0.65         0.18
0.93     0.95
 35   3   4      16.38    0.33    0.10    0.74    3.03    0.13        0.10    0.01    0.65         0.18
0.93     0.95
 36   3   5      15.79    0.33    0.10    0.74    3.03    0.12        0.10    0.01    0.65         0.18
0.93     0.95
 37   3   6      15.22    0.33    0.10    0.74    3.04    0.12        0.10    0.01    0.65         0.18
0.93     0.95
 38   3   7      14.68    0.33    0.10    0.74    3.04    0.12        0.10    0.01    0.64         0.18
0.93     0.95
 39   3   8      14.15    0.33    0.10    0.74    3.04    0.11        0.10    0.01    0.64         0.18
0.93     0.95
 40   3   9      13.65    0.33    0.10    0.74    3.04    0.11        0.10    0.01    0.64         0.18
0.93     0.95
 41   3  10      13.16    0.33    0.10    0.74    3.04    0.10        0.10    0.01    0.64         0.18
0.93     0.95
 42   3  11      12.70    0.33    0.10    0.74    3.04    0.10        0.10    0.01    0.64         0.18
0.93     0.95
```

```
         STREAM QUALITY SIMULATION
OUTPUT PAGE NUMBER     5
         QUAL-2E STREAM QUALITY ROUTING MODEL                                                   Version 3.22
--  May 1996
                                                 ***** STEADY STATE SIMULATION *****

                                                     ** DISSOLVED OXYGEN DATA **

                                                                  COMPONENTS OF DISSOLVED OXYGEN MASS BALANCE
(MG/L-DAY)
ELE RCH ELE              DO              DO     DAM     NIT
ORD NUM NUM    TEMP     SAT       DO     DEF   INPUT   INHIB      F-FNCTN   OXYGN                     NET
              DEG-F    MG/L     MG/L    MG/L    MG/L    FACT        INPUT   REAIR   C-BOD     SOD     P-R
NH3-N   NO2-N

  1   1   1   67.98    8.89    13.12   -4.23    0.00    1.00        30.10   -2.75   -0.13   -0.74    0.39   -
0.87   -0.15
  2   1   2   67.41    8.94    11.50   -2.56    0.00    1.00         0.00   -1.65   -0.12   -0.74    0.42   -
0.77   -0.20
  3   1   3   67.10    8.97    10.33   -1.36    0.00    1.00         0.00   -0.87   -0.12   -0.74    0.44   -
0.68   -0.21
  4   1   4   66.94    8.99     9.48   -0.50    0.00    1.00         0.00   -0.32   -0.11   -0.74    0.44   -
0.62   -0.21
  5   1   5   66.84    9.00     8.87    0.13    0.00    1.00         0.00    0.08   -0.11   -0.74    0.42   -
0.56   -0.20
  6   1   6   66.79    9.00     8.41    0.59    0.00    0.99         0.00    0.38   -0.11   -0.74    0.37   -
0.51   -0.18
  7   1   7   66.76    9.01     8.06    0.95    0.00    0.99         0.00    0.61   -0.11   -0.74    0.28   -
0.46   -0.17
  8   1   8   66.75    9.01     7.77    1.23    0.00    0.99         0.00    0.79   -0.10   -0.74    0.17   -
0.42   -0.15
  9   1   9   66.74    9.01     7.54    1.47    0.00    0.99         0.00    0.94   -0.10   -0.74    0.06   -
0.38   -0.14
 10   1  10   66.74    9.01     7.35    1.66    0.00    0.99         0.00    1.06   -0.10   -0.74   -0.02   -
0.35   -0.13
 11   1  11   66.73    9.01     7.20    1.81    0.00    0.99         0.00    1.16   -0.10   -0.74   -0.08   -
0.32   -0.12


 12   2   1   66.72    9.01     7.09    1.92    0.00    0.99         0.00    1.23   -0.09   -0.93   -0.10   -
0.29   -0.11
 13   2   2   66.72    9.01     6.97    2.04    0.00    0.98         0.00    1.31   -0.09   -0.93   -0.11   -
0.27   -0.10
```

```
 14   2   3   66.72    9.01    6.88    2.13    0.00    0.98         0.00    1.36   -0.09   -0.93   -0.12   -
0.25   -0.09
 15   2   4   66.71    9.01    6.82    2.19    0.00    0.98         0.00    1.40   -0.09   -0.93   -0.12   -
0.24   -0.09
 16   2   5   66.71    9.01    6.78    2.24    0.00    0.98         0.00    1.43   -0.09   -0.93   -0.11   -
0.22   -0.08
 17   2   6   66.71    9.01    6.75    2.26    0.00    0.98         0.00    1.44   -0.09   -0.93   -0.11   -
0.21   -0.08
 18   2   7   66.71    9.01    6.74    2.27    0.00    0.98         0.00    1.45   -0.08   -0.93   -0.10   -
0.19   -0.07
 19   2   8   66.71    9.01    6.74    2.27    0.00    0.98         0.00    1.45   -0.08   -0.93   -0.10   -
0.18   -0.07
 20   2   9   66.71    9.01    6.74    2.27    0.00    0.98         0.00    1.45   -0.08   -0.93   -0.09   -
0.17   -0.06
 21   2  10   66.71    9.01    6.76    2.26    0.00    0.98         0.00    1.44   -0.08   -0.93   -0.08   -
0.16   -0.06
 22   2  11   66.71    9.01    6.77    2.24    0.00    0.98         0.00    1.43   -0.08   -0.93   -0.08   -
0.15   -0.05
 23   2  12   66.71    9.01    6.79    2.22    0.00    0.98         0.00    1.42   -0.08   -0.93   -0.07   -
0.14   -0.05
 24   2  13   66.71    9.01    6.82    2.20    0.00    0.98         0.00    1.40   -0.08   -0.93   -0.07   -
0.13   -0.05
 25   2  14   66.71    9.01    6.84    2.17    0.00    0.98         0.00    1.39   -0.07   -0.93   -0.06   -
0.12   -0.04
 26   2  15   66.71    9.01    6.86    2.15    0.00    0.98         0.00    1.37   -0.07   -0.93   -0.06   -
0.11   -0.04
 27   2  16   66.71    9.01    6.89    2.12    0.00    0.98         0.00    1.36   -0.07   -0.93   -0.05   -
0.10   -0.04
 28   2  17   66.71    9.01    6.91    2.10    0.00    0.98         0.00    1.34   -0.07   -0.93   -0.05   -
0.10   -0.04
 29   2  18   66.71    9.01    6.94    2.08    0.00    0.98         0.00    1.33   -0.07   -0.93   -0.05   -
0.09   -0.03
 30   2  19   66.71    9.01    6.96    2.05    0.00    0.98         0.00    1.31   -0.07   -0.93   -0.04   -
0.08   -0.03
 31   2  20   66.71    9.01    6.99    2.03    0.00    0.98         0.00    1.29   -0.07   -0.93   -0.03   -
0.08   -0.03


 32   3   1   67.15    8.97    8.35    0.61    0.00    0.99        13.01    0.39   -0.05   -0.33    0.14   -
0.03   -0.01
 33   3   2   67.04    8.98    8.38    0.60    0.00    0.99         0.00    0.38   -0.05   -0.33    0.14   -
0.03   -0.01
```

```
 34   3   3   66.95    8.99    8.40    0.59    0.00    0.99         0.00    0.38   -0.05   -0.33    0.13   -
0.02   -0.01
 35   3   4   66.89    8.99    8.42    0.57    0.00    0.99         0.00    0.37   -0.05   -0.33    0.13   -
0.02   -0.01
 36   3   5   66.84    9.00    8.44    0.56    0.00    0.99         0.00    0.36   -0.05   -0.33    0.12   -
0.02   -0.01
 37   3   6   66.80    9.00    8.45    0.56    0.00    0.99         0.00    0.36   -0.05   -0.33    0.12   -
0.02   -0.01
 38   3   7   66.78    9.01    8.46    0.55    0.00    0.99         0.00    0.35   -0.05   -0.33    0.12   -
0.02   -0.01
 39   3   8   66.76    9.01    8.46    0.54    0.00    0.99         0.00    0.35   -0.04   -0.33    0.11   -
0.01   -0.01
 40   3   9   66.75    9.01    8.47    0.54    0.00    0.99         0.00    0.34   -0.04   -0.33    0.11   -
0.01    0.00
 41   3  10   66.74    9.01    8.47    0.54    0.00    0.99         0.00    0.34   -0.04   -0.33    0.10   -
0.01    0.00
 42   3  11   66.73    9.01    8.48    0.53    0.00    0.99         0.00    0.34   -0.04   -0.33    0.10   -
0.01    0.00
```

Attachment 4: BATHTUB Model Files

- **Herrin Old / IL_RNZD**
  - **Calibration input**
  - **Calibration output**
- **Johnston City / IL_RNZE**
  - **Calibration input**
  - **Calibration output**
- **Arrowhead (Williamson) / IL_RNZX**
  - **Calibration input**
  - **Calibration output**
- **West Frankfort Old / IL_RNP**
  - **Calibration input**
  - **Calibration output**
- **West Frankfort New/ IL_RNQ**
  - **Calibration input**
  - **Calibration output**

```
Vers 6.20 (03/06/2014)
Old Herrin Res (RNZD)
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",.4167,0
2,"PRECIPITATION (METERS)",.4096,0
3,"EVAPORATION (METERS)",.4096,0
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",4
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",0
5,"SECCHI DEPTH",0
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",1
8,"NITROGEN CALIBRATION",1
9,"ERROR ANALYSIS",0
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1.6,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",1,0
15,"Avail Factor - Ortho P",0,0
16,"Avail Factor - TN",0,0
17,"Avail Factor - Inorganic N",0,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",30,0
3,"TOTAL N",0,0
4,"ORTHO P",0,0
5,"INORGANIC N",0,0
2,"Segments"
1,"Segment 1",0,1,.041,6.4,.212,.93,0,.68,0,.2,0,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",12,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,.7,0
1,"TOTAL P    MG/M3",46,0,1,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A      MG/M3",0,0,1,0
1,"SECCHI         M",0,0,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
2,"Segment 2",1,1,.163,4.27,.7,2.01,0,1.05,0,.1,0,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"CONSERVATIVE SUB",0,0,.7,0
2,"TOTAL P    MG/M3",24,0,1,0
2,"TOTAL N    MG/M3",0,0,1,0
2,"CHL-A      MG/M3",0,0,1,0
2,"SECCHI         M",0,0,1,0
2,"ORGANIC N  MG/M3",0,0,1,0
2,"TP-ORTHO-P MG/M3",0,0,1,0
2,"HOD-V  MG/M3-DAY",0,0,1,0
```

```
2,"MOD-V  MG/M3-DAY",0,0,1,0
1,"Tributaries"
1,"Inlet Tributary",2,1,6.24,2.9,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",29,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
1,"Row Crop"
1,"Runoff",.2596,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",493,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
2,"Grassland"
2,"Runoff",.2596,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",493,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"Forest"
3,"Runoff",.2596,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",493,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"Urban"
4,"Runoff",.2596,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",493,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,"Wetland"
5,"Runoff",.2596,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",493,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,"Other"
6,"Runoff",.2596,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",493,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Single reservoir
2 segments
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Vers 6.20 (03/06/2014)
Johnston City Lake (RNZE)
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.4096,0
3,"EVAPORATION (METERS)",.4096,0
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",4
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",0
5,"SECCHI DEPTH",0
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",1
9,"ERROR ANALYSIS",0
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1.6,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",1,0
15,"Avail Factor - Ortho P",0,0
16,"Avail Factor - TN",0,0
17,"Avail Factor - Inorganic N",0,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",30,0
3,"TOTAL N",0,0
4,"ORTHO P",0,0
5,"INORGANIC N",0,0
2,"Segments"
1,"Segment 1",0,1,.076,3.05,.23,.93,0,.68,0,.2,0,0,0
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1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
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1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A      MG/M3",0,0,1,0
1,"SECCHI         M",0,0,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
2,"Segment 2",1,1,.167,1.52,.75,1.3,0,1.05,0,.1,0,0,0
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2,"TOTAL N",0,0
2,"CONSERVATIVE SUB",0,0,1,0
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2,"TOTAL N    MG/M3",0,0,1,0
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2,"SECCHI         M",0,0,1,0
2,"ORGANIC N  MG/M3",0,0,1,0
2,"TP-ORTHO-P MG/M3",0,0,1,0
2,"HOD-V  MG/M3-DAY",0,0,1,0
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2,"MOD-V  MG/M3-DAY",0,0,1,0
1,"Tributaries"
1,"Inlet Tributary",2,1,9.05,4.3,0,0
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1,"TOTAL P",40.48,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
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8,"Land Use Export Categories"
1,"Row Crop"
1,"Runoff",.2596,0
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1,"TOTAL N",0,0
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1,"INORGANIC N",0,0
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2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
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3,"Runoff",.2596,0
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4,"Runoff",.2596,0
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4,"TOTAL N",0,0
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4,"INORGANIC N",0,0
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5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,"Other"
6,"Runoff",.2596,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",493,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Single reservoir
2 segments
```

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Vers 6.20 (03/06/2014)
Arrowhead Lake (RNZX)
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.4096,0
3,"EVAPORATION (METERS)",.4096,0
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",4
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",0
5,"SECCHI DEPTH",0
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",1
9,"ERROR ANALYSIS",0
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1.6,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",1,0
15,"Avail Factor - Ortho P",0,0
16,"Avail Factor - TN",0,0
17,"Avail Factor - Inorganic N",0,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",30,0
3,"TOTAL N",0,0
4,"ORTHO P",0,0
5,"INORGANIC N",0,0
3,"Segments"
1,"Segment 1",0,1,.05,4.88,.155,.93,0,.68,0,.2,0,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",12,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,.5,0
1,"TOTAL P    MG/M3",175,0,1,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A      MG/M3",0,0,1,0
1,"SECCHI         M",0,0,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
2,"Segment 2",1,1,.063,2.44,.468,2.01,0,1.05,0,.1,0,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"CONSERVATIVE SUB",0,0,.5,0
2,"TOTAL P    MG/M3",58,0,1,0
2,"TOTAL N    MG/M3",0,0,1,0
2,"CHL-A      MG/M3",0,0,1,0
2,"SECCHI         M",0,0,1,0
2,"ORGANIC N  MG/M3",0,0,1,0
2,"TP-ORTHO-P MG/M3",0,0,1,0
2,"HOD-V  MG/M3-DAY",0,0,1,0
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```
2,"MOD-V  MG/M3-DAY",0,0,1,0
3,"Segment 3",1,1,.035,1.52,.418,1,0,1.41,0,.08,0,0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",0,0
3,"TOTAL N",0,0
3,"CONSERVATIVE SUB",0,0,.5,0
3,"TOTAL P    MG/M3",62,0,1,0
3,"TOTAL N    MG/M3",0,0,1,0
3,"CHL-A      MG/M3",0,0,1,0
3,"SECCHI         M",0,0,1,0
3,"ORGANIC N  MG/M3",0,0,1,0
3,"TP-ORTHO-P MG/M3",0,0,1,0
3,"HOD-V  MG/M3-DAY",0,0,1,0
3,"MOD-V  MG/M3-DAY",0,0,1,0
2,"Tributaries"
1,"Inlet Tributary",2,1,1.092,.52,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",45.8,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"Inlet Tributary",3,1,.72,.35,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",45.81,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
1,"Row Crop"
1,"Runoff",.2596,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",493,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
2,"Grassland"
2,"Runoff",.2596,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",493,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"Forest"
3,"Runoff",.2596,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",493,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"Urban"
4,"Runoff",.2596,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",493,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,"Wetland"
5,"Runoff",.2596,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",493,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,"Other"
6,"Runoff",.2596,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",493,0
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6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Single reservoir
3 segments
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Vers 6.20 (03/06/2014)
West Frankfort Old Res. (RNP)
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.4096,0
3,"EVAPORATION (METERS)",.4096,0
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",4
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",0
5,"SECCHI DEPTH",0
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",1
9,"ERROR ANALYSIS",0
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1.6,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",1,0
15,"Avail Factor - Ortho P",0,0
16,"Avail Factor - TN",0,0
17,"Avail Factor - Inorganic N",0,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",30,0
3,"TOTAL N",0,0
4,"ORTHO P",0,0
5,"INORGANIC N",0,0
2,"Segments"
1,"Segment 1",0,1,.197,4.94,.36,.93,0,.68,0,.2,0,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",40,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,.3,0
1,"TOTAL P    MG/M3",327,0,1,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A      MG/M3",0,0,1,0
1,"SECCHI         M",0,0,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
2,"Segment 2",1,1,.445,2.35,1.17,2.01,0,1.05,0,.1,0,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"CONSERVATIVE SUB",0,0,.3,0
2,"TOTAL P    MG/M3",165,0,1,0
2,"TOTAL N    MG/M3",0,0,1,0
2,"CHL-A      MG/M3",0,0,1,0
2,"SECCHI         M",0,0,1,0
2,"ORGANIC N  MG/M3",0,0,1,0
2,"TP-ORTHO-P MG/M3",0,0,1,0
2,"HOD-V  MG/M3-DAY",0,0,1,0
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2,"MOD-V  MG/M3-DAY",0,0,1,0
1,"Tributaries"
1,"Inlet Tributary",2,1,9.29,4.4,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",164,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
1,"Row Crop"
1,"Runoff",.2596,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",493,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
2,"Grassland"
2,"Runoff",.2596,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",493,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"Forest"
3,"Runoff",.2596,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",493,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"Urban"
4,"Runoff",.2596,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",493,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,"Wetland"
5,"Runoff",.2596,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",493,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,"Other"
6,"Runoff",.2596,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",493,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Single reservoir
2 segments
```

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Vers 6.20 (03/06/2014)
West Frankfort New Res. (RNQ)
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.4096,0
3,"EVAPORATION (METERS)",.4096,0
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",4
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",0
5,"SECCHI DEPTH",0
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",1
9,"ERROR ANALYSIS",0
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1.6,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",1,0
15,"Avail Factor - Ortho P",0,0
16,"Avail Factor - TN",0,0
17,"Avail Factor - Inorganic N",0,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",30,0
3,"TOTAL N",0,0
4,"ORTHO P",0,0
5,"INORGANIC N",0,0
3,"Segments"
1,"Segment 1",0,1,.164,4.42,.49,.93,0,.68,0,.2,0,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",90,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P    MG/M3",510,0,1,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A      MG/M3",0,0,1,0
1,"SECCHI         M",0,0,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
2,"Segment 2",1,1,.372,2.71,1,2.01,0,1.05,0,.1,0,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",35,0
2,"TOTAL N",0,0
2,"CONSERVATIVE SUB",0,0,1,0
2,"TOTAL P    MG/M3",394,0,1,0
2,"TOTAL N    MG/M3",0,0,1,0
2,"CHL-A      MG/M3",0,0,1,0
2,"SECCHI         M",0,0,1,0
2,"ORGANIC N  MG/M3",0,0,1,0
2,"TP-ORTHO-P MG/M3",0,0,1,0
2,"HOD-V  MG/M3-DAY",0,0,1,0
```

```
2,"MOD-V  MG/M3-DAY",0,0,1,0
3,"Segment 3",1,1,.297,.79,1,.7,0,1.41,0,.08,0,0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",25,0
3,"TOTAL N",0,0
3,"CONSERVATIVE SUB",0,0,1,0
3,"TOTAL P    MG/M3",483,0,1,0
3,"TOTAL N    MG/M3",0,0,1,0
3,"CHL-A      MG/M3",0,0,1,0
3,"SECCHI         M",0,0,1,0
3,"ORGANIC N  MG/M3",0,0,1,0
3,"TP-ORTHO-P MG/M3",0,0,1,0
3,"HOD-V  MG/M3-DAY",0,0,1,0
3,"MOD-V  MG/M3-DAY",0,0,1,0
1,"Tributaries"
1,"Inlet Tributary",3,1,19.16,8.9,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",148.5,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
1,"Row Crop"
1,"Runoff",.2596,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",493,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
2,"Grassland"
2,"Runoff",.2596,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",493,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"Forest"
3,"Runoff",.2596,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",493,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"Urban"
4,"Runoff",.2596,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",493,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,"Wetland"
5,"Runoff",.2596,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",493,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,"Other"
6,"Runoff",.2596,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",493,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
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7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Single reservoir
3 segments
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Old Herrin Res (RNZD)

File: **\Upper Big Muddy\BATHTUB\Input_Output_Files\Calibration_inputs\RNZD\RNZD.btb**

Variable: **TOTAL P MG/M3**

	Predicted		Observed	
Segment	**Mean**	**CV**	**Mean**	**CV**
Segment 1	44.0	0.00	46.0	0.00
Segment 2	23.9	0.00	24.0	0.00
Area-Wtd Mean	27.9	0.00	28.4	0.00

Johnston City Lake (RNZE)

File: **\Upper Big Muddy\BATHTUB\Input_Output_Files\Calibration_inputs\RNZE\RNZE.btb**

Variable: **TOTAL P MG/M3**

	Predicted		Observed	
Segment	**Mean**	**CV**	**Mean**	**CV**
Segment 1	71.2	0.00	70.0	0.00
Segment 2	74.8	0.00	79.0	0.00
Area-Wtd Mean	73.7	0.00	76.2	0.00

Arrowhead Lake (RNZX)

File: **\Upper Big Muddy\BATHTUB\Input_Output_Files\Calibration_inputs\RNZX\RNZX.btb**

Variable: **TOTAL P MG/M3**

	Predicted		Observed	
Segment	**Mean**	**CV**	**Mean**	**CV**
Segment 1	179.1	0.00	175.0	0.00
Segment 2	53.8	0.00	58.0	0.00
Segment 3	51.5	0.00	62.0	0.00
Area-Wtd Mean	95.6	0.00	98.5	0.00

West Frankfort Old Res. (RNP)

File: **\Upper Big Muddy\BATHTUB\Input_Output_Files\Calibration_inputs\RNP\RNP.btb**

Variable: **TOTAL P MG/M3**

	Predicted		Observed	
Segment	**Mean**	**CV**	**Mean**	**CV**
Segment 1	318.1	0.00	327.0	0.00
Segment 2	150.5	0.00	165.0	0.00
Area-Wtd Mean	201.9	0.00	214.7	0.00

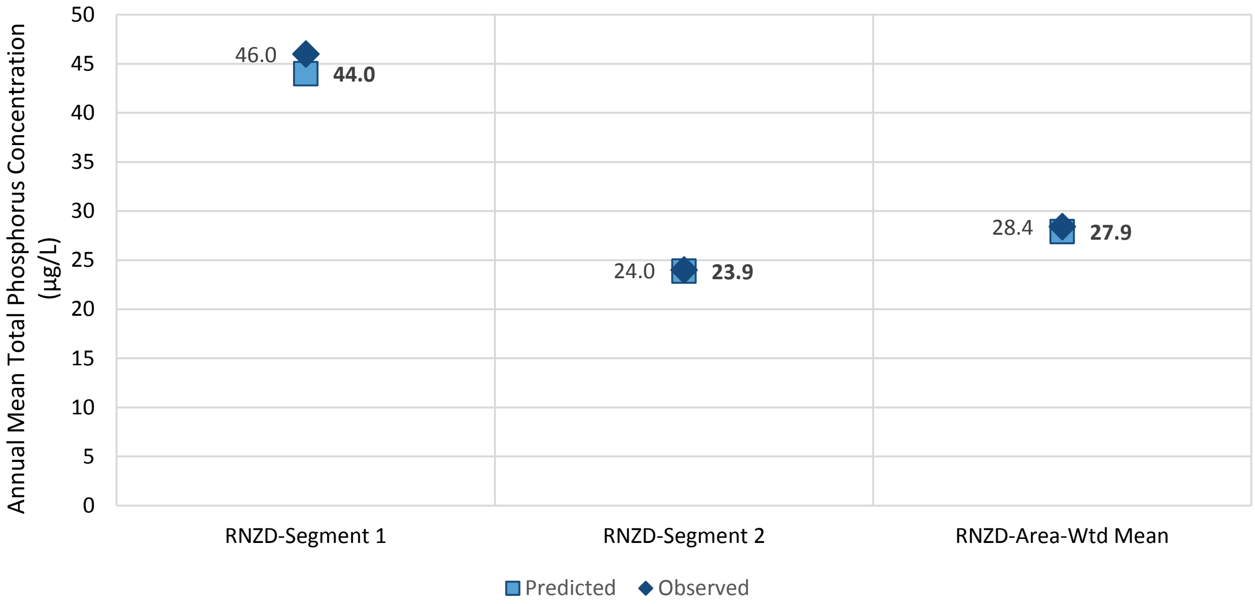
West Frankfort New Res. (RNQ)

File: **\Upper Big Muddy\BATHTUB\Input_Output_Files\Calibration_inputs\RNQ\RNQ.btb**

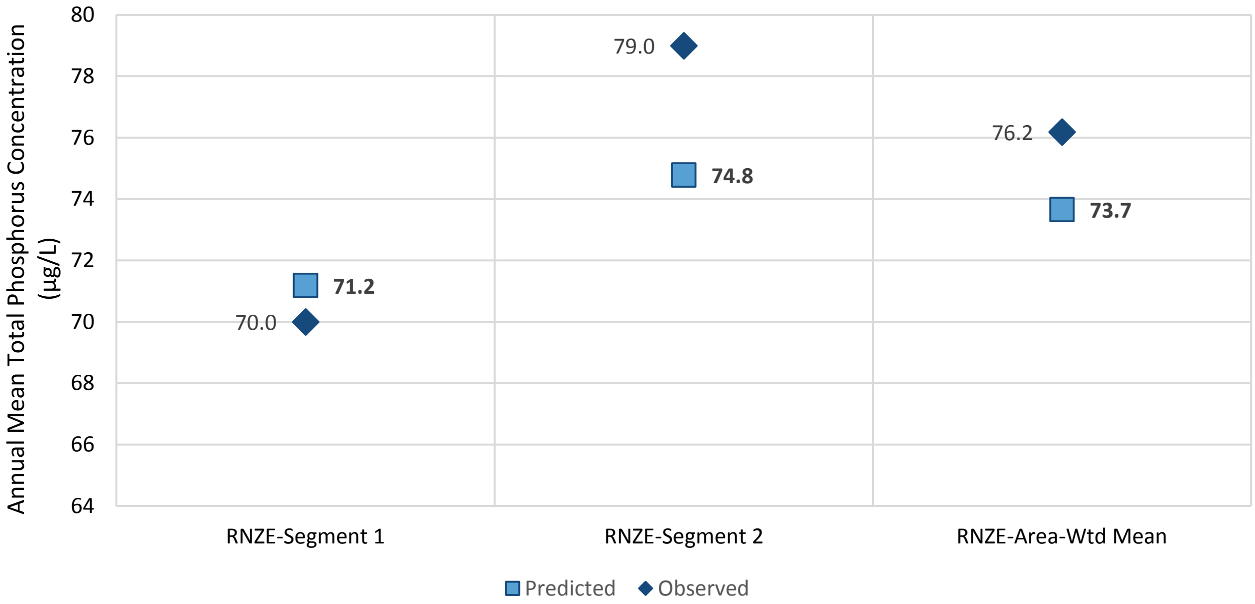
Variable: **TOTAL P MG/M3**

	Predicted		Observed	
Segment	**Mean**	**CV**	**Mean**	**CV**
Segment 1	492.2	0.00	510.0	0.00
Segment 2	384.4	0.00	394.0	0.00
Segment 3	488.6	0.00	483.0	0.00
Area-Wtd Mean	442.8	0.00	448.6	0.00

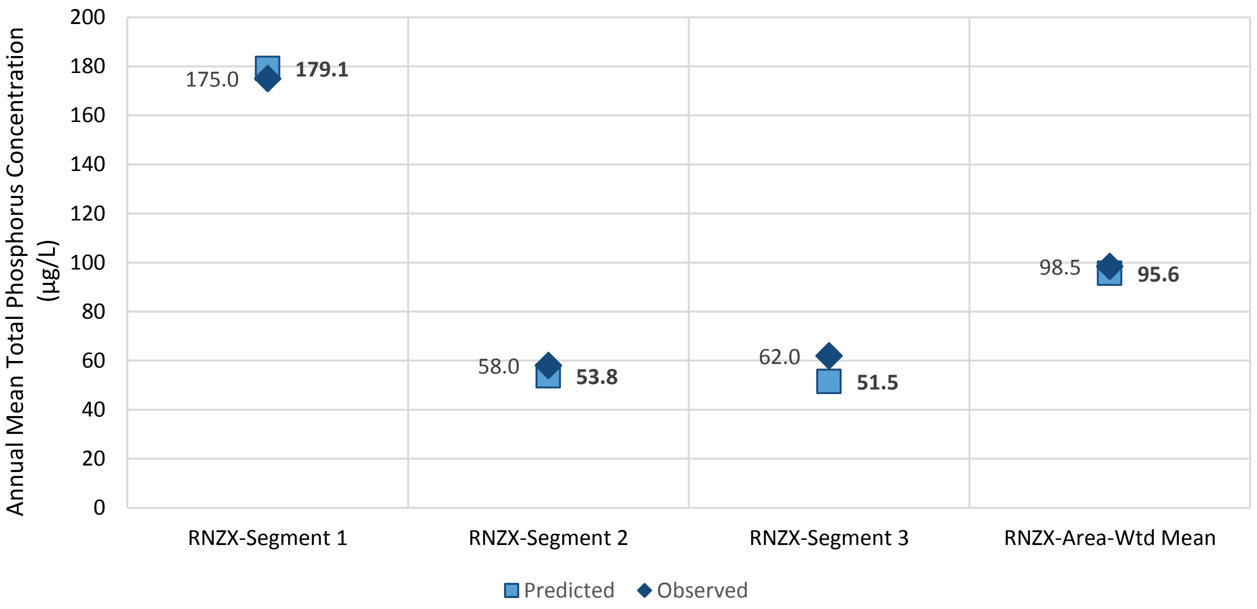
RNZD


Annual Mean Total Phosphorus Concentration (µg/L)
50
45
40
35
30
25
20
15
10
5
0
46.0
44.0
24.0
23.9
28.4
27.9
RNZD-Segment 1
RNZD-Segment 2
RNZD-Area-Wtd Mean
Predicted
Observed

RNZE

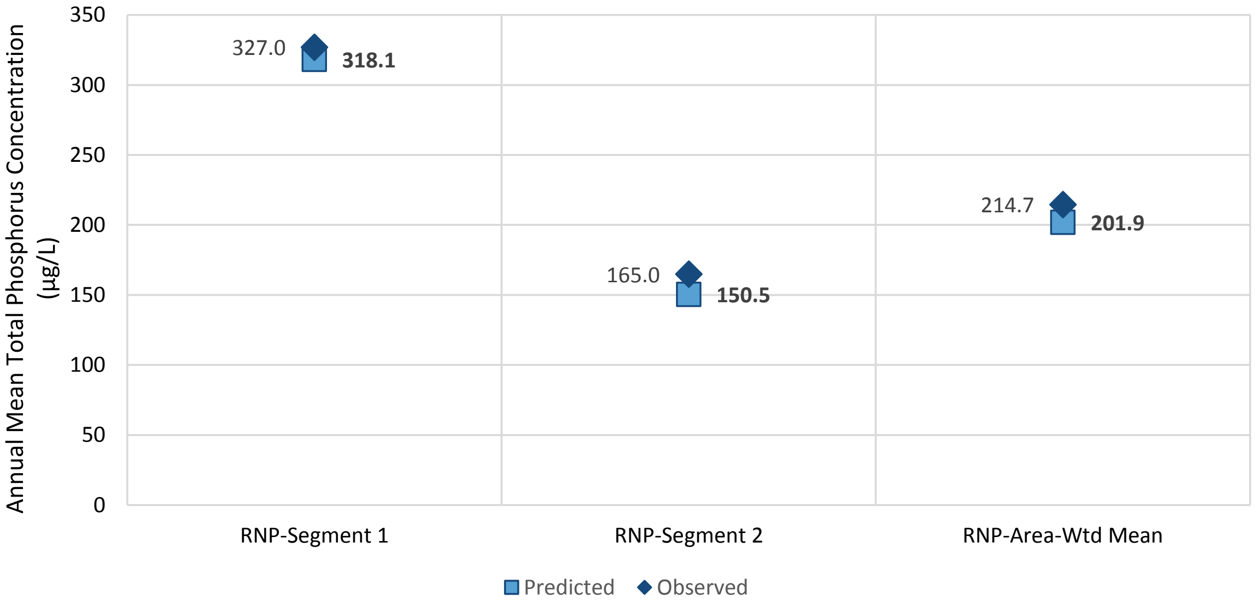

Annual Mean Total Phosphorus Concentration (µg/L)
80
78
76
74
72
70
68
66
64
71.2
70.0
79.0
74.8
76.2
73.7
RNZE-Segment 1
RNZE-Segment 2
RNZE-Area-Wtd Mean
Predicted
Observed

RNZX



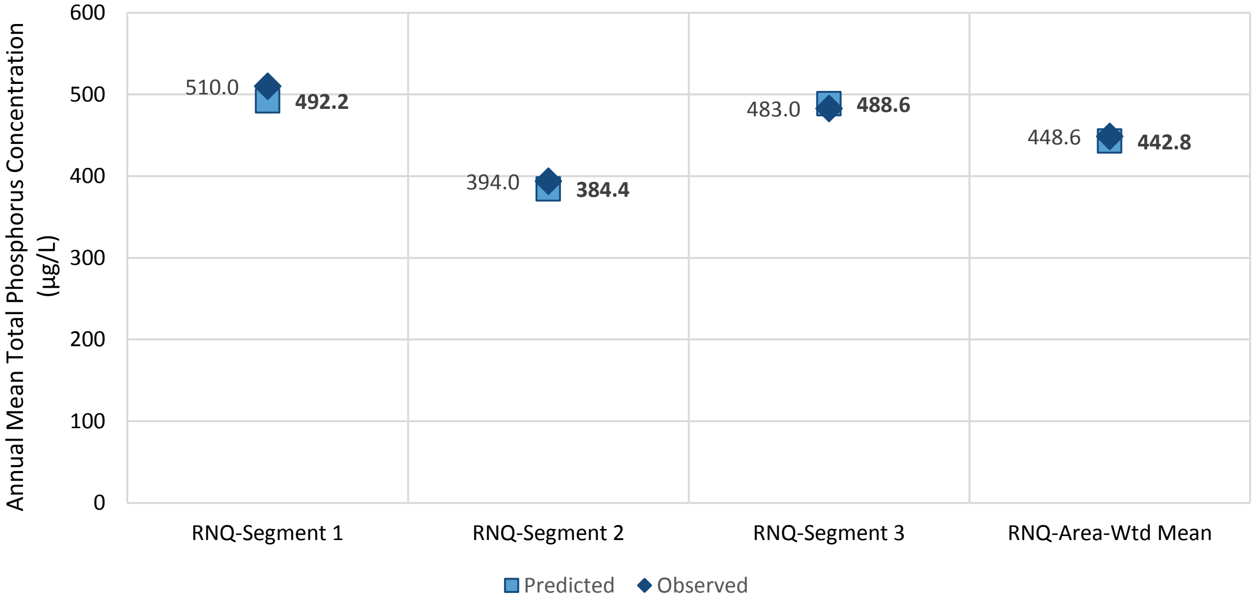
Annual Mean Total Phosphorus Concentration (µg/L)
200
180
160
140
120
100
80
60
40
20
0
175.0
179.1
58.0
53.8
62.0
51.5
98.5
95.6
RNZX-Segment 1
RNZX-Segment 2
RNZX-Segment 3
RNZX-Area-Wtd Mean
■ Predicted
◆ Observed

RNP



Annual Mean Total Phosphorus Concentration (µg/L)
350
300
250
200
150
100
50
0
327.0
318.1
165.0
150.5
214.7
201.9
RNP-Segment 1
RNP-Segment 2
RNP-Area-Wtd Mean
■ Predicted
◆ Observed

RNQ


Annual Mean Total Phosphorus Concentration (µg/L)
600
500
400
300
200
100
0
510.0
492.2
394.0
384.4
483.0
488.6
448.6
442.8
RNQ-Segment 1
RNQ-Segment 2
RNQ-Segment 3
RNQ-Area-Wtd Mean
Predicted
Observed

Attachment 5: Load Duration Curve Analysis

IL_N-11 Fecal Coliform LDC
IL_NZN-13 Iron LDC
IL_NG-02 Chloride LDC
IL_NGAZ-JC-D1 Manganese LDC
IL_NH-06 Fecal Coliform LDC

Stream Name	*Upper Big Muddy River*
Site ID	*N-11*
USGS Gage	
8-Digit HUC	
Drainage Area	*76.9*

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Fecal Coliform (CFU/100mL)**	**Fecal Coliform Load**
5/19/1999	12:30	109.7	37.6%	95	2.55E+11
7/7/1999	13:30	40.6	57.6%	116	1.15E+11
8/16/1999	16:30	14.2	84.9%	78	2.71E+10
9/14/1999	16:50	13.8	86.2%	60	2.03E+10
10/26/1999	11:30	13.4	87.5%	133	4.36E+10
5/25/2000	13:15	31.3	62.4%	3600	2.75E+12
6/20/2000	13:35	186.8	26.6%	135	6.17E+11
7/19/2000	14:00	377.7	14.9%	20	1.85E+11
9/6/2000	14:40	12.2	93.2%	140	4.17E+10
10/11/2000	13:45	11.8	94.6%	44	1.27E+10
5/1/2001	13:30	25.2	66.7%	46	2.83E+10
5/31/2001	13:35	69.0	47.2%	500	8.45E+11
7/16/2001	18:30	18.7	74.6%	51	2.33E+10
8/20/2001	13:30	52.8	52.8%	240	3.10E+11
10/17/2001	15:00	162.4	29.3%	560	2.23E+12
5/23/2002	12:50	105.6	38.3%	32	8.27E+10
6/5/2002	10:45	33.7	60.9%	62	5.11E+10
9/9/2002	14:40	11.4	95.9%	42	1.17E+10
10/24/2002	11:40	8.1	100.0%	100	1.99E+10
5/15/2003	15:30	138.1	32.4%	42	1.42E+11
6/12/2003	16:15	6091.7	1.4%	4500	6.71E+14
7/29/2003	10:45	12.6	91.4%	36	1.11E+10
9/30/2003	16:00	12.6	91.4%	76	2.34E+10
11/4/2003	8:30	13.0	89.5%	64	2.03E+10
12/3/2003	13:05	25.2	66.7%	64	3.94E+10
1/20/2004	17:10	138.1	32.4%	230	7.77E+11
2/23/2004	11:45	81.2	44.0%	50	9.94E+10
4/14/2004	12:30	52.8	52.8%	5	6.46E+09
5/17/2004	9:00	56.9	51.3%	300	4.17E+11
6/24/2004	10:30	21.9	70.1%	32	1.72E+10
8/9/2004	10:15	15.8	80.3%	40	1.55E+10
9/7/2004	14:00	40.6	57.6%	80	7.95E+10
10/21/2004	17:20	73.1	46.2%	720	1.29E+12
5/4/2005	16:00	85.3	43.0%	90	1.88E+11
8/9/2005	18:00	15.0	82.5%	210	7.72E+10
5/2/2006	13:10	5238.8	1.7%	1040	1.33E+14
6/29/2006	11:20	22.3	69.6%	30	1.64E+10
8/15/2006	11:20	14.6	83.5%	200	7.15E+10
9/19/2006	14:15	28.4	64.3%	1800	1.25E+12
10/26/2006	13:35	247.7	20.9%	90	5.45E+11
5/21/2009	11:00	203.1	24.6%	28	1.39E+11

Stream Name	***Upper Big Muddy River***
Site ID	***N-11***
USGS Gage	
8-Digit HUC	
Drainage Area	***76.9***

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Fecal Coliform (CFU/100mL)**	**Fecal Coliform Load**
6/24/2009	13:50	60.9	49.9%	30	4.47E+10
7/28/2009	11:40	24.0	67.8%	30	1.76E+10
9/2/2009	11:35	12.6	91.4%	23	7.08E+09
10/13/2009	16:10	60.9	49.9%	81	1.21E+11
5/5/2010	17:00	199.0	25.1%	120	5.84E+11
7/1/2010	16:35	17.9	76.0%	52	2.27E+10
8/24/2010	16:00	17.5	76.7%	170	7.26E+10
9/13/2010	16:00	11.4	95.9%	260	7.23E+10
10/6/2010	15:20	12.2	93.2%	66	1.97E+10

Stream Name	***Andy Creek***
Site ID	***NZN-13***
USGS Gage	
8-Digit HUC	
Drainage Area	***20.4***

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Iron (mg/L)**	**Iron Load**
5/13/2008		11.6	25.5%	1.11	69.2
6/11/2008		2.3	51.2%	0.081	1.0
8/15/2008		0.3	73.6%	0.038400002	0.1

Stream Name	***Pond Creek***
Site ID	***NG-02***
USGS Gage	
8-Digit HUC	
Drainage Area	***31.7***

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Chloride (mg/L)**	**Chloride Load**
3/2/2004		187.6	10.3%	18.2	18372.8
4/13/2004		10.9	51.7%	42.8	2520.4
5/18/2004		215.8	9.3%	22.1	25656.2
6/7/2004		8.8	54.9%	18.8	885.7
6/7/2004		8.8	54.9%	28.9	1361.5
8/4/2004		0.7	83.8%	29.6	104.6
10/21/2004		2.2	70.1%	25.1	299.8
11/3/2004		153.2	12.1%	12.5	10305.2
12/7/2004		681.8	3.9%	9.22	33817.3
1/26/2005		23.1	40.6%	29.3	3648.0
3/2/2005		31.3	35.7%	27	4542.7
3/29/2005		785.0	3.4%	10.9	46031.1
5/5/2005		13.1	48.7%	29.6	2091.7
6/21/2005		1.2	77.8%	69.2	430.8
8/16/2005		0.8	81.7%	66	288.7
9/13/2005		0.0	100.0%	52	0.0
10/26/2005		0.0	100.0%	44	0.0
11/28/2005		100.1	16.2%	44.8	24120.1
1/17/2006		134.5	13.4%	18.5	13384.2
2/28/2006		20.3	42.5%	44.5	4866.6
4/3/2006		106.3	15.7%	16.20000076	9267.1
6/28/2006		5.0	60.8%	51.29999924	1381.0
8/22/2006		0.8	81.7%	43.09999847	188.5
9/20/2006		3.1	66.0%	59	992.7
10/25/2006		2.5	68.8%	29.20000076	388.1
12/11/2006		40.7	31.7%	35	7655.3
1/22/2007		240.8	8.6%	8.069999695	10454.8
5/15/2008		375.3	6.3%	43.79999924	88431.5
6/12/2008		12.5	49.5%	240	16151.9
7/24/2008		0.0	93.5%	1420	238.9

Stream Name	***Beaver Creek***
Site ID	***IL_NGAZ-JC-D1***
USGS Gage	
8-Digit HUC	
Drainage Area	***0.6***

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Manganese (mg/L)**	**Manganese Load**
8/6/2008	13:55	0.0	67.5%	6.41	0.6

Stream Name	***Upper Big Muddy River***
Site ID	***NH_06***
USGS Gage	
8-Digit HUC	
Drainage Area	***160.6***

Sample Date	Sample Time	Flow *(cfs)*	Flow Rank	Fecal Coliform (CFU/100mL)	Fecal Coliform Load
5/20/1999	12:30	33.4	48.3%	1960	1.60E+12
7/8/1999	13:30	16.9	61.3%	181	7.49E+10
8/17/1999	16:30	7.5	83.5%	80	1.47E+10
9/30/1999	16:50	7.3	84.9%	120	2.15E+10
10/27/1999	11:30	6.9	87.5%	1075	1.81E+11
5/25/2000	13:15	16.1	62.4%	2600	1.02E+12
6/20/2000	13:35	96.1	26.6%	285	6.70E+11
7/19/2000	14:00	194.2	14.9%	20000	9.50E+13
8/22/2000	14:40	14.0	65.1%	80	2.74E+10
10/11/2000	13:45	6.1	94.6%	200	2.96E+10
5/1/2001	13:30	12.9	66.7%	350	1.11E+11
5/31/2001	13:35	35.5	47.2%	4820	4.19E+12
7/16/2001	18:30	9.6	74.6%	580	1.36E+11
9/19/2001	13:30	23.0	56.3%	63600	3.57E+13
10/17/2001	15:00	83.5	29.3%	440	8.99E+11
5/23/2002	12:50	54.3	38.3%	90	1.20E+11
6/5/2002	10:45	17.3	60.9%	68	2.88E+10
8/12/2002	14:40	5.6	96.9%	37	5.10E+09
9/10/2002	11:40	5.8	95.9%	18	2.58E+09
10/28/2002	15:30	25.1	54.5%	46	2.82E+10
5/29/2003	16:15	50.1	39.9%	9000	1.10E+13
6/11/2003	10:45	469.9	7.9%	11500	1.32E+14
7/10/2003	16:00	9.0	76.7%	42	9.23E+09
9/23/2003	8:30	6.3	93.2%	52	7.97E+09
10/29/2003	13:05	6.7	89.5%	310	5.07E+10
5/18/2004	17:10	27.1	52.8%	220	1.46E+11
6/7/2004	11:45	20.3	58.0%	122	6.05E+10
8/4/2004	12:30	9.4	75.3%	1760	4.05E+11
9/14/2004	9:00	9.4	75.3%	120	2.76E+10
5/5/2005	10:30	37.6	46.2%	143	1.32E+11
9/13/2005	10:15	7.5	83.5%	96	1.77E+10
5/2/2006	14:00	2694.1	1.7%	6100	4.02E+14
6/28/2006	17:20	15.2	63.3%	230	8.58E+10
8/22/2006	16:00	5.4	98.0%	440	5.85E+10
9/20/2006	18:00	8.4	79.5%	115	2.35E+10
10/25/2006	13:10	6.3	93.2%	110	1.69E+10
5/21/2009	11:20	104.4	24.6%	260	6.64E+11
6/24/2009	11:20	31.3	49.9%	225	1.72E+11
7/28/2009	14:15	12.3	67.8%	390	1.18E+11
9/2/2009	13:35	6.5	91.4%	6	9.50E+08
10/13/2009	11:00	31.3	49.9%	105	8.05E+10

5/5/2010	13:50	102.3	25.1%	270	6.76E+11
7/1/2010	11:40	9.2	76.0%	760	1.71E+11
8/24/2010	11:35	9.0	76.7%	1100	2.42E+11
9/13/2010	16:10	5.8	95.9%	180	2.58E+10
10/6/2010	17:00	6.3	93.2%	35	5.36E+09

Stream Name	*Upper Big Muddy River*
Site ID	*N-11*
USGS Gage	
8-Digit HUC	
Drainage Area	*76.9*

Sample Date	Sample Time	Flow *(cfs)*	Flow Rank	Fecal Coliform (CFU/100mL)	Fecal Coliform Load
5/19/1999	12:30	109.7	37.6%	95	2.55E+11
7/7/1999	13:30	40.6	57.6%	116	1.15E+11
8/16/1999	16:30	14.2	84.9%	78	2.71E+10
9/14/1999	16:50	13.8	86.2%	60	2.03E+10
10/26/1999	11:30	13.4	87.5%	133	4.36E+10
5/25/2000	13:15	31.3	62.4%	3600	2.75E+12
6/20/2000	13:35	186.8	26.6%	135	6.17E+11
7/19/2000	14:00	377.7	14.9%	20	1.85E+11
9/6/2000	14:40	12.2	93.2%	140	4.17E+10
10/11/2000	13:45	11.8	94.6%	44	1.27E+10
5/1/2001	13:30	25.2	66.7%	46	2.83E+10
5/31/2001	13:35	69.0	47.2%	500	8.45E+11
7/16/2001	18:30	18.7	74.6%	51	2.33E+10
8/20/2001	13:30	52.8	52.8%	240	3.10E+11
10/17/2001	15:00	162.4	29.3%	560	2.23E+12
5/23/2002	12:50	105.6	38.3%	32	8.27E+10
6/5/2002	10:45	33.7	60.9%	62	5.11E+10
9/9/2002	14:40	11.4	95.9%	42	1.17E+10
10/24/2002	11:40	8.1	100.0%	100	1.99E+10
5/15/2003	15:30	138.1	32.4%	42	1.42E+11
6/12/2003	16:15	6091.7	1.4%	4500	6.71E+14
7/29/2003	10:45	12.6	91.4%	36	1.11E+10
9/30/2003	16:00	12.6	91.4%	76	2.34E+10
11/4/2003	8:30	13.0	89.5%	64	2.03E+10
12/3/2003	13:05	25.2	66.7%	64	3.94E+10
1/20/2004	17:10	138.1	32.4%	230	7.77E+11
2/23/2004	11:45	81.2	44.0%	50	9.94E+10
4/14/2004	12:30	52.8	52.8%	5	6.46E+09
5/17/2004	9:00	56.9	51.3%	300	4.17E+11
6/24/2004	10:30	21.9	70.1%	32	1.72E+10
8/9/2004	10:15	15.8	80.3%	40	1.55E+10
9/7/2004	14:00	40.6	57.6%	80	7.95E+10
10/21/2004	17:20	73.1	46.2%	720	1.29E+12
5/4/2005	16:00	85.3	43.0%	90	1.88E+11
8/9/2005	18:00	15.0	82.5%	210	7.72E+10
5/2/2006	13:10	5238.8	1.7%	1040	1.33E+14
6/29/2006	11:20	22.3	69.6%	30	1.64E+10
8/15/2006	11:20	14.6	83.5%	200	7.15E+10
9/19/2006	14:15	28.4	64.3%	1800	1.25E+12
10/26/2006	13:35	247.7	20.9%	90	5.45E+11
5/21/2009	11:00	203.1	24.6%	28	1.39E+11

Stream Name	***Upper Big Muddy River***
Site ID	***N-11***
USGS Gage	
8-Digit HUC	
Drainage Area	***76.9***

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Fecal Coliform (CFU/100mL)**	**Fecal Coliform Load**
6/24/2009	13:50	60.9	49.9%	30	4.47E+10
7/28/2009	11:40	24.0	67.8%	30	1.76E+10
9/2/2009	11:35	12.6	91.4%	23	7.08E+09
10/13/2009	16:10	60.9	49.9%	81	1.21E+11
5/5/2010	17:00	199.0	25.1%	120	5.84E+11
7/1/2010	16:35	17.9	76.0%	52	2.27E+10
8/24/2010	16:00	17.5	76.7%	170	7.26E+10
9/13/2010	16:00	11.4	95.9%	260	7.23E+10
10/6/2010	15:20	12.2	93.2%	66	1.97E+10

Stream Name	***Andy Creek***
Site ID	***NZN-13***
USGS Gage	
8-Digit HUC	
Drainage Area	***20.4***

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Iron (mg/L)**	**Iron Load**
5/13/2008		11.6	25.5%	1.11	69.2
6/11/2008		2.3	51.2%	0.081	1.0
8/15/2008		0.3	73.6%	0.038400002	0.1

Stream Name	*Pond Creek*
Site ID	*NG-02*
USGS Gage	
8-Digit HUC	
Drainage Area	***31.7***

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Chloride (mg/L)**	**Chloride Load**
3/2/2004		187.6	10.3%	18.2	18372.8
4/13/2004		10.9	51.7%	42.8	2520.4
5/18/2004		215.8	9.3%	22.1	25656.2
6/7/2004		8.8	54.9%	18.8	885.7
6/7/2004		8.8	54.9%	28.9	1361.5
8/4/2004		0.7	83.8%	29.6	104.6
10/21/2004		2.2	70.1%	25.1	299.8
11/3/2004		153.2	12.1%	12.5	10305.2
12/7/2004		681.8	3.9%	9.22	33817.3
1/26/2005		23.1	40.6%	29.3	3648.0
3/2/2005		31.3	35.7%	27	4542.7
3/29/2005		785.0	3.4%	10.9	46031.1
5/5/2005		13.1	48.7%	29.6	2091.7
6/21/2005		1.2	77.8%	69.2	430.8
8/16/2005		0.8	81.7%	66	288.7
9/13/2005		0.0	100.0%	52	0.0
10/26/2005		0.0	100.0%	44	0.0
11/28/2005		100.1	16.2%	44.8	24120.1
1/17/2006		134.5	13.4%	18.5	13384.2
2/28/2006		20.3	42.5%	44.5	4866.6
4/3/2006		106.3	15.7%	16.20000076	9267.1
6/28/2006		5.0	60.8%	51.29999924	1381.0
8/22/2006		0.8	81.7%	43.09999847	188.5
9/20/2006		3.1	66.0%	59	992.7
10/25/2006		2.5	68.8%	29.20000076	388.1
12/11/2006		40.7	31.7%	35	7655.3
1/22/2007		240.8	8.6%	8.069999695	10454.8
5/15/2008		375.3	6.3%	43.79999924	88431.5
6/12/2008		12.5	49.5%	240	16151.9
7/24/2008		0.0	93.5%	1420	238.9

Stream Name	***Upper Big Muddy River***
Site ID	***NH_06***
USGS Gage	
8-Digit HUC	
Drainage Area	***160.6***

Sample Date	**Sample Time**	**Flow *(cfs)***	**Flow Rank**	**Fecal Coliform (CFU/100mL)**	**Fecal Coliform Load**
5/20/1999	12:30	33.4	48.3%	1960	1.60E+12
7/8/1999	13:30	16.9	61.3%	181	7.49E+10
8/17/1999	16:30	7.5	83.5%	80	1.47E+10
9/30/1999	16:50	7.3	84.9%	120	2.15E+10
10/27/1999	11:30	6.9	87.5%	1075	1.81E+11
5/25/2000	13:15	16.1	62.4%	2600	1.02E+12
6/20/2000	13:35	96.1	26.6%	285	6.70E+11
7/19/2000	14:00	194.2	14.9%	20000	9.50E+13
8/22/2000	14:40	14.0	65.1%	80	2.74E+10
10/11/2000	13:45	6.1	94.6%	200	2.96E+10
5/1/2001	13:30	12.9	66.7%	350	1.11E+11
5/31/2001	13:35	35.5	47.2%	4820	4.19E+12
7/16/2001	18:30	9.6	74.6%	580	1.36E+11
9/19/2001	13:30	23.0	56.3%	63600	3.57E+13
10/17/2001	15:00	83.5	29.3%	440	8.99E+11
5/23/2002	12:50	54.3	38.3%	90	1.20E+11
6/5/2002	10:45	17.3	60.9%	68	2.88E+10
8/12/2002	14:40	5.6	96.9%	37	5.10E+09
9/10/2002	11:40	5.8	95.9%	18	2.58E+09
10/28/2002	15:30	25.1	54.5%	46	2.82E+10
5/29/2003	16:15	50.1	39.9%	9000	1.10E+13
6/11/2003	10:45	469.9	7.9%	11500	1.32E+14
7/10/2003	16:00	9.0	76.7%	42	9.23E+09
9/23/2003	8:30	6.3	93.2%	52	7.97E+09
10/29/2003	13:05	6.7	89.5%	310	5.07E+10
5/18/2004	17:10	27.1	52.8%	220	1.46E+11
6/7/2004	11:45	20.3	58.0%	122	6.05E+10
8/4/2004	12:30	9.4	75.3%	1760	4.05E+11
9/14/2004	9:00	9.4	75.3%	120	2.76E+10
5/5/2005	10:30	37.6	46.2%	143	1.32E+11
9/13/2005	10:15	7.5	83.5%	96	1.77E+10
5/2/2006	14:00	2694.1	1.7%	6100	4.02E+14
6/28/2006	17:20	15.2	63.3%	230	8.58E+10
8/22/2006	16:00	5.4	98.0%	440	5.85E+10
9/20/2006	18:00	8.4	79.5%	115	2.35E+10
10/25/2006	13:10	6.3	93.2%	110	1.69E+10
5/21/2009	11:20	104.4	24.6%	260	6.64E+11
6/24/2009	11:20	31.3	49.9%	225	1.72E+11
7/28/2009	14:15	12.3	67.8%	390	1.18E+11
9/2/2009	13:35	6.5	91.4%	6	9.50E+08
10/13/2009	11:00	31.3	49.9%	105	8.05E+10

5/5/2010	13:50	102.3	25.1%	270	6.76E+11
7/1/2010	11:40	9.2	76.0%	760	1.71E+11
8/24/2010	11:35	9.0	76.7%	1100	2.42E+11
9/13/2010	16:10	5.8	95.9%	180	2.58E+10
10/6/2010	17:00	6.3	93.2%	35	5.36E+09

Attachment 6: Illinois EPA Load Reduction Strategy (LRS) Methodology

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Load Reduction Strategy

As part of the TMDL development process the Agency started to include Load Reduction Strategies (LRS) in TMDL watershed projects in 2012 for those pollutants that do not currently have a numeric water quality standards. Developing an LRS involves determining the loading capacity and load reduction necessary that is needed in order for the water body to meet "**Full Use Support"** for its designated uses. The load capacity is not divided into WLA, LA, or MOS, these are represented by one number as a target concentration for load reduction within each unique watershed. This LRS here is only for two parameters (Total Phosphorus and Total Suspended Solids); all other parameters such as Sedimentation/Siltation and Turbidity will be addressed separately. The Load Reduction Strategy provides guidance (with no regulatory requirements) for voluntary nonpoint source reduction efforts by implementing agricultural and urban stormwater best management practices (BMPs).

To arrive at these results, three tasks were performed: **Identification**, **Analysis**, and **Application**.

Identification:

1. For each TMDL watershed, the US Geological Survey ten-digit Hydrologic Unit Code, or HUC-10 was identified.
2. Within each HUC-10, each and every stream segment or lake was identified.
3. Each stream segment or lake was checked against the Illinois EPA Assessment Data Base (or ADB) to determine those segments and lakes that are in full support for aquatic life.
4. For each HUC-10 basin, full-support stream segments and lakes were grouped to show where each unique watershed is at its best in providing a healthy environment for aquatic plants and animals. A statewide "one size fits all" approach was purposefully avoided to allow the distinct nature of each watershed to become apparent.

Analysis:

1. For each stream segment or lake that fully supports designated uses, the water quality data from 1999 through 2013 was compiled. This includes data from the Illinois EPA's Surface Water Section's ambient monitoring, intensive basin surveys, and special studies. The pollutants (or parameters) for which data compiled data are Total Phosphorus (TP) and Total Suspended Solids (TSS), those pollutants requiring an LRS be developed.
2. This data underwent a last quality control check and carefully discriminated against any data that did not pass all the rigorous quality assurance checks. Only the data that passed all checks was used to calculate the targets in this strategy.
3. Mathematical operations were kept to a minimum in order to establish targets which are as accurate and relevant as possible. For each stream segment (or lake), the raw average of all available data from 1999 through 2013 was calculated for TP and TSS, respectively.

Application:

1. For each stream segment or lake, an average concentration for TP and/or TSS over the entire time period was calculated.
2. Within each unique watershed, these long-term results for TP and TSS for all the fully supporting segments and streams in the watershed were averaged together. This allows these healthy waters to most accurately represent the level of aquatic life support the watershed is capable of providing.
3. The average concentrations for the aquatic-life-supporting water bodies were then assigned as targets for all water bodies of the same type in the watershed, e.g. stream targets for streams, lake targets for lakes. The rationale for assigning this composite average is that within a given watershed, all streams for example share similar geology, soil type, land use, agricultural practices, and topography. The same holds true for lakes.

   Finally, the average of these long-term concentrations can be the target concentrations for impaired stream segments or lakes requiring an LRS be developed.

The targets for each watershed are presented below:

Pecatonica Watershed-Wide Load Reduction Targets

USGS HUC-10 Basins Addressed: 0709000311, 0709000312, 0709000313, 0709000314, 0709000315, 0709000316, 0709000408, and 0709000215.

The following stream segments are full use support in the Pecatonica watershed:

- Pecatonica River PW-07
- Pecatonica River PW-02
- Waddams Creek PWQ-04
- Raccoon Creek PWA-01
- Sugar Creek PWB-03
- Sumner Creek PWH-02
- Rock Run PWI-01
- Richland Creek PWP-06
- Cedar Creek PWPA-01
- Otter Creek PWBA-02

The averages of data for each fully supporting stream segment are as follows:

Stream Name	Total Phosphorus	Total Suspended Solids
Pecatonica River PW-07	0.19 mg/l	93 mg/l
Pecatonica River PW-02	0.206 mg/l	66 mg/l
Waddams Creek PWQ-04	0.4 mg/l	14 mg/l
Raccoon Creek PWA-01	0.091 mg/l	20 mg/l
Sugar Creek PWB-03	0.16 mg/l	63 mg/l
Sumner Creek PWH-02	0.036 mg/l	13.5 mg/l
Rock Run PWI-01	0.074 mg/l	18 mg/l
Richland Creek PWP-06	0.17 mg/l	53 mg/l
Cedar Creek PWPA-01	0.062 mg/l	22 mg/l
Otter Creek PWBA-02	0.165 mg/l	35 mg/l
Raw Average	0.156 mg/l	40 mg/l

Based on an average of validated, real-world data for these streams over a period from 1999 to 2013, the load reduction targets for all streams in this watershed are as follows:

Total Phosphorus: 0.156 milligrams/liter

Total Suspended Solids: 40 milligrams/liter

Lake Le-Aqua-Na (RPA) (Cause of TSS listed) has this target:

The Total Suspended Solids: 17 milligrams/liter {analysis of 1999 – 2013 data}

Galena Sinsinawa Watershed-Wide Load Reduction Targets

USGS HUC-10 Basins Addressed: 0706000502 and 0706000503.

The following stream segments are full use support in the Galena Sinsinawa watershed:

- Little Menominee River MT-01
- Menominee River MU-01
- East Fork Galena River MQB-01

The averages of data for each fully supporting stream segment are as follows:

Stream Name	Total Phosphorus	Total Suspended Solids
Little Menominee River MT-01	0.157 mg/l	{no data}
Menominee River MU-01	0.158 mg/l	34.2 mg/l
East Fork Galena River MQB-01	0.101 mg/l	14.1 mg/l
Raw Average	0.138 mg/l	24.1 mg/l

Based on an average of validated, real-world data for these streams over a period from 1999 to 2013, the load reduction targets for all streams in this watershed are as follows:

Total Phosphorus: 0.138 milligrams/liter

Total Suspended Solids: 24.1 milligrams/liter

Little Vermillion Watershed-Wide Load Reduction Targets

USGS HUC-10 Basin Addressed: 0713000103

The following stream segments are full use support in the Little Vermillion watershed:

- Little Vermillion River DR-04
- Tomahawk Creek DRA

The averages of data for each fully supporting stream segment are as follows:

Stream Name	Total Phosphorus	Total Suspended Solids
Little Vermillion River DR-04	0.454 mg/l	21.6 mg/l
Tomahawk Creek DRA	0.124 mg/l	29.1 mg/l
Raw Average	0.289 mg/l	25.3 mg/l

Based on an average of validated, real-world data for these streams over a period from 1999 to 2013, the load reduction targets for all streams in this watershed are as follows:

Total Phosphorus: 0.289 milligrams/liter

Total Suspended Solids: 25.3 milligrams/liter

Middle Sangamon Watershed-Wide Load Reduction Targets

USGS HUC-10 Basins Addressed: 0713000605, 0713000606, 0713000607, and 0713000608.

The following stream segments are full use support in the Middle Sangamon watershed:

- Sangamon River E-05
- Sangamon River E-06
- Sangamon River E-09
- Sangamon River E-16
- Stevens Creek ES-13

The averages of data for each fully supporting stream segment are as follows:

Stream Name	Total Phosphorus	Total Suspended Solids
Sangamon River E-05	1.801 mg/l	33.2 mg/l
Sangamon River E-06	0.173 mg/l	20.1 mg/l
Sangamon River E-09	0.222 mg/l	25.4 mg/l
Sangamon River E-16	1.412 mg/l	44.0 mg/l
Stevens Creek ES-13	0.091 mg/l	11.9 mg/l
Raw Average	0.739 mg/l	26.9 mg/l

Based on an average of validated, real-world data for these streams over a period from 1999 to 2013, the load reduction targets for all streams in this watershed are as follows:

Total Phosphorus: 0.739 milligrams/liter

Total Suspended Solids: 26.9 milligrams/liter

Prairie Langan Watershed-Wide Load Reduction Targets

USGS HUC-10 Basins Addressed: 0712000209 and 0712000212.

The following stream segment meets full use support in the Prairie Langan watershed:

- Langan Creek FLE-01

The averages of data for this fully supporting stream segment are as follows:

Stream Name	Total Phosphorus	Total Suspended Solids
Langan Creek FLE-01	0.104 mg/l	16.2 mg/l

Based on an average of validated, real-world data for this stream over a period from 1999 to 2013, the load reduction targets for all streams in this watershed are as follows:

Total Phosphorus: 0.104 milligrams/liter

Total Suspended Solids: 16.2 milligrams/liter

Lake Springfield and Sugar Creek Watershed Load Reduction Targets

USGS HUC-10 Basin Addressed: 0713000707

The following water body in this watershed supports aquatic life, while not being Full Use Support:

- Lake Springfield REF

The load reduction target is as follows:

Total Suspended Solids: 19 milligrams/liter {analysis of 1999 – 2013 data}

Streams in This Watershed: There are no stream segments in this watershed that meet full use support. Illinois EPA took the approach to use the load reduction target analysis from Middle Sangamon Watershed, since these two watersheds are nearly identical in their land use, agricultural practices, topography, and soil geology. Given this similarity and proximity, the load reduction targets for streams in the Middle Sangamon watershed are assigned to streams in the Lake Springfield and Sugar Creek watershed. These targets are as follows:

Total Phosphorus: 0.739 milligrams/liter

Total Suspended Solids: 26.9 milligrams/liter

Rend Lake Watershed Load Reduction Targets

USGS HUC-10 Basins Addressed: 0714010601, 0714010602, and 0714010603.

The following stream segments are in full use support in the Rend Lake watershed:

- Rayse Creek NK-01
- Rayse Creek NK-02

The averages of data for each fully supporting stream are as follows:

Stream Name	Total Phosphorus	Total Suspended Solids
Rayse Creek NK-01	0.207 mg/l	53.4mg/l
Rayse Creek NK-02	0.112 mg/l	17.1 mg/l
Raw Average	0.159 mg/l	35.2 mg/l

Based on an average of validated, real-world data for these streams over a period from 1999 to 2013, the load reduction targets for all streams in this watershed are as follows:

Total Phosphorus: 0.159 milligrams/liter

Total Suspended Solids: 35.2 milligrams/liter

In addition to the streams, Rend Lake (RNB) supports aquatic life, while not being Full Use Support.

The load reduction target for Rend Lake is as follows:

Total Suspended Solids: 13 milligrams/liter {analysis of 1999 – 2013 data}

Upper Big Muddy Load Reduction Targets

USGS HUC-10 Basins Addressed: 0714010604, 0714010605, and 0715010607.

The following stream segments are full use support in the Upper Big Muddy watershed:

- Ewing Creek NHB-01
- Middle Fork, Upper Big Muddy River NH-26

The averages of data for each fully supporting stream segment are as follows:

Stream Name	Total Phosphorus	Total Suspended Solids
Ewing Creek NHB-01	0.04 mg/l	8.5 mg/l
Mid. Fk. Upper Big Muddy R. NH-26	0.395 mg/l	56 mg/l
Raw Average	0.217 mg/l	32.2 mg/l

Based on an average of validated, real-world data for these streams over a period from 1999 to 2013, the load reduction targets for all streams in this watershed are as follows:

Total Phosphorus: 0.217 milligrams/liter

Total Suspended Solids: 32.2 milligrams/liter

The following lakes in this watershed support aquatic life, while not being Full Use Support:

- West Frankfort Old Lake (RNP)
- West Frankfort New Lake (RNQ)
- Johnston City Reservoir (RNZE)

For all lakes in the watershed, the load reduction targets are as follows:

Total Suspended Solids: 23 milligrams/liter {analysis of 1999 – 2013 data}

Horseshoe Lake in Alexander County Watershed Load Reduction Targets

USGS HUC-10 Basin Addressed: 0714010803

In this watershed, the Cache River through segment IX-08 is full use support. A review of the available validated data from 1999 through 2013 shows the following concentrations:

- **Total Phosphorus**: 0.141 milligrams/liter
- **Total Suspended Solids**: 58.4 milligrams/liter

These concentrations should then be the load reduction targets for all streams in this watershed.

In addition to the streams, Horseshoe Lake (RIA) supports aquatic life, while not being Full Use Support.

For Horseshoe Lake and all other lakes in this watershed, the load reduction targets are:

- **Total Suspended Solids**: 31 milligrams/liter {analysis of 1999 – 2013 data}

Attachment 7: Public Notice

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NOTICE OF PUBLIC MEETING

Upper Big Muddy River Watershed

(Franklin, Hamilton, Jackson,

and Williamson Counties)

Illinois Environmental Protection Agency Bureau of Water will hold a public meeting on

Thursday, November 15, 2018 (3:30 pm)

at the

West Frankfort Public Library
402 East Poplar
West Frankfort, IL

The purpose of this meeting is to provide an opportunity for the public to receive information and comment on the draft Total Maximum Daily Load (TMDL) concerning impairments to 16 (sixteen) waterbody segments within the Upper Big Muddy River Watershed -- Big Muddy River (IL_N-06, IL_N-11, IL_N-17), Hurricane Creek (IL_NF-01), Prairie Creek (IL_NZM-01), Andy Creek (IL_NZN-13), Herrin Old (IL_RNZD), Pond Creek (IL_NG-02), Lake Creek (IL_NGA-02), Beaver Creek (IL_NGAZ-JC-D1), Johnson City (IL_RNZE), Arrowhead (IL_RNZX), Middle Fork Big Muddy River (IL_NH-06, IL_NH-07)) West Frankfort Old (IL_RNP), and West Frankfort New (IL_RNQ).

The potential causes of impairment for these segments are Dissolved Oxygen (DO), Fecal Coliform, Chloride, Phosphorus, Manganese, Iron, and Sulfates. In addition, a Load Reduction Strategy (LRS) has been developed for Sedimentation/Siltation, and Total Suspended Solids (TSS).

This Draft TMDL report includes watershed characterization, data analysis, and pollutant loading capacity analysis that have been used to determine the reductions necessary to meet designated uses and water quality standards. Also included is an implementation plan designed to meet the reductions needed.

Illinois EPA implements the TMDL program in accordance with Section 303(d) of the federal Clean Water Act. A TMDL is the sum of the allowable amounts of a single pollutant (such as phosphorus, metals, etc.) that a waterbody can receive from all contributing sources and still meet water quality standards or designated uses.

Stakeholders and participants will also be asked for input on potential nonpoint source Best Management practices and projects that could be included as part of the implementation plan in the final draft Stage 3 report.

The draft Stage 3 report for Upper Big Muddy River Watershed TMDL is available on-line at www.epa.state.il.us/public-notices. A hard copy of the draft report is available for viewing at West Frankfort Public Library, Herrin City Hall, Christopher City Hall or Ewing Village Hall during business hours.

Questions about the draft TMDL report should be directed to the project manager, Margaret Fertaly by phone at 618-993-7200 or email **Margaret.Fertaly@illinois.gov,** or contact Abel Haile by phone at 217-782-3362 or email (see contact information below).

Closure of the Meeting Record

The meeting record will close as of midnight, December 15, 2018. Written comments need not be notarized but must be postmarked before midnight and mailed to:

Abel Haile, Manager, Planning (TMDL) Unit
Watershed Management Section, Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
P. 0. Box 19276
Springfield, IL 62794-9276
Phone 217-782-3362

TDD (Hearing impaired) 217-782-9143
E-mail: Abel.Haile@illinois.gov
Fax: 217-785-1225

Attachment 8: Public Comments

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From: Michael D Covell <emike@siu.edu>
Sent: Saturday, December 15, 2018 10:03 AM
To: Haile, Abel
Subject: [External]

NO COAL MINE DISCHARGES INTO THE BIG MUDDY RIVER! We must stop corporate destruction of the planet! All pollution of the planet must cease or our little blue dot in the vast universe will look like our neighbor Mars.

From: paula whowantstoknow <erpavo@gmail.com>
Sent: Saturday, December 15, 2018 7:29 PM
To: Haile, Abel
Subject: [External] Big Muddy River Dumping

Dear Sir,

As a resident of Carbondale, living close to the Big Muddy, I am dismayed to hear of the plans to dump toxic coal byproducts into the river.

Who deliberately poisons water? That seems insane. Only terrorists and the insanely greedy would do such a thing.

The government of Illinois is supposed to protect the residents from the insane and the greedy.

Please do not grant permission for deliberate destruction of our water.

