UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 7
11201 Renner Boulevard
Lenexa, Kansas 66219

JUN 14 2019

Mr. Alex Moon
Water Quality Bureau Chief
Iowa Department of Natural Resources
Wallace Building,
Wallace State Office Building E. 9th St.
Des Moines, Iowa 50319

Dear Mr. Moon:

RE: Approval of TMDL document for Rathbun Lake

This letter responds to the submission from the Iowa Department of Natural Resources, originally received by the U.S. Environmental Protection Agency, Region 7 on July 26, 2017, for a Total Maximum Daily Load document which contained TMDLs for Turbidity. Rathbun Lake was identified on the 2016 Iowa Section 303(d) List as being impaired by Turbidity. This submission fulfills the Clean Water Act statutory requirement to develop TMDLs for impairments listed on a state's §303(d) list. The specific impairments (water body segments and causes) are:

Water Body	WBIDs	Segment Description	Causes
Rathbun Lake	IA 05-CHA-1309	Main Lake near dam	Turbidity
	IA 05-CHA-2027	S. Fk Chariton River arm	Turbidity
	IA 05-CHA-2028	Chariton River arm	Turbidity
	IA 05-CHA-2030	Honey Creek arm	Turbidity

The EPA has completed its review of the TMDL document with supporting documentation and information. By this letter, the EPA approves the TMDLs submitted under § 303(d). Enclosed with this letter is Region 7, TMDL Decision Document which summarizes the rationale for the EPA's approval of the TMDLs. The EPA believes the separate elements of the TMDLs described in the enclosed document adequately address the cause of concern, taking into consideration seasonal variation and a margin of safety.

Although the EPA does not review the monitoring or implementation plans submitted by the state for approval, the EPA acknowledges the state's efforts. The EPA understands that the state may use the monitoring plan to gauge the effectiveness of the TMDL and determine if future revisions are necessary or appropriate to meet applicable water quality standards. The EPA recognizes that technical guidance and support are critical to determining the feasibility of and achieving the goals outlined in these TMDLs. Therefore, the implementation plan in this TMDL document provides information regarding implementation efforts to achieve the loading reductions identified.

The EPA appreciates the thoughtful effort that the IDNR has put into these TMDLs. We will continue to cooperate with and assist, as appropriate, in future efforts by the IDNR, to develop TMDLs. If you have any questions, contact Jennifer Kissel, of my staff, at (913) 551-7982.

Sincerely,

Jeffery Robichaud
Director
Water Division

Enclosure

United States Environmental Protection Agency
Region 7
Total Maximum Daily Load Approval

Rathbun Lake
in Iowa

Turbidity

Jeffery Robichaud
Director
Water Division

6/14/19
Date

(This page intentionally left blank)

EPA Region 7 TMDL Review

TMDL ID: IA 05-CHA-1309, 2027, 2028 and 2030 (Legacy IA 05-CHA-0020-L_1, 2, 3 and 4)
State: IA
Document Name: Rathbun Lake

Basin(s): Chariton River
HUC(s): 10280201
Water body(ies): Rathbun Lake
Tributary(ies): Chariton River, South Fork Chariton River and Honey Creek
Cause(s): Turbidity

Submittal Date: July 26, 2017 **Approved:** Yes

Submittal Letter and Total Maximum Daily Load Revisions

The state submittal letter indicates final TMDL(s) for specific pollutant(s) and water(s) were adopted by the state and submitted to the EPA for approval under Section 303(d) of the Clean Water Act [40 CFR § 130.7(c)(1)]. Include date submitted letter was received by the EPA, date of receipt of any revisions and the date of original approval if submittal is a revised TMDL document.

The Total Maximum Daily Load (TMDL) document for Rathbun Lake (Water body Identification Numbers IA 05-CHA-1309, 2027, 2028 and 2030 (Legacy IA 05-CHA-0020-L_1, 2, 3 and 4)) was submitted by the Iowa Department of Natural Resources to the U.S. Environmental Protection Agency on July 26, 2017.

Water Quality Standards Attainment

The targeted pollutant is validated and identified through assessment and data. The water body's loading capacity for the applicable pollutant is identified and the rationale for the method used to establish the cause-and- effect relationship between the numeric target and the identified pollutant sources is described. The TMDL(s) and associated allocations are set at levels adequate to result in attainment of applicable water quality standards [40 CFR § 130.7(c)(1)]. A statement that the WQS will be attained is made.

The targeted pollutant is validated and identified through assessment and data.

Rathbun Lake is on Iowa's 2014 and 2016 303(d) lists of impaired water because its aquatic life and primary contact recreation used are impaired. The impairment is caused by excess sediment and turbidity.

The assessment of Rathbun Lake is based on results of the statewide survey of Iowa lakes conducted by Iowa State University, Iowa DNR Watershed Improvement Section, U.S. Army Corps of Engineers, USGS, data NES COOP, PRISM Climate Group, NOAA, USDA, and USACE. Sampling dates and lake water quality data are tabulated in Appendix C of the TMDL document.

The IDNR's review and interpretation of the water quality provides justification for linking phosphorus loads to turbidity. Most phosphorus enters Rathbun Lake attached to sediment associated from land in agricultural production and streambank gully erosion.

The narrative Iowa water quality standard which applies is;

"61.3(2) General water quality criteria. The following criteria are applicable to all surface waters including general use and designated use waters, at all places and at all times for the uses described in 61.3(1)"a."

a. Such waters shall be free from substances attributable to point source wastewater discharges that will settle to form sludge deposits.
b. Such waters shall be free from floating debris, oil, grease, scum and other floating materials attributable to wastewater discharges or agricultural practices in amounts sufficient to create a nuisance.
c. Such waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor or other aesthetically objectionable conditions.
d. Such waters shall be free from substances attributable to wastewater discharges or agricultural practices in concentrations or combinations which are acutely toxic to human, animal, or plant life.
e. Such waters shall be free from substances, attributable to wastewater discharges or agricultural practices, in quantities which would produce undesirable or nuisance aquatic life."

Iowa does not have numeric water quality criteria for turbidity. The designated uses for Rathbun Lake are based on a narrative water quality standard, "free from aesthetically objectionable conditions." For 303(d) listing purposes, aesthetically objectionable conditions are present in a water body when the average Carlson's TSI for the median growing season chlorophyll *a* or Secchi depth exceeds 65. From 2004 to 2014, measured TSI values in Rathbun Lake that exceeded 65 Secchi Depth TSI. To meet this narrative criterion, the state has targeted the numerical translator it would use to delist the water. This target is a trophic state index of 63 for Secchi transparency. Since the lake has a low level of non-algal turbidity the chlorophyll a target of 27 micrograms per liter will result in a Secchi transparency of no less than 0.8 meters (TSI 63).

The TMDL targets are set at a level to attain and maintain water quality standards.

The Loading Capacity expressed as the allowable annual average which is helpful in the water quality assessment and for watershed planning and management, is as follows:

TMDL = LC = WLA + LA + MOS
Where: TMDL = total maximum daily load; LC = loading capacity; WLA = sum of wasteload allocations (point sources); LA = sum of load allocations (nonpoint sources); MOS = margin of safety (to account for uncertainty).

The maximum daily load was estimated from the growing season average load using a statistical approach outlined in Appendix F of the TMDL document, based on the EPA's guidance, Options for Expressing Daily Loads in TMDLs. This approach uses a lognormal distribution to calculate the daily maximum from the long-term (e.g., seasonal) average load. The LC expressed as the maximum daily load is as follows:

TMDL = LC = WLA (0 lb-TP/day) + LA (XX lb-TP/day) + MOS (XXX lb-TP/day) = XXX lb-TP/day

Table 1: Rathbun required reductions and load capacities

Segment	Description	Required TP Load Reductions	LC (tons/yr)	LC (lbs/day)
IA 05-CHA-1309	Main Lake near dam	21.5%	458.3	31,786
IA 05-CHA-2027	S. Fk Chariton River arm	83.8%	94.5	6,554
IA 05-CHA-2028	Chariton River arm	74%	149.9	10,396
IA 05-CHA-2030	Honey Creek arm	30.6%	405.3	28,110

The EPA agrees that the TMDL targets will attain and maintain water quality standards.

Designated Use(s), Applicable Water Quality Standard(s) and Numeric Target(s)

The submittal describes applicable water quality standards, including beneficial uses, applicable numeric and/or narrative criteria, and a numeric target. If the TMDL(s) is based on a target other than a numeric water quality criterion, then a numeric expression, site specific if possible, was developed from a narrative criterion and a description of the process used to derive the target is included in the submittal.

Rathbun Lake segments are protected for the following designated uses:

- Primary contact recreation – Class A1: Waters in which recreational or other uses may result in prolonged and direct contact with the water, involving considerable risk of ingesting water in quantities sufficient to pose a health hazard. Such activities would include, but not be limited to, swimming, diving, water skiing and water contact recreational canoeing.
- Aquatic life, Warm water – Type 1 Class B(WW-1): Waters in which temperature, flow and other habitat characteristics are suitable to maintain warm water game fish populations along with a resident aquatic community that includes a variety of native nongame fish and invertebrate species. These waters generally include border rivers, large interior rivers, and the lower segments of medium-size tributary streams.
- Human Health – Class HH: Waters in which fish are routinely harvested for human consumption or waters both designated as a drinking water supply and in which fish are routinely harvested for human consumption.

Additionally, there is a surface drinking water intake for the Rathbun Regional Water Associated located in the main segment of the lake (05-CHA-1309) near the dam that has an additional use:

- Drinking water supply (Class "C"): Waters which are used as a raw water source or potable water supply.

The state of Iowa's Water Quality Standards are published in the Iowa Administrative Code, Environmental Protection Rule 567, Chapter 61. Although the state of Iowa does not have numeric criteria for sediment, narrative water quality criteria are in the WQS. Chapter 61.3(2) of the WQS contains the general water quality criteria, which are applicable to all surface waters. These narrative criteria include that waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor or other aesthetically objectionable conditions.

The TMDL target for the median growing season is a Carlson's TSI not to exceed 63 in two consecutive listing cycles, which corresponds to a measured Secchi depth of 0.8 meters. The IDNR established target will ensure long-term protection to fully support primary contract recreation and aquatic life. All other uses will be protected at the stated TP targets.

The TSI target for listing and delisting of Rathbun Lake is measured at four locations within the lake. The numerical translation is protective of the narrative criteria which includes, "free from aesthetically objectionable conditions." As there are no EPA-approved water quality criteria to address the allocated pollutant, total phosphorus, to address the impairment cause of turbidity, this TMDL targets the narrative criteria applicable through the quantitative translator used for delisting a lake for this cause.

The EPA agrees that the TMDL LC will attain and maintain water quality standards.

Pollutant(s) of Concern

A statement that the relationship is either directly related to a numeric water quality standard or established using surrogates and translations to a narrative WQS is included. An explanation and analytical basis for expressing the TMDL(s) through surrogate measures, or by translating a narrative water quality standard to a numeric target is provided (e.g., parameters such as percent fines and turbidity for sediment impairments, or chlorophyll-a and phosphorus loadings for excess algae). For each identified pollutant, the submittal describes analytical basis for conclusions, allocations and a margin of safety that do not exceed the loading capacity. If the submittal is a revised TMDL document, there are refined relationships linking the load to water quality standard attainment. If there is an increase in the TMDL(s), there is a refined relationship specified to validate that increase (either load allocation or wasteload allocation). This section will compare and validate the change in targeted load between the versions.

There is an established link between the narrative water quality standard for Rathbun Lake and the total phosphorus target. Rathbun lake is impaired for excessive non-algal turbidity. Data interpretation indicates that phosphorus load reduction will best address this impairment. The non-algal turbidity is caused by suspended or re-suspended sediments entering the lake. Much of the phosphorus enters the lake attached to those sediments. Therefore, practices to reduce phosphorus will also reduce the sediment levels. The primary focus of the TMDL document is quantifying and reducing phosphorus loads to remediate the water clarity issues. Total phosphorus and sediment loading are highly correlated (r^2=0.962 to r^2=0.973 depending on segment, shown in supplemental files), reduction of total phosphorus will result in concurrent reduction in sediment loads. The TMDL loading capacity for total phosphorus will also ensure that algal growth will not increase as turbidity decreases. This will result in protection from any future chlorophyll-a impairment.

The EPA agrees that the TMDL document targets the appropriate pollutant.