Sincerely
Paula Bradshaw
1801 New Era Road
Carbondale, Il.
62901

From: Cade Bursell <cadebursell@gmail.com>
Sent: Saturday, December 15, 2018 3:48 PM
To: Haile, Abel
Subject: [External] Upper Big Muddy Watershed TMDL Public Comment
Attachments: EPA Pond Creek Mine - Big Muddy River..pdf

To: Illinois EPA
Email: Abel.Haile@illinois.gov
RE: Upper Big Muddy Watershed TMDL Public Comment
Pond Creek Mine Proposal, Williamson Energy LLC to Discharge into Big Muddy River

Dear Illinois EPA,

Do not allow Pond Creek Mine to construct a pipeline and diffuser for its toxic water to drain into the Big Muddy River. The Big Muddy River is an essential waterway for those of us who live nearby and care about preserving clean water and the environment for future generations.

My dogs and I love to hike to Lewis Creek. This beautiful creek runs through the bottoms of the 35 acres my family is privileged to live on. It also curves through Shawnee National Forest. Deer, coyotes, possums, squirrels, all sort of birds along with many other critters live out here. We are home to numerous native species of plants, and the forest here includes some beautiful older oaks and maple trees. Lewis Creek feeds into the Big Muddy River. If more water is added to the flow of the river more than likely an increase in flooding will occur and this contaminated water will backflow into the creeks.

The Big Muddy River is connected to many waterways that meander through both private and public land before merging with the Mississippi River. The Big Muddy River is home to approximately 71 native fish species.1 Recreational users can often be seen enjoying the river. That said, the Big Muddy River is also challenged by contaminants from industrial and agricultural sources. Currently, the Illinois Department of Public Health has a mercury advisory for Common Carp, Crappie and Large Mouth Bass. There also is a PCB advisory for Common Carp near Rend Lake. Because of contaminants, the river is listed as impaired on the 2018 EPA 303(d) list. The Big Muddy River is also prone to flooding. This plan proposes to add an average of 2.7 million gallons to 3.5 million of gallons of high chloride and sulfate wastewater per day to the river resulting in approximately 1/3 more water than its current flow rate, making flooding all the more likely, flooding that may back up into many connecting waterways. Further, there are no references in the application to research into alternatives for wastewater disposal aside from this plan.

According to the application, discharges from the mine would include very high chloride and sulfate levels. Chloride and sulfate alone are detrimental to fish reproduction and the survival to other aquatic species. It is unclear what heavy metals or other possible contaminants such as arsenic or radioactive materials and what the cumulative effect of additional pollutants will be. The application is also unclear about whether there is a chance of this water mixing with acid mine drainage.

Acid mine drainage, as defined by your organization, is *the formation and movement of highly acidic water rich in heavy metals. This acidic water forms through the chemical reaction of surface water (rainwater, snowmelt, pond water) and shallow subsurface water with rocks that contain sulfur-bearing minerals, resulting in sulfuric acid. Heavy metals can be leached from rocks that come in contact with the acid, a process that may be substantially enhanced by bacterial action. The resulting fluids may be highly toxic and, when mixed with groundwater, surface water, and soil, may have harmful effects on humans, animals and plants.2.*

Foresight Energy, the parent company of Williamson and Pond Creek Mines, showed earnings in the first quarter of 2018 of a total revenue of $270 million yet the budget for reclamation of the damage they will do given the pipeline, diffuser, and contamination of waterways is a mere $21,000. This is laughable when thinking about the cumulative costs to the ecosystem. This company has a terrible record and should not be trusted. In 2014, state regulators at the Illinois EPA issued a violation notice for polluting groundwater with salt and heavy metals related to a failed slurry impoundment at one of its mines in Macoupin county. This company dodged their responsibility by conducting a site remediation study that lasted 12 years.

The 1977 Surface Mining Control and Reclamation Act says that mining companies should not cause "material damage to the environment to the extent that it is technologically and economically feasible." The Stream Protection Rule was created to clarify vague and problematic components of SMCRA. The Trump administration supported by our local representative, Mike Bost rescinded the law, so here we are. This law however problematic and vague should be used to mitigate the damage caused by Foresight Energy. Southern Illinois should stop being the dumping grounds for corporations and the IDNR should, as its mission statement claims "manage, conserve and protect Illinois' natural, recreational and cultural resources, further the public's understanding and appreciation of those resources, and promote the education, science and public safety of Illinois' natural resources for present and future generations."

Foresight Energy is responsible for finding a way of disposing its own wastewater from Pond Creek Mine without dumping its contaminated water into the Big Muddy River, which would undoubtedly cause material harm to the environment. If the on-site impoundments continue to fail and contaminate groundwater, if the mine tunnels continues to flood and put workers in harm's way, if the operations continue to destroy the environment, including small rural townships whose representatives, seem to be silent in the face of such corporate power, if it can't manage its own waste than it should be shut down.

The rivers are public commons. They are waters of the state and should not be used for private gain. The profiteers from the mine will poison our rivers, spend $21,500 on land reclamation, and make millions of dollars in profits. Will the Environmental Protection Agency allow this? What's wrong with this picture? Please protect our waterways!

1. Fishes of the Big Muddy River Drainage With Emphasis on Historical Changes Brooks M. Burr Department of Zoology Southern Illinois University Carbondale, Illinois 62901 and Melvin L. Warren, Jr. U.S. Forest Service Southern Forest Experiment Station Forest Hydrology Laboratory Oxford, Mississippi 38655

2. https://www.epa.gov/nps/abandoned-mine-drainage

Cade Bursell
301 Rubyfruit Lane
Murphysboro, Il 62966
618-521-3804

To: Illinois EPA
Email: Abel.Haile@illinois.gov
RE: Upper Big Muddy Watershed TMDL Public Comment
Pond Creek Mine Proposal, Williamson Energy LLC to Discharge into Big Muddy River

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2. https://www.epa.gov/nps/abandoned-mine-drainage

Cade Bursell
301 Rubyfruit Lane
Murphysboro, Il 62966
618-521-3804

From: Shannon Griffin <shannongriffin1980@gmail.com>
Sent: Saturday, December 15, 2018 9:42 AM
To: Haile, Abel
Subject: [External] Upper Big Muddy Watershed TMDL Public Comment

To the Illinois EPA:

I am very concerned that pollutant loading from coal mine discharges is not being fully considered for the current TMDL review of the

Upper Big Muddy River. Numerous currently operating coal mines are discharging contaminated water into tributaries or directly to the Big

Muddy and there are plans for 2.5 to 3.7 million gallons of very high chloride and sulfate water daily from the Pond Creek Coal Mine to be

added to the River via a mixing zone 14 miles south of Rend Lake. These types of mine discharges to the Big Muddy must be stopped.

At one time the river was stated to the the following importance for fishing:: "A total of 106 fish species, representing 25 families, have been

recorded from the Big Muddy River drainage from 1892 to 1992… Of these, 97 species are considered native, and 9 occur in the drainage as a result

of introductions of exotics or transplantations… Just over half (51.9%) of the total (187 species) native fish fauna known from Illinois (Burr 1991) occur

in the Big Muddy River drainage." [Source: Burr, Brooks M. and Warren, Melvin L., Jr. 'Fishes of the Big Muddy River Drainage With Emphasis on

Historical Changes.' Biological Report 19].The Big Muddy River is also listed as having varieties of mussels and information on any mussel beds

and their future needs to be included in consideration of the current TMDL review. I am concerned that pollution levels will continue

increasing from coal mine discharges and this defeats the entire purpose of your TMDL process. Coal mines must treat polluted water before discharge

as a cost of doing business and not rely on public waters of Illinois as their corporate dumping area. I ask IEPA to be sure to include concerns

for increased coal mine discharges to the Upper Big Muddy River in your TMDL review. The known ecosystem damages from high chloride and sulfate waters should be an essential part of your TMDL review and these are in great part from coal mine discharges.

Sincerely,

Shannon L Griffin

341 San Francisco Road

Carbondale IL 62901

shannongriffin1980@gmail.com

From: Rich Whitney <richwhitney@frontier.com>
Sent: Saturday, December 15, 2018 7:51 PM
To: Haile, Abel
Subject: [External] Upper Big Muddy River Watershed TMDL Public Comment

To the Illinois EPA:

I am very concerned that pollutant loading from coal mine discharges is not being fully considered for the current TMDL review of the Upper Big Muddy River. Numerous currently operating coal mines are discharging contaminated water into tributaries or directly into the Big Muddy and there are plans for 2.5 to 3.7 million gallons of very high chloride and sulfate water daily from the Pond Creek Coal Mine to be added to the River via a mixing zone 14 miles south of Rend Lake. These types of mine discharges to the Big Muddy must be stopped. At one time the river was stated to the following importance for fishing: “A total of 106 fish species, representing 25 families, have been recorded from the Big Muddy River drainage from 1892 to 1992… Of these, 97 species are considered native, and 9 occur in the drainage as a result of introductions of exotics or transplantations… Just over half (51.9%) of the total (187 species) native fish fauna known from Illinois (Burr 1991) occur in the Big Muddy River drainage.” [Source: Burr, Brooks M. and Warren, Melvin L., Jr. ‘Fishes of the Big Muddy River Drainage With Emphasis on Historical Changes.’ Biological Report 19].The Big Muddy River is also listed as having varieties of mussels and information on any mussel beds and their future needs to be included in consideration of the current TMDL review. I am concerned that pollution levels will continue increasing from coal mine discharges and this defeats the entire purpose of your TMDL process. Coal mines must treat polluted water before discharge as a cost of doing business and not rely on public waters of Illinois as their corporate dumping area.

I ask IEPA to be sure to include concerns for increased coal mine discharges to the Upper Big Muddy River in your TMDL review. The known ecosystem damages from high chloride and sulfate waters should be an essential part of your TMDL review and these are in great part from coal mine discharges. I live only about a mile from where the Big Muddy flows near Airport Road just north of Carbondale, and I also enjoy hiking in and around Little Grand Canyon. I am extremely concerned by the impacts on fish, fowl and other wildlife caused by an increased pollution load and am strongly opposed to permitting any increase in discharges into the Big Muddy.

Thank you for your attention to this matter.

Sincerely,
Rich Whitney

1801 New Era Road
Carbondale, IL 62901
richwhitney@frontier.com

From: Cameron Smith <cjs@artapult.com>
Sent: Saturday, December 15, 2018 9:35 AM
To: Haile, Abel
Subject: [External] Upper Big Muddy River Watershed TMDL Public Comment

Abel Hale
TMDL Unit, IEPA Bureau of Water

To the Illinois EPA:

On May 3, 2011 the Big Muddy River reached a record high of 40.47 feet at the Murphysboro, IL gauge station on the Route 127 bridge. At that time the 127 bridge was closed and under water. The river water was so high you could no longer see the guard rails on either the side of the bridge. The Route 13 bridge was being threatened too, but remained open and was closely monitored by IDOT. During that flood the water was so high and strong that the water was vibrating the bridge, so it was decided by IDOT to rebuild and raise the bridge on Route 13. I have to wonder what that cost the state of Illinois.

Meanwhile when this flood was happening I was busy sandbagging around, and pumping out the water in the basement of, The Historic Douglass School of Murphysboro. I believe I was on the sixth day of running three sump pumps in two basements on May 3. At the crest of the river I calculated that the water would have been 20 inches deep in the basements without the pumps. If the river had risen to the projected height of 42 feet above flood level, as predicted, the water would have flowed over the basement door. As the water receded I was able to calculate that the old sewer lines through which the river water was coming into the building, are at 38.5 feet above flood level. Later on I was able to plug up the old lines so the next time the water reached 38.56 feet on May 6, 2017 I had no problems. The Fredrick Douglass School was first built in 1897, way before the building of the Rend Lake Dam; it was Murphysboro's segregated school and they built it next to the Big Muddy River. So it is not a matter of **if** it will flood, it is **when** it will flood.

Now the IDNR is considering letting the Pond Creek Mine pump 2.5 million gallons of additional water into the Big Muddy River per day, everyday though a 12" pipe traveling 14 miles. This pipe will cross over private and public lands, including tunneling under I-57. Because it is a pipeline, does that mean it will be granted eminent domain, or will the mine owner purchase easements from land owners? Plus what about the pipe crossing over a county line, Williamson to Franklin. How does that work? If the pipeline breaks in one county does the other county have to pay for the cleanup? And pipes do break. What recourse will Jackson County farmers have when it floods again and damages their fields?

The real sneaky trick that the Pond Creek Mine wants to do is to put the diffusing pipe outlet downstream of the Big Muddy River gauge station at Plumfield. There are only three river gauge stations on the Big Muddy River: the one at Rend Lake, Plumfield and Murphysboro; which is about 2000 feet upstream from the Douglass School. By putting the outlet pipe downstream of the Plumfield gauge station, the Core of Engineers would not have a true reading of the water level and may release more water at Rend Lake, causing more flooding downstream.

I guess I could talk about all the extra salt and sulfide coming out of the mine being dumped unprocessed into the river every day, and how the toxins will affect the creatures that live in the water and the animals that drink from it. I have to wonder what will happen to my property when it floods again with the extra salt and sulfides and dead wildlife washing in. The Big Muddy River **will** flood again without the extra 2.5 million gallons of water from the

Pond Creek Mine on my property. If IDNR allows a multibillion dollar private business to take advantage of other private businesses, that is unconscionable.

The Douglass School Art Place (The Doug) is an old school turned into artist studio spaces, where I own and operate a hot glass studio with my wife and business partner. The Douglass School is our livelihood, it is our investment. It is a strange feeling when you watch the water rise around you on a nice sunny day and there is nothing you can do about it. I guess if IDNR decided to go through with this permit, I could always build a levee around the Doug. I wonder if I can get the Pond Creek Mine to pay for it.

Sincerely,

Cameron J. Smith
900 Douglass St.
Murphysboro, IL 62966
cjs@artapult.com

From: Jon Womack <womackdaddy55@gmail.com>
Sent: Saturday, December 15, 2018 9:35 AM
To: Haile, Abel
Subject: [External] Upper Big Muddy River Watershed TMDL Public Comment

To the Illinois EPA:

I am very concerned that pollutant loading from coal mine discharges is not being fully considered for the current TMDL review of the Upper Big Muddy River. Numerous currently operating coal mines are discharging contaminated water into tributaries or directly to the Big
Muddy and there are plans for 2.5 to 3.7 million gallons of very high chloride and sulfate water daily from the Pond Creek Coal Mine to be added to the River via a mixing zone 14 miles south of Rend Lake. These types of mine discharges to the Big Muddy must be stopped.
At one time the river was stated to the following importance for fishing:: "A total of 106 fish species, representing 25 families, have been recorded from the Big Muddy River drainage from 1892 to 1992… Of these, 97 species are considered native, and 9 occur in the drainage as a result of introductions of exotics or transplantations… Just over half (51.9%) of the total (187 species) native fish fauna known from Illinois (Burr 1991) occur in the Big Muddy River drainage." [Source: Burr, Brooks M. and Warren, Melvin L., Jr. 'Fishes of the Big Muddy River Drainage With Emphasis on
Historical Changes.' Biological Report 19].

The Big Muddy River is also listed as having varieties of mussels and information on any mussel beds
and their future needs to be included in consideration of the current TMDL review. I am concerned that pollution levels will continue increasing from coal mine discharges and this defeats the entire purpose of your TMDL process. Coal mines must treat polluted water before discharge as a cost of doing business and not rely on public waters of Illinois as their corporate dumping area. I ask IEPA to be sure to include concerns
for increased coal mine discharges to the Upper Big Muddy River in your TMDL review. The known ecosystem damages from high chloride and sulfate waters should be an essential part of your TMDL review and these are in great part from coal mine discharges.

We live in the Shawnee National Forest and enjoy the Big Muddy and its many creeks that drain into it. We cannot give away our beautiful natural resources and damage our environment in the process. So much damage can be done in a few years by this plan that took millions of years of evolutionary change to give us this natural treasure we should be fighting to protect. Please do not allow coal mine discharge.

Sincerely,

Jon Wesley Womack
2010 Hickory Ridge Road
Pomona, IL 62975
dulce55@yahoo.com

From: Jan thomas <jan@artapult.com>
Sent: Saturday, December 15, 2018 10:07 AM
To: Haile, Abel
Subject: [External] Upper Big Muddy River Watershed TMDL Public Comment
Attachments: Pond Creek Mine letter - 1 November 2018.docx

To the UEPA

I am concerned that pollution levels in the Big Muddy River will continue increasing from coal mine discharges and this defeats the entire purpose of your TMDL process. Coal mines must treat polluted water before discharge as a cost of doing business and not rely on public waters of Illinois as their corporate dumping area. I ask IEPA to be sure to include concerns for increased coal mine discharges to the Upper Big Muddy River in your TMDL review. The known ecosystem damages from high chloride and sulfate waters should be an essential part of your TMDL review and these are in great part from coal mine discharges.

I am attaching a copy of the letter I wrote on November 2, 2018 to the IDNR specifically requesting that they deny the Pond Creek Mine application to pollute the Big Muddy.

The citizens of Illinois look to you to protect our rapidly diminishing environment from corporate polluters. Please do your jobs and protect the resources we have left from further pollution. The day is rapidly approaching when this will be crucial to our survival.

Thank you very much for listening and taking good action.

Sincerely,
Jan Thomas
Douglass School Art Place
Murphysboro, IL 62966

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2 November 2018

Mr. Nick San Diego
IDNR, Land Reclamation Division
One Natural Resources Way
Springfield, IL 62701-1271

Re: Permit Application #456, Pond Creek Mine

Dear Mr. San Diego,

My thanks to the IDNR for promptly posting the minutes of the Hearing held on October 23, 2018 in Benton IL on the above application. I attended that Hearing, but I missed quite a bit of the comments due to poor acoustics. Being able to read them is very useful, and I am quite impressed by the range and quality of the comments. The citizens of Illinois are well informed, and on very short notice, too. As we need to be in order to protect ourselves from abuses of the system by entities like Foresight Energy. I earnestly implore you to reject this application.

Citizens spoke at the Hearing of problems like the lack of any environmental impact study by Foresight of the affects their toxic waste will have all along the length of the Big Buddy River. The fact that we know the concentrations of chlorides and sulfides will be above EPA recommended concentrations by factors of four or five, and that these high concentrations have been condemned by the EPA for longer than a few days, while Foresight plans to dump that much daily and for the indefinite future into the Big Muddy River, a Water of the State. The fact that these chemicals are toxic to fish, amphibians, crustaceans, mussels, reptiles, livestock and probably humans in such high concentrations. The fact that the Big Muddy floods frequently and will carry its toxic burden onto farmlands, public and private property and heritage sites such as LaRue Pine Hills. The fact that the Big Muddy is already overloaded with toxic chemicals from former mines which have never been cleaned up; it is already listed as impaired on the 2018 IEPA 303(d) list.

Foresight Energy is a highly lucrative company which sells Illinois coal both to other states and abroad. The profits do not remain in Illinois, but the resource is exported. They do not even pay a Severance Tax for removing this resource. The company owns three longwall coal mines, 75 miles of rail spurs and rail loading facilities, three locomotives, over 1000 railroad cars, and a 20 million ton per year barge loading terminal, serviced by three railroads, on the Ohio River. Yet this incredibly wealthy company is offering only $21,500 in potential clean-up fund if something should go wrong! At the very least, they should be required to build a treatment facility, on their own premises, to detoxify the water before it is dumped into the Big Muddy. This won't fix the hydrological problem of depleting the groundwater in Williamson County and increasing the flow of the Big Muddy by 25-30%, but it would at least be less toxic. Every city and town in the state is required to clean up its waste before dumping it into a Water of the State. Why should Foresight Energy be exempt?

No matter how good a citizen Foresight Energy is, sponsoring little league teams and funding scholarships, no matter that they employ 750 or so miners and those jobs are important, no matter even if have a good safety record, they should still have to bear all the costs of doing business themselves, not off-load it onto the people of Illinois. The potential for devastating consequences, of all kinds, for the rest of us is just too great.

The Illinois Constitution Article XI, "Environment," states: "The public policy of the state and the duty of each person is to provide and maintain a healthful environment for the benefit of this and future generations. The General Assembly shall provide by law for the implementation and enforcement of this public policy." The ILGA has provided us with the IDNR to protect our healthful environment, and our biggest asset is our water. There's a lot of talk these days about the coming horrors that climate change will bring. One thing is certain—life cannot exist without clean water. We should be doing everything we can to clean up these precious waters of the state and absolutely stop adding further pollution to them. The lives of our children and grandchildren will truly depend on that.

Please deny this Permit.

Sincerely ,
Jan Thomas

From: Karen Fiorino <claylickcreek@gmail.com>
Sent: Saturday, December 15, 2018 10:08 AM
To: Haile, Abel
Subject: [External] Upper Big Muddy River Watershed TMDL Public Comment

To the Illinois EPA:

Dear Mr. Haile:

I am very concerned that pollutant loading from coal mine discharges is not being fully considered for the current TMDL review of the Upper Big Muddy River. Numerous currently operating coal mines are discharging contaminated water into tributaries or directly to the Big Muddy and there are plans for 2.5 to 3.7 million gallons of very high chloride and sulfate water daily from the Pond Creek Coal Mine to be added to the River via a mixing zone 14 miles south of Rend Lake. These types of mine discharges to the Big Muddy must be stopped.
At one time the river was stated to the the following importance for fishing:: “A total of 106 fish species, representing 25 families, have been recorded from the Big Muddy River drainage from 1892 to 1992… Of these, 97 species are considered native, and 9 occur in the drainage as a result of introductions of exotics or transplantations… Just over half (51.9%) of the total (187 species) native fish fauna known from Illinois (Burr 1991) occur in the Big Muddy River drainage.” [Source: Burr, Brooks M. and Warren, Melvin L., Jr. ‘Fishes of the Big Muddy River Drainage With Emphasis on Historical Changes.’ Biological Report 19].The Big Muddy River is also listed as having varieties of mussels and information on any mussel beds and their future needs to be included in consideration of the current TMDL review. I am concerned that pollution levels will continue increasing from coal mine discharges and this defeats the entire purpose of your TMDL process.

Coal mines must treat polluted water before discharge as a cost of doing business and not rely on public waters of Illinois as their corporate dumping area. *These mines have the money to treat the water before discharging and I resent corporations not having to pay for their actions and in this case dumping pollutants into water, taking the easy way out. With this administration's asinine roll backs of the clean water act and the gutting of the EPA in general, one has to ask, who's greediness is profiting on the health of the people of this country along with the animal and plant life that humans coexist with.*

I ask IEPA to be sure to include concerns for increased coal mine discharges to the Upper Big Muddy River in your TMDL review. The known ecosystem damages from high chloride and sulfate waters should be an essential part of your TMDL review and these are in great part from coal mine discharges.

Sincerely,

Karen Fiorino

45 Old US WY 51
Makanda, IL 62958
claylickcreek@gmail.com

From:	Barbara Mckasson <babitaji@aol.com>
Sent:	Saturday, December 15, 2018 10:54 PM
To:	Haile, Abel
Cc:	biojean@peoplepc.com; jane.cogie@gmail.com; joblumen@yahoo.com
Subject:	[External] Upper Big Muddy River Watershed TMDL Comments
Attachments:	Big Muddy River.docx

Dear Mr. Haile,
Attached are my personal comments on the Upper Big Muddy River Watershed TMDL Draft Stage 3 Report and Implementation Plan. Please send me a return Email to confirm that you have received and retrieved my comments. Thank you for this opportunity for public comments. In addition, please give me notice if/when IEPA decides to work on a watershed plan for the Upper Big Muddy watershed.

Barbara McKasson
2 Hillcrest Drive
Carbondale, IL 62901
babitaji@aol.com

Barbara McKasson
2 Hillcrest Drive
Carbondale, IL 62901
babitaji@aol.com

Sent via Email to:
Abel.Haile@illinois.gov

Re: Comments on the Upper Big Muddy River Watershed draft Total Maximum Daily Load (TMDL) Stage 3 Report and Implementation Plan

Dear Mr. Haile:

I have canoed and kayaked on the Big Muddy River. I also have hiked along the banks of the river and spent time observing the wildlife in and around the Big Muddy River. I am urging you to give more weight to the welfare of fish, mussels, turtles and other wildlife in and around the Big Muddy River. I am also urging you to give more consideration to the enjoyment of people (such as myself) who want to continue boating on the Big Muddy River, but do not want to have to worry about coming into direct contact with the water because of toxic pollutants and do not want to have to smell or see the effects of excessive discharges from mines and pipelines. It would be a shame to see portions of the Big Muddy that have improved in water quality be degraded again if you should decide to lower the TMDL standards and level of concern for the Upper Big Muddy and its tributaries.

In addition, I am an outings leader for Shawnee Group Sierra Club, which has in the past conducted canoeing outings on the Big Muddy River. We have a number of members who canoe and kayak on local bodies of water and have within the past couple of years held canoeing and kayaking outings for Shawnee Group.

I am very concerned about the proposed changes in the draft TMDL changes for the Upper Big Muddy River Watershed and fear that changes are being proposed without sufficient information on levels of the various pollutants. For example, I am very concerned that Pond Creek should be carefully evaluated for current levels at various water volumes for chlorides and sulfates, considering that Foresight Energy is proposing to dump wastewater from Pond Creek Mine into the upper Big Muddy River – millions of gallons of polluted water per day. This would be in addition to current mine drainage from “closed” and currently operating mines that border the Upper Big Muddy River and its tributaries.

I am urging you to refrain from removing the “impaired waters” designation for TMDLs on the Upper Big Muddy until further biological and environmental assessments have been conducted on the effects of the mine drainage and discharge related to chlorides and sulfates.

I have read and do endorse the comments found in the “Illinois Sierra Club Comments on the Upper Big Muddy River Watershed TMDL Draft Stage 3 Report and Implementation Plan.”

Sincerely,
Barbara McKasson

From: Katrina Phillips <katrina.phillips@sierraclub.org>
Sent: Saturday, December 15, 2018 6:24 PM
To: Haile, Abel
Cc: Albert Ettinger; swenson.peter@epa.gov
Subject: [External] Sierra Club comments on Upper Big Muddy River Watershed
Attachments: Sierra Club Comments on Upper Big Muddy River Watershed TMDL.pdf; BigMuddy_mussels.pdf; fishes of the big muddy river system ja_burr002.pdf; HighSalinityMussels.pdf

Hello Mr. Haile,

Please accept these comments and attachments on behalf of the Illinois Sierra Club in regards to the Illinois EPA's draft Stage 3 report and implementation plan for the Upper Big Muddy River Watershed TMDL.

We look forward to seeing our comments and questions addressed.

Thank you,
Katrina

Katrina Phillips
Clean Water Advocate
Sierra Club, Illinois Chapter
312-229-4688
katrina.phillips@sierraclub.org

SIERRA CLUB
-ILLINOIS CHAPTER-
70 E. LAKE, SUITE 1500
CHICAGO, IL 60601
(312) 251-1680

December 15, 2018

Sent via email to Abel.Haile@illinois.gov

Abel Haile
Manager, Planning (TMDL) Unit
Watershed Management Section
Bureau of Water Illinois Environmental Protection Agency
1021 North Grand Avenue East
P.O. Box 19276 Springfield, IL 62794-9276

Re: Illinois Sierra Club Comments on the Upper Big Muddy River Watershed TMDL Draft Stage 3 Report and Implementation Plan

Dear Mr. Haile,

These comments are offered by the Illinois Chapter of the Sierra Club on the draft Upper Big Muddy River Watershed TMDL Report and Implementation Plan ("draft report"). Members of our organizations live and recreate along the Upper Big Muddy River and depend on clean water in the river and its tributaries as well as lakes within the watershed for activities including fishing, rowing, paddling, birdwatching and other wildlife viewing and would use these bodies of water more often were they cleaner and supporting of all uses. We appreciate all of the work that has gone into developing this TMDL and Implementation Plan and hope to work together to ensure its implementation improves water quality and environmental health in the watershed.

The impairments in the Upper Big Muddy River watershed are a threat to the health and safety of the people and wildlife that use the river, streams and lakes and the aquatic organisms that live in the water. In order to meet water quality standards and attain all designated uses of the waterways, the Illinois Environmental Protection Agency (IEPA) must work with local stakeholders to develop a stronger, more detailed and specific implementation plan in order to meet the target reductions for these parameters which are identified in the draft TMDL report.

Our Concerns for the Big Muddy River Ecosystem

We raise these concerns about the draft TMDL because of our desire to protect and restore this significant watershed within the state of Illinois. The Big Muddy River is stated to have the following historic importance for fish: "A total of 106 fish species, representing 25 families, has been recorded from the Big Muddy River drainage from 1892 to 1992… Of these, 97 species are considered native, and 9 occur in the drainage as a result of introductions of exotics or transplantations… Just over half (51.9%) of the total (187 species) native fish fauna known from Illinois (Burr 1991) occur in the Big Muddy River drainage." [Source: Burr, Brooks M. and Warren, Melvin L., Jr. 'Fishes of the Big Muddy River Drainage With Emphasis on Historical Changes.' Biological Report 19].

The Big Muddy River is also listed as having varieties of mussels. The "Freshwater Mussels of the Big Muddy River," INHS Technical Report 2012 (11) by Diane K. Shasteen, Alison L. Price and Sarah A. Bales, states on page 4 that according to historical records, 25 species are known from the Big Muddy River Basin (Tiemann et al. 2008). The results of the data collected in the 2009/2010 basin survey showed eight sites in the big Muddy River basin ranked as Moderate mussel resources. Nineteen species were recorded live and six species previously detected were not found. Impacts of water quality on this river resource and conditions for the future survival of mussel populations need to be considered.

Concerns and Recommendations on TMDL Development and Implementation

We believe there are needed improvements and additional work that must be done to ensure progress towards the goals of the TMDL. We urge the IEPA to address the questions, concerns and recommendations outlined below in a revised TMDL report or subsequent implementation plans.

Development of LRS targets

It does not appear to us that the total phosphorus LRS target of 0.217 mg/L was developed properly. Is the value the average of all bodies of water in the Upper Kaskakia watershed? Or is it only the average of streams in the Upper Kaskaskia watershed that have no aquatic life impairments? Does the stream set on which the value was developed represent streams that do not have any high levels or chlorophyll a or unnatural plant growth?

Basing the LRS target on streams in the Upper Kaskaskia watershed, a watershed that has its own issues, is not the way to set a LRS target. We note that USEPA's ecoregional criterion for streams in Ecoregion IX: Southeastern Temperate Forested Plains and Hills where this watershed is located is 0.03656 mg/L. The Upper Kaskaskia watershed is in another ecoregion: Ecoregion VI: Corn Belt and Northern Great Plains See https://www.epa.gov/nutrient-policy-data/ecoregional-criteria. We also note that Illinois' Nutrient Science Advisory Committee has just sent its recommendation for phosphorus criteria for Illinois' rivers and streams to IEPA; we do not yet know what their recommendation is but it, along with the ecoregional criterion, should be taken into consideration when developing a phosphorus target for streams in the Big Muddy River watershed. Why did IEPA not make use of the ecoregion criterion?

As with the phosphorus LRS, we have questions about how the LRS target of 32.2 mg/L TSS was developed for the Big Muddy watershed. Again, the Upper Kaskaskia watershed is not representative of the ecoregion that the Big Muddy watershed is located in. Was the target based on an average of all available data for the Upper Kaskaskia watershed or was it based only on the "several streams that are in full support of aquatic life"?

Additional Questions and Concerns Regarding TMDL Calculations:

- There is no discussion of mining operations as a possible source of chloride or manganese. An inventory of operating and closed mines located within the watershed should be conducted and factored into the TMDLs.
- It seems that all sulfate listings were delisted with no basis given for doing so. We ask that IEPA also look at levels of total dissolved solids in this watershed and apply the draft USEPA conductivity guidance in order to protect sensitive organisms. See https://www.epa.gov/wqc/draft-field-based-methods-developing-aquatic-life-criteria-specific-conductivity.
- In Chapter 2 Stage 2 sampling, it is stated that dissolved oxygen (DO) data was collected in the watershed during September and October 2015. Were these data extrapolated in the modeling to summer months when DO violations are more likely to occur? Does the QUAL2E model used take into account the differences in water temperatures over the summer and fall months?
- Section 4.2.5 Pond Cr. / IL_NG-02 – Chloride Load Duration Curve- There are several references to fecal coliform in this section. We assume they are cutting and pasting errors and are meant to refer to chlorides. While other modeling efforts described in Chapter 4 reference the point sources that discharge to the stream reach, we note that this section fails to note the presence of discharges from the Pond Creek mine. Pond Creek mine #1 has 8 outfalls to tributaries to Pond Creek. There definitely is an existing pollutant load source to this creek that should be addressed, so a chloride TMDL should have been developed. (See section below on the numerous violations of chloride and sulfate limits at this mine.)
- Only a single data point was used for manganese (p. 26). Are there plans to collect more data in the bodies of water where manganese water quality standards have been violated?

Point sources must be properly addressed to provide reasonable assurance

The draft report says that "The Illinois EPA NPDES regulatory program and the issuance of an NPDES permit provide the reasonable assurance that the WLAs in the TMDL will be achieved" (p. 72). While we agree this tool is intended and should be used to ensure the waterways are protected and the WLAs are achieved, we are concerned with a history of violations by point sources in the watershed and an apparent lack of enforcement for their permit limits, some of which may be too high to properly protect the receiving waters and allow them to be delisted in the foreseeable future.

For example, the Johnston City STP is reported to have exceeded limits for ammonia nitrogen and $CBOD_5$ in 2015 (p.20). A review of ECHO shows that this facility is continuing to have problems meeting these standards from 2016 to the present. This plant clearly needs to be upgraded and/or should face enforcement action by IEPA for its exceedances.

Thompsonville STP must be upgraded to meet 1.0 mg/L TP, at least. Could this facility convert to reuse or land application of its wastewater in order to eliminate its loading to West Frankfort New Reservoir and reduce the need for a 79% reduction from non-point sources in the watershed? ECHO shows that the facility has not been filing its monthly reports so we are unable to see what other issues there may be at this plant (p.67).

This TMDL is incredibly deficient in that it does not factor in the many operating and closed coal mines in the watershed. The only reference made to a mine in the TMDL is as a geographic reference: "Johnston City Lake / IL_RNZE is an impoundment of Lake Creek; it is just east of Freeman No. 4 Mine" (p. 34). The Implementation Plan does recognize 'mine dumps' as a present land use in the watershed but then says nothing further about them. As stated above, a thorough inventory of mines within the watershed is needed. We note in the following paragraphs the pollution issues that we have identified with just a subset of currently-operating mines and old mine sites.

Pond Creek Mine (NPDES Permit No. IL0077666) has numerous violations of sulfate and chloride in the past 12 quarters listed in their ECHO facility report (in addition to violations of suspended solids, total suspended solids and pH).[1] These violations are recent, with a 220% violation of sulfate and chloride reported for the last (and current) quarter of 2018. They should not be permitted to discharge high levels of these pollutants into an impaired waterway. IEPA must work with Williamson Energy, LLC to address these unacceptable violations and reduce pollution coming from the mine. In addition to these serious numeric violations, the facility has had three other serious violations reported in ECHO: unapproved bypass, unauthorized discharge and improper operation and maintenance. We cannot afford to have bad actors discharging to an impaired waterway that IEPA is attempting to restore and delist. Certainly, no new proposal to discharge additional pollutant loads should be approved for this mine into either Pond Creek or the Big Muddy River itself.

Sugar Camp Mine #1 (NPDES Permit No. IL0078565) has repeated violations of chloride, manganese and total suspended solids in the past twelve quarters listed in the ECHO facility report (in addition to violation of iron and pH). [2] Several violations are recent with chloride levels in quarters one and three of 2018 at 1080% and 520%. They should not be permitted to

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[1] https://echo.epa.gov/detailed-facility-report?fid=110023026884

[2] https://echo.epa.gov/detailed-facility-report?fid=110037943795

discharge high levels of these pollutants into an impaired waterway. Receiving streams include several tributaries to the Middle Fork Big Muddy River. No new proposed discharges of additional pollutant loads should be approved for this mine into tributaries of the Big Muddy River.

Other mines in the watershed are a concern for pollutant loading and the total impacts of coal mine discharges appears to be lacking in consideration for this TMDL. The Russell Minerals West Frankfort, Inc. Old Ben No. 9 site (NPDES Permit No. IL0070912) is in reclamation, however, there is an approved discharge to an unnamed tributary to Pond Creek adding more sulfate and chloride to the watershed. Numerous other mines in reclamation and old mine works in the watershed could well be placing additional pollution loading burdens on the Big Muddy River watershed.

Concerns and Recommendations Regarding the Implementation Plan

The implementation plan does not properly address chloride. It appears there are violations at low flows which may be due to resident chloride or low flow loadings. Sources of chloride such as road salt and mining should be addressed, including the coal mines referenced above. The Implementation Plan must prohibit any new loadings of chloride to the system until the cause of the exceedance is determined and fully addressed with controls providing reasonable assurance and a margin of safety in addition to that needed to accommodate the new loading.

The Implementation Plan says that "One of the most important aspects of implementing nonpoint source controls is obtaining adequate funding to implement voluntary or incentive-based programs" (p. 76). Various potential funding sources are listed that could be leveraged to implement measures to reduce pollution. How will IEPA ensure that this funding is obtained and utilized to achieve real progress towards the TMDL goals?

We agree with the recommendation that a watershed group be formed for the Upper Big Muddy River watershed, and we hope to work with IEPA and others to encourage and support local stakeholders in coming together around restoring and protecting these waterways. We urge IEPA, an agency familiar with watershed efforts around the state and the history of watershed groups forming, to do outreach and serve as a resource to parties interested in forming a watershed group.

Additional concerns regarding the Implementation Plan include:

- The Implementation Plan should establish additional monitoring to effectively evaluate progress towards attaining the TMDL targets.
- The report should reconsider the targets for phosphorus, chloride, and TSS and consider targets for total dissolved solids.

- The Implementation Plan lacks specifics and must adopt controls to meet the targets of the TMDL, rather than just listing best practices.
- Point sources discharging to this watershed must be properly addressed and must comply with protective permit limits in order to make progress on implementation, as explained above.

Additional Questions Regarding the Stage 3 Report and Implementation Plan

- In Table 1-1, how was it determined that a number of bodies of water be delisted as impaired for sulfate?
- In Table 1-1, was continuous monitoring for dissolved oxygen (DO) conducted on the bodies of water that are proposed to be listed for their DO impairment?
- Is it an error in Table 1-1 that Pond Creek is listed to be delisted for its chloride impairment? Table 1-2 says that a chloride TMDL will be developed. Given the documentation in ECHO of recent exceedances of the chloride water quality standard in discharges from the Pond Creek Mine into tributaries to Pond Creek, a TMDL should be developed for chloride for this waterway.
- Has the presence of freshwater mussels in the watershed been taken into account when developing targets for pollutants such as TDS, conductivity, chloride and sulfate? Recent studies indicate that USEPA criteria and current state standards for these pollutants are not protective of mussels, especially glochidia. See for example, Patnode KA, Elizabeth Hittle, Anderson RM, Zimmerman L, Fulton JW. 2015. Effects of high salinity wastewater discharges on unionid mussels in the Allegheny River, Pennsylvania. Journal of Fish and Wildlife Management 6(1):55-70 and references therein. This study reports that "A chloride concentration of 78 mg/L or less would be required to maintain NRS [northern riffleshell] reference survival rates and prevent added mortality of this [federally] endangered mussel.' The sensitivity of species of mussels historically and currently found in the watershed need to be taken into account in the TMDL and Implementation Plan for the Upper Big Muddy River watershed.
- Is there phosphorus in leaking septic systems that should be addressed? (p.53)
- Page 38 of the implementation plan identifies point sources as part of fecal problem. Isn't phosphorus also in such discharges?
- Is it anticipated that the TMDL will be re-done so using revised phosphorus and chloride standards?

Thank you for your consideration of our comments. We look forward to seeing our questions and concerns addressed and continuing to work together to protect Illinois waterways.

Sincerely,

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<u>Attachments</u>

Burr, Brooks M. and Warren, Melvin L., Jr. ‘Fishes of the Big Muddy River Drainage With Emphasis on Historical Changes.’ Biological Report 19

“Freshwater Mussels of the Big Muddy River,” INHS Technical Report 2012 (11)

Patnode KA, Elizabeth Hittle, Anderson RM, Zimmerman L, Fulton JW. 2015. Effects of high salinity wastewater discharges on unionid mussels in the Allegheny River, Pennsylvania. Journal of Fish and Wildlife Management 6(1):55-70

ILLINOIS NATURAL
HISTORY SURVEY
PRAIRIE RESEARCH INSTITUTE

Freshwater Mussels of the Big Muddy River

Diane K. Shasteen, Alison L. Price, Sarah A. Bales

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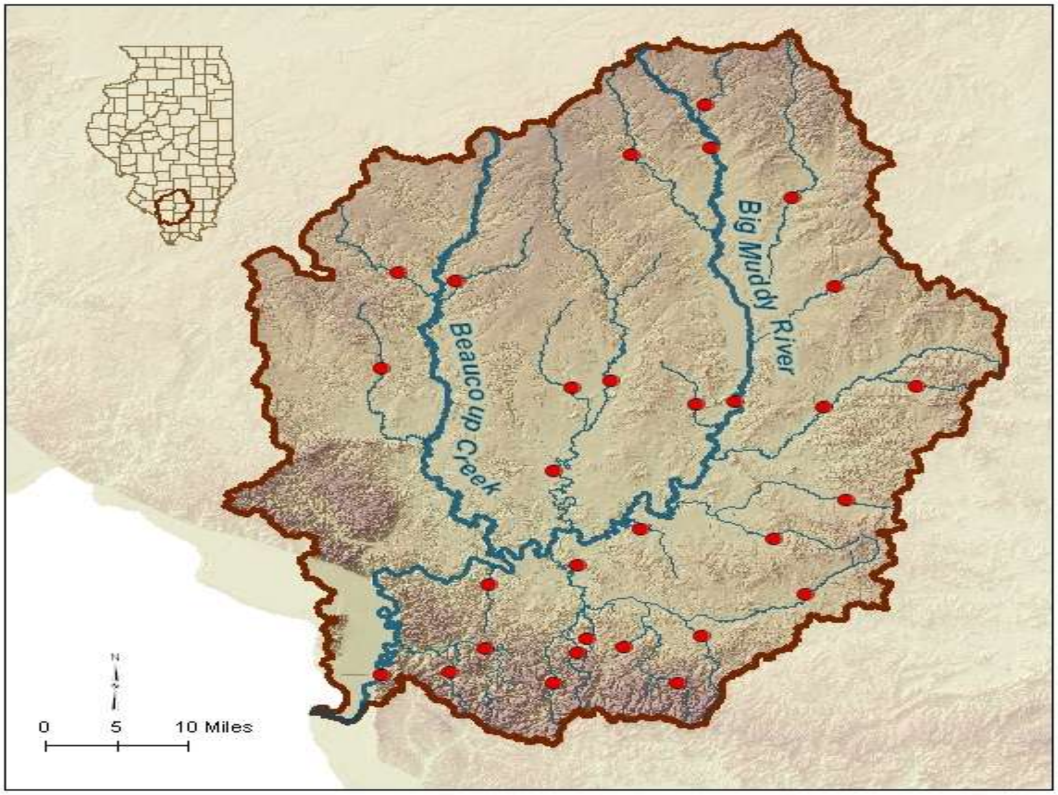
Freshwater Mussels of the Big Muddy River



2012

Illinois Natural History Survey, Prairie Research Institute, University of Illinois
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Preface

While broad geographic information is available on the distribution and abundance of mussels in Illinois, systematically collected mussel-community data sets required to integrate mussels into aquatic community assessments do not exist. In 2009, a project funded by a US Fish and Wildlife Service State Wildlife Grant was undertaken to survey and assess the freshwater mussel populations at wadeable sites from 33 stream basins in conjunction with the Illinois Department of Natural Resources (IDNR)/Illinois Environmental Protection Agency (IEPA) basin surveys. Inclusion of mussels into these basin surveys contributes to the comprehensive basin monitoring programs that include water and sediment chemistry, instream habitat, macroinvertebrate, and fish, which reflect a broad spectrum of abiotic and biotic stream resources. These mussel surveys will provide reliable and repeatable techniques for assessing the freshwater mussel community in sampled streams. These surveys also provide data for future monitoring of freshwater mussel populations on a local, regional, and watershed basis.

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Introduction

Freshwater mussel populations have been declining for decades and are among the most seriously impacted aquatic animals worldwide (Bogan 1993, Williams et al. 1993). It is estimated that nearly 70% of the approximately 300 North American mussel taxa are extinct, federally-listed as endangered or threatened, or in need of conservation status (Williams et al. 1993, Strayer et al. 2004). In Illinois, 25 of the 62 extant species (44%) are listed as threatened or endangered (Illinois Endangered Species Protection Board 2011). While broad geographic information is available on the distribution and abundance of mussels in Illinois, systematically collected mussel-community data sets required to integrate mussels into aquatic community assessments do not exist. Sampling of mussels has been very sporadic and limited in the Big Muddy River basin and no known reports pertaining to mussel communities of the basin have been published. This report summarizes the mussel survey conducted in the Big Muddy River basin in 2009-2010 in conjunction with IDNR and IEPA basin surveys.

The Big Muddy River basin drains 3798 km^2 (2360 mi^2) in the southern part of Illinois and contains principal tributaries of Casey Fork, Middle Fork Big Muddy, Beaucoup Creek, Little Muddy River, and Crab Orchard Creek (Page et al. 1992). Originating near Cravat in Jefferson County, the Big Muddy River basin drains through the counties of Jefferson, Washington, Perry, Franklin, Williamson, and Jackson. The river mainstem forms the Jackson /Union county line and joins the Mississippi River south of Grand Tower (Figure 1). The Big Muddy River basin flows through four natural divisions, including the Lower Mississippi River Bottomlands, Ozark, Shawnee Hills, and Southern Till Plain (Schwegman 1973). The Southern Till Plain comprises the majority of the basin which is characterized by hilly upland topography and a broad flood plain (Forbes and Richardson 1908).

Land-use and Instream Habitat

In the Big Muddy River basin, land use varies slightly by county with approximately 50 to 75% of the area in agriculture. Forested lands account for 8 to nearly 25% of the landscape with the larger forested areas being located in Jackson and Williamson counties (IDA 2000). Three of the largest cities in southern Illinois with populations between 15,000 and 28,000 (Marion, Mt. Vernon, and Carbondale) are also located in this basin (IEPA 1996, US Census Bureau 2010). In 1965, the Big Muddy River was dammed near Benton and thus Rend Lake, the second largest inland impoundment in the state, was created (Page et al. 1992, USACE 2005). This reservoir provides over 15 million gallons of water per day to approximately 300,000 people in over 60 communities throughout the basin. It is also used extensively for recreational activities including boating, fishing, waterfowl hunting and camping (USACE 2005). These recreational activities are also popular in the Shawnee National Forest, Giant City State Park, Lake Kinkaid and Murphysboro, Crab Orchard National Wildlife Refuge, and LaRue Pine Hills Ecological Area, which are all located within the Big Muddy River basin. In the southwestern part of this basin, especially near the Murphysboro area, strip mining for coal was prevalent during the early 20th century and pollution from the remaining spoil banks continues to be a problem in the basin (Page et al. 1992).

During glacial activity in the region, the Mississippi River exceeded its sediment transporting capacity thus closing off the mouths of its tributary streams, including the Big Muddy River. The Big Muddy River temporarily formed a lake; once the natural process of removing sediment returned to the Mississippi River a deeper channel emerged. As the Big Muddy River drained, soils typical of a lake bed were left behind (LeTellier 1971). Today, the soils of the Big Muddy basin consist of impervious clays, silt and fine sand. The substrates in all of the streams of this basin were dominated by some combination of sand, silt, and clay. Excessive siltation along with large woody debris was common at many sites within the basin (Figure 2 and 3). Most of the sites in the basin had wadeable water depths; however sampling sites were limited on the mainstem of the Big Muddy and on Beaucoup Creek due to non-wadeable water depths (e.g., depth>1m).

Methods

During the 2009/2010 surveys, freshwater mussel data were collected at 30 sites: 3 mainstem and 27 tributary sites in the Big Muddy River basin (Figure 1, Table 1). Locations of sampling sites are listed in Table 1 along with information regarding IDNR/IEPA sampling at the site. In most cases, mussel survey locations were the same as IDNR/IEPA sites.

Live mussels and shells were collected at each sample site to assess past and current freshwater mussel occurrences. Live mussels were surveyed by hand grabbing and visual detection (e.g. trails, siphons, exposed shell) when water conditions permitted. Efforts were made to cover all available habitat types present at a site including riffles, pools, slack water, and areas of differing substrates. A four-hour timed search method was implemented at each site. Live mussels were held in the stream until processing.

Following the timed search, all live mussels and shells were identified to species and recorded (Table 2). For each live individual, shell length (mm), gender, and an estimate of the number of growth rings were recorded. Shell material was classified as recent dead (periostracum present, nacre pearly, and soft tissue may be present) or relict (periostracum eroded, nacre faded, shell chalky) based on condition of the best shell found. A species was considered extant at a site if it was represented by live or recently dead shell material (Szafoni 2001). The nomenclature employed in this report (Appendix 1) follows Turgeon et al. (1998) except for recent taxonomic changes to the gender ending of lilliput (*Toxolasma parvum*), which follows Williams et al. (2008). Voucher specimens were retained and deposited in the Illinois Natural History Survey

Mollusk Collection. All non-vouchered live mussels were returned to the stream reach where they were collected.

Parameters recorded included extant and total species richness, presence of rare or listed species, and individuals collected, expressed as catch-per-unit-effort (CPUE; Table 2). A population was considered to indicate recent recruitment if individuals less than 30 mm in length or with 3 or fewer growth rings were recorded. Finally, mussel resources were classified as Unique, Highly Valued, Moderate, Limited, or Restricted (Table 2) based on the above parameters (Table 3) and following criteria outlined in Table 4 (Szafoni 2001).

Results

Species Richness

A total of 19 species of freshwater mussels were observed in the Big Muddy River basin, all of which were collected live (Table 2). Across all sites, the number of live species collected, the number of extant species collected (live + dead), and the total number of species collected (live + dead + relict) ranged from 0 to 13. The giant floater (*Pyganodon grandis*) had the most occurrences across sites sampled with live mussels present (11 of 30 sites; 37%; Figure 4). The lilliput (*Toxolasma parvum*), paper pondshell (*Utterbackia imbecillis*), pondhorn (*Uniomerus tetralasmus*) and white heelsplitter (*Lasmigona complanata*) were other commonly occurring species (Figure 4), occupying 17% of these sites. Site 6, the Big Muddy River near Benton, had the greatest species richness with 12 live species.

Abundance and Recruitment

A total of 358 individuals were collected across 30 sites. The number of live specimens collected at a given site ranged from 0 to 133, with an average of 16 mussels per site where live mussels were collected (22 of 30 sites; Table 2). A total of 120 collector-hours were spent sampling with an average of three mussels collected per hour. Nine sites yielded more than 10 live individuals and 2 of the 9 sites (sites 6 and 15) yielded more than 45 live individuals. The most common species collected in the Big Muddy basin were giant floater (*n*=131), mapleleaf (*Quadrula quadrula*; n=37), white heelsplitter (n=34), lilliput (n=24), and pink papershell (*Potamilus ohiensis;* n=20), which together comprised approximately 70% of the individuals collected.

Recruitment for each species was determined by the presence of individuals less than 30mm or with 3 or fewer growth rings. Smaller (i.e., younger) mussels are harder to locate by hand grab methods and large sample sizes can be needed to accurately assess population reproduction. However, a small sample size can provide evidence of recruitment if it includes individuals that are small or possess few growth rings. Alternatively, a sample consisting of very large (for the species) individuals with numerous growth rings suggests a senescent population.

Recruitment at individual sites ranged from none observed to high across the basin. Recruitment levels, referred to in Table 3 as Reproduction Factor, varied from one to five, and three of the sites in the Big Muddy River basin exhibited high to very high recruitment. Recruitment was over 50% at site 7, Andy Creek, and 30 to 50% at sites 1 and 9, Snow Creek and Middle Fork Big Muddy (Figure 5). Sites 2 and 29, Big Muddy River and Cedar Creek, exhibited recruitment from 1 to 30% of species collected. Recruitment may be occurring at site 30, Big Muddy mainstem, where dead shells of nearly all species collected were less than 3 years of age. All other sites in the Big Muddy River basin (24 of 30) exhibited no observed recruitment during this survey.

Mussel Community Classification

Based on the data collected in the 2009/2010 basin surveys, nearly 75% of the sites in the Big Muddy River basin have Restricted or Limited mussel communities using the current MCI classification system (Table 4, Figure 5). No sites are ranked as Unique or Highly Valued in the basin. Eight sites (sites 1, 2, 6, 7, 9, 15, 23, and 29) in the Big Muddy River basin were ranked as Moderate mussel resources.

Noteworthy Finds

According to historical records, 25 species are known from the Big Muddy River basin (Tiemann et al. 2007). All 19 species found during this survey had been recorded in the basin historically. However, three of these species had not been recorded live since 1969; these species included Wabash pigtoe (*Fusconaia flava*), pondmussel (*Ligumia subrostrata*), and deertoe (*Truncilla truncata*). Historic species not detected during this survey include creeper (*Strophitus undulatus*), spike (*Elliptio dilatata*), pimpleback (*Quadrula pustulosa*), plain pocketbook (*Lampsilis cardium*), pink heelsplitter (*Potamilus alatus*), and fawnsfoot (*Truncilla donaciformis*).

A possible range expansion may be occurring with the Louisiana fatmucket (*Lampsilis hydiana)* which occurs in the upper Arkansas, White and St. Francis rivers and in Louisiana and East Texas (NatureServe 2011). Specimens collected during this survey were classified as *Lampsilis siliquoidea* (*hydiana*) due to morphological features that resemble the Louisiana fatmucket (pers. comm. Kevin Cummings). Additional genetic testing would need to be conducted to correctly determine which species, *Lampsilis siliquoidea* or *Lampsilis hydiana*, exists in the Big Muddy basin.

Discussion

Our survey documented 19 species from the Big Muddy River basin, all were recorded live. No new species were found that had previously been undetected and six species previously detected were not found during our survey. Of these six species, only the plain pocketbook has been documented as live in the basin. This species was found at three tributaries in the late 1990's to early 2000's; however these streams were not sampled during our survey. These sites would need to be surveyed to determine if this species is still present in the basin. Of the remaining five species not collected, deertoe and creeper have been documented only by relict shell, and the pink heelsplitter, pimpleback, and spike have not been documented since the late 1800's, early 1900's. All of these species were collected from the Big Muddy mainstem. These particular species, except for spike, are widespread and common throughout most of Illinois (Cummings and Mayer 1992) and all of these species are known from other major Mississippi River tributaries including the Rock, Illinois, and Kaskaskia Rivers (INHS Mollusk Collection Database). Sampling the mainstem of the Big Muddy was hindered by non-wadeable water depths; therefore additional sampling by alternative means would need to be conducted to determine if these species have indeed been extirpated from the basin.

Recruitment

Data collected during this survey indicate that very recent recruitment may not be occurring at most (25 of 30) sites in the Big Muddy basin. Only 3 of the 30 sites exhibited high to very high recruitment and 2 other sites had moderate recruitment noted. This finding suggests that most mussel communities of the Big Muddy may not be viable and self-maintaining. Although very few mussels collected during this basin survey fell into the category of 3 age rings or younger, many of them ranged from 4 to 10 years of age. This would indicate that the populations observed in most streams are within the age range thought to be reproductively active (Haag and Staton 2003). Therefore, we cannot conclusively state that the mussel communities of this system are void of recruitment. Recruitment may also be occurring on the Big Muddy mainstem near the Mississippi as nearly all of the dead shells found at site 30 were less than 3 years of age. Sampling methods to target juvenile mussels would be necessary to better assess the reproductive status of these populations.

Mussel community of the Big Muddy River basin

There is limited mussel community information relating to this basin from past surveys and reports. Nearly 90% of the sites sampled had no historical data available (Table 2), and there is no known intensive survey for mussels in this basin. Our surveys documented the existence of 19 species in the Big Muddy River basin from which 25 species were known historically. Additionally, our surveys found that all 19 species were represented by live individuals. Five of the six species not collected during this survey are represented by either relict shell or pre-1930 collections.

Other major Mississippi tributaries such as the Kaskaskia, Rock, and Illinois Rivers have a larger mussel fauna base according to historical records and recent surveys. Historically, these basins contained 43, 47, and 49 species, respectively, while the Big Muddy has only 25 recorded species (Tiemann et al. 2007). Several theories could be offered on the disparity of species in this basin including the inability to conduct wadeable surveys, challenging diving conditions, lack of river access by vehicle, or the lack of suitable substrate composition for varying species. Substrates such as gravel, cobble, and boulder are practically nonexistent in the Big Muddy basin. As mentioned in the introduction, the substrate of the Big Muddy is predominately impervious clay, silt, and sand. The Big Muddy basin provides suitable substrates for many mussel species such as the giant floater, white heelsplitter, and other Anodontines. However, many species that occur in the other major Mississippi tributaries such as mucket (*Actinonaias ligamentina*), black sandshell (*Ligumia recta*), and threehorn wartyback (*Obliquaria reflexa*) prefer a mixture of substrate types including gravel, sand, and cobble (Cummings and Mayer 1992). Sedimentation and siltation of the streams in this basin may be another factor influencing the lack of these species. These factors are listed as impairments for aquatic life for many mainstem sites on the Big Muddy and several tributaries within the basin (IEPA 2010). With the lack of coarser substrates from the basin both today and historically, it may be safe to assume that many of these species have never existed in the basin. However, this statement cannot be made conclusively, due to a lack in historical information.

Living up to its name, sampling in the Big Muddy basin is challenging at best due to water depths (Big) and high turbidity (Muddy). The Big Muddy mainstem and many of its larger tributaries, such as Beaucoup and Drury Creeks, are not easily surveyed for freshwater mussels, thus it is difficult to accurately determine species richness of the basin. It is possible that the Big Muddy River provides a haven for the recruitment of many mussel species, based on the dead shells less than 3 years of age found at site 30, the nature of its substrates, and the river's connection with the Mississippi River. We are unable to conclusively state that the Big Muddy is serving as a source population for mussel species because of the lack of historical data and difficulty in sampling the basin. Additional sampling, either diving or boating to shallow areas on the lower portion of the mainstem and larger tributaries, would be needed to adequately determine the mussel fauna of this basin.

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Table1. 2009/2010 Big Muddy River Intensive Basin Survey. Types of samples include MU-mussel sampling, BE-boat electrofishing, ES-electric fish seine, SH-fish seine hauls, FF-fish flesh contaminate, H-habitat, M-macroinvertebrate, S-sediment, W-water chemistry. *Drury Creek Survey not completed due to water depth >3m.

Site Number	IEPA Code	Stream	Types of Samples	County	Location	Watershed Area (km^2)
1	NL-01	Snow Creek	MU, ES,H,M,S,W	Jefferson	6 mi NW Mt Vernon; Rd 1850N	49.60
2	N-05	Big Muddy River	MU, ES,H,M,S	Jefferson	1.5 mi NE Woodlawn Co Rd; 1450N	154.04
3	NK-02	Rayse Creek	MU	Jefferson	3.7 mi W Woodlawn; Rd 1400N	119.89
4	NJ-26	Casey Fork	MU	Jefferson	SE Mt Vernon; DNS Rt 142	196.87
5	NI-01	Gun Creek	MU, ES,H,M,S,W	Jefferson	3.3 mi E Ina	35.62
6	N-06	Big Muddy River	MU, BE,H,M,S,W	Franklin	Rt 14 Br; 3 mi W Benton	1287.86
7	NZN-15	Andy Creek	MU, ES,H,M,S,W	Franklin	Satch Road; 1.6 mi NE of Christopher	33.54
8	NHG-01	Akin Creek	MU, ES,H,M,S,W	Franklin	N Botail Road; 8.8 mi E of Benton	21.98
9	NH-23	Middle Fork	MU, BE,H,M,S	Franklin	2.2 mi SE Bent; Us Rt 34	329.47
10	NG-05	Pond Creek	MU, SH,H,M,S,W	Williamson	Liberty School Rd; 4.7 mi SE of West Frankfort	31.84
11	NGA-02	Lake Creek	MU, ES,H,M,S,W	Williamson	Co Rd 1200E; 0.3 mi S Johnston City	40.90
12	NF-01	Hurricane Creek	MU, ES,H,M,S,W	Williamson	4 mi WNW Herrin	60.67
13	NE-04	Little Muddy River	MU	Perry	Rt 14 Br; 2 mi E Old Duquoin	426.62
14	NEB-02	Reese Creek	MU, ES,H,M,S,W	Perry	2 mi E Duquoin on Park St	60.79
15	NE-05	Little Muddy River	MU, BE,H,M,S,W	Jackson	1.3 mi E of Elkville	684.39
16	ND-04	Crab Orchard Creek	MU, ES,H,M,S,W	Williamson	Rt 13 Br; E edge of Marion	82.52
17	NDJ-01	Wolf Creek	MU, ES,H,M,S,W	Williamson	E Rt 148; old railroad	44.74
18	NDD-03	Grassy Creek	MU, ES,H,M,S,W	Williamson	At Wolf Creek Rd	14.84
19	NDDA-01	Little Grassy	MU, ES,H,M,S,W	Williamson	6 mi SSW Carterville	47.11
20	NDC-99*	Drury Creek	ES,H,M,S,W	Jackson	0.2 mi US Makanda business dist	47.29
21	NDCB-01	Indian Creek	MU, ES,H,M,S,W	Jackson	2.5 mi NE Makanda	14.01
22	NDCA-01	Sycamore Creek	MU, ES,H,M,S,W	Jackson	2 mi E of Boskydell	5.27
23	ND-01	Crab Orchard Creek	MU, BE,H,M,S,W	Jackson	4 mi NE Carbondale	693.93
24	NCK-02	Swanwick Creek	MU, ES,H,M,S,W	Perry	Misty Road; 5.8 mi NW of Pinckneyville	117.41
25	NCI-01	Little Beaucoup Creek	MU, ES,H,M,S,W	Perry	6 mi NNE Pinckneyville	46.96
26	NCDB-01	Little Galum Creek	MU, SH,H,M,S,W	Perry	Galum Cr Rd; 0.5 mi N Pyramid St	30.47
27	NZL-01	Mud Creek	MU, ES,H,M,S,W	Jackson	West Lake Road; 2.1 mi SE of Muphysboro	25.54
28	NAC-02	Cave Creek	MU, ES,H,M,S,W	Jackson	Jerusalem Hill Road; 0.2 mi W of Ponoma	15.24
29	NA-03	Cedar Creek	MU, ES,H,M,S	Jackson	1 mi S Brewer School on Dutch Ridge	80.38
30	N-99	Big Muddy River	MU, BE,H,M,S	Jackson	5 mi E Grandtower at Rattlesnake Ferry	6064.97

Table 2. Mussel data for sites sampled during 2009/2010 surveys (Table 1). Numbers in columns are live individuals collected; "D" and "R" indicates dead or relict shells collected. Shaded boxes are historic collections at the specific site location obtained from the INHS Mollusk Collection records. Species in bold are federally or state-listed species or species in Greatest Need of Conservation by IL DNR. Proportion of total is number of individuals of a species divided by total number of individuals at all sites. Extant species is live + dead shell and total species is live + dead + relict shell. NDA represents no historical data available. MCI scores and Resource Classification are based on values in Tables 3 and 4 (R= Restricted, L= Limited, M= Moderate, HV= Highly Valued, and U= Unique). *Includes *Strophitus undulatus*, *Elliptio dilatata*, *Quadrula pustulosa*, *Lampsilis cardium*, *Potamilus alatus*, and *Truncilla donaciformis*, historical species not collected during this survey.

	Site Number																						**Proportion of Total**
	1	2	3	5	6	7	9	11	13	14	15	16	17	19	23	24	25	26	27	28	29	30	
Anodontinae																							
Anodonta suborbiculata					1		2				D												1%
Arcidens confragosus											4				D							D	1%
Lasmigona complanata					19					1	9				1						4		9%
Pyganodon grandis		12	1	R	30		23	2	2	21	19	R	D	12	D	D			1		8	D	37%
Strophitus undulatus																							0%
Utterbackia imbecillis	1	1			D		3				1										2	D	2%
Ambleminae																							
Amblema plicata		1			4				1		3												3%
Elliptio dilatata																							0%
Fusconaia flava					1																		0%
Megalonaias nervosa					16										1								5%
Quadrula pustulosa																							0%
Quadrula quadrula					26				2		6				3							▨	10%
Tritogonia verrucosa					1																		0%
Uniomerus tetralasmus	1	R				2				1							2	D	R	1			2%
Lampsilinae																							
Lampsilis cardium																							0%
Lampsilis siliquoidea (hydiana)		3														D							1%
Lampsilis teres					4						4				1						5	▨	4%
Leptodea fragilis					8				1	1	D				1							D	3%
Ligumia subrostrata	4	4	2									R		4									4%
Potamilus alatus																							0%
Potamilus ohiensis					19						1											D	6%
Toxolasma parvum	16	3	3											1							1		7%
Toxolasma texasiensis	1	5	D			4	D			D													3%
Truncilla donaciformis																						▨	0%
Truncilla truncata					4										6								3%
																							Total
Individuals	23	29	6	0	133	6	28	2	6	24	47	0	0	17	13	0	2	0	1	1	20	0	358
Live Species	5	7	3	0	12	2	3	1	4	4	8	0	0	3	6	0	1	0	1	1	5	0	19
Extant Species	5	7	4	0	13	2	4	1	4	5	10	0	1	3	8	2	1	1	1	1	5	5	19
Total Species	5	9	4	1	13	2	4	1	4	5	10	2	1	3	8	2	1	1	2	1	5	5	19
Historical Species	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	2	NDA	NDA	NDA	1	NDA	NDA	1	6	25*
Catch per unit effort (CPUE)	5.76	7.02	1.50	0.00	33.33	1.50	6.97	0.50	1.50	6.00	11.78	0.00	0.00	4.25	3.25	0.00	0.50	0.00	0.25	0.25	5.00	0.00	
Mussel Community Index (MCI)	10	10	7	0	11	10	10	4	7	7	10	0	0	6	8	0	4	0	4	4	9	0	
Resource Classification	M	M	L	R	M	M	M	R	L	L	M	R	R	L	M	R	R	R	R	R	M	R	

Table 3. Mussel Community Index (MCI) parameters and scores.

Extant species in sample	Species Richness	Catch per Unit Effort (CPUE)	Abundance (AB) Factor
0	1	0	0
1-3	2	1-10	2
4-6	3	>10-30	3
7-9	4	>30-60	4
10+	5	>60	5
% live species with recent recruitment	Reproduction Factor	# of Intolerant species	Intolerant species Factor
0	1	0	1
1-30	3	1	3
>30-50	4	2+	5
>50	5		

Table 4. Freshwater mussel resource categories based on species richness, abundance, and population structure. MCI = Mussel Community Index Score

Unique Resource MCI ≥ 16	Very high species richness (10 + species) &/or abundance (CPUE > 80); intolerant species typically present; recruitment noted for most species
Highly Valued Resource MCI = 12- 15	High species richness (7-9 species) &/or abundance (CPUE 51-80); intolerant species likely present; recruitment noted for several species
Moderate Resource MCI = 8 - 11	Moderate species richness (4-6 species) &/or abundance (CPUE 11-50) typical for stream of given location and order; intolerant species likely not present; recruitment noted for a few species
Limited Resource MCI = 5 - 7	Low species richness (1-3 species) &/or abundance (CPUE 1-10); lack of intolerant species; no evidence of recent recruitment (all individuals old or large for the species)
Restricted Resource MCI = 0 - 4	No live mussels present; only weathered dead, sub-fossil, or no shell material found

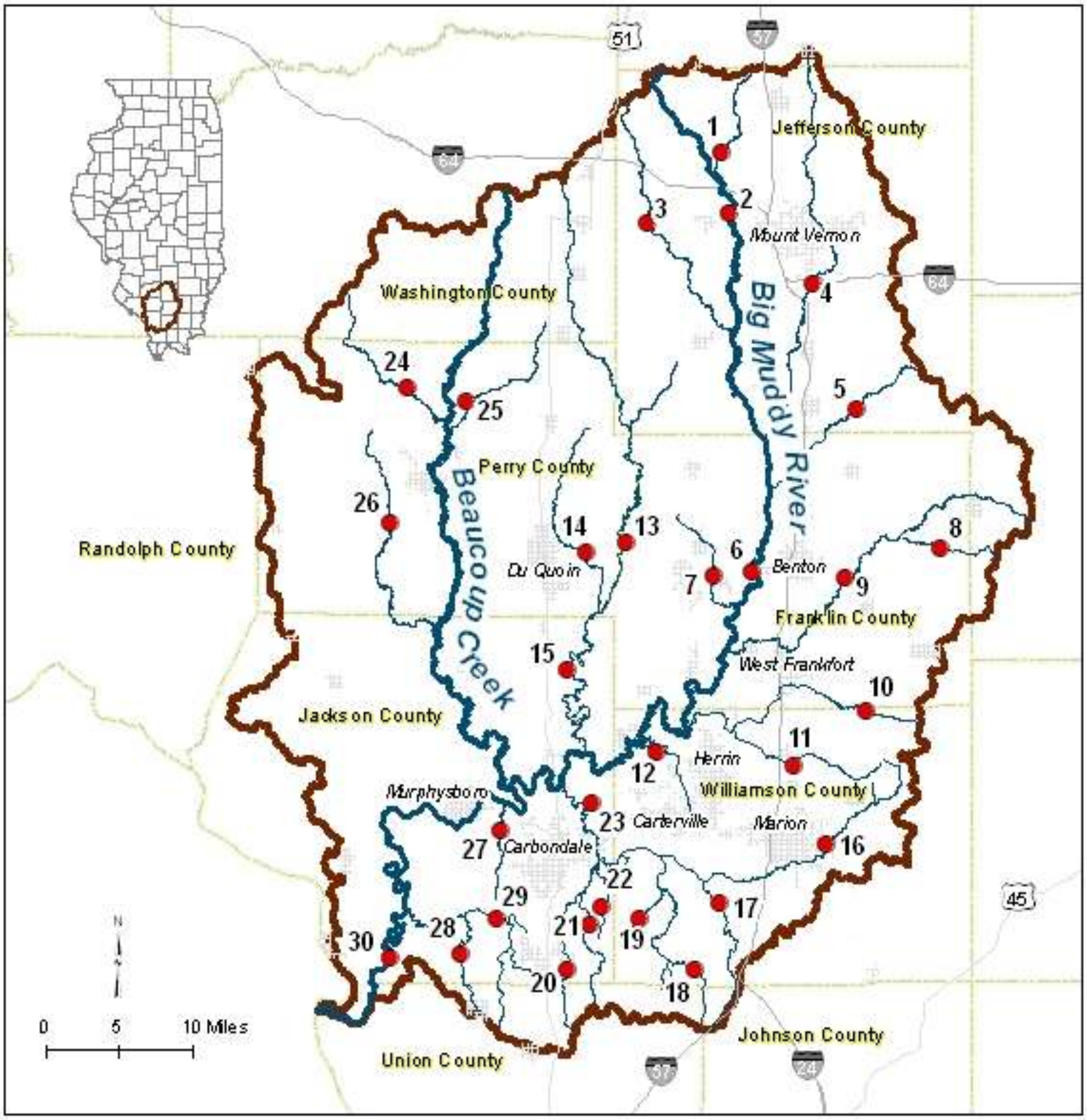

Figure 1. Sites sampled in the Upper and Lower Big Muddy River basin during 2009. Site codes referenced in Table 1.

Figure 2. Big Muddy near Benton, Illinois (Site 6). Note excessive sedimentation and turbidity of river. Alison Price and A. J. Berger measuring mussels sunk up to thighs and waist in silt.

Figure 3. Casey Fork near Mt. Vernon, Illinois (Site 4). Note large woody debris in stream, silt/clay banks, and turbidity of river.