Source Analysis

Important assumptions made in developing the TMDL document, such as assumed distribution of land use in the watershed, population characteristics, wildlife resources and other relevant information affecting the characterization of the pollutant of concern and its allocation to sources, are described. Point, nonpoint and background sources of pollutants of concern are described, including magnitude and location of the sources. The submittal demonstrates all significant sources have been considered. If this is a revised TMDL document any new sources or removed sources will be specified and explained.

In the absence of a national pollutant discharge elimination system permit, the discharges associated with sources

were applied to the load allocation, as opposed to the wasteload allocation for purposes of this TMDL document. The decision to allocate these sources to the LA does not reflect any determination by the EPA as to whether these discharges are, in fact, unpermitted point source discharges within this watershed. In addition, by establishing these TMDL(s) with some sources treated as LAs, the EPA is not determining that these discharges are exempt from NPDES permitting requirements. If sources of the allocated pollutant in this TMDL document are found to be, or become, NPDES-regulated discharges, their loads must be considered as part of the calculated sum of the WLAs in this TMDL document. Any WLA in addition to that allocated here is not available.

The TMDL document identifies both point and nonpoint sources of TP loading.

Rathbun Lake is a 12,040-acre man-made lake that was constructed in 1964 and is surrounded by 22,900 acres of public land in the following counties: Appanoose, Clarke, Decatur, Lucas, Monroe, and Wayne. Recreational opportunities include boating, fishing, and swimming.

The existing TP load to Rathbun lake is mainly from nonpoint sources of pollution. Nonpoint sources in the Rathbun Lake watershed include: sheet and rill erosion from various land use sources, runoff and subsurface flows from lands that receive manure or fertilizer application, stream and gully erosion, poorly functioning septic systems, manure deposited by wildlife, atmospheric deposition and resuspension of previously deposited sediment.
There are some minor point sources of TP in the watershed as well (see Table 2 below).

Table 2: Average Annual Total Phosphorus input (Table 3-6 in the TMDL document.)

Source	**Description**	**TP Load (tons/yr)**	**Percent (%)**
Row Crops (conventional)	Includes land in corn and soybean rotations and continuous corn	240.9	41.3
Streambank Erosion	Streambank and channel erosion	114.3	19.6
Pasture/Grass	Includes grazed and ungrazed grassland/ Does not include direct deposition of manure in streams	117.8	20.2
Row Crops (extended)	Includes land in extended rotations that include small grains and/or hay in addition to row crops	56.5	9.7
Gully Erosion	Classic gullies, not in-field ephemeral gullies	17.9	3.1
Developed Areas	Includes roads, urban areas, and rural homesteads	12.4	2.1
Instream Deposition	Direct deposition of manure into streams (primarily by beef cattle)	7.3	1.3
Alfalfa/Hay	Includes all forms of perennial hay	5.5	0.9
Timber/Forest	Includes both grazed and ungrazed timber and shrub/scrub. Does not include direct deposition of manure in streams	4.7	0.8
Point sources	Includes public, semi-public, and private wastewater treatment systems	2.7	0.5
Atmospheric	Deposition on the lake from wind, rain, etc	1.6	0.3
Wildlife	Includes direct deposition by deer and other wildlife into streams	1.3	0.2
Septic Systems	Private on-site wastewater systems (does not include discharging systems permitted under GP#4)	0.6	0.1
Geese	Geese, primarily at the lake	0.2	<0.1
	Total	**583.7**	**100**

Point Sources:
Sixteen point sources discharge to the tributaries of Rathbun Lake, but there are no direct discharges to the lake. Specific WLAs are identified in the TMDL by the tributary into which they discharge (TMDL Table 3-7). These facilities are minor compared to the nonpoint sources loads in the watershed, accounting for 2-3 percent of the loading capacity for each arm and 1 percent of the LC of the main stem dam segment.
Facility types in the Rathbun watershed included in the TMDL document:

- Municipal waste stabilization lagoon
- Municipal aerated lagoon
- Homeowners association wastewater treatment facility
- Onsite wastewater disposal facilities that discharge under General Permit #4
- Onsite wastewater facilities

- CAFO (swine)

Livestock:
The IDNR reports that there are 5 CAFOs in the watershed. All CAFO's within Rathbun Lake are assigned a WLA of zero. Any CAFO that does not obtain an NPDES permit must operate as a no-discharge facility. A discharge from an unpermitted CAFO is a violation of Section 301 of the Clean Water Act. It is the EPA's position that all CAFOs should obtain an NPDES permit because it provides clarity of compliance requirements. This TMDL document does not reflect a determination by the EPA that such facilities do not meet the definition of a CAFO nor that the facility does not need to obtain a permit. To the contrary, a CAFO that discharges has a duty to obtain a permit. If it is determined that any such operation is a CAFO that discharges, any future WLA assigned to the facility must not result in an exceedance of the sum of the WLAs in this TMDL document as approved. Grazing livestock were assumed to have direct stream access in the watershed, and an estimated annual TP load of 9,940 kg yr^{-1} for the entire watershed.

Wildlife:
Deer population trend models for the Iowa DNR Rathbun Wildlife Unit estimated 26 deer per square mile. Since population data for other wildlife is unkown, a higher assumption for direct deposition of deer waste in the watershed was made. The estimated total deer and wildlife TP load of 1,849 kg-P yr^{-1}.
Nutrients are also deposited into and near the lake by geese and other waterfowl. Estimated TP loads of 165 kg yr^{-1} were assumed to be uniformly distributed across the lake.

Land use:
Table 3 Land use composition of Rathbun Lake watershed (Table 2-1 in the TMDL document)

General Land Use	**Land Use Description**	**Area**		
		(ha)	**(ac)**	**%**
Grassland	Both pasture and ungrazed grassland	54,058.4	133,581.0	37.7
Row Crops w/ Conventional Rotations	Corn-soybean, soybean-corn, and continuous corn	39,857.8	98,490.5	27.8
Row Crops w/ Extended Rotations	Includes areas with multiple years of non-row crop (e.g., alfalfa)	13,097.2	32,363.8	9.1
Forest/Timber	All forested areas	19,817.4	48,969.7	13.8
Water/Wetlands	Ponds, lakes, and wetlands	6,706.9	16,573.1	4.7
Urban/Developed	Includes all developed areas	5,951.4	14,706.1	4.2
Alfalfa/Hay	Alfalfa and hay not in extended rotations	3,784.3	9,351.2	2.6
	Rounded Totals:	142,273	354,035	100

Septic Systems:
There is an estimated contribution of 785 kg $^{-1}$ yr $^{-1}$ of TP loading from non-discharging septic systems for the entire watershed. The TMDL document notes that sediment and TP loads delivered to the lake from streambank erosion are lower than source loads in Table D-12 in the TMDL document due to upstream deposition. The streambank erosion estimate in the Rathbun watershed was 450,431 tons/year. Population is not expected to significantly grow in the watershed.

Stream/Channel Erosion:
DNR conducted a two-year bank erosion field assessment to estimate the magnitude of stream bank erosion.

Gully Erosion:
While gullies were not surveyed in this watershed, an estimated TP loads are ~20% of channel erosion or 27 tons/year.

Runoff:
Rathbun watershed is primarily composed of soils with low permeability, meaning the watershed is susceptible to high runoff rates and soil erosion.

The TMDL document has identified all known sources of phosphorus in the watershed.

Allocation - Loading Capacity

The submittal identifies appropriate loading capacities, wasteload allocations for point sources and load allocations for nonpoint sources. If no point sources are present, the WLA is stated as zero. If no nonpoint sources are present, the LA is stated as zero [40 CFR § 130.2(i)]. If this is a revised TMDL document the change in loading capacity will be documented in this section. All TMDLs must give a daily number. Establishing TMDL "daily" loads consistent with the U.S. Court of Appeals for the D.C. circuit decision in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006).

The SWAT, FLUX32 and BATHTUB models were the methodology for calculating the annual loading capacity for Rathbun Lake. The target total phosphorus load, also referred to as the loading capacity, for the main stem dam segment is 458.3 tons per year.

The following equation represents the TMDL and its components for Rathbun Lake:

TMDL = LC = ∑WLA + ∑LA + MOS

Once the loading capacity, wasteload allocations, load allocations and margin of safety have all been determined for the Rathbun Lake watershed; the general equation above can be expressed for the Rathbun Lake non-algal turbidity TMDL.

An annual average is helpful for water quality assessment and watershed management. Below is an example of annual loads and daily loads for segment 1309:

Annual = LC = ∑WLA (4.8 tons-TP/year) + ∑LA (407.7 tons-TP/year) + MOS (45.8 tons-TP/year) = 458.3 lb tons-TP/year

Table 4: Annual average loads for Rathbun Lake

Water Body ID	TMDL (LC) (tons/yr)	∑WLA (tons/yr)	∑LA (tons/yr)	MOS (tons/yr)
IA 05-CHA-1309	458.3	4.8	407.7	45.8
IA 05-CHA-2027	94.5	2.5	82.5	9.5
IA 05-CHA-2028	149.9	2.3	132.6	15
IA 05-CHA-2030	405.3	0.005	364.8	40.5

Expressed as the allowable maximum daily load as required by the EPA:

TMDL = LC = ∑WLA (93lb-TP/day) + ∑LA (28,514 lb-TP/day) + MOS (3,179 lb-TP/day) = 31,786 lb-TP/year

Table 5: Allowable maximum daily loads for Rathbun Lake

Water Body ID	TMDL (LC) (tons/day)	∑WLA (tons/day)	∑LA (tons/day)	MOS (tons/day)
IA 05-CHA-1309	31,786	93	28,514	3,179
IA 05-CHA-2027	6,554	49	5,850	655
IA 05-CHA-2028	10,396	44	9,312	1,040
IA 05-CHA-2030	28,110	0.1	25,299	2,811

The LCs identified in this document are established to attain and maintain water quality standards.

Wasteload Allocation Comment

The submittal lists individual wasteload allocations for each identified point source [40 CFR § 130.2(h)]. If a WLA is not assigned it must be shown that the discharge does not cause or contribute to a water quality standard

excursion, the source is contained in a general permit addressed by the TMDL, or extenuating circumstances exist which prevent assignment of individual WLA. Any such exceptions must be explained to a satisfactory degree. If a WLA of zero is assigned to any facility it must be stated as such [40 CFR § 130.2(i)]. If this is a revised TMDL document, any differences between the original TMDL(s) WLA and the revised WLA will be documented in this section.

The WLAs were aggregated after being calculated individually. Facilities not expected contribute have their WLAs set to zero. A future growth reserve wasteload allocation is also included in these calculations. The facility by facility WLAs are given in Table 3-7 in the TMDL document.

Table 6: Phase II WLA at median flow (lbs/day). (Table 3-10 in the TMDL document)

Waterbody ID	WLA
05-CHA-0020-L_1	93
05-CHA-0020-L_2	49
05-CHA-0020-L_3	44
05-CHA-0020-L_4	0.1

Load Allocation Comment

All nonpoint source loads, natural background and potential for future growth are included. If no nonpoint sources are identified, the load allocation must be given as zero [40 CFR § 130.2(g)]. If this is a revised TMDL document, any differences between the original TMDL(s) LA and the revised LA will be documented in this section.

The LA is the amount of the pollutant load that is assigned to nonpoint sources and includes all existing and future nonpoint sources, as well as natural background contributions. LAs are calculated as the remainder of the LC after the allocations to the WLA and the MOS.

Table 7: Phase II WLA at median flow (lbs/day). (Table 3-10 in the TMDL document)

Waterbody ID	WLA
05-CHA-0020-L_1	28,514
05-CHA-0020-L_2	5,580
05-CHA-0020-L_3	9,312
05-CHA-0020-L_4	25,299

The TMDL document has identified all known nonpoint sources of TP in the watershed.

Margin of Safety

The submittal describes explicit and/or implicit margins of safety for each pollutant [40 CFR § 130.7(c)(1)]. If the MOS is implicit, the conservative assumptions in the analysis for the MOS are described. If the MOS is explicit, the loadings set aside for the MOS are identified and a rationale for selecting the value for the MOS is provided. If this is a revised TMDL document, any differences in the MOS will be documented in this section.

To account for uncertainties in data and modeling, a margin of safety is a required component of all TMDLs. An explicit total phosphorus MOS of 10 percent (see Allocation – Loading Capacity above) was used in the development of the TMDL. These uncertainties may include the water quality in the various segments of Rathbun Lake, some of which may be sources or sinks of pollutants to other segments, depending on the time of year and climate conditions. Further monitoring will provide insight, which can improve the level of uncertainty in the lake system.

The EPA agrees that the state has provided explicit MOS to support the TMDL.