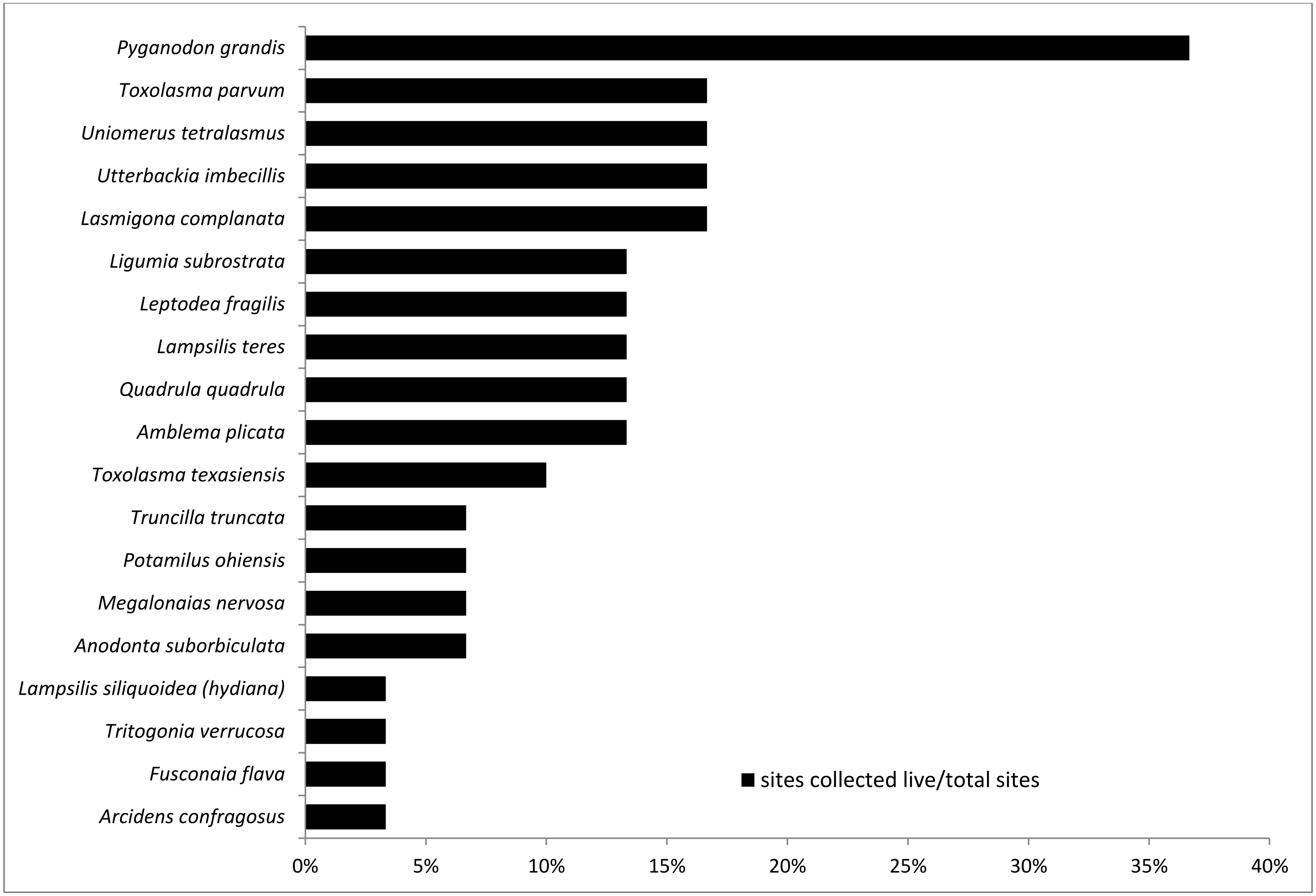

Figure 4. Number of sites where a species was collected live compared to the number of total sites sampled (30 total sites).

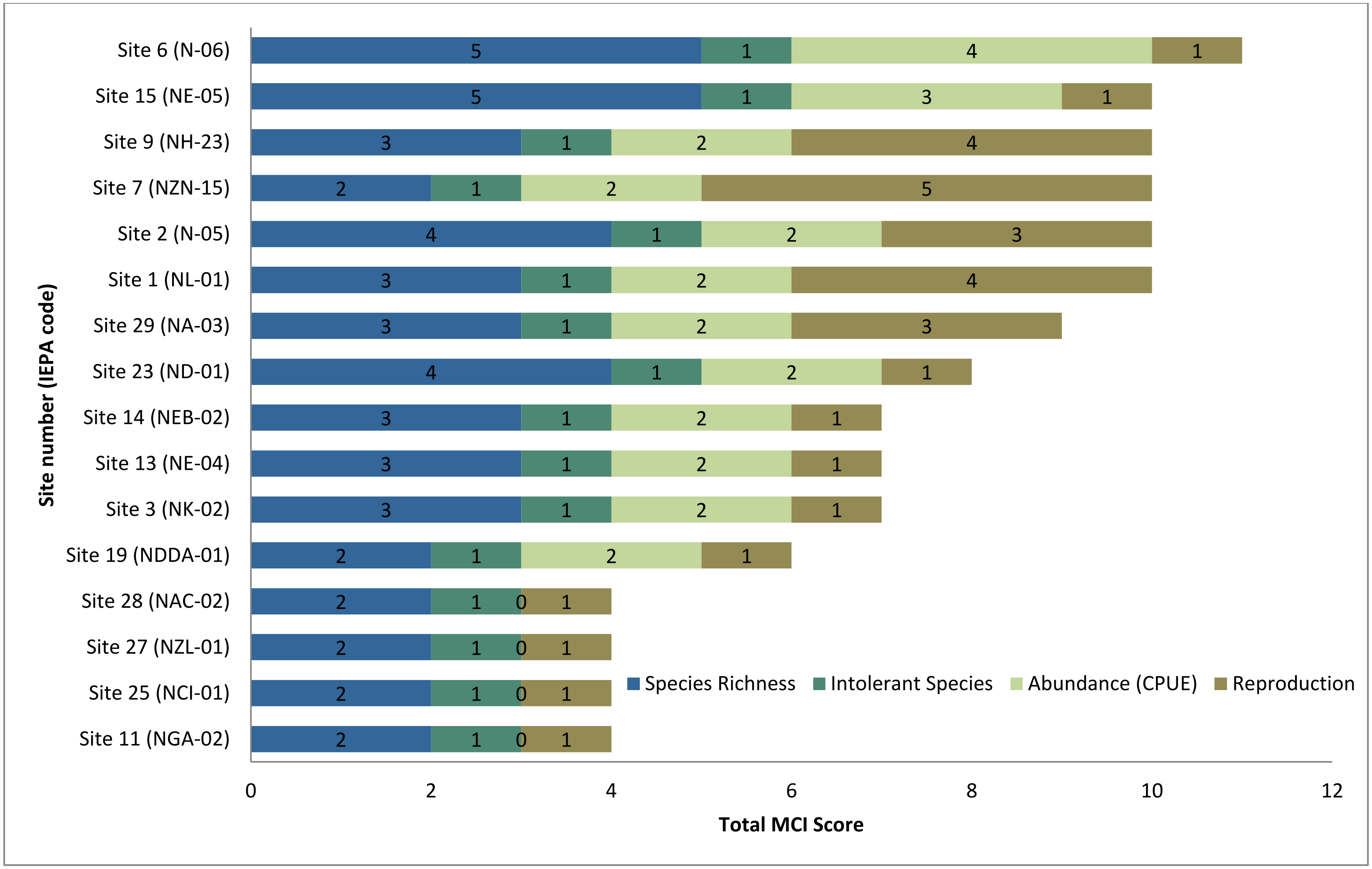

Figure 5. Comparison of Mussel Community Index (MCI) and MCI component scores for Big Muddy River basin sites based on factor values from Table 3.

Appendix 1. Scientific and common names of species. ST= state threatened.

Scientific Name	Common Name	Status
Subfamily Anodontinae		
Anodonta suborbiculata	flat floater	
Arcidens confragosus	rock pocketbook	
Lasmigona complanata	white heelsplitter	
Pyganodon grandis	giant floater	
Strophitus undulatus	creeper	
Utterbackia imbecillis	paper pondshell	
Subfamily Ambleminae		
Amblema plicata	threeridge	
Elliptio dilatata	spike	ST
Fusconaia flava	Wabash pigtoe	
Megalonaias nervosa	washboard	
Quadrula pustulosa	pimpleback	
Quadrula quadrula	mapleleaf	
Tritogonia verrucosa	pistolgrip	
Uniomerus tetralasmus	pondhorn	
Subfamily Lampsilinae		
Lampsilis cardium	plain pocketbook	
Lampsilis siliquoidea hydiana	Louisiana fatmucket	
Lampsilis teres	yellow sandshell	
Leptodea fragilis	fragile papershell	
Ligumia subrostrata	pondmussel	
Potamilus alatus	pink heelsplitter	
Potamilus ohiensis	pink papershell	
Toxolasma parvum	lilliput	
Toxolasma texasiensis	Texas lilliput	
Truncilla donaciformis	fawnsfoot	
Truncilla truncata	deertoe	

Fishes of the Big Muddy River Drainage With Emphasis on Historical Changes

by

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Abstract. The Big Muddy River, a lowland stream located in southwestern Illinois and draining an area of about 6,182 km^2, contains a moderately diverse fish fauna of 106 species. The river is properly named, as the mainstem carried historically and continues to transport great quantities of silt. Historically, a large portion of the watershed was wooded, but much of the land has been cleared and put under cultivation. This has exacerbated siltation and eliminated former wetlands adjacent to and communicating with the mainstem and tributaries. Most of the drainage suffers from excessive siltation; dessication during drought periods; and oil-field, sewage effluent, strip-mine, and other industrial pollution. The construction of Crab Orchard, Little Grassy, Devil's Kitchen, Kincaid, Cedar, and Rend lakes effectively eliminated some of the highest quality streams in the drainage. One detrimental effect of these various stresses has been the disappearance of at least 10 native fish species over the past 100 years, including some of sport or commercial value (e.g., blue sucker, burbot). Suggested solutions to these problems include (1) a community ecology approach to future management of the drainage itself and the human made lakes; (2) maintenance or re-establishment of wooded riparian corridors, as well as wetlands adjacent to the river and tributaries, as spawning and nursery sites; (3) continued vigorous reclamation of abandoned mine lands and treatment of acid mine drainage; and (4) discontinuance of stocking of nonnative fishes (e.g., grass carp, bighead carp, striped bass, inland silverside) until their impact can be assessed.

Similar to most big river drainages in the largely agricultural state of Illinois, the Big Muddy River drainage, situated in the southwestern portion of the state (Fig. 1), has been subjected to an array of environmental stresses that have permanently disrupted its hydrological cycle, and ultimately altered its fish fauna. A century ago, the first fish collections were made in the Big Muddy River (Forbes and Richardson 1908), at about the time that the bottomland forests were beginning to be cleared for cultivation. In subsequent years, much of the well-drained, tillable ground was cleared, followed by

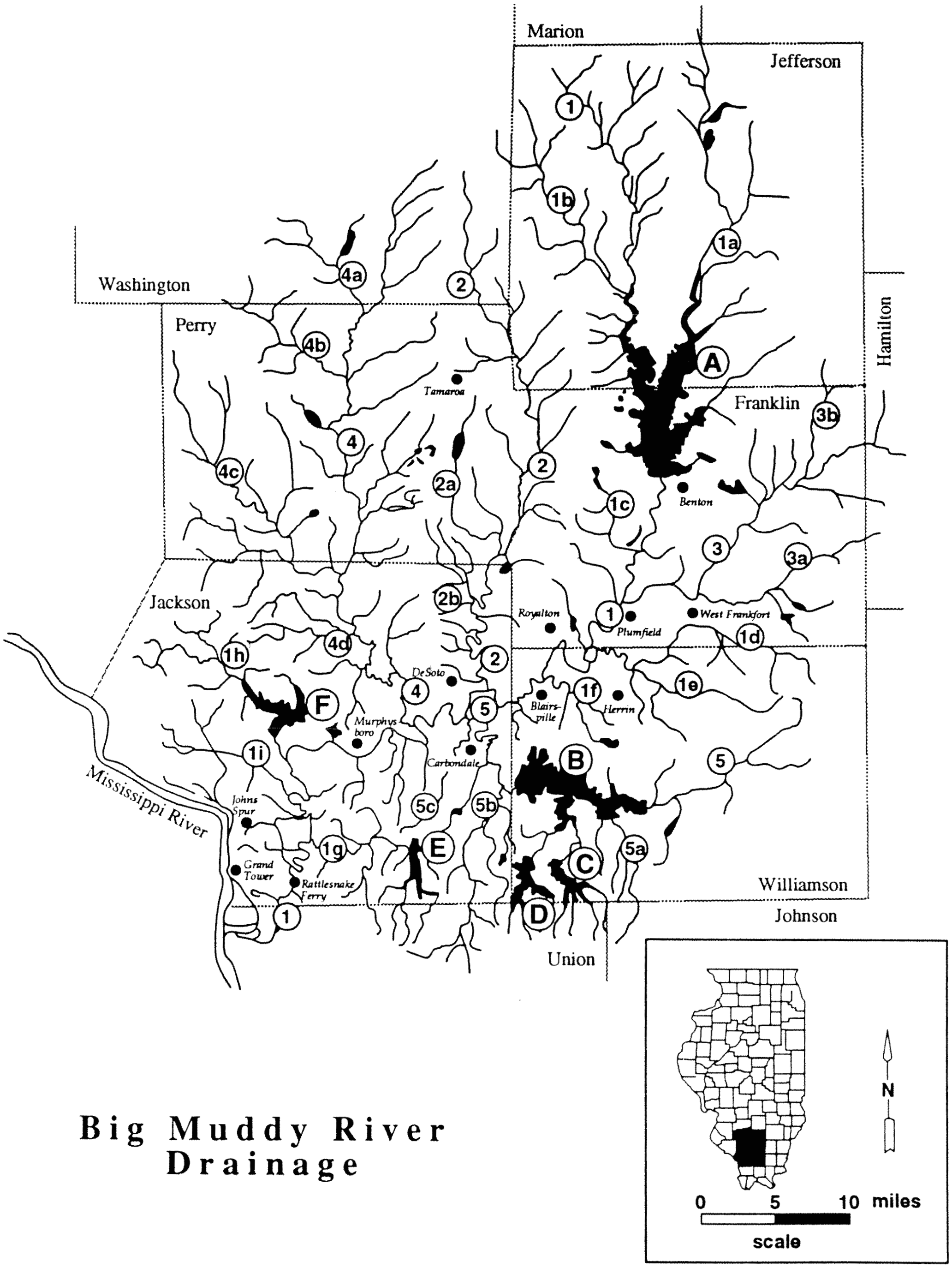

Fig. 1. Stream names, cities, counties, and reservoirs of the Big Muddy River drainage. A, Rend Lake; B, Crab Orchard Lake; C, Devil's Kitchen Lake; D, Little Grassy Lake; E, Cedar Lake; F, Kincaid Lake. 1, Big Muddy River; 1a, Casey Fork; 1b, Rayse Creek; 1c, Prairie Creek; 1d, Pond Creek; 1e, Long Creek; 1f, Hurricane Creek; 1g, Cedar Creek; 1h, Kincaid Creek; 1i, Worthen Bayou. 2, Little Muddy River; 2a, Reese C reek; 2b, Six Mile Creek. 3, Middle Fork Big Muddy River; 3a, Ewing Creek; 3b, Sugar Camp Creek. 4, Beaucoup Creek; 4a, Locust Creek; 4b, Swanwick Creek; 4c, Galum Creek; 4d, Rattlesnake Creek. 5, Crab Orchard Creek; 5a, Wolf Creek; 5b, Drury Creek; 5c, Little Crab Orchard Creek.

the draining of floodplain wetlands and clearing of riparian areas. Early in the 20th century, large-scale extraction of bituminous coal badly polluted tributaries of the upper and middle reaches of the river with silt and acid runoff; these problems plague the drainage to this day. More recently, construction of impoundments destroyed miles of stream habitat, altered natural discharge patterns, blocked migration of large-river fishes, and isolated many small-stream fish communities in headwaters of embayed tributaries.

Over 50% of the Big Muddy River drainage is in agriculture, much of which is under intensive tillage and subject to severe erosion. The drainage, nevertheless, serves as a major center in Illinois for water-based activities such as boating, fishing, waterfowl hunting, and camping. These activities are supported in part by three moderate to large reservoirs in the drainage—Rend, Crab Orchard, and Kincaid lakes—as well as numerous smaller impoundments. Rend Lake, in Franklin and Jefferson counties, is the second largest inland impoundment in the state. Recreational activity in the drainage is multifaceted and not strictly reservoir-based, being focused also around unique natural features or managed multiple-use areas such as the Shawnee National Forest (including Oakwood Bottoms), Crab Orchard National Wildlife Refuge, Giant City State Park, Little Grand Canyon, and Panther Den Wilderness.

In compiling our review of the drainage, we found (not surprisingly) that the fish fauna of the Big Muddy River drainage has been sampled systematically using standard methods in only a limited manner, but there is a considerable body of data on fisheries of the basin's reservoirs. We chose not to review the reservoir fisheries but refer the interested reader to Whitacre (1952), Allen and Wayne (1974), and Garver (1970, 1974). From a riverine standpoint, integrated, long-term ecological studies of the mainstem and large tributaries are noticeably lacking. In that vein, the work of Atwood (1988) and Hite et al. (1991) provides a much-needed foundation for beginning to understand the ramifications of anthropogenic change on the river's ecology.

Nevertheless, owing to a long history of collection of fishes in streams of the drainage, the native fish fauna is reasonably well-known and documented in regional and national fish collections. We assembled these data on the fish fauna of the Big Muddy River drainage into five eras of collecting activity. The first investigations date back to the classical work on Illinois fishes by Forbes and Richardson (1908), who reported on at least 12 collections made in the drainage during a period from about 1892 to 1900. From 1939 to 1940, A. C. Bauman, a former student of C. L. Hubbs, then at the University of Michigan, made 10 fish collections in the drainage. Beginning in the early 1950's, W. M. Lewis, Sr. and his students conducted several aquatic studies in the drainage and made at least 30 fish collections. The most comprehensive sampling of the Big Muddy River was by P. W. Smith and his colleagues, from 1963 to 1978, which resulted in 65 collections from throughout the drainage (Smith 1979). More recent efforts (1980–92), under the auspices of one of us (B. M. Burr), have resulted in 55 collections and the discovery of several fishes previously unreported from the drainage.

With this background, our primary objective is to present a description of the Big Muddy River drainage and its fish fauna, historically and today. We also identify impacts that have detrimentally affected the entire native aquatic community, provide a basic outline of management and monitoring needs for the river, and summarize requirements for restoration of the aquatic riverine resources in the drainage.

Sources and Methods

Information on the fish fauna of the Big Muddy River has been drawn from a variety of sources: (1) the primary literature—Forbes and Richardson (1908), Lewis (1955), Stegman (1959), Smith (1971, 1979), Burr and Page (1986), Warren and Burr (1988, 1989), and Burr (1991); (2) the gray literature—Whitacre (1952), Price (1965), Atwood (1988), Davin and Sheehan (1991), Hite et al. (1991), Burr et al. (1992), and Page et al. (1992); (3) vouchered specimen records in museum or university collections—University of Michigan Museum of Zoology, Illinois Natural History Survey, and Southern Illinois University at Carbondale; and (4) personal knowledge and field experience in the drainage over the past 20 years.

Physical, geological, and chemical features of the drainage were compiled from Rolfe (1908), Walker (1952), Schuster (1953), Price (1965), Smith (1971), Lopinot (1973), Illinois Environmental Protection Agency (1976), Ogata (1975), Hite and Bertrand (1989), Hite et al. (1991), and Illinois Environmental Protection Agency (1992). Streams, communities, and counties mentioned in the text are identified in Fig. 1.

Only limited standard sampling emphasizing catch per unit effort (CPUE) has been conducted on the fish fauna of the drainage. We assessed sampling effort from fish collections made over the past 100 years by competent fish biologists searching for maximum fish diversity in all available habitats at about 100 record stations in the drainage (Fig. 2). As already noted, we recorded sampling effort for different periods (eras), with credit given to the individuals making the most collections or directing the most effort during a given era (Table 1). Techniques used to sample fish over the years have included hook-and-line; wing, hoop, and gill nets; electrofishing; rotenone; and seining with various size nets and meshes. For purposes here, a collection is defined as thorough sampling of available habitats at a given locality using a variety of methods. Unfortunately, amount of effort and specific gear type at a given locality are largely unknown for collections made near the turn of the century and through the 1960's. It is therefore not possible to compare CPUE at a given site with the same gear type for one species.

The Big Muddy River Drainage

General Features

The Big Muddy River, one of the principal tributaries of the Mississippi River in southwestern Illinois, drains an area of 6,182 km^2 (Ogata 1975). The river's somewhat elliptical basin extends 168.9 km from north to south and 112.6 km from east to west (Lewis 1955), with a median length of 115.8 km and an average width of 53.1 km (Hite et al. 1991). Major tributaries within the Big Muddy River drainage include Casey Fork, Middle Fork, and Little Muddy River; and Crab Orchard, Galum, Kincaid, Cedar, and Beaucoup creeks (Fig. 1). The drainage includes the greater part of Franklin, Jackson, Jefferson, Perry, and Williamson counties; the southeastern portion of Washington County; the northern portions of Union and Johnson counties; the western edge of Hamilton County; and the southern part of Marion County (Fig. 1).

Four natural divisions are encompassed—Lower Mississippi River Bottomlands, Ozark, Shawnee Hills, and Southern Till Plain (Schwegman 1973). The Southern Till Plain composes most of the basin. The drainage lies at the extreme southwestern edge of the district covered by the Illinoisan drift sheet, lying in the low section just north of the Ozark ridge. The drainage is characterized by hilly upland topography and broad flat lowlands along the principal streams. The lower 32.2 km of the river flows through the Mississippi River Bottomlands. With the exception of the Ozark ridge on the southern border, which stands 182–243 m above mean sea level, the basin has few points rising above 167 m, the average level being 122–152 m. The immediate borders of the main valley fall below 122 m, and the mouth of the stream at low water in the Mississippi River is about 97 m. The bank-full channel of the mainstem throughout most of its course is 8–15 m wide and 15–21 m deep. A few sandstone outcrops, a common stratum in five of eight of the river's principal tributaries, and some patches of gravel are found in the main channel.

The Big Muddy River has the characteristics of an old stream, in an area long exposed to erosion (Rolfe 1908). Its bed has been cut down to drainage level, and its sinuous course runs over a broad floodplain. The river originates in northernmost Jefferson County and flows directly south and then generally southwest to empty into the Mississippi River about 8 km downstream from Grand Tower in Jackson County, at river km (rkm) 122 (Fig. 1). The length of the river, estimated from its point of origin, is about 248 km (Hite et al. 1991). Beaucoup Creek enters from the north about 40–48 km from the mouth, and Little Muddy River enters from the same side about 16 km farther upstream. These two streams together (2,222 km^2) drain about the same area as the mainstem above the Little Muddy River confluence. Beaucoup Creek (1,487 km^2) drains about twice the area of the Little Muddy River (736 km^2). An eastern tributary—Crab Orchard Creek—enters the mainstem from the south between the mouths of Beaucoup Creek and Little Muddy River and drains about 749 km^2 of the area bordering the Ozark ridge.

Hydrography

The Big Muddy River mainstem is at least as sluggish today as it was over a century ago (Rolfe 1908). Increased erosion and drainage of lowlands have exacerbated the silt load in the mainstem. Historically, in times of spring flood, Rolfe (1908) noted heavy silt loads that rendered the bottom a "creeping mass, shifting its contour with every change in rate of flow"; conversely, during summer drought the mainstem was reduced to a series of nearly stagnant pools. The river is properly named because with the exception of riffle areas the

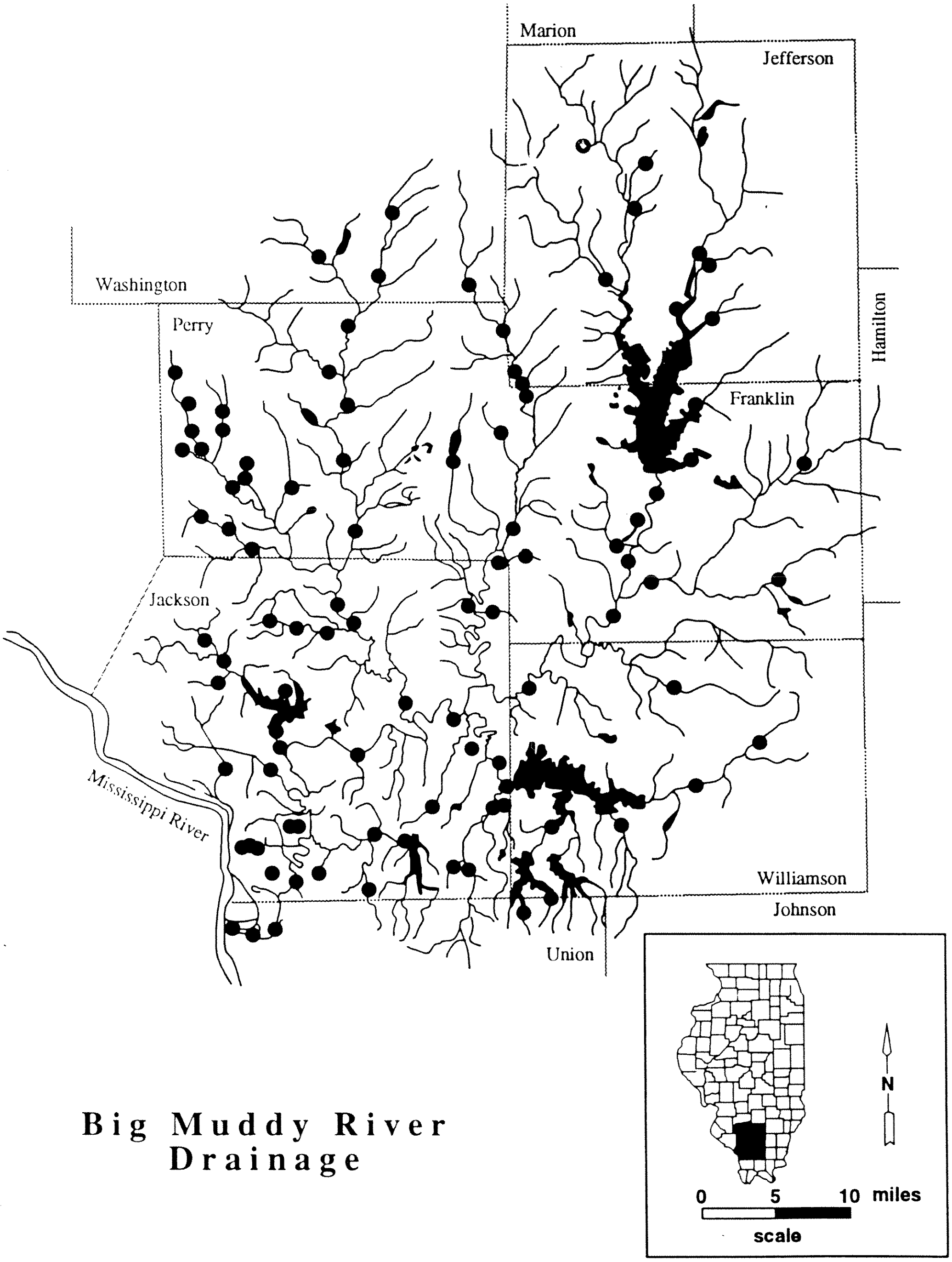

Fig. 2. Map of fish sampling sites in the Big Muddy River drainage represented in the Illinois Natural History Survey, University of Michigan Museum of Zoology, and Southern Illinois University at Carbondale ichthyological collections. Approximately 100 sites have been sampled at least once from 1892 to 1992.

Table 1. Fishes recorded from the Big Muddy River drainage, Illinois, in the period 1892–92, categorized by major historical periods of sampling. Classification and nomenclature of fish species follows Page and Burr (1991) VN = vouchered with a museum specimen and native to the drainage; I = introduced fish species deliberately or inadvertently moved into the drainage; L = literature record considered valid, species regarded as native; IE = introduced fish species with established population; IPE = introduced fish species without the status of a permanent population, but reproducing in an area where its elimination by humans would be impractical; R = record of an introduced fish species without evidence of reproduction, and vouchered with a museum specimen. Numbers in parentheses are number of collections made during a given period. SE = Illinois State Endangered; ST = Illinois State Threatened.

Family Species	S. A. Forbes and R. E. Richardson 1892–1900 (12)	A. C. Bauman 1939–40 (10)	W. M. Lewis 1950–59 (30)	P. W. Smith 1963–78 (65)	B. M. Burr 1980–92 (55)
Petromyzontidae					
1. *Ichthyomyzon castaneus*			VN		
Acipenseridae					
2. *Scaphirhynchus platorynchus*				VN	
Polyodontidae					
3. *Polyodon spathula*				VN	VN
Lepisosteidae					
4. *Atractosteus spatula* ST	L				
5. *Lepisosteus oculatus*					VN
6. *L. osseus*	L		L		
7. *L. platostomus*			L	VN	VN
Amiidae					
8. *Amia calva*	VN		VN	VN	VN
Anguillidae					
9. *Anguilla rostrata*			L		
Clupeidae					
10. *Alosa chrysochloris*			VN	VN	
11. *Dorosoma cepedianum*		VN	VN	VN	VN
12. *D. petenense*				VN	VN
Hiodontidae					
13. *Hiodon alosoides*			VN	VN	VN
Salmonidae					
14. *Oncorhynchus mykiss* I					IPE
Umbridae					
15. *Umbra limi*	L			VN	VN
Esocidae					
16 *Esox americanus*	VN	VN	VN	VN	VN
17. *E. lucius* I					IE
18. *E. masquinongy* I					IE
Cyprinidae					
19. *Campostoma anomalum*	L	VN	VN	VN	VN
20. *Ctenopharyngodon idella* I					IPE
21. *Cyprinella lutrensis*	VN	VN	VN	VN	VN
22. *C. spiloptera*					VN
23. *C. venusta*		VN			
24. *C. whipplei*	L	VN	VN		
25. *Cyprinus carpio* I	IE	IE	IE	IE	IE
26. *Ericymba buccata*		VN	VN	VN	
27. *Hybognathus hayi* SE		VN			
28. *H. nuchalis*	VN	VN		VN	VN
29. *Hybopsis amnis* SE	VN	VN			
30. *Hypophthalmichthys nobilis* I					IPE

Table 1. *Continued.*

Family Species	S. A. Forbes and R. E. Richardson 1892–1900 (12)	A. C. Bauman 1939–40 (10)	W. M. Lewis 1950–59 (30)	P. W. Smith 1963–78 (65)	B. M. Burr 1980–92 (55)
31. *Luxilus chrysocephalus*	L	VN			
32. *Lythrurus fumeus*		VN		VN	VN
33. *L. umbratilis*	L	VN	VN	VN	VN
34. *Macrhybopsis storeriana*	L				
35. *Notemigonus crysoleucas*	VN	VN	VN	VN	VN
36. *Notropis atherinoides*	VN	VN	VN	VN	VN
37. *N. blennius*	L				VN
38. *N. ludibundus*		VN	VN	VN	VN
39. *N. shumardi*		VN		VN	VN
40. *N. volucellus*		VN	L		VN
41. *Opsopoeodus emiliae*	VN	VN		VN	VN
42. *Phenacobius mirabilis*	L	VN	VN	VN	VN
43. *Pimephales notatus*	VN	VN	VN	VN	VN
44. *P. promelas*					VN
45. *P. vigilax*	VN	VN	VN	VN	VN
46. *Platygobio gracilis*				VN	
47. *Semotilus atromaculatus*	VN	VN	L	VN	VN
Catostomidae					
48. *Carpiodes carpio*		VN	VN		
49. *C. cyprinus*		VN	VN		VN
50. *Catostomus commersoni*		VN	VN	VN	VN
51. *Cycleptus elongatus*			L		
52. *Erimyzon oblongus*	VN	VN	VN	VN	VN
53. *E. sucetta*				VN	
54. *Hypentelium nigricans*				VN	
55. *Ictiobus bubalus*			VN	VN	
56. *I. cyprinellus*		VN	VN	VN	VN
57. *I. niger*				VN	VN
58. *Minytrema melanops*	L	VN	VN	VN	VN
59. *Moxostoma erythrurum*		VN	VN	VN	VN
60. *M. macrolepidotum*					VN
Ictaluridae					
61. *Ameiurus melas*	VN	VN	VN	VN	VN
62. *A. natalis*	L	VN	VN	VN	VN
63. *A. nebulosus*			VN		
64. *Ictalurus furcatus*			L		
65. *I. punctatus*	L	VN	VN	VN	VN
66. *Noturus gyrinus*	VN	VN	VN	VN	VN
67. *N. nocturnus*					VN
68. *Pylodictis olivaris*			VN		VN
Percopsidae					
69. *Percopsis omiscomaycus*		VN			
Aphredoderidae					
70. *Aphredoderus sayanus*	VN	VN	VN	VN	VN
Amblyopsidae					
71. *Forbesichthys agassizi*					VN
Gadidae					
72. *Lota lota*			L		
Fundulidae					
73. *Fundulus notatus*	VN	VN	VN	VN	VN
74. *F. olivaceus*	VN	VN		VN	VN
Poeciliidae					

Table 1. *Continued.*

Family Species	S. A. Forbes and R. E. Richardson 1892–1900 (12)	A. C. Bauman 1939–40 (10)	W. M. Lewis 1950–59 (30)	P. W. Smith 1963–78 (65)	B. M. Burr 1980–92 (55)
75. *Gambusia affinis*		VN	VN	VN	VN
Atherinidae					
76. *Labidesthes sicculus*					VN
77. *Menidia beryllina*					VN
Moronidae					
78. *Morone chrysops*	L		L	VN	VN
79. *M. mississippiensis*			L	VN	VN
80. *M. saxatilis* I				R	R
Centrarchidae (Percichthyidae)					
81. *Centrarchus macropterus*	VN		VN	VN	VN
82. *Lepomis cyanellus*		VN	VN	VN	VN
83. *L. gibbosus* I					R
84. *L. gulosus*	VN	VN	VN	VN	VN
85. *L. humilis*	VN	VN	VN	VN	VN
86. *L. macrochirus*	L	VN	VN	VN	VN
87. *L. megalotis*	L	VN	VN	VN	VN
88. *L. microlophus*				VN	VN
89. *Micropterus punctulatus*			L	L	VN
90. *M. salmoides*	VN	VN	VN	VN	VN
91. *Pomoxis annularis*	L	VN	VN	VN	VN
92. *P. nigromaculatus*	VN	VN	VN	VN	VN
Percidae					
93. *Etheostoma asprigene*	L	VN		VN	VN
94. *E. chlorosomum*	VN	VN	L	VN	VN
95. *E. flabellare*		VN	VN	VN	VN
96. *E. gracile*	VN	VN	L	VN	VN
97. *E. nigrum*	L	VN	VN	VN	VN
98. *E. proeliare*		VN		VN	
99. *E. spectabile*		VN	VN	VN	VN
100. *Perca flavescens* I					IPE
101. *Percina caprodes*		VN	VN	VN	VN
102. *P. maculata*	L	VN	VN	VN	VN
103. *P. shumardi*		VN	VN	VN	VN
104. *Stizostedion canadense*			VN	VN	
105. *S. vitreum*			VN	VN	
Sciaenidae					
106. *Aplodinotus grunniens*	L	VN	VN		VN
Total native species	45	58	65	68	71
Total introduced species	1	1	1	2	9
Total species	46	59	66	70	80

substrate of the mainstem and many tributaries is composed of thick layers of silt and mud. In the first 18 km from its origin the gradient is nearly 3 m/km, but ranges from less than 0.3 m/km in the middle reaches to 0.06 m/km at the confluence with the Mississippi River.

Major impoundments and the draining of wetlands have altered the hydrology of the watershed over the past 100 years. Flows have been decreased, especially on tributaries, and the timing and extent of flood pulses have been disrupted on the mainstem. Average daily stream flow for a 259-km^2 area ranges from 0.80 cubic feet per second (cfs) in the northwestern part of the drainage to 1.1 cfs in the southeastern part (Illinois Environmental Protection Agency 1976). Seven-day, 10-year low flows on

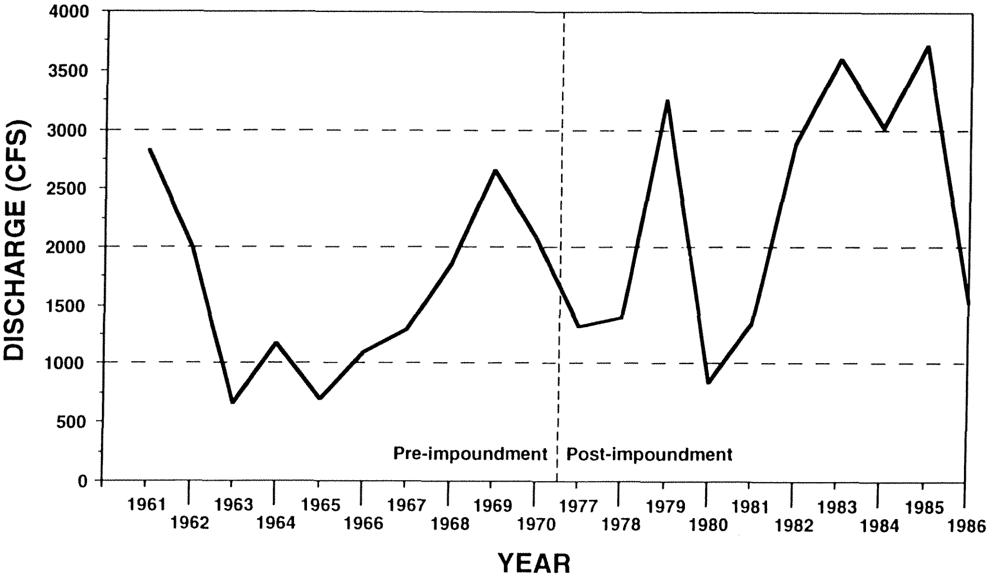

Fig. 3. Mean annual discharge pattern of the Big Muddy River as recorded by U.S. Geological Survey at the Murphysboro gaging station for a 10-year period (1961–70) before completion of Rend Lake and a 10-year period (1977–86) after completion of Rend Lake.

gaged streams in the drainage range from 0.0 cfs on several intermittent streams to 36.3 cfs on the mainstem near its mouth (Singh and Stall 1973). The rather extreme sinuosity of the Big Muddy River channel, a total fall of only 94 m, and an overall low gradient are the primary physical attributes collectively responsible for low stream velocities (U.S. Corps of Engineers 1968). Mean annual discharge recorded at the Murphysboro gaging station (Fig. 3) varied from 664 cfs in 1963 to 2,821 cfs in 1961 before completion of Rend Lake in 1970. After completion of Rend Lake, mean annual discharge varied from 839 cfs in 1980 to 3,599 cfs in 1983. Mean annual discharge does not appear to have stabilized since the lake was filled; however, this does not take into account the timing of the pulse and flow pattern during the spring.

Throughout the greater portion of its course, the Big Muddy River meanders about in a broad floodplain that is filled with drift and alluvium to a depth of 152–182 m or more above the bedrock. Upstream from Murphysboro (Fig. 1), the banks are neither abrupt nor high, and they and the bed of the stream are chiefly clay. Just below Murphysboro, the valley becomes constricted to a width of about 1.6 km as it breaches the elevated ridge that borders the Mississippi River. In its course through the Mississippi River Bottomlands its eastern shore hugs the ridge with a line of bluffs that rise 61–71 m above the river. On its west is the low, flat floodplain of the Mississippi River.

At Murphysboro (Fig. 1), where the channel is about 49 m wide, the water has sometimes risen 9 m, inundating the surrounding flats. Backwater from the Mississippi River is felt at that point and may even extend 138 km upstream to the vicinity of Plumfield (Hite et al. 1991).

Annual average rainfall of 106.7 cm and runoff of 31.8 cm, as well as soils of low permeability, make the Big Muddy River drainage suitable for surface water storage in reservoirs (U.S. Department of Agriculture 1968). Major impoundments in the drainage, all constructed since 1940, include Rend Lake (7,655 ha, completed in 1970), Crab Orchard Lake (2,821 ha, completed in 1940), Devil's Kitchen Lake (328 ha, completed in 1959), Little Grassy Lake (405 ha, completed in 1942), Cedar Lake (729 ha, completed in 1973), and Kincaid Lake (1,400 ha, completed in 1970). Numerous municipal reservoirs occupy smaller portions of the drainage. Rend Lake is an important source of flow in the Big Muddy River, providing a year-round flow of at least 30 cfs as required by the U.S. Army Corps of Engineers.

Physiography

About 90% of the Big Muddy River drainage is located in the physiographic subdivision termed the Mount Vernon Hill Country of the Central Lowland Province (Leighton et al. 1948). Most of the remaining land area, the southwestern part of the basin, is in the Shawnee Hills section of the Interior Low Plateaus Province, which joins the Ozark Mountains in Missouri and Arkansas. A small portion of the drainage lies on the Mississippi River floodplain.

The Mount Vernon Hill Country is characterized by low rolling hills and broad alluvial valleys along the major streams. The relief in this region is not pronounced. Upland prairies are flat to moderately hilly, and the valleys are shallow. The land surface is controlled primarily by bedrock, which has been modified only slightly by glacial drift deposits. While the southern boundary of the Mount Vernon Hill Country lies within a few kilometers of the limits of glaciation, moraine ridges essentially are absent in the area.

The Shawnee Hills are south and southwest of the Mount Vernon Hill Country and provide striking contrast to that region. This section is unglaciated and characterized by rocky ridges and deep valleys. This area displays a complex, bedrock-controlled topography.

In its lower 32 km, the Big Muddy River flows on the Mississippi River floodplain. The floodplain is nearly flat except where it is broken by an outcrop of bedrock—Fountain Bluff—which rises about 122 m above the river channel at its base.

Geology

The entire Big Muddy River drainage lies in a preglacial valley. Over the greater portion of the area the drift is thin, and rock divides separating the preglacial drainages are plainly visible. During the Pleistocene, meltwaters from receding glaciers caused the Mississippi River to exceed its transporting capacity. The Mississippi valley filled with sediment deposits that closed the mouths of some tributary streams. The Big Muddy River, one of the impounded tributaries, formed a lake. When the Mississippi River was once more able to transport, the natural process of downcutting occurred, and the Big Muddy Lake was drained. Typical of a lake bed long subject to erosion, the soils of the Big Muddy River drainage contain little humus, are acidic, and consist of impervious clays and silts, interlaced with very fine sands (LeTellier 1971).

The Big Muddy River drainage is in the southern part of the geologic structure known as the Illinois Basin. Over most of the basin the bedrock lies nearly flat, sloping gently toward the east. The Pennsylvanian bedrock underlies about 80% of the basin and in places reaches thicknesses of 790 m. It generally is composed of shale, sandy shale, and sandstone interbedded with thin limestone layers and coal. A small area of Mississippian, Devonian, and Silurian bedrock occurs in the southwestern portion of the basin. The Devonian and Silurian bedrock consists of limestones and sandstones that, together with Pennsylvanian rocks, uplifted and formed portions of the Shawnee Hills.

Bedrock in the basin is overlain by discontinuous deposits of Pleistocene glacial till, a clay-rich slowly permeable material. Uplands may be mantled with up to 7.6 m of loess (a moderately to slowly permeable silty soil), the depth and permeability of which decrease from southwest to northeast across the basin. The loess, a highly erodible soil, is about 0.6 m thick at the upstream border of the basin and increases to 6 m near the mouth of the Big Muddy River (U.S. Department of Agriculture 1968). The stream valleys contain alluvium and lake clays, generally with low permeability and high water table levels. The Mississippi River floodplain, a small part of the drainage, contains deposits of outwash consisting of sand and gravel interbedded with layers of silt and clay. In addition, occasional small granular deposits such as alluvium, dune sand, and various types of glacial outwash deposits may be found in the basin.

Land Use

Cropland, forest, and pastureland are the predominant land uses in the central and lower Big Muddy River drainage, composing 51.5%, 24.5%, and 12.6%, respectively (U.S. Department of Agriculture 1968). The remaining 11.4% includes urban areas, industrial sites,. residential areas, roads, coal mines, and oil fields. About 2% of the basin has been strip-mined for coal, and many areas have not been reclaimed. Gob and other waste materials are exposed on numerous old underground coal mine sites in Franklin County; these areas continue to contribute to water quality problems associated with acid runoff (Hite et al. 1991).

Substantial changes in the regional landscape have occurred since the time of settlement. In 1820, the five principal counties drained by the Big Muddy River were composed of 518,805 ha of forest and 124,132 ha of prairie (Iverson et al. 1989). By 1924 forested acreage was reduced to 109,796 ha (Iverson et al. 1989).

Mainstem Habitat

During August 1988, a period of near record low-flow conditions, the Illinois Environmental Protection Agency (Hite et al. 1991) collected a variety of habitat data that in our experience typifies the Big Muddy River mainstem. The mainstem averaged about 25 m wide and 0.73 m deep. Stream discharge ranged from 44 cfs west of Benton (just below the Rend Lake tailwaters) to 63 cfs at a downstream site near Murphysboro. Mean velocity at five sites was 0.12 m/s. The mean percentage of pool was 60.6 and of riffle 2.1. Average instream cover was about 8.8%; shading was sparse to moderate at 27%. Silt-mud (33.5%) was the predominant bottom substrate, followed by gravel (28.8%), plant detritus (10.6%), submerged logs (7.0%), cobble (6.9%), claypan-compacted soil (6.6%), sand (5.1%), boulders (1.2%), and other substrates. In comparison with other Illinois streams (e.g., Kaskaskia River to the north), the Big Muddy River had the highest means for width, depth, discharge, percent pool, and percent silt-mud—all characteristics of a low-gradient stream.

Natural Resources

The major natural resources available in the Big Muddy River drainage are soil, minerals, forests, and surface water. Groundwater supplies are scanty and of poor quality except along the extreme western edge of the drainage. The widespread construction of impoundments has provided adequate water supplies throughout the basin (Illinois Environmental Protection Agency 1976).

The principal mineral resources in the basin are coal and oil. These two commodities are in active production and are shipped from the area in quantities sufficient to make the Big Muddy River drainage a leading fuel-producing region. Pennsylvanian coal layers have been mined extensively for over a century, with production peaking from the late 1950's to the early 1970's. Coal reserves are substantial and probably exceed 15 billion metric tons.

Oil pools are known to exist in Franklin, Hamilton, Jefferson, and Washington counties. Most of the basin's oil production is from fields in Franklin and Jefferson counties. Estimated oil reserves in these two counties exceed 40 million barrels.

Other mineral resources in the basin are sand, gravel, limestone, sandstone, clay, and shale. These commodities are not recovered in large amounts, and production is used to supply local demands.

Water Quality and Environmental Impacts

As noted previously, pollution within the basin is associated with the various discharges and conditions inherent to coal mining and oil recovery as well as industrial and domestic effluent (Price 1965). The various forms of pollution and other environmental impacts (i.e., impoundments) are categorized below.

Drought

Extremely low flows during summer months and concomitant pooling of the mainstem were reported by early observers in the basin (Rolfe 1908). However, in recent decades the water table in Illinois has fluctuated more widely than it did before 1930 (Smith 1971). During some of the worst droughts affecting the basin (late 1980's), once permanently flowing streams dried up, seeps and springs ceased flow, and the mainstem temporarily became a medium-sized or even small stream. The effects of the most recent (1988) drought included massive fish kills in tributary streams primarily because of oxygen depletion.

Municipal and Industrial Discharges

Inadequate domestic sewage treatment, as well as discharges from various industries, accounts for poor water quality in some areas of the basin, particularly downstream of Rend Lake. Twelve communities have a population of 3,000 or greater, and 11 of these lie downstream of Rend Lake, discharging wastewater either directly into the mainstem or into tributaries (Hite et al. 1991). Numerous other point and nonpoint sources, including small wastewater treatment plants, industrial sites, and active and inactive coal mines, discharge nutrients, metals, and other constituents directly or indirectly into the lowermost 167 km mainstem of Big Muddy River.

Historically, these discharges have degraded water quality and aquatic life in the river, particularly during periods of low flow. Early studies conducted by students of W. M. Lewis, Sr. at Southern Illinois University at Carbondale concluded that toxic pollution in the drainage was spasmodic and localized and that the most toxic conditions were confined to tributaries. The major pollutants in the early 1950's were sewage, creosols, silt, garbage wastes, iron, acid-mine drainage, and other coal-mine wastes (Walker 1952; Schuster 1953). Fish kills were documented on several occasions in the Crab Orchard Creek drainage near a railroad cross-tie plant, where creosote accumulation was washed into the creek during rainy periods (Lewis 1955). Price (1965) recorded a pH below 3.0, black water with frequent gas bubbles, and no fish near a municipal sewage discharge in Crab Orchard Creek about 8 stream km above the head of Crab Orchard Lake. Effluent sampling conducted in 1988 from 10 municipal wastewater treatment plants (Hite et al. 1991) revealed considerable variability in many parameters; however, phosphorus, un-ionized ammonia, and chemical oxygen demand were elevated more frequently than other constituents. In recent years, however, all major wastewater treatment plants that discharge to the lower Big Muddy River drainage have renovated or plan to upgrade treatment facilities through the state grant construction program (Hite et al. 1991). Because 70% of these plants have now made structural improvements in existing facilities, higher quality effluent would be expected in future studies.

Coal Mine Discharge

The presence of large waste piles from surface and underground mining presents a constant source of potential and oft-realized pollution in the drainage. Mining pollution was particularly acute during the 1950's and 1960's before the advent of regulation and reclamation. Although extensive mining activities are present in other Big Muddy River tributaries, including the Little Muddy River and Beaucoup Creek, the majority of mine drainage originates in Franklin and Williamson counties. Twenty-four mine discharges, permitted under the National Pollutant Discharge Elimination System, shunt effluent to the lower Big Muddy River or tributaries downstream from Rend Lake in Franklin and Williamson counties. Discharge types include surface runoff, reclamation runoff, pit pumpage, underground pumpage, untreated acid mine drainage, and treated acid mine drainage. At least nine known unpermitted and untreated mine discharges also release acid waters to the Big Muddy River in Franklin and Williamson counties (Hite et al. 1991). Runoff from the numerous spoil piles has resulted in water of undesirable quality flowing into the drainage. The pumping of water from old strip mines to rework the strip area for additional coal often results in even poorer quality water being discharged into waterways.

In 1964, Illinois Department of Conservation fishery biologist O. M. Price sampled Lake and Pond creeks, Williamson County (see Fig. 1) and recorded pH values of 3.5, a bright orange precipitate on the stream bottom and shoreline, and no fish at either station. In Lake Creek, a water velocity of over 0.15 m/s through a channel averaging 7.6 m in width and 0.6 m in depth, represented a considerable volume of polluted water flowing into the nearby mainstem. Fish kills from acidic waters continue to this day; the Illinois Environmental Protection Agency investigated a series of fish kills near Royalton on the Big Muddy River and in Prairie Creek from 1988 to 1990. The agency recorded pH values as low as 2.5 and high manganese concentrations in the Royalton drinking water (Hite et al. 1991). These problems are directly attributable to several mines just upstream of Royalton. Plans are underway for reclamation of these sites.

Water Quality

Water quality as measured at 27 sites on the mainstem and tributaries by Illinois Environmental Protection Agency personnel (Hite et al. 1991) during 1988 revealed that negative effects originated largely from municipal effluents and runoff from coal mines and agricultural activities. Water quality in 1988 generally was rated as borderline between fair/good and poor, although very good and very poor water also existed. Very good water was noted immediately downstream of Rend, Crab Orchard, and Kincaid lakes, which was indicative of reservoir trapping efficiency, specifically for nutrients and suspended solids. This effect was evident in the tailwaters of the major impoundments relative to water quality elsewhere in the basin. Very poor water was rare in the mainstem and more prevalent in tributaries. Middle Fork and its tributary, Ewing Creek, displayed the poorest water. Water quality in these two streams was influenced largely by runoff from abandoned mines in the Middle Fork watershed. Illinois General Use Water Quality Standard violations were common in the Big Muddy River and tributaries but were not generally extreme. The standard most often violated was for manganese, followed by dissolved oxygen and then sulfate. The standard for pH was often violated; however, violations of these standards were limited to Big Muddy River tributaries (Hite et al. 1991).

Oil Pollution

Smith (1971) noted that oil-field pollution had been a problem in the Big Muddy River drainage for many years. There seems, however, to be little documentation of oil brine pollution affecting the fishes in the drainage. Price (1965) observed oil scum on the water surface, as well as on the shoreline vegetation, and debris in Galum Creek and the Middle Fork. Both of these sites contained poor fish diversity (8 and 13 species, respectively), and the fish assemblages were dominated by tolerant species (i.e., red shiner [*Cyprinella lutrensis*], redfin shiner [*Lythrurus umbratilis*], western mosquitofish [*Gambusia affinis*], bluegill [*Lepomis macrochirus*]).

Siltation, Stream Dredging, and Wetland Drainage

The cycle of poor soil conservation practices accelerating stream siltation, which in turn provides impetus for dredging, draining, and channelization projects, has plagued aquatic habitats in the basin for some time (Price 1965). The results include loss of adequate woody riparian corridors, loss of perennial and ephemeral riparian wetlands, a decrease in low flows (especially in tributaries), degradation of the floodplain, blockage of high flow channels, and homogenization of in-stream habitats. According to Smith (1971) excessive siltation ranks first in Illinois as the principal factor responsible for changes in fish populations. Its effects include loss of water clarity and subsequent disappearance of aquatic vegetation, and the deposition of silt over substrates that were once bedrock, rubble, gravel, and sand. Feeding and spawning sites have surely been reduced by siltation in the Big Muddy River drainage in this century. Likewise, the draining of floodplain wetlands has eliminated specialized spawning and nursery habitats for some fishes and reduced the primary habitat for others (see section on extirpated fishes). Smith (1971) ranked the drainage of wetlands as the second most important factor responsible for changes in fish populations in Illinois. At least 80 stream km of the Big Muddy River drainage have been channelized (Lopinot 1972), allegedly for flood control and to increase arable land. The effects of channelization include the straightening of natural stream meanders, denuding of the banks, and widening and deepening of the channel. The change in substrate and loss of instream cover and shade from channelization have resulted in stream fish communities represented by only the most tolerant species. Given the historical evidence that the mainstem generally carried a heavy silt load and often pooled up in the summer, we speculate that the effects of these factors on fishes were probably most severe in the river's tributaries.

Garbage

Various streams in the Big Muddy River drainage have been the dumping grounds for human garbage for many years (Walker 1952). While this irresponsible behavior results in an aesthetically unappealing and perhaps unhealthy environment, it is difficult to assess the long-term ecological effects of such abuse on the fish fauna.

Impoundments

The richness of the Big Muddy River fish fauna presumably is related directly to the number of different habitats available (Smith 1971). Flowing streams consist of alternating riffles and pools, each of which has many distinct microhabitats formed by various permutations of substrate type, depth, cover, and velocity. When the river and its tributaries were impounded, riffles and their respective microhabitats were eliminated and, in the shallow reservoirs of the Big Muddy River drainage (e.g., Rend Lake), the bottom was covered quickly with silt, resulting in only one basic fish habitat. Dams constructed to form impoundments also blocked natural migration and dispersal of fishes. Historically, the blue sucker (*Cycleptus elongatus*) was known to make spring spawning runs up the Big Muddy River; it has not been reported in the drainage since the 1950's (Lewis 1955). The paddlefish (*Polyodon spathula*) has been observed in the tailwaters of Crab Orchard and Rend lakes, but their dams prevent further upstream migration and spawning that may have occurred historically. Although preimpoundment data generally are lacking and distributional information is scant (Smith 1979), we suspect that dam construction also impeded spring spawning runs of important sportfishes in the river, such as walleye (*Stizostedion vitreum*), white bass (*Morone chrysops*), and perhaps yellow bass (*Morone mississippiensis*), and hence diminished the potential of the river's fishery. As noted previously, there are numerous small, medium, and large reservoirs in the Big Muddy River drainage. Unfortunately, the construction of Cedar, Kincaid, Little Grassy, and Devil's Kitchen lakes destroyed some of the least affected and most aesthetically pleasing streams in the drainage.

Because of the basin's pollution history, some impoundments have exhibited elevated levels of trace metals in the fish populations, particularly mercury. In the past decade biomagnification of mercury in the flesh of various sportfishes was reported from Crab Orchard, Cedar, and Kincaid lakes (Call 1989). Call (1989) pointed out, however, that the sediments in these lakes ultimately may serve as a sink for trace metals, and thereby aid in mitigation of biological effects.

The Fish Fauna

General Faunal Composition

A total of 106 fish species, representing 25 families, has been recorded from the Big Muddy River drainage from 1892 to 1992 (Table 1). Of these, 97 species are considered native, and 9 occur in the drainage as a result of introductions of exotics or transplantations of species native to other parts of the continent. Just over half (51.9%) the total (187 species) native fish fauna known from Illinois (Burr 1991) occur in the Big Muddy River drainage. The native fish fauna of the drainage constitutes just over one-fourth of the 375 freshwater fishes found in the Mississippi River basin (Burr and Mayden 1992). The five dominant families are Cyprinidae (26 species), Catostomidae (13 species), Percidae (12 species), Centrarchidae (11 species), and Ictaluridae (8 species); in total they comprise 72% (70 species) of the native fauna. The families Petromyzontidae, Acipenseridae, Polyodontidae, Amiidae, Anguillidae, Hiodontidae, Umbridae, Percopsidae, Aphredoderidae, Amblyopsidae, Gadidae, Poeciliidae, and Sciaenidae are each represented by one extant native species.

The Kaskaskia River, the next major river drainage (15,022 km^2) to the north of the Big Muddy River, has at least 103 native species, and the Cache River, a major river drainage (2,717 km^2) to the south of the Big Muddy River, has at least 71 native species (Burr and Page 1986). Adjusting for catchment size (species per kilometer^2), the Big Muddy River drainage with about 0.02 species/km^2 has over twice the species density of the larger Kaskaskia River drainage (0.007) and slightly more than half that of the smaller Cache River drainage (0.03). Differences in catchment size, habitat diversity, and geological history are among the most important factors influencing native species diversity in the upper Mississippi River basin (Burr and Page 1986), and almost certainly account for the differences in native species diversity and density among the Big Muddy, Cache, and Kaskaskia rivers.

Unusual fishes known from the drainage that are apparently year-round residents with limited ranges in Illinois (Smith 1979) include the paddlefish, spotted gar (*Lepisosteus oculatus*), central mudminnow (*Umbra limi*), Mississippi silvery minnow (*Hybognathus nuchalis*), pugnose minnow (*Opsopoeodus emiliae*), lake chubsucker (*Erimyzon sucetta*), shorthead redhorse (*Moxostoma macrolepidotum*), freckled madtom (*Noturus nocturnus*), spring cavefish (*Forbesichthys agassizi*), mud darter (*Etheostoma asprigene*), and river darter (*Percina shumardi*). Exposed rock riffles during low flow on the mainstem near Murphysboro and at Rattlesnake Ferry often yield 25–30 species, including nearly all of the species listed above.

Unsubstantiated or Erroneous Fish Records

As with any major river system in North America, several fish species have been reported from the Big Muddy River drainage that remain unsubstantiated by voucher specimens or are considered erroneous. If recognized, they would constitute an extension of the range of a species, an enigmatic zoogeographic occurrence, or an improbable occurrence in a given habitat, or they could represent any of several similar species. Erroneous records are those misidentified as confirmed by examination of extant voucher specimens. Species reported from the drainage that remain unsubstantiated or erroneous include smallmouth bass (*Micropterus dolomieu*[= *M. salmoides*]), rock bass (*Ambloplites rupestris*, probably *L. gulosus*, no voucher; Forbes and Richardson 1908); highfin carpsucker (*Carpiodes velifer*, probably *C. cyprinus*, no voucher;

from Lewis 1955); steelcolor shiner (*Cyprinella whipplei* [= *C. lutrensis*] Lewis and Gunning 1959); mooneye (*Hiodon tergisus*, probably *H. alosoides*, no voucher), black redhorse (*Moxostoma duquesnei*, probably *M. erythrurum*, no voucher; Atwood 1988); river redhorse (*M. carinatum*, probably *M. macrolepidotum*, no voucher; Hite et al. 1991).

Rare and Extirpated Species

Over the last century at least 10 species are indicated as having been extirpated from the Big Muddy River drainage (Table 2), and several others are rare, uncommon, or distributionally problematic in the basin. Three of the 10 species considered as extirpated have received conservation status rankings from the state of Illinois (Illinois Endangered Species Protection Board 1990): alligator gar (*Atractosteus spatula*), cypress minnow (*Hybognathus hayi*), and pallid shiner (*Hybopsis amnis*). None of these species has been reported from the drainage in over 50 years (Table 2). Two other species, the blacktail shiner (*Cyprinella venusta*) and cypress darter (*Etheostoma proeliare*), are on the Illinois watch list (Burr 1991).

The alligator gar, a large-river and lowland species, was reported from the drainage by Forbes and Richardson (1908). The species rarely has been seen anywhere in Illinois since the 1960's (Smith 1979) and has declined precipitously throughout the upper Mississippi River valley (Burr and Page 1986). The cypress minnow was last collected in the drainage from three sites in the Little Muddy River and Beaucoup Creek in 1940 by A. Bauman (Warren and Burr 1989). He took large numbers (>30 specimens) at each site by seining, indicating the species was a relatively common, if somewhat localized (3 of 10 sites), component of the fish fauna. In an effort to rediscover the cypress minnow in the drainage, we resampled Bauman's localities, as well as others, without success, and we consider the species extirpated from the drainage (Warren and Burr 1989). Our sampling of a few remaining riparian wetland habitats (e.g., along Beaucoup Creek) that might potentially support cypress minnows generally yielded a depauperate and tolerant assemblage of fish (e.g., sunfishes, gizzard shad [*Dorosoma cepedianum*], western mosquitofish) and lacked native cyprinids, with the exception of the ubiquitous golden shiner (*Notemigonus crysoleucas*). We suggest that drainage of floodplain wetlands for agriculture was a prime factor in the disappearance of the cypress minnow. Wetlands adjacent to stream channels apparently were used by the species as spawning and nursery areas (Warren and Burr 1989). Agriculture and mining pollution (particularly in the case of Beaucoup Creek) also may be implicated in the extirpation of this once relatively common member of the fauna. The pallid shiner was taken in 1900 and 1940 at three sites, including the Big Muddy River mainstem, Crab Orchard Creek, and the Little Muddy River (Warren and Burr 1988). Despite specific searches for the species, extant populations have not been reported since 1940 (Warren and Burr 1988). The cypress minnow and pallid shiner persist elsewhere in Illinois and nearby states, albeit tenuously in much of the upper Mississippi valley. The alligator gar, however, is poorly represented throughout its range, and there is no evidence of

Table 2. Fish recorded from the Big Muddy River drainage, Illinois, in the period 1892–1992, and now considered extirpated.

Species	Years of collection or probable occurrence			
	1900	1920	1940	1960
Atractosteus spatula	0[a]	X[b]		
Hybopsis amnis	0	----------	0	
Hybognathus hayi	X	----------	0	
Percopsis omiscomaycus	X	----------	0	
Luxilus chrysocephalus	X	----------	0	
Cyprinella venusta	X	----------	0	
Cycleptus elongatus	0	----------	----------	X
Lota lota	0	----------	----------	X
Anguilla rostrata	0	----------	----------	X
Cyprinella whipplei	X	0	----------	0

[a] 0 = occurrences documented by specimens in museums or recorded in the literature and considered valid.

[b] X = probable occurrence of a species at a given time, on the basis of collection or reliable reports in other parts of the drainage.

reproduction anywhere in the upper Mississippi valley.

During the course of status surveys conducted in 1992 (Burr et al. 1992), the blacktail shiner and cypress darter were not found in the Big Muddy River drainage. Both are on the northern edge of their range in Illinois (Smith 1979; Page and Burr 1991), were known from only one or two localities each in the drainage, and were taken originally in small numbers. The cypress darter's habitat now is impounded by Lake Kincaid, and the blacktail shiner probably occurred as a waif in the lower reaches of the mainstem from the Mississippi River. Both species survive elsewhere in southern Illinois and in suitable habitat to the south but can no longer be considered extant in the Big Muddy River drainage.

At least three of the extirpated species, including the American eel (*Anguilla rostrata*), burbot (*Lota lota*), and blue sucker (Table 2), are of some commercial value, and all were present before dam construction and excessive industrial, urban, and agricultural pollution. The striped shiner (*Luxilus chrysocephalus*) and steelcolor shiner (*Cyprinella whipplei*) were known from the lower mainstem. Both have suffered range compression in western Illinois, a pattern attributed to siltation, turbidity, and conversion of perennial to ephemeral streams (Smith 1979), certainly factors operating in the Big Muddy River drainage. Interestingly, Smith (1979) noted that in Illinois the steelcolor shiner was being replaced by the more ecologically tolerant spotfin shiner (*Cyprinella spiloptera*), a species recently recorded for the first time in the Big Muddy River drainage (Table 1).

The former occurrence of the trout-perch (*Percopsis omiscomaycus*) in the Big Muddy River drainage is near the southernmost edge of its range (Gilbert and Lee 1980; Burr et al. 1988). Two collections of the species were made in the 1940's in Kincaid Creek, where the species was apparently common (15 specimens at one site; Burr et al. 1988); now both Kincaid Creek sites are impounded by Lake Kincaid, and no subsequent collections have been made of this species in the drainage. The species is considered extirpated from the drainage.

Based on Table 1, several other species, although not considered extirpated, are rare or at least present problematic distributions in the basin. In 1978, the lake chubsucker was discovered in the basin in a large remnant wetland in the floodplain of the lower river (Burr et al. 1988). Although historical substantiation is lacking, we suggest its restricted distribution in the drainage is a product of the demise of the basin's wetlands. Four other species in the drainage have not been taken for at least 30 years (Table 1), including chestnut lamprey (*Ichthyomyzon castaneus*), silver chub (*Macrhybopsis storeriana*), river carpsucker (*Carpiodes carpio*), and blue catfish (*Ictalurus furcatus*). These species, all characteristic of the Mississippi River, are not rare, sensitive, or extirpated and probably continue to enter the Big Muddy River near the mouth.

On a smaller spatial scale, drainage alteration and watershed deforestation in the Galum Creek system before the 1960's probably contributed to the extirpation of three fishes from that system: Mississippi silvery minnow, emerald shiner (*Notropis atherinoides*), and pugnose minnow (Carney 1990). Five species historically known from Galum Creek were represented only in Little Galum Creek samples in 1989. Little Galum Creek is the only stream in the Galum Creek system that has not been diverted or modified for mining activities (Carney 1990).

Introduced Species

As with most impounded waters in the Midwest, exotic or transplanted sportfishes and forage species have been introduced into all of the moderate to large reservoirs in the drainage. The presence of introduced species raises questions as to their source, their ecological role in the drainage, and their importance to human welfare. The potential ecological effects of introduced and exotic fish on native aquatic communities include habitat alterations (e.g., removal of vegetation, degradation of water quality); introduction of parasites and diseases; trophic alterations (e.g., predation, competition for food); and hybridization, and spatial alterations (e.g., overcrowding; Taylor et al. 1984).

Of the nine introductions in the drainage, eight were apparently intentional, and one, the bighead carp (*Hypophthalmichthys nobilis*), is a recent invader from introductions made elsewhere in the Mississippi River basin. Three of the species are natives of Europe or Asia (grass carp, *Ctenopharyngodon idella*; common carp, *Cyprinus carpio*; bighead carp), one is from western North America (rainbow trout, *Oncorhynchus mykiss*), one originates from the Atlantic Slope (striped bass, *Morone saxatilis*), and the remainder are native to more northern or eastern waters. A plethora of tropical and subtropical aquarium fishes has been released into the impoundments in the drainage only to perish in the ensuing winter. During the summer of 1992, anglers caught South American pacus (*Colossoma* spp.) from Little Grassy Lake and Southern Illinois University at Carbondale Campus Lake. Rainbow trout have been stocked into Devil's Kitchen and Crab Orchard lakes; they are not known to oversummer in Crab Orchard Lake. Two pikes, *Esox lucius* (northern pike) and *E. masquinongy* (muskellunge), have been transplanted into Kincaid Lake, where the northern pike reproduced the first 2 years. For ostensible vegetation control, the grass carp has been introduced into the Southern Illinois University at Carbondale Campus Lake and numerous farm ponds in the Big Muddy River catchment. On 4 August 1992 one of us (B. M. Burr) documented a single young-of-the-year (27 mm SL) grass carp from the lower mainstem of the river, the only record of natural reproduction of this species in Illinois waters. In the past 2 years, adult bighead carp were taken by anglers from the lowermost mainstem. We recently (4 August 1992), however, documented a single young-of-the-year (24 mm SL) bighead carp from the lower mainstem at Rattlesnake Ferry, again the first confirmation of natural reproduction of this species in the state. We are not certain that either of these species spawned in the Big Muddy River, but plan to conduct additional field work in 1993 in an effort to substantiate reproduction. The common carp was the first and only exotic found in the drainage during the Forbes and Richardson (1908) era, and it remains the most common exotic species. The striped bass has been introduced into Kincaid, Rend, and Crab Orchard lakes as a sportfish and has escaped over the spillways in all three lakes, although nothing is known regarding the survival of the escaped individuals. Humanmade ponds on the Crab Orchard National Wildlife Refuge have received introductions of the pumpkinseed (*Lepomis gibbosus*), and one adult male of unknown origin is documented from Beaucoup Creek. The yellow perch (*Perca flavescens*), transplanted to Crab Orchard and Devil's Kitchen lakes, has reproduced in the latter. The threadfin shad (*Dorosoma petenense*), native to the lower reaches of the drainage, and the inland silverside have been introduced in various impoundments as forage. The inland silverside is dispersing rapidly throughout the lower drainage.

Obviously, some of these introduced species are localized, uncommon, or small and apparently ecologically unimportant. In contrast, many others are voracious predators (e.g., northern pike) on or potential competitors (e.g., recently introduced carps) with native fishes. We do not have enough information to predict the long-term effect of these introductions, but we do note that the ratio of extant native to introduced fish has decreased from 97:1 in 1900 to 9.7:1 today. Given the model provided by the common carp, finding evidence of potential reproduction of bighead carp and grass carp in the drainage is disturbing. If we can confirm that these species are using the river as a spawning and nursery area, we speculate that the mainstem riverine fauna may be given over to these exotics, as it is to some extent now by the common carp.

Sport, Commercial, and Forage Fishes

In 1977, Illinois Department of Conservation fishery biologists, expending at least 60 min of effort per site, sampled five stations on the Big Muddy River with a boat-mounted electrofishing unit. From 1978 to 1986 annual sampling was continued at stations located near the mouth (Rattlesnake Ferry) and middle reaches of the river (near Benton). A comparison of total electrofishing catch at the five 1977 stations indicated greater fish population density near the river's mouth and near the Rend Lake tailwater than elsewhere (Atwood 1988). Over all years (1978–86) sampled, the most abundant fishes listed in decreasing order were common carp, gizzard shad, bigmouth buffalo (*Ictiobus cyprinellus*), bluegill, longear sunfish (*Lepomis megalotis*), largemouth bass (*Micropterus salmoides*), smallmouth buffalo (*Ictiobus bubalus*), freshwater drum (*Aplodinotus grunniens*), channel catfish (*Ictalurus punctatus*), black crappie (*Pomoxis nigromaculatus*), and bowfin (*Amia calva*).

The Quality Sport Fisheries Index (QSFI) also was calculated for the Illinois Department of Conservation samples. The QSFI is derived from sample abundances of a given sportfish weighted by a measure of angler preference (Atwood 1988). According to recent angler preference in southern Illinois, the five most popular sportfishes are catfish, crappie, largemouth bass, white/yellow bass, and sunfish (Atwood 1988). All of the 1977 Big Muddy River stations had either fair or poor QSFI ratings. Over the 10-year monitoring period, the site at Rattlesnake Ferry (near the mouth) had the highest QSFI ratings. Ratings were correlated (Pearson product-moment correlations [r]), in part, with discharge at the time of sampling (r = .773) and mean annual discharge (r = .741). Low catch rates at some stations probably resulted from high stream temperature, low stream flow, and low dissolved oxygen. Low dissolved oxygen levels could have resulted because of high nutrient loading from substandard sewage treatment facilities at West Frankfort and Herrin (Hite et al. 1991), and also from high organic content of the silt/mud sediments. These factors also may account for the high densities of common carp at some stations.

Composition and relative abundance of species taken during the Illinois Department of Conservation surveys of 1977–86 are similar to those reported by Lewis (1955). He emphasized that most fishing in the river at that time was of a commercial nature. In 1951, only one full-time and 10 part-time commercial fishermen operated on the river. Catches were dominated by common carp and buffalofish (Starrett and Parr 1951). Few commercial operations still exist on the Big Muddy River in large part because of the resultant low standard of living (i.e., low price per kilogram). Today, most commercial fishermen harvest buffalofish (*Ictiobus* spp.), carpsuckers (*Carpiodes* spp.), common carp, and catfishes (channel catfish and flathead catfish, *Pylodictis olivaris*).

Lewis (1955) suggested that the sportfish populations were controlled by extreme fluctuations in water level, lack of spawning sites, and mine-waste pollution. To produce better recreational stream fishing, he urged the elimination of chemical pollution and that more impoundments be built to completely control water-level fluctuations. Ironically, except for Rend Lake, most of the large dams since constructed in the basin have no means of controlling the amount or timing of tailwater release. Garver (1974) described fishing opportunities as abundant in the Big Muddy River, with many desirable species of large size being present, but indicated that fishing pressure was light. Allen and Wayne (1974) described the fishing pressure as heavy at the Rend Lake tailwater, light to moderate in middle downstream sections, and becoming progressively heavier in the lowermost reaches near the river's confluence with the Mississippi. In a survey of stream access, Davin and Sheehan (1991) noted that about one-fourth of all fishing trips in Illinois are made to streams. Weekday pressure accounted for 70% of total fishing pressure (a total of 25,342 h) on the Big Muddy River. At the most commonly used access site on the Big Muddy River (near the mouth), only 15% of the use was for angling purposes during 1989–90. Compared with the nearby Ohio and Kaskaskia rivers, fishing pressure on the Big Muddy River is low. Of the 6,664 h of angling effort recorded by creel clerks during a 20-month period in 1989–90, 52% of that effort was directed to the Ohio River, 34% to the Kaskaskia River, and only 2% to the Big Muddy River (Davin and Sheehan 1991). Poor access to fishing sites is a primary limiting factor. The top four species harvested in southern Illinois during this same period were crappies (combined), bluegill, channel catfish, and largemouth bass.

Index of Biotic Integrity

Hite et al. (1991) sampled seven sites in the drainage with a boat-mounted electrofishing unit in an effort to assess community structure and to evaluate the fish fauna with the Alternate Index of Biotic Integrity (AIBI; Karr et al. 1986). Categories used for the AIBI included (1) species richness and composition, (2) trophic composition, and (3) fish abundance and condition. Hite et al. (1991) collected 947 fish representing 33 species at seven mainstem sites on 15–18 August 1988 (Table 3). Seven species, including shortnose gar (*Lepisosteus platostomus*), gizzard shad, common carp, smallmouth buffalo, channel catfish, bluegill, and freshwater drum, were present at all sites. The common carp was the most abundant species, followed by freshwater drum and bluegill. Centrarchids dominated the 1988 samples, accounting for 31% of all fish collected (mostly bluegill), followed by cyprinids (22.9%), sciaenids (13.6%), clupeids (11.9%), catostomids (8.7%), ictalurids (6.6%), and lepisosteids (3.4%).

Biotic integrity of mainstem fish communities was rated fair based on AIBI values ranging from 31.6 at a station on the lower river (Turkey Bayou) to 38.2 at a station near the mouth (Rattlesnake Ferry) and a more centrally located station (Route 14 West of Benton) out of a total possible AIBI of 51–60. The closest point source pollution to the Turkey Bayou site is 26.4 km upstream at the Murphysboro wastewater treatment plant. This may account, in part, for the low AIBI scores at that site. The AIBI values were generally higher in the upper section (downstream from Rend Lake, southeast of DeSoto, at Blairsville) of the mainstem even though this area has been affected historically by point source pollution.

In the Galum Creek system, Carney (1990) found mean AIBI values to vary from 34.9 to 42.0. Little Galum Creek yielded the highest biotic integrity

Table 3. Summary of 1988 fish community characteristics as used in the Alternate Index of Biotic Integrity (AIBI) at seven sites on the mainstem of the Big Muddy River (Hite et al. 1991). Sampling stations are as follows: N-06 (Rt. 14 W Benton); N-11 (1.1 km W Plumfield); N-17 (Cambria Rd. @ Blairsville); N-16 (3.2 km SE DeSoto); N-12 (Rt. 127 S Murphysboro); N-23 (4.8 km E Johns Spur); N-99 (Rattlesnake Ferry). ND = not determined.

	Site							
Community categories, metrics, and ratings	N-06	N-11	N-17	N-16	N-12	N-23	N-99	Totals
Species richness/composition								
Total species	18	15	20	16	21	16	21	33
Sucker species	2	4	2	4	4	3	4	6
Sunfish species	5	4	7	4	4	2	5	7
Darter species	0	0	0	0	0	0	0	0
Intolerant species	2	3	1	2	2	1	2	4
Trophic composition (%)								
Green sunfish	0	0	1.5	0	0	0	0	0.2
Omnivores	30.5	42.2	39.7	48.1	43.8	36.8	18.7	33.9
Insectivorous cyprinids	6.0	0	2.3	2.8	0	1.1	0.4	2.1
Carnivores	13.0	15.7	10.7	12.3	21.0	24.1	14.5	15.1
Fish abundance/condition								
Proportion of hybrids	0	0	0	0	0	0	0	0
Proportion diseased	ND	ND	ND	ND	ND	ND	ND	ND
Total no. individuals	200	83	131	106	105	87	235	947
Index of Biotic Integrity (AIBI)	38.2	38.2	36.0	36.0	33.8	31.6	38.2	
Stream quality assessment	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Stream classification (BSC)	C	C	C	C	C	C	C	

scores among nine sites sampled in the system in 1989. Except for Little Galum Creek, the other major streams in the Galum Creek system have been diverted and modified as a result of mining activities. The higher AIBI values in the undiverted Little Galum Creek were because of the presence of more native species, particularly darters and suckers.

Fish Contaminants

In 1988, Hite et al. (1991) removed 48 fish representing six species (29 common carp, 1 bigmouth buffalo, 1 flathead catfish, 15 channel catfish, 1 spotted bass (*Micropterus punctulatus*), 1 walleye) from four mainstem sites on the Big Muddy River for contaminant analysis (Table 4). Chlordane, DDT, and PCB's occurred at low levels but attest to the persistence and probably widespread historical use of these compounds in the watershed. Total mercury concentrations were higher in some common carp fillets from river samples than in those from Crab Orchard Lake but did not warrant issuance of a consumption advisory (Hite et al. 1991). The sources of mercury in the drainage are probably from sewage and industrial effluents.

Changes in Fish Assemblages

The 12 collections (Table 1) made in the drainage between 1892 and 1900 contained 45 native species and 1 exotic (Forbes and Richardson 1908). A. C. Bauman made 10 collections in 1939–40 totaling 58 native species and 1 exotic. The surveys of W. M. Lewis from 1950 to 1959 included at least 30 collections containing 64 native species and 1 exotic. P. W. Smith and his colleagues made 65 collections in the drainage from 1963 to 1978 and found 67 native species and 2 introductions. From 1980 to 1992, we made 55 collections in the drainage and recorded 71 native species and 9 introductions. Species richness during each of these periods plotted against the respective number of collections indicates that richness primarily is a function of effort (Fig. 4). Considering sampling techniques, sampling period, effort, and locations sampled, the overall native species composition from several decades of record has changed only moderately in the Big Muddy River drainage (Table 1). Except for some large-river fishes known only from near the mouth of the river, presumed extirpated species, and the more recent fish introductions, Bauman's

Table 4. Concentrations of organochlorine compounds, mercury, and lipids in whole fish samples at selected sites in the Big Muddy River mainstem, 1988 (Hite et al. 1991). Results are as μg/g (parts per million) except as otherwise noted.

Station[a]	Species	Sample type	No. of fish	Length (mm)	Weight (g)	Lipid (%)	Total mercury	Total chlordane	Alpha + gamma chlordane	Dieldrin	Total DDT	Total PCB's	Heptachlor epoxide
N-06	Spotted bass	whole	1	272	300	2.0	0.15	0.09	0.03	0.01[b]	0.04	0.14	0.01[b]
	Flathead catfish	whole	1	458	1090	1.2	0.30	0.07	0.03	0.01[b]	0.02	0.12	0.01[b]
	Bigmouth buffalo	whole	1	437	1180	0.4	0.17	0.02[b]	0.02	0.01[b]	0.03	0.19	0.01[b]
	Common carp	whole	1	465	1340	2.9	0.36	0.07	0.04	0.01[b]	0.02	0.13	0.01[b]
N-11	Common carp	whole	1	487	1420	4.4	0.37	0.33	0.14	0.01	0.09	0.46	0.01[b]
	Common carp	whole	1	455	1150	7.5	0.23	0.53	0.26	0.01[b]	0.12	0.53	0.01
N-12	Walleye	whole	1	467	870	3.1	0.83	0.26	0.11	0.01[b]	0.18	0.89	0.01[b]
	Channel catfish	whole	1	443	710	4.8	0.13	0.17	0.07	0.01	0.15	0.61	0.01[b]
	Common carp	whole	1	411	910	6.3	0.32	0.26	0.11	0.02	0.34	0.78	0.01[b]
N-06	Common carp	fillet	5	398[c]	744[c]	2.5	0.33	0.07	0.05	0.01[b]	0.03	0.29	0.01[b]
N-11	Channel catfish	fillet	4	365[c]	423[c]	0.8	0.45	0.03	0.02[b]	0.01[b]	0.11	0.10[b]	0.01[b]
	Common carp	fillet	5	389[c]	689[c]	1.0	1.05	0.04	0.02[b]	0.01[b]	0.02	0.10[b]	0.01[b]
	Common carp	fillet	5	381[c]	705[c]	3.8	0.89	0.21	0.11	0.01	0.05	0.22	0.01[b]
N-12	Channel catfish	fillet	5	396[c]	554[c]	1.7	0.36	0.03	0.02[b]	0.01[b]	0.03	0.10	0.01[b]
	Common carp	fillet	5	455[c]	1327[c]	1.8	0.80	0.11	0.05	0.01[b]	0.07	0.13	0.01[b]
N-99	Channel catfish	fillet	5	374[c]	499[c]	1.6	0.45	0.05	0.03	0.01[b]	0.04	0.10	0.01[b]
	Common carp	fillet	5	400[c]	822[c]	1.6	0.85	0.02	0.02[b]	0.01[b]	0.03	0.10[b]	0.01[b]

[a] Sample sites are identified in Table 3.

[b] Less than detection limit.

[c] Average length and weight of multiple fish.

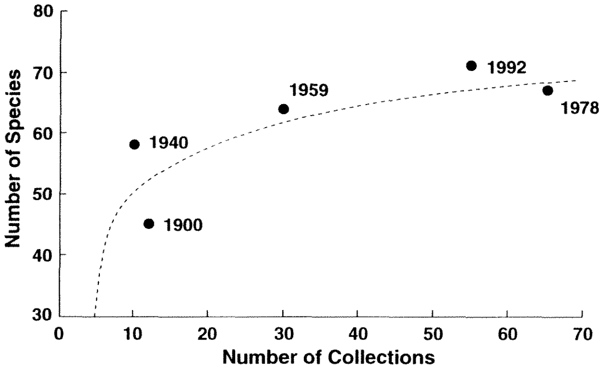

Fig. 4. Relation between fish species diversity and sampling effort (number of collections) over time in the Big Muddy River drainage. Years correspond to the five eras as discussed in the text: 1900 (Forbes and Richardson); 1940 (A. C. Bauman); 1959 (W. M. Lewis, Sr.); 1978 (P. W. Smith); and 1992 (B. M. Burr). The line was fitted by visual inspection.

samples from 1939–40 seem to be representative of the present known native fish fauna. This interpretation of the data, however, may be misleading and may overlook some important subtleties. For instance, could Bauman's results of 58 species in 10 collections be repeated today? We suspect not.

Changes in the fauna are not as readily apparent in species richness as in assemblage structure. Examination of Bauman's collection records from tributaries and comparison with other collections from the same localities made at later dates (Table 5) demonstrate rather striking changes in cyprinid fish assemblages over time. For example, one site on the Little Muddy River near Tamaroa has been sampled for maximum species diversity and abundance on four different occasions (Table 5). Three species (cypress minnow, pallid shiner, pugnose minnow) taken in Bauman's samples have not been collected at this site in over 50 years. Interestingly, Bauman did not collect any of the tolerant cyprinids that are now common at this site and elsewhere in the drainage. Even in 1963, the now abundant red shiner was not present at this site. The original cyprinid assemblage at the Little Muddy River site and elsewhere in the basin appears to have been replaced by aggressive minnows (e.g., red shiner, common carp) that are either tolerant of a wide range of chemical and physical parameters (i.e., dissolved oxygen, temperature, turbidity, siltation) or spawn readily in disturbed habitats (e.g., ribbon shiner [*Lythrurus fumeus*], redfin shiner). Considering the dramatic physical and chemical alterations that have occurred in the drainage for over 100 years, the permanence of the bulk of the fauna is a testament to the ability of fish communities to respond and persist under a variety of stochastic processes.

Discussion

As a matter of historical record, we have emphasized the many changes that have taken place in a century of use by humans living, working, and recreating in the Big Muddy River drainage. From written history, the river always has displayed lowland characteristics, and because of its muddy banks, predominantly silt substrate, and sluggish flow has never been particularly popular with anglers, boaters, and other potential users. The drainage also has been as abused environmentally as any in the Midwest; conversely, portions of the drainage are as scenic (e.g., Little Grand Canyon, Giant City State Park) and heavily used for a variety of purposes as any in Illinois. Except for the heavy angling use on reservoirs, the fishery resources have been underused historically in the river. Several small upland streams in the basin contain significant populations of spotted bass, and the mainstem maintains large populations of important commercial and sport fishes and smaller populations of desirable sport fishes, all of which have received little fishing pressure, as judged from surrounding areas.

Illinois is a model state in view of its excellent database documenting changes in fish distributions over time. Although we have learned a great deal about the effects of human activities on the aquatic environment in the Big Muddy River, we must continue to conduct basic survey work on its fish populations and to document long-term changes in the fauna. Because fishes are sensitive indicators of environmental quality, continued collection of data will aid in monitoring a variety of stream-quality parameters and assist public agencies in identifying quality habitats in need of protection. Many of the smaller streams in the Big Muddy watershed have never been sampled adequately for fishes or had their environments assessed in any modern sense.

Because of the number of species extirpated or endangered in the Big Muddy River drainage, we need to establish a monitoring program and status surveys of species on the watch list. The most effective course of action might be to allocate funds and efforts on species that may be realistically

Table 5. Changes in the minnow (*Cyprinidae*) fauna over time as recorded from Little Muddy River, 8 km east Tamaroa, Jefferson County, Illinois. Data are number of specimens collected.

Species	Bauman 1940	Smith et al. 1963	Burr & Mayden 1979	Burr & Warren 1988
Hybognathus hayi	37			
Hybopsis amnis	2			
Opsopoeodus emiliae	3			
Notemigonus crysoleucas	62	4		
Semotilus atromaculatus	1	2		
Lythrurus fumeus		10	5	10
L. umbratilis		6	35	2
Pimephales notatus		11	6	41
Cyprinella lutrensis			17	57
Cyprinus carpio				4

recoverable, rather than expending efforts on species already nearing extirpation in the basin.

Over the past several years, we have come to recognize that single-species fish management, developed largely to placate the perceived needs of predominant users (i.e., anglers), often results in overly expensive programs emphasizing simplified ecological principles and low biological diversity. Future management practices should strongly consider a fish-community approach that encompasses an entire basin and its fauna, not just the artificial milieu of reservoirs. In view of this, more funding is needed for studies on basic fish biology, especially nonsport fishes, emphasizing reproductive biology, trophic ecology, predator-prey interactions, and parasites and diseases.

Game and sportfishes have been stocked in Big Muddy River reservoirs for years. Observations by several biologists have confirmed that many of these species disperse over the dams, and their presence has been confirmed in the tributaries and mainstem. The ecological effects on stream fishes never subjected to such major predators as striped bass and muskellunge are unknown but are probably detrimental. In addition, the long-term ecological and economic effects of the recently introduced Eurasian carps (i.e., grass and bighead carps), both of which are documented here for the first time to be either reproducing in the river or using it as a nursery area, are again unknown. We strongly recommend discontinuance of stocking of nonnative sportfishes and nonnative forage species until their effects on the river fauna can be monitored and assessed.

An education program for potential users of the Big Muddy River could be developed to convince anglers to seek out fish in the drainage because its "muddy" condition is natural. In addition, resource managers could control harvest of sportfishes to create a trophy fishery for catfishes. This might attract anglers and thus build a base of concerned users.

While environmental problems of nearly every conceivable kind have plagued many of the tributaries and parts of the mainstem for decades, recent changes in legislation and regulation regarding wastewater treatment, strip-mine reclamation, and water quality standards have greatly improved the condition of the river and presumably the fish populations. Much of the previous pollution that continued unabated for years has now been either halted, or plans for improvement are being implemented. These improvements probably will not allow recovery of already extirpated species but may allow rare species to survive in the habitat available.

The drainage of wetlands adjacent to the river has historically eliminated spawning and nursery areas for some species and year-round habitat for others. We recommend that wetland drainage be halted on any scale until an ecological plan for the entire drainage can be formulated. Moreover, we advocate recovery of lost riparian wetlands and the development of a land acquisition program to achieve more wetlands in the watershed. Likewise, reservoir construction and stream channelization also should be discontinued because of the destructive effects these practices have on large expanses of stream habitat.

Some practical and economically feasible suggestions (Davin and Sheehan 1992) to increase use of the Big Muddy River include (1) improving stream access sites (e.g., clean-up silt loads at boat ramps), (2) providing more support facilities near access sites, and (3) adding additional access sites to provide opportunity for additional use of the resources. In addition, we recommend establishment of permanent mainstem and tributary sampling stations where annual or biannual standard (i.e., CPUE) monitoring can be conducted.

There is still a need to identify stream segments of exceptional quality in the Big Muddy River drainage that warrant special consideration for protection. Continued vigorous reclamation of abandoned mine lands and treatment of acid mine drainage is imperative. Finally, we must focus greater emphasis on the importance of valuable stream resources and an awareness of where these resources exist.

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Article

Effects of High Salinity Wastewater Discharges on Unionid Mussels in the Allegheny River, Pennsylvania

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Abstract

We examined the effect of high salinity wastewater (brine) from oil and natural gas drilling on freshwater mussels in the Allegheny River, Pennsylvania, during 2012. Mussel cages ($N = 5$ per site) were deployed at two sites upstream and four sites downstream of a brine treatment facility on the Allegheny River. Each cage contained 20 juvenile northern riffleshell mussels *Epioblasma torulosa rangiana*). Continuous specific conductance and temperature data were recorded by water quality probes deployed at each site. To measure the amount of mixing throughout the entire study area, specific conductance surveys were completed two times during low-flow conditions along transects from bank to bank that targeted upstream (reference) reaches, a municipal wastewater treatment plant discharge upstream of the brine-facility discharge, the brine facility, and downstream reaches. Specific conductance data indicated that high specific conductance water from the brine facility (4,000–12,000 μS/cm; mean 7,846) compared to the reference reach (103–188 μS/cm; mean 151) is carried along the left descending bank of the river and that dilution of the discharge via mixing does not occur until 0.5 mi (805 m) downstream. Juvenile northern riffleshell mussel survival was severely impaired within the high specific conductance zone (2 and 34% at and downstream of the brine facility, respectively) and at the municipal wastewater treatment plant (21%) compared to background (84%). We surveyed native mussels (family Unionidae) at 10 transects: 3 upstream, 3 within, and 4 downstream of the high specific conductance zone. Unionid mussel abundance and diversity were lower for all transects within and downstream of the high conductivity zone compared to upstream. The results of this study clearly demonstrate in situ toxicity to juvenile northern riffleshell mussels, a federally endangered species, and to the native unionid mussel assemblage located downstream of a brine discharge to the Allegheny River.

Keywords: mussels; endangered; conductivity; chloride; toxicity; brine; wastewater

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Introduction

Oil and natural gas development and extraction have occurred in western Pennsylvania for >150 y. Natural gas extraction increased from 2008 to 2012 in Pennsylvania, Ohio, and West Virginia as a result of technological advances in drilling. In Pennsylvania alone, 30,784 new drilling permits for oil, gas, and coal bed methane were issued between 2008 and 2012 compared to 12,324 in 2000 to 2004 (Pennsylvania Department of Environmental Protection [PADEP] 2013). Extraction of petroleum produces high salinity water that flows to the surface in advance of the oil or gas. This sodium–calcium–chloride solution (hereafter “brine”) is more concentrated than seawater and is produced by more than 95% of the Pennsylvania oil and gas wells sampled to date (Dresel and Rose 2010). Discharge of brine from oil and gas drilling has been linked anecdotally to dramatic declines of mussels of the family Unionidae (Williams 1969), yet substantiating field studies are lacking. Considering the continued and expanding development of oil and natural gas reserves, it is important to understand the effects of permitted discharges of brine treatment wastewater and accidental releases of brine on unionid mussels, particularly at-risk mussels, some of which are confined to streams that continue to receive substantial discharges of high salinity wastewater.

The PADEP is evaluating a statewide chloride water quality criterion for the protection of aquatic life based on U.S. Environmental Protection Agency (EPA) and Iowa evaluations. The current EPA 304(a) national criteria for chloride are 860 mg/L for acute exposures and 230 mg/L for chronic exposures (EPA 1988). The EPA has obtained additional toxicity testing data (EPA 2008). The acute toxicity of chloride to four freshwater invertebrate species (water flea *Ceriodaphnia dubia*, fingernail clams *Sphaerium simile* and *Mucsulium transversum*, planorbid snail *Gyraulus parvus*, and tubificid worm *Tubifex tubifex*) was determined under different levels of water hardness and sulfate concentrations (Soucek et al. 2011). The fingernail clam *S. simile* was most sensitive to chloride. Increased hardness was found to ameliorate the acute toxicity of chloride for three species, whereas sulfate appeared to have a negligible additive effect on chloride toxicity to *C. dubia* (Soucek et al. 2011). Although EPA has not acted on these new data, Iowa Department of Natural Resources (IADNR) incorporated them with data from 31 other species to derive new chloride criteria of 254.3 (acute) and 161.5 mg/L (chronic) with hardness and sulfate corrections (IADNR 2009). In 2013, Indiana adopted this same approach in the Indiana Administrative Code (IAC 2013). Given that a fingernail clam was the most sensitive species tested for chloride toxicity and that water quality criteria are not designed to protect the most sensitive species (EPA 2012), it is necessary to evaluate the degree to which recently adopted or proposed criteria are protective of unionid mussels, particularly those that are listed as threatened and endangered pursuant to the US Endangered Species Act (ESA 1973, as amended).

The Canadian Council of Ministers of the Environment (CCME) developed chloride criteria using a species sensitivity distribution approach (CCME 2011). The substantial difference from the EPA approach is the inclusion of toxicity data for larval unionid mussels (glochidia), obligate parasites on fish for several weeks before transforming to free-living juvenile mussels. The resulting CCME acute and chronic chloride criteria are 640 and 120 mg/L, respectively. In contrast to the Iowa criteria, the CCME criteria are not adjusted for sulfate or hardness because the number of suitable chronic exposure studies for these factors did not meet data requirements. The CCME criteria are also designed to protect the most sensitive life stage of the most sensitive species. As these chloride criteria are based on multiple species of unionid mussels, they may be more relevant to waters supporting threatened and endangered unionid mussels (ESA 1973), such as the Allegheny River in Pennsylvania.

Studies examining the toxicity of chronic chloride exposures to unionid mussels are limited. All life stages are highly sensitive to elevated chloride concentrations in acute exposures (Bringolf et al. 2007), but sensitivity varies substantially among unionid species and glochidia are particularly sensitive to acute exposures (Gillis 2011; Echols et al. 2012). Glochidia of three *Epioblasma* species were nearly an order of magnitude more acutely sensitive to methylmercuric chloride than *Villosa iris* glochidia (Valenti et al. 2006). Fewer studies have been conducted using juvenile unionids to evaluate a chronic (28-d) exposure period for chloride. Survival of juvenile *V. iris* was reduced by 56% after exposure for 28 d to brine at 2,625 μS/cm (chloride not reported; Echols et al. 2012). Chronic exposure studies are unavailable for juvenile northern riffleshell mussel *Epioblasma torulosa rangiana*; northern riffleshell, hereafter NRS). Juvenile unionid mussel studies are lacking for exposures greater than 28 d that would be more representative of chronic exposures in the wild.

The purpose of this study was to assess the mixing of oil and gas high salinity wastewater discharges and determine its toxicity to mussels in the Allegheny River in Pennsylvania. This river is of particular interest because it has low water hardness, which reduces the potential for amelioration of chloride toxicity (Soucek et al. 2011), and it supports a diverse unionid mussel assemblage including several species listed as endangered under the ESA (Villella and Nelson 2006). Specifically, we used a triad approach to 1) document brine concentrations and mixing throughout the river channel, 2) determine chronic exposures to ambient brine concentrations that are lethal to juvenile NRS based on in situ exposures and, 3) assess the effects of brine on adult unionid mussel distribution.

Study Site

The study was conducted during 2012 in the Allegheny River at Warren, Pennsylvania, from the confluence of Conewango Creek to Mead Island (Figure 1). This location met the study criteria of 1) available water quality data obtained from probes deployed on August 11, 2011, as part of regional and national EPA studies; 2) the presence of suitable unionid mussel habitat based on previous surveys; 3) a high saline discharge; and 4) an established U.S. Geological Survey (USGS) streamflow-gaging station where stage and discharge are continuously recorded. The study area receives effluent from the Warren municipal wastewater treatment plant as well as the Waste Treatment Corporation brine treatment plant (hereafter referred to as brine treatment facility), which is authorized to receive and discharge high saline wastewater. The high saline wastewater is generally discharged Monday through Friday for 8–15 h a day. The timing and duration of the discharge vary with the amount of brine received by the treatment plant.

The average monthly flow of the Allegheny River varies from generally less than 56.5 cubic meters per second (cms; about 2,000 cubic feet per second [cfs]) to more than 396 cms (about 14,000 cfs) in some years, as measured at USGS streamflow-gaging station 03015310 Allegheny River below Conewango Creek at Warren. Streamflow in the study reach is affected by regulation from the Allegheny Reservoir (station 03012550 Allegheny

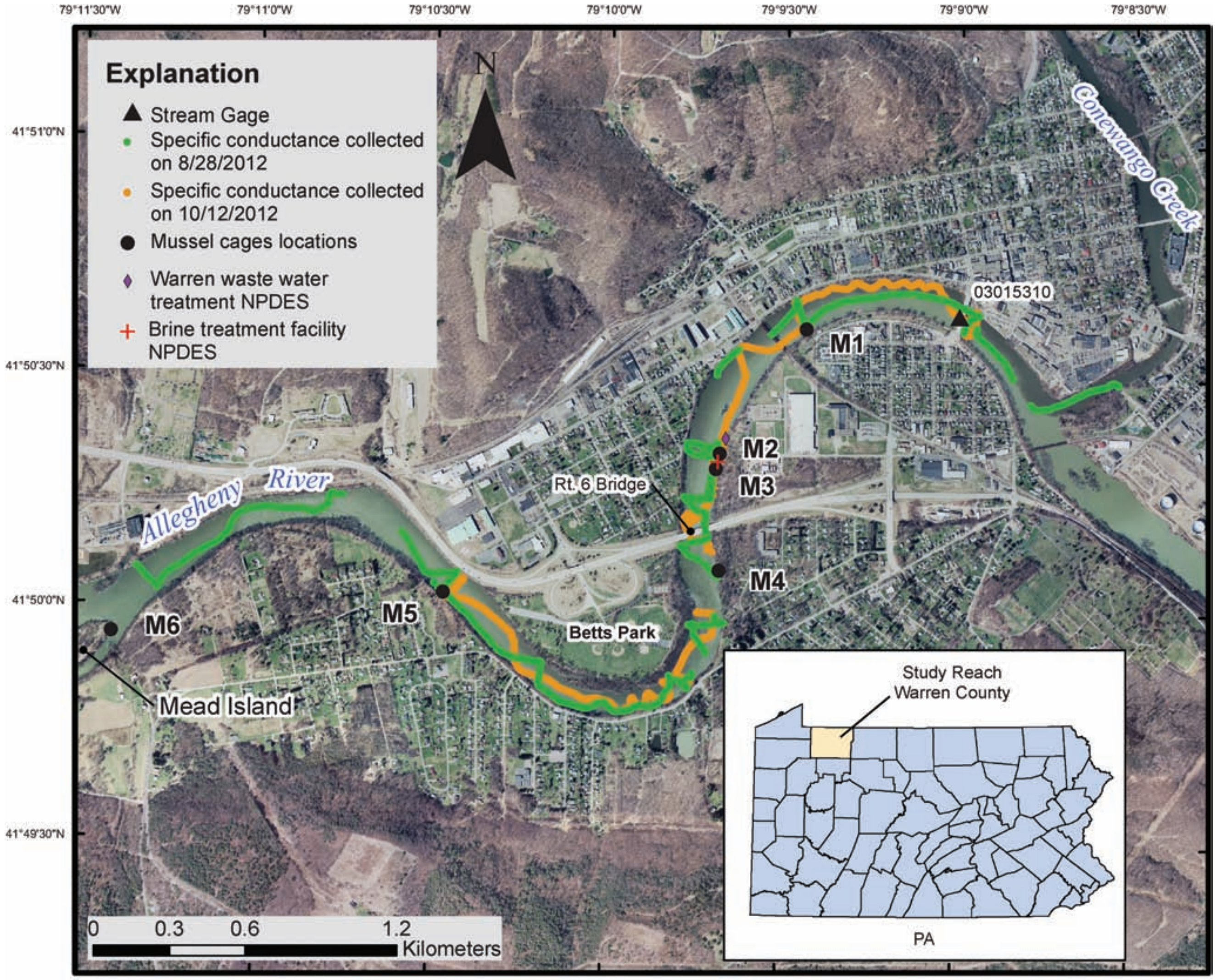

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Figure 1. Allegheny River study area at Warren, Pennsylvania, depicting northern riffleshell mussel *Epioblasma torulosa rangiana* cage sites M1 (upstream), M2 (Warren wastewater treatment discharge), M3 (brine treatment facility wastewater discharge), M4 (first downstream location), M5 (second downstream location), and M6 (final downstream location), Warren wastewater treatment discharge, brine treatment facility wastewater discharge, and specific conductance transect locations during the study period (August 11–October 16, 2012).

River at Kinzua Dam, 18.9 km upstream of 03015310) and streamflow from Conewango Creek (station 03015000 Conewango Creek at Russell, approximately 13 km upstream of the junction of Conewango Creek and the Allegheny River). Flow from these three stations during the study period from August 11 to October 16, 2012, is available in Supplemental Material (Figure S1). Instantaneous discharge at station 03015310 ranged from 34.83 to 78.15 cms and was generally steady and near long-term median values until September 22, after which time flow was below long-term median values (http://nwis.waterdata.usgs.gov/pa/nwis/uv/?cb_00060=on&format=gif_default&period=&begin_date=2012-08-11&end_date=2012-10-16&site_no=03015310).

In the study location, the river is about 100 m wide and consists of a series of pools and riffles. Based on previous surveys cataloged by the Pennsylvania Natural Heritage Program (PNHP 2014), mussels inhabit the river upstream, within, and below the study reach in areas with gravel and cobble substrate. During the surveys, the water depth was generally between 0.5 and 1 m, with the riffle areas less than 0.3 m deep. Pools were 3–5 m deep throughout the reach. Water quality samples were collected at the US Route 6 bridge, about 3 km upstream of the Conewango Creek, six times per year as part of the PADEP Water Quality Network monitoring and analyzed for parameters such as specific conductance, pH, hardness, major and minor ions, and nutrients (http://nwis.waterdata.usgs.gov/pa/nwis/qwdata/?site_no=03012600&agency_cd=USGS&); these data indicate chloride concentrations commonly are less than 20 mg/L at this upstream site on the Allegheny River.

We established six sampling sites denoted M1–M6 within the study reach (Figure 1) for collection of water quality data and placement of cages for in situ juvenile

NRS exposure trials. The sites were located upstream (M1) and downstream (M2) of the Warren municipal wastewater treatment plant, downstream of the brine treatment facility jetty that effectively limits exposure to only the brine effluent (M3), and at three sites at increasing distances downstream of the discharges (M4–M6).

Methods

Basic water quality sampling

Specific conductance probes were deployed to provide data for selection of study sites and to determine the relationship between conductance and ion concentrations. We evaluated hourly specific conductance and water temperature data from EPA's regional monitoring probes (HOBO U24-001 conductivity data logger; Onset) deployed on August 11, 2011 (these locations became M1, M4, and M6 in this study; Figure 1). The USGS deployed In-Situ Aqua Troll 100 specific conductance and temperature probes at sites M2, M3, M4 (redundant probe used to demonstrate consistency between probe models), and M5 on August 1, 2012. The EPA and USGS probes were set to record at 15-min intervals from the beginning of the mussel exposure period (day 0 on August 14, 2012) and collected when the mussels were removed (day 63 on October 16, 2012). During the course of the study, we cleaned and transferred data from the probes three times (August 1 [EPA probes only], August 28, and October 26). We measured instantaneous specific conductance and water temperature at deployment, each data transfer and at final retrieval with a model 6820V2 multiparameter (YSI) or MS-5 multiprobe (Hydrolab). Meters were calibrated with conductance standards to permit adjustment of the probe data with the instantaneous readings in accordance with agency protocols (Wagner et al. 2006).

Water grab samples were collected on two separate occasions by EPA and PADEP. The EPA analyzed water samples collected on October 4, 2012, from all six mussel cage sites (A. Bergdale, EPA R3, personal communication). The PADEP collected water samples on October 18, 2012, at five locations from immediately upstream of the municipal wastewater discharge to immediately upstream of M4, including a location between M2 and M3 (Brancato and Williams 2013). We used analytical water quality data from these samples to define the relationship between conductance and ion sum (chloride, bromide, sulfate, nitrate, lithium, sodium, ammonium, magnesium, and calcium) and conductance and chloride.

Distribution and mixing of brine contamination

To define the zone of high conductance and areas of mixing, we measured conductance along transects in the river channel during two separate low flow events. We sampled the transects on August 28 and October 12, 2012, when the mean discharge was 57.48 cms (2,030 cfs) and 45.87 cms (1,620 cfs), respectively (Figure S1); these values are less than the average monthly mean for August of 80.14 cms (2,830 cfs) for 1988–1998. Based on a typical low-flow day of 49.27 cms (1,740 cfs) the travel time of the brine plume from M3 to M6 is approximately 2.5 h (graphs for this analysis are shown in Figure S3). We began transect sampling after the brine plant had been discharging for at least 2 h (as evidenced by a rise in conductance). The exact location of transects differed slightly between sampling dates, but both encompassed nearly the entire length of the study reach from the mouth of Conewango Creek downstream to M5 or M6 (Figure 1). Upstream of the brine treatment plant, transects generally proceeded longitudinally down the river channel (roughly parallel to flow). Downstream of this point, we sampled bank to bank in a downstream direction to cover as much of the cross-sectional area of the channel as possible. In addition, we sampled across the channel (perpendicular to flow) at each sampling site and at likely water mixing areas, such as downstream of riffles and bridges.

During both events, we measured specific conductance and water temperature at midcolumn depth every 5 s with a calibrated MS-5 probe located at the front of a jon boat equipped with a 2.5-horsepower engine. At depths greater than 1.5 m, we measured vertical specific conductance profiles to assess any differences throughout the water column. At no time was a difference seen in the vertical column, indicating vertical mixing; therefore, we did not change the sampling strategy based on depth. Due to the draft of the boat, we did not collect data where the water was very shallow (e.g., flowing over riffles) and when water velocity was great enough to force the probe out of the water. The geographic position of the probe was recorded with a RiverSurveyor M9 (Sontek M9; Sontek) system, an acoustic Doppler current profiler (ADCP) equipped with a global positioning system (GPS) that also records water velocity and depth. We deployed the Sontek M9 in a tethered float off the front of the boat. Due to separation of the GPS antenna and the water quality probe, the probe reading locations have a precision of ±1.5 m.

In situ juvenile mussel exposures

Juvenile NRS were cultured at the USFWS White Sulphur Springs National Fish Hatchery, White Sulphur Springs, West Virginia. Female mussels were collected in April from French Creek, Crawford County, Pennsylvania. At the hatchery, glochidia were extracted from females and infested on mottled sculpins *Cottus bairdi*. Juvenile NRS were excysted from their host fish 3–4 wk later and reared until mid-August, at which time the 2-mo-old juveniles were approximately 2 mm in length. On August 14, 2012, we placed 20 randomly selected juvenile NRS into each cage chamber.

We assessed survival of juvenile NRS under ambient brine concentrations by installing cages at each sampling site (M1–M6). Cages are flow-through, screened chambers (3 in. × 4 in. [7.6 × 10.1 cm] [diameter × height]) housed in a domed concrete base (8 in. × 6 in. [20.3 cm × 15.2 cm]) that are used for culturing juvenile unionid mussels (Barnhart 2006). We installed five cages at each of the six sampling sites. At each site, cages were placed about 1.5 m apart in a triangular array, and we placed a probe in the middle of the array for continuous water quality monitoring at the site (see Figure S2). Mean values of specific conductance during cage exposure trials were computed using only data points collected during brine discharge periods at M3 and M4 (i.e., intermittent exposure).

We assessed NRS survival, condition, and behavior at days 3, 6, 9, 14, 22, 29, 44, and 63 after installation. Each juvenile was recorded as live if we observed organ activity or presence of food through the translucent valves, foot movement, or gaping to feed during a 10-min period while the cage was held in a container of site river water. We ensured adequate water flow through the cages by cleaning the mesh and cage opening of algae and debris during each visit. Surviving juveniles were photographed at day 63 to evaluate growth. Final length of each individual from M1, M5, and M6 was measured from digital images using digital caliper software (Pixel Stick). On day 64, we released all surviving juveniles back to the site of the adult female collection in French Creek. We compared data on survival between sites using repeated measures analysis of variance with the R statistical package (R Core Team 2012). The Tukey's honestly significant difference test (de Mendiburu 2014) was used to identify significant differences between sites at days 29 and 63. Growth data were evaluated at day 63 using analysis of variance. We evaluated the relationship between survival and conductance using the Finney method of probit analysis in the BioStat (AnalystSoft, Inc. 2012) and R (R Core Team 2012) statistical software packages to identify the no adverse effect concentration (NOAEC) relative to the upstream reference (i.e., no added mortality above background).

Unionid mussel surveys

We described unionid mussel diversity, species relative abundance, and total abundance at several locations within the study reach to examine the relationship between unionid mussel assemblages and brine discharge. Using methods modified from Smith et al. (2000, 2001) we sampled unionid mussels along 10 transects located throughout the study reach; each transect was about 1 m wide and spanned the river perpendicular to flow (Figure 2). Three transects were located upstream of wastewater discharges (T1–T3), three were located immediately downstream of the discharges (T4–T6), and the other four (T7–T10) were located farther downstream. We surveyed these transects August 27–31, 2012, using a pair of divers. Each transect was divided into 10-m segments, and each diver sampled approximately 0.5 m of substrate on each side of the transect line for a minimum of 7 min. The actual sampling time necessary to search the entire segment was recorded, but some segments were not sampled due to high water velocity that made diving hazardous. When feasible, we overturned larger rocks and disturbed the upper 5–10 cm of sediment to find buried unionid mussels. We placed all collected unionid mussels in mesh bags and brought them to the surface for identification and measurement (anterior-posterior shell length) before returning them to the river. Because some species are difficult to detect (particularly small species), we augmented transect sampling data with searches of shell middens on shore to construct a species list for the area. Substrate size and composition were estimated and depth was recorded for each 10-m segment along all transects.

Results

Continuous recording probes documented significant differences in specific conductance between study sites as determined by a Wilcoxon rank-sum test. Background-specific conductance for the Allegheny River ranged from 103 to 188 μS/cm (mean 151 μS/cm) based on data collected at M1. Specific conductance measured at M2 (municipal wastewater discharge) ranged from 122 to 755 μS/cm (mean 294 μS/cm). All of the probes located downstream of the brine facility documented the daily and weekly signature of brine treatment facility (i.e., operates Monday through Friday, 8–15 h a day). When the facility was actively discharging, specific conductance at M3 ranged from 4,000 to12,000 μS/cm (mean 7,846 μS/cm). At M4, the specific conductance was 1,050 to 5,270 μS/cm (mean 3,863 μS/cm) when the brine discharge was reaching this site. The specific conductance at the most distant sites (i.e., M5 and M6) ranged from 158 to 275 μS/cm (Figure 3). The differences in the sites can be graphically represented by specific conductance duration curves. Figure 4 shows the percent of time an indicated specific conductance is exceeded at each site. For example, sites M3 and M4 exceeded 1,000 μS/cm approximately 40% of the time that the caged NRS were in situ. Data for probe graphs are included in Table S1.

The August 28, 2012, and October 12, 2012, specific conductance surveys revealed a similar pattern of low background specific conductance upstream of the brine facility, high values immediately downstream of the discharge, and an attenuation of specific conductance values in a downstream direction (Figure 5). These data also showed that the high specific conductance zone is largely restricted to a plume that parallels the left descending bank. Stream flow in the Allegheny River can affect the mixing and dilution of the high specific conductance discharge. This is illustrated by the specific conductance difference between the two surveys downstream of S4 and subsequent decreased dilution of the brine wastewater. Specific conductance data for Figure 5 are included in Supplemental Material (Table S2).

Juvenile NRS cumulative survival after 63 d showed a strong response to discharges from both brine and wastewater treatment plants (Figure 6). Mean cumulative survival (of 20 juveniles in each of five cages) upstream of both discharges (M1) after 63 d was 84%. Survival declined dramatically to 21% immediately below the wastewater discharge (M2) and to 2 and 34% immediately downstream of and approximately 0.4 km downstream of the brine discharge (M3 and M4, respectively). Mean survival at downstream sites M5 and M6 (91% for both sites) was not statistically different from M1 ($P < 0.05$) throughout the study, showing a dilution of wastewater and brine effluents. Mean survival differed significantly between M1 and M2 and M1 and M4 by day 63. The difference between M1 and M3 was significant at day 29 and persisted at day 63. Survival data for Figure 6 are included in Supplemental Material (Table S3). NRS shell length (in millimeters) was statistically lower at M1 (mean 4.6) than M5 (mean 5.1;

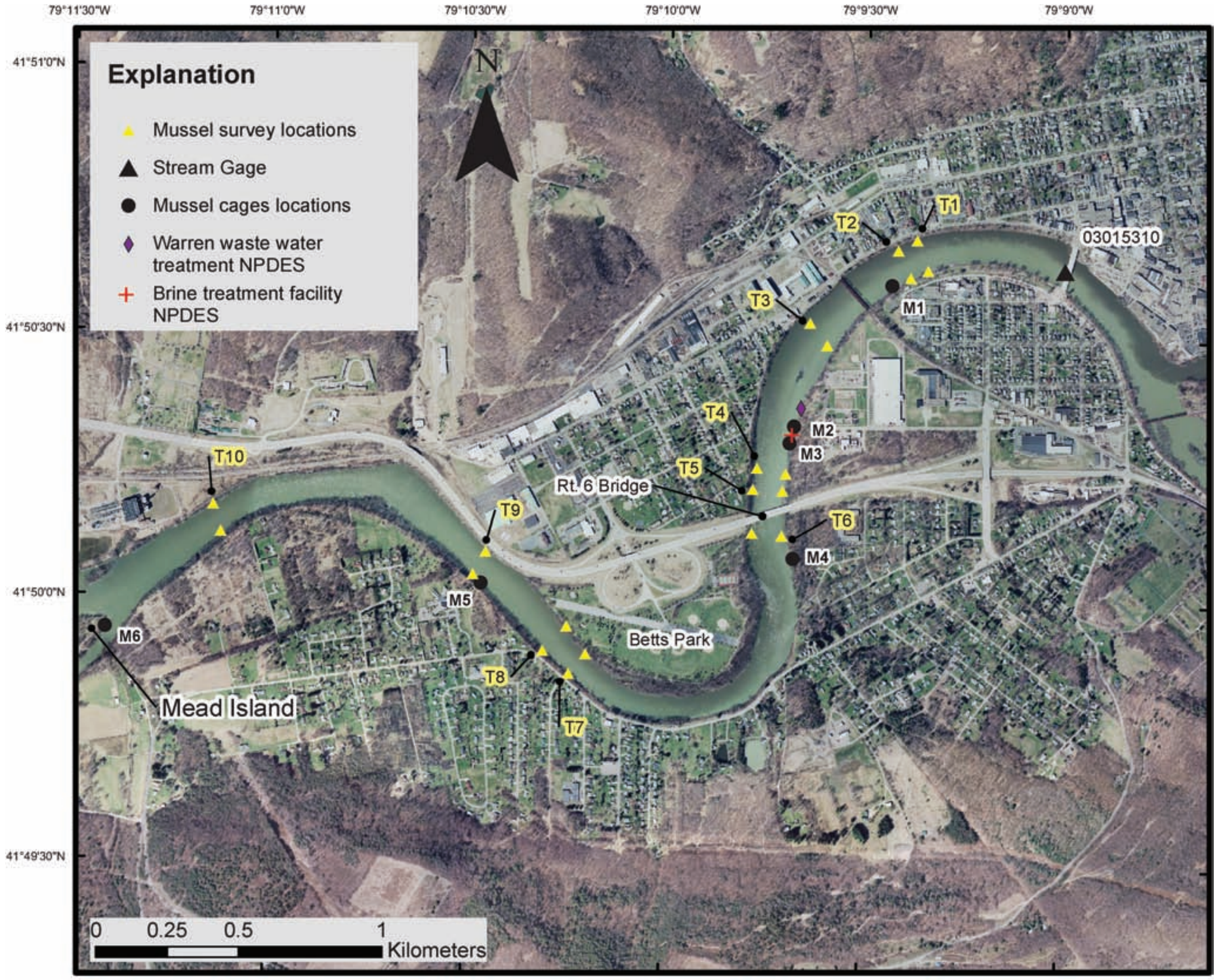

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Figure 2. Native unionid mussel transects upstream (T1–T3), within discharge (T4–T6), downstream (T7–T9), and Mead Island (T10) on the Allegheny River near Warren, Pennsylvania, surveyed by divers August 27–31, 2012.

$P < 0.001$) and M6 (mean 5.0; $P < 0.001$), but the biological relevance of this difference is unknown. Insufficient numbers of live NRS were available for M2, M3, and M4 to evaluate growth.

Variability in survival between cages and over time provides additional insight into effluent toxicity. Survival varied widely from 0 to nearly 70% among cages at M2 downstream of the municipal wastewater discharge. Due to cage placement, cages furthest into the river likely received less exposure to the plume as higher mortality was observed in the immediate vicinity of the discharge pipe (see Figure S2). This observation is consistent with benthic macroinvertebrate assessments by PADEP showing impairment at M2, but substantial recovery immediately upstream of the brine treatment discharge (Brancato and Williams 2013). In contrast, high-to-severe NRS mortality was observed in all cages at sites M3 and M4 downstream of the brine discharge, as well as severe impairment of the benthic invertebrate community (Brancato and Williams 2013). Mortality increased substantially from day 14 to day 63 at M2 and M3. The delayed and chronic nature of this rise in mortality and our observations of live juvenile NRS suggest that mussels attempted to avoid exposure by remaining closed. Unlike M2 and M3, live juvenile NRS at M1, M4, M5, and M6 were routinely agape, evidently respiring and feeding. Time series evaluation of specific conductance readings indicates that M2 discharge did not contribute significant ions to M3. In addition, our observations of minor algal growth at M3, the absence of chironomids common to sewage treatment effluent in the cages, observations of normal feeding behavior of M3 NRS when brine was not discharging, substantial recovery of benthic invertebrates between M2 and M3 (Brancato and Williams 2013), and evaluation of maximum potential WWTP contaminant exposure indicated that the severe toxicity at M3 resulted primarily from exposure to the brine discharge.

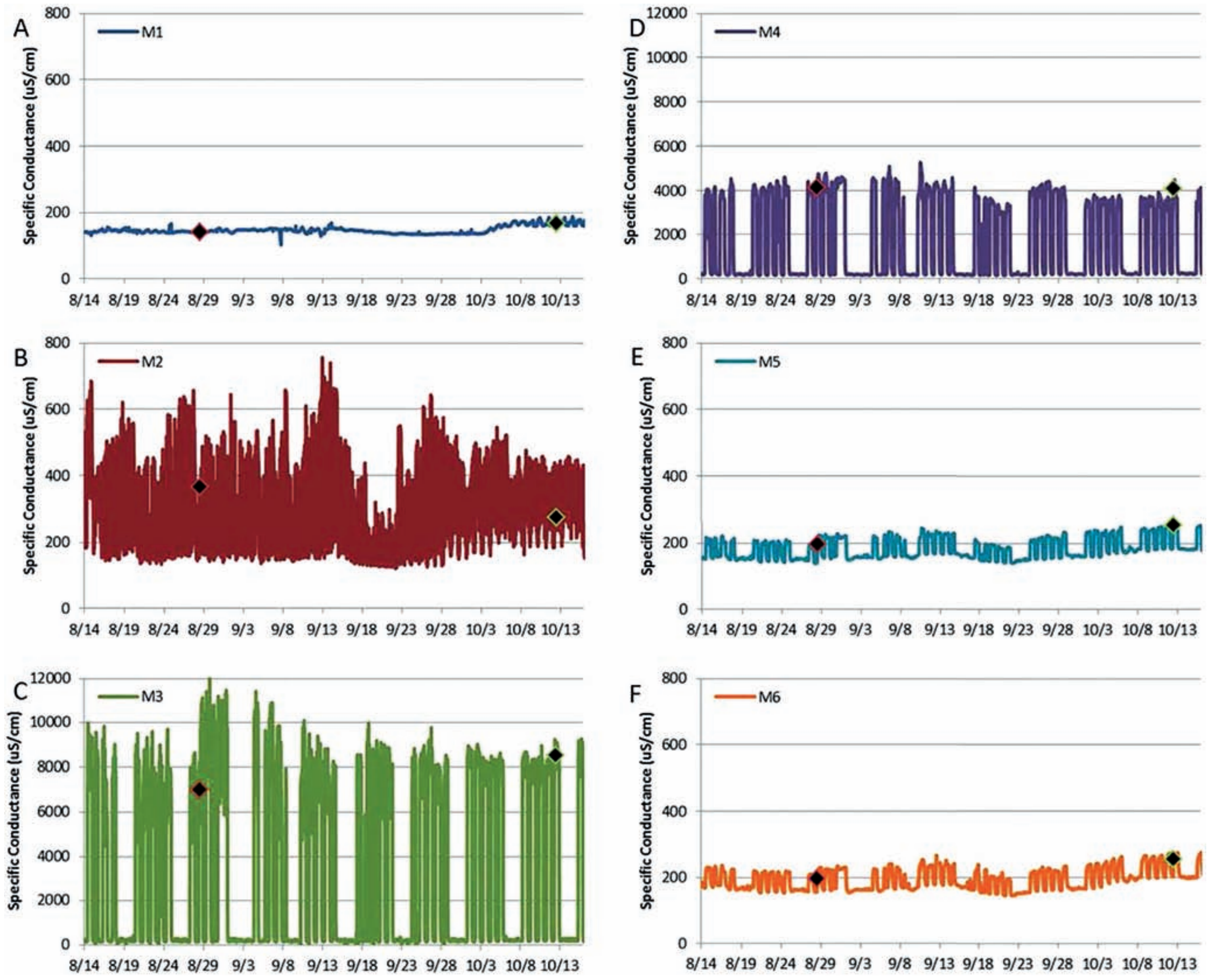

Figure 3. Specific conductance readings from probes deployed at mussel sites M1 (**A**), M2 (**B**), M3 (**C**), M4 (**D**), M5 (**E**) and M6 (**F**) on the Allegheny River near Warren, Pennsylvania, during the study period (August 11–October 16, 2012). M1, M2, M5, and M6 are shown at the same scale to show the specific conductance outside the brine plume. M3 and M4 are shown at the same scale to show the specific conductance within the brine plume. The dates when the specific conductance surveys were conducted are shown as black diamonds on each graph. All sites are significantly different from each other at the 95% confidence level as determined by a Wilcoxon rank-sum test.

A strong dose–response relationship between juvenile mortality and specific conductance was observed. Chi-square goodness of fit for the dose–response curve (Figure 7) was significant ($P = 0.003$), and linear regression of $\log_{10}$ conductivity and probit percent mortality were predictive ($r^2 = 0.9983$). Absence of juvenile exposures in the 1,000–3,000-μS/cm specific conductance range limited our ability to identify the lowest observable effect concentration or the lethal concentration 50. However, this limitation is not critical to estimating an NOAEC with two exposures (M5 and M6) exhibiting survival comparable to a reference site (M1). Data from M2 were not included in this analysis due to high variability between replicates and rapid recovery of benthic macroinvertebrate populations, indicating spatially limited toxicity as well as predominance of nonbrine contaminants (e.g., ammonia, chlorine). Conductivity data for M3 and M4 were limited to periods of active brine discharge. The highest specific conductance resulting in no adverse effect compared to background (NOAEC; 84% survival; lethal concentration 16) after 63 d of exposure is 247 (lower confidence limit 148, upper confidence limit 370) μS/cm. When calculated over the typical chronic laboratory exposure time of 28 d, the NOAEC value was 573 (lower confidence limit 224, upper confidence limit 1,095) μS/cm. Survival data for juvenile NRS monitoring are included in Supplemental Material (Table S3).

Water sample analysis indicated that the high specific conductance and ion sum concentrations from the brine discharge are driven by chloride. The EPA water samples document that 60% of the ion sum (milligrams per liter) at the brine discharge (M3) is attributable to chloride compared to 28% at the reference site (M1; Table S4). A strong linear correlation was found between specific

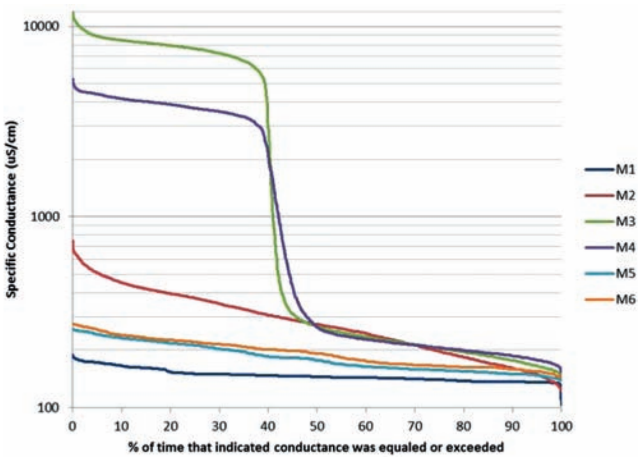

Figure 4. Graph showing the specific conductance duration curve for each cage containing northern riffleshell mussel *Epioblasma torulosa rangiana* (M1-M6) during the study period (August 11–October 16, 2012) in the Allegheny River near Warren, Pennsylvania. The percentage of time a particular specific conductance was exceeded at each silo during the study period is represented.

conductance and ion sum and between specific conductance and chloride (Figure 8). Using the NOAEC for specific conductance of 247 μS/cm, the calculated NOAECs for ion sum and chloride are 122 and 78 mg/L, respectively. Following the IADNR (2009) protocol, the chronic chloride criterion is adjusted for hardness and sulfate by the following equation:

$$\text{chronic criterion} = 161.5(\text{hardness})^{0.20579}(\text{sulfate})^{-0.0745}$$

Based on measured background hardness and sulfate at the reference site (2.338 and 0.839 mg/L, respectively; Brancato and Williams 2013), the adjusted chronic chloride criterion for the Allegheny River is 316.71 mg/L. Based on measured hardness and sulfate at the brine discharge site (4.305 and 0.779 mg/L, respectively), the adjusted chronic chloride criterion would be 541.86 mg/L. Ion concentrations for the water samples are included in Supplemental Material (Table S4).

Transect surveys further demonstrated that the unionid mussel assemblage is impaired within the plume of the brine discharge. Reduced unionid mussel abundance was evident within the discharge plume along the left descending bank downstream from the brine facility (T4–T6) through the downstream transects (T7–T9) compared to upstream (T1–T3) and Mead Island (T10; Figure 9). Mean abundance along the left descending side (0–40 m) was 7 (range 3–10) for upstream, 0.8 (0–2) near the discharge, 0.3 (0–1) downstream of the brine treatment discharge, and 9.5 (2–20) at Mead Island. Species richness was also reduced within the high specific conductance zone, as well as in mussel habitat downstream compared to upstream of the discharge (Figure 10). Mean species number was 3.6 (range 2–6) upstream, 1.5 (0–3) near the discharge, 0.3 (0–1) downstream of the discharge, and 3.5 (2–4) at Mead Island. Most of the unionid mussel species native to the Allegheny River, including NRS, are associated with clean-swept cobble and gravel substrates in riffle-and-run flow (Ortmann 1919; Parmalee and Bogan 1998; Smith and Crabtree 2010; USFWS 1994; Watters et al. 2009). With the exception of the right descending bank at Mead Island, the substrate and overall habitat conditions in all transects was comparable to that in other reaches of this river supporting large numbers of unionid mussels. Furthermore, although not the target of this study, divers reported other species often associated with Allegheny River mussel assemblages including darters (*Etheostoma* sp.) and hellbenders *Cryptobranchus alleganiensis*. Adult NRS were documented at T7 near the right descending bank and transect T10 near the left descending bank. Living and freshly dead shells of NRS were also located on the right descending bank near T7 and T8 outside of the transect survey area. Transect data are included in Table S5.

Discussion

Using a triad approach, we defined the zone of high conductivity resulting from brine discharge, demonstrated direct toxic effects to the endangered NRS (ESA 1973), and identified direct and potential indirect changes in unionid mussel communities within and downstream of the high specific conductance zone in the Allegheny River near Warren, Pennsylvania. The chemical and transect data define a zone of high specific conductance where the plume from the brine facility influences water quality. The plume was virtually unmixed along the left descending side of the river until it reaches the first pool 0.45 mi (724 m) downstream of the discharge. Daily and weekly signatures of the brine facility discharge were evident to the furthest point that we assessed over 2 mi (3 m) downstream. The area encompassed by the high specific conductance zone that we observed during this study was specific to the flow and effluent discharge conditions under which we took measurements. A change in volume or concentration of the discharge or river flow would likely alter the area of the high specific conductance zone and could result in periodic expansion and contraction of the mixing zone.

The in situ toxicity trials showed a clear negative effect of brine exposure on NRS survival, and probit analysis demonstrated that specific conductance was a suitable parameter for predicting juvenile NRS survival. Chloride is the presumed primary toxin based on known unionid sensitivity to this ion from laboratory testing (CCME 2011).

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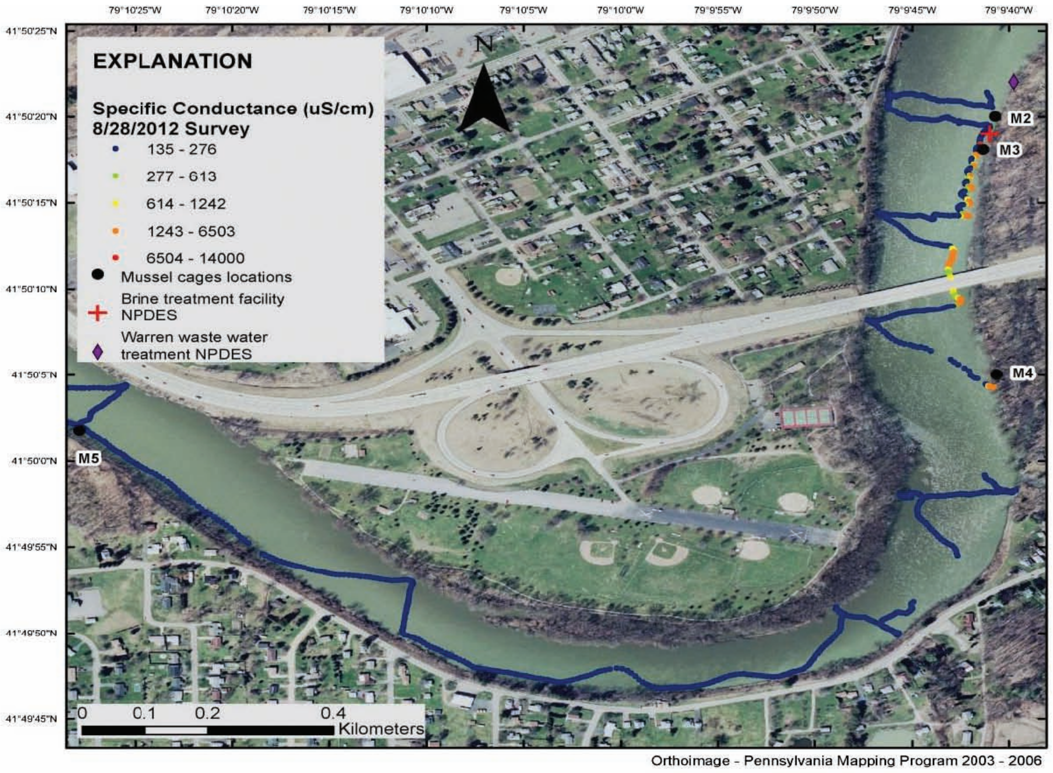
Figure 5. Specific conductance readings for the reach between M2 (Warren wastewater treatment discharge) and M5 (second downstream location) in the Allegheny River near Warren, Pennsylvania, based on the August and October 2012 transect sampling events. All values upstream of M2 and downstream of M5 were less than 246 μS/cm.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79°9'45"W
79°9'40"W
41°50'25"N
41°50'20"N
41°50'15"N
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EXPLANATION
Specific Conductance (uS/cm)
8/28/2012 Survey
135 - 276
277 - 613
614 - 1242
1243 - 6503
6504 - 14000
Mussel cages locations
Brine treatment facility NPDES
Warren waste water treatment NPDES
N
M2
M3
M4
M5
0
0.1
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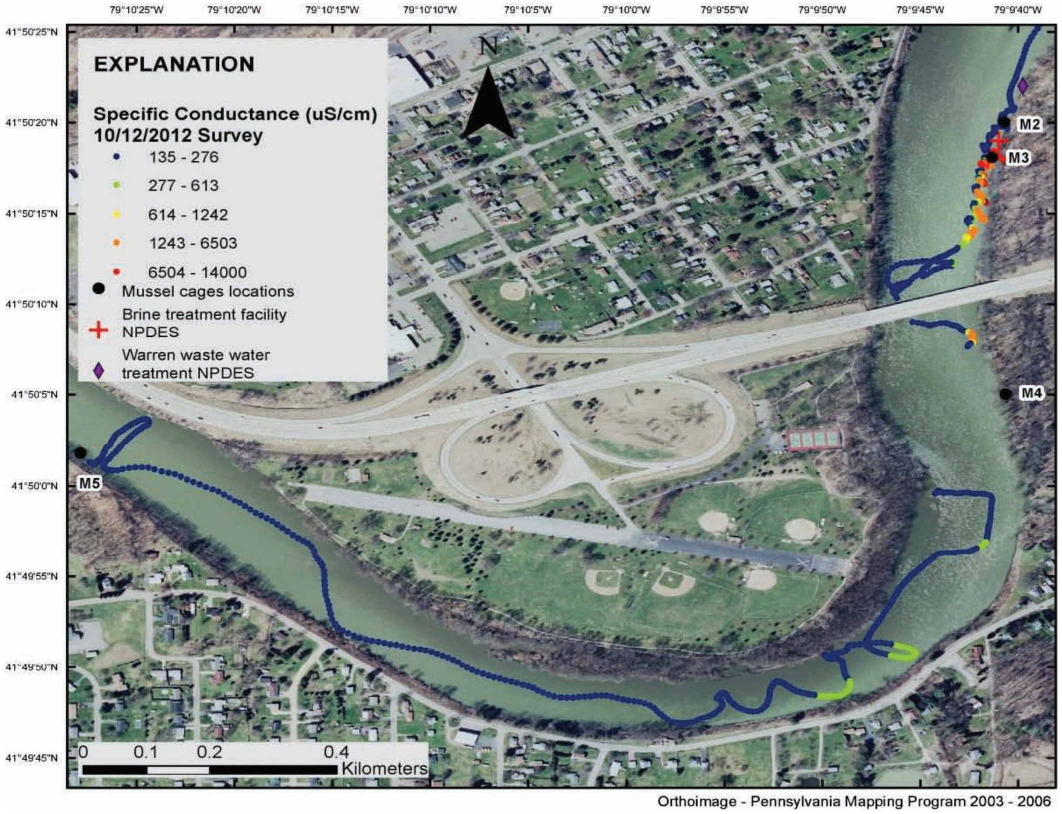
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41°49'55"N
41°49'50"N
41°49'45"N
EXPLANATION
Specific Conductance (uS/cm)
10/12/2012 Survey
135 - 276
277 - 613
614 - 1242
1243 - 6503
6504 - 14000
Mussel cages locations
Brine treatment facility NPDES
Warren waste water treatment NPDES
N
M2
M3
M4
M5
0
0.1
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0.4
Kilometers
Orthoimage - Pennsylvania Mapping Program 2003 - 2006

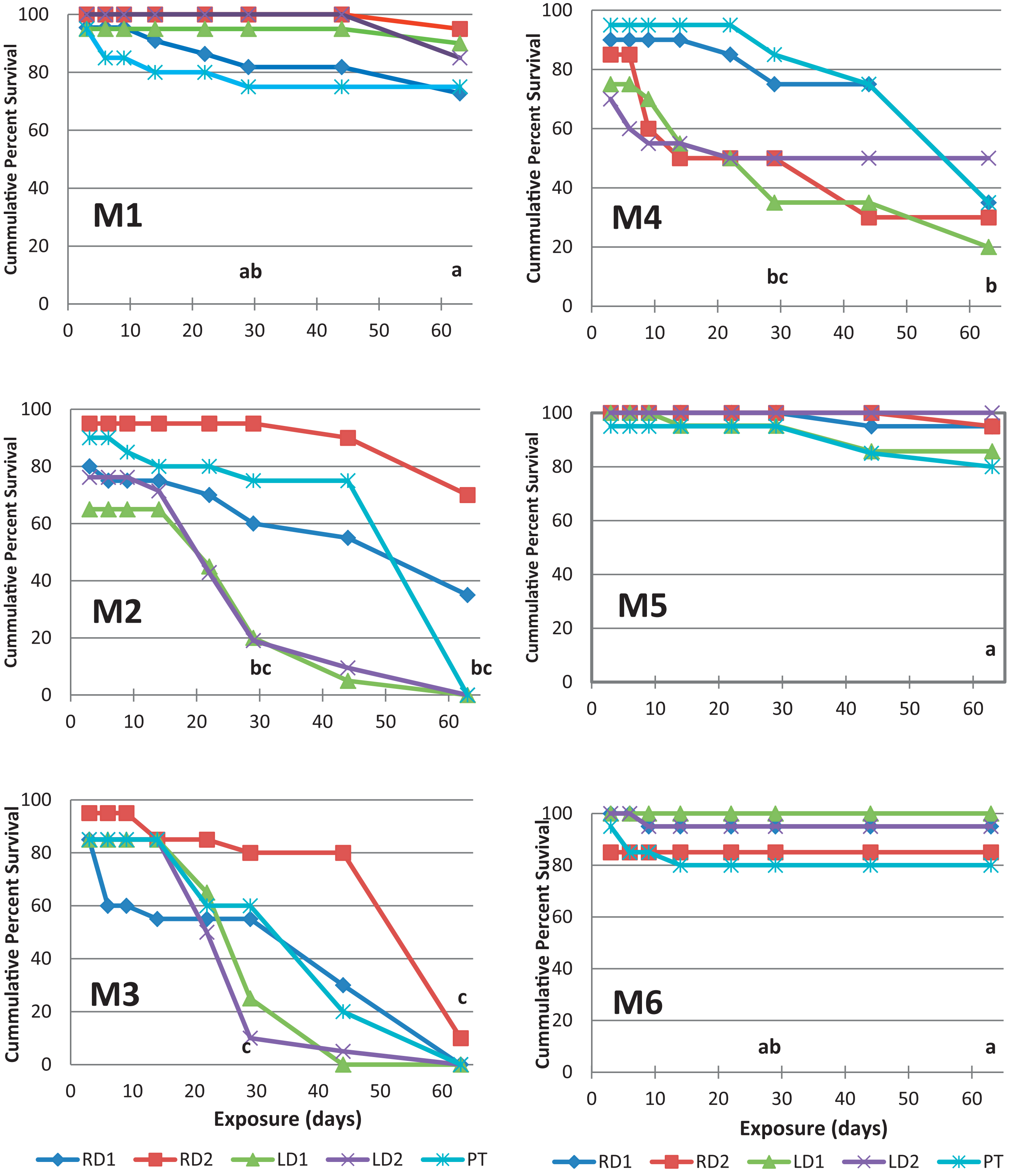

Figure 6. Cumulative percent survival of juvenile northern riffleshell mussel *Epioblasma torulosa rangiana* from days 0 to 63 by mussel cage site (M1-M6) and within cage array (see Figure S2) on the Allegheny River near Warren, Pennsylvania, for August 14–October 16, 2012. Positions in array are most upstream point (PT), first on left descending side (LD1), second on left descending side (LD2), first on right descending side (RD1), and second on right descending side (RD2). Dissimilar letters (a, b, c) denote statistically significant differences (Tukey's honestly significant difference) in cumulative survival between mussel sites at days 29 and 63.

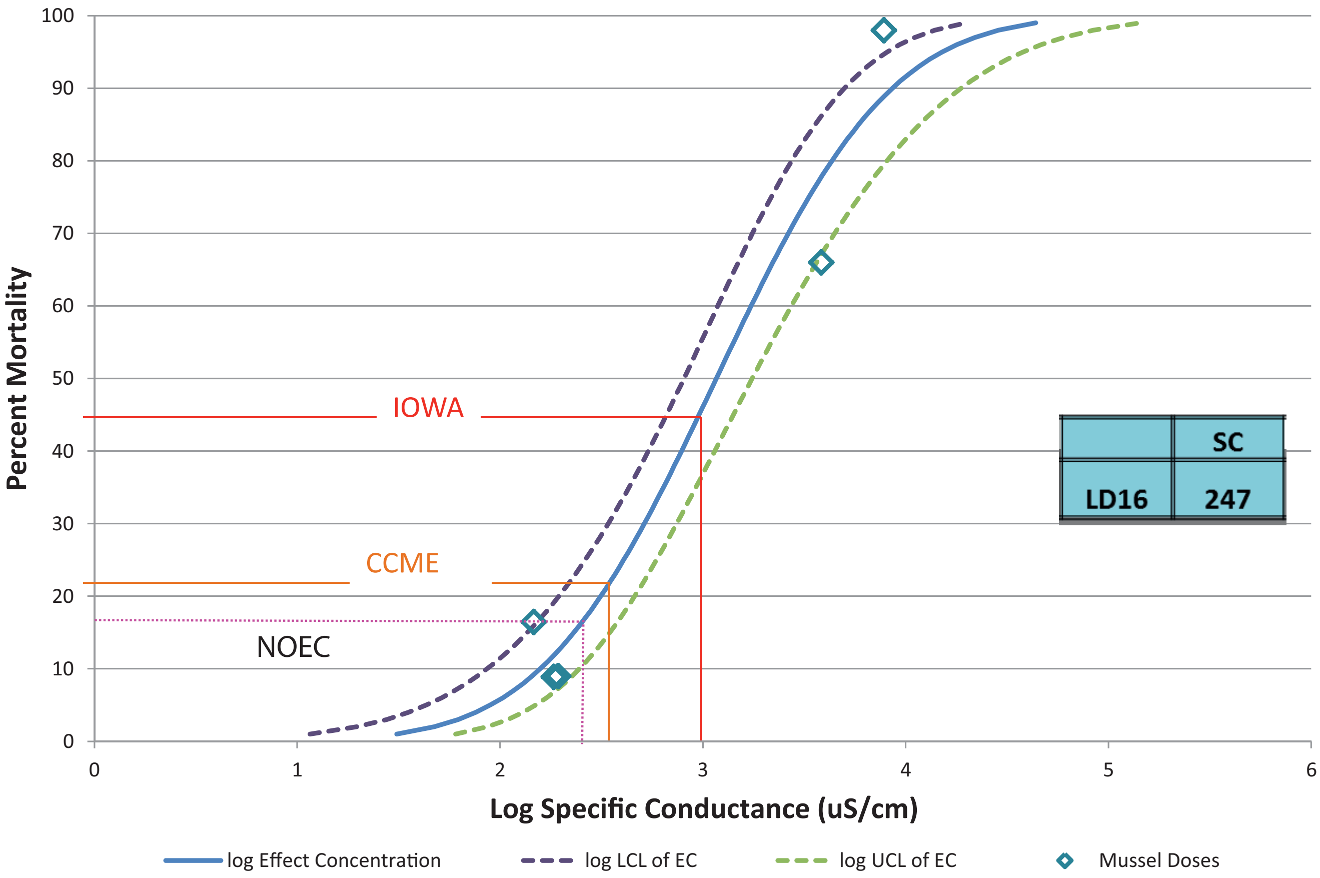

Figure 7. Mean cumulative percent mortality of northern riffleshell mussel *Epioblasma torulosa rangiana* at day 63 in response to mean specific conductance data during discharge periods from probes attached to each first left descending side cage in the array for mussel cages in the Allegheny River near Warren, Pennsylvania, from August 14 to October 16, 2012. Chi-square goodness of fit for the curve was significant ($P = 0.003$) and linear regression of $\log_{10}$ conductivity and probit percent mortality was predictive ($r^2 = 0.9983$). M2 (Warren wastewater treatment discharge) data were omitted due to potential confounding effects of nonbrine contaminants. Dissimilar letters reflect significant differences in mortality between mussel sites. NOAEC = specific conductance with predicted background mortality (lethal concentration 16), UCL = 95% upper confidence limit. LCL = 95% lower confidence limit.