Seasonal Variation and Critical Conditions

The submittal describes the method for accounting for seasonal variation and critical conditions in the TMDL(s) [40 CFR § 130.7(c)(1)]. Critical conditions are factors such as flow or temperature which may lead to the excursion of the WQS. If this is a revised TMDL document, any differences in conditions will be documented in this section.

To account for uncertainties in data and modeling, a margin of safety is a required component of all TMDLs. An explicit total phosphorus MOS of 10 percent (see Allocation – Loading Capacity above) was used in the development of the TMDL. These uncertainties may include the water quality in the various segments of Rathbun Lake, some of which may be sources or sinks of pollutants to other segments, depending on the time of year and climate conditions. Further monitoring will provide insight, which can improve the level of uncertainty in the lake system.

The EPA agrees that the state considered seasonal variation and critical conditions during the analysis of this TMDL and the setting of the TMDL targets.

Public Participation

The submittal describes required public notice and public comment opportunities and explains how the public comments were considered in the final TMDL(s) [40 CFR § 130.7(c)(1)(ii)].

Public involvement is important in the Total Maximum Daily Load process since it is the land owners, tenants and citizens who directly manage land and live in the watershed that determine the water quality in Rathbun Lake.

Public Meetings

August 5, 2014:
Stakeholder meeting with local watershed association. Discussions of modeling, planning and support

September 29, 2015:
Meeting held to present initial findings and simulations based on selection of final model methodology.

April 1, 2016 and April 7, 2017:
Meeting with watershed association board to discuss project

July 7, 2017:
Public meeting to present results of TMDL process. Attended by approximately 10 people.

The IDNR also posted the TMDL document on their website for public access, review and comment.

The public comment period began June 22 and ended July 24, 2017. One written comment was received during the public comment period and is included in Appendix I of the TMDL document, along with an official response from the IDNR.

The public has had a meaningful opportunity to comment on the TMDL document.

Monitoring Plan for TMDL(s) Under a Phased Approach

The TMDL identifies a monitoring plan that describes the additional data to be collected to determine if the load reductions required by the TMDL lead to attainment of water quality standards, and a schedule for considering revisions to the TMDL(s) (where a phased approach is used) [40 CFR § 130.7]. If this is a revised TMDL document, monitoring to support the revision will be documented in this section. Although the EPA does not approve the monitoring plan submitted by the state, the EPA acknowledges the state's efforts. The EPA

understands that the state may use the monitoring plan to gauge the effectiveness of the TMDLs and determine if future revisions are necessary or appropriate to meet applicable water quality standards.

Future monitoring will depend on the collaboration of local partners, including:

- The Rathbun Land & Water Alliance (RLWA);
- Iowa Department of Natural Resources (DNR); and
- The U.S. Army Corps of Engineers.

The TMDL document also recommends continued watershed/tributary monitoring in addition to basic in-lake monitoring to evaluate the effectiveness of BMPs. If desired, an expanded watershed monitoring plan with higher resolution data could be used to better evaluate the spatial patterns of sediment and phosphorus transport and the impacts of BMPs. Historically, in-lake grab bag sampling was used because it was appropriate for long-term average conditions in Rathbun. However, there may be a need to collect more information to provide insight on short-term effects of weather, seasonal trends or internal processes. Section 5 in the TMDL document outlines extensive monitoring that can be helpful to direct implementation of watershed load reductions.

Reasonable Assurance

Reasonable assurance only applies when less stringent wasteload allocation are assigned based on the assumption that nonpoint source reductions in the load allocation will be met [40 CFR § 130.2(i)]. This section can also contain statements made by the state concerning the state's authority to control pollutant loads. States are not required under Section 303(d) of the Clean Water Act to develop TMDL implementation plans and the EPA does not approve or disapprove them. However, this TMDL document provides information regarding how point and nonpoint sources can or should be controlled to ensure implementation efforts achieve the loading reductions identified in this TMDL document. The EPA recognizes that technical guidance and support are critical to determining the feasibility of and achieving the goals outlined in this TMDL document. Therefore, the discussion of reduction efforts relating to point and nonpoint sources can be found in the implementation section of the TMDL document, and are briefly described below.

The states have the authority to issue and enforce state operating permits. Inclusion of effluent limits into a state operating permit and requiring that effluent and instream monitoring be reported to the state should provide reasonable assurance that instream water quality standards will be met. Section 301(b)(1)(C) requires that point source permits have effluent limits as stringent as necessary to meet WQS. However, for wasteload allocations to serve that purpose, they must themselves be stringent enough so that (in conjunction with the water body's other loadings) they meet WQS. This generally occurs when the TMDL(s)' combined nonpoint source load allocations and point source WLAs do not exceed the WQS-based loading capacity and there is reasonable assurance that the TMDL(s)' allocations can be achieved. Discussion of reduction efforts relating to nonpoint sources can be found in the implementation section of the TMDL document.

Reasonable assurances are provided by the current and long-standing implementation of erosion reduction underway in the watershed. The watershed is under an EPA-approved management plan which has already resulted in the delisting of this water body for algal growth for all the lake segments. In addition, all permitted facilities are given WLAs to account for their loads to the lake.

A general implementation plan is included in the TMDL document for use by local agencies, watershed managers and citizens for decision-making support and planning purposes. The best management practices discussed represent a package of potential tools that will help achieve water quality goals if appropriately used. EPA-approved watershed management plan (Protect Rathbun Lake: Interim Watershed Management Plan, 2014-2019 is already being used in the watershed, and will be updated with information provided by this Water Quality Improvement Plan and associated TMDLs.

The primary focus of this implementation plan will be reducing sediment and phosphorus loads to remediate the turbidity impairment in Rathbun Lake. Reduction of sediment inputs will reduce the amount of total phosphorus entering the lake as well as the non-algal turbidity.

Table 8: Potential Land Management BMPS (Table 4-2 in the TMDL document)

BMP or Activity	**[1]Potential TP Reduction**
Conservation Tillage:	

Moderate vs. Intensive Tillage	50%
No-Till vs. Intensive Tillage	70%
No-Till vs. Moderate Tillage	45%
Cover Crops	50%
Diversified Cropping Systems (i.e., extended rotations)	50%
In-Field Vegetative Buffers	50%
Pasture/Grassland Management	
Livestock Exclusion from Streams	75%
Rotational Grazing vs. Constant Intensive Grazing	25%
Seasonal Grazing vs. Constant Intensive Grazing	50%
Phosphorus Nutrient Application Techniques	
[2]Deep Tillage Incorporation vs. Surface Broadcast	-15%
[2]Shallow Tillage Incorporation vs. Surface Broadcast	-10%
Knife/Injection Incorporation vs. Surface Broadcast	35%
Phosphorus Nutrient Application Timing and Rates	
Spring vs. Fall Application	30%
Soil-Test P Rate vs. Over-Application Rates	40%
Application: 1-month prior to runoff events vs. 1-day	30%

[1] Adopted from Dinnes (2004) with professional judgement. Actual reduction percentages may vary widely across sites and runoff events.

[2] Note: Tillage incorporation can increase TP in runoff in some cases.

Table 9: Potential Structural BMPs (Table 4-3 in the TMDL document)

BMP or Activity	Secondary Benefits	[1]Potential TP Reduction
Terraces	Soil	50%
Grass Waterways	Prevent in-field gullies, prevent washouts, some ecological services	50%
[2]Sediment Control Structures	Some ecological services, gully prevention	Varies
[3]Wetlands	Ecological services, potential flood mitigation, aesthetic value	15%
[4]Sediment Forebay	Ecological services, aesthetic value	55%
Riparian Buffers	Ecological services, aesthetic value, alternative agriculture	45%

[1] Adopted from Dinnes (2004) with professional judgment. Actual reduction percentages may vary widely across sites and runoff events.

[2] Not discussed in Dinnes (2004). Phosphorus removal in sediment basins varies widely and is dependent upon the size of the structure relative to the drainage area, the length: width ratio, and drawdown time of a specified rainfall/runoff event.

[3] Note: TP reductions in wetlands vary greatly depending on site-specific conditions, such as those listed for sediment control structures. Generally, removal of phosphorus is lower in wetlands than in sediment control structures. Wetland can sometimes be sources, rather than sinks, of phosphorus

[4] Average of removal efficiencies from EPA Wet Pond Fact Sheet (http://cfpub.epa.gov/npdes/stromwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=68)

Table 10: Potential in-lake BMPS (Table 4-4 in the TMDL document)

In-Lake BMPs	Comments
Fisheries management	Moderate reductions in internal phosphorus load may be attained via fisheries improvement. The potential reduction of in-lake phosphorus as a result of this practice is uncertain, but the overall health of the aquatic ecosystem may be improved, which typically improves overall water quality as well. The size and depth of the reservoir may make a full fish renovation impractical in Rathbun Lake.

Targeted dredging and sediment forebay improvement	Targeted dredging in shallow inlet areas would create pockets of habitat for predatory fish that would help control rough fish populations. Strategic dredging would also increase the sediment capacity of the inlet areas, thereby reducing sediment and phosphorus loads to the larger, open water area of the lake. Sediment and phosphorus capture via construction of forebays in the upper reaches of the lake may be challenging, given the size of the watershed and peak flows experienced in the major tributaries to Rathbun Lake.
Shoreline stabilization	Helps establish and sustain vegetation, which provides erosion protection and competes with algae for nutrients. Lake-wide water quality impacts of individual projects may be small but can improve water clarity near the affected shoreline. Cumulative effects of widespread stabilization projects can be an important part of overall water quality improvement as well. The entire shoreline of Rathbun Lake is publicly owned, making this alternative feasible from an access and permission standpoint. Because of rapid and significant changes in water level in this reservoir, shoreline erosion is a documented problem.

Water Quality Improvement Plan for

Rathbun Lake

Appanoose, Clarke, Decatur, Lucas, Monroe, and Wayne Counties in South-Central Iowa

Total Maximum Daily Loads
for Turbidity

clean water
starts with you.
IOWA DNR WATERSHED IMPROVEMENT

Prepared by:
Charles D. Ikenberry, P.E., Ph.D.

Iowa Department of Natural Resources
Watershed Improvement Section
2017

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Units of measure:

ac	acre
cfs	cubic feet per second
cm	centimeter
cms	cubic meters per second
d	day
g	gram
ha	hectare
hm	hectometer
hr	hour
in	inch
kg	kilogram
km	kilometer
L	liter
lb	pound
m	meter
mg	milligram
Mg	megagram (= 1 mt)
mi	mile
mL	milliliter
mo	month
mt	metric ton (= 1 Mg)
ppm	parts per million
ppb	parts per billion
s	second
t	ton (English)
yd	yard
yr	year

Other abbreviations (see Glossary in Appendix B for definitions):

AFO	animal feeding operation
BMP	best management practice
Chl-a	chlorophyll *a*
E. coli	*Escherichia coli*
N	nitrogen
ortho-P	ortho-phosphate
P	phosphorus
TN	total nitrogen
TP	total phosphorus
TSI	trophic state index (Carlson’s)
WQS	water quality standard

General Report Summary

What is the purpose of this report?

This Water Quality Improvement Plan (WQIP) serves multiple purposes. First, it is a resource for increased understanding of watershed and water quality conditions in and around Rathbun Lake in south-central Iowa. Second, it satisfies the Federal Clean Water Act (CWA) requirement to develop Total Maximum Daily Loads (TMDLs) for impaired waterbodies. Third, it is a resource for the continuation of locally-driven watershed and water quality improvement efforts. Finally, it may be useful for obtaining financial assistance to implement projects to remove Rathbun Lake from the Federal 303(d) list of impaired waters.

What's wrong with Rathbun Lake?

Rathbun Lake has four impaired segments on the 2014 and draft 2016 303(d) lists that are not supporting all of their designated uses. The impaired uses include primary contact recreation and / or support of aquatic life. The cause of impairment is poor water transparency due to excess sediment and turbidity, which gives the water a muddy appearance. Past assessments indicated that algal blooms have also impaired water clarity, but no algal impairments are included in the most recent assessments.

What is causing the problem?

Turbidity impairments are caused by displaced soil (sediment) particles that enter the water column of the lake. Algae impairments are caused by overly-abundant nutrients, particularly phosphorus, in the lake. In the landscape surrounding Rathbun Lake, erosion and transport of sediment particles carry large amounts of phosphorus, and nearly all phosphorus transported to the lake is attached to sediment particles. When sediment and phosphorus levels in the water column are excessive, they can hinder recreational uses and create conditions unfavorable to a healthy aquatic ecosystem.