Because ion concentrations of effluents can change without altering the total dissolved solids, it is more consistent to derive water quality criteria based on the presumed primary toxic constituent in this high salinity effluent (i.e., chloride). The relationship of specific conductance to chloride can be used to evaluate the protectiveness of literature-based chloride criteria for sensitive unionid species. The NRS survival data at this site indicate that the site-specific chloride criterion of 316.71 mg/L derived using the Iowa formula (IADNR 2009) would increase NRS mortality by approximately 30% compared to a 6% increase if the CCME (2011) 120 mg/L criterion were used. A chloride concentration of 78 mg/L or less would be required to maintain NRS reference survival rates and prevent added mortality of this endangered mussel (ESA 1973).

Differences between literature-based chloride criteria and criteria determined from this study could be due to the limited toxicity data with juvenile unionids, the inappropriateness of the sulfate and hardness corrections in the Iowa formula for the Allegheny River, the variability in this field study dose (i.e., discharge concentration), and the differences in the duration of exposure. The CCME (2011) species sensitivity distribution depicts NRS as the species most sensitive to chloride. However, NRS were not included in the derivation of the Iowa criteria (IADNR 2009). The CCME (2011) also found that insufficient data were available to develop a hardness relationship for chronic toxicity. Laboratory testing with NRS and other unionid species should be conducted to provide controlled chloride exposures that span our field-derived criterion. These tests should be designed to determine whether hardness and sulfate have an ameliorative effect on chloride toxicity before adoption of criteria with hardness and sulfate corrections.

The duration and pattern of exposure in this study influenced the NOAEC. Based on our observations, it is likely that juvenile NRS avoid exposure by limiting feeding and respiration. Similar behavioral changes have been observed in bivalves exposed to high sulfate concentrations (Soucek 2007). This response apparently minimized mortality during the first week of exposure and lengthened the period of chronic mortality. This behavioral adaptation has ramifications for both acute and chronic pollutant criteria determination for juvenile unionid mussels (>2 mo) that would not be observed in

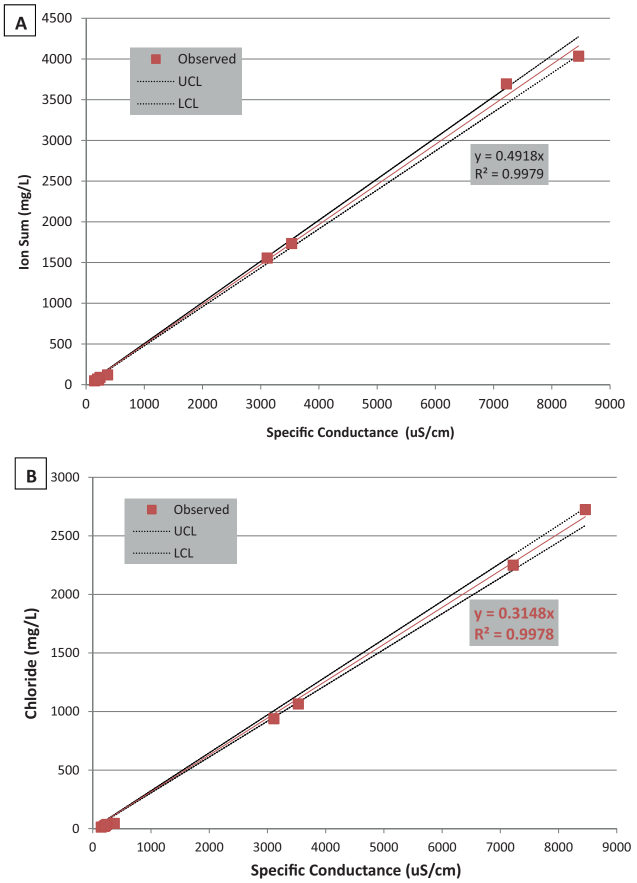

Figure 8. Relationship between specific conductance and (**A**) ion sum (TDS) and (**B**) chloride in grab samples collected by U.S. Environmental Protection Agency and Pennsylvania Department of Environmental Protection in October 2012 in the Allegheny River near Warren, Pennsylvania.

glochidia or newly transformed unionid mussels that are unable to close their valves. Cessation of our study at day 29 would have resulted in a more than two-fold higher NOAEC for specific conductance as significant mortality occurred in the period from 30 to 63 d. Although criteria derived using 28-d studies would be relevant for exposures of limited duration, they may not be applicable to long-term exposures often seen in the wild. Modifications to the duration of the current testing protocol should be considered before its use for the development of water quality standards applicable to unionid mussel habitat.

The native adult unionid mussel assemblage has reduced abundance and diversity along the left descending side of the Allegheny River below the brine treatment facility discharge compared to reaches upstream, along the right descending side of the river, and the most distant downstream site (T10). This observation adds evidence that the discharge has impaired and continues to affect mussel populations within this high specific conductance zone. The presence of a robust unionid mussel assemblage and the distribution of NRS outside of the high specific conductance zone demonstrate that the physical and chemical habitat in the vicinity of Warren is suitable for this endangered mussel (ESA 1973), as well as other species in this unionid mussel assemblage. Villella and Nelson (2006) regularly observed NRS in similar habitat at their survey sites downstream of Mead Island.

Like all the other native unionid mussel species encountered in this study (Table S5), NRS depend on transport of juveniles through an obligate parasitic life stage on fish, most likely several species of *Etheostoma* and *Percina* darters (Zanatta and Murphy 2007). Due to their relatively sedentary nature, this is the primary means of unionid mussel dispersal. Although the fish assemblage was not specifically documented, surveyors observed darters, smallmouth bass *Micropterus dolomieu*, and other potential unionid host fish during transect surveys immediately downstream of the discharges. Juvenile unionid mussels that drop off of host fish in the discharge area likely have a low chance of survival. Moreover, the absence of a robust unionid mussel assemblage within the high specific conductance zone appears to have indirect effects downstream (e.g., left descending sides of T7–T9). Although our in situ study indicated that juvenile NRS can survive in this downstream reach of the river, the lack of reproduction in the upstream high specific conductance zone could be responsible for poor recruitment and thus, reduced unionid mussel numbers and species along the left descending side of the river. Alternatively, periodic downstream expansion of the toxicity zone would repeatedly set back recolonization by increasing juvenile mortality. The unionid mussel survey data including the presence of NRS at the most downstream transect (T10) suggest that chronically toxic concentrations rarely reach mussel habitat at the upstream end of Mead Island and that any acute events are brief enough that unionid mussels can survive.

The results of this study demonstrate that this triad approach can provide information to support wastewater discharge permit limits in unionid mussel habitats. In rivers with complex hydrodynamics, specific conductance field surveys combined with continuous monitoring at a waste discharge is a quick and effective way to document the mixing. A continuous monitor is necessary to determine the discharge pattern and range of specific conductance of the source. Once a pattern is determined, the optimal time for the survey can be identified. Two surveys (to ensure repeatability) at low flow (to capture the worst-case scenario) can be accomplished to give managers a field map of the mixing zone instead of relying on model-derived maps.

In situ toxicity testing combined with adult unionid mussel surveys provide strong weight of evidence for effects on individuals and populations within and beyond the mixing zone. As rivers typically have multiple stressors, it is critical to locate cages and survey transects to segregate confounding influences. The study also shows that further toxicity testing with juvenile unionid mussels, particularly including longer duration tests, is needed to ensure that state and national water quality criteria for chloride are protective of unionid mussels. Test duration for juvenile unionid mussels should be reevaluated to account for variability in field exposures and potential

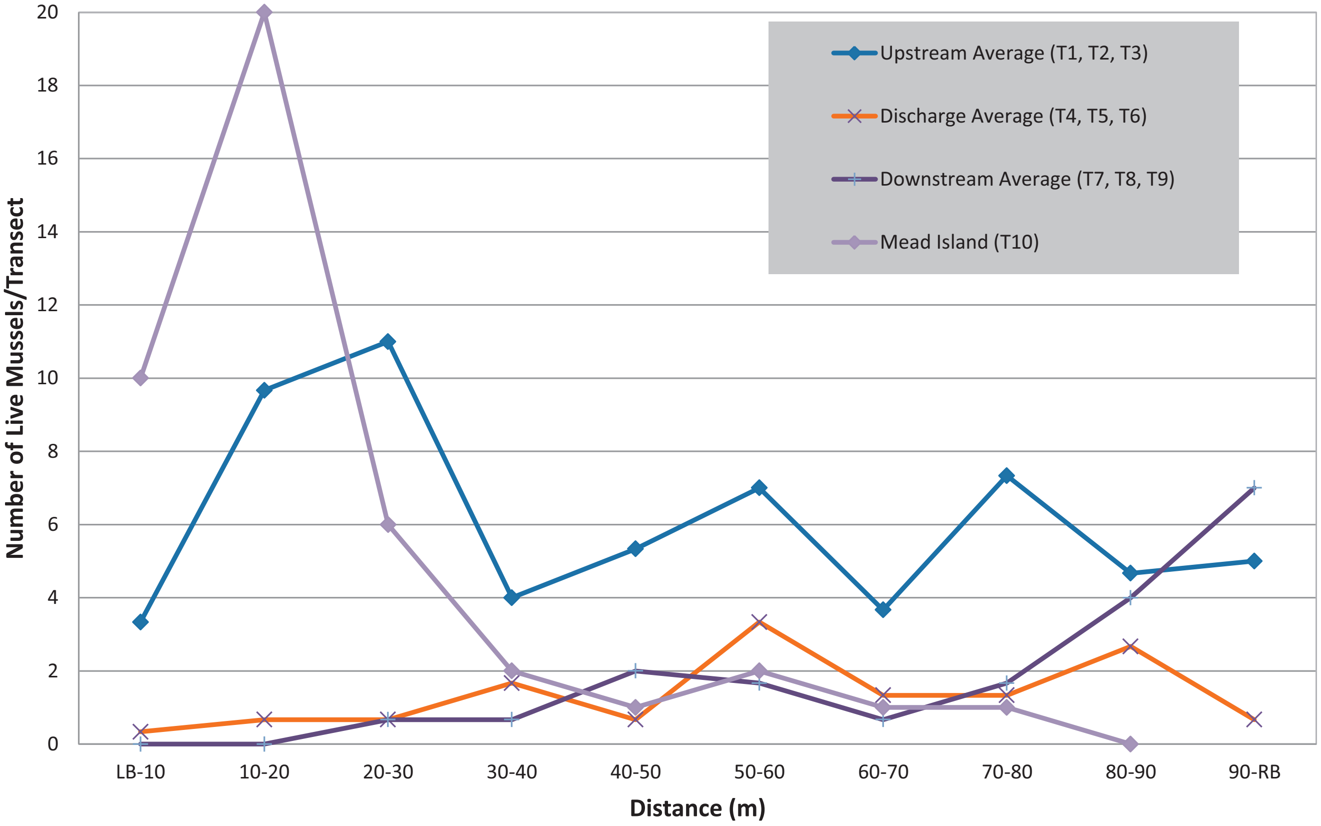

Figure 9. Native unionid mussel survey adult numbers from August 2012 for 10 transects between Conewango Creek and Mead Island from left descending bank (LB) to right descending bank (RB) on the Allegheny River near Warren, Pennsylvania. Transect data were compiled as upstream (T1–T3), discharge (T4–T6), downstream (T7–T9), and Mead Island (T10).

behavioral adaptations that reduce exposure and extend the period of chronic mortality.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Table S1. Specific conductance data from U.S. Environmental Protection Agency and U.S. Geological Survey continuous water quality probes at cage sites for northern riffleshell mussels *Epioblasma torulosa rangiana* from upstream (M1) to downstream (M6) on the Allegheny River near Warren, Pennsylvania, from August to October 2012.

Found at DOI: 10.3996/052013-JFWM-033.S1 (948 KB XLS).

Table S2. Specific conductance readings at five second intervals for the surveys performed on August 28, 2012, and October 12, 2012, on the Allegheny River near Warren, Pennsylvania.

Found at DOI: 10.3996/052013-JFWM-033.S2 (404 KB XLS).

Table S3. Juvenile northern riffleshell mussel *Epioblasma torulosa rangiana* counts in cages from upstream (M1) to downstream (M6) on the Allegheny River near Warren, Pennsylvania, from August to October 2012.

Found at DOI: 10.3996/052013-JFWM-033.S3 (94 KB DOC).

Table S4. Ion concentrations in water samples collected by U.S. Environmental Protection Agency at cage sites for northern riffleshell mussels *Epioblasma torulosa rangiana* from upstream (M1) to downstream (M6) in the Allegheny River near Warren, Pennsylvania, in October 2012.

Found at DOI: 10.3996/052013-JFWM-033.S4 (32 KB DOC).

Table S5. Summary data for transects from upstream (T1) to downstream (T10) for the unionid mussel survey conducted on the Allegheny River near Warren, Pennsylvania, in August 2012.

Found at DOI: 10.3996/052013-JFWM-033.S5 (324 KB DOC).

Figure S1. Stream flow from August 14 to October 16, 2012, as determined by U.S. Geological Survey station 03015310 Allegheny River below Conewango Creek at Warren, Pennsylvania. The stream flow for stations 03012550 Allegheny River at Kinzua Dam and 03015000 Conewango Creek at Russell, which combine to give total flow at station 03015310 are also shown. Stream

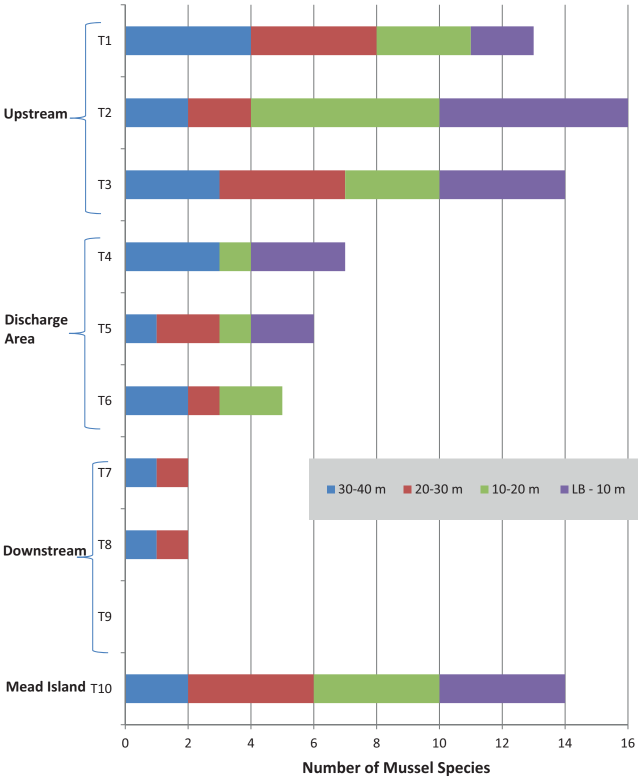

Figure 10. Native unionid mussel survey adult species richness from August 2012 for 10 transects (T1-T10) from left descending bank to 40 m into channel between Conewango Creek and Mead Island on the Allegheny River near Warren, Pennsylvania. No mussels were observed in the first 40 m on T9.

flow during the specific conductivity surveys are shown as yellow diamonds on the graph.
Found at DOI: 10.3996/052013-JFWM-033.S6 (133 KB PDF).

Figure S2. Cage array at M2 and M3 northern riffleshell mussel *Epioblasma torulosa rangiana* cage sites with discharge pipes on the Allegheny River near Warren, Pennsylvania, from August to October 2012. Cage arrays upstream (M1) and downstream (M4–M6) were comparable absent discharge pipes.
Found at DOI: 10.3996/052013-JFWM-033.S7 (457 KB PDF).

Figure S3. Temporal specific conductance data used to determine transit time for specific conductance transects from August to October 2012. The blue line shows the specific conductance readings at M3 (brine treatment plant), and the red line shows the conductance readings at M6 (furthest downstream). Note that the trailing edge of the specific conductance plume takes approximately 2.5 h to reach M6.
Found at DOI: 10.3996/052013-JFWM-033.S8 (51 KB PDF).

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The mussel culture expertise of Rachel Mair and Catherine Gatenby of USFWS made testing of NRS possible. Specific conductance data at three of the mussel cage sites were provided by Lou Reynolds and Kelly Krock of the EPA Region 3 Freshwater Biology Team. Water grab sample analytical data were shared with us by Amy Bergdale of EPA Region 3 and Joe Brancato of PADEP Northwest Region. Mussel cages were provided by Jess Jones, USFWS at the Virginia Tech Freshwater Mollusk Conservation Center. We thank the anonymous reviewers and Subject Editor of the *Journal of Fish and Wildlife Management* for constructive comments.

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From: gthom@accessus.net
Sent: Friday, December 14, 2018 3:12 PM
To: Haile, Abel
Cc: joblumen@yahoo.com
Subject: [External] Protecting the Big Muddy from pollutants TMDL Public Comment

Dear Mr. Abel Haile:

I gave testimony at the October 23, 2018 meeting held in Benton. I spoke on behalf of the members of the Southern Illinois Kayak and Canoe Club because several members have used the Big Muddy River for recreation and even fishing. I appreciated the chance to express our concerns over the proposed pipeline that is to dump water from the Pond Creek Mining operation.

I was unable to attend the subsequent meeting that was recently scheduled because the weather conditions did not permit us to safely leave the Lake of Egypt region where we live. Therefore I am contacting you to appeal to you to not permit the Pond Creek Mine to further pollute the Big Muddy River. As anyone who has seen the river, it is far from pristine already. The water quality is murky on the best days. The banks are so muddy that there are limited locations to access the river, and it is particularly challenging if a person found it necessary to try and exit a kayak and leave the river.

Adding more pollutants to the river could put our members at risk if they happened to tip their kayaks or canoes. Considering that the pipeline is proposing to add between 2 to 3 million gallons per day of water contaminated with sulfides and chlorides, there is serious concern about how this will impact a public waterway that is regularly used for recreation.

I have friends who live along the Big Muddy, and they are also concerned about what impact the added pollution will have on their property when the river floods and dumps contaminants on their property and into their ponds. This has potential of impacting their property value, as well as their health.

I understand that the IEPA has already issued advisories discouraging people from eating fish from the Big Muddy River due to contaminant levels. This proposed pipeline can do nothing but increase the health risks for folks who use the river for fishing and recreation.

Tourism and recreation are valuable resources in Southern Illinois. Please help protect this resource by not issuing the permit for this pipeline.

Sincerely,

Galen R. Thomas

305 Campers Lane, Creal Springs, IL 62922

From: Retha Daugherty <rethadaugherty@gmail.com>
Sent: Saturday, December 15, 2018 3:51 PM
To: Haile, Abel
Subject: [External] Pond Creek Coal Mine

I am writing to you encourage you to PLEASE do the right thing, and deny this dastardly proposal. So many reasons why this is one of the dumbest proposals ever, and I suspect you know them as well as anyone.

Again, please do the right thing. It's the biggest thing we could all use.

Thank you,

Retha Daugherty
Business owner and grandmother who has enjoyed the Big Muddy for most of my life.

Sent from my iPhone

From: Evelyn Stenseth-Johnsen <stevelynj@gmail.com>
Sent: Saturday, December 15, 2018 11:01 AM
To: Haile, Abel
Subject: [External] Polluting the Big Muddy River

Mr. Haile:

I am deeply disturbed by the very thought of allowing more pollution in our rivers. The coal company has already stated that the effluent is dangerous, and yet the State of Illinois is considering allowing discharge into the Big Muddy River. It is desperately important to quit using our rivers as sewers - especially when there is no sewerage treatment to help mitigate the damage - and yet, private companies push to move the toxins from THEIR RESPONSIBILITY to the people of the state, and those of every state south. I understand that coal is important to the state, but health needs to be much more important, and private companies need to quit being profitable only by shirking their own responsibilities.

--
Evelyn Stenseth-Johnsen

From: Marion A <madams10@seattlecentral.edu>
Sent: Saturday, December 15, 2018 8:10 AM
To: Haile, Abel
Subject: [External] Illinois EPA/ Protect the Big Muddy River

To Whom It May Concern,

I am writing to you from Carbondale, IL. I grew up in Murphysboro IL. My parents own land in Murphysboro and my sisters and I grew up playing in forests near the Shawnee National Forest and in Lewis Creek, a small creek that we well knew eventually flowed into the Big Muddy.

The Big Muddy River is a point of pride and a beloved treasure for us down here. It may be murky, muddy and slow, but it's our river. As children we are taught that it flows to the Great Mississippi, connecting us to the rest of the country and a storied past.

Please do all you can to prevent a short-sighted plan from destroying our river. We "down-staters" don't have much but we have a deep love for the land and our natural resources. I want to raise my children in a place that is protected and safe for them to thrive.

I thank you for your time and consideration.

Marion Adams Sai
3rd generation Southern Illinoisan, Carbondale, IL

From: Sarah Lewison <sacamixta@gmail.com>
Sent: Saturday, December 15, 2018 3:06 PM
To: Haile, Abel
Subject: [External] Fwd: Permit Application No. 456, Williamson Energy, LLC, Pond Creek Mine, Williamson County

Regarding Permit Application No. 456, Williamson Energy, LLC, Pond Creek Mine, Williamson County

Please accept the following letter from a resident and citizen who lives near the Big Muddy River.

Sarah A Lewison
56 Hansen Way
Murphysboro, IL 62966

Thursday, November 1, 2018

Dear Abel Haile,

I am very concerned that pollutant loading from coal mine discharges is not being fully considered for the current TMDL review of the Upper Big Muddy River. Numerous currently operating coal mines are discharging contaminated water into tributaries or directly to the Big Muddy and there are plans for 2.5 to 3.7 million gallons of very high chloride and sulfate water daily from the Pond Creek Coal Mine to be added to the River via a mixing zone 14 miles south of Rend Lake. These types of mine discharges to the Big Muddy must be stopped.

At one time the river was stated to the the following importance for fishing:: “A total of 106 fish species, representing 25 families, have been recorded from the Big Muddy River drainage from 1892 to 1992… Of these, 97 species are considered native, and 9 occur in the drainage as a result of introductions of exotics or transplantations… Just over half (51.9%) of the total (187 species) native fish fauna known from Illinois (Burr 1991) occur in the Big Muddy River drainage.” [Source: Burr, Brooks M. and Warren, Melvin L., Jr. ‘Fishes of the Big Muddy River Drainage With Emphasis on Historical Changes.’ Biological Report 19].The Big Muddy River is also listed as having varieties of mussels and information on any mussel beds and their future needs to be included in consideration of the current TMDL review. I am concerned that pollution levels will continue increasing from coal mine discharges and this defeats the entire purpose of your TMDL process. Coal mines must treat polluted water before discharge as a cost of doing business and not rely on public waters of Illinois as their corporate dumping area. I ask IEPA to be sure to include concerns for increased coal mine discharges to the Upper Big Muddy River in your TMDL review. The known ecosystem damages from high chloride and sulfate waters should be an essential part of your TMDL review and these are in great part from coal mine discharges.

Such action will expose fish, insects, soils and mammals to chemicals and substances that put undue stress on the biological and ecological systems proximal and within the river. The application asks to permit the discharge of highly acidic water that is a discharge of the mining process, literally the toxic wastes that have been removed from the coal in order to ensure it burns cleanly. If these substances deemed too dangerous to put into the air, why then, is it deemed by any means acceptable for these same substances to be dumped into the water? This contaminated water, containing high proportions of chloride and sulfate, also potentially contain unknown and unchecked acids and substances formed from the interaction of these chlorides and sulfates with groundwater, minerals, substrate and rock.

The proposed discharges also add, according to the application, an average of 2.7 million gallons of this chloride and sulfate contaminated wastewater per day to the river. This increase of flow will be added to a river that already regularly floods into adjacent forests, fields, lawns and basements, including areas inhabited by humans. Each flooding incident will potentially expose the areas adjacent to the river to the contaminants coming from the mining operation, along with the additional burden of heavy metals that are ordinarily associated, and usually unmonitored, that are present in acid mine waste. Besides heavy metals, there is the possibility of other pollutants such as arsenic and radioactive materials. These are toxic substances that cannot be easily removed once they enter the biological stream; the best option is to not allow them to enter in the first place. The best option is prevention the responsibility for prevention rests squarely with your office. Further, it is imperative that the polluting company step up and take a more responsible action with the contaminated wastes their operation is producing.

My neighbors and I use the Big Muddy River for canoeing, kayaking and fishing- in fact there are many people in this area who supplement their incomes by obtaining food from the river. I have friends who come from places as distant as Chicago to enjoy this river, the health of which is already overstressed by contamination and run-off from the agricultural lands through which it winds. According to law, the corporation that is profiting from the extraction of coal from the ground is also responsible for the ambient environment impacted by their operations. To allow a company to contaminate a river with toxic compounds of unknown quantity is an obviously unreasonable request that any sensible person should be able to understand and refuse. I hope you will agree with me and deny this application. Rivers are a vital element of ecosystem functioning that provide benefits of habitat, recreation, and drainage of the land. Once damaged to the extent that riverine life is extinguished, the recovery will be much more expensive. We already are facing a decline and imbalance in species in our state rivers; they should not be used as a toilet for toxic mine refuse. As a taxpaying citizen of the State of Illinois, I ask you deny this permit to Pond Creek Mine.

Thank you for your time.

Sarah Lewison
56 Hansen Way
Murphysboro IL 62966

From:	Sabrina Hardenbergh <sabrina@midwest.net>
Sent:	Wednesday, December 12, 2018 2:51 PM
To:	Haile, Abel
Cc:	Fertaly, Margaret; Pressnall, Chris; DNR.Mmlrd; San Diego, Nick
Subject:	[External] Draft TMDL public comment; and relation to Permit Application No. 456, Williamson Energy, LLC, Pond Creek Mine, Williamson County

Abel Haile, Manager
Planning (TMDL) Unit Watershed Management Section
Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276
Email: Abel.Haile@illinois.gov

Re: Public Comment re TMDL Stage 3 report on Big Muddy River Watershed due Dec. 15th

Dear Abel Haile:

Via the following weblink (below), please read and enter into your TMDL public comment record the review article I recently wrote for the Shawnee Trails newsletter (that I edit quarterly the past 6 years). It and its many weblinks explain my observations on your draft Total Maximum Daily Load Stage 3 report for the Big Muddy Watershed and other related variables. I would have liked more time to research the issue, but other work and family holiday obligations have not opened time for such; you could have given better notice and time. I do not agree with recalculating the method of determining TMDL as the report suggests, given that it then allows you to be permissive to industry to continue their pollution of our streams, watersheds and rivers. That the state IEPA would be complicit in our recent federal government's erasure of the many Acts and Rules for protecting our water, air, land, wildlife, and public health is unconscionable and a misuse of tax dollars, and it goes against what should be the mission of an environmental protection agency. Please **do not** give in to Chris Cline, Bob Murray, and other fossil fuel industry influences that are behind possible approval of this report in its current draft. You **should not be permitting** them to continue wrecking and polluting the Big Muddy Watershed and the rest of southern Illinois. We should instead be continuing on the path toward renewable energy, energy efficiency, and less climate change. If we eventually get universal health care, the public health hazards these industries inflict upon us must not continue to remain a very costly cost of doing business that is offloaded on everyone else. Rural Southern Illinois is already enough of an environmental justice area, as the IEPA staff should know, and it shouldn't be subjugated into spiraling further into such a black hole that our coal mines, oil wells, and Veolia, Metro East, Koppers, Crab Orchard and other factory sites epitomize. Damaging the wildlife habitat and outdoor recreation in and around the Big Muddy and other waterways in southern Illinois does our region no good. Outdoor recreation is among southern Illinois' best features, should we be allowed to keep it. Your TMDL on a watershed, also needs to consider the broader acute and "diluted/diffused" "TMDL" of health and other socioeconomic hazards on our region. Although, it's pretty shocking that way too many of our southern Illinois waterways are 303(d) listed in one way or another; that's an environmental justice issue that requires a regional approach to rectification with input from a broader variety of residents/stakeholders, beyond industry personhoods. And we've learned from our other community organization investigations and advocacy that the present standard water testing doesn't even include all the possible contaminants.

https://www.sierraclub.org/sites/www.sierraclub.org/files/sce/shawnee-group/ShawneeTrailsDec2018forWeb.pdf
(Also accessed here, in the Dec. 2018 - Feb. 2019 edition: https://www.sierraclub.org/illinois/shawnee/newsletters)

Outside the TMDL report, I'm also concerned that the recent attempt to eliminate the Clean Water Act (and its 303(d) listing) is of no help to southern Illinois' long-term physical and economic health either. IEPA as a state entity, along with our Attorney General, needs to stand up to the recent misguided federal administration, and hold up water, air, land and health protections. The fossil fuel industry cannot continue in its bullying, co-opting our government, and recklessness, as has been so blatantly displayed since Trump's and his Cabinet's time in office (albeit ALEC influence in government has been around for many years). Municipal sanitation and agricultural waste are further issues, but dealing more with local people (albeit, for many, agriculture has become a global industry outside local control too).

Reorient to the general idea of the Clean Power Plan concept. Reorient to a Green Deal concept. Reconnect with what should be your mission of environmental protection, instead of it having become a Beltway double-speak buzzword for land/resource grabbing.

I am interested to read two IEPA emails in my inbox this morning about grants for community outreach, investigation and remediation concerning environmental public health pollution problems. I'll hope you will keep the different parts of our governmental agencies working toward a healthier communities/environment goal.

Sincerely,

Sabrina Hardenbergh
1 Hardenbergh Road
Carbondale, IL 62902
618-549-2608 (landline)
sabrina@midwest.net

From: Jane Cogie <jane.cogie@gmail.com>
Sent: Sunday, December 16, 2018 1:03 AM
To: Haile, Abel
Subject: [External] Comments on the Upper Big Muddy River Watershed Draft, TMDL 3

Jane Cogie
1010 S. Oakland Avenue
Carbondale, IL 62901
jane.cogie@gmail.com

Sent via email to
Abel.Haile@illinois.gov

Re: Comments on the Upper Big Muddy River Watershed draft Total Maximum Daily Load (TMDL) Stage 3 Report and Implementation Plan

Dear Mr. Hale:

As citizen of southernmost Illinois, living only a few miles from the Big Muddy, I want to weigh in on the toxins from the Pond Creek Mine that would be discharged into the backyards of many of us and into the river where many of us canoe and kayak depending on the decision you make on the TMDR for the Big Muddy Watershed. The amount of toxins that are proposed to be discharged into it will cause harm to the wildlife and the aquatic life that live in and nearby the river. It would be particularly harmful to the fresh water muscles that help filter the river water and keep it clean. Please don't let the Big Muddy, which belongs to all of us and supports the nature we all depend on, become the dumping ground for industries that should be responsible for cleaning up the waste they produce.

Sincerely,
Jane Cogie

From: Deborah Endres <debendres2002@icloud.com>
Sent: Saturday, December 15, 2018 4:13 PM
To: Haile, Abel
Subject: [External] Big muddy

Dear EPA
Please fight the dumping of coal waste water into the big muddy river. Companies should clean up their own waste, not dump it into local communities. The big muddy already has problems. Don’t make it worse. Please protect our water.

Thank you,
Deb Endres
301 rubyfruit lane
Murphysboro il 62966
Sent from my iPhone

Attachment 9: Responsiveness Summary

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Attachment: 9

Responsiveness Summary

Upper Big Muddy River Watershed

Total Maximum Daily Load

The responsiveness summary responds to questions and comments received during the public comment period from November 15, 2018, through December 15, 2018.

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 Upper Big Muddy River Watershed** 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 **Upper Big Muddy River Watershed** located in southern Illinois. The portion of the watershed in Illinois, which this TMDL addresses, covers nearly 490 square miles and includes lands within Hamilton, Franklin, Williamson, Jefferson, and Jackson counties.

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. Therefore, a Dissolved Oxygen (DO) TMDL was developed for Lake Creek (IL_NGA-02). Fecal Coliform TMDLs were developed for the Big Muddy River (IL_N-11) and Middle Fork Big Muddy (IL_NH-06). A Manganese TMDL was developed for Beaver Creek (IL_NGAZ-JC-D1), a Chloride TMDL was developed for Pond Creek (IL_NG-02), and an Iron TMDL was developed for Andy Creek (IL_NZN-13). Total Phosphorus TMDLs were developed for Herrin Old Reservoir (IL_RNZD), Johnston City Reservoir (IL_RNZE), Arrowhead (Williamson) Lake (IL_RNZX), West Frankfort Old Lake (IL_RNP), and West Frankfort New Lake (IL_RNQ).

These waterbodies are listed as impaired per the 2012-2018 Draft Illinois Integrated Water Quality Report and Section 303(d) List.

In addition, a Load Reduction Strategy (LRS) was developed for pollutant(s) that do not have a numeric water quality standard. These include total suspended solids (TSS) LRSs for the Big Muddy River (IL_N-11 and IL_N-17). Sedimentation/siltation LRSs were developed for the Big Muddy River (IL_N-06, IL_N-11 and IL_N-17), Pond Creek (IL_NG-02), and Middle Fork Big Muddy (IL_NH-07).

Illinois EPA contracted with LimnoTech (a TMDL Consultant) to prepare the TMDL report for the Upper Big Muddy River Watershed project.

Public Meetings

The draft Stage 1 public meeting was held on December 17, 2013, at 3:30 pm in the West Frankfort Public Library in West Frankfort, Illinois. Approximately 25 people participated in the public meeting and the public comment period for the Stage 1 meeting closed on January 16, 2014.

The draft Stage 3 public meeting was planned to be held on November 15, 2018, at 3:30 pm, at the West Frankfort Public Library in West Frankfort, Illinois (due to inclement weather the Library closed early, and the public meeting was re-located to the nearby West Frankfort Chamber of Commerce, on E. Nolen St.). Approximately 10 people participated in the public meeting and the public comment period ended at midnight on December 15, 2018.

Illinois EPA provided public notice for all meetings by placing a display-ad in West Frankfort – Daily American (the local newspaper). In addition, a direct mailing was sent to several stakeholders/Permittees in the watershed. The notice gave the date, time, location, and purpose of the meeting. The notice also provided references on how to obtain additional information about this specific site, the TMDL program, and other related information. The draft TMDL report was available for review in hard copy at the West Frankfort Public Library, Herrin City Hall, Christopher City Hall, Ewing Village Hall, and electronically on the Agency’s webpage: www2.illinois.gov/epa/public-notices/Pages/general-notices.aspx.

Questions & Comments

1. The Big Muddy River is stated to have the following historic importance for fish: "A total of 106 fish species, representing 25 families, has been recorded from the Big Muddy River drainage from 1892 to 1992… Of these, 97 species are considered native, and 9 occur in the drainage as a result of introductions of exotics or transplantations… Just over half (51.9%) of the total (187 species) native fish fauna known from Illinois (Burr 1991) occur in the Big Muddy River drainage." [Source: Burr, Brooks M. and Warren, Melvin L., Jr. 'Fishes of the Big Muddy River Drainage with Emphasis on Historical Changes.' Biological Report 19]. The Big Muddy River is also listed as having varieties of mussels. The "Freshwater Mussels of the Big Muddy River," INHS Technical Report 2012 (11) by Diane K. Shasteen, Alison L. Price and Sarah A. Bales, states on page 4 that according to historical records, 25 species are known from the Big Muddy River Basin (Tiemann et al. 2008). The results of the data collected in the 2009/2010 basin survey showed eight sites in the big Muddy River basin ranked as Moderate mussel resources. Nineteen species were recorded live and six species previously detected were not found. Impacts of water quality on this river resource and conditions for the future survival of mussel populations need to be considered.

   Has the presence of freshwater mussels in the watershed been taken into account when developing targets for pollutants such as TDS, conductivity, chloride and sulfate? Recent studies indicate that USEPA criteria and current state standards for these pollutants are not protective of mussels, especially glochidia. See for example, Patnode KA, Elizabeth Hittle, Anderson RM, Zimmerman L, Fulton JW. 2015. Effects of high salinity wastewater discharges on unionid mussels in the Allegheny River, Pennsylvania. Journal of Fish and Wildlife Management 6(1):55-70 and references therein. This study reports that "A chloride concentration of 78 mg/L or less would be required to maintain NRS [northern riffle shell] reference survival rates and prevent added mortality of this [federally] endangered mussel.' The sensitivity of species of mussels historically and currently found in the watershed need to be taken into account in the TMDL and Implementation Plan for the Upper Big Muddy River watershed.

   Response:

   As stated in the background information above, the Agency is required to develop TMDL to address impaired waterbodies that are on the 303(d) list and develop load capacity (wasteload allocation for point sources, load allocation for nonpoint sources, and margin of safety) based on applicable water quality standards for the impaired waterbodies to meet their

designated uses. The comment above is beyond the scope of the TMDL development process in Illinois.

2. It does not appear to us that the total phosphorus LRS target of 0.217 mg/L was developed properly. Is the value the average of all bodies of water in the Upper Kaskaskia watershed? Or is it only the average of streams in the Upper Kaskaskia watershed that have no aquatic life impairments? Does the stream set on which the value was developed represent streams that do not have any high levels or chlorophyll a or unnatural plant growth? Basing the LRS target on streams in the Upper Kaskaskia watershed, a watershed that has its own issues, is not the way to set a LRS target. We note that USEPA's ecoregional criterion for streams in Ecoregion IX: Southeastern Temperate Forested Plains and Hills where this watershed is located is 0.03656 mg/L. The Upper Kaskaskia watershed is in another ecoregion: Ecoregion VI: Corn Belt and Northern Great Plains See https://www.epa.gov/nutrient-policydata/ecoregional-criteria. We also note that Illinois' Nutrient Science Advisory Committee has just sent its recommendation for phosphorus criteria for Illinois' rivers and streams to IEPA; we do not yet know what their recommendation is but it, along with the ecoregional criterion, should be taken into consideration when developing a phosphorus target for streams in the Big Muddy River watershed. Why did IEPA not make use of the ecoregion criterion?

   As with the phosphorus LRS, we have questions about how the LRS target of 32.2 mg/L TSS was developed for the Big Muddy watershed. Again, the Upper Kaskaskia watershed is not representative of the ecoregion that the Big Muddy watershed is located in. Was the target based on an average of all available data for the Upper Kaskaskia watershed or was it based only on the "several streams that are in full support of aquatic life"?

   Response:

   As outlined in the TMDL Report, Section 3.1 (Development of TMDLs and LRS Targets), in the absence of total phosphorus (TP) water quality standards for streams in Illinois, IEPA developed Load Reduction Strategy (LRS) based on waterbodies that have been in Full Use Support for their designated uses to support development of watershed-based plans. When site specific information is not available a comparable watershed information (in this case, Upper Kaskaskia Watershed) has been used to develop LRS targets. (Refer to Attachment 1, Stage 1 TMDL Report) for the methodology used to develop the LRS targets). Although, Illinois EPA originally recommended to use the Ecoregion VI: Corn Belt and Northern Great Plains criteria (referenced in the comment above) to develop LRS for

total phosphorus in several watersheds, stakeholders objected to the Ecoregion criteria and requested to use a site-specific target number that represents the characteristics and land use of the watershed.

3. There is no discussion of mining operations as a possible source of chloride or manganese. An inventory of operating and closed mines located within the watershed should be conducted and factored into the TMDLs.

   Response:

   A reference to the mining operations as a source of the chloride to Pond Creek has been added. There are no known active or closed mines in the small Beaver Creek watershed, which is the waterbody with a manganese TMDL proposed. Since there are no mining operations within that watershed, it is not a suspected source of manganese contributing to the impairment in that stream.

4. It seems that all sulfate listings were delisted with no basis given for doing so. We ask that IEPA also look at levels of total dissolved solids in this watershed and apply the draft USEPA conductivity guidance in order to protect sensitive organisms. See https://www.epa.gov/wqc/draft-field-based-methods-developing-aquatic-life-criteria-specific-conductivity

   Response:

   For Prairie Creek (IL_NZM-01), the analysis of the data provided under Stage 1 (three samples), the existing data did not exceed water quality standards and does support the listed impairments, thus it is recommended for delisting from the 303(d) list.

   For the Big Muddy River (IL_N-11), a review of the sulfate concentrations from 2004 through 2011 at station N-11 indicates that there was one (1) exceedance (sampled on 1/24/2007) of the WQS out of the 7 years of sampling data for that station (56 total samples). As noted in the Illinois Integrated Water Quality Report and Section 303(d) List:

   When interpreting water chemistry data for assessing attainment of aquatic life use, we do not consider a single exceedance of a water quality criterion as indicative of impairment. Such an event does not account for at least two other aspects critical for determining how physicochemical conditions in water affect aquatic life: the frequency and duration of the exceedances

(Barnett and O'Hagan 1997; National Research Council 2001). Illinois EPA uses "frequency of exceedance" guidelines (Table C-3) that better represent the true risk of impairment to aquatic life than do single-exceedance guidelines.

In applying the Illinois EPA guidelines for using water-chemistry data to indicate the potential for impairment of aquatic life use in streams contained in Table C-3 of the Illinois Integrated Water Quality Report and Section 303(d) List), there are no exceedances in the 27 samples collected in most recent consecutive three years of data (2009-2011) evaluated in preparing this TMDL. For a water chemistry condition to indicate the potential for impairment to the aquatic life, two or more observations would need to exceed the applicable standard (since there are more than 10 observations available for review).

5. In Chapter 2, Stage 2 sampling, it is stated that dissolved oxygen (DO) data was collected in the watershed during September and October 2015. Were these data extrapolated in the modeling to summer months when DO violations are more likely to occur? Does the QUAL2E model used take into account the differences in water temperatures over the summer and fall months?

   Response:

   Increased air and water temperatures were considered in the QUAL-2E model when evaluating the loading capacity of the streams. In the stream segments where the Sediment Oxygen Demand (SOD) dominates the oxygen demand, this causes dissolved oxygen to drop below the water quality standards (even with complete load reduction).

6. Section 4.2.5 Pond Cr. / IL_NG-02 – Chloride Load Duration Curve - There are several references to fecal coliform in this section. We assume they are cutting and pasting errors and are meant to refer to chlorides. While other modeling efforts described in Chapter 4 reference the point sources that discharge to the stream reach, we note that this section fails to note the presence of discharges from the Pond Creek mine. Pond Creek mine #1 has 8 outfalls to tributaries to Pond Creek. There definitely is an existing pollutant load source to this creek that should be addressed, so a chloride TMDL should have been developed.

Response:

The cutting and pasting errors noted above have been corrected. A chloride TMDL was not developed for Pond Creek (IL_NG-02) based on the Stage 1 Report's recommendations to delist the segment. However, Illinois EPA will gather additional low flow monitoring data to confirm if the stream is still impaired and proceed accordingly (either develop a Chloride TMDL or delist the segment in the next cycle of the Draft 2020 Integrated Report).

7. Only a single data point was used for manganese (p. 26). Are there plans to collect more data in the bodies of water where manganese water quality standards have been violated?

Response:

Monitoring recommendations have been included in the Watershed Implementation Plan.

8. The draft report says that “The Illinois EPA NPDES regulatory program and the issuance of an NPDES permit provide the reasonable assurance that the WLAs in the TMDL will be achieved” (p. 72). While we agree this tool is intended and should be used to ensure the waterways are protected and the WLAs are achieved, we are concerned with a history of violations by point sources in the watershed and an apparent lack of enforcement for their permit limits, some of which may be too high to properly protect the receiving waters and allow them to be delisted in the foreseeable future. For example, the Johnston City STP is reported to have exceeded limits for ammonia nitrogen and CBOD5 in 2015 (p.20). A review of ECHO shows that this facility is continuing to have problems meeting these standards from 2016 to the present. This plant clearly needs to be upgraded and/or should face enforcement action by IEPA for its exceedances.

Response:

The Illinois EPA-BOW/DWPC- Permit Section & Compliance Assurance Sections have been advised to address NPDES permit noncompliance issues in accordance with Section 31 of the Environmental Protection Act.

9. Thompsonville STP must be upgraded to meet 1.0 mg/L TP, at least. Could this facility convert to reuse or land application of its wastewater in order to eliminate its loading to West Frankfort New Reservoir and reduce the need for a 79% reduction from non-point sources in the watershed? ECHO shows that the facility has not been filing its monthly reports, so we are unable to see what other issues there may be at this plant (p.67).

   Response:

   Thompsonville STP is not required to meet 1.0 mg/L of phosphorus as P. The Thompsonville STP is a lagoon facility, with an untreated waste load of less than 2500 population equivalents, and therefore, does not qualify for a limit of 1.0 mg/L of phosphorus as P as per 35 Ill. Adm. Code 304.123(b).

   In order to estimate total phosphorus loading for each POTW, the average total phosphorus concentration was calculated for all available effluent data in the watershed for lagoon treatment systems. Based on a review of effluent data and permit language for similar POTWs in the region and using best professional judgement, the estimated effluent concentration of 2.425 mg/L, is within a reasonable range of expected phosphorus concentrations in the effluent. If the contributing facility is not currently discharging more than this concentration, the WLA will not require additional nutrient removal. However, the TMDL report has recommended for TP monitoring to be included in future NPDES permit renewals.

   Illinois EPA/BOW – Permit Section & Compliance Assurance Sections have been advised to address the NPDES permit noncompliance issues in accordance with Section 31 of the Environmental Protection Act.

10. This TMDL is incredibly deficient in that it does not factor in the many operating and closed coal mines in the watershed. The only reference made to a mine in the TMDL is as a geographic reference: “Johnston City Lake / IL_RNZE is an impoundment of Lake Creek; it is just east of Freeman No. 4 Mine” (p. 34). The Implementation Plan does recognize ‘mine dumps’ as a present land use in the watershed but then says nothing further about them. As stated above, a thorough inventory of mines within the watershed is needed. We note in the following paragraphs the pollution issues that we have identified with just a subset of currently-operating mines and old mine sites.

Response:

A map of mine locations and areas of active and historical mining was included in the Stage 1 report (which was attached to the TMDL documents). Additional details on the potential for mine discharges as sources of pollutants have been added in the Andy Creek (iron) and Beaver Creek (manganese) sections of the implementation plan. The impairments identified in Johnston City Lake and the other lakes within this watershed are based on total phosphorus, and not on pollutants that are typically associated with mine discharges, such as sulfate and metals.

11. Pond Creek Mine (NPDES Permit No. IL0077666) has numerous violations of sulfate and chloride in the past 12 quarters listed in their ECHO facility report (in addition to violations of suspended solids, total suspended solids and pH).1 These violations are recent, with a 220% violation of sulfate and chloride reported for the last (and current) quarter of 2018. They should not be permitted to discharge high levels of these pollutants into an impaired waterway. IEPA must work with Williamson Energy, LLC to address these unacceptable violations and reduce pollution coming from the mine. In addition to these serious numeric violations, the facility has had three other serious violations reported in ECHO: unapproved bypass, unauthorized discharge and improper operation and maintenance. We cannot afford to have bad actors discharging to an impaired waterway that IEPA is attempting to restore and delist. Certainly, no new proposal to discharge additional pollutant loads should be approved for this mine into either Pond Creek or the Big Muddy River itself.

    Other mines in the watershed are a concern for pollutant loading and the total impacts of coal mine discharges appears to be lacking in consideration for this TMDL. The Russell Minerals West Frankfort, Inc. Old Ben No. 9 site (NPDES Permit No. IL0070912) is in reclamation, however, there is an approved discharge to an unnamed tributary to Pond Creek adding more sulfate and chloride to the watershed. Numerous other mines in reclamation and old mine works in the watershed could well be placing additional pollution loading burdens on the Big Muddy River watershed.

    Response:

    See Response #8.

12. Sugar Camp Mine #1 (NPDES Permit No. IL0078565) has repeated violations of chloride, manganese and total suspended solids in the past twelve quarters listed in the ECHO facility report (in addition to violation of iron and pH). Several violations are recent with chloride discharge high levels of these pollutants into an impaired waterway. Receiving streams include several tributaries to the Middle Fork Big Muddy River. No new proposed discharges of additional pollutant loads should be approved for this mine into tributaries of the Big Muddy River.

Response:

See Response #8.

The Agency has sent a Violation Notice (VN) on 3/25/19 to the permittee to address the NPDES Permit noncompliance issues.

13. The implementation plan does not properly address chloride. It appears there are violations at low flows which may be due to resident chloride or low flow loadings. Sources of chloride such as road salt and mining should be addressed, including the coal mines referenced above. The Implementation Plan must prohibit any new loadings of chloride to the system until the cause of the exceedance is determined and fully addressed with controls providing reasonable assurance and a margin of safety in addition to that needed to accommodate the new loading.

Response:

A chloride TMDL was not developed for Pond Creek (IL_NG-02) based on the Stage 1 Report's recommendations to delist the segment. However, Illinois EPA will gather additional low flow monitoring data to confirm if the stream is still impaired and proceed accordingly (either develop a Chloride TMDL or delist the segment in the next cycle of the Draft 2020 Integrated Report).

14. The Implementation Plan says that “One of the most important aspects of implementing nonpoint source controls is obtaining adequate funding to implement voluntary or incentive-based programs” (p. 76). Various potential funding sources are listed that could be leveraged to implement measures to reduce pollution. How will IEPA ensure that this funding is obtained and utilized to achieve real progress towards the TMDL goals?

Response:

Upon final approval of the TMDL report, Illinois EPA (IEPA) Watershed Management Section staff will contact existing watershed stakeholders to help implement the TMDL. In the absence of a watershed stakeholder workgroup, IEPA will contact the Soil and Water Conservation Districts (SWCDs) within the TMDL watershed to facilitate the development of a watershed stakeholder group to help implement the TMDL.

In addition, IEPA's Watershed Management Section\Planning (TMDL) Unit will notify appropriate Agency BOW - Programs, that the TMDL is complete and should be reviewed for opportunities for those specific recommendations to follow up with stakeholders to assist with TMDL implementation. The Watershed Management Section\Nonpoint Source Unit does follow-up regarding the Section 319 and 604 financial assistance programs. The Agency will also notify appropriate sister-agencies and organizations (local, state, and federal) regarding the opportunity to help implement the TMDL, such as the Illinois Department of Public Health regarding septic systems operation and maintenance.

The Water Pollution Control State Revolving Loan Funding Program (WPCSRF) is also available from the Agency's BOW-Infrastructure Financial Assistance Section (IFAS) for nonpoint source projects designed to improve water quality issues in the watershed.

15. We agree with the recommendation that a watershed group be formed for the Upper Big Muddy River watershed, and we hope to work with IEPA and others to encourage and support local stakeholders in coming together around restoring and protecting these waterways. We urge IEPA, an agency familiar with watershed efforts around the state and the history of watershed groups forming, to do outreach and serve as a resource to parties interested in forming a watershed group.

Response:

The Illinois EPA will continue to reach out to stakeholder in the watershed to develop watershed-based plans to address the impairments identified in the TMDL report.

16. The Implementation Plan should establish additional monitoring to effectively evaluate progress towards attaining the TMDL targets.

    Response:

    Monitoring is one of the components of a watershed implementation plan. It is recommended to conduct monitoring before and after implementation of best management practices (BMPs) to evaluate the effectiveness of the BMP selected.

17. The Implementation Plan lacks specifics and must adopt controls to meet the targets of the TMDL, rather than just listing best practices. Point sources discharging to this watershed must be properly addressed and must comply with protective permit limits in order to make progress on implementation.

    Response:

    In order to meet the TMDL targets, applicable wasteload allocations (WLA) will be addressed through future NPDES permit renewal cycles, while the nonpoint source contributions from urban stormwater and agricultural areas [load allocation (LA)] can be addressed by developing watershed-based plans for implementing best management practices.

18. In Table 1-1, how was it determined that a number of bodies of water be delisted as impaired for sulfate?

    Response:

    See Response #4.

19. In Table 1-1, was continuous monitoring for dissolved oxygen (DO) conducted on the bodies of water that are proposed to be listed for their DO impairment?

Response:

The monitoring performed in Stage 2 of this TMDL development did not include continuous monitoring, however it did include monitoring for DO in the early morning, and late afternoon/evening to quantify diurnal variations in the DO due to algae/plant respiration.

20. Is there phosphorus in leaking septic systems that should be addressed (p.53)?

Response:

Leaking septic systems could be potential sources of phosphorus (total) impairments, and the Watershed Implementation Plan, Section 4.2 - Potential Management Practices has recommended for proper septic system maintenance.

Once the Final Draft TMDL is approved, the Watershed Management Section will inform the Illinois Department of Public Health (IDPH) and the County Health Departments within the TMDL watershed that an approved TMDL report is available.

In Illinois, the IDPH and County Health Departments implement the Department of Public Health Act (20 ILCS 2305/1.1) and regulate the private sewage disposal systems (such as septic tanks and seepage fields). The County Health Departments will take the lead to work with local homeowners and stakeholder to address the septic system issues outlined in the Watershed Implementation Plan as they overlap with the Department of Public Health Act.

21. Page 38 of the implementation plan identifies point sources as part of fecal problem. Isn’t phosphorus also in such discharges?

Response:

Refer to Response # 20.

This is correct, phosphorus (total) could be a potential source from failing septic systems, and this parameter has been added in Section 3.1-

Identification of Pollutant Sources (refer to page 38, of the Watershed Implementation Plan).

22. The report should reconsider the targets for phosphorus, chloride, and TSS and consider targets for total dissolved solids. Is it anticipated that the TMDL will be re-done so using revised phosphorus and chloride standards?

    Response:

    Illinois EPA has addressed the total phosphorus impairments in this watershed and developed the TMDL load capacity based on applicable water quality standards, while LRS was developed for TSS.

    Chloride TMDL was not developed (refer to Response # 13). This TMDL may be reopened in the future, if new or revised water quality standards are adapted by the Illinois Pollution Control Board and approved by USEPA.

23. I am deeply disturbed by the very thought of allowing more pollution in our rivers. The coal company has already stated that the effluent is dangerous, and yet the State of Illinois is considering allowing discharge into the Big Muddy River. It is desperately important to quit using our rivers as sewers - especially when there is no sewerage treatment to help mitigate the damage - and yet, private companies push to move the toxins from THEIR RESPONSIBILITY to the people of the state, and those of every state south. I understand that coal is important to the state, but health needs to be much more important, and private companies need to quit being profitable only by shirking their own responsibilities.

    [Similar additional comments are in Attachment: 8 – Public Comments]

    Response:

    The Agency has received discharge permit modification for Williamson Energy, LLC – Pond Creek Mine, NPDES Permit No.IL0077666 to relocate the current outfall from Pond Creek to the Big Muddy River.

    The flow of this discharge will be dependent on the flow and concentration of the receiving stream and the concentration of the effluent. Based on mixing with 25% of the receiving stream, they will base their discharge so as not to exceed the water quality standards. (35 IAC 302.102(8))

The applicant must be able to demonstrate that the water quality standards are being met in the receiving stream and they must go through the antidegradation requirements. As part of the antidegradation requirements they must show the social and economic benefits of the proposed activity and must demonstrate that alternatives have been considered. (35 IAC 302.105)

Concentrations of chlorides and sulfates in the Big Muddy River are well below water quality standards. Illinois EPA will only issue a water discharge permit that ensures the river continues to meet existing water quality standards. Illinois does not expect any impact to aquatic life, plant life or related issues as a result of the proposed discharge.

Once, the Draft NPDES permit is issued for public notice, there will be an opportunity for the public to comment on the contents of the draft permit.

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Watershed Implementation Plan

To Achieve the TMDLs and Load Reduction Strategy in the Upper Big Muddy River Watershed

Prepared for:
Illinois EPA

Final Report
May 2019

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Environment | Engineers

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Watershed Implementation Plan To Achieve the TMDLs and Load Reduction Strategy in the Upper Big Muddy River Watershed

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LimnoTech

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1 Introduction to the Implementation Plan

The Upper Big Muddy River watershed is located in southern Illinois, in Franklin, Jackson, Williamson and Hamilton Counties. The watershed study area is approximately 313,435 acres (490 mi^2) in size, but this area does not include drainage areas upstream of Rend Lake Dam. The impaired reach of the main stem of the Upper Big Muddy begins at Rend Lake Dam and extends approximately 48 miles downstream (waterbody segments IL_N-06, IL_N-11, and IL_N-17). Major tributaries include: Middle Fork Big Muddy River (waterbody segments IL_NH-06 and IL_NH-07) and Pond Creek (waterbody segment IL_NG-02).

This watershed implementation plan was prepared to document the conditions causing water body impairments and the plan to address those impairments. Specifically, the plan is intended to address only those impairments identified in the State of Illinois 2012-2016 Integrated Water Quality Report and Section 303(d) List, and refined based on the findings discussed in the Stage 3 report. Figure 1 shows a map of the watershed and includes some key features such as waterways, subwatersheds, and the waterbodies with TMDLs or LRSs to be implemented under this plan The TMDL and LRS development process and results for the Upper Big Muddy River watershed waterbodies are documented in the Upper Big Muddy River Watershed Stage 3 TMDL Report. The waterbody segments within Upper Big Muddy River Watershed with TMDLs and LRSs developed as a part of this project are shown in Table 1-1.

Table 1-1. Waterbody TMDL/LRS Summary

Waterbody/ Segment ID	Size (mile/ac)	Impaired Designated Use	Impairment Cause	TMDL or LRS?
Big Muddy R. / IL_N-06	15.13 mi	Aquatic life	Sedimentation/Siltation	LRS
Big Muddy R. / IL_N-11	11.48 mi	Primary contact recreation	Fecal Coliform	**TMDL**
		Aquatic life	Sedimentation/Siltation, TSS	LRS
Big Muddy R. / IL_N-17	21.48 mi	Aquatic life	Sedimentation/Siltation, TSS	LRS
Andy Cr. / IL_NZN-13	11.7 mi	Aquatic life	Iron	**TMDL**
Herrin Old / IL_RNZD	51.3 ac	Aesthetic Quality	Phosphorus (Total)	**TMDL**
Pond Cr. / IL_NG-02	23.53 mi	Aquatic life	Sedimentation/Siltation	LRS
Lake Cr. / IL_NGA-02	12.33 mi	Aquatic life	Dissolved Oxygen	**TMDL**
Beaver Cr. / IL_NGAZ-JC-D1	1.7 mi	Aquatic life	Manganese	**TMDL**
Johnston City / IL_RNZE	64 ac	Aesthetic Quality	Phosphorus (Total)	**TMDL**
Arrowhead (Williamson) / IL_RNZX	30 ac	Aesthetic Quality	Phosphorus (Total)	**TMDL**
M. Fk. Big Muddy / IL_NH-06	12.52 mi	Primary contact recreation	Fecal Coliform	**TMDL**
M. Fk. Big Muddy / IL_NH-07	19.74 mi	Aquatic life	Sedimentation/Siltation	LRS
West Frankfort Old / IL_RNP	146 ac	Aesthetic Quality	Phosphorus (Total)	**TMDL**
West Frankfort New/IL_RNQ	214 ac	Aesthetic Quality	Phosphorus (Total)	**TMDL**

As described in the Stage 3 report, TMDLs and Load Reduction Strategies were calculated for each impaired lake and stream segment. Some of the impaired streams and lakes with TMDLs had permitted points sources noted as a source of the impairments, and included required waste load allocations. These water bodies are shown in Table 1-2.

Table 1-2. TMDLs with Point Source Wasteload Allocations

Waterbody/ Segment ID	Impairment Cause	NPDES Facilities with WLAs
Lake Cr. / IL_NGA-02	Dissolved Oxygen	IL0029301 (Johnston City STP)
West Frankfort New/IL_RNQ	Phosphorus (Total)	IL0072478 (Village of Thompsonville STP)

It is anticipated that those TMDLs that require reductions to the WLAs for point sources will be addressed through the NPDES permit process by the Illinois EPA permits section during the next cycle of permit renewal. The source of the impairment for Lake Creek (IL_NGA-02) was identified as being primarily from a point source, so there are no plans for implementation of management measures for non-point sources in this plan. West Frankfort New reservoir (IL_RNQ) has both non-point source and point source pollutant load reductions required to meet the TMDL, and the recommendations for implementation measures to address non-point sources are identified in this plan.

It is important to note that this watershed implementation plan is specifically intended to address excess pollutant loadings identified above and is not intended to address other watershed conditions that may exist in the Upper Big Muddy River watershed. A comprehensive watershed characterization was developed and is presented in Section 2 of this plan, which provides a solid baseline of relevant information necessary to understand the sources of identified impairments and identify appropriate and effective actions to address them. Sections 3 through 7 are organized and written to address the nine key watershed plan elements identified by USEPA in the *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* for achieving improvements in water quality (USEPA, 2008).

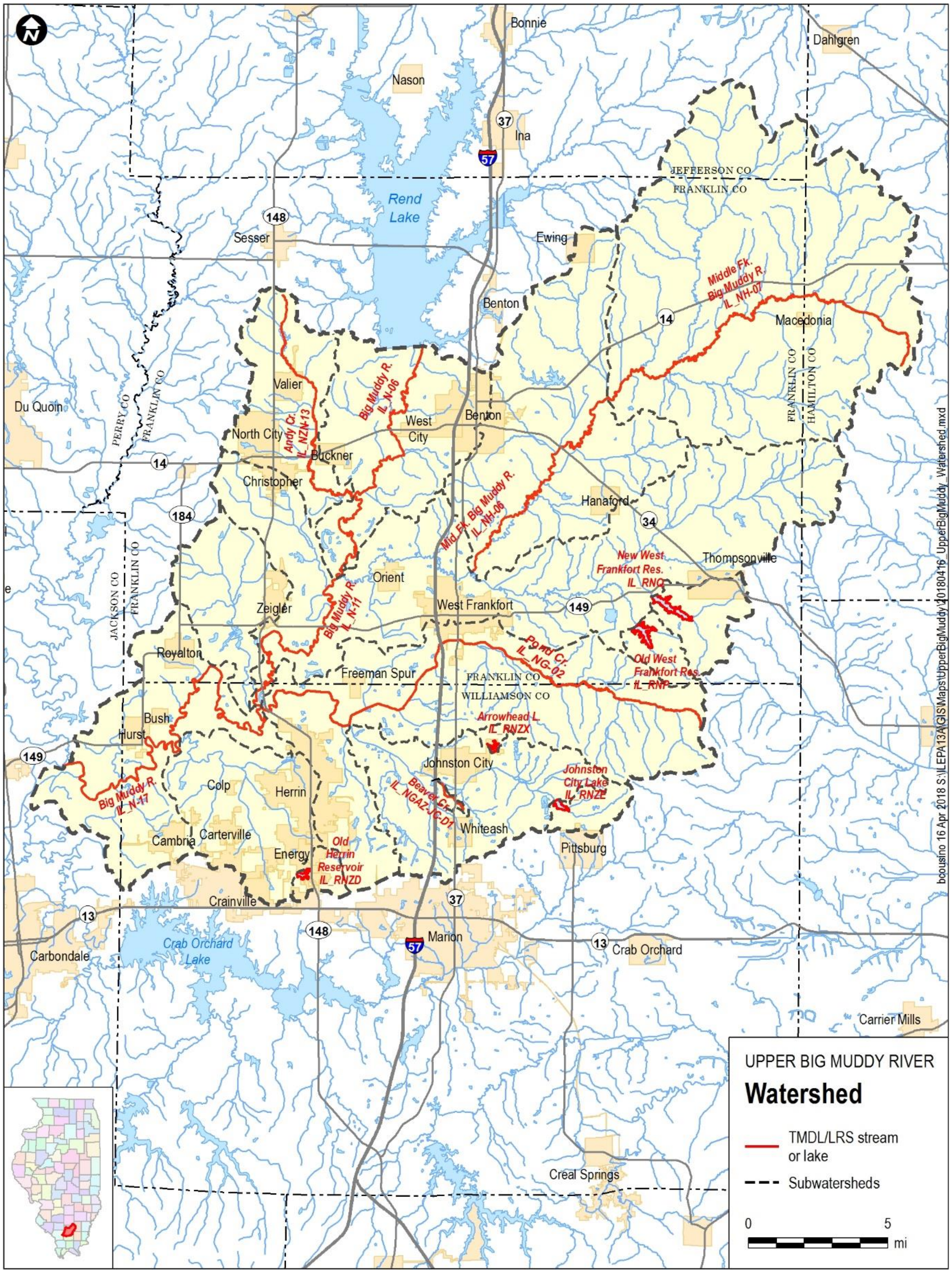

Figure 1-1. The Upper Big Muddy River Watershed, Showing Waterbodies with TMDLs or LRSs

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2 Watershed Characterization

As stated in Section 1, this implementation plan was prepared to address excess phosphorus, fecal coliform, sediment, iron, and manganese in the several waterbodies throughout the Upper Big Muddy River watershed. The sections that follow provide a broad overview of the characteristics of the Upper Big Muddy River watershed to inform the pollutant source identification, and selection of management practices to control the pollutants.

2.1 Watershed Boundaries and Geographic Focus of the Plan

The Upper Big Muddy River watershed is located in southern Illinois, in Franklin, Jackson, Williamson and Hamilton Counties (Figure 2-1). The watershed study area is approximately 313,435 acres (490 mi^2) in size, but this area does not include drainage areas upstream of Rend Lake Dam. The impaired reach of the main stem of the Upper Big Muddy begins at Rend Lake Dam and extends approximately 48 miles downstream (IL_N-06, IL_N-11, and IL_N-17). Major tributaries include: Middle Fork Big Muddy River (units IL_NH-06 and IL_NH-07) and Pond Creek (IL_NG-02).

2.2 Watershed Characteristics

The Upper Big Muddy River watershed was characterized by compiling and analyzing data and information from various sources. Where available, data were obtained in electronic or Geographic Information System (GIS) format to facilitate mapping and analysis. To develop a better understanding of land management practices in the watershed, local agencies were contacted to obtain information on cropping practices, tillage practices and best management practices (BMPs), and other land uses employed.

After the watershed boundaries for the impaired waterbodies in the project watershed were delineated from topographic and stream network (hydrography) information, other relevant information was obtained. This spatial information was supplemented from various other publicly available sources. The following watershed characteristics are described in this section:

- Topography
- Climate and Hydrology
- Geology
- Soils
- Demographics and Urbanization
- Land Cover

2.2.1 Topography

The Upper Big Muddy River watershed is generally flat, with gentle slopes in the headwaters. The highest elevations in the watershed (about 610 feet) are found west of Akin in Hamilton County. The lowest elevation (about 380 feet) in the watershed occurs at the outlet near De Soto in Jackson County. A topographic map of the watershed is presented as Figure 2-2.

Slopes in the Upper Big Muddy River watershed range from 0% to 115%, with an area-weighted average slope of 2.9%. A topographic map of the watershed is presented as Figure 2-2.

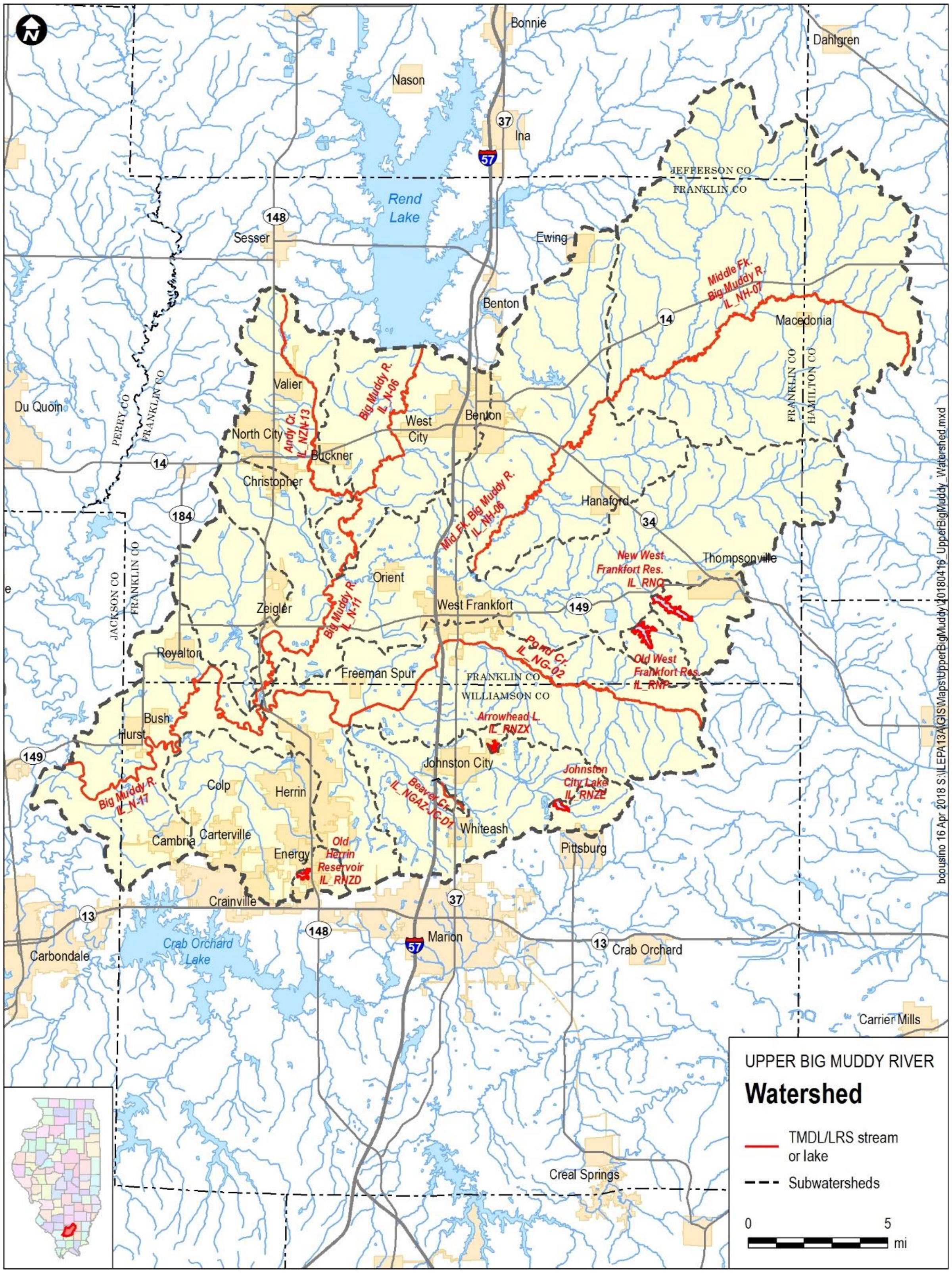

Figure 2-1. Upper Big Muddy River Watershed

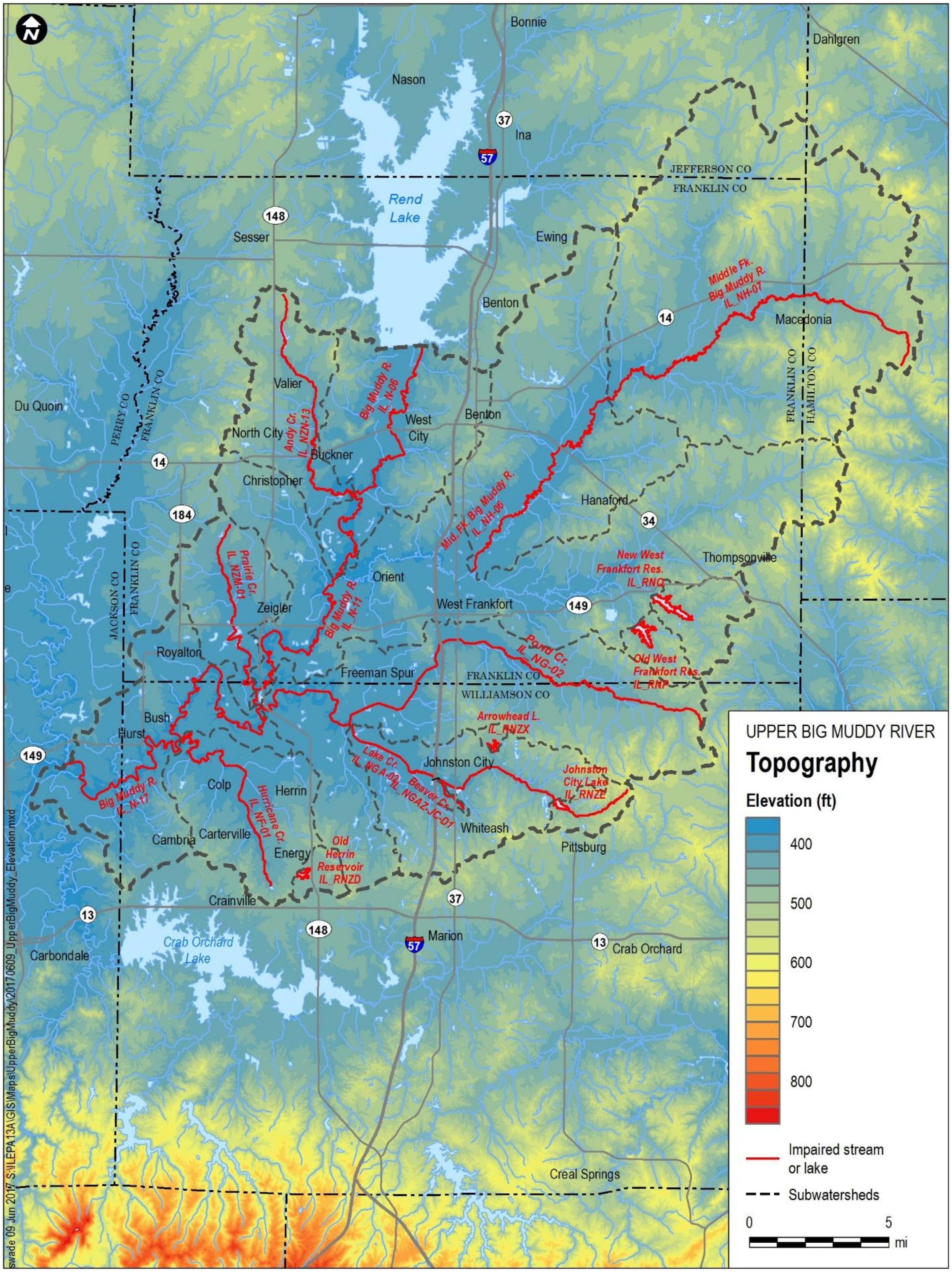

Figure 2-2. Topography of the Upper Big Muddy River Watershed

2.2.2 Climate and Hydrology

The Upper Big Muddy watershed has a continental climate with cold winters and hot, humid summers. The National Weather Service (NWS) maintained a weather station in the watershed at Benton, Illinois that closed in February 2009. Benton is relatively near the center of the targeted watershed and is a reasonable approximation of climate in the watershed.