There are six permitted point sources of phosphorus upstream of Rathbun Lake. Point sources are easily identified and discharge to surface water at a known, single location. These sources include sewage treatment facilities in the Cities of Allerton, Corydon, Derby, Humeston, and Russell, a sewage treatment facility owned and operated by the Indian Ridge Homeowners Association, and a small number of private onsite wastewater systems that discharge under General Permit #4. Although these point sources do contribute phosphorus loads to Rathbun Lake, they are relatively small sources, and do not contribute significantly to high turbidity levels and poor water clarity observed in the reservoir.

Nonpoint sources are discharged in an indirect and diffuse manner and are often difficult to locate and quantify. Nonpoint sources of sediment and phosphorus in the these watersheds include sheet and rill erosion from various land uses, runoff and subsurface flows from lands that receive manure or fertilizer application, stream and gully erosion, poorly functioning septic systems, manure deposited by wildlife, and particles carried by dust and wind (i.e., atmospheric deposition). A portion of the sediment and phosphorus carried to the lake eventually settles to the bottom and accumulates, taking up valuable water storage. Under certain conditions, accumulated sediments can be resuspended, causing turbidity and poor water clarity. Additionally, phosphorus attached to these sediments can be released and become available for algal uptake and growth. These recycling processes do not appear to be a significant factor in Rathbun Lake at this time; however they could be important in the future, and are more likely to occur in the shallow, upper reaches of the lake than in the deeper, main body of water.

What can be done to improve Rathbun Lake?

To improve the water quality and overall health of Rathbun Lake, the amount of sediment and phosphorus entering the lake must be reduced. A combination of preventative land management, structural mitigation, and in-lake restoration practices are often required to obtain reductions in phosphorus to meet water quality standards. Management practices such as extended crop rotations that include small grains and / or hay, reduced / conservation tillage, cover crops, and increased perennial vegetation, help prevent soil erosion and phosphorus loss at the source. Special attention should be given to steep slopes and poor soils adoption of no-till, cover crops, or perennial strips may be especially beneficial.

Implementing or improving existing structural practices such as terraces, grass waterways, and sediment retention basins will reduce transport of sediment and phosphorus to the lake. Placement of structural practices in locations with high erosion and transport rates is important to optimize both treatment and economic efficiency. Restoring watershed hydrology and / or constructing grade control structures to mitigate streambank and gully erosion are challenging, but can reduce sediment and phosphorus transport to the lake. Restoring watershed hydrology also benefits stream ecology, riparian habitat, and can help protect man-made infrastructure (e.g., culverts, bridges, roads, and buildings) from flooding and eroding stream banks.

Because nonpoint source pollution is largely unregulated and responsible for the vast majority of sediment and phosphorus entering the lake, voluntary management of land, animals, and the lake itself will be required to achieve measurable improvements to water quality. Many of the practices that protect and improve water quality also benefit soil health, overall health of the agroecosystem, and the sustained value and productivity of the land. Practices that improve water quality and enhance the long-term viability of agricultural production should appeal to producers, land owners, and lake-users. Improving water quality in this lake, while also improving and protecting the quality of the surrounding land and streams, will require collaborative participation by various stakeholder groups, with land owners playing an especially important role.

Who is responsible for cleaner Rathbun Lake?

Everyone who lives, works, or recreates in the watershed has a role in water quality improvement. The Rathbun Regional Water Association (RRWA) and its customers have a special interest in protecting this resource, because RRWA provides drinking water to nearly 16,000 households in the region (http://www.rrwa.net/). The raw water supply is obtained from a surface water intake located in Rathbun Lake. Water removed from the lake via the intake is treated and distributed to the service area. Although the drinking water use is fully supported at this time, protecting this use is extremely important. RRWA works closely with other members of the Rathbun Land & Water Alliance (RLWA), a local stakeholder group with the following mission statement: "…to foster a voluntary approach driven by landowners, water users, and public and private organizations to protect and enhance land, water, and economic resources in the Rathbun region (http://rathbunlandwateralliance.blogspot.com/)."

Does a TMDL guarantee water quality improvement?

The Iowa Department of Natural Resources (DNR) recognizes that technical guidance and support are critical to achieving the goals outlined in this WQIP. Without implementation, this document and the TMDLs it contains cannot improve or protect water quality. Therefore, a basic implementation plan is included for use by RRWA, RLWA, local agencies, and citizens for decision-making support and planning purposes. It is DNR's hope and expectation that the information and analysis in this WQIP, including the implementation plan, will help RLWA partners build on their efforts to improve and protect the watershed and water quality of Rathbun Lake.

What are the primary challenges for water quality implementation?

Reducing pollutants from unregulated nonpoint sources requires voluntary implementation of best management practices. Many solutions have benefits to soil health and sustained productivity as well as water quality. However, quantifying the value of those ecosystem services is difficult, even if those benefits are qualitatively recognized. Consequently, wide-spread and targeted adoption of voluntary conservation practices is often difficult to achieve. A continued, coordinated watershed improvement effort by local partners is the best means of addressing these barriers. In cooperation with the DNR, the NRCS, and other agencies and funding sources, the local partners should continue to provide financial assistance, technical resources, and information to landowners to encourage and facilitate adoption of conservation practices.

In this landscape, water quality improvement will likely require some changes in land management and / or agricultural operations in addition to extensive implementation of structural BMPs. Management decisions may include changes in the number of acres that are intensively tilled and the diversity and rotation of crops produced. These changes present challenges to producers by: requiring new equipment (e.g., no-till planters); narrowing planting, harvesting, and fertilization windows; and necessitating more complex farm management. Additionally, potential short-term losses in yields are more easily recognized and quantified than long-term benefits to soil health and sustained productivity. On steeper slopes that were historically grazed but are now in row crop production, implementation of well-managed rotational grazing systems would help improve water quality while maintaining agriculturally productive use of the land.

It is not easy to overcome existing incentives and the momentum of current practices. Promoting a long-term view with an emphasis on soil health, sustained production, and profitability over yields, will be essential for successful, voluntary implementation by willing conservation partners. Water quality improvement, enhancement of Rathbun Lake as a recreational resource, and protection of the water supply it provides are attainable goals. These desirable and tangible benefits and the presence of a committed partnership such as the RLWA present a best-case scenario for water quality improvement.

Technical Elements of the TMDL

<table>
<tr>
<td>Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:</td>
<td>Rathbun Reservoir, IA 05-CHA-0020-L_1 (L_1)
Appanoose County approximately 6 miles north of Centerville.

Rathbun Reservoir, IA 05-CHA-0020-L_2 (L_2)
From main lake basin to inflow from the South Fork Chariton River. S36, T70N, R20W in Wayne County.

Rathbun Reservoir, IA 05-CHA-0020-L_3 (L_3)
From main lake basin to inflow of the Chariton River at the Wayne/Lucas county line.

Rathbun Reservoir, IA 05-CHA-0020-L_4 (L_4)
From main lake basin to the inflow of Honey Creek in NW1/4, S8, T70N, R18W in Appanoose County.</td>
</tr>
<tr>
<td>Surface water classification and designated uses:</td>
<td>A1 – Primary contact recreation
B(WW-1) – Aquatic life
C – Drinking water
HH – Human health (fish consumption)

<table>
<tr><th>Segment</th><th>A1</th><th>B(WW-1)</th><th>C</th><th>HH</th></tr>
<tr><td>L_1</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>L_2</td><td>X</td><td>X</td><td></td><td>X</td></tr>
<tr><td>L_3</td><td>X</td><td>X</td><td></td><td>X</td></tr>
<tr><td>L_4</td><td>X</td><td>X</td><td></td><td>X</td></tr>
</table>
</td>
</tr>
<tr>
<td>Impaired beneficial uses:</td>
<td>
<table>
<tr><th>Segment</th><th>A1</th><th>B(WW-1)</th></tr>
<tr><td>L_1</td><td>X</td><td></td></tr>
<tr><td>L_2</td><td>X</td><td>X</td></tr>
<tr><td>L_3</td><td>X</td><td>X</td></tr>
<tr><td>L_4</td><td>X</td><td></td></tr>
</table>
</td>
</tr>
<tr>
<td>Identification of the pollutants and applicable water quality standards (WQS):</td>
<td>Total phosphorus (TP) load to meet turbidity goals (Secchi depth TSI ≤ 63) in all four assessed segments of the lake.</td>
</tr>
</table>

Quantification of the pollutant loads that may be present in the waterbody and still allow attainment and maintenance of WQS (loading capacity):

	L_1	L_2	L_3	L_4
Average Annual (tons/yr)	458.3	94.5	149.9	405.3
Daily Max (lbs/day)	31,786	6,554	10,396	28,110

Quantification of the amount or degree by which the current pollutant loads in the waterbody, including the pollutants from upstream sources that are being accounted for as background loading, deviate from the pollutant loads needed to attain and maintain WQS:

	L_1	L_2	L_3	L_4
Required Reduction (%)	21.5	83.8	74.3	30.6

Identification of pollution source categories:

Six wastewater treatment facilities contribute relatively small loads of phosphorus to the lake. The primary sources of turbidity are caused by nonpoint sources such as sheet and rill, streambank, and gully erosion. Other sources include fertilizer and manure in runoff and direct access of cattle to streams. Wildlife, septic systems, and atmospheric deposition are minor nonpoint sources.

Wasteload allocations (WLAs) for pollutants from point sources:

Aggregate WLAs for each impaired lake segment are shown in the table below.

	L_1	L_2	L_3	L_4
Average Annual (tons/yr)	4.8	2.5	2.3	0.005
Daily Max (lbs/day)	93	49	44	0.1

Individual WLAs are reported in Section 3.5 of this report.

<table>
<tr><td>Load allocations (LAs) for pollutants from nonpoint sources:</td><td>Aggregate LAs for each impaired lake segment are shown in the table below.
<table><tr><th></th><th>L_1</th><th>L_2</th><th>L_3</th><th>L_4</th></tr><tr><td>Average Annual (tons/yr)</td><td>407.7</td><td>82.5</td><td>132.6</td><td>364.8</td></tr><tr><td>Daily Max (lbs/day)</td><td>31,786</td><td>6,554</td><td>10,396</td><td>28,110</td></tr></table>
LAs are discussed in detail in Section 3.5 of this report.</td></tr>
<tr><td>A margin of safety (MOS):</td><td>An explicit 10% MOS is incorporated into the TMDL for each segment.</td></tr>
<tr><td>Consideration of seasonal variation:</td><td>The TMDL is based on annual TP loading. Although daily maximum loads are provided to address EPA guidance, the average annual loads are critical to in-lake water quality, lake and watershed management decisions, and implementation of other CWA programs (i.e., Water Quality Standards, Water Quality Assessment, Impaired Waters, NPDES, etc.)</td></tr>
<tr><td>Reasonable assurance that load and wasteload allocations will be met:</td><td>Reasonable assurance is provided by the active engagement and implementation efforts lead by the Rathbun Land and Water Alliance (RLWA) and other local soil and water conservation partners. An EPA-approved watershed management plan (Protect Rathbun Lake: Interim Watershed Management Plan, 2014-2019) is already being implemented, and will be updated with information provided by this Water Quality Improvement Plan and associated TMDL.</td></tr>
<tr><td>Allowance for reasonably foreseeable increases in pollutant loads:</td><td>Allowances for increases in TP loads are provided by reserve WLAs for potential new and expanded discharges of phosphorus.</td></tr>
<tr><td>Implementation plan:</td><td>An implementation plan is outlined in Section 4 of this Water Quality Improvement Plan. Sediment and TP loads and associated impairments must be addressed through a variety of voluntary land management strategies, structural conservation practices, and possible in-lake improvements.</td></tr>
</table>

1. Introduction

The Federal Clean Water Act requires all states to develop lists of impaired waterbodies that do not meet water quality standards (WQS) and support designated uses. This list of impaired waterbodies is referred to as the state's 303(d) list. In addition to developing the 303(d) list, a Total Maximum Daily Load (TMDL) must be developed for each impaired waterbody included on the list. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can tolerate without exceeding WQS and impairing the waterbody's designated uses. The TMDL calculation is represented by the following general equation:

$$TMDL = LC = \Sigma\ WLA + \Sigma\ LA + MOS$$

Where: TMDL = total maximum daily load
LC = loading capacity
Σ WLA = sum of wasteload allocations (point sources)
Σ LA = sum of load allocations (nonpoint sources)
MOS = margin of safety (to account for uncertainty)

One purpose of this Water Quality Improvement Plan (WQIP) is to provide the required TMDLs for turbidity in four segments of Rathbun Lake in south-central Iowa. The numeric TMDLs are presented in Section 3 of this WQIP. Another purpose is to provide local stakeholders and watershed managers, such as the Rathbun Land & Water Alliance (RLWA) and the Rathbun Regional Water Association (RRWA), with a tool to promote awareness and understanding of water quality issues, develop a comprehensive watershed management plan, obtain funding assistance, and implement water quality improvement projects. Over-abundance of sediment and phosphorus is responsible for poor water clarity, and at times, excessive algal growth in segments of Rathbun Lake. Excessive levels of turbidity are impairing recreational uses and support of aquatic life in the lake. The impairments are addressed by development of TMDLs that limit total phosphorus (TP) loads to the lake, which will require reductions in sediment as well. The reductions recommended in this WQIP should result in increased water clarity and prevention of future algal blooms to achieve full support of all designated uses.

Section 3 of this WQIP includes an inventory of TP sources to the lake. Section 4 includes an Implementation Plan, summarizes TP loads by planning subbasin and by major land use category. Section 4 also includes descriptions of potential best management practices (BMPs) and their potential TP reductions. The purpose of this information / analysis is to provide objective information for prioritizing conservation efforts and a toolbox of potential strategies for water quality improvement. This toolbox is neither prescriptive nor all-inclusive, but provides information that can be integrated into the existing watershed management plan developed and implemented by RLWA and its partners.

The Iowa Department of Natural Resources (DNR) recommends a phased approach to watershed management. A phased approach is helpful when the origin, interaction, and quantification of pollutants contributing to water quality problems are complex and difficult to fully understand and predict. Iterative implementation of improvement practices and additional water quality assessment (i.e., monitoring) will help ensure progress towards water quality standards, maximize efficiency, and prevent unnecessary or ineffective implementation of costly BMPs. Implementation of the previous watershed management plan for Rathbun Lake has been ongoing since 2001. Past success should be measured in part by the data compiled and summarized in this WQIP. Future success should be measured by comparing future trends in TP loads and in-lake water quality with existing measures and the numeric targets set forth in the TMDLs. To that end, watershed and lake water quality monitoring guidance is provided in Section 5.

This WQIP will be of limited value unless additional watershed improvement activities and BMPs are implemented. This will require the active engagement of local stakeholders and land owners. Experience has shown that locally-led watershed plans have the highest potential for success, and the committed group of partners collaboratively working to protect and improve Rathbun Lake is a model for other large watersheds in Iowa to follow. The Watershed Improvement Section of DNR has designed this WQIP for use by RLWA and its partners and is committed to providing ongoing support for the improvement of water quality in Rathbun Lake.

2. Description and History

2.1. Rathbun Lake

General History and Background
The construction of Rathbun Dam was authorized by the Federal Flood Control Act of 1954. Construction of the dam and reservoir began in 1964, with an initial construction cost of $26 million. Authorized purposes of the dam included flood reduction, recreation, fish and wildlife management, and water supply. The U.S. Army Corps of Engineers (USACE) began operating the lake as a flood control reservoir in 1969. The lake was dedicated in 1971 by then President Richard Nixon, with Governor Robert Ray, Senator Jack Miller, and Congressman John Kyl all in attendance. From its earliest days, the significance of this water resource has been widely recognized.

Rathbun Lake is a reservoir constructed near the confluence of the Chariton and South Fork Chariton Rivers in south-central Iowa, just north of the Iowa-Missouri border (Figure 2-1). Rathbun Dam is a rolled earth embankment constructed across the river valley approximately 8 miles north of Centerville in Appanoose County, Iowa. The embankment measures 10,600 feet long, 30 feet wide at the crown, and 800 feet wide at its base, with the top of the dam over 100 feet above the river bed. During normal operation, water leaves the reservoir via a concrete intake tower, passes through the dam in a concrete pipe, and discharges to a stilling basin to dissipate energy before re-entering the Chariton River. The surface area at normal pool (mean sea elevation of 904 feet) is approximately 11,000 acres, which nearly doubles to 21,000 acres at peak flood storage (mean sea elevation of 926 feet). The USACE estimates that since operations began in 1969, the reservoir has prevented over $142 million in flood damage downstream, serving as part of a network of USACE reservoirs in the Missouri and Mississippi River basins.

In addition to flood control, Rathbun Lake and its surrounding area provides many recreational opportunities. There are 22,900 acres of public land surrounding over 150 miles of shoreline. These recreational opportunities include camping, lodging, boating, fishing, picnic shelters, playgrounds, swimming areas, and hiking trails. Together these amenities bring more than one million visitors to the lake vicinity each year, with great economic benefits to the local / regional economy. The watershed is within a three-hour drive of several metropolitan areas, including Des Moines (85 miles), Cedar Rapids (141 miles), Waterloo (144 miles), Columbia, Missouri (158 miles), and Kansas City, Missouri (185 miles).

Soil Conservation and Water Quality History
The regional significance of Rathbun Lake for flood control, recreation, and water supply is widely recognized. As a result, there is a history of water quality related assessment, planning, and conservation projects in this watershed. The Rathbun Land and Water Alliance (RLWA) completed a comprehensive plan in 2001, which was titled *Assessment and Management Strategies for the Rathbun Lake Watershed* (RWLA, 2001). This plan

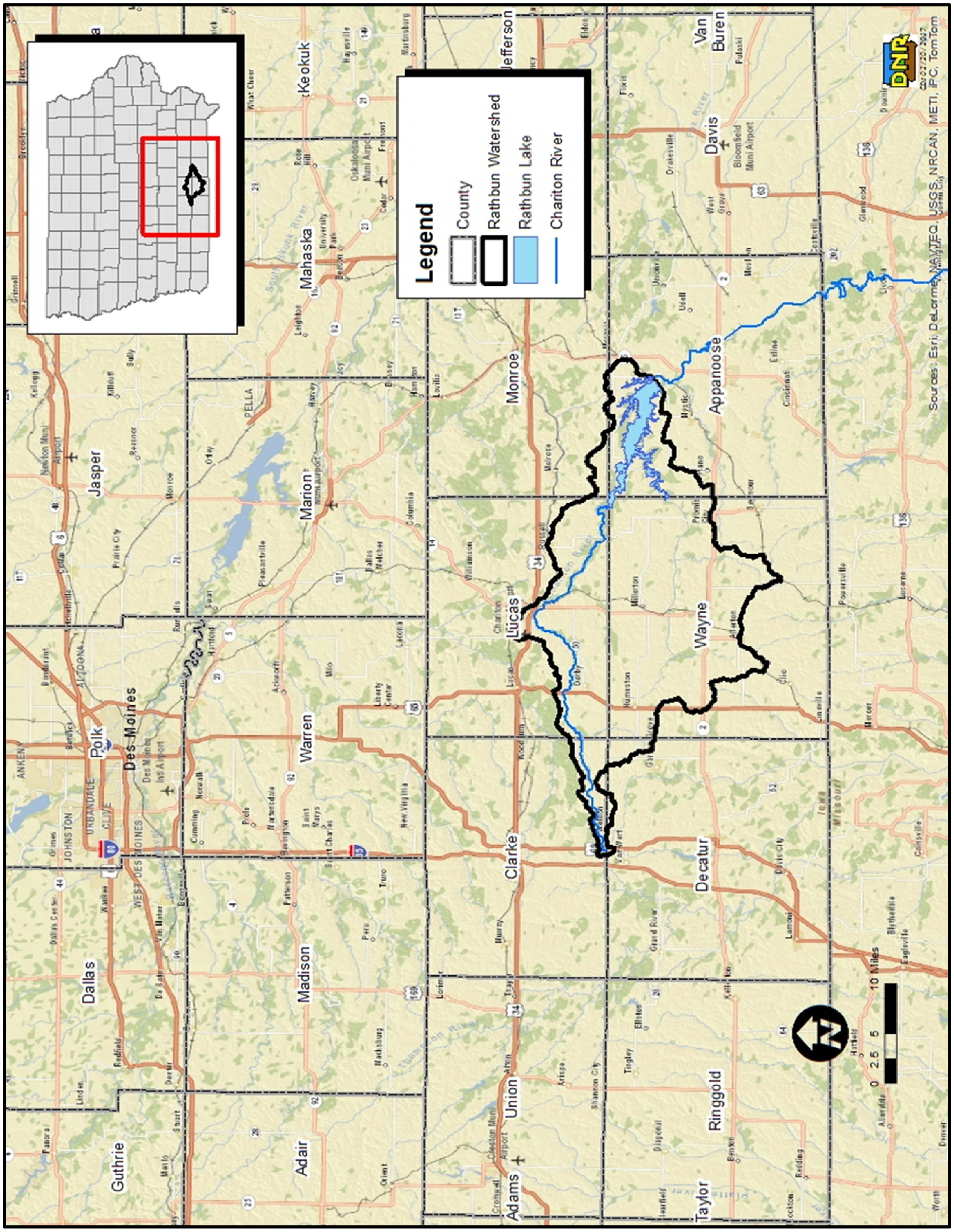


Figure 2-1. Rathbun Lake and watershed vicinity map.

included a thorough documentation of water quality issues, an inventory of relevant lake and watershed information, a variety of analysis / modeling efforts, and a suite of management strategies to improve and protect the lake and its watershed (RLWA, 2001).

Supplemental studies developed as part of the 2001 plan included a time of travel study (Kost, 2001), a sediment and erosion assessment (Opsomer et al., 2001), a watershed simulation to assess land use impacts on water quality (Neppel et al., 2001), and an evaluation of the ecological integrity of stream corridors in the watershed (Isenhart and Sitzmann, 2001). Each study is included in its entirety in the 2001 plan. Other studies initiating out of concern for soil conservation and water quality issues in the Rathbun watershed included an analysis of stream bank erosion as a source of sediment and phosphorus (Tufekcioglu et al., 2012), a lake sediment characterization study (James, 2009), and measurements of sediment accumulation within the reservoir (USACE, unpublished data).

In 2014, RWLA prepared an updated, interim plan: *Protect Rathbun Lake: Interim Watershed Management Plan 2014-2019* (RWLA, 2014). This Interim Plan updated the 2001 plan by reflecting current watershed conditions related to land use trends, water quality, prior implementation of BMPs, and additional priority / target areas (i.e., areas with high erosion rates) for future implementation. In the Interim Plan, it was estimated that BMPs had been implemented on more than 10,000 acres of priority land, resulting in a reduction of 42,000 tons of sediment and 179,000 pounds (lbs) of phosphorus delivered to the lake. The goal of the Interim Plan was to provide planning and implementation guidance for watershed managers to build on prior efforts until completion of this Water Quality Improvement Plan (WQIP) and Total Maximum Daily Loads (TMDLs). Incorporation of this WQIP into long-term planning efforts will help satisfy evolving program requirements (e.g., development of a nine-element watershed management plan) by relating watershed load reductions to improvement in in-lake water quality.

Morphometry

According to 2010 bathymetric data used to develop area and volume relationships for the reservoir, the surface area of Rathbun Lake was estimated to be 12,040 acres (compared with the historical estimate of 11,000 acres). This discrepancy is not as large as it seems given the relationship between surface area and water surface fluctuations. The estimated volume of the lake using the 2010 bathymetry is 214,554 ac-ft. The mean depth of the lake is 17.8 ft, with extreme variation throughout the lake. The maximum depth is 48 ft at the ambient monitoring location near the lake’s outlet structure, based on the surface elevation of 904 ft and bathymetric data collected by USACE in 2010.

The reservoir, like most man-made stream impoundments, has a very long, dendritic (i.e., branched) shape, with a long and narrow northwest to southeast aspect. The watershed-to-lake ratio of 29-to-1 is larger than ideal (less than 20-to-1) for protecting and improving water quality, but is quite low relative to most man-made impoundments of similar size. Visual assessment of the upper reaches of the lake and quantitative assessments using bathymetry both indicate that sediment delivery to Rathbun Lake is high. The shoreline development index of Rathbun Lake is 1.4. Values greater than 1.0

suggest the shoreline is highly dissected and indicative of a high degree of watershed influence (Dodds, 2000); however, indices for reservoirs often exceed 4.0. Overall, the watershed-to-lake ratio and shoreline development index indicate that lake morphometry is favorable for good water quality relative to many reservoirs. But both characteristics also reveal that watershed processes are critical to in-lake water quality.

2.2. The Rathbun Watershed

Land Use

The U.S. Department of Agriculture National Agricultural Statistics Service Cropland Data Layer (CDL) reflecting 2006 conditions (USDA-NASS, 2013) was used to develop baseline land use information for the Rathbun Lake watershed. This grid coverage is comprised of 30-meter by 30-meter pixels each having a unique value assigned to it using satellite imagery combined with field assessments conducted by NASS. Each unique pixel value represents a specific land cover, such as corn, soybeans, alfalfa, pasture, and various other categories. The NASS grid was recoded by Iowa DNR to simplify the land cover classifications and make it more suitable for SWAT model development.