Precipitation data from 1912 through station closure were downloaded and summarized (Table 2-1, Figure 2-3). The 96 years of historical precipitation data for Station 110608 in Benton average 40.5 inches of precipitation each year. The highest monthly average is May, with a long-term average of 4.2 inches of precipitation. The lowest monthly average occurs in February (2.6 inches). The most intense storms, based upon the daily maximum precipitation, may come during spring, summer or fall; precipitation events are typically milder during winter.

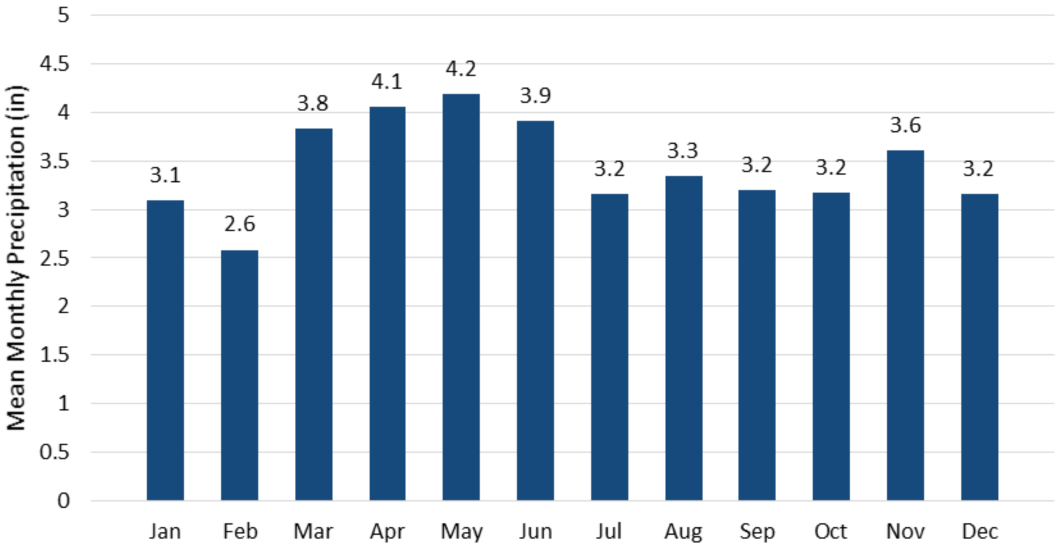

Figure 2-3. Average Monthly Precipitation in the Upper Big Muddy River Watershed

Air temperature data from the entire period of record were downloaded and summarized as well. The monthly mean, low, and high temperature data is reported for 1902 – 1920, 1976 – 1979, and 1998 – 2009, with limited or no reporting in between. The average air temperature data from the periods reported at this gage is summarized in Figure 2-4.

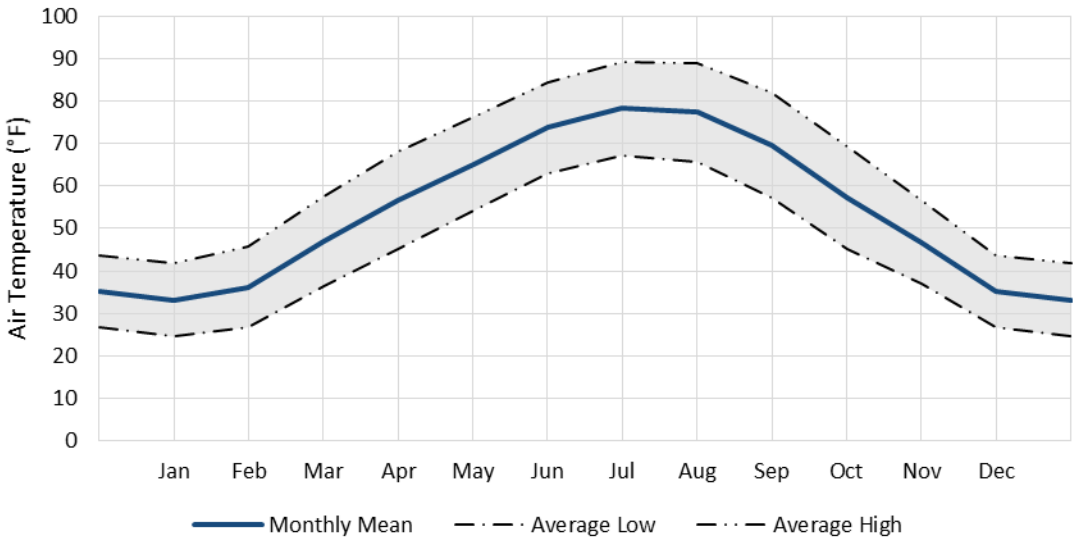

Figure 2-4. Average Monthly Air Temperature in the Upper Big Muddy River Watershed

Table 2-1. Long-term Precipitation Statistics for Benton, Illinois

Month/Season	Precipitation (in)	Days of Rain	Max Daily Precipitation (in)
1	3.1	8	1.2
2	2.6	7	1.0
3	3.8	9	1.3
4	4.1	9	1.4
5	4.2	9	1.4
6	3.9	8	1.4
7	3.2	7	1.3
8	3.3	6	1.4
9	3.2	6	1.4
10	3.2	7	1.3
11	3.6	7	1.4
12	3.2	8	1.2
Spring	12.0	26	2.0
Summer	10.3	21	2.1
Fall	9.8	20	2.0
Winter	8.8	22	1.8
Annual	40.5	89	3.1

Source: Downloaded from http://www.isws.illinois.edu/dat/

There is an active USGS streamflow gage in the watershed, located on the Big Muddy River at Plumfield, Illinois where State Highway 149 crosses the river (gage 05597000). The gage is about 1.9 miles downstream from the confluence with the Middle Fork Big Muddy River. The drainage area at this gage is 792 square miles and daily discharge measurements are available from 1908 to present.

Hydrology of the river has been significantly altered since the construction and filling of the Rend Lake Dam in the early 1970s. Maximum recorded discharge before Rend Lake Dam construction is 42,900 ft³/s on May 10, 1961. There was no flow at times in 1908-9, 1914, 1936, and 1940-41. Maximum recorded discharge since construction of Rend Lake is 14,200 ft³/s on May 1, 1996. The minimum discharge since construction of Rend Lake is 6.8 ft³/s on Oct. 13, 1970. Average daily flow over the past 42 years is 735 ft³/s.

Flow durations represent the percentage of time that a specified streamflow is equaled or exceeded during a given period. Figure 2-5 is a flow duration curve for USGS gaging station 0559700. Such analyses are a summary of the past hydrologic events (in this case, daily discharge). And if the streamflow during the period for which the duration curve is based is a sufficiently long period of record, the statistics can be used as an indicator of probable future conditions. Figure 2-5 illustrates the tremendous effect that Rend Lake has had on the hydrology of the Big Muddy River. It has significantly altered the hydrology, generally reducing the highest flows with the flow attenuation storage that is provided by the dam, and increasing the lower flow encountered with controlled flow release from Rend Lake.

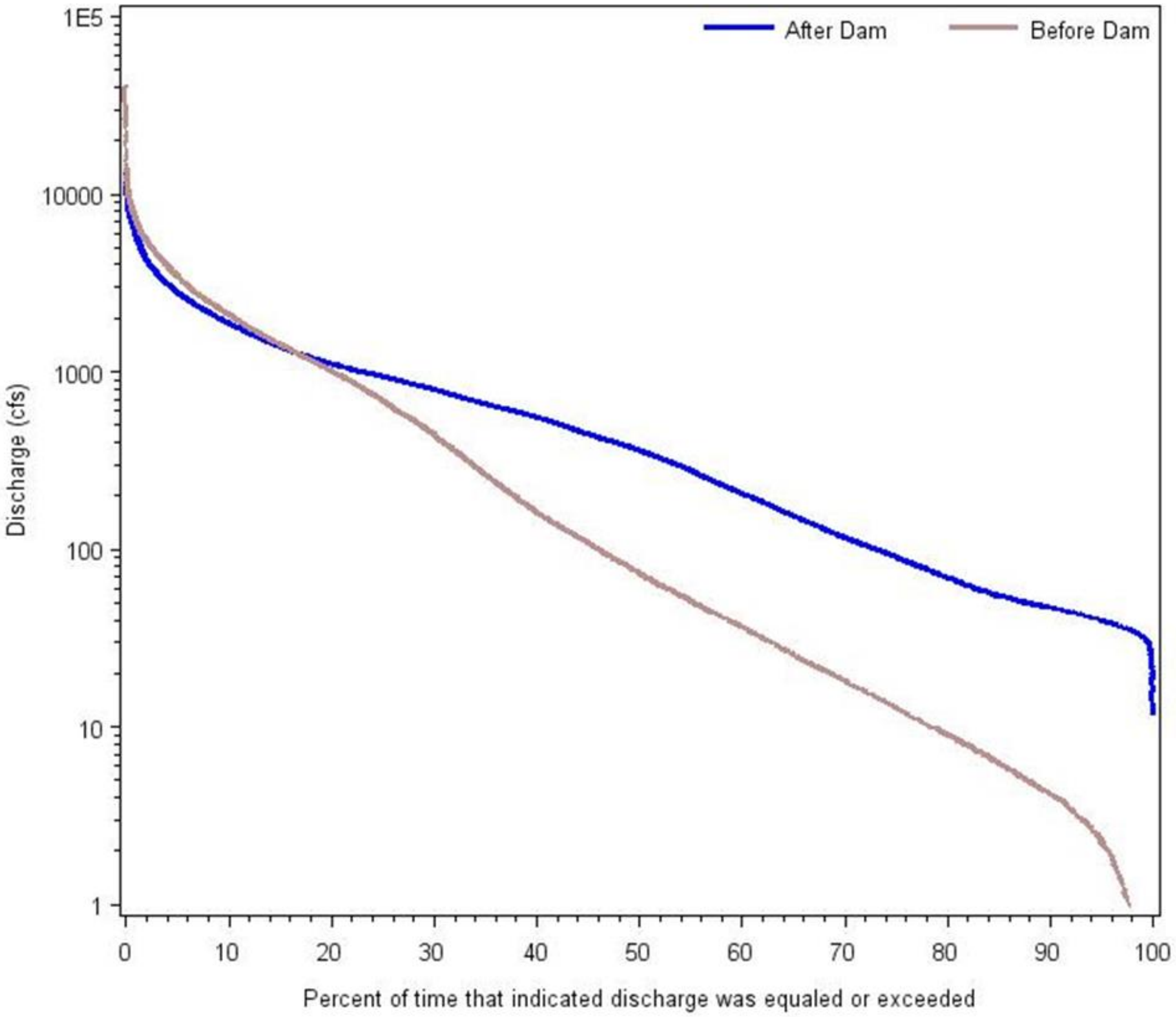

Figure 2-5. Flow Duration Curve, USGS Station 05597000, Big Muddy River at Plumfield, IL, Before and After Dam Construction

2.2.3 Geology

Bedrock geology in the Upper Big Muddy River watershed is a mixture of (60.6%) Pennsylvanian shale and Pennsylvanian limestone (39.4%) formations (Figure 2-6).

Surface geology of the Upper Big Muddy River watershed, like most of Illinois, is dominated by glacial drift. Glacial drift thickness is variable within the watershed, ranging from less than 25 feet to 200 feet (see Figure 2-7). The majority of the watershed (52%) has glacial drift thickness less than 25 feet, generally located in the upland areas. There are bedrock valleys that underlie the major drainage courses within the watershed, although the present streams channels do not always align with the bedrock valleys. These areas contain thicker unconsolidated glacial deposits, with 24.8% of the watershed area containing 25 to 50 feet of glacial drift, and 22.2% of the watershed with glacial drift thickness of 50-100 feet. Less than 1% of the watershed has glacial drift more than 100 feet thick, and those areas are located in the southern portion of the watershed in Williamson and Jackson Counties.

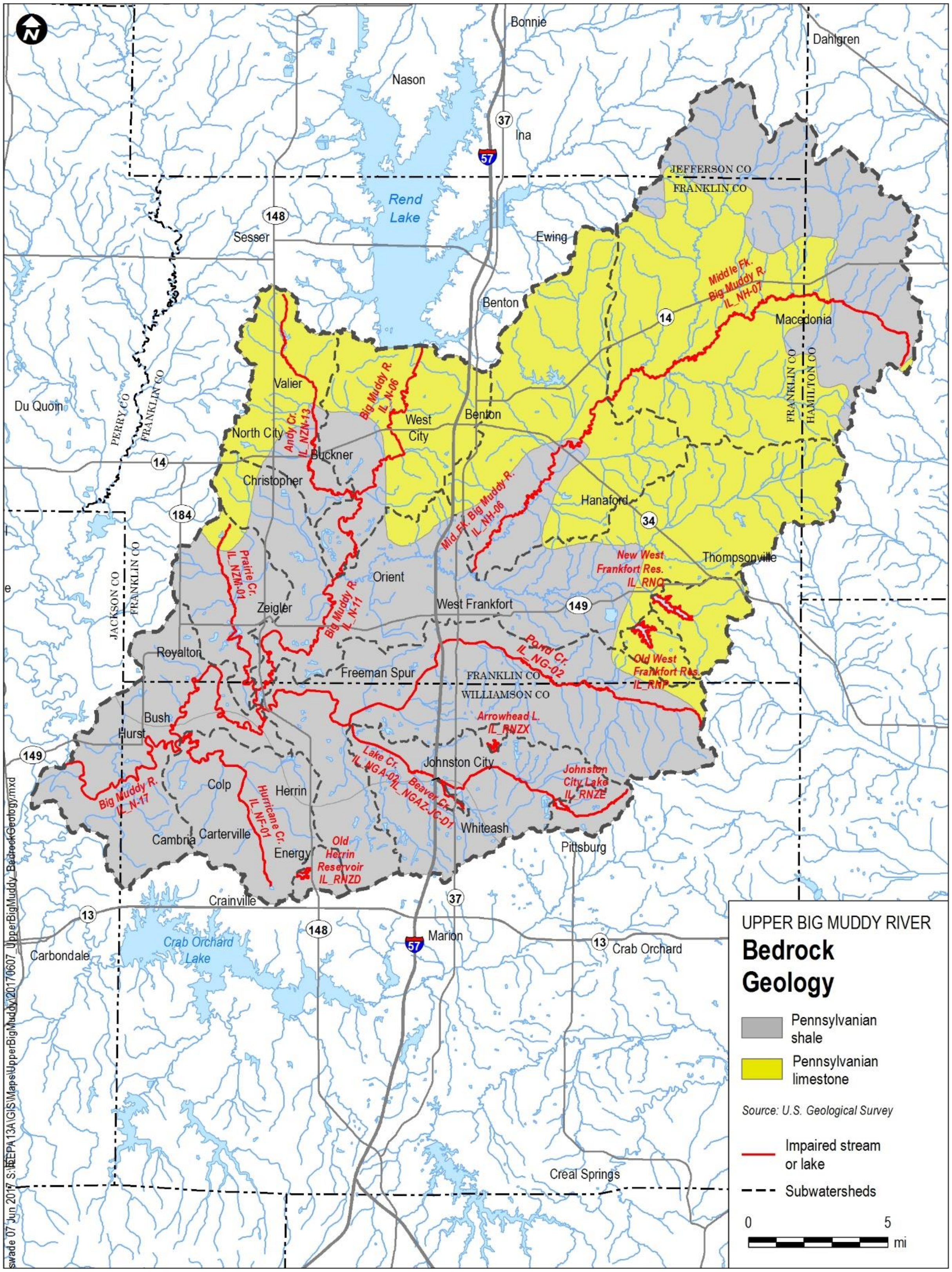

Figure 2-6. Geologic Units in the Upper Big Muddy River Watershed

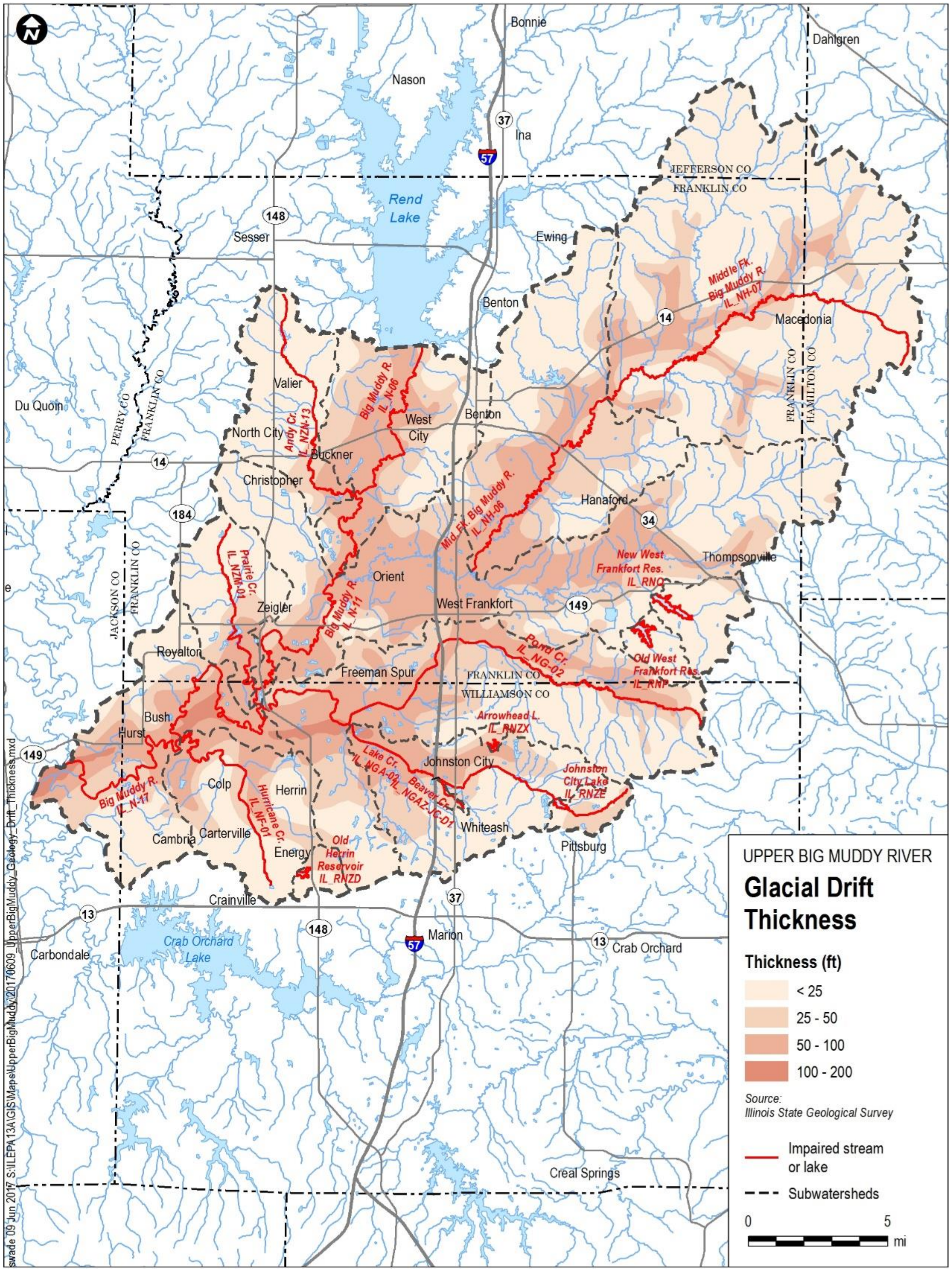

Figure 2-7. Glacial Drift Thickness in the Upper Big Muddy River Watershed

2.2.4 Soils

Together with topography, the nature of soils in a watershed play an important role in the amount of runoff generated and soil erosion. The Natural Resources Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database was reviewed to characterize study area soils. The target watershed has rich silt loam soils, lying predominately on slopes less than 2%. The most common soil types in the watershed are silt loam (78%) and silty clay loam (15%). The remaining soil types occur in much smaller percentages in the watershed. Soil texture distribution is shown in Figure 2-8 and a map of soil texture classes in the Upper Big Muddy River watershed is shown in Figure 2-10.

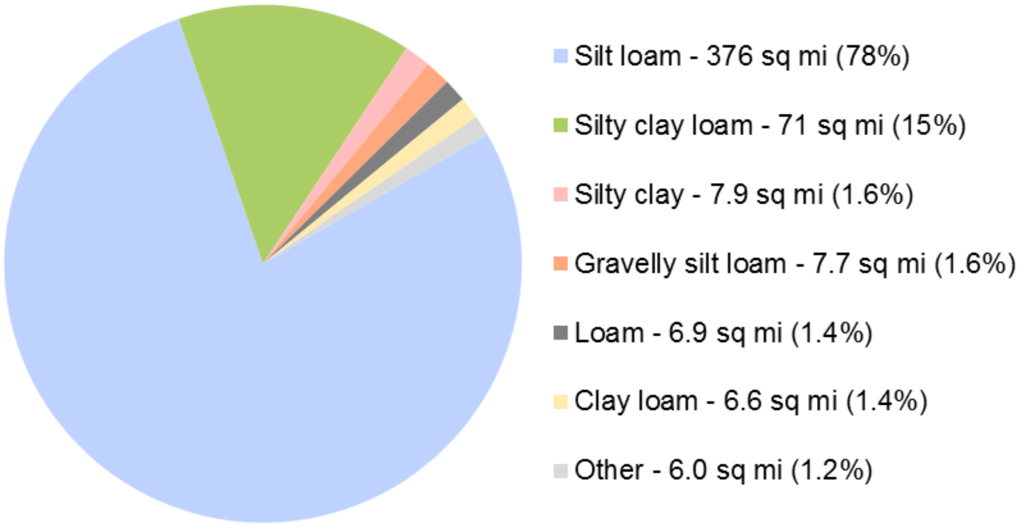

Figure 2-8. Distribution of Soil Texture Classes in the Upper Big Muddy River Watershed

The most predominant hydrologic soil group is C (49.7%), followed by D (24.4%), and soils that are C when drained, D when not drained (11.6%). 14.2% of the watershed soils are hydrologic soil group B and B/D (Figure 2-9). Approximately 2.6% of the HSG in the watershed are not classified. Those are primarily associated with water, urban, and mine dump map units. Hydrologic soil groups are mapped in Figure 2-11.

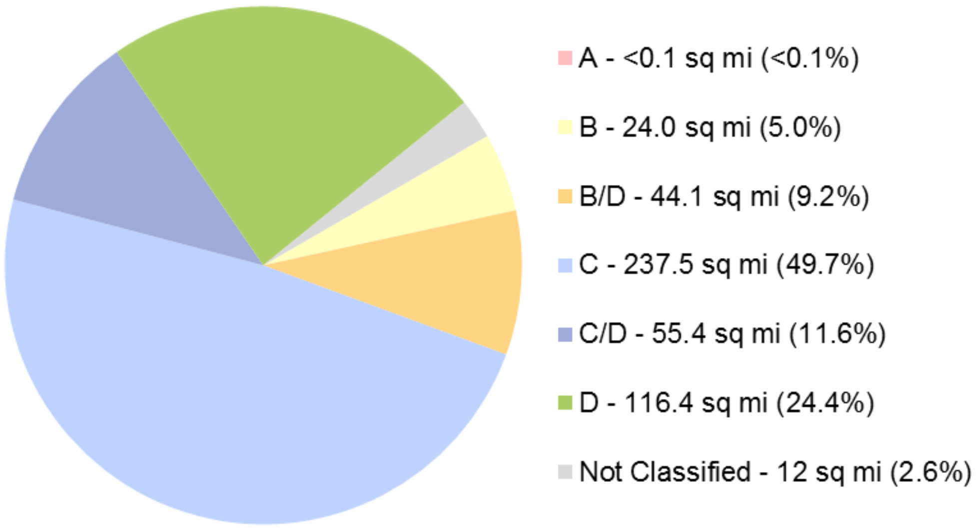

Figure 2-9. Distribution of Hydrologic Soil Groups (HSG) in the Upper Big Muddy River Watershed

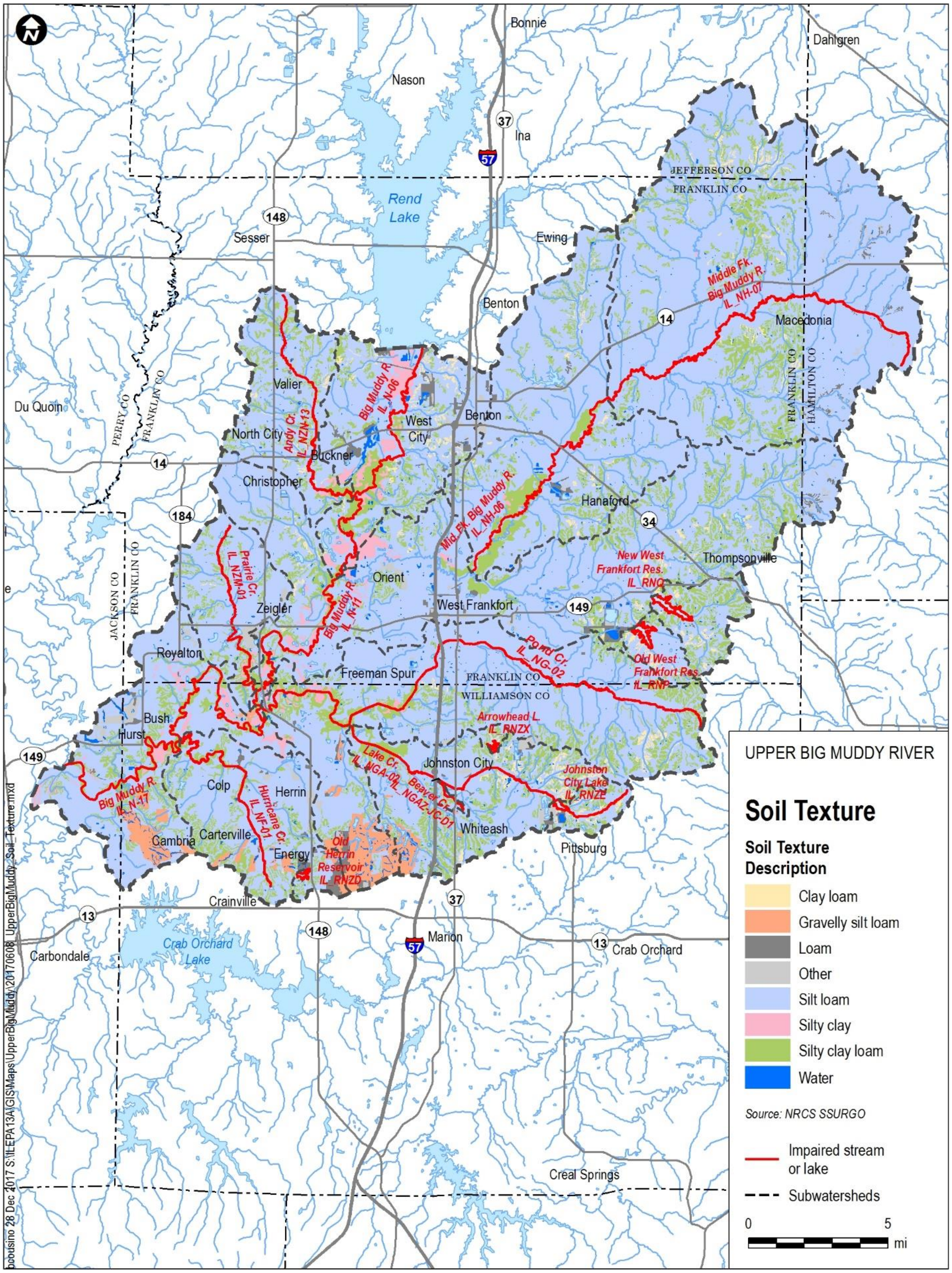

Figure 2-10. Soil Texture Classes in the Upper Big Muddy River Watershed

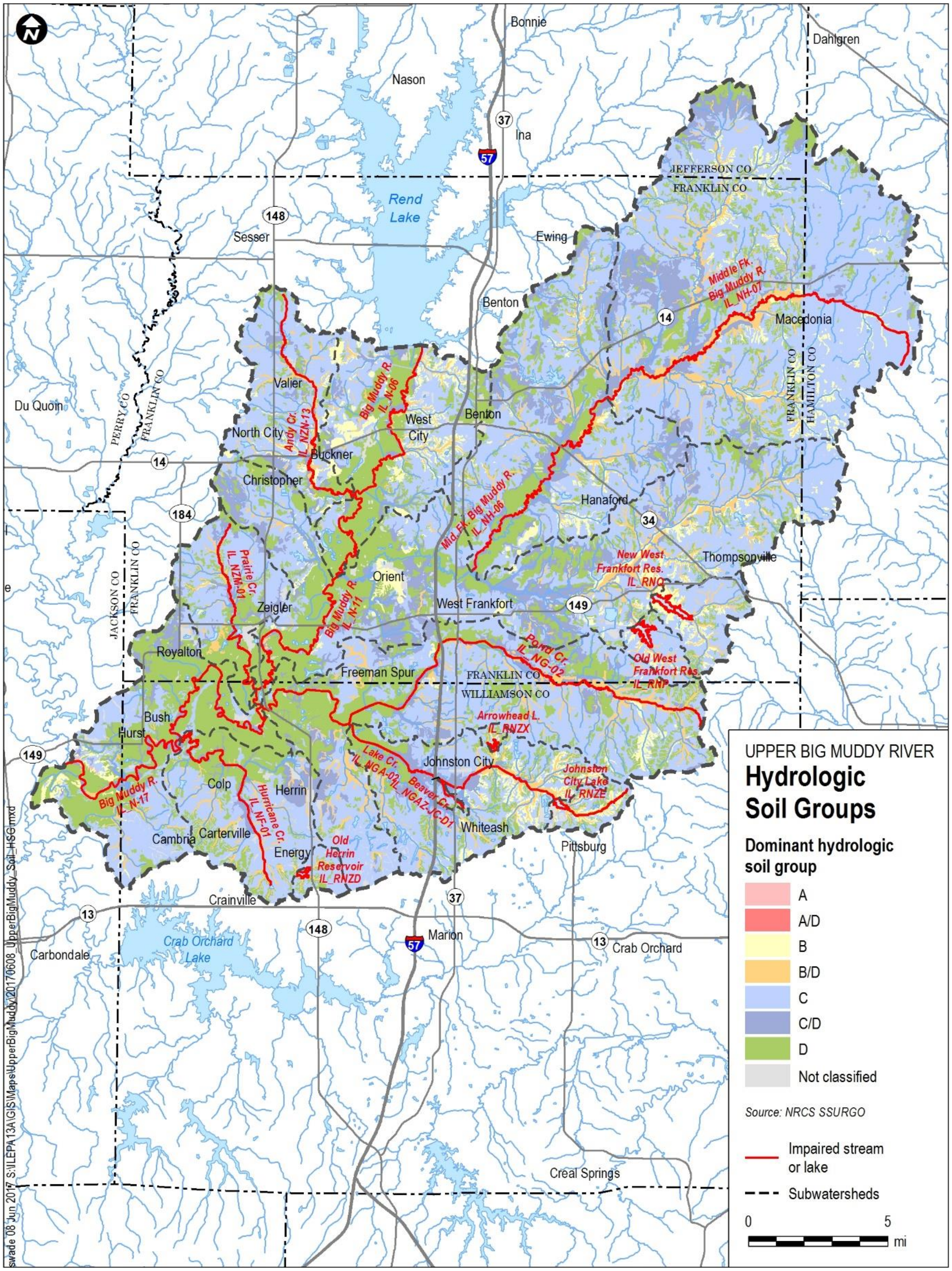

Figure 2-11. Hydrologic Soil Groups in the Upper Big Muddy River Watershed

The preceding discussion of topography, soil texture and hydrologic soil group classifications paint a picture of a watershed with steeper slopes near the headwaters, and flatter regions farther downstream, with poorly to very poorly drained soils dominating. According to soil drainage classification by the Natural Resource Conservation Service (NRCS, Figure 2-12), 13% of soil in the Upper Big Muddy River watershed is classified as “very poorly drained” or “poorly drained”, with another 46% classified as “somewhat poorly drained”. 27% of soil in the watershed is classified as “well drained” or “moderately well drained”.

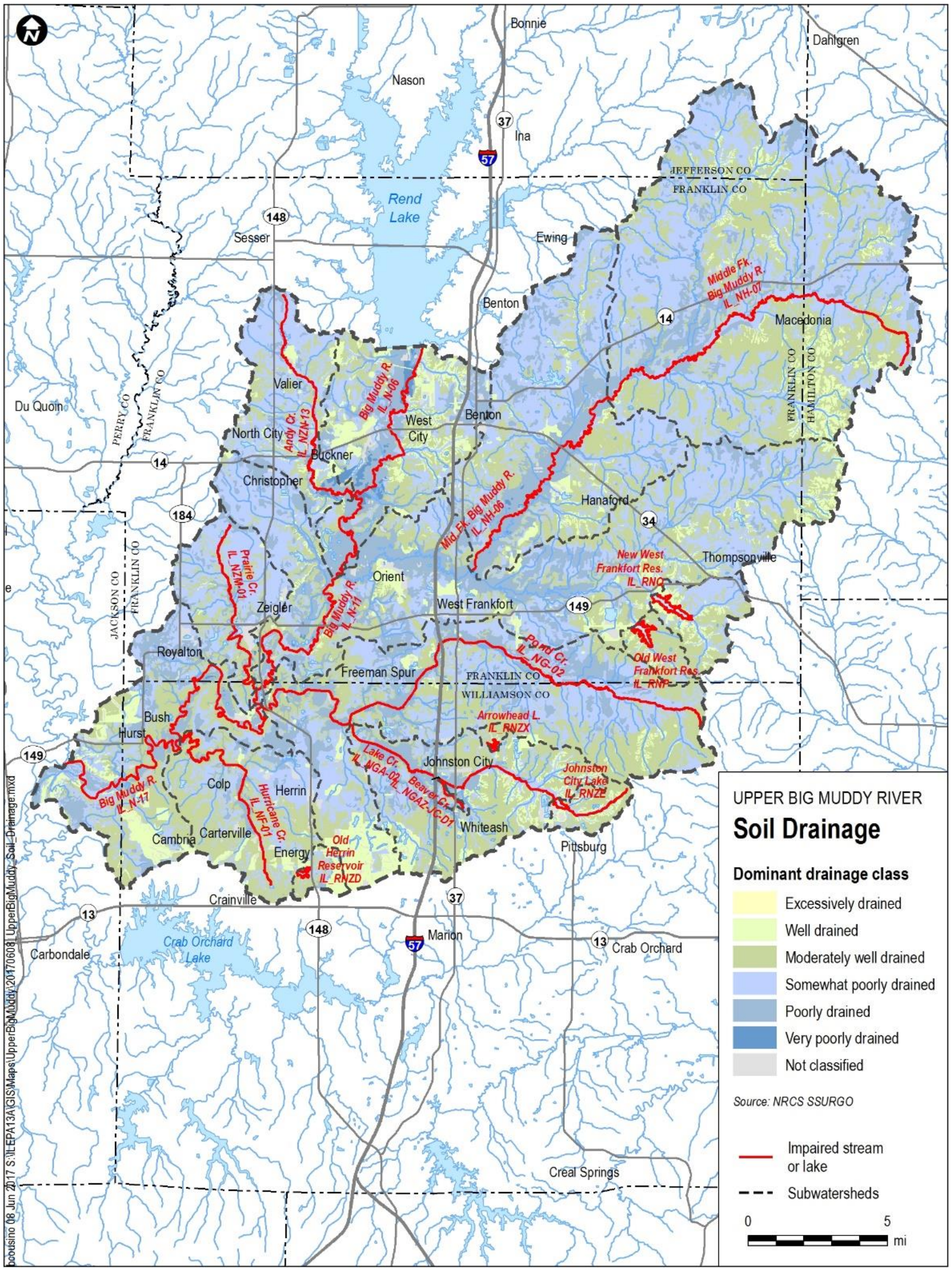

Figure 2-12. Soil Drainage Classification in the Upper Big Muddy River Watershed

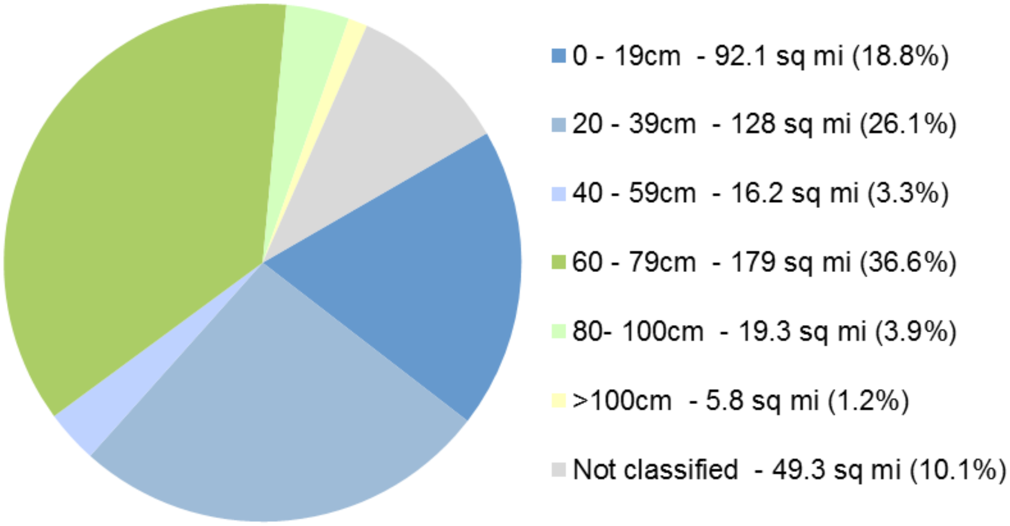

Figure 2-13. Depth to Groundwater in the Upper Big Muddy River Watershed

Groundwater in some areas of the watershed is very shallow (Figure 2-13 and Figure 2-14), with 18.8% of the watershed having an annual minimum water table depth of 15 cm (~6 inches). Overall, 88% of the watershed has an annual minimum water table depth of 79 cm (~31 in.) or less. Furthermore, 19% of the soils in the watershed are classified as hydric (Figure 2-15). These conditions suggest that roughly a fifth of the Upper Big Muddy River Creek watershed may have been covered by wetlands in the past. Based on recent land cover data (Illinois Cropland Data Layer 2011), there is less than 1% of the watershed that is currently covered with wetlands.

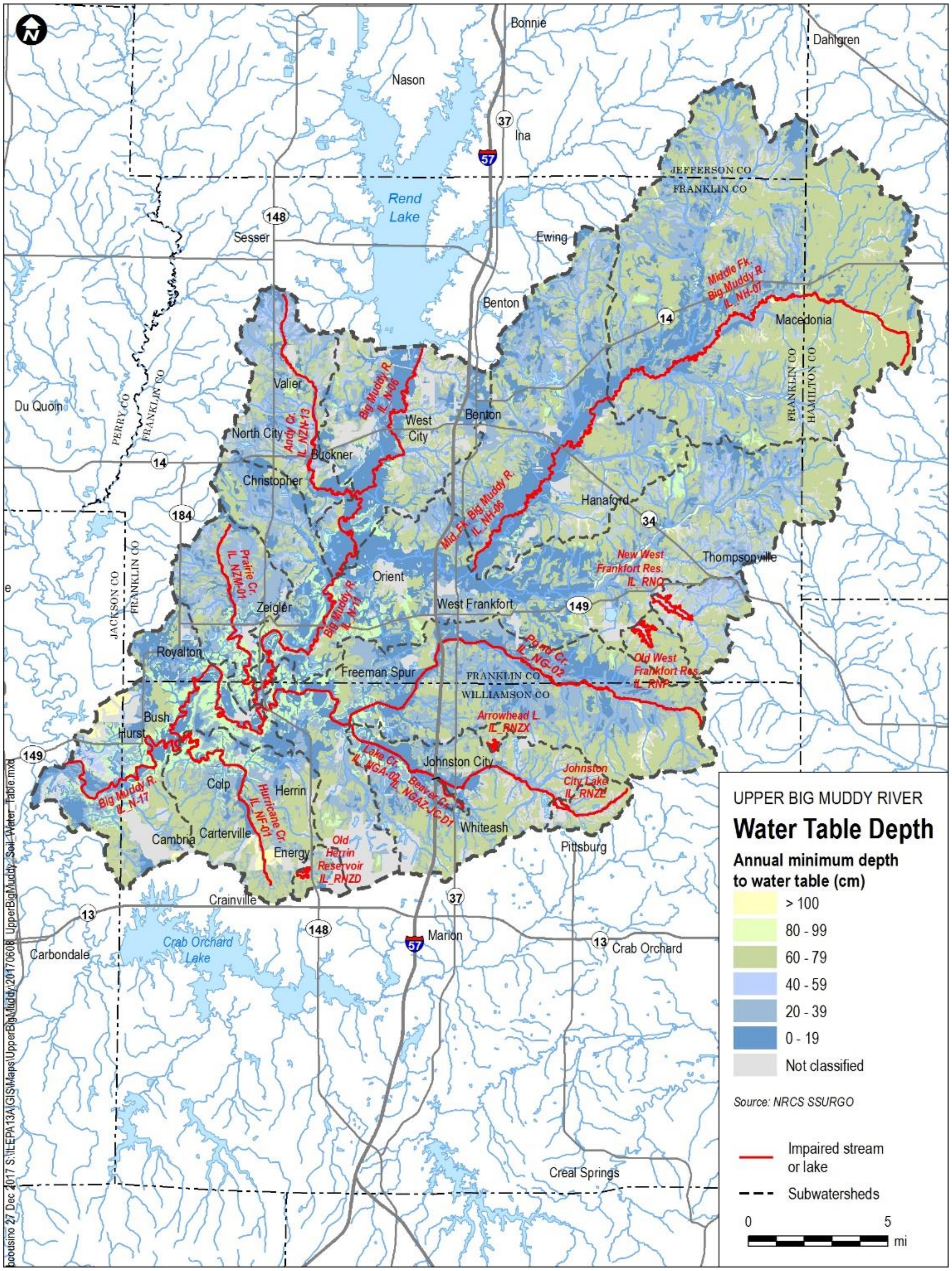

Figure 2-14. Depth to Groundwater in the Upper Big Muddy River Watershed

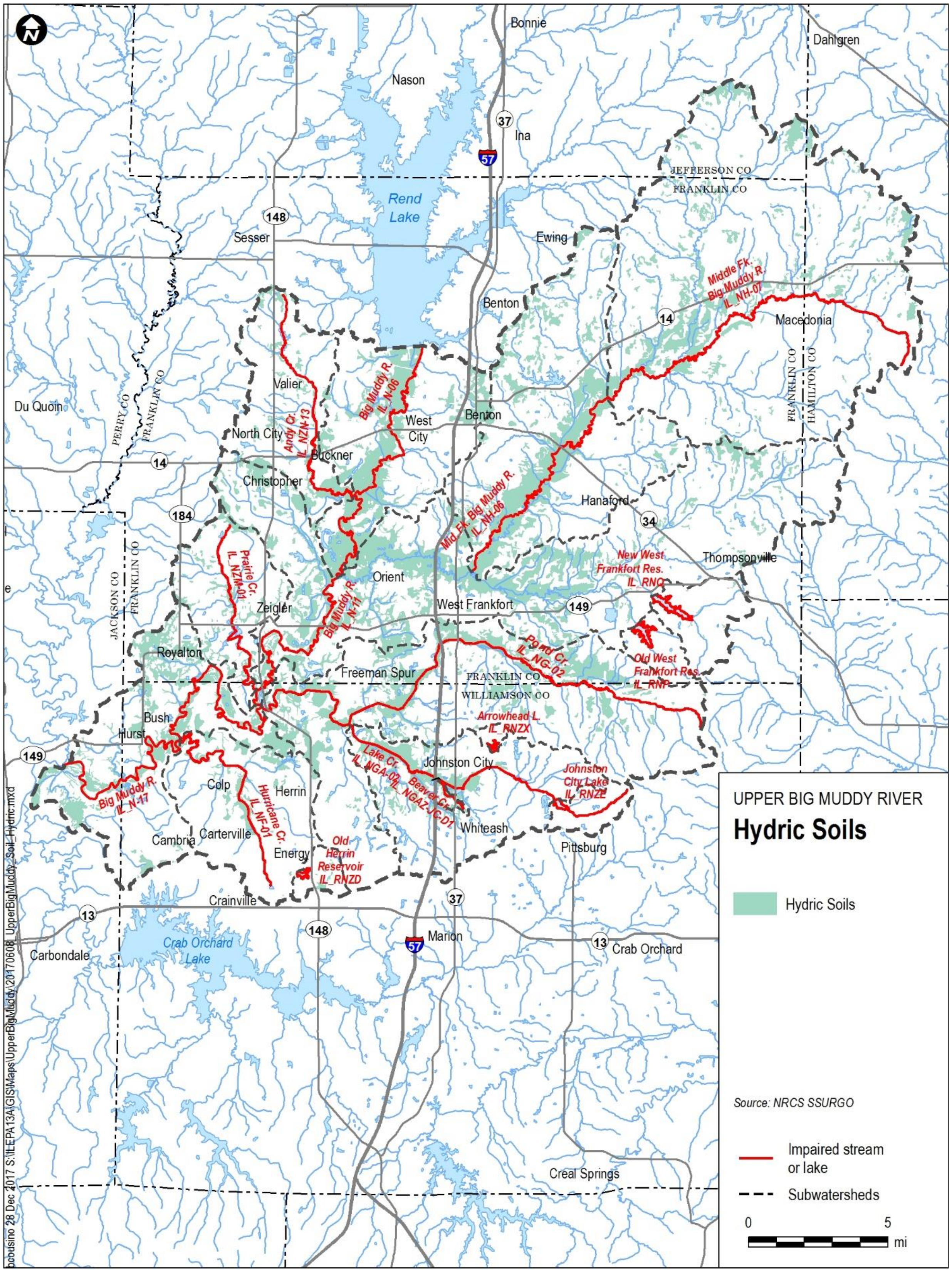

Figure 2-15. Hydric Soils in the Upper Big Muddy River Watershed

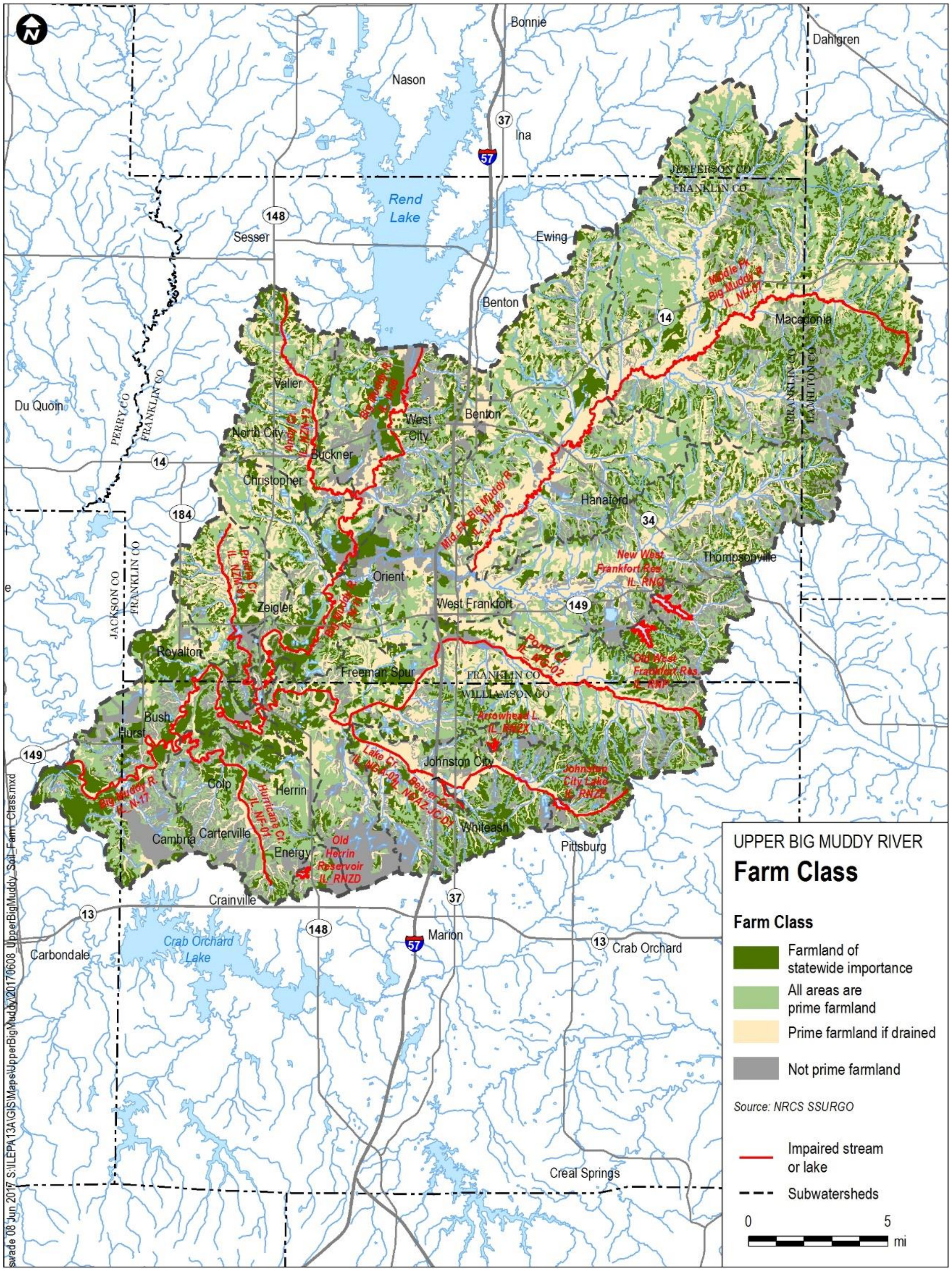

Figure 2-16. Farmland Quality in the Upper Big Muddy River Watershed

The NRCS classifies the agricultural quality of soils and 30.9% of the Upper Big Muddy River watershed is classified as "prime farmland if drained" or "prime farmland if drained and either protected from flooding or not frequently flooded during the growing season". 20.3% is classified as farmland of statewide importance. Another 30.6% of the watershed is classified as "prime farmland" and 18.1% is classified as "not prime farmland" (Figure 2-16).

76.7% of soil in the Upper Big Muddy River watershed is classified as having high erodibility and 20.9% is classified as having moderate erodibility (Figure 2-17). None of the soils with erodibility classifications within the watershed were classified as low erodibility. 2.5% of the areas within watershed were unclassified, primarily areas that were urban land, mine dumps, or water.

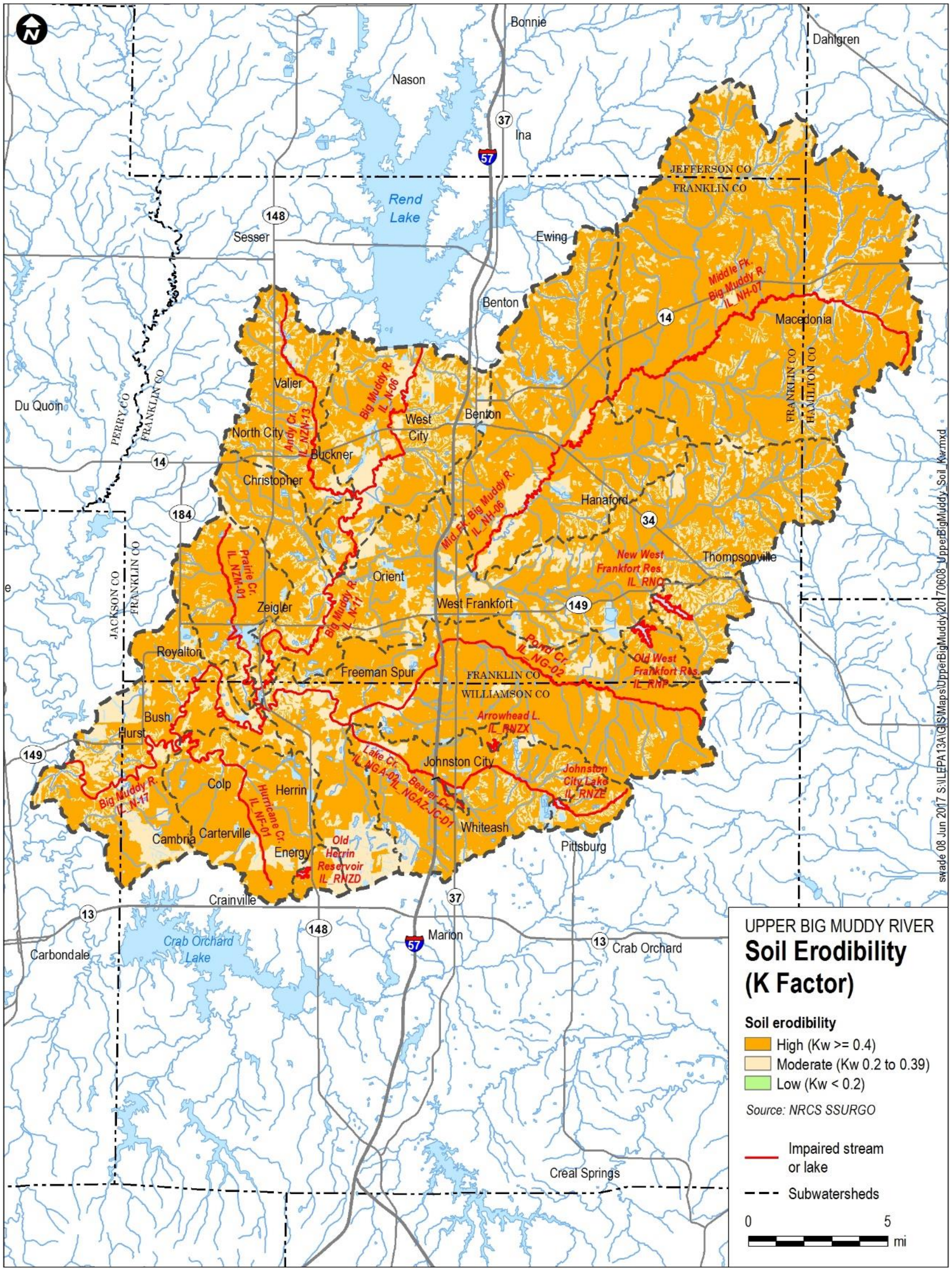

Figure 2-17. Soil Erodibility in the Upper Big Muddy River Watershed

2.2.5 Demographics and Urbanization

Population statistics and projections are available on a county basis. A majority of the watershed lies in Franklin and Williamson Counties, with smaller portions of the watershed in Jackson, Hamilton, and

Jefferson Counties. According to recent estimates from the United States Census Bureau, the population of Franklin County was 39,156, Williamson County was 67,560, Jackson County was 58,870, Jefferson County was 38,460, and Hamilton County was 8,061, as of July 1, 2016, which is the most recent data available[1]. The total 2016 population of these five counties equals 202,107, down from a total 5-county population of 213,851 in 2010. Population in Franklin, Jackson, Hamilton, and Jefferson counties decreased from 2010 to 2016. Williamson County saw an increase of 1.8% of population growth, but that was offset by the population losses from the other counties.

Urbanization in the watershed is centered in the towns of Herrin, West Frankfort, Benton, Johnston City, and Christopher (Table 2-2). The land cover data indicates that the watershed is approximately 7% urbanized, but very little of it is considered heavily developed. Any urban areas in this region are considered low intensity development.

Table 2-2. Estimated Watershed Population[2] of Towns in the Upper Big Muddy Watershed

NAME	Total Area (sq. mi)	Area In Watershed (sq. mi)	Percentage of Area in Watershed	Total Population	Estimated Watershed Population
Herrin	9.68	9.07	94%	12868	12067
West Frankfort	5.02	5.02	100%	7941	7941
Benton	5.66	4.77	84%	7148	6025
Johnston City	2.15	2.15	100%	3521	3521
Christopher	1.59	1.59	100%	2982	2982
Carterville	5.30	2.19	41%	5742	2375
Zeigler	1.37	1.37	100%	1771	1771
Cambria	1.41	1.23	87%	1337	1166
Energy	1.19	1.19	100%	1166	1166
Royalton	1.12	1.12	100%	1124	1124
West City	1.63	1.63	100%	789	789
North City	2.24	2.22	99%	755	749
Hurst	0.86	0.86	100%	705	705
Crainville	1.66	0.80	48%	1456	702
Thompsonville	2.05	2.01	98%	645	634
Valier	1.13	1.13	100%	601	601
Buckner	0.89	0.89	100%	467	467
Orient	0.75	0.75	100%	350	350
Whiteash	0.89	0.89	100%	328	328
Hanaford	1.01	1.01	100%	323	323
Freeman Spur	0.40	0.40	100%	254	254
Bush	0.46	0.46	100%	244	244
Colp	0.14	0.14	100%	219	219
Ewing	1.01	0.74	73%	294	216
Macedonia	0.27	0.27	100%	82	82

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[1] https://www.census.gov/quickfacts/fact/table/US/PST045218, accessed 12/21/17.
[2] Estimated 2000 populations obtained from Wikipedia on 5/31/17.

2.2.6 Land Cover

Using the 2011 Cropland Data Layer (CDL) for Illinois from the NRCS, it is apparent that the Upper Big Muddy River watershed is has significant agricultural land cover with approximately 34.2% of the watershed being cultivated crops and 24.2% being pasture and hay. Forest covers approximately 27% of the watershed and the remainder consists of developed open areas (Figure 2-18 and Table 2-3). Of the cultivated crops, nearly all of them are corn and soybeans. Corn accounts for 45% while soybeans account for 44%. Most of the remainder is a double crop of winter wheat/soybeans. Land cover is mapped in Figure 2-19.

Table 2-3. Upper Big Muddy River Watershed Land Cover

Classification	Acres
Cultivated crop	107,348
Developed, high intensity	383
Developed, low intensity	14,156
Developed, medium intensity	2,440
Developed, open	20,648
Forest	84,922
Grassland/pasture/hay	75,733
Water	4,604
Wetlands	3,088
Barren	112
Total	**313,435**

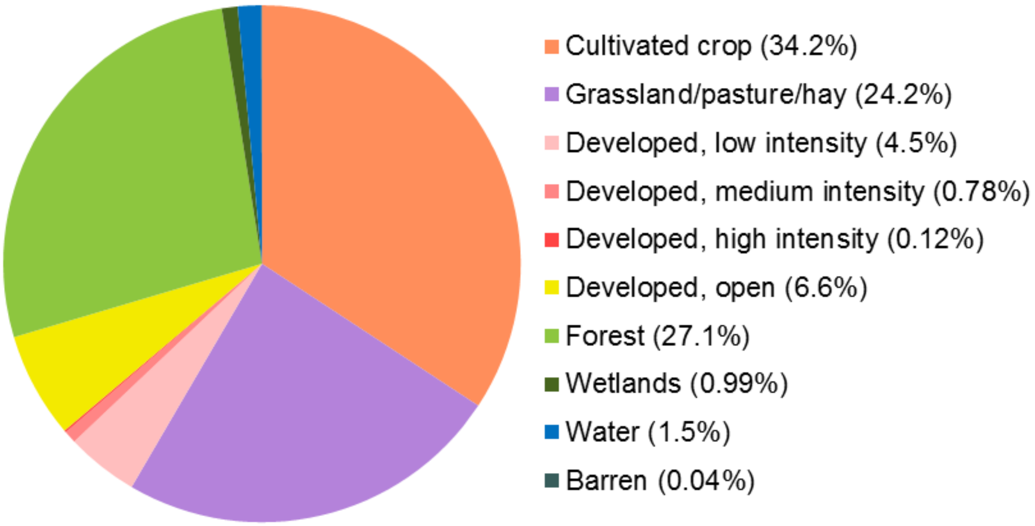

Figure 2-18. Upper Big Muddy River Watershed Land Cover Distribution

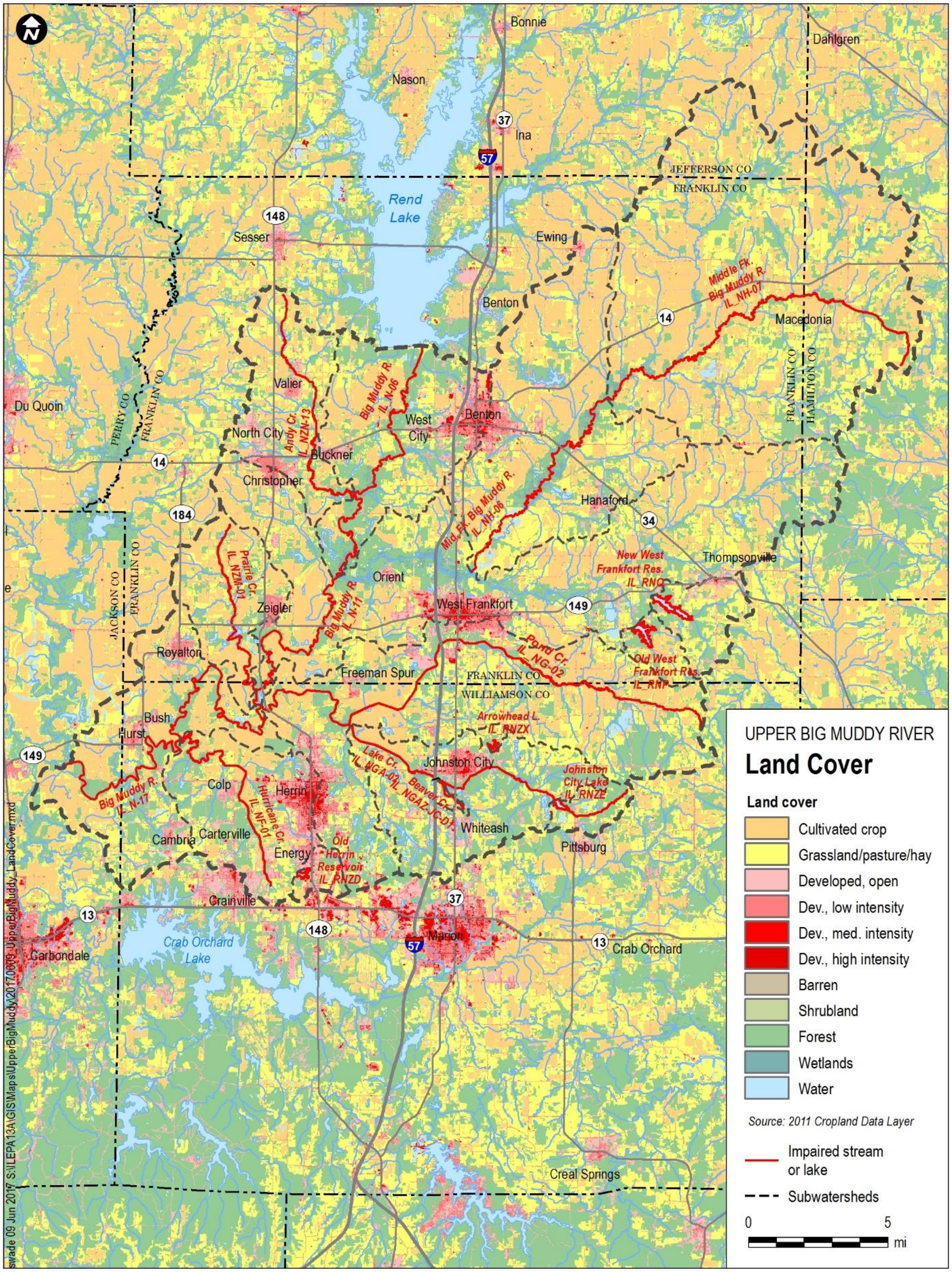

Figure 2-19. Land Cover in the Upper Big Muddy River Watershed

2.3 Additional Information Gathering

In addition to the desktop characterization described above, supplemental watershed inventory information was collected through a watershed tour and interviews with public officials. Additional information was obtained during the Stage 1 public meeting and public comment period. These activities are described below.

2.3.1 Watershed Tour

A tour of the Upper Big Muddy River watershed was conducted in 2013. This tour focused on the parts of the watershed containing impaired waters. The objectives of the watershed tour were:

- To verify observations made during the desktop analysis.
- To observe conditions at, and immediately upstream of, Illinois EPA water quality sampling locations.
- To identify concerns or potential causes of water quality impairment not previously identified

Most stream observations were made from bridge crossings or within a short hike of bridge crossings. A windshield survey of developed areas (towns) was conducted, but given the dominance of agriculture in the watershed, this contributed little information.

One significant observation made during the watershed tour was the prevalence of streambank erosion at all locations visited, including the lakes. Gully erosion was observed in the agricultural fields. Tile drains were observed as pipes protruding from streambanks, in some cases several feet above water level. The Upper Big Muddy River and its tributaries were generally mud-colored, which is logical based on the erodibility of the soils in the watershed, and the name of the river. In many cases, cropland was observed to extend to the edge of the streams.

2.3.2 Interviews with Local Officials

In addition to the extensive desktop watershed study and the watershed tour, the following local officials were contacted for information on a range of relevant subjects:

- Illinois EPA – source identification, mining, facility inspection reports, CAFOs, sampling, watershed groups.
- NRCS – ongoing implementation of watershed projects

These interviews did not reveal new information, but confirmed information previously developed, as well as the understanding of pollutant sources.

2.3.3 Public Input

A public meeting was conducted at the West Frankfort Public Library in West Frankfort, Illinois on Tuesday, December 17, 2013 a 3:30 PM, to present the findings of the watershed characterization and gather any additional information available from the public. The meeting was advertised, and public notices were mailed directly to the Soil and Water Conservation Districts, the Natural Resource Conservation Service, Illinois Farm Bureau and NPDES permittees in the watershed. A hard copy of the draft report was available for viewing prior to the meeting at the West Frankfort Public Library, Herrin City Hall, Christopher City Hall or Ewing Village Hall during business hours. The report was also available on-line at https://www2.illinois.gov/epa/public-notices/. Approximately 25 people attended the meeting, in addition to the meeting organizers. A background presentation was made on the watershed characterization, covering the following topics:

- The TMDL process and water quality goals;
- Target water quality issues in the Upper Big Muddy River watershed; and
- Potential sources of pollutants.

Questions were invited and input was requested at the meeting. The public in attendance was in overall agreement with the findings of the watershed characterization.

3 Identification of Causes of Impairment and Pollutant Sources

As stated previously, this implementation plan was prepared to address excess phosphorus, fecal coliform, sediment, iron, and manganese in the several waterbodies throughout the Upper Big Muddy River watershed. This section addresses the likely pollutant sources within the subwatersheds contributing to the impaired water bodies. Pollutant sources were evaluated using the watershed characterization information presented in Section 2, available monitoring data, simple watershed modeling, GIS analysis of watershed characteristics, a site visit and calls to local agencies.

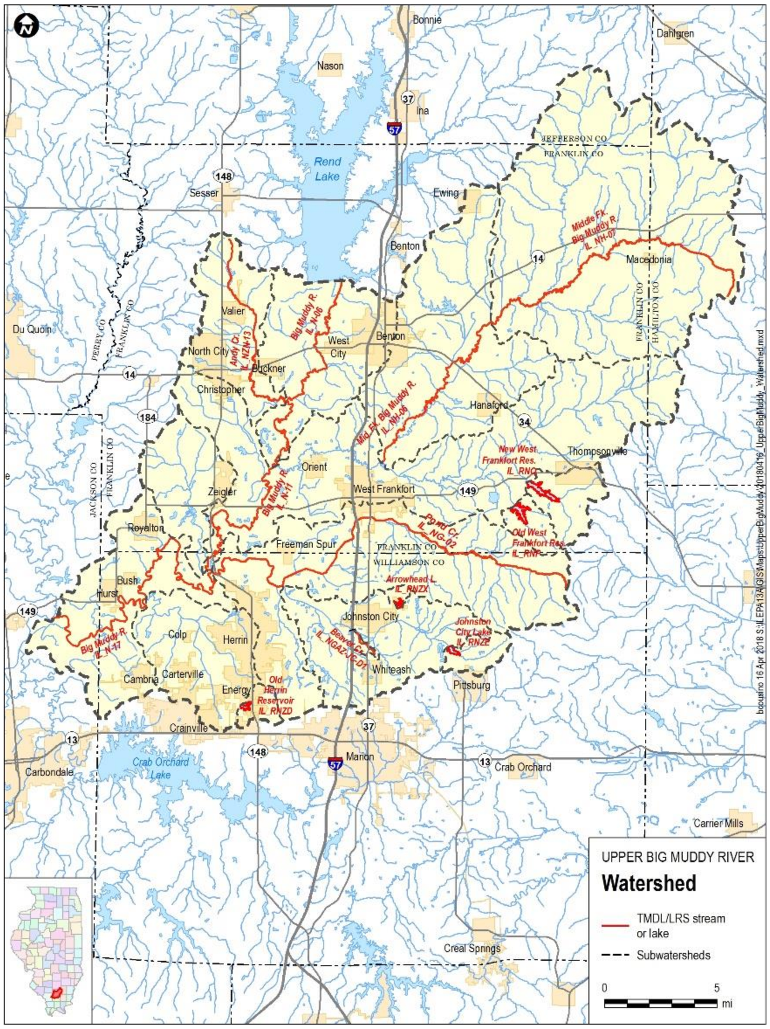

Figure 3-1. Study area map

3.1 Identification of Potential Pollutant Sources

The pollutants causing the waterbody impairments identified in the TMDLs and LRSs for the Upper Big Muddy River watershed include the following:

- Iron
- Manganese
- Chloride
- Sedimentation/Siltation
- Fecal Coliform
- Dissolved Oxygen
- Phosphorus (Total)

There are several potential sources of these pollutants loadings in predominantly agricultural watersheds, including:

- Agricultural runoff (iron, manganese, phosphorus, sediment, fecal coliform)
- Developed area runoff (iron, manganese, phosphorus, sediment, fecal coliform)
- Active and closed mines (iron, manganese, chloride)
- Streambank erosion (phosphorus, sediment)
- Legacy phosphorus in lake sediments (phosphorus)
- Point sources (fecal coliform, chloride)

To estimate the existing loads from each of the sources, and their relative contributions to the impairments, watershed models were developed within Model My Watershed, which is a web-based application of the GWLF-E model. It includes separate models for estimating the surface runoff loads, as well as the streambank erosion loads. Each of the potential sources is evaluated below, with the watershed model results by impaired waterbody segment.