In addition to 2006 land cover data, crop rotation data for the Rathbun watershed was obtained from the USDA Agricultural Research Service (ARS) National Laboratory for Agriculture and the Environment (NLAE) in Ames, Iowa. The crop rotation coverage was created by NLAE, which utilized field boundaries and 2008-2013 CDL coverages to develop a 6-year crop rotation database (Tomer et al., 2013). Crop rotations were combined with the modified CDL coverage and used to distinguish fields that were in 2-year corn and soybean rotations from those fields that contained continuous corn or some type of extended rotation with corn, soybeans, and alfalfa or grass. The resulting land use information is illustrated in Figure 2-2 and summarized in Table 2-1.

Soils and Topography

Nine soils series comprise over 77% of the Rathbun watershed. These soils are largely glacial till underlying loess deposits on the surface. High clay content and low permeability soils dominate the landscape, making the watershed susceptible to high runoff rates and soil erosion, particularly on steep slopes. The topography consists of rolling hills interspersed with level, upland divides and alluvial lowlands. The drainage pattern is dendritic, with the upland plains highly dissected by stream valleys. As a result, there are many hillslopes, and over 50% of the watershed has a slope exceeding 5%, whereas only 20% of the watershed has a slope less than 2% (Table 2-2). The flattest slopes are found in the alluvial floodplains and a few upland ridgelines between drainage divides. The dominant soil series are illustrated in Figure 2-3 and reported in Table 2-3, and Figure 2-4 illustrates the four slope classifications.

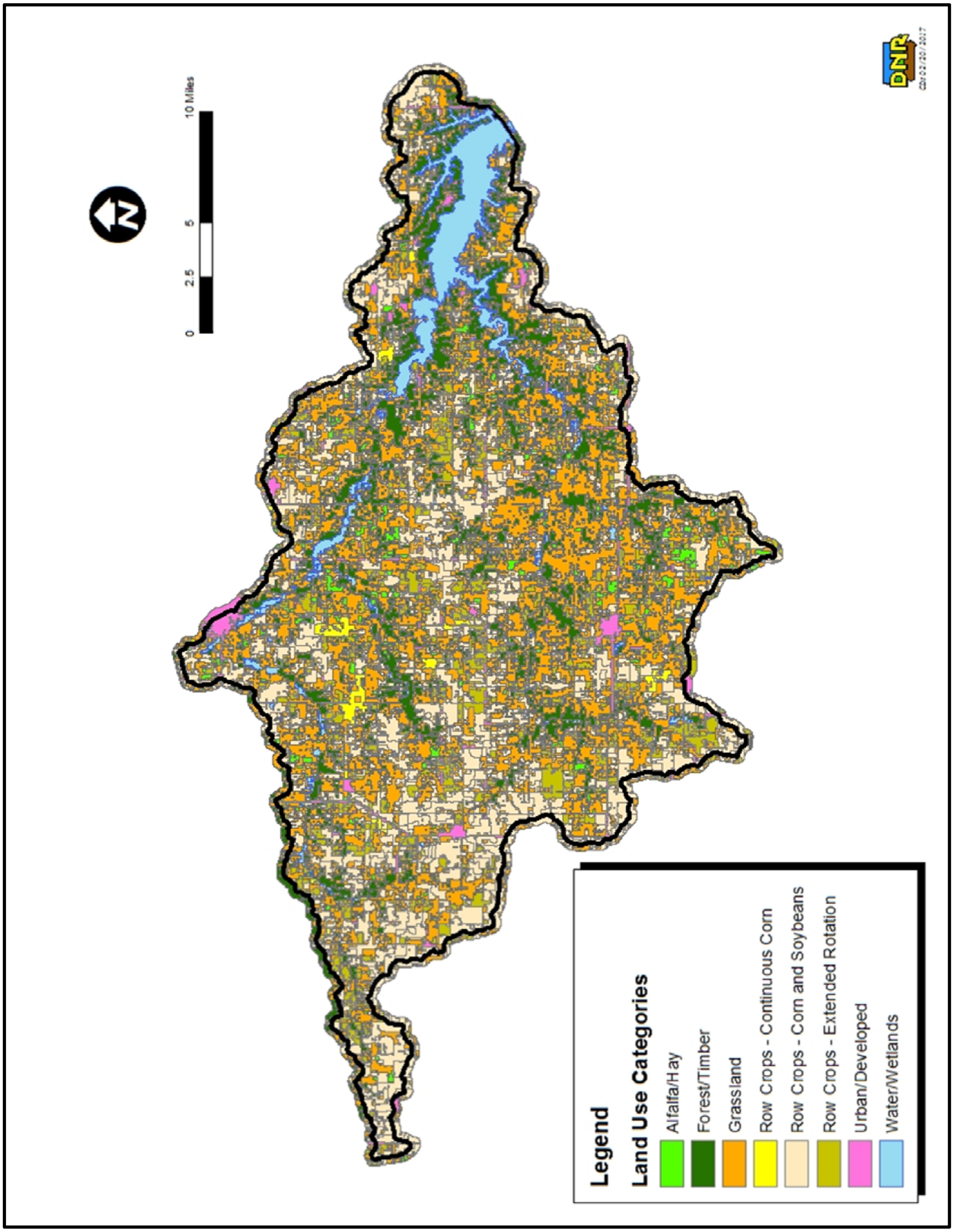


Figure 2-2. Rathbun Lake watershed land use map.

Table 2-1. Land use composition of the Rathbun Lake watershed.

General Land Use	Land Use Description	Area (ha)	(ac)	%
Grassland	Both pasture and ungrazed grassland	54,058.4	133,581.0	37.7
Row Crops w/ Conventional Rotations	Corn-soybean, soybean-corn, and continuous corn	39,857.8	98,490.5	27.8
Row Crops w/ Extended Rotations	Includes areas with multiple years of non-row crop (e.g., alfalfa)	13,097.2	32,363.8	9.1
Forest/ Timber	All forested areas	19,817.4	48,969.7	13.8
Water/ Wetlands	Ponds, lakes, and wetlands	6,706.9	16,573.1	4.7
Urban/ Developed	Includes all developed areas	5,951.4	14,706.1	4.2
Alfalfa/ Hay	Alfalfa and hay not in extended rotations	3,784.3	9,351.2	2.6
	Rounded Totals:	143,273	354,035	100

Table 2-2. Slope classifications in Rathbun Lake watershed.

Slope (%)	Description	Watershed Area (%)
0-2	Level and nearly level	21.6
2-5	Gently sloping	26.7
5-9	Moderately sloping	26.0
>9	Strongly sloping to very steep	25.7

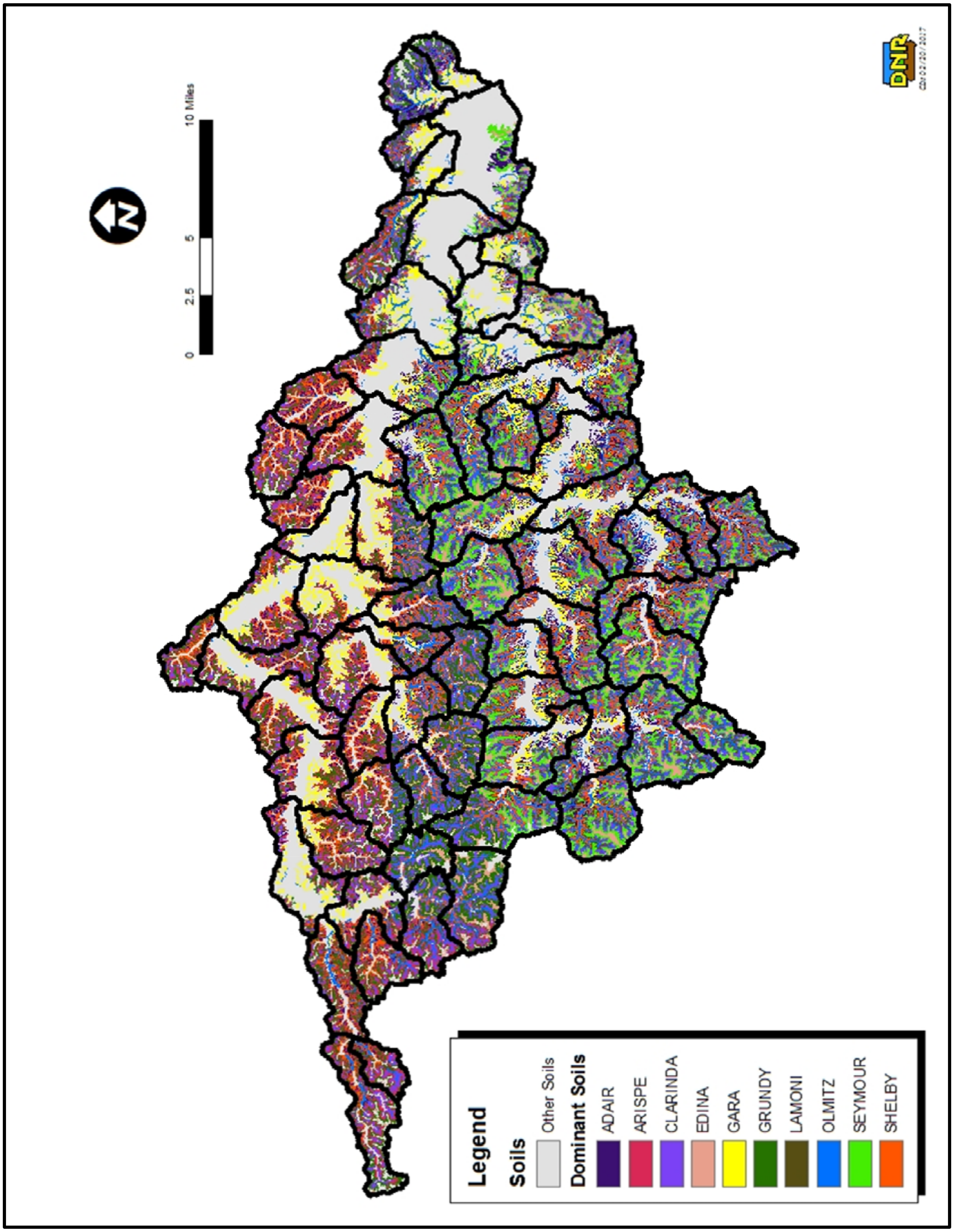


Figure 2-3. Rathbun Lake watershed soil map.

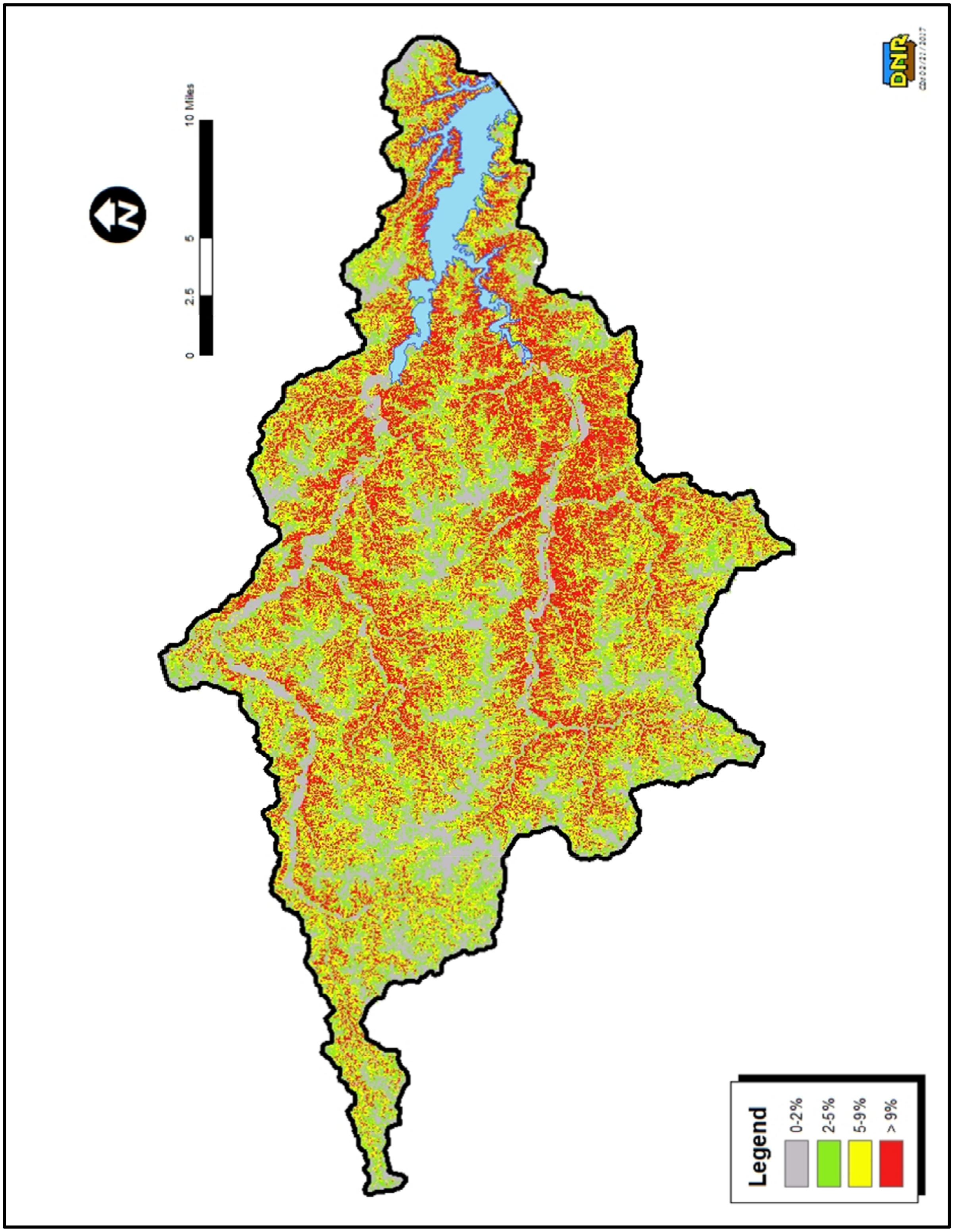


Figure 2-4. Rathbun Lake watershed slope classifications.

Table 2-3. Predominant soils and topographic characteristics.

Soil Name	Watershed Area (%)	Typical Landscape Location	Drainage Class	Typical Slope (%)
Clarinda	11.3	Side slopes and head[a] slopes	Poorly drained	5-9
Shelby	9.3	Convex side slopes, crests, and narrow interfluves[b]	Well drained	>9
Seymour	8.9	Ridge tops and side slopes	Somewhat poorly drained	2-5
Grundy	8.1	Watershed divides and interfluves[b]	Somewhat poorly drained	2-5
Olmitz	6.6	Base slopes and alluvial fans	Moderately well drained	2-5
Adair	6.1	Interfluves[b] and side slopes	Somewhat poorly drained	>9
Edina	5.7	Ridgetops and upland depressions	Very poorly drained	0-2
Gara	5.4	Interfluves[b], convex side slopes, and nose[c] slopes	Well drained	>9
Arispe	5.4	Convex side slopes and head† slopes	Somewhat poorly drained	2-5
Lamoni	5.3	Side slopes	Somewhat poorly drained	5-18
All others	28.1	Varies	Varies	Varies

[a] Head slopes are hillslope situated at the upper end of a valley or drainage way.
[b] Interfluves are uplands or ridges between valleys or drainage ways.
[c] Nose slopes are hillslopes forming the projecting end of an interfluve.

Climate and Hydrology

There are six weather stations in or within 8 miles of the Rathbun Lake watershed at which temperature and precipitation are measured and recorded. These include National Weather Service (NWS) Cooperative Program (COOP) stations in Allerton, Chariton, and Osceola (IEM, 2015). Additionally, there are National Climatic Data Center (NCDC) stations at Leon, Promise City, and at the Rathbun Lake Dam from which temperature and precipitation data were obtained (NOAA, 2015). Daily observations from all six sites were used for watershed model development, with stations spatially assigned to the nearest model subbasin(s). Based on the Rathbun Lake Dam weather station, average annual precipitation near Rathbun Lake was 40.2 inches from 1995-2014 (Figure 2-5).

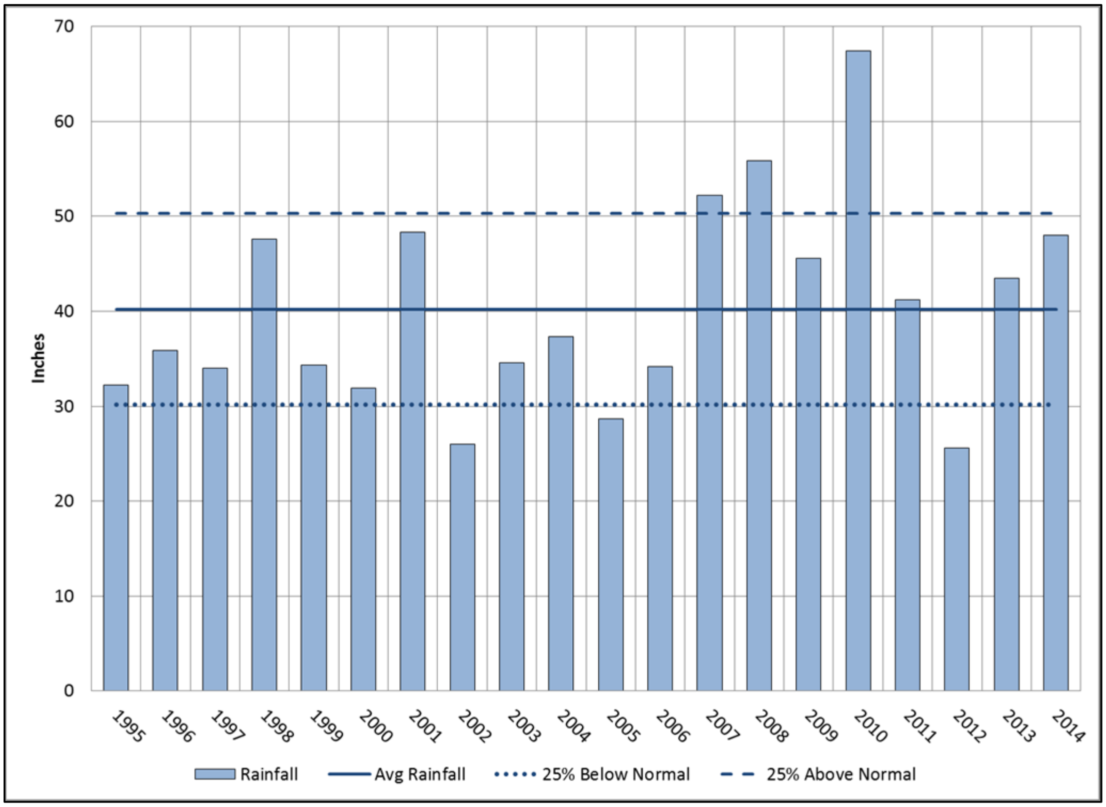


Figure 2-5. Annual rainfall totals at the Rathbun Lake Dam from 1995-2014.

The climate of south-central Iowa is relatively humid, with precipitation exceeding evapotranspiration (ET) nearly year-round, with some exceptions in late summer months (Figure 2-6). However, in very dry years such as 2012, ET can exceed precipitation. Precipitation in the Rathbun lake area varies not only from year-to-year, but also seasonally. Over 71% of the annual precipitation falls from April to September (i.e., during the growing season). From 2007-2014, conditions were wetter than normal, with an average annual rainfall of 47.4 inches. Years 2007, 2008, and 2010 were extreme years with several flooding events and annual rainfall totals more than 25% above normal each year. These extreme years can have inordinate impacts on erosion and nutrient transport, and hence, water quality in Rathbun Lake.

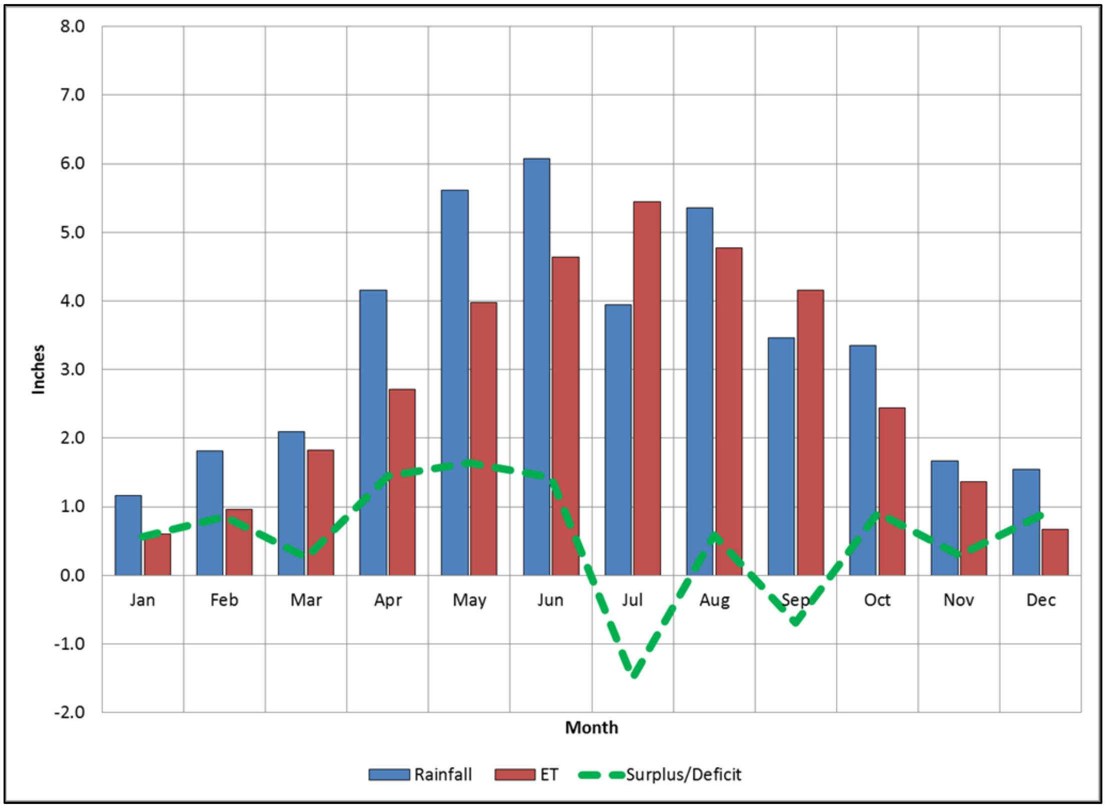


Figure 2-6. Monthly rainfall and estimated evapotranspiration (ET) for the watershed. The surplus/deficit is calculated by subtraction ET from rainfall.

2.3. References

Dodds, W. 2000. Freshwater Ecology: Concepts and Environmental Applications. Draft textbook. Division of Biology, Kansas State University, Manhattan, Kansas.

Iowa Environmental Mesonet (IEM). 2015. Iowa State University Department of Agronomy. Iowa Ag Climate Network. Download available at http://mesonet.agron.iastate.edu/request/coop/fe.phtml. Last accessed in February 2015.

Isenhart, T., and V. Sitzman. Assessment of the Ecological Integrity of Stream Corridors in the Rathbun Lake Watershed Using the Stream Visual Assessment Protocol. Appendix E Assessment and Management Strategies for the Rathbun Lake Watershed. Iowa State University and Rathbun Land and Water Alliance.

James, W.F. 2009. Sediment Characteristics for Reservoirs in the USACE District, Kansas City. Engineer Research and Development Center (ERDC). Spring Valley, Wisconsin.

Kost, J. A. 2001. Time of Travel for South Fork Chariton and Chariton Rivers Within Rathbun Watershed. Appendix B Assessment and Management Strategies for the Rathbun Lake Watershed. Iowa State University.

Neppel, J., S. Tim, R. Cruse, M. Braster, and T. Jacobsen. 2001. Modeling Switchgrass Production Effects on Runoff Water Quality. Appendix D Assessment and Management Strategies for the Rathbun Lake Watershed. Iowa State University and Rathbun Land and Water Alliance.

National Oceanic and Atmospheric Administration (NOAA). 2015. National Climatic Data Center (NCDC). Download available at http://www.ncdc.noaa.gov/. Last accessed in February 2015.

Opsomer, J., Z. Wu, R. Cruse, T. Isenhart, V. Sitzmann, T. Jacobsen, J.Y. Kim, and C. Botts. 2001. Environmental Assessment for the Rathbun Lake Watershed: Sampling Design, Methods and Results. Appendix C Assessment and Management Strategies for the Rathbun Lake Watershed. Iowa State University and Rathbun Land and Water Alliance.