Pollutant loads from surface runoff and streambank erosion were calculated within Model My Watershed , which implements GWLF-E for runoff loads and estimates the watershed average lateral streambank erosion (LER) using an empirical method. This empirical method for streambank erosion is based on the average monthly flow, and a regression factor based on five key watershed parameters including animal density, curve number soil erodibility (k factor), mean watershed slope and percent of developed land in the watershed. This method was developed by Evans et al., 2003 based on sediment loading data from several watersheds within Pennsylvania. After a value for the LER has been computed, the total sediment load from streambank erosion within the watershed is calculated by multiplying the LER by the total length of streams in the watershed, the average streambank height, and the average soil bulk density. Within Model My Watershed, the default values for average streambank height of 1.5 m (4.92 ft) and 1500 kg/m^3 (93.6 lb /ft^3) are used for and soil bulk density, respectively. Runoff from cropland is calculated to contribute 48% of the total sediment load, and streambank erosion is calculated to contribute 51% of the total sediment loads. Runoff from the remaining land cover categories in the watershed contributes 1% or less of the total load each. Severe streambank erosion was observed in many locations (Figure 3-2).

Figure 3-2. Examples of streambank erosion in the Upper Big Muddy River watershed

3.2 Big Muddy River (IL_N-06)

This waterbody segment is impaired for sedimentation/siltation, with a LRS target of 26.2% reduction of TSS. This segment of the river is immediately downstream of the Rend Lake dam, so the hydrology has been significantly altered by the construction of the dam.

The Model My Watershed model results for the sediment loads in the HUC12 watershed that drain to this segment of the river was created are summarized in the figure below.

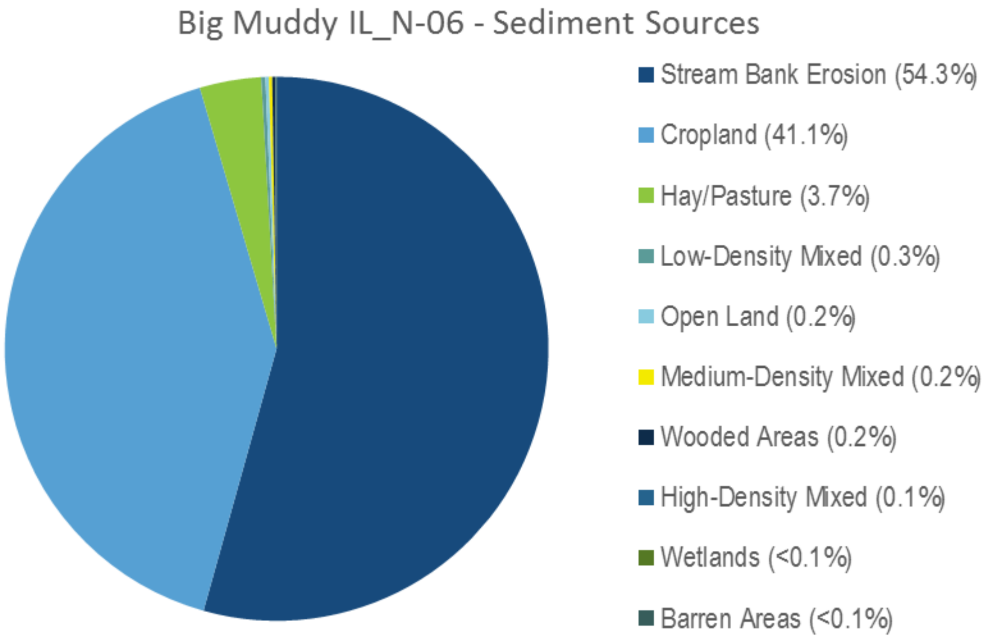

Figure 3-3. Big Muddy River IL_N-06 Sediment Sources

The model results indicate the stream bank erosion is the largest contributing source of sediment in this sub-watershed, followed by runoff from cropland and hay/pasture land cover. Management measures that focus on the reduction of those sources will be necessary to meet the LRS target reductions.

3.3 Big Muddy River (IL_N-11)

This waterbody segment is impaired for sedimentation/siltation, and for fecal coliform. The sediment/siltation impairment has a LRS target of 39.3% reduction of TSS. The fecal coliform has a TMDL that requires a 95.4% reduction in the load during wet weather flows. The analysis of the sources for sediment and siltation are analyzed separately below.

3.3.1 Sediment/Siltation

The Model My Watershed model results for the sediment loads in the HUC12 watershed that drain to this segment of the river are summarized in the figure below.

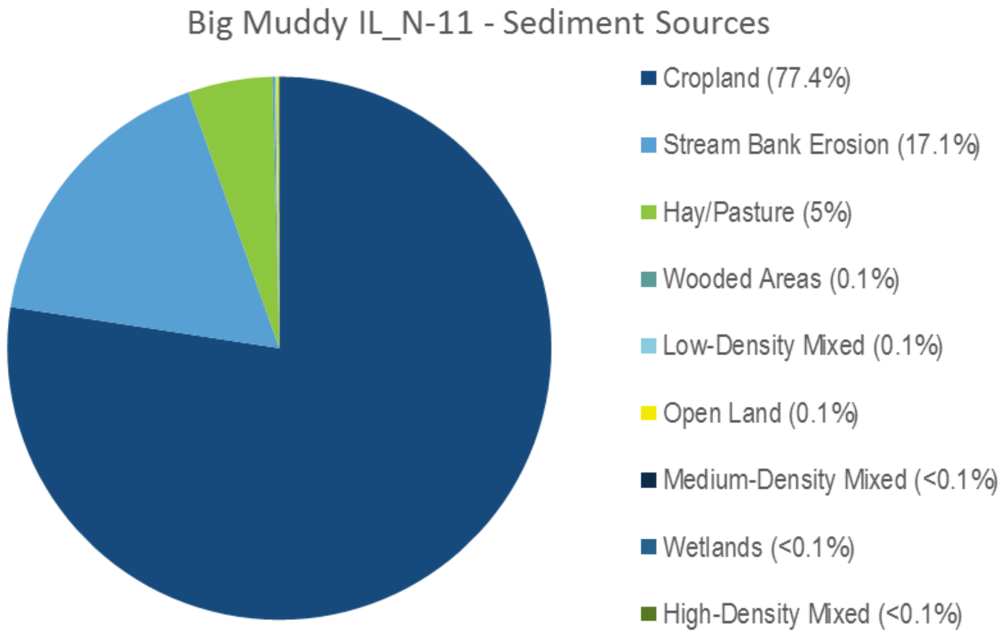

Figure 3-4. Big Muddy IL_N-11 Sediment Sources

The model results indicate the runoff from cropland and hay/pasture land cover are the largest contributing sources of sediment in this sub-watershed, followed by stream bank erosion. Management measures that focus on the reduction of those sources will be necessary to meet the LRS target reductions.

3.3.2 Fecal Coliform

Fecal coliform monitoring data collected in this segment of the Upper Big Muddy River at station IL_N-11 show a correlation between flow and fecal coliform concentrations. The majority of the water quality standard violations occur at higher flow conditions indicating fecal coliform is primarily being delivered to the river during wet weather conditions. Potential sources of fecal coliform during wet weather flow include nonpoint source runoff including runoff carrying waste from livestock, wildlife and pets. Sewage treatment plants and failing septic systems/surface discharging systems may also contribute, however, due to the low effluent flow of the sewage treatment plants in the watershed (<0.04 MGD), they are not identified as contributing significant fecal coliform loads to the creek. Septic systems and aeration units (wastewater is aerated, treated with chlorine and discharged to the surface) are used for sewage treatment in rural areas. Improperly functioning septic systems and aeration units would have a larger impact on the creek during dry weather conditions, but could also have an impact during wet weather conditions, if the septic system was not working properly or the surface discharge was not chlorinated. The contribution of these sources is not known, but a ballpark load was calculated, using literature values and assumptions regarding per capita flows (90 gal/person/day), 5% failure rate and homes served by septic systems (665). It is possible that failing onsite treatment systems could contribute 4% of the current bacteria load, and as such they are identified as a potential source that should be investigated further. This plan recommends coordination with the local health department to identify septic/aeration unit systems in need of improvement or repair.

Livestock can contribute fecal coliform loads via waste runoff, and if the animals are not fenced away from waterways, they may be a direct source to the streams. According to the most recent (2012) census of agriculture (NASS, 2017), cattle farms are the most common type of livestock farm within Jackson, Williamson, Hamilton, Jefferson, and Franklin Counties, but there are almost three times as many hogs as cattle suggesting hogs are more concentrated.

The potential fecal coliform load from livestock was calculated using available information. First, the number of animals in the Upper Big Muddy River watershed was approximated by scaling the countywide numbers of livestock and farms to the area of the watershed in each county. Fecal coliform loads were calculated for the three most common livestock, cattle and hogs, and turkeys, based on manure produced/animal and literature values describing the concentration of bacteria in manure (USEPA, 2001; http://www.agronext.iastate.edu/immag/pubs/smanure.pdf; and https://www.nrcs.usda.gov/wps/portal/nrcs/detail/null/?cid=nrcs143_014211, https://engineering.purdue.edu/adt/PoultryManure/PoultryManureSurveyFinalReport.pdf).

This load is an estimate of what is produced. The load that reaches the stream is expected to be less due to bacterial decay, reductions from existing vegetative filters and other management practices to capture or treat bacteria, and other factors. However, this calculation showed that livestock could potentially contribute up to 50% of the current fecal coliform load, although the true contribution is uncertain.

Table 3-1. Livestock and Poultry Census Data (2012) and Estimated Fecal Coliform Loads

Census Item	Est. # of Farms	# of Animals	**Fecal coliform/yr**
Cattle, including calves - inventory	7	246	6.3E+15
Hogs and pigs – inventory	1	653	2.5E+14
Turkeys	1	3,187	3.4E+14

Fecal coliform loads in runoff may also originate from wildlife although their contribution is unknown. Management measures that slow and filter runoff will help reduce loads from these sources.

3.4 Big Muddy River (IL_N-17)

This waterbody segment is impaired for sedimentation/siltation, with a LRS target of 70.8% reduction of TSS. The Model My Watershed model results for the sediment loads in the HUC12 watershed that drain to this segment of the river was created are summarized in the figure below.

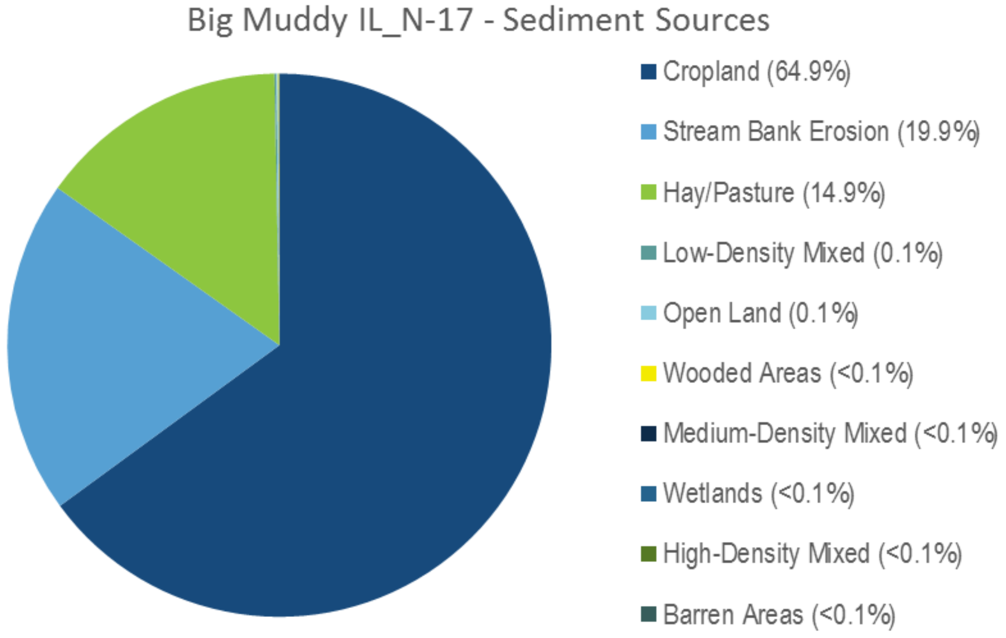

Figure 3-5. Big Muddy IL_N-17 Sediment Sources

The model results indicate the runoff from cropland and hay/pasture land cover are the largest contributing sources of sediment in this sub-watershed, followed by stream bank erosion. Management measures that focus on the reduction of those sources will be necessary to meet the LRS target reductions.

3.5 Pond Creek (IL_NG-02)

This waterbody segment is impaired for sedimentation/siltation and for chloride. Illinois EPA will be gathering addition chloride data during low flow season to verify if impairment still exists. The LRS target requires a 62.7% reduction of TSS. The Model My Watershed model results for the sediment loads in the HUC12 watershed that drain to this segment of the river was created are summarized in the figure below.

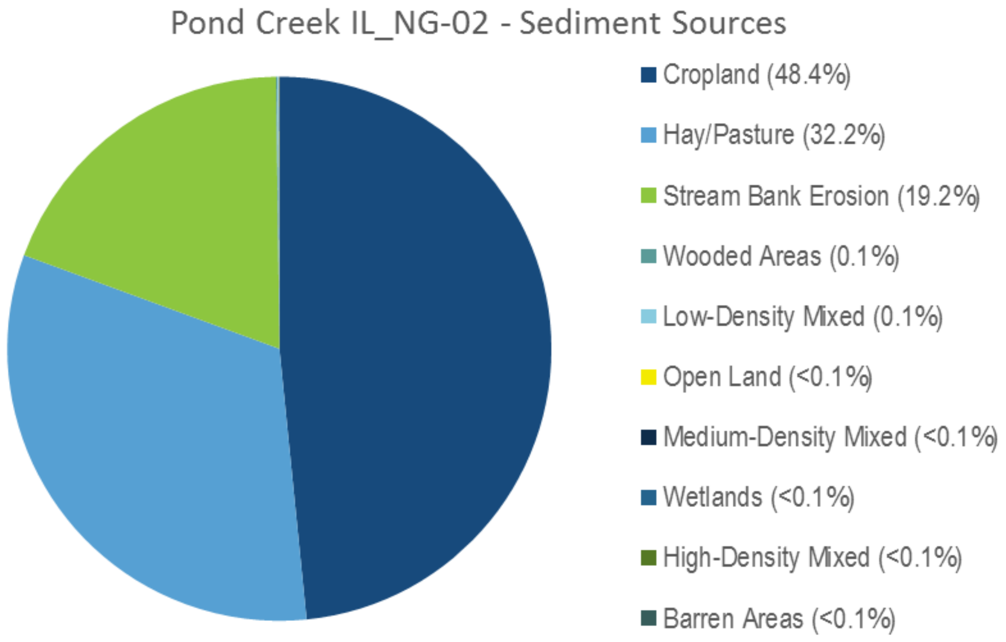

Figure 3-6. Pond Creek IL_NG-02 Sediment Sources

The model results indicate the runoff from cropland and hay/pasture land cover are the largest contributing sources of sediment in this sub-watershed, followed by stream bank erosion. Management measures that focus on the reduction of those sources will be necessary to meet the LRS target reductions.

3.6 Middle Fork Big Muddy River (IL_NH-07)

This waterbody segment is impaired for sedimentation/siltation, with a LRS target of 55.5% reduction of TSS. The Model My Watershed model results for the sediment loads in the subwatershed that drains to this segment of the river was created are summarized in the figure below.

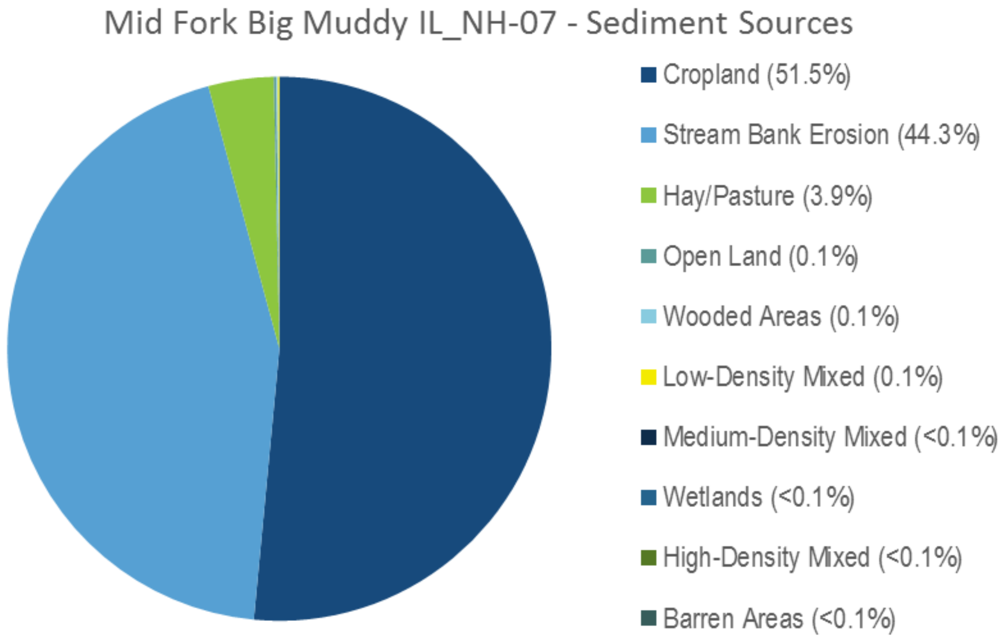

Figure 3-7. Middle Fork Big Muddy IL_NH-07 Sediment Sources

The model results indicate the runoff from cropland and hay/pasture land cover are the largest contributing sources of sediment in this sub-watershed, followed by stream bank erosion. Management measures that focus on the reduction of those sources will be necessary to meet the LRS target reductions.

3.7 Beaver Creek (IL_NGAZ-JC-D1)

There was only one water quality sample analyzed for manganese in Beaver Creek, and it exceeded the water quality standard. The sample was taken during a flow at the lower end of the normally encountered flows (30% to 70%), indicating that there are dry weather sources that could be contributing to this impairment. Since there is only one sample, there is no information on whether this impairment is further impacted by wet weather sources.

In the Soil Survey of Williamson County, Illinois, the description of the soil profiles for all of the soils in the Beaver Creek subwatershed are noted as having rounded masses of iron and manganese in the top horizons of the soil profile. In addition, there are several areas under the Beaver Creek watershed containing underground coal mines that are no longer active. A review of the Illinois State Geological Survey Coal Mine maps for Franklin County (https://www.isgs.illinois.edu/research/coal/maps/county/franklin) indicate that there are no mine shafts within the Beaver Creek watershed. Investigations should be performed to identify if there are any discharges from closed mines that could be contributing to the manganese loads in the stream. The most likely source of the manganese in the stream is from agricultural and developed area runoff during wet weather events carrying eroded soils that contain manganese. Management measures focused on reducing soil erosion will be the most effective way to reduce the manganese in the stream.

The Model My Watershed model results for the sediment loads in the Beaver Creek watershed are summarized in the figure below.

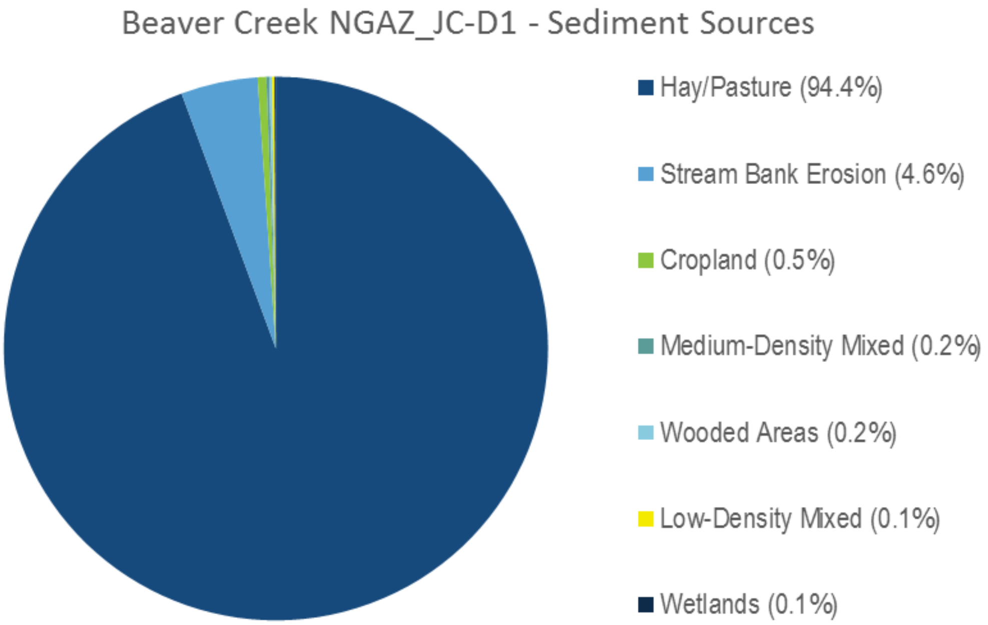

Figure 3-8. Beaver Creek NGAZ_JC-D1 Sediment Sources

The model results indicate the runoff from hay/pasture land cover is the largest contributing sources of sediment in this sub-watershed, followed by stream bank erosion.

3.8 Andy Creek (IL_NZN-13)

This stream segment is listed as being impaired by excess dissolved iron loads. The load duration curve for Andy Creek indicates that iron loads exceed the allowable loads during the higher flow levels, indicating that wet weather sources or runoff contribute to the observed violation of the water quality standard. In the Soil Survey of Franklin County, Illinois, the description of the soil profiles for over 90% of the soils in the Andy Creek subwatershed are noted as having rounded masses of iron and manganese in the top horizons of the soil profile. In addition, much of the area under the Andy Creek watershed contains underground coal mines that are no longer active. Investigations should be performed to identify if there are any discharges from closed mines that could be contributing to the iron loads in the stream. The most likely sources of the iron in the stream is from agricultural and developed area runoff during wet weather events, and potentially from closed mine discharges.

The Model My Watershed model results for the sediment loads in the Andy Creek are summarized in the figure below.

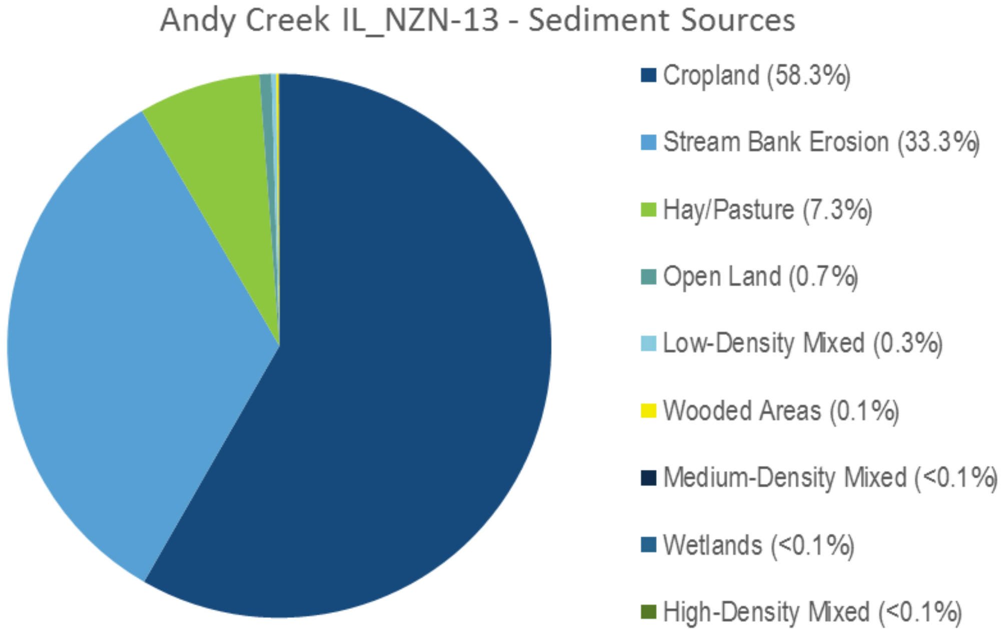

Figure 3-9. Andy Creek IL_NZN-13 Sediment Sources

The model results indicate the runoff from cropland and hay/pasture land cover is the largest contributing sources of sediment in this sub-watershed, followed by stream bank erosion. Reducing the sources of sediment supply to the stream will help to reduce the iron concentrations due to the high iron content in the soils.

3.9 Middle Fork Big Muddy River (IL_NH-06)

Fecal coliform monitoring data collected in the Middle Fork Big Muddy River at station IL_NH-06 show a correlation between flow and fecal coliform concentrations. The majority of the water quality standard violations occur at higher flow conditions indicating fecal coliform is primarily being delivered to the river during wet weather conditions. Potential sources of fecal coliform during wet weather flow include nonpoint source runoff including runoff carrying waste from livestock, wildlife and pets. Sewage treatment plants and failing septic systems/surface discharging systems may also contribute, however, due to the low effluent flow of the sewage treatment plants in the watershed (<0.04 MGD), they are not identified as contributing significant fecal coliform loads to the creek. Septic systems and aeration units (wastewater is aerated, treated with chlorine and discharged to the surface) are used for sewage treatment in rural areas. Improperly functioning septic systems and aeration units would have a larger impact on the creek during dry weather conditions, but could also have an impact during wet weather conditions, if the septic system was not working properly or the surface discharge was not chlorinated. The contribution of these sources is not known, but a ballpark load was calculated, using literature values and assumptions regarding per capita flows (90 gal/person/day), 5% failure rate and homes served by septic (665). It is possible that failing onsite systems could contribute 4% of the current bacteria load, and as such they are identified as a potential source that should be investigated further. This plan recommends coordination with the local health department to identify systems in need of improvement or repair.

Livestock can contribute fecal coliform loads via waste runoff, and if the animals are not fenced away from waterways, they may be a direct source to the streams. According to the most recent (2012) census of agriculture (NASS, 2017), cattle farms are the most common type of livestock farm within Jackson, Williamson, Hamilton, Jefferson, and Franklin Counties, but there are almost three times as many hogs as cattle suggesting hogs are more concentrated.

The potential fecal coliform load from livestock was calculated using available information. First, the number of animals in the Upper Big Muddy River watershed was approximated by scaling the countywide numbers of livestock and farms to the area of the watershed in each county. Fecal coliform loads were calculated for the three most common livestock, cattle and hogs, and turkeys, based on manure produced/animal and literature values describing the concentration of bacteria in manure (USEPA, 2001; http://www.agronext.iastate.edu/immag/pubs/smanure.pdf; and https://www.nrcs.usda.gov/wps/portal/nrcs/detail/null/?cid=nrcs143_014211, https://engineering.purdue.edu/adt/PoultryManure/PoultryManureSurveyFinalReport.pdf).

This load is an estimate of what is produced. The load that reaches the stream is expected to be less due to bacterial decay, reductions from existing vegetative filters and other management practices to capture or treat bacteria, and other factors. However, this calculation showed that livestock could potentially contribute up to 50% of the current fecal coliform load, although the true contribution is uncertain.

Table 3-2. Livestock and Poultry Census Data (2012) and Estimated Fecal Coliform Loads

Census Item	Est. # of Farms	# of Animals	**Fecal coliform/yr**
Cattle, including calves – inventory	19	654	1.7E+16
Hogs and pigs – inventory	3	1,733	6.5E+14
Turkeys – inventory	1	8,461	9.1E+14

Fecal coliform loads in runoff may also originate from wildlife although their contribution is unknown. Management measures that slow and filter runoff will help reduce loads from these sources.

3.10 Herrin Old Reservoir (IL_RNZD)

In preparing the TMDL for the Herrin Old Reservoir, it was determined that the primary source of the elevated phosphorus concentrations contributing to the impairment was from the internal loading from phosphorus released from organic sediments that have accumulated in the reservoir. The sampling data indicated that the only exceedances of the water quality standard were at the deepest parts of the lake, which indicates phosphorus is entering the water column from legacy phosphorus in the lake bottom sediments, and that internal phosphorus source needs to be reduced. The internal phosphorus flux could be reduced using by either capping the sediments (e.g. alum treatment or similar), management actions to remove organic sediments from the lake (dredging), as well as a long-term decrease in the future in response to external phosphorus load reductions.

Historical phosphorus loads to the lakes may accumulate in bottom sediments, and the resulting unusually high sediment phosphorus can subsequently be introduced into water over time. These areas are known as legacy sediment sources. In-lake phosphorus data collected at various depths indicates Legacy phosphorus loads from the sediments could be confirmed with sediment sampling and remediation could be pursued by dredging out the sediments.

3.11 Johnston City Reservoir (IL_RNZE)

In preparing the TMDL for the Johnston City Reservoir, it was determined that the primary source of the elevated phosphorus concentrations contributing to the impairment was from the internal loading from phosphorus released from organic sediments that have accumulated in the reservoir. The sampling data indicated that the only exceedances of the water quality standard were at the deepest parts of the lake, which indicates phosphorus is entering the water column from legacy phosphorus in the lake bottom sediments, and that internal phosphorus source needs to be reduced. The internal phosphorus flux could be reduced using by either capping the sediments (e.g. alum treatment or similar), management actions to remove organic sediments from the lake (dredging), as well as a long-term decrease in the future in response to external phosphorus load reductions.

3.12 Arrowhead Reservoir (Williamson) (IL_RNZX)

The TMDL loading capacity calculated for the Arrowhead (Williamson) Reservoir shows that the phosphorus loadings to this lake require a 30% reduction from existing tributary loads as well as eliminating the internal phosphorus loading from organic sediments that have accumulated in the reservoir. The internal phosphorus flux could be reduced using by either capping the sediments (e.g. alum treatment or similar), management actions to remove organic sediments from the lake (dredging), as well as a long-term decrease in the future in response to external phosphorus load reductions.

The Model My Watershed model results for the watershed phosphorus loads in the contributing watershed are summarized in the figure below.

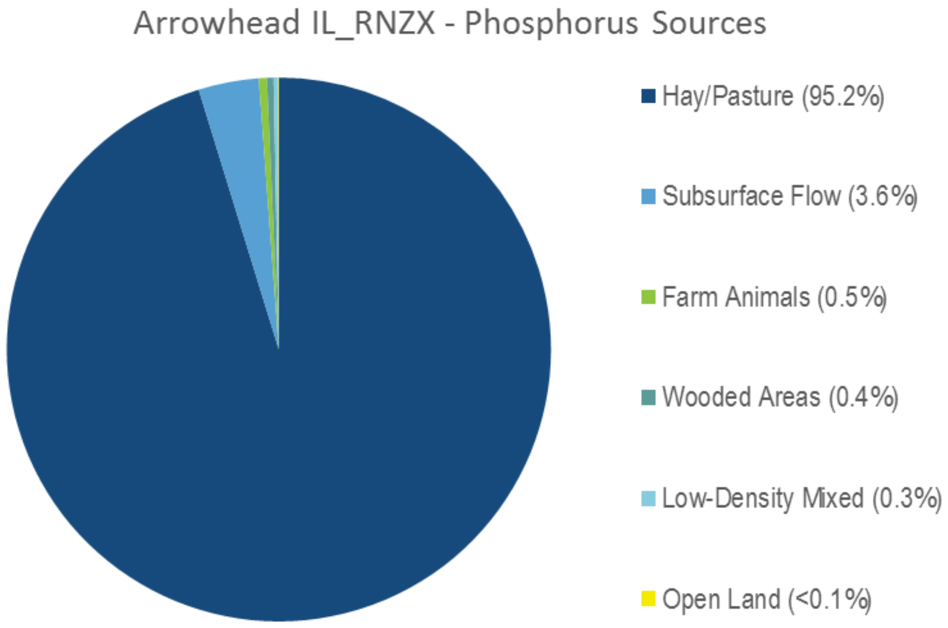

Figure 3-10. Arrowhead IL_RNZX Phosphorus Sources

The model results indicate the runoff from hay/pasture land cover is the largest contributing sources of phosphorus in this sub-watershed. The land cover within the watershed indicates that that pasture/hay covers approximately 48.8% of the watershed. Management actions within this watershed should focus on that land use to reduce the watershed phosphorus loads.

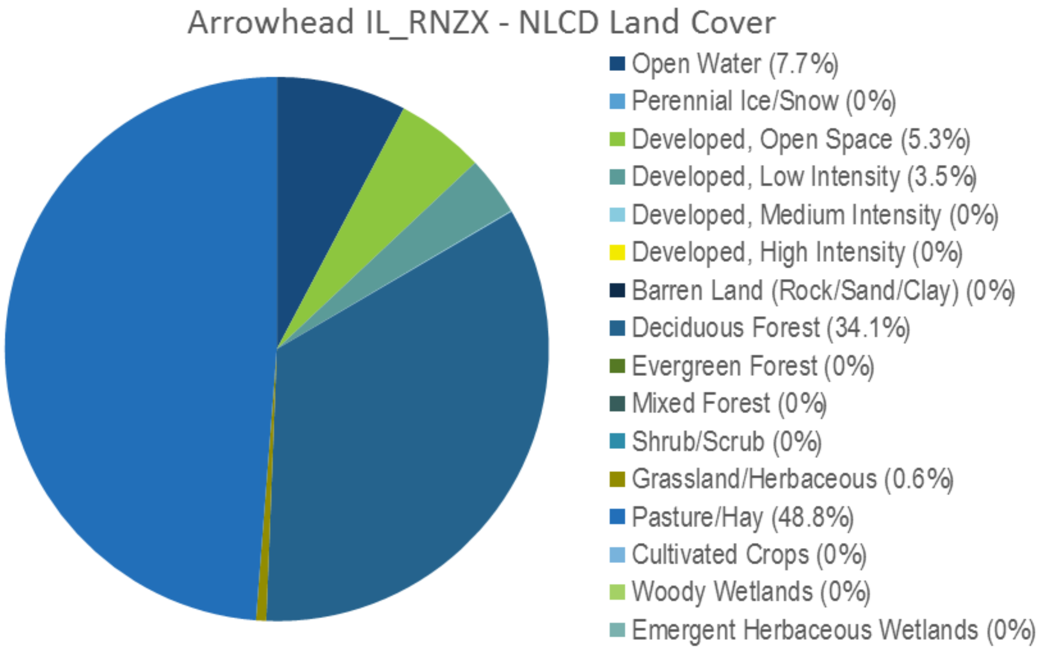

Figure 3-11. Arrowhead IL_RNZX Land Cover

3.13 West Frankfort Old Reservoir (IL_RNP)

The TMDL loading capacity calculated for the West Frankfort Old Reservoir shows that the phosphorus loadings to this lake require a 75% reduction from existing tributary loads, as well as eliminating the internal phosphorus loading from organic sediments that have accumulated in the reservoir. The internal phosphorus flux could be reduced using by either capping the sediments (e.g. alum treatment or similar), management actions to remove organic sediments from the lake, as well as a long-term decrease in the future in response to external phosphorus load reductions.

The Model My Watershed model results for the watershed phosphorus loads in the contributing watershed are summarized in the figure below.

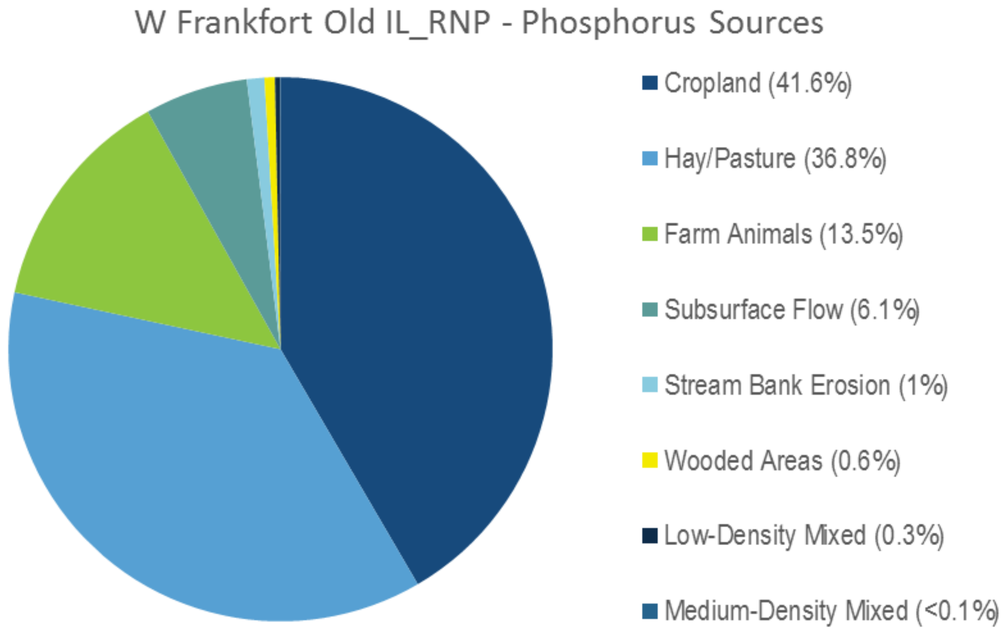

Figure 3-12. W. Frankfort Old IL_RNP Phosphorus Sources

The model results indicate the runoff from cropland and hay/pasture land cover is the largest contributing sources of phosphorus in this sub-watershed, followed by sources from farm animals. The land cover within the watershed indicates that that pasture/hay covers approximately 42.1% of the watershed, and cropland covers 12.8%. Management actions within this watershed should focus on those land uses to reduce the watershed phosphorus loads, as well as actions related to nutrient reductions in animal waste.

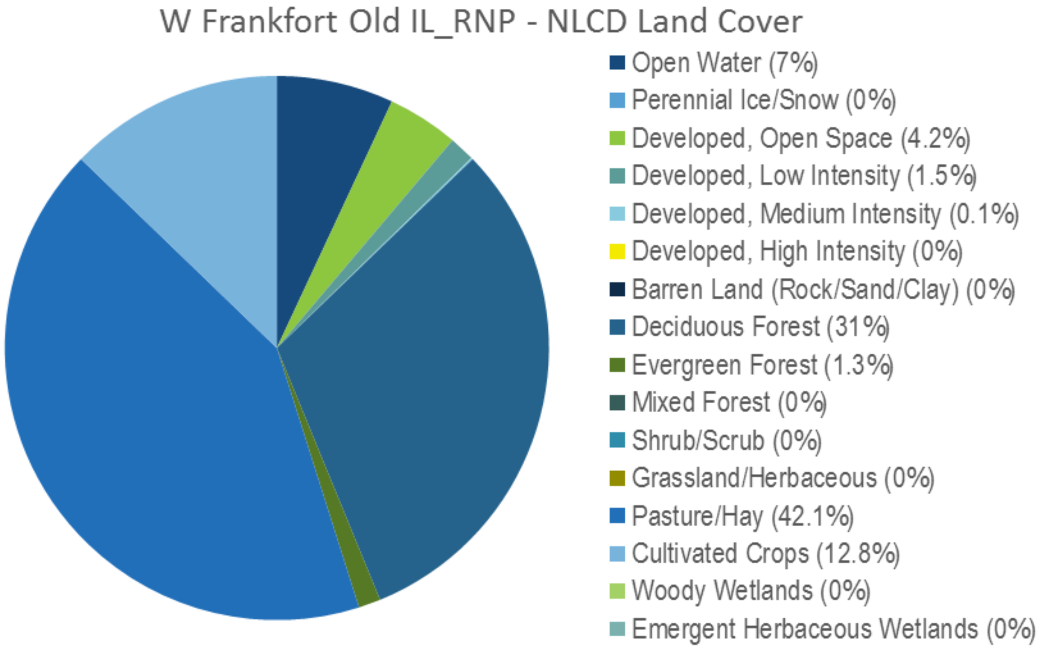

Figure 3-13. W. Frankfort Old IL_RNP Land Cover

3.14 West Frankfort New Reservoir (IL_RNQ)

The TMDL loading capacity calculated for the West Frankfort Old Reservoir shows that the phosphorus loadings to this lake require a 95% reduction from existing tributary loads, as well as eliminating the internal phosphorus loading from organic sediments that have accumulated in the reservoir, and implementing waste load reductions at the Thompsonville STP. The internal phosphorus flux could be reduced using by either capping the sediments (e.g. alum treatment or similar), management actions to remove organic sediments from the lake, as well as a long-term decrease in the future in response to external phosphorus load reductions.

The Model My Watershed model results for the watershed phosphorus loads (excluding the Thompsonville STP) in the contributing watershed are summarized in the figure below.

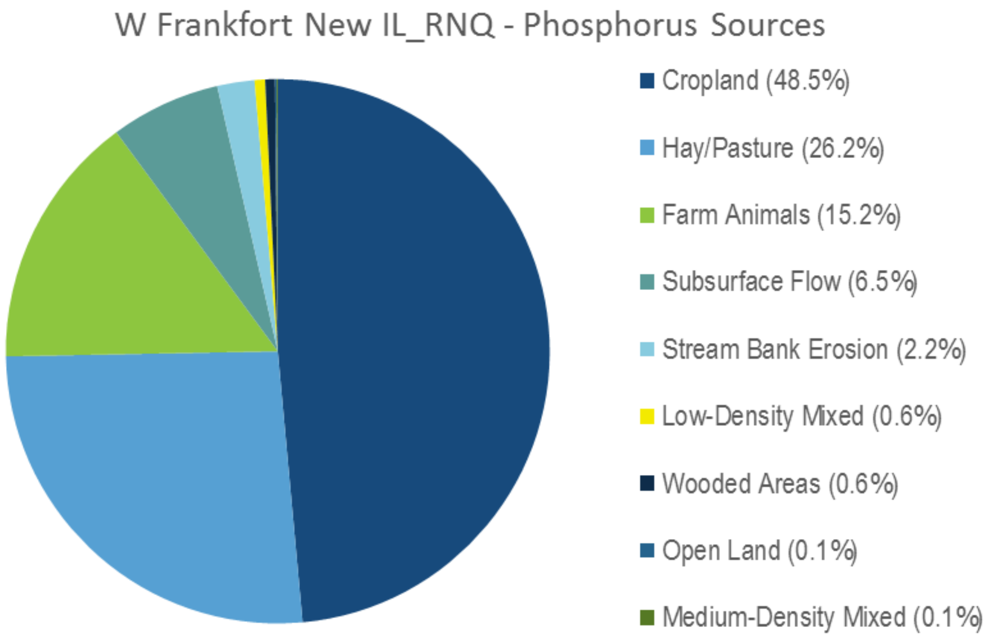

Figure 3-14. W. Frankfort New IL_RNQ Phosphorus Sources

The model results indicate the runoff from cropland and hay/pasture land cover is the largest contributing sources of phosphorus in this sub-watershed, followed by sources from farm animals. The land cover within the watershed indicates that that pasture/hay covers approximately 42.1% of the watershed, and cropland covers 12.8%. Management actions within this watershed should focus on those land uses to reduce the watershed phosphorus loads, as well as actions related to nutrient reductions in animal waste.

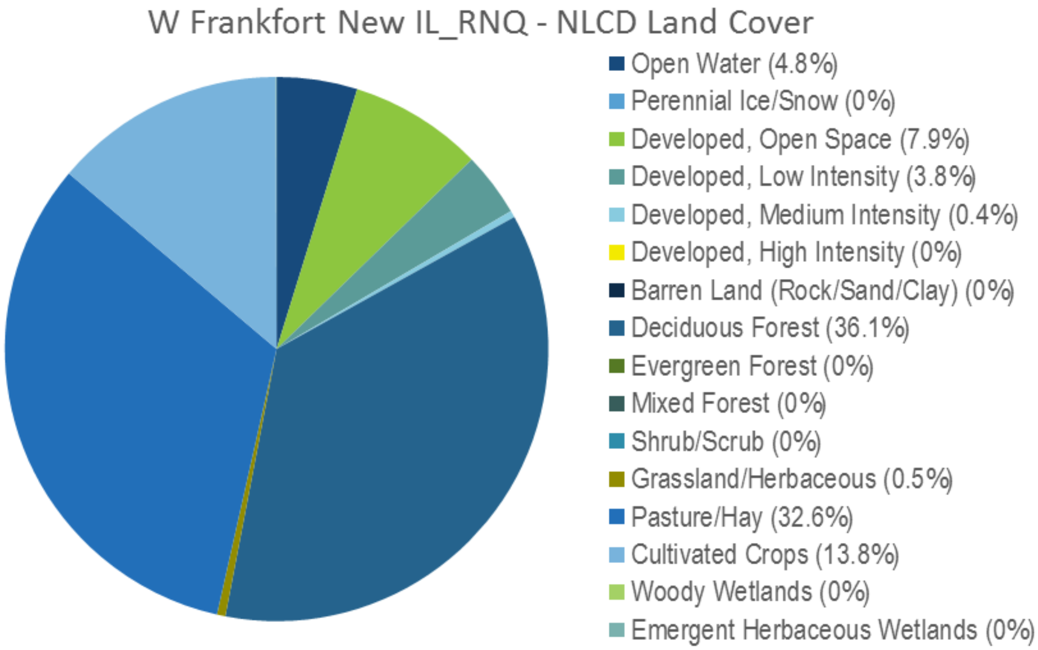

Figure 3-15. W. Frankfort New IL_RNQ Land Cover

3.15 Summary of Priority Sources of Pollutants

Based on the watershed characterization and evaluation of potential sources of pollutants in the drainage areas of the impaired waterbodies in the Upper Big Muddy River watershed, the following conclusions regarding priority sources of are supported:

- Runoff is the primary pathway for phosphorus, sediment, iron, manganese, and fecal coliform loading to the impaired waterbodies, with streambank erosion also contributing to sediment loading.
- Runoff from agricultural lands with livestock is a significant contributor of fecal coliform bacteria. Failing septic systems or surface discharging systems may also be contributing a smaller portion of the bacteria load. Other sources such as wildlife may also be contributing, but their contribution is unknown.

The controls described in subsequent sections of this implementation plan are focused on reducing the pollutants associated with the waterbody impairments from these sources.

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4 Recommended Management Measures

Load reduction targets and recommended non-point source control measures to reduce pollutant loading in the Upper Big Muddy River watershed are discussed in this section.

4.1 TMDL and Load Reduction Targets

4.1.1 Sediment LRS Targets

The Upper Big Muddy River Watershed TMDL Stage 3 Report (LimnoTech, 2019) presents the TSS LRS for the stream segments impaired by sedimentation/siltation (TSS). The target TSS reductions are presented in Table 4-1. For purposes of this implementation plan, a watershed model was developed to calculate the current TSS load contribution from different sources. These results were used in conjunction with percent reductions to determine the actual loads that can be reduced by controls targeted at different sources. Table 4-1 presents the current average annual TSS load, the percent load reduction needed and the load of TSS to be reduced to meet the LRS target.

Table 4-1. TSS Reduction Target

Stream (Segment)	Current Average TSS Load (lbs./yr.)	Target Percent Reduction	Target Average Annual TSS Load to be Reduced (lbs./yr.)
Big Muddy R. (IL_N-06)	12,173,346	26.2%	3,189,417
Big Muddy R. (IL_N-11)	9,577,780	39.3%	3,764,068
Big Muddy R. (IL_N-17)	16,541,907	70.8%	11,711,670
Pond Cr. (IL_NG-02)	20,746,432	62.7%	13,008,013
M. Fk. Big Muddy (IL_NH-07)	44,360,594	55.5%	24,620,130

The load contribution by source was calculated using watershed modeling, and the model-based TSS loads by source are shown above in Section 3. In general, the dominant TSS sources are runoff from cropland and hay/pasture land cover, and streambank erosion.

4.1.1 Iron TMDL Target

The Upper Big Muddy River Watershed TMDL Stage 3 Report (LimnoTech, 2019) presents the TMDL for iron for Andy Creek (IL_NZN-13). Because the iron loads to the stream are most likely related to soil erosion and runoff due to the iron content of the soils in the watershed, a watershed model was developed to calculate the current sediment load contributions from different sources. Management measures to control the sediment loads will help to reduce the iron loads accordingly. These results were used in conjunction with the iron TMDL reductions to determine the actual loads that can be reduced by controls targeted at different sources. Table 4-2 presents the current average annual sediment load, the percent load reduction needed to meet the iron load reduction in the TMDL, and the load of sediment to be reduced to meet the iron TMDL reduction.

Table 4-2. Andy Creek (IL_NZN-13) Sediment Reduction Target to meet Iron TMDL

Stream (Segment)	Current Average TSS Load (lbs./yr.)	Target Percent Reduction	Target Average Annual TSS Load to be Reduced (lbs./yr.)
Andy Creek (IL_NZN-13)	8,082,330	9.9%	800,151

The load contribution by source was calculated using watershed modeling, and the model-based TSS loads by source are shown above in Section 3. Sediment loads are primarily runoff from cropland and streambank erosion.

4.1.1 Manganese TMDL Target

The Upper Big Muddy River Watershed TMDL Stage 3 Report (LimnoTech, 2019) presents the TMDL for manganese for Beaver Creek (NGAZ_JC-D1). Because the manganese loads to the stream are most likely related to soil erosion and runoff due to the manganese content of the soils in the watershed, a watershed model was developed to calculate the current sediment load contributions from different sources. Management measures to control the sediment loads will help to reduce the manganese loads accordingly. These results were used in conjunction with the manganese TMDL reductions to determine the actual loads that can be reduced by controls targeted at different sources. Table 4-3 presents the current average annual sediment load, the percent load reduction needed to meet the manganese load reduction in the TMDL, and the load of sediment to be reduced to meet the manganese TMDL reduction.

Table 4-3. Beaver Creek (NGAZ_JC-D1) Sediment Reduction Target to meet Manganese TMDL

Stream (Segment)	Current Average TSS Load (lbs./yr.)	Target Percent Reduction	Target Average Annual TSS Load to be Reduced (lbs./yr.)
Beaver Creek (NGAZ_JC-D1)	155,867 lbs./yr.	24.4%	38,032

The load contribution by source was calculated using watershed modeling, and the model-based TSS loads by source are shown above in Section 3. TSS loads are primarily from runoff from hay/pasture land cover.

4.1.2 Phosphorus TMDL Target

The Upper Big Muddy River Watershed TMDL Stage 3 Report (LimnoTech, 2019) presents the total phosphorus LRS and total phosphorus TMDL for Herrin Old (IL_RNZD), Johnston City (IL_RNZE), Arrowhead (Williamson) (IL_RNZX), West Frankfort Old (IL_RNP), and West Frankfort New (IL_RNQ) reservoirs, respectively. The percent reduction in phosphorus load is presented in Table 4-4. For purposes of this implementation plan, a watershed model was developed to calculate current phosphorus loads from different land uses (USEPA, 2000), as well as livestock. These results were used in conjunction with percent reductions to determine the actual loads that can be reduced by controls targeted at different sources. Table 4-4 presents the current average annual phosphorus load for each lake, the percent load reduction needed and the targeted load of total phosphorus to be reduced in each subwatershed.

Table 4-4. Total Phosphorus Reduction Targets to meet TMDLs

Lake (ID)	Current Average Annual Watershed Phosphorus Load (lbs./yr.)	Target Percent Reduction	Target Average Annual Phosphorus Load to be Reduced (lbs./yr.)
Herrin Old (IL_RNZD)	186	0.0%	0
Johnston City (IL_RNZE)	387	0.0%	0
Arrowhead (Williamson) (IL_RNZX)	87.5	30.0%	26.25
West Frankfort Old (IL_RNP)	1,599	75.0%	1,199
West Frankfort New (IL_RNQ)	1,998	95.0%	1,898

The source contributions from the watersheds are noted in Section 3 above, and are primarily runoff from cropland and hay/pasture land cover.

All of the lakes noted in the table above have historical phosphorus loads that have accumulated in the bottom sediments, and the resulting unusually high sediment phosphorus can subsequently be introduced into water over time, particularly during summer months with low dissolved oxygen at the bottom of the reservoir. These areas are known as legacy sediment sources. In-lake phosphorus data collected at various depths indicates phosphorus is entering the water column from legacy phosphorus in the lake bottom sediments. Legacy phosphorus loads from the sediments could be confirmed with sediment sampling and remediation could be pursued by dredging out the sediments, or capping the sediments (e.g. alum treatment). Those management measures will need to be pursued in addition to the reductions in watershed loads noted in the table able.

4.1.3 Fecal coliform

The Upper Big Muddy River Watershed TMDL Stage 3 Report (LimnoTech, 2019) presents the fecal coliform TMDLs for two stream segments within the Upper Big Muddy River watershed. Reductions are needed over a range of flow conditions; however, the largest reductions are needed during the highest flow conditions.

Table 4-5 presents the current fecal coliform load for the Upper Big Muddy River (IL_N-11) and the Middle Fork Big Muddy River (IL_NH-06), the percent load reduction needed and the targeted load of fecal coliform to be reduced. The current load was calculated using the median flow in the higher (0 – 30 percentile) flow intervals of the LDC multiplied by the highest instream concentration in this flow interval. The 99% reduction was applied to the current load to determine load of fecal coliform that needs to be reduced (Table 4-5).

Table 4-5. Fecal Coliform Reduction Target

Stream (Segment)	Current Fecal Coliform Load (cfu/day)	Target Percent Reduction	Target Fecal Coliform Load to be Reduced (cfu/day)
Upper Big Muddy River (IL_N-11)	6.71E+13	95.6%	6.41E+13
Middle Fork Big Muddy River (IL_NH-06)	9.38E+13	99%	9.29E+13

Based on estimated fecal coliform loads calculated from livestock data, available monitoring data from permitted sewage treatment plants and a conversation with the local health department regarding septic systems, it is likely that the most significant source of fecal coliform loads is agricultural runoff from land with livestock. Fecal coliform loads generated from livestock (cattle, hogs, and turkeys) within the subwatershed that drains to the IL_N-11 segment are estimated to be 6.9E+15 cfu/yr. (1.9E+13 cfu/day), supporting the conclusion that this source may be significant, particularly if it can be transported to the streams with runoff during rainfall. Within the subwatershed that drains to the IL_N-11 segment, septic systems or surface discharging systems in need of repair may also contribute bacteria loads, with an estimated load of 3.3E+15 cfu/yr. (9.0 E+12 cfu/day). This is based on an average density of 1 house per 3 acres in the low and medium density residential areas outside of the boundaries of Christopher, and Zeigler.

Fecal coliform loads generated from livestock ((cattle, hogs, and turkeys within the watershed that drains to the IL_NH-06 segment are estimated to be 1.8E+16 cfu/yr. (5.0E+13 cfu/day), supporting the conclusion that this source may be significant, particularly if it can be transported to the streams with runoff during rainfall. Within the watershed that drains to the IL_N-11 segment, septic systems or surface discharging systems in need of repair may also contribute bacteria loads, with an estimated load of 4.3E+15 cfu/yr. (1.2E+13 cfu/day). This is based on an average density of 1 house per 3 acres in the low and medium density residential areas outside of the boundaries of Benton, Hanaford, and Ewing.

4.2 Potential Management Practices

The TMDLs and LRSs defined necessary load reductions needed to meet targets. The previous section described the sources that should be targeted preferentially to achieve the largest reductions. There are many potential management measures that could be implemented to reduce pollutant loads. Local officials were contacted to assess which practices would be the best fit for the Upper Big Muddy River watershed, recognizing runoff is a predominant pollutant source. These are described below along with other potential management practices commonly used in Illinois. These are:

- Streambank Stabilization
- Conservation Tillage
- Conservation Buffers
- Cover Crops
- Treatment Wetlands
- Nutrient Management Plans
- Livestock Management Controls
- Sediment Control Basins (includes terraces, dry dams, ponds and water & sediment control basins)
- Septic System Maintenance
- Connections to municipal sewer system
- Phosphorus Inactivation

Each of these is briefly described below.

4.2.1 Streambank Stabilization

Streambank erosion is prevalent within the Upper Big Muddy River watershed, and significant portions of the sediment load to the waterbodies with sediment LRSs is estimated to originate from this source based on Model My Watershed calculations described in Section 3. Bank erosion can be caused by erosive streamflow, and one way to address streambank erosion is to reduce peak runoff flows using some of the measures described previously in this section. Erosion can also be addressed by stabilizing streambanks. There are many options for streambank stabilization, ranging from vegetating the banks (e.g., using willows and seed), to heavy armoring using rocks and rip-rap.

The willow-post method for streambank stabilization has been described by the Illinois State Water Survey (ISWS) in Miscellaneous Publication 130. This method uses native willow cuttings to stabilize eroding streambanks. The willow roots work to bind the soil together and the foliage slows floodwaters near the eroding bank. ISWS reports that this method has been used most successfully along streams in agricultural floodplains without tree cover, and that it is most effective when erosion control is implemented on land upstream of the eroded bank. "On land sloping more than 2%, reduced till and no-till farming should be practiced. Pasture and timber areas on steep slopes should be managed for adequate vegetative cover in order to slow water runoff." Dense tree cover can prevent groundcover growth, so vegetation should not be used for streambank stabilization in heavily shaded, wooded areas. An additional consideration is that vegetation is very hard to establish on banks that are frequently wet.

Costs are highly variable depending on a variety of site-specific factors. Installation costs for the willow-post method range from $7 to $15 per foot, with little or no maintenance. These costs are low compared to 'traditional methods' that rely on riprap, cement or steel retaining structures. ISWS reports costs for traditional methods ranging from $50 to $200 per foot, and notes that these require maintenance and repair through the year. Illinois NRCS Engineering Standard Drawings for Streambank Stabilization can be found online at:
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/il/technical/engineering/?cid=nrcs141p2_030565

4.2.2 Conservation Tillage

The objective of conservation tillage is to provide profitable crop production while minimizing soil erosion (Simmons and Nafziger, undated). This reduction in erosion also reduces the amount of phosphorus lost from the land and delivered to the streams. The NRCS has replaced the term conservation tillage with the term crop residue management, or the year-round management of residue to maintain the level of cover needed for adequate control of erosion. This often requires more than 30% residue cover after planting (Simmons and Nafziger, undated). Conservation tillage/crop residue management systems are recognized as a cost-effective means of significantly reducing soil erosion and maintaining productivity.

Corn accounts for around 45% of the crop production in the Upper Big Muddy River watershed and soybeans account for around 44%. The remainder is primarily a double crop of winter wheat/soybeans. Based on Illinois Department of Agriculture Soil Conservation Transect Survey Report results for 2013, weighted by county for the watershed, approximately 55% of corn is conventionally tilled. Roughly three-quarters (74%) all of the soybeans have some form of conservation tillage. Conventional tillage has a higher soil loss rate than other forms of conservation tillage for both corn and soybeans.

The implementation of additional conservation tillage measures for corn and soybeans is expected to result in reduced phosphorus and sediment loss. In systems where surface soil test phosphorus values are within recommended ranges, researchers have found that total phosphorus export from no-till fields may be reduced up to 67% when compared to conventional tillage due to the reduction in sediment load and associated phosphorus (DeLaune & Sij, 2012). The Illinois Nutrient Loss Reduction Strategy estimates phosphorus loss is decreased by 50% if reduced tillage is applied to soils which were experiencing soil losses greater than "T", the tolerable soil loss (IDOA and IEPA, 2015). However, fields which are losing soil in excess of "T" tend to be more sloped than the flat soils found in the study watersheds. In general, conservation tillage and no-till practices are moderate to highly effective at reducing particulate phosphorus, but exhibit low or even negative effectiveness in reducing dissolved phosphorus (NRCS, 2006).

Total sediment loss from no till is 78% less than conventional till (DeLaune & Sij, 2012). A range of estimates are available for assessing the costs of moving to a no-till system. The Illinois Nutrient Loss Reduction Strategy assigns savings of $17/acre when moving from conventional to reduced tillage (IDOA and IEPA, 2015). Soil and Water Conservation District (SWCD) estimates from another region of Illinois indicate the cost of no till and strip till is $33.33/acre, but costs were not provided for mulch-till. Overall, the total cost per acre for machinery and labor decreases as the amount of tillage decreases and farm size increases (Simmons and Nafziger, undated).

4.2.3 Conservation Buffers

Conservation buffers are areas or strips of land maintained in permanent vegetation to help control pollutants, generally by slowing the rate of runoff, while filtering sediment and nutrients as well as other pollutants. Additional benefits may include the creation of wildlife habitat, improved aesthetics, and potential economic benefits from marketing specialty forest crops (Trees Forever, 2005). This category of controls includes buffer strips, field borders, filter strips, vegetative barriers, riparian buffers, etc. The total cost of buffers presented in the Illinois Nutrient Loss Reduction Strategy (IDOA and IEPA, 2015), taking costs related to lost income potential, planting and maintenance is $294/acre.

Based on the NHD high-resolution flowlines (streams), there are roughly 705 miles of streams in the Upper Big Muddy River watershed. A GIS analysis was conducted to identify stream lengths that already have some sort of buffer, and found that 398 miles of streams are already buffered by vegetation (forest, trees, wetlands), indicating 307 miles of streams (43.5% of the stream miles in the watershed) could benefit from this control. Within those 307 miles, the largest adjacent land uses noted are cultivated crops (120 miles) and pasture/hay (142 miles), with approximately 8 miles adjacent to developed land uses, and 21 miles adjacent to developed open land.

Filter strips and similar vegetative control methods can be very effective in trapping sediment and nutrients, and reducing the velocity of runoff flow, allowing greater infiltration of dissolved pollutants. According to the Illinois Nutrient Loss Reduction Strategy (IDOA and IEPA, 2015), the total phosphorus reduction per acre for buffers on cropland ranges from 25 to 50%, with a median removal rate of 37.5%. According to an Illinois EPA fact sheet[3], the sediment reduction per acre for buffers ranges from 70 to 95%, with an average removal rate of 82.5%. One study of vegetated buffers to reduce fecal coliform bacteria runoff from dairy pastures (Downing and Gamroth, 2007) found that the presence of a vegetated buffer of any size generally reduced the median bacteria concentration in runoff by more than 99%.

The Conservation Practices Cost-Share Program (CPP), part of the Illinois Partners for Conservation Fund, provides cost sharing for conservation practices including field borders and filter strips[4] . The Department of Agriculture distributes funding for the cost-share program to Illinois' Soil and Water Conservation Districts (SWCDs), which prioritize and select projects. The Illinois Buffer Partnership offers cost sharing for installation of streamside buffer plantings at selected sites. An additional program that may be of interest is the Visual Investments to Enhance Watersheds (VIEW), which involves a landscape design consultant in the assessment and design of targeted BMPs within a watershed. Sponsored by Trees Forever[5], VIEW guides a committee of local stakeholders through a watershed landscape planning process. Additional funding for conservation buffers may be available through other sources such as the Conservation Reserve Program.

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[3] http://www.epa.state.il.us/water/conservation/lake-notes/shoreline-buffer.pdf

[4] https://www2.illinois.gov/sites/agr/Resources/Conservation/Pages/default.aspx

[5] http://www.treesforever.org/Illinois_Buffer_Partnership

4.2.4 Cover Crops

Cover crops are grasses, legumes, rye or forbs that are planted seasonally to cover soil when it would usually be bare (Miller et al., 2012; IDOA and IEPA, 2015). While these crops are not usually sold or utilized agronomically, they have other benefits which make them useful to producers. Cover crops are planted for a variety of purposes including erosion reduction from wind and water, increasing soil organic matter and capturing, recycling, or redistributing excess soil nutrients. Cover crops can benefit water quality through three pathways – by increasing the soil's ability to infiltrate rainfall, by scavenging and taking up nutrients, and by intercepting raindrop impact in order to reduce soil crusting and erosion (Miller et al., 2012).

Cover crops effectively reduce both nitrate-nitrogen and total phosphorus losses while also improving soil tilth and other important properties (IDOA and IEPA, 2015). The Illinois Nutrient Loss Reduction Strategy indicates cover crops can reduce total phosphorus by 30% per acre (IDOA and IEPA, 2015). According to IDOA and IEPA, 2015, cover crops may introduce additional management challenges, particularly in adverse years. Establishing cover crops may be difficult in years with dry summers and falls. Cover crop planting and termination operations may also introduce logistical issues on farms. Landowners and producers in the watershed are encouraged to work with their local agronomist, certified crop advisor, or seed retailer to determine the type of cover crops that would best suit their soil types and cropping operations. Based on the Illinois EQIP payment schedule[6], the cost of cover crops ranges from $36.24 to $88.10/acre. An average cost of $63.16 is assumed in this implementation plan.

4.2.5 Treatment Wetlands

Soils in the Upper Big Muddy River watershed are poorly drained and drainage has likely been enhanced using tile drains in agricultural areas in much of the watershed. The exact areas with tile drains is unknown.

Treatment wetlands have been shown to be effective at reducing phosphorus from tile drain flow, if they are properly sited and sized. A pilot study on an experimental farm indicates that treatment wetlands that intercepted tile drains removed approximately 47-57 percent of the total phosphorus from water (IDOA and IEPA, 2015).

According to IDOA and IEPA (2015), the reduction practice is the construction of 5 acres of wetland for every 100 acres of production, and costs are $60.63/acre/yr. if a wetland is assumed to provide treatment for 20 years, the farmland taken out of production is charged against the remaining cropland, and $3 per acre yearly maintenance cost. Using the reported total costs (IDOA & IEPA, 2015), inclusive of the per acre purchase price, and dividing the total out over 20 years produces annual costs of $683/acre. Of note, this practice represents a large decrease in income-generating potential if the acreage taken out of cropland was agronomically productive ground.

4.2.6 Nutrient Management Plans

Nutrient management plans are designed to minimize nutrient losses from agricultural lands and improve nutrient use efficiency of the crop, and therefore minimize the amount of phosphorus transported to waterbodies. Because agriculture is the most common land use in the watershed (roughly 90%), controls focused on reducing phosphorus loads from these areas are expected to help reduce phosphorus loads delivered to the streams. The focus of a nutrient management plan is to increase the efficiency with which applied nutrients are used by crops, thereby reducing the amount available to be transported to both surface and ground waters (USEPA, 2003).

Nutrient management is defined as managing the amount, source, placement, form, and timing of plant nutrients and soil amendments (NRCS Illinois, 2013). The NRCS Practice Standard for nutrient

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[6] https://www.nrcs.usda.gov/wps/portal/nrcs/main/il/programs/financial/eqip/

management notes that this practice applies on all lands where plant nutrients and soil amendments are applied. Additional details regarding nutrient management are provided in the NRCS Illinois Practice Standard (NRCS Illinois, 2013 and chapter 8 of the Illinois Agronomy Handbook (Fernandez and Hoeft, undated), and two example practices are described below.

- Site-specific or variable-rate nutrient application: "This application method uses several remote sensing technologies, yield monitors, global positioning systems, geographical information systems, and variable-rate technology (VRT). These technologies can improve the efficacy of fertilization and promote more environmentally sound placement of fertilizer compared to single-rate applications derived from the conventional practice of collecting a composite soil sample to represent a large area of the field. Research has shown that this technology often reduces the amount of fertilizer applied over an entire field. However, one of the drawbacks of this placement method is the expense associated with these technologies. Also, VRT can only be as accurate as the soil test information used to guide the application rate" (Fernandez and Hoeft, undated).

- Deep fertilizer placement: "With this system any combination of N, P, and K can be injected at a depth of 4 to 8 inches. The knife spacing varies, but generally it is 15 to 18 inches apart for close-grown crops such as wheat and 30 inches for row crops. (Fernandez and Hoeft, undated). This practice may be beneficial (as long as the subsurface band application does not create a channel for water and soil movement) in areas where the potential for surface water runoff is high.

The Illinois Agronomy Handbook (Fernandez and Hoeft, undated) gives a broad overview of phosphorus recommendations in Chapter 8. For producers in the Upper Big Muddy River watershed, it is important to keep in mind that they are in a region of "low" available subsoil phosphorus. This means it is recommended that soil test values be built up to 50 pounds per acre (measured by Bray P_1) to ensure corn and soybean crop yields will not be restricted by phosphorus availability (Fernandez and Hoeft, undated). Soils testing between 50 and 70 pounds per acre should have fertilizer applied only in the amount of expected removal of the current crop while soils showing greater than 70 pounds per acre of phosphorus will experience no agronomic advantage in additional application (Fernandez and Hoeft, undated).

Nutrient management is generally effective, but for phosphorus, most fertilizer is applied to the surface of the soil where it is subject to transport (NRCS, 2006). Tillage will incorporate this surface-applied fertilizer; however a no-till system will leave the phosphorus on the surface. In an extensively cropped watershed, the loss of even a small fraction of the fertilizer-applied phosphorus can have a significant impact on water quality. It is recommended that nutrient management plans be developed and implemented based on soil testing conducted at least every four years and applied to all cropland acres in the watershed.

The approximate cost of developing ($4/acre) and implementing ($12/acre) a nutrient management plan totals $16/acre. This cost may be offset in part by savings associated with using less fertilizer. For example, a study in Iowa showed that improved nutrient management on cornfields led to a savings of about $5/acre (EPA, 2003).

Phosphorus rate reduction resulting from implementation of nutrient management plans was estimated to reduce TP export by 7%. This estimate was provided by the Illinois Nutrient Loss Reduction Strategy (IDOA and IEPA, 2015).

4.2.7 Livestock Management Controls

BMPs to reduce fecal coliform from livestock include activities on the grounds to manage manure and reduce runoff and the proper siting, construction and management of lagoons, settling basins and holding ponds, to reduce groundwater and surface water impacts. Land application of manure can be environmentally beneficial, and a few examples of land application BMPs to reduce nutrient and bacteria runoff include: development of a manure management plan, scheduling application times that are compatible with crop rotations, having sufficient land available to land apply, locating land application sites away from valleys, and applying manure on fields that are not highly erodible. Many more examples can be found on-line[7]. There are a large number of EQIP-eligible conservation practices for confined livestock and manure management, as well as grazing land operations, including ponds (payment cap of $20,000 per pond), roofs and covers (payment cap of $100,000), and fencing (no payment cap listed).[8]

In addition to manure management and runoff reduction from livestock areas, the appropriate management of pasture or grazing-based livestock production can minimize nutrient and fecal coliform losses by eliminating uncontrolled livestock access to streams, providing shade and water sources away from streams, and maintaining healthy grass stands that reduce runoff (IDOA and IEPA, 2015). Fencing, together with the development of alternate watering systems can help restrict livestock access to streams. . USEPA (2003) reports that livestock exclusion from waterways and other grazing management measures could reduce fecal coliform counts by 29% to 46% percent. Farm ponds can be designed to capture runoff and provide water for livestock. When installed in line with the stream, ponds can reduce sediment, nutrient and bacteria loading. Fencing should be placed outside of the filter strip/riparian area. Wildlife access is harder to restrict with fencing and buffers that filter runoff are likely to be more effective than measures aimed at restricting wildlife access to the streams. Fencing costs are variable, and based on the Illinois EQIP and RCPP-EQIP payment schedule[7], can range from $0.79/foot to $4.89/foot. An average cost of $2.02/foot is assumed for this implementation plan.

4.2.8 Sediment Control Basins (includes terraces, dry dams, ponds and water & sediment control basins (WASCOB))

Sediment control basins are defined here to include water and sediment control basins, terraces, dry dams, and ponds and are designed to trap sediments prior to reaching a receiving water. Sediment control basins trap runoff and the associated sediment load from upgradient areas, slowing runoff and reducing gully erosion. Water is released slowly, reducing peak runoff flows and streamflow erosivity/streambank erosion.

Sediment control basins are usually designed to capture drainage from an area of 30 acres or less and should be large enough to control runoff from at least a 10-year, 24-hour storm. The local NRCS is a great resource for information regarding design, installation and funding. Replanting or reseeding may be needed to maintain vegetation, and trapped sediment may need to be periodically removed. Locations are determined based on slopes, tillage, and crop management, and the local NRCS can often provide information and advice for design and installation.

Terracing implemented on steeper slopes can reduce runoff flow volume and velocity, as well as soil erosion. Terrace systems have been shown to remove as much as 85 percent of sediment and 70 percent of total phosphorus from runoff (USEPA 2003).

4.2.9 Septic system maintenance

Routine maintenance of a septic system can extend the life of the system, and prevent failure and ultimately replacement. To keep a septic tank in good working order, routine cleanings should be scheduled every two to three years with a reputable provider. The cost to pump a typical septic tank is variable, but on average costs approximately $250, depending on the number of gallons pumped and the disposal fee for the area. This is much less than the cost of installing a new system ($8,000 - $10,000).

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[7] http://www.epa.state.il.us/water/cafo/publications/pork-bmp.pdf and http://web.extension.illinois.edu/sfmm/beef.cfm

[8] https://www.nrcs.usda.gov/wps/portal/nrcs/main/il/programs/financial/eqip/

Health departments typically provide inspection of new system installations, septic system permits, and provide homeowner problem consultation/complaint investigations, and may be a good resource for disseminating information on septic system maintenance. The National Small Flows Clearinghouse is another good resource for information on septic systems. http://www.nesc.wvu.edu/subpages/septic.cfm

4.2.10 Connections to municipal sewer systems

In the subwatersheds with fecal coliform TMDLs, connecting residences to municipal sewer system should be investigated in areas surrounding the municipalities with POTWs. This will help to reduce the fecal coliform loads from poorly performing septic systems in areas where it is a feasible option. The following communities have municipal sewer systems within or near the watershed of the Middle Fork Big Muddy River (IL_NH-06) which is impaired for fecal coliform:

- City of Benton
- Village of Hanaford.

The following communities have municipal sewer systems within or near the watershed of the Middle Fork Big Muddy River (IL_N-11)

- City of Zeigler
- City of Orient
- City of West Frankfort
- City of Christopher

The ability to extend sewer service from these municipalities will depend on the existing capacity of the plant, the plans for future growth, and the cost of extending the sewer system and adding additional treatment capacity, if necessary. In addition, it may require additional inter-governmental agreements if sewer service is extended beyond municipal boundaries. The costs for this option are highly variable, depending on the distance that sewers would need to be extended, the available treatment capacity, and the number of properties that could be connected to the sewer system. Typical costs for extending sewer service range from $10,000 to $20,000 per home.

4.2.11 Phosphorus Inactivation

Phosphorus inactivation involves application of aluminum salts or calcium compounds to the lake to reduce phosphorus in the water column and slow its release from sediments (McComas, 1993). This can be an effective means of mitigating excess phosphorus in lakes and reservoirs (NALMS, 2004). Addition of aluminum sulfate (alum) is most common, but compounds such as calcium carbonate and calcium hydroxide (lime) can also be used (McComas, 1993). When alum is added to lake water, a series of chemical hydrolysis steps leads to the formation of a solid precipitate that has a high capacity to absorb phosphates. This flocculent material settles to the lake bottom, removing the phosphorus from the water column and providing a barrier that retards release of phosphorus from the sediments (NALMS, 2004). Aluminum concentrations in lake water are usually at acceptable levels for drinking water shortly after alum application (NALMS, 2004).

This alternative is best used in combination with a reduction in phosphorus inputs from watershed sources. If the external phosphorus load is being addressed, and most of the phosphorus comes from in-place sediments, a single dose treatment will likely be sufficient. If watershed sources are not controlled, repeated treatments will be needed. Often, it is possible to do repeat dosing over several years, giving a partial dose every three to five years. Studies have indicated that the effectiveness of alum at controlling internal phosphorus loading in stratified lakes averaged 80% over several years of observation (Welch and Cooke, 1999). Costs for phosphorus inactivation are approximately $1,300 to $1,600 per acre (Sweetwater, 2006). This alternative is recommended in concert with other watershed load reductions.

4.3 Summary of Management Measure Applicability

Many management measures are available for reducing pollutant loads. Table 4-6 below summarizes the identified measures and provides an assessment of potential applicability for this watershed based on similar measures adopted in other watersheds, and feedback from local agencies.

Table 4-6. Assessment of Management Measure Applicability for Upper Big Muddy River Watershed

Management Measure	Currently used?	Potential within Upper Big Muddy River watershed
Conservation tillage	Unknown	High potential - Commonly used in agricultural areas across Illinois. Larger potential for pollutant reductions in Hamilton, Jefferson and Franklin Counties due to lower adoption rate.
Conservation buffers	Unknown	High potential - Commonly used in agricultural areas across Illinois
Cover crops	Unknown	High potential - Commonly used in agricultural areas across Illinois. Great potential for expanding cover crops
Treatment wetlands	Unknown	Unknown
Nutrient management plans	Unknown	High potential - Commonly used in agricultural areas across Illinois.
Livestock management controls	Unknown	High potential, high cost may be a hurdle.
Sediment basins	Unknown	High potential. See ~90% flow reduction
Streambank stabilization	Unknown	High potential. Rock is preferred. Willow posts not popular
Septic system maintenance	Unknown	Unknown – depends on failure rate, and implementation or programs to regularly inspect and maintain systems, such as point-of-sale inspections.
Connection to municipal sewer system	Unknown	Unknown – depends on available capacity, cost to connect, and governmental agreements to extend service.
Phosphorus Inactivation	Unknown	High potential – needs detailed investigation in lakes before it can be implemented.

4.4 Recommended Management Measures

Based on the preceding information, recommended non-point source management measures to reduce pollutant loading in the Upper Big Muddy River watershed are discussed in the following sections by subwatershed.

4.4.1 Big Muddy River (IL_N-06)

The non-point source sediment load reduction target for this segment of the Big Muddy River is 26.2% and will require implementation of management measures to reduce sediment from agricultural runoff and streambank erosion, including the following:

- ***Conservation Tillage*** – Of the 4,646 acres of cultivated cropland, roughly 4,135 acres are corn and soybeans. Of this, roughly 36% of corn and soybean acreage is conventionally tilled. If conservation tillage with an estimated reduction efficiency of 78% were implemented on 75% of the conventionally tilled acres (1,261 acres), this would reduce sediment loading in this subwatershed by approximately 9% of the total sediment load.
- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 31.6 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on 50% of all currently unbuffered streams would add buffers to 4.92 miles of stream (20.9 acres), controlling about 5% of runoff from agricultural land. At a median removal effectiveness of 82.5%, this would reduce sediment loading in this subwatershed by approximately 2%.
- ***Streambank Stabilization*** – The extent of streambank erosion is not known, but it was observed to be prevalent in the watershed. A GIS analysis identified 41.5 miles of streams in this subwatershed. If it is assumed that streambank stabilization reduces 100% of the sediment load from the target bank, implementation of streambank stabilization on 29% of the eroding streambanks (12 miles) would reduce sediment loads to the target of 26.2%.

4.4.2 Big Muddy River (IL_N-11)

The non-point source sediment load reduction target for this segment of the Big Muddy River is 39.3% and will require aggressive implementation of management measures to reduce sediment from agricultural runoff and streambank erosion. In addition, this river segment has a required fecal coliform load reduction of 95.6% during wet weather flows. Recommended management measures to address the non-point sources of these pollutants include the following:

- ***Conservation Tillage*** – Of the 5,775 acres of cultivated cropland, roughly 5,140 acres are corn and soybeans. Of this, roughly 36% of corn and soybean acreage is conventionally tilled. If conservation tillage with an estimated reduction efficiency of 78% were implemented on 75% of the conventionally tilled acres (1,567 acres), this would reduce sediment loading in this subwatershed by approximately 16% of the total sediment load.
- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 71.6 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on 50% of all currently unbuffered streams would add buffers to 29.5 miles of stream (125 acres), controlling about 28% of runoff from agricultural land. At a median removal effectiveness of 82.5%, this would reduce sediment loading in this subwatershed by approximately 19%.

One study of vegetated buffers to reduce fecal coliform bacteria runoff from dairy pastures (Downing and Gamroth, 2007) found that the presence of a vegetated buffer of any size generally reduced the median bacteria concentration in runoff by more than 99%. Adding conservation buffers on these streams acres are calculated to reduce current fecal coliform loads by 27%.

- ***Streambank Stabilization*** – The extent of streambank erosion is not known, but it was observed to be prevalent in the watershed. A GIS analysis identified 130.5 miles of streams in this subwatershed. If it is assumed that streambank stabilization reduces 100% of the sediment load from the target bank, implementation of streambank stabilization on 20% of the eroding streambanks (26.1 miles) would reduce total watershed sediment loads to the target of 39.3%.
- ***Restrict Livestock Access to Stream:*** The extent to which livestock currently have access to the Big Muddy River and its tributaries within this subwatershed is unknown, although a GIS analysis indicates there are 26 stream miles traversing land with pasture/hay. For this analysis, it was assumed the livestock are located on pasture/hay land only, although field reconnaissance is recommended to identify pasture/hay land that currently support livestock with stream access. Restricting livestock access to the creeks will not only reduce bacteria loads, but will also reduce streambank erosion. USEPA (2003) reports that livestock exclusion from waterways and other grazing management measures could reduce fecal coliform counts by 29% to 46% percent. Fecal loads delivered to the streams within this subwatershed generated by cattle and hogs can be estimated using literature values, county-wide livestock counts, and assumptions regarding their distribution. If these loads are reduced by 29% (to be conservative), adding fencing 20 miles of streams could reduce fecal coliform loads by 8%. This value is highly uncertain because current livestock access to the Middle Fork Big Muddy River and its tributaries is unknown.
- ***Septic maintenance:*** Maintenance of septic systems can ensure they are performing as designed, and do not contribute bacteria or other pollutants to local waterways. If all low and medium intensity development (291 acres) is assumed to be serviced by onsite systems, and it is assumed that there is one house/3 acres, then there are an estimated 97 onsite systems in the Big Muddy River IL_N-11 subwatershed. Assuming a failure rate of 5%, then approximately 5 systems would be in need of maintenance or repair. If these were contributing a volume of 90 gallons/person/day for 2.5 people/household, with a raw sewage concentration of 5.01E+07 cfu/100 ml, the load generated would equal 7.5E+14 cfu/yr. Maintenance of failing systems would eliminate this load, reducing current loads by 3% (assuming assumptions regarding this load are accurate).

If fully implemented, these measures would results in an estimated 38% fecal coliform load reduction. Attainment of a 95.6% reduction may not be feasible without a more detailed investigation of sources and targeted controls on the largest contributing sources. Additional monitoring during both dry and wet weather to identify locations of high fecal coliform bacteria counts are recommended to help further identify specific sources and locations within the watershed where BMPs should be focused.

4.4.3 Big Muddy River (IL_N-17)

The non-point source sediment load reduction target for this segment of the Big Muddy River is 70.8% and will require aggressive implementation of management measures to reduce sediment from agricultural runoff and streambank erosion, including the following:

- ***Conservation Tillage*** – Of the 8,137 acres of cultivated cropland, roughly 7,242 acres are corn and soybeans. Of this, roughly 36% of corn and soybean acreage is conventionally tilled. If conservation tillage with an estimated reduction efficiency of 78% were implemented on 100% of the conventionally tilled cropland (2,945 acres), this would reduce sediment loading in this subwatershed by approximately 18% of the total sediment load.

- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 34.2 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on all currently unbuffered streams would add buffers to 13.7 miles of stream (58 acres), controlling about 9% of runoff from agricultural land. At a median removal effectiveness of 82.5%, this would reduce sediment loading in this subwatershed by approximately 6%.

- ***Cover Crops*** – The quantity of land draining directly to the Big Muddy River IL_N-17 segment and its tributaries managed using cover crops is not known, but is assumed to be 10% or less for this plan. If cover crops are added to the management of the remaining 90% of agricultural land (7,323 acres), with an estimated sediment reduction rate of 50%, the watershed sediment load can be reduced another 29%.

- ***Streambank Stabilization*** – The extent of streambank erosion is not known, but it was observed to be prevalent in the watershed. A GIS analysis identified 47.9 miles of streams and rivers in this subwatershed. If it is assumed that streambank stabilization reduces 100% of the sediment load from the target bank, implementation of streambank stabilization on 87% (41.7 miles) of the eroding streambanks within the watershed would reduce sediment loads in this subwatershed an additional 17%, which combined with the management measures identified meets the target identified above.

- ***Sediment Basins***– If the common management measures described above are implemented in the Big Muddy River (IL_N-17) watershed, at the aggressive levels of implementation described, their combined, estimated sediment load reduction will reach the 70.8% target identified above. If there are areas where the measures described above are not able to be implemented, the remaining load would have to be controlled by other means and of the measures described here, the most effective would be sediment basins. During implementation of the measures described here, additional monitoring should be performed to ensure that the target reduction is met. If additional load reductions are required, installing sediment basins to control runoff from agricultural and developed lands should be considered.

This segment is the downstream portion of the watershed in consideration for study as well. Following the implementation of conservation tillage, streambank stabilization, cover crops, and conservation buffers within this subwatershed, implementation of addition sediment reduction measures upstream may also reduce the sediment load in this river segment to meet the TSS LRS target.

4.4.4 Pond Creek (IL_NG-02)

The non-point source sediment load reduction target for this segment of Pond Creek is 62.7% and will require aggressive implementation of management measures to reduce sediment from agricultural runoff and streambank erosion, including the following:

- ***Conservation Tillage*** – Of the 6,407 acres of cultivated cropland, roughly 5,702 acres are corn and soybeans. Of this, roughly 36% of corn and soybean acreage is conventionally tilled. If conservation tillage with an estimated reduction efficiency of 78% were implemented on 100% of the conventionally tilled cropland (2,319 acres), this would reduce sediment loading in this subwatershed by approximately 14% of the total sediment load.

- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 52.71 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on all currently unbuffered streams would add buffers to 37.7 miles of stream (160 acres), controlling about 22% of runoff from agricultural land. At a median removal effectiveness of 82.5%, this would reduce sediment loading in this subwatershed by approximately 14%.

- ***Cover Crops*** – The quantity of land in the Pond Creek watershed managed using cover crops is not known, but is assumed to be 10% or less for this plan. If cover crops are added to the management of the remaining 90% of agricultural land (5,767 acres), with an estimated sediment reduction rate of 50%, the watershed sediment load can be reduced another 22%.

- ***Streambank Stabilization*** – The extent of streambank erosion is not known, but it was observed to be prevalent in the watershed. A GIS analysis identified 90.4 miles of streams and rivers in this subwatershed. If it is assumed that streambank stabilization reduces 100% of the sediment load from the target bank, implementation of streambank stabilization on 66% (59.7 miles) of the eroding streambanks within the watershed would reduce sediment loads in this subwatershed an additional 13%, which combined with the management measures identified above will meet the target load reduction of 62.7%.

- ***Sediment Basins***– If the common management measures described above are implemented in the Pond Creek watershed, at the aggressive levels of implementation described, their combined, estimated sediment load reduction will reach the 62.7% target. If there are areas where the measures described above are not able to be implemented, the remaining load would have to be controlled by other means and of the measures described here, the most effective would be sediment basins. During implementation of the measures described here, additional monitoring should be performed to ensure that the target reduction is met. If additional load reductions are required, installing sediment basins to control runoff from agricultural and developed lands should be considered.

4.4.5 Middle Fork Big Muddy (IL_NH-07)

The non-point source sediment load reduction target for this segment of the Middle Fork of the Big Muddy River is 55.5% and will require aggressive implementation of management measures to reduce sediment from agricultural runoff and streambank erosion, including the following:

- ***Conservation Tillage*** – Of the 30,226 acres of cultivated cropland, roughly 26,901 acres are corn and soybeans. Of this, roughly 36% of corn and soybean acreage is conventionally tilled. If conservation tillage with an estimated reduction efficiency of 78% were implemented on all of the conventionally tilled acres (10,939 acres), this would reduce sediment loading in this subwatershed by approximately 15% of the total sediment load.

- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 88.6 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on 100% of all currently unbuffered streams would add buffers to 82.6 miles of stream (351 acres), controlling about 14% of runoff from agricultural land. At a median removal effectiveness of 82.5%, this would reduce total sediment loading in this subwatershed by approximately 6%.

- ***Streambank Stabilization*** – The extent of streambank erosion is not known, but it was observed to be prevalent in the watershed. A GIS analysis identified 171.2 miles of streams in this subwatershed. If it is assumed that streambank stabilization reduces 100% of the sediment load from the target bank, implementation of streambank stabilization on 78% of the eroding streambanks (133.6 miles) would reduce sediment loads to the target of 55.5%.

4.4.6 Beaver Creek (IL_NGAZ-JC-D1)

The non-point source manganese load reduction target for this segment of Beaver Creek is 24.4%. Because of the prevalence of manganese in the local soils, BMPs implemented to address the manganese impairment will be designed to reduce soil erosion, and will require aggressive implementation of management measures to reduce sediment from agricultural runoff and streambank erosion, including the following:

- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 1.37 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on all currently unbuffered streams would add buffers to 0.31 miles of stream (25 acres), controlling about 15% of runoff from agricultural/pasture/hay land. At a median removal effectiveness of 82.5%, this would reduce sediment loading in this subwatershed by approximately 12%.

- ***Streambank Stabilization*** – The extent of streambank erosion is not known, but it was observed to be prevalent in the watershed. A GIS analysis identified 1.68 miles of streams and rivers in this subwatershed. If it is assumed that streambank stabilization reduces 100% of the sediment load from the target bank, implementation of streambank stabilization on 100% of the eroding streambanks within the watershed would reduce sediment loads in this subwatershed an additional 5%, which combined with the management measures identified above 16.9%, which is significantly below the target identified above.

- ***Sediment Basins***– If the common management measures described above are implemented in the Pond Creek watershed, at the aggressive levels of implementation described, their combined, estimated manganese/sediment load reduction will be would fall short of the 24.4% target by 7.5%. This remaining load would have to be controlled by other means and of the measures described here, the most effective would be sediment basins. Sediment basins are estimated to have a sediment removal effectiveness of 85%. To achieve the additional 7.5% manganese/sediment reduction, sediment basins would be needed to treat runoff from roughly 9% (15 acres) of pasture/hay, agricultural, and developed land in the subwatershed.

4.4.7 Andy Creek (IL_NZN-13)

The non-point source iron load reduction target for this segment of Andy Creek is 9%. Because of the prevalence of iron in the local soils, BMPs implemented to address the iron impairment will be designed to reduce soil erosion, and will aggressive implementation of management measures to reduce sediment from agricultural runoff to meet the required reduction target, including the following:

- ***Conservation Tillage*** – Of the 3,548 acres of cultivated cropland, roughly 3,158 acres are corn and soybeans. Of this, roughly 36% of corn and soybean acreage is conventionally tilled. If conservation tillage with an estimated reduction efficiency of 78% were implemented on 50% of the conventionally tilled land (642 acres), this would reduce sediment loading in this subwatershed by approximately 8% of the total sediment load.

- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 16.4 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on 25% of currently unbuffered streams would add buffers to 3.16 miles of stream (13.4 acres), controlling about 4% of runoff from agricultural/pasture/hay land. At a median removal effectiveness of 82.5%, this would reduce sediment loading in this subwatershed by approximately 2%. Combined with the conservation tillage noted above, this is enough to meet the target reduction in this subwatershed.

4.4.8 Middle Fork Big Muddy (IL_NH-06)

The non-point source fecal coliform load reduction target for the Middle Fork Big Muddy River watershed varies from 88-99% over a range of flows, with the highest reduction required at the higher flows. Attainment of this target will require aggressive implementation of management measures to reduce fecal coliform bacteria from nonpoint source runoff, including the following:

- ***Conservation buffers:*** One study of vegetated buffers to reduce fecal coliform bacteria runoff from dairy pastures (Downing and Gamroth, 2007) found that the presence of a vegetated buffer of any size generally reduced the median bacteria concentration in runoff by more than 99%. 49% (41.8 miles) of the streams in the Middle Fork Big Muddy River watershed are currently without a buffer. Buffers on these streams controlling are calculated to reduce current fecal coliform loads by 48%. Assuming that conservation buffers are 35 feet wide, the area of buffers added will be 178 acres.
- ***Restrict Livestock Access to Stream:*** The extent to which livestock currently have access to the Middle Fork Big Muddy River and its tributaries within this subwatershed is unknown, although a GIS analysis indicates there are 20 stream miles traversing land with pasture/hay. For this analysis, it was assumed the livestock are located on pasture/hay land only, although field reconnaissance is recommended to identify pasture/hay land that currently support livestock with stream access. Restricting livestock access to the creeks will not only reduce bacteria loads, but will also reduce streambank erosion. USEPA (2003) reports that livestock exclusion from waterways and other grazing management measures could reduce fecal coliform counts by 29% to 46% percent. Fecal loads delivered to the streams within this subwatershed generated by cattle and hogs can be estimated using literature values, county-wide livestock counts, and assumptions regarding their distribution. If these loads are reduced by 29% (to be conservative), adding fencing 20 miles of streams could reduce fecal coliform loads by 14%. This value is highly uncertain because current livestock access to the Middle Fork Big Muddy River and its tributaries is unknown.
- ***Septic maintenance:*** Maintenance of septic systems can ensure they are performing as designed, and do not contribute bacteria or other pollutants to local waterways. If all low and medium intensity development (1,621 acres) is assumed to be serviced by onsite systems, and it is assumed that there is one house/3 acres, then there are an estimated 540 onsite systems in the Middle Fork Big Muddy River watershed. Assuming a failure rate of 5%, then 27 systems would be in need of maintenance or repair. If these were contributing a volume of 90 gallons/person/day for 2.5 people/household, with a raw sewage concentration of 5.01E+07 cfu/100 ml, the load generated would equal 4.2E+15 cfu/yr. Maintenance of failing systems would eliminate this load, reducing current loads by 12% (assuming assumptions regarding this load are accurate).

If fully implemented, these measures would results in an estimated 74% fecal coliform load reduction. Attainment of a 99% reduction may not be feasible without a more detailed investigation of sources and targeted controls on the largest contributing sources. Additional monitoring during both dry and wet weather to identify locations of high fecal coliform bacteria counts are recommended to help further identify specific sources and locations within the watershed where BMPs should be focused.

4.4.9 Herrin Old Reservoir (IL_RNZD)

The BATHTUB modeling of the Herrin Old Reservoir indicated that the primary source of the phosphorus that is impairing the waterbody is the release of phosphorus from sediment that has accumulated in the reservoir. Without removing this source of phosphorus, the waterbody will not be able to reach compliance with the water quality standards, even with reductions in the watershed loads. The internal phosphorus source needs to be address, either through phosphorus inactivation or dredging and removal of the sediment. For the purposes of this report, phosphorus inactivation of the sediments using alum is considered, however, prior to implementation, the reservoir owner may consider sediment removal as an alternative.

- ***Phosphorus Inactivation***– To inactivate the phosphorus contained in the water column and sediment within the reservoir, the entire surface area of the lake will need to be treated with alum, or some other phosphorus binding agent. This reservoir has a surface area of 51.3 acres that need to be treated.

4.4.10 Johnston City Reservoir (IL_RNZE)

The BATHTUB modeling of the Johnston City Reservoir indicated that the primary source of the phosphorus that is impairing the waterbody is the release of phosphorus from sediment that has accumulated in the reservoir. Without removing this source of phosphorus, the waterbody will not be able to reach compliance with the water quality standards, even with reductions in the watershed loads. The internal phosphorus source needs to be address, either through phosphorus inactivation or dredging and removal of the sediment. For the purposes of this report, phosphorus inactivation of the sediments using alum is considered, however, prior to implementation, the reservoir owner may consider sediment removal as an alternative.

- ***Phosphorus Inactivation***– To inactivate the phosphorus contained in the water column and sediment within the reservoir, the entire surface area of the lake will need to be treated with alum, or some other phosphorus binding agent. This reservoir has a surface area of 64 acres that need to be treated.

4.4.11 Arrowhead Reservoir (Williamson) (IL_RNZX)

The non-point source total phosphorus load reduction target for this lake is 30%, in addition to the elimination of the internal phosphorus source from lake sediments. In the watershed that drains to the Arrowhead Reservoir, the ModelMyWatershed model results show that majority of the phosphorus load is from runoff from pasture/hay fields. There are no defined streams within the NHD dataset, which limits the applicability of conservation buffers and streambank stabilization in this watershed. The most applicable BMP in this small watershed is to install treatment wetland or sediment basins downstream of the hay/pasture and agricultural lands to remove the phosphorus.

- ***Phosphorus Inactivation***– To inactivate the phosphorus contained in the water column and sediment within the reservoir, the entire surface area of the lake will need to be treated with alum, or some other phosphorus binding agent. This reservoir has a surface area of 30 acres that need to be treated.
- ***Treatment Wetlands or Sediment Basins***– The 30% phosphorus load reduction will have to be controlled by sediment basins or treatment wetlands. Sediment basins are estimated to have a phosphorus removal effectiveness of 70% and wetlands are estimated to have a median phosphorus

removal effectiveness of 52%. To achieve the 30% phosphorus reduction, sediment basins would be needed to treat runoff from roughly 45% (106 acres) of the hay/pasture and agricultural land in the watershed. Alternatively, treatment wetlands will be needed for treat runoff from roughly 61% (142 acres) of hay/pasture and agricultural land in the subwatershed. If space is available, an in-lake sedimentation basin could be implemented to capture and treat runoff before it reaches the main body of the lake.

4.4.12 West Frankfort Old Reservoir (IL_RNP)

The average annual phosphorus load reduction from non-point sources for the West Frankfort New Reservoir is 75%, in addition to the elimination of the internal phosphorus source from lake sediments. This is a very high phosphorus load reduction target, which will required aggressive implementation of management measures to reduce phosphorus from agricultural runoff and streambank erosion, including the following:

- ***Phosphorus Inactivation***– To inactivate the phosphorus contained in the water column and sediment within the reservoir, the entire surface area of the lake will need to be treated with alum, or some other phosphorus binding agent. This reservoir has a surface area of 146 acres that need to be treated.

- ***Conservation Tillage*** – Of the 682 acres of cultivated cropland in this watershed, roughly 314 acres are corn and soybeans. Of this, roughly 36% of corn and soybean acreage is conventionally tilled. If conservation tillage with an estimated phosphorus load reduction efficiency of 67% were implemented on all of the conventionally tilled land (114 acres), this would reduce phosphorus loading in this subwatershed by approximately 11%.

- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 2.44 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on all currently unbuffered streams would add buffers to 1.82 miles of stream (8.44 acres), controlling about 12% of runoff from agricultural/pasture/hay land. At a median removal effectiveness of 37.5%, this would reduce phosphorus loading in this subwatershed by approximately 3%.

- ***Cover Crops*** – The quantity of land in the West Frankfort New Reservoir watershed managed using cover crops is not known, but is assumed to be 10% or less for this plan. If cover crops are added to the management of the remaining 90% of agricultural land (282 acres), with an estimated phosphorus reduction rate of 30%, the watershed phosphorus load can be reduced another 14%.

- ***Streambank Stabilization*** – The extent of streambank erosion is not known, but it was observed to be prevalent in the watershed. A GIS analysis identified 4.43 miles of streams and rivers in this subwatershed. If it is assumed that streambank stabilization reduces 100% of the phosphorus load from the target bank, implementation of streambank stabilization on 100% of the eroding streambanks within the watershed, that would reduce sediment loads in this subwatershed an additional 1%, which combined with the management measures identified above would control 27% of the total phosphorus loads, which is significantly below the target identified above.

- ***Treatment Wetlands or Sediment Basins***– The additional 48% phosphorus load reduction necessary to meet the target for this subwatershed will have to be controlled by other means. Of the potential measures described in this report, the most effective would be sediment basins or treatment wetlands. Sediment basins are estimated to have a phosphorus removal effectiveness of 70% and wetlands are estimated to have a median phosphorus removal effectiveness of 52%. To achieve the additional 48% phosphorus reduction, sediment basins would be needed to treat runoff from roughly 87% (1,178 acres) of the hay/pasture and agricultural land in the watershed. In addition, sediment basins can be used to capture and control sediment from developed land uses as well. Alternatively, treatment wetlands will be needed for treat runoff from a portion of the land, however, since they are less effective at phosphorus removal, additional area would need to be controlled above the 83% identified above. If space is available, an in-lake sedimentation basin could be implemented to capture and treat runoff before it reaches the main body of the lake. Regular maintenance and removal of the captured sediment would be required to maintain the effectiveness of this management measure.

4.4.13 West Frankfort New Reservoir (IL_RNQ)

The average annual phosphorus load reduction from non-point sources for the West Frankfort New Reservoir is 97%. This is a very high phosphorus load reduction target, which will required aggressive implementation of management measures to reduce phosphorus from agricultural runoff and streambank erosion, including the following:

- ***Phosphorus Inactivation***– To inactivate the phosphorus contained in the water column and sediment within the reservoir, the entire surface area of the lake will need to be treated with alum, or some other phosphorus binding agent. This reservoir has a surface area of 214 acres that need to be treated.

- ***Conservation Tillage*** – Of the 682 acres of cultivated cropland in this watershed, roughly 607 acres are corn and soybeans. Of this, roughly 36% of corn and soybean acreage is conventionally tilled. If conservation tillage with an estimated phosphorus load reduction efficiency of 67% were implemented on all of the conventionally tilled land (247 acres), this would reduce phosphorus loading in this subwatershed by approximately 13%.

- ***Conservation Buffers*** – Based on the spatial analysis described above, roughly 5.42 miles of streams in this subwatershed are currently buffered (adjacent to forest or wetlands). Assuming that conservation buffers control runoff from land within an eighth of a mile of the stream, each mile of buffer can control runoff from 80 acres of land. Adding conservation buffers on all currently unbuffered streams would add buffers to 1.82 miles of stream (7.7 acres), controlling about 6% of runoff from agricultural/pasture/hay land. At a median removal effectiveness of 37.5%, this would reduce phosphorus loading in this subwatershed by approximately 2%.

- ***Cover Crops*** – The quantity of land in the West Frankfort New Reservoir watershed managed using cover crops is not known, but is assumed to be 10% or less for this plan. If cover crops are added to the management of the remaining 90% of agricultural land (614 acres), with an estimated phosphorus reduction rate of 30%, the watershed phosphorus load can be reduced another 14%.

- ***Streambank Stabilization*** – The extent of streambank erosion is not known, but it was observed to be prevalent in the watershed. A GIS analysis identified 7.24 miles of streams and rivers in this subwatershed. If it is assumed that streambank stabilization reduces 100% of the phosphorus load from the target bank, implementation of streambank stabilization on 100% of the eroding streambanks within the watershed, that would reduce sediment loads in this subwatershed an additional 2%, which combined with the management measures identified above would control 31.6% of the total phosphorus loads, which is significantly below the target identified above.

- ***Treatment Wetlands or Sediment Basins***– The additional 63.4% phosphorus load reduction necessary to meet the target for this subwatershed will have to be controlled by other means. Of the potential measures described in this report, the most effective would be sediment basins or treatment wetlands. Sediment basins are estimated to have a phosphorus removal effectiveness of 70% and wetlands are estimated to have a median phosphorus removal effectiveness of 52%. To achieve the additional 63.4% phosphorus reduction, sediment basins would be needed to treat runoff from all of the hay/pasture and agricultural land in the watershed (2,296 acres). In addition, sediment basins can be used to capture and control sediment from developed land uses as well. If space is available, an in-lake sedimentation basin could be implemented to capture and treat runoff before it reaches the main body of the lake. Regular maintenance and removal of the captured sediment would be required to maintain the effectiveness of this management measure.

4.5 Estimated Costs of Recommended Management Measures

The overall capital costs of implementing the recommended non-point source management measures in the Upper Big Muddy River watershed were estimated on a unit cost basis. Unit costs for on-field or edge-of-field measures were obtained from various sources such as the Illinois Nutrient Loss Reduction Strategy, and where possible, are specific to Illinois.

- ***Conservation Tillage*** – The estimated cost of no till and strip till is estimated to be $33.33/acre.
- ***Conservation Buffers*** – The estimated cost of critical area planting is variable and may be as high as $350/acre. The total cost of buffers presented in the Illinois Nutrient Loss Reduction Strategy (IDOA and IEPA, 2015), taking costs related to lost income potential, planting and maintenance is $294/acre, possibly reflecting geographic variability in farmland value. For purposes of this plan, the higher value of $350/acre is used.
- ***Cover Crops*** – The estimated the cost of cover crops to be $63.16/acre.
- ***Nutrient Management Plans*** – The estimated cost of developing ($4/acre) and implementing ($12/acre) a nutrient management plan totals $16/acre.
- ***Water and Sediment Control Basins*** – According to 2014 Illinois Conservation Partnership Annual Report, constructed wetlands cost $113.79 per acre of land benefited. The average basin was constructed to control an area of approximately 25 acres. Accounting for inflation of approximately 2% per year, a unit cost of $125 per acre of land benefitted was used for estimating the costs in this report.
- ***Constructed Wetlands*** – According to 2015 Illinois Nutrient Loss Reduction Strategy, constructed wetlands cost $60.63/acre/yr. if a wetland is assumed to provide treatment for 20 years, the farmland taken out of production is charged against the remaining cropland, and $3 per acre yearly maintenance cost. Using the reported total costs, inclusive of the per acre purchase price, and dividing the total out over 20 years produces annual costs of $683/acre.
- ***Livestock Management*** – Fencing is assumed to cost $2.02/foot, based on the average cost from the Illinois EQIP and RCPP-EQIP payment schedule.
- ***Streambank Stabilization*** – Streambank stabilization costs vary significantly depending on the method used (e.g., willow post vs. armoring with rock) and site conditions. The cost of $200/foot is used for estimation purposes, but the actual cost will need to be reevaluated based on the site and selected method.
- ***Septic Maintenance*** – The cost to pump a typical septic tank is variable, but on average costs $250, depending on the number of gallons pumped and the disposal fee for the area. New systems can cost between $8,000 and $10,000.

A summary of the proposed management measures proposed for each basin are included below along with the cost estimate for implementation.

Table 4-7. Summary of Proposed Management Measures and Estimated Costs

Waterbody	Recommended Management Measures	Quantity	Units	Unit Cost	Estimated Cost
Big Muddy R. (IL_N-06)	Conservation Tillage	1,261	acres	$33.33	$ 840,600
	Conservation Buffers	21	acres	$350	$ 7,300
	Streambank Stabilization	12.0	miles	$1,056,000	$ 12,672,000
Big Muddy R. (IL_N-11)	Conservation Tillage	1,567	acres	$33.33	$ 1,044,600
	Conservation Buffers	125	acres	$350	$ 43,800
	Streambank Stabilization	26.1	miles	$1,056,000	$ 27,561,600
	Restrict Livestock Access to Stream	26.0	miles	$21,330	$ 554,600
	Septic Maintenance	97	systems	$250	$ 24,300
Big Muddy R. (IL_N-17)	Conservation Tillage	2,945	acres	$33.33	$ 1,963,100
	Conservation Buffers	58	acres	$350	$ 20,300
	Cover Crops	7,323	acres	$63.16	$ 9,250,400
	Streambank Stabilization	41.7	miles	$1,056,000	$ 44,006,700
	Water and Sediment Control Basins	As needed	acres of land benefitted	$125	$ -
Pond Cr. (IL_NG-02)	Conservation Tillage	2,319	acres	$33.33	$ 1,545,800
	Conservation Buffers	160	acres	$350	$ 56,000
	Cover Crops	5,767	acres	$63.16	$ 7,284,900
	Streambank Stabilization	59.7	miles	$1,056,000	$ 63,005,200
	Water and Sediment Control Basins	As needed	acres of land benefitted	$125	$ -
M. Fk. Big Muddy (IL_NH-07)	Conservation Tillage	10,939	acres	$33.33	$ 7,291,900
	Conservation Buffers	351	acres	$350	$ 122,900
	Streambank Stabilization	134	miles	$1,056,000	$ 141,081,600
Beaver Creek (NGAZ_JC-D1)	Conservation Buffers	25	acres	$350	$ 8,800
	Streambank Stabilization	1.7	miles	$1,056,000	$ 1,774,100
	Water and Sediment Control Basins	15	acres of land benefitted	$125	$ 1,900
Andy Creek (IL_NZN-13)	Conservation Tillage	642	acres	$33.33	$ 428,000
	Conservation Buffers	13	acres	$350	$ 4,700
Middle Fork Big Muddy River (IL_NH-06)	Conservation Buffers	178	acres	$350	$ 62,300
	Restrict Livestock Access to Stream	20	miles	$21,330	$ 426,600
	Septic Maintenance	540	systems	$250	$ 135,000
Herrin Old (IL_RNZD)	Sediment Phosphorus Inactivation	51.3	acres	$1,600	$ 82,100
Johnston City (IL_RNZE)	Sediment Phosphorus Inactivation	64	acres	$1,600	$ 102,400
Arrowhead (Williamson) (IL_RNZX)	Sediment Phosphorus Inactivation	30	acres	$1,600	$ 48,000
	Water and Sediment Control Basins	106	acres of land benefitted	$125	$ 13,300

Waterbody	Recommended Management Measures	Quantity	Units	Unit Cost	Estimated Cost
West Frankfort Old (IL_RNP)	Sediment Phosphorus Inactivation	146	acres	$1,600	$ 233,600
	Conservation Tillage	114	acres	$33.33	$ 76,000
	Conservation Buffers	8	acres	$350	$ 3,000
	Cover Crops	282	acres	$63.16	$ 356,200
	Streambank Stabilization	4.4	miles	$1,056,000	$ 4,678,100
	Water and Sediment Control Basins	1,178	acres of land benefitted	$125	$ 147,300
West Frankfort New (IL_RNQ)	Sediment Phosphorus Inactivation	214	acres	$1,600	$ 342,400
	Conservation Tillage	247	acres	$33.33	$ 164,700
	Conservation Buffers	8	acres	$350	$ 2,700
	Cover Crops	614	acres	$63.16	$ 775,600
	Streambank Stabilization	7.2	miles	$1,056,000	$ 7,645,400
	Water and Sediment Control Basins	2,296	acres of land benefitted	$125	$ 287,000

4.6 Potential Funding Sources

One of the most important aspects of implementing nonpoint source controls is obtaining adequate funding to implement voluntary or incentive-based programs. Table 4-8 presents potential funding sources for the recommended controls. This is not an exhaustive source of funding opportunities, but is intended to facilitate the pursuit of funding from applicable sources. Other programs and funding sources may also be available beyond those identified herein. Additional information regarding potential funding sources is provided below.

Table 4-8. Potential Funding Sources for Recommended Conservation Practices

Conservation Practice	Applicable, potential funding sources
Conservation Buffers	Funded under EQIP as field border (386), riparian herbaceous cover (390), or riparian forest buffer (391). Also funded under the Conservation Practices Cost-Share Program.
Conservation Tillage	Funded under EQIP as residue and tillage management, no-till (329). Also funded under the Conservation Practices Cost-Share Program, with some restrictions.
Cover Crops	Funded under EQIP as cover crop (340). Both cover and green manure crops are also funded under the Conservation Practices Cost-Share Program, with some restrictions.
Livestock Management Controls	Funded under EQIP as fence (382) and access control (472).

Conservation Practice	Applicable, potential funding sources
Nutrient Management Plans	Funded under EQIP as comprehensive nutrient management plan (102), nutrient management plan - written (104), and nutrient management (590). Both nutrient management planning and implementation are also funded under the Conservation Practices Cost-Share Program.
Treatment wetlands	Funded under EQIP as constructed wetland (656) and wetland restoration (657). Wetland reserve easements are also available to help protect, restore, ad enhance wetlands through the Agricultural Conservation Easement Program.
Water & Sediment Control Basins	Funded under EQIP as sediment basin (350) and water and sediment control basin (638). This practice is also funded under the Conservation Practices Cost-Share Program.
Streambank Stabilization	The Streambank Stabilization and Restoration Program provides support for low cost techniques to stabilize eroding stream banks.
Watershed Planning	Water Quality Management Planning Grants are available to regional public comprehensive planning organizations and other entities to carry out water quality management planning activities.

4.6.1 Federal Programs

Clean Water Act Section 319 grants[9] to address nonpoint source pollution. Section 319(h) of the Clean Water Act provides Federal funding for states and tribal agencies for the implementation of approved nonpoint source (NPS) management programs. These funds are received and administered by the Illinois EPA. Funding under these grants is used in Illinois to finance projects that demonstrate cost-effective solutions to NPS problems. Projects must address water quality issues relating directly to NPS pollution. This program funds the establishment and management of conservation tillage, cover crops, filter strips, wetlands, and other agriculturally-related BMPs, specifically in watersheds with approved management plans that address reducing nutrient loading to Illinois waters. Of the total project cost, up to 60% can be awarded through the fund. Grantees must provide at least 40% of the costs as an in-kind match or cash. Funds can be used to develop watershed-based plans and for the implementation of watershed-based plans, including the development of information and education programs, and for the installation of best management practices. This is a reimbursement program. Applications are due each year by close of business on August 1st to the Illinois EPA.

Conservation Reserve Program[10] administered by the Farm Service Agency. The Conservation Reserve Program (CRP) provides technical and financial assistance to eligible farmers and ranchers to

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[9] https://www2.illinois.gov/epa/topics/water-quality/watershed-management/nonpoint-sources/Pages/section-319.aspx
[10] http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index

address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. CRP is administered by the Farm Service Agency, with NRCS providing technical land eligibility determinations, conservation planning and practice implementation. In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10-15 years in length.

Agricultural Conservation Easement Program (ACEP)[11] This program is administered by the NRCS in Illinois and is a voluntary program offering landowners the opportunity to protect, restore, and enhance agricultural land and wetlands on their property. This program includes the Wetland Reserve Easement Program (WREP). The NRCS provides technical and financial support to help landowners with their restoration efforts. This program offers landowners an opportunity to establish long-term conservation and wildlife practices and protection.

Environmental Quality Incentive Program (EQIP)[12] This program is administered by the NRCS in Illinois and provides a voluntary conservation program for farmers and ranchers that promotes agricultural production and environmental quality as compatible national goals. EQIP offers financial and technical assistance to eligible participants to install or implement structural and management practices on eligible agricultural land. Contracts may last for up to 10 years. Special payment schedules are in place for socially disadvantaged, beginning and limited resource farmers, Indian tribes, and veterans.

Application is a competitive process and EQIP applicants compete for funds by ‘funding pool’, a process that allows similar applicants to be grouped together for consideration. Payments are set by practice and are provided to the participants after the implementation of activities identified in their EQIP plan of operations. Incentive payments may be provided for up to three years to encourage producers to carry out management practices they may not otherwise use without the incentive. As part of the changes contained within the 2014 Farm Bill, the former Wildlife Habitat Incentive Program (WHIP), which provided both technical assistance and cost-share payments to help establish and improve fish and wildlife habitat, was folded in the EQIP program. Additional changes include un-waivable payment limits of $450,000.

Conservation Stewardship Program (CSP)[13] This program is administered by the NRCS in Illinois and assists agricultural producers with the maintenance and continued improvement of their in-place conservation systems. In addition, the program can provide assistance in the adoption of additional conservation practices which address priority resource concerns. These resource concerns can be water quality/quantity, habitat quality, soil quality, air quality, and energy conservation. Two payment types are offered, both on five-year contracts: a supplemental payment for adopting resource-conserving crop rotations, and annual payments for the adoption or installation of new conservation activities or maintenance of existing practices.

4.6.2 State Programs

Partners for Conservation (PFC) Cost-share Program[14] The Illinois Department of Agriculture administers several initiatives through the PFC cost-share program that promotes nutrient management, conservation tillage and the use of cover crops. Conservation practices that are eligible for cost-share

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[11] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/easements/acep

[12] general information at http://www.nrcs.usda.gov/PROGRAMS/EQIP/; Illinois information and materials at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/il/programs/financial/eqip/

[13] http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/

[14] https://www2.illinois.gov/sites/agr/Resources/Conservation/Pages/default.aspx

assistance through PFC include terraces, grassed waterways, water and sediment control basins, grade stabilization structures, crop residue management, cover crops and nutrient management plans.

This program is designed to take a broad-based, long-term ecosystem approach to conserving, restoring, and managing Illinois' natural lands, soils, and water resources while providing additional high-quality opportunities for outdoor recreation. New programs under this fund must meet two key criteria:

1. They must be voluntary, and based on incentives rather than government regulation.
2. They must be broad-based, locally-organized efforts, incorporating the interests and participation of local communities, and of private, public and corporate landowners.

The Sustainable Agriculture Grant Program administered through this fund is seeking proposals from parties wishing to complete on-farm research or demonstrations, outreach and education, or university research in the area of agricultural sustainability. Up to $20,000 of support is available per grant.

Conservation Practices Cost-Share Program. Another component of Partners for Conservation Fund, the Conservation Practices Program (CPP) focuses on conservation practices, such as terraces, filter strips and grass waterways that are aimed at reducing soil loss on Illinois cropland to tolerable levels. IDOA distributes funding for the cost-share program to Illinois' SWCDs, which prioritize and select projects. Construction costs are divided between the state and landowners.

Illinois Conservation Reserve Enhancement Program (CREP)[15]. As an outgrowth of the Conservation Reserve Program, CREP pays the owners of environmentally sensitive land an annual rental rate in exchange for ceasing production and implementing conservation practices. CREP is different from CRP in that CREP focuses on the partnership between state and/or tribal agencies and the federal government. As of 2016, there are 126,805 acres enrolled in the Federal CREP program in Illinois at an average rental rate of $212.30 per acre. Approximately 90,990 acres are protected by CREP easements executed by the State (Illinois CREP, 2016). FSA administers the Federal component of CREP as they do for CRP. The Illinois Department of Natural Resources (IDNR) along with the local SWCD administers the State component and also provides technical assistance. Once the Federal CRP contract has expired, the State component of CREP extends the benefits of the established conservation practices through 15 or 35-year extensions, or in perpetuity with a permanent easement. If a landowner chooses to enroll in a permanent easement, they have the option of enrolling and receiving payment on adjacent additional acres, which would not otherwise be eligible for CRP or CREP, due to a lack of cropping history.

Water Quality Management Planning Grants[16]. Grants are available to regional public comprehensive planning organizations and other entities to carry out water quality management planning activities that protect water quality in Illinois. Projects must address water quality issues.

Grant funds can be used to determine the nature, extent, and causes of point and nonpoint source water pollution; develop water quality management plans; develop technical and administrative guidance tools for water pollution control; develop preliminary designs for best management practices (BMPs) to address water quality problems; implement administrative water pollution controls; and educate the public about the impact and importance of water pollution control.

Illinois EPA receives these funds through Section 604b of the Clean Water Act and administers the program within Illinois. The project period is two years unless otherwise approved. This is a reimbursement program.

Streambank Stabilization and Restoration Program (SSRP). The Illinois Department of Agriculture, with assistance from Soil and Water Conservation Districts, administers the SSRP. This

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[15] https://www.dnr.illinois.gov/conservation/CREP/Pages/default.aspx

[16] https://www2.illinois.gov/epa/topics/water-quality/watershed-management/wqmp/Pages/grants.aspx

program, funded through Partners for Conservation, provides support for using low-cost techniques (e.g., rock riffles, stone toe protection and bendway weirs) to stabilize eroding stream banks.

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5 Public Engagement, Education and Information

The pollutants of concern are predominantly from non-point sources, including agricultural land used for crop cultivation and livestock management, and implementation of recommended nonpoint source management measures will be completely voluntary. The previous section provided an initial priority ranking of subwatersheds; however, the final ranking should consider public interest in adopting management measures. Wet weather monitoring is strongly recommended to identify specific areas generating higher pollutant loads.

Achieving the pollutant load reduction targets in the watershed will require organized and sustained efforts in public engagement, education and information. Such efforts will create a culture of stewardship, a broad understanding of the need for pollutant control and increase the implementation of management measures to reduce pollutant loads.

5.1 Watershed Group Formation

There is currently no known active watershed group that is active throughout the Upper Big Muddy River watershed. There are a watershed group that is meeting on a regular basis for the Lake Creek and Pond Creek watersheds organized through the Greater Egypt Regional Planning and Development Commission. The NRCS has been active in portions of the watershed in the past, working with some agricultural property owners and others to implement practices to reduce pollutant loads.

It is recommended that an overall watershed group be formed to serve as the primary watershed group in the Upper Big Muddy River watershed. This group could coordinate their efforts with the Lake Creek Watershed Council, but allow for BMP project identification and implementation on a braaoder scale across the watershed. This group should meet to identify whether there are additional stakeholders with an interest in improving water quality, and develop a plan to reach out to these stakeholders. Potential stakeholders may include NRCS, SWCD, Illinois EPA, County Health Departments, Farm Service Agency staff, Greater Egypt Regional Planning and Development Commission staff, local producers, and other interested residents. Functions of a citizen-driven watershed group are numerous, including:

- Provide a forum for like-minded citizens to discuss issues, actions and priorities for the watershed;
- Be a source of watershed information for the public;
- Organize meetings and watershed events;
- Create vehicles for distributing watershed information such as newsletters, blogs, e-mailings and a web site; and
- Solicit donations and obtain grant funding from government agencies and foundations.

This watershed group will likely need to complete the following tasks to help it accomplish its goals:

- Inform the public that a watershed plan has been developed to gain interest in implementing recommended actions.
- Educate the public on the plan and benefits of the plan.
- Develop a web page and social media outlets which are appropriate for their target audience. These should allow the group to provide updates, post callouts for volunteer events, gather and display data, and present progress.

- Create 1-2 page fact sheets or brochures which can be distributed at public meetings and events. This educational material should educate landowners and community members on their opportunities to implement best management practices and the influence these practices may have on their local water quality. It is ideal to have promotional material which is targeted to residential landowners (perhaps including information on septic systems) and agricultural landowners.
- Identify local events where their outreach can have an effective impact on the watershed community. This might be a local festival, a school science fair, a library event, or anywhere where people from the community gather and there is an opportunity to set up a booth or hand out flyers.

This group will want to think carefully about how to cultivate the membership to be sure that all relevant members of the community can be represented. It can be important to have members from many different sectors: agribusiness operators, recreation groups, rural non-farm and farm residents, urban/suburban residents, environmental interests, elected officials, and farmers (both those who own the land they farm and who rent).

5.2 Public Education and Outreach

Group activities should include public education and outreach to inform watershed residents of the problems with in the watershed, share the implementation plan, and to solicit input on controls that stakeholders are willing to implement. Once the core membership has been formed, the watershed group will be well positioned to plan further outreach to the general public. To promote buy-in, the group should be prepared to offer insight into what any member of the community may do to advance watershed health. This could include developing strategic plans for unique watershed users – both by geography and by topic. For example, residents of the reservoir watersheds may want to develop their own group focused on phosphorus load reduction. Livestock producers may want to form a separate group focused on issues unique to livestock production. NRCS staff may be able to share data from past successes in other watersheds, to encourage more wide-spread adoption of measures that have been successful. Group activities should also focus on reaching elected and appointed government officials to educate them on the role that they can play in implementing BMPs within their communities to help improve the water quality in the Upper Big Muddy River watershed. Funding opportunities described in this report should also be shared with interested landowners. Table 5-1 presents details regarding public information and education, and milestones are presented in Section 6.

As is clear from the prior section, the first scheduled task should be to organize and convene a watershed group. A lead organization will need to be identified or organized to convene the group, or as a foundation group to build on, if there is a need to expand membership to reach a diversity of stakeholder groups. This group should meet to identify and reach out to additional stakeholders, and should also begin compiling past reports and information regarding implementation. The first year of implementation should be devoted to solidifying this group, understanding measures already implemented and their success, and beginning the public outreach and education aspects of implementation, as described in Table 5-1. Guidance for subsequent years is also provided in this table.

Table 5-1. Information & Education Plan Start-Up Schedule

Information & Education Action	Target Audience	Information/ Education Component	Schedule	Lead and (supporting organizations)	Outcomes	Cost
Organize watershed group	General public	Inform the public and local agencies that the group is expanding	Immediately following plan completion	To Be Determined (IEPA, County Health Departments, NRCS, SWCD, agricultural retailer)	Establishment of a watershed group within 1 year of plan completion, including designation of a coordinator or coordinating committee and if desired, development of a logo.	No cost, assuming the coordinator is a volunteer and a volunteer develops the logo (if desired).
Develop a website for the watershed group and link to any partner websites	All stakeholders	Develop a website to keep people informed about watershed issues and opportunities.	Immediately following plan completion	To Be Determined	Establishment of a website and other social media accounts. Website should minimally include information on the watershed, watershed group and goals, the watershed plan, contact information, email addresses, links, downloads, and a calendar.	$500/year for direct costs to establish a new website. This assumes a watershed group member with aptitude for web development can set up and maintain the site for free.
Compile and review information describing previous implementation and planning	Watershed group	Identify where work has been done, and document what's been successful, who was involved and time frame of the work.	Immediately following watershed group formation	To Be Determined (NRCS, SWCD)	Summary of existing documents and past implementation success compiled.	No cost if using existing resources.

Table 5-1 (continued)

Information & Education Action	Target Audience	Information/ Education Component	Schedule	Lead and (supporting organizations)	Outcomes	Cost
Inform the general public that an implementation plan has been developed for the Upper Big Muddy River watershed to gain interest in implementing recommended actions	General public	Inform the public about the plan and share information on how public may participate in implementation via existing media newspapers, newsletters and social media	Immediately following watershed group formation	To Be Determined (NRCS, SWCD)	Majority of the public in the watershed are well educated on watershed conditions and know who to contact to get involved.	No cost if using existing resources. If desired, flyers and posters could be developed. Approximate costs would be: $34 for 25 brochures Price based on costs to develop a brochure using preset options http://www.fedex.com/us/office/brochure-printing.html $210 for three mounted posters Assumes 3 posters (22" x 28"). Pricing based on http://www.fedex.com/us/office/poster-printing.html
Identify priority locations and actions for years 2-5	Watershed group	Review initial priority ranking of subwatersheds, priority actions, and other factors that may impact ranking (shovel-ready projects, public interest, past success, fund availability, etc.)	Immediately following watershed group formation	To Be Determined (NRCS, SWCD, USEPA, IEPA)	Watershed group agrees on priority actions and locations for years 2-5, that can be funded by available grants, government programs, etc.	No cost if using existing resources

Table 5-1 (continued)

Information & Education Action	Target Audience	Information/ Education Component	Schedule	Lead and (supporting organizations)	Outcomes	Cost
Educate private riparian landowners along the Upper Big Muddy River and tributaries how to properly manage their land to reduce pollutant loads.	Private land owners along the Upper Big Muddy River and tributary streams	Conduct workshops for riparian land owners that recommend pollutant controls, funding sources, and qualified contractors.	Once every five years	To Be Determined or Consultant (NRCS, SWCD, IEPA)	Private land owners recognize the benefits of watershed controls.	$3,000 per event
Hold an annual watershed tour for elected officials and others interested in watershed activities	Elected officials; all stakeholders	Offer an annual bus tour of the Upper Big Muddy River watershed for elected officials and others to see restoration areas, areas that are in need of improvement and failed projects	Annually	Municipalities, NRCS, SWCD	Elected officials become more familiar with existing and potential restoration projects and learn more about what is/is not working. Decisions regarding future proposed projects are better informed	$2,000 per event
Implement demonstration projects or highlight existing case studies within the watershed	Elected officials; general public; all stakeholders	Use many forms of media to inform the public when and where demonstration projects are implemented (radio, newspapers, social media, websites, etc.)	Immediately following plan completion and when projects are implemented	To Be Determined (NRCS, SWCD)	The majority of the public in the watershed know about demonstration projects, their benefits and where they are located. The public begins to accept and support watershed improvement projects	$5,000/project

Table 5-1 (continued)

Information & Education Action	Target Audience	Information/ Education Component	Schedule	Lead and (supporting organizations)	Outcomes	Cost
Install “Upper Big Muddy River Watershed” signs along major roads in the watershed	General Public	Design and install signs at key points along major roads in the watershed that inform drivers and passengers that they are entering the Upper Big Muddy River watershed.	Following plan completion	Municipalities	Signs will increase the public’s awareness of the watershed boundary, and will alert them to areas that have an impact on water quality in the creek.	$50,000 for fifty signs

6 Implementation Schedule and Milestones

This section describes an implementation schedule for the recommended measures described in Section 4. These should begin in year 2, after the public engagement, education and outreach program described in Section 5 has been initiated. This schedule should be followed concurrently with the monitoring described in Section 7.

6.1 Implementation Priority

Implementation of management measures works well if the area targeted is of a manageable size. In the absence of site-specific information on local partnerships and watershed protection restoration activities within the watershed, the implementation priorities identified in Table 6-1 are generally based on implementing from upstream to downstream in the watershed. This maximizes the impact of management actions taken in the high priority/early implementation since reductions in the upstream loads can also impact the downstream pollutant loads as well.

Table 6-1. Recommended Watershed Implementation Priority

Waterbody/ Segment ID	Recommended Watershed Implementation Priority
Big Muddy R. / IL_N-06	High
Big Muddy R. / IL_N-11	High
Big Muddy R. / IL_N-17	Low
Andy Cr. / IL_NZN-13	Medium
Pond Cr. / IL_NG-02	High
Lake Cr. / IL_NGA-02	High
Beaver Cr. / IL_NGAZ-JC-D1	Medium
M. Fk. Big Muddy / IL_NH-06	Medium
M. Fk. Big Muddy / IL_NH-07	Medium
Herrin Old / IL_RNZD	Low
Johnston City / IL_RNZE	Low
Arrowhead (Williamson) / IL_RNZX	Medium
West Frankfort Old / IL_RNP	Medium
West Frankfort New/IL_RNQ	High

This suggested implementation priority should be reviewed by the watershed group upon formation, and modified as necessary to meet their goals, or to identify areas where there is existing support for early implementation.

6.2 Implementation Milestones

As outlined above, there are several interim milestones that should be evaluated to assess progress as the implementation plan moves forward. With the exception of the initial convening the watershed group, all measureable milestones should be finalized by the group. Achievement of these milestones will assure the watershed group that they are making progress in their role. However, additional criteria should be developed which will specifically document the group's progress at improving water quality. These criteria should be decided by the watershed group after formation, but should include the following elements:

- A defined plan for documenting and tracking pollutant concentrations over time.
- A mechanism for tracking implementation of practices in each watershed, or documenting interest in or commitments to implementing practices for future follow-up.
- A mechanism for including the following concepts in their tracking of water quality:
    - Annual fluctuations in precipitation and/or temperature
    - Appreciable adoption of best management practices
    - The addition or removal of any point source facilities
    - The patterns displayed by the dominant crops in the watershed (was there a drought which impacted the crops ability to accumulate biomass, did the planting occur early or late, etc.)
    - The season and 7-day prior conditions during which the samples were taken
- The target concentrations

The watershed group should acknowledge that it may be difficult to determine progress at an early stage of implementation. As enumerated above, any number of factors may alter the in-stream concentrations on a year to year basis. It may be necessary to plan for a multi-year effort which will allow the longer term collection of data and determination of a long term concentration average.

Implementation milestones proposed for tracking progress toward water quality goals are described in Table 6-2, and assume year one of implementation is in 2019. These milestones should be reviewed by the watershed group leading implementation and adjusted to reflect local knowledge and preferred practices.

Table 6-2. Implementation Milestones for Water Quality

Year	Management Measure Action	Milestones/Measures of Success	Milestone Date
2	Identify candidate sites in high priority watersheds for conservation buffers (157 acres), water and sediment control basins (953 acres), and conservation tillage (2,697 acres) – 50% of implementation targets. Identify potential locations with failing onsite systems.	Viable sites identified, suitable for grant application	End of 2020
2	Establish cover crop practices on 3,190 acres (50% of high priority target), focusing in high priority subwatersheds	Acres of cover crop	End of 2020
2-3	Begin work to establish conservation buffers (157 acres), water and sediment control basins (953 acres), and conservation tillage (2,697 acres) in high priority watersheds implementation targets (half of target)	Acres of conservation buffers established, acres of land controlled with sediment basins, acres of conservation tillage started	End of 2021
2-3	Conduct a streambank erosion inventory to identify locations for streambank stabilization in high priority watersheds.	Completion of streambank erosion inventory in high priority watersheds. Viable sites identified and stream miles to be stabilized	End of 2021
2-3	Conduct an inventory of locations where livestock has access to streams in high priority watersheds	Completion of inventory of livestock stream access locations in high priority watersheds. Viable sites identified and stream miles to be fenced.	End of 2021
3	Communicate with Health Department and landowners with failing systems to develop a plan and identify funding to improve onsite systems.	Development of a plan and identification of a funding source to improve failing onsite systems.	End of 2021
3-4	Perform alum lake treatment for phosphorus inactivation in West Frankfort New reservoir (IL_RNP)	Alum lake treatment for phosphorus inactivation in West Frankfort New reservoir (IL_RNP)	End of 2022
3-5	Begin streambank stabilization in areas identified as having the most severe erosion, ultimately targeting 105 miles in high priority watersheds	Miles of streambank stabilized	End of 2023
3-5	Begin installing fences to restrict livestock access to streams, targeting 100% of sites identified in inventory.	Miles of streambank protected from livestock	End of 2023
4	Identify candidate sites for additional conservation buffers (157 acres) and conservation tillage (2,697 acres) (remaining 50% of target).	Viable site identified, suitable for grant application	End of 2022
4-7	Establish conservation buffers (157 acres), water and sediment control basins (953 acres), and conservation tillage (2,697 acres) in high priority	Stream miles with new conservation buffers acres of land controlled with sediment	End of 2025

Year	Management Measure Action	Milestones/Measures of Success	Milestone Date
	watersheds implementation targets (remaining 50% of target)	basins, acres of conservation tillage established	
4-7	Establish cover crop practices on 3,191 (remaining 50% of high priority target), focusing in high priority subwatersheds	Acres of cover crop	End of 2025
5	Conduct 5-year review of implementation plan and prepare updated plan	Completion of updated implementation plan, based on 5-year review	End of 2023
5-6	Identify candidate sites for conservation buffers (575 acres), water and sediment control basins (1,299 acres), and conservation tillage (11,695 acres) (100% of target in medium priority watersheds).	Viable sites identified, suitable for grant application	End of 2024
7-10	Establish cover crop practices on 141 acres in medium priority subwatersheds (half of target)	Acres of cover crop	End of 2028
5-6	Conduct a streambank erosion inventory to identify locations for streambank stabilization in medium and low priority watersheds	Completion of streambank erosion inventory in high priority watersheds. Viable sites identified and stream miles to be stabilized	End of 2024
7-8	Perform alum lake treatment for phosphorus inactivation in Arrowhead (Williamson) (IL_RNZX) and West Frankfort Old (IL_RNP) reservoirs	Alum lake treatment for phosphorus inactivation Arrowhead (Williamson) (IL_RNZX) and West Frankfort Old (IL_RNP) reservoirs	End of 2026
7-10	Establish conservation buffers (575 acres), water and sediment control basins (1,299 acres), and conservation tillage (11,695 acres) in high priority watersheds implementation targets	Acres of conservation buffers established, acres of land controlled with sediment basins, acres of conservation tillage	End of 2028
7-10	Begin streambank stabilization in areas identified as having the most severe erosion, ultimately targeting 140.1 miles in medium priority watersheds	Miles of streambank stabilized	End of 2028
7-10	Establish cover crop practices on 141 acres in medium priority subwatersheds (remaining 50% of target)	Acres of cover crop	End of 2028
10	Conduct 5-year review of implementation plan and prepare updated plan	Completion of updated implementation plan, based on 5-year review	End of 2028
11-14	Begin streambank stabilization in areas identified as having the most severe erosion, ultimately targeting 42 miles in low priority watersheds	Miles of streambank stabilized	End of 2032
11-14	Establish conservation buffers (58 acres) and conservation tillage (2,945 acres) in low priority watershed implementation targets.	Acres of conservation buffers established, acres of conservation tillage	End of 2032

Year	Management Measure Action	Milestones/Measures of Success	Milestone Date
11-14	Establish cover crop practices on 7,323 acres in low priority subwatersheds	Acres of cover crop	End of 2032
15	Perform alum lake treatment for phosphorus inactivation in Herrin Old (IL_RNZD) and Johnston City (IL_RNZE) reservoirs	Alum lake treatment for phosphorus inactivation Herrin Old (IL_RNZD) and Johnston City (IL_RNZE) reservoirs	End of 2033
15	Conduct 5-year review of implementation plan, progress towards water quality targets, and prepare updated plan	Completion of updated implementation plan, based on 5-year review.	End of 2033

These are long-term goals, recognizing the need for a local watershed group to be established, educated, secure funding and partnerships, and begin implementation of BMPs. These goals will need to be modified by the watershed group as they begin implementation to meet their locally established priorities.

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7 Monitoring

A monitoring program should be implemented to measure progress in applying the recommended management measures and tracking water quality improvements. Illinois EPA conducts a variety of lake and stream monitoring programs, including: a statewide Ambient Water Quality Monitoring Network (AWQMN); an Intensive Basin Survey Program that covers all major watersheds on a five-year rotation basis; and a Facility-Related Stream Survey Program.

The Illinois EPA Southern Monitoring Unit currently samples two waterbodies in the Upper Big Muddy River watershed under the AWQMN; the Middle Fork Big Muddy River at station NH-06, and the Big Muddy River at station N-11. These stations are sampled nine times per water year (a water year runs from October 1 to September 30) on an approximately six-week cycle.

Illinois EPA is scheduled to perform additional sampling in the Upper Big Muddy River watershed as part of the 2018 Intensive Basin Survey. This watershed will likely be sampled again in 2023, as part of IEPA's five-year rotating schedule. Monitoring by Illinois EPA under this program will provide information on the change in pollutant concentrations over time, reflecting improvements following implementation of management measures.

The watershed group should encourage IEPA to monitor additional locations during the 2023 Intensive Basin Survey, in particular adding locations within the priority watersheds to monitor the progress towards meeting the target pollutant load reductions.

Additional monitoring is also recommended to supplement data collected by Illinois EPA. It may be possible that sampling can be conducted by volunteers to reduce costs. Local sewage treatment plants could be contacted to see if they are willing to donate laboratory analytical services. Prior to monitoring, it is recommended that a Quality Assurance Project Plan (QAPP) be developed. If external funding for monitoring is required, the watershed group will need to identify funding sources potentially from USEPA grant programs. Once funding is secured and the monitoring points identified, the watershed group will conduct the sampling. The frequency of sampling and number of sampling locations will depend on available resources. The group should plan to interface with IEPA about sampling events within the watershed to help them assess pollutant load reductions. The recommended schedule for setting up the watershed monitoring to track progress towards TMDL/LRS implementation is shown in Table 7-1.

Table 7-1. Watershed Monitoring Schedule

Year	Action	Notes	Milestones/Measures of Success
1	Plan sampling; line up laboratory analysis services	Sampling should include total and dissolved phosphorus, total suspended solids, fecal coliform, total iron, and manganese; plan should include sampling locations map	Written plan
1	Prepare QAPP	Illinois EPA can provide examples	Written QAPP
1	Present sampling plan to public; seek volunteers	The sampling plan should be presented at the first annual public watershed meeting	Public meeting with sampling plan presentation
2	Prepare sampling schedule	Based on volunteer availability and availability of laboratory resources, plan sampling schedule	Sampling schedule posted to web site

Year	Action	Notes	Milestones/Measures of Success
2	Seek supplemental funding	If needed, apply for grants to support sampling program	Grant(s) for supplemental funding
2	Conduct sampling	Collect samples as planned	Completion of sampling event(s) by local watershed group
2	Evaluate results; review program; determine need for changes	Identify successes, problems, challenges from initial sampling; revise plan accordingly	Revised sampling plan
3-15	Implement sampling program	Review program every year and identify new resources, areas for improvement. Results should be evaluated for trends over time, as well as compared to target pollutant concentrations to determine whether goals have been attained.	

7.1 Stream Monitoring

Supplemental sampling for streams during the implementation of the TMDLs and LRSs to track progress towards the pollutant reductions and improvements in water quality. A minimum of monthly sampling at stream stations shown in Table 7-2 in years when Illinois EPA does not conduct sampling at those stations. Both low and high flow conditions should be targeted over the course of the year, targeting to sample during at least 3 wet weather impacted flow events annually, since all of these TMDLs and LRSs have runoff related sources.

Table 7-2. River/Stream Monitoring Stations

Waterbody/ Segment ID	Monitoring Stations
Big Muddy R. / IL_N-06	N-06, N-10
Big Muddy R. / IL_N-11	N-11
Big Muddy R. / IL_N-17	N-17
Andy Cr. / IL_NZN-13	NZN-15
Pond Cr. / IL_NG-02	NG-02, NG-05
Lake Cr. / IL_NGA-02	NGA-02
Beaver Cr. / IL_NGAZ-JC-D1	NGAZ-JC-D1
M. Fk. Big Muddy / IL_NH-06	NH-06
M. Fk. Big Muddy / IL_NH-07	NH-07

Annual sampling will provide more frequent data which will help identify temporal trends, as well as patterns related to weather. In addition, more frequent data will allow better discernment of the impacts of management measures as they are implemented.

Additional sampling locations could be added to create a richer data set to assess water quality in streams and may provide a means to better observe the effects of management measures by providing upstream/downstream sampling pairs. During implementation planning for each subwatershed, it is recommended that the watershed group identify additional locations for sampling stations that could be used to monitor water quality.

Stream sampling should include fecal coliform, and total suspended sediment. Where possible, flow measurement should be conducted as a component of stream monitoring, particularly on the tributary streams and the Middle Fork Big Muddy River, since the USGS gage located at station N-11 on the Big Muddy River is impacted by the release of flows from Rend Lake.

7.2 Lake Monitoring

IEPA has historically sampled each of the reservoirs in the watershed at 3 locations. Lake sampling should include measurements of total phosphorus concentrations at these locations for comparison to past data for trend assessment. Monitoring in the tributaries draining to the lakes has not been conducted in the past, but could also be initiated near the point where the streams enter the lakes, to characterize the phosphorus concentrations entering the lakes.

Table 7-3. Lake Monitoring Stations

Waterbody/ Segment ID	Existing Monitoring Stations
Herrin Old / IL_RNZD	RNZD-1, RNZD-2, RNZD-3
Johnston City / IL_RNZE	RNZE-1, RNZE-2, RNZE-3
Arrowhead (Williamson) / IL_RNZX	RNZX-1, RNZX-2, RNZX-3
West Frankfort Old / IL_RNP	RNP-1, RNP-2, RNP-3
West Frankfort New/IL_RNQ	RNQ-1, RNQ-2, RNQ-3

A map showing the current monitoring stations in the watershed is shown in Figure 7-1. Within each of the lakes, the monitoring locations are generally located near the dam at the downstream end, in the middle of the lake, and near the upstream end to capture the spatial variability in the water quality conditions.

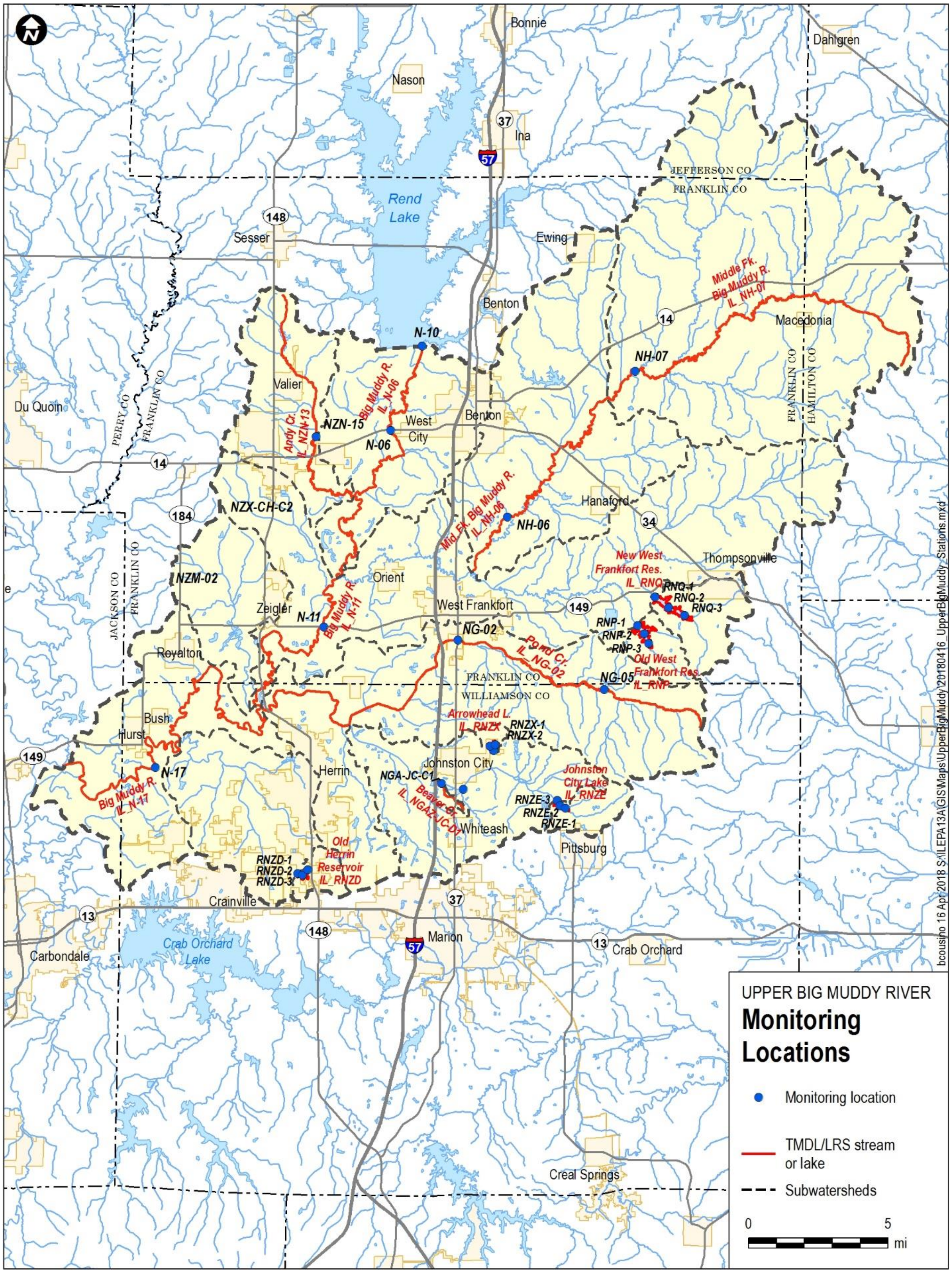

Figure 7-1. Upper Big Muddy River Monitoring Locations

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