Rathbun Land and Water Alliance (RLWA). 2001. Assessment and Management Strategies for the Rathbun Lake Watershed. A cooperative effort by the members and partners of the Rathbun Land and Water Alliance. December 2001.

Rathbun Land and Water Alliance (RLWA). 2014. Protect Rathbun Lake: Interim Watershed Management Plan (2014-2019).

Tomer, M.D., S.A. Porter, D.E. James, K.M.B. Boomer, J.A. Kostel, and E. McLellan. 2013. Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning. J. Soil Water Conserv. 68(5):113A-120A.

Tufekcioglu, M., T.M. Isenhart, R.C. Schultz, D.A. Bear, J.L. Kovar, and J.R. Russell. 2012. Stream bank erosion as a source of sediment and phosphorus in grazed pastures of the Rathbun Lake Watershed in southern Iowa, United States. Journal of Soil and Water Conservation. 67(6):545-555. doi: 10.2489/jswc.67.6.545

U.S. Department of Agriculture – National Agricultural Statistical Summary (USDA-NASS). 2013. http://nassgeodata.gmu.edu/CropScape/. Accessed August 2014.

3. TMDLs for Rathbun Lake

A Total Maximum Daily Load (TMDL) is required for Rathbun Lake by the Federal Clean Water Act. This section of the Water Quality Improvement Plan (WQIP) quantifies the maximum amount of total phosphorus (TP) the lake can assimilate and still fully support primary contact recreation and aquatic life in Rathbun Lake, which is impaired by non-algal turbidity on the 2014 and Draft 2016 303(d) impaired waters lists. The primary driver of the current impairments is sediment entering the lake from the watershed. However, large amounts of phosphorus are associated with this influx of sediment. The total phosphorus (TP) targets set forth in this TMDL will require reduction of sediment and are also protective of potential algae impairments, which have occurred in prior 303(d) listing cycles. This section of the WQIP also includes an evaluation of Rathbun Lake water quality, documents the relationship between water quality variables, and quantifies potential point and nonpoint sources of phosphorus entering the lake.

3.1. Problem Identification

Each waterbody classification segment of Rathbun Lake is protected for primary contact recreation – Class A1, aquatic life – Class B(LW), and fish consumption – Class HH. A surface water intake for the Rathbun Regional Water Association (RRWA) is located in the main segment of the lake near the dam (IA 05-CHA-0020-L_1), therefore this segment is also protected for drinking water – Class C.

The 2014 Section Integrated Report states that primary contact recreation and aquatic life uses in multiple segments of Rathbun Lake are assessed (monitored) as either "partially supported" or "not supported" due to elevated turbidity, which causes aesthetically objectionable conditions and can adversely affect aquatic organisms. The approved 2014 303(d) list can be accessed here: http://www.iowadnr.gov/Environmental-Protection/Water-Quality/Water-Monitoring/Impaired-Waters.

Applicable Water Quality Standards
The State of Iowa Water Quality Standards (WQS) are published in the Iowa Administrative Code (IAC), Environmental Protection Rule 567, Chapter 61 (http://www.legis.iowa.gov/DOCS/ACO/IAC/LINC/Chapter.567.61.pdf) [Note: This link must be copied and pasted into a web browser]. Although the State of Iowa does not have numeric criteria for sediment, nutrients, or algae (chlorophyll *a*), general (narrative) water quality criteria below do apply:

61.3(2) General water quality criteria. The following criteria are applicable to all surface waters including general use and designated use waters, at all places and at all times for the uses described in 61.3(1)"a."

- *a. Such waters shall be free from substances attributable to point source wastewater discharges that will settle to form sludge deposits.*

b. *Such waters shall be free from floating debris, oil, grease, scum and other floating materials attributable to wastewater discharges or agricultural practices in amounts sufficient to create a nuisance.*
c. *Such waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor or other aesthetically objectionable conditions.*
d. *Such waters shall be free from substances attributable to wastewater discharges or agricultural practices in concentrations or combinations which are acutely toxic to human, animal, or plant life.*
e. *Such waters shall be free from substances, attributable to wastewater discharges or agricultural practices, in quantities which would produce undesirable or nuisance aquatic life.*

For 303(d) listing purposes, aesthetically objectionable conditions are present in a waterbody when Carlson's Trophic State Index (TSI) for the median growing season chlorophyll *a* (Chl-a) or Secchi depth exceeds 65. In order to de-list the turbidity impairments for Rathbun Lake, the median growing season Secchi depth TSI must not exceed 63 in two consecutive listing cycles, per DNR de-listing methodology. A TSI value of 63 corresponds to a measured Secchi depth of 0.8 meters.

Problem Statement
Rathbun Lake is impaired because primary contact recreation and aquatic life uses are not fully supported due to violations of WQS. Poor water clarity resulting from sediment loads to the lake cause the current impairments, with high phosphorus levels leading to algal blooms in some years. Sediment loads must be reduced in order to improve water clarity and fully support the lake's designated uses. To develop a more comprehensive WQIP, TMDL targets are based on TP loads to the lake. This approach addresses the sediment and turbidity with which TP is associated, but is also protective of potential algal blooms.

Data Sources
Sources of data used in the development of this TMDL include those used in the 2014 305(b) report, several sources of additional flow and water quality data, and watershed / landscape related data used for model development. Specific data includes:

- Results of statewide surveys of Iowa lakes sponsored by DNR and conducted by Iowa State University Limnological Laboratory (ISULL) and State Hygienic Laboratory (SHL) at the University of Iowa as part of the Ambient Lake Monitoring Program and / or TMDL monitoring
- Stream and lake data collected by Iowa DNR Watershed Improvement Section staff for the purpose of TMDL development
- Stream and lake data collected by U.S. Army Corps of Engineers (USACE), Kansas City District, as part of its reservoir monitoring program
- Streamflow data collected by the U.S. Geological Survey (USGS) at multiple surface water gaging stations (USGS, 2015)

- Precipitation and temperature data from the National Weather Service Cooperative Observer Program (NWS COOP) (IEM, 2015)
- Spatially-interpolated rainfall data from the PRISM Climate Group (PRISM, 2016)
- Precipitation and temperature data from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) (NOAA, 2015)
- 10-m Digital Elevation Model (DEM) available from DNR GIS library
- SSURGO soils data maintained by United States Department of Agriculture – Natural Resource Conservation Service (USDA-NRCS)
- U.S. Department of Agriculture National Agricultural Statistics Service Cropland Data Layer (CDL) reflecting 2006 conditions (USDA-NASS, 2013)
- Six-year crop rotation data for 2008-2013 developed by the USDA National Laboratory for Agriculture and the Environment (USDA-NLAE) (Tomer et al., 2013)
- Aerial images (various years) collected and maintained by DNR
- Lake bathymetric data collected by USACE in the 1970s and in 2010

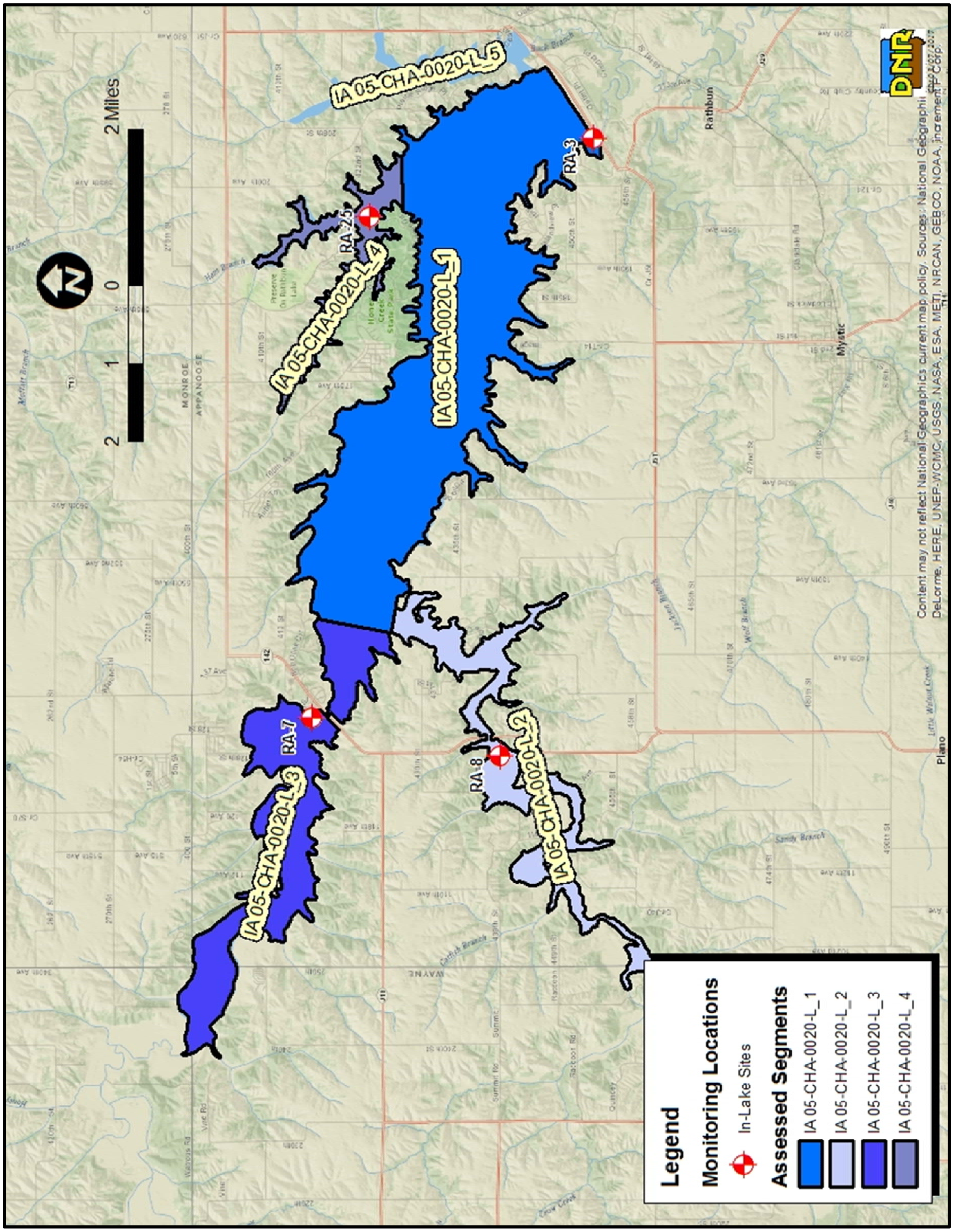
3.2. Interpreting Rathbun Lake Data

Trophic State Indices
In-lake water quality data is collected at four locations within the lake, including the ambient monitoring location located near the dam and outlet structure (Figure 3-1). Development of 303(d) list, the in-lake target, and the TMDL for each segment are based on data collected at these locations, per DNR assessment methodology. In-lake water quality data is provided in Appendix C, with analysis and interpretation provided in this section.

Carlson's Trophic State Index (TSI) is a frequently-used measure of biomass productivity in lakes. Higher TSI values are associated with higher levels of productivity and / or turbidity, and hence, lower water clarity. TSI values increase with increasing TP and Chl-a concentrations, and decrease with increasing Secchi depth. In simplified terms, the higher the TSI, the lower water quality in terms of algal growth, turbidity, and nutrient enrichment. Iowa DNR's assessment methodology for lakes includes TSI impairment thresholds of 65 and delisting criteria of 63 for Chl-a and Secchi depth. Therefore much of the data interpretation that follows is based on TSI values calculated from in-lake concentrations / measurements. Corresponding in-lake measurements associated with the TSI criteria are shown in Table 3-1.

Table 3-1. Threshold TSI values and corresponding measurements.

Status	TSI (Chl-a)	Chl-a (ppb)	TSI (Secchi)	Secchi depth (m)
Impaired	≥ 65	≥ 33.3	≥ 65	≤ 0.7
Delisted	≤ 63	≤ 27.3	≤ 63	≥ 0.8



Content may not reflect National Geographic's current map policy. Sources: National Geographic, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Figure 3-1. Monitoring locations corresponding to assessed lake segments.

Figure 3-2 illustrates the 3-year rolling average of observed TP TSI values for the 4 impaired lake segments from 2004-2014. The data show that, not surprisingly, TP levels are lower in the segment near the dam (RA-3) than in the upper arms of the lake at the mouths of the Chariton River (RA-7) and S. Fork Chariton River (RA-8). This is due, in part, to the settling of sediment and attached phosphorus as the water entering the lake slows down as the lake widens and deepens. TP levels at the Honey Creek location (RA-25) are similar to those observed near the dam (RA-3).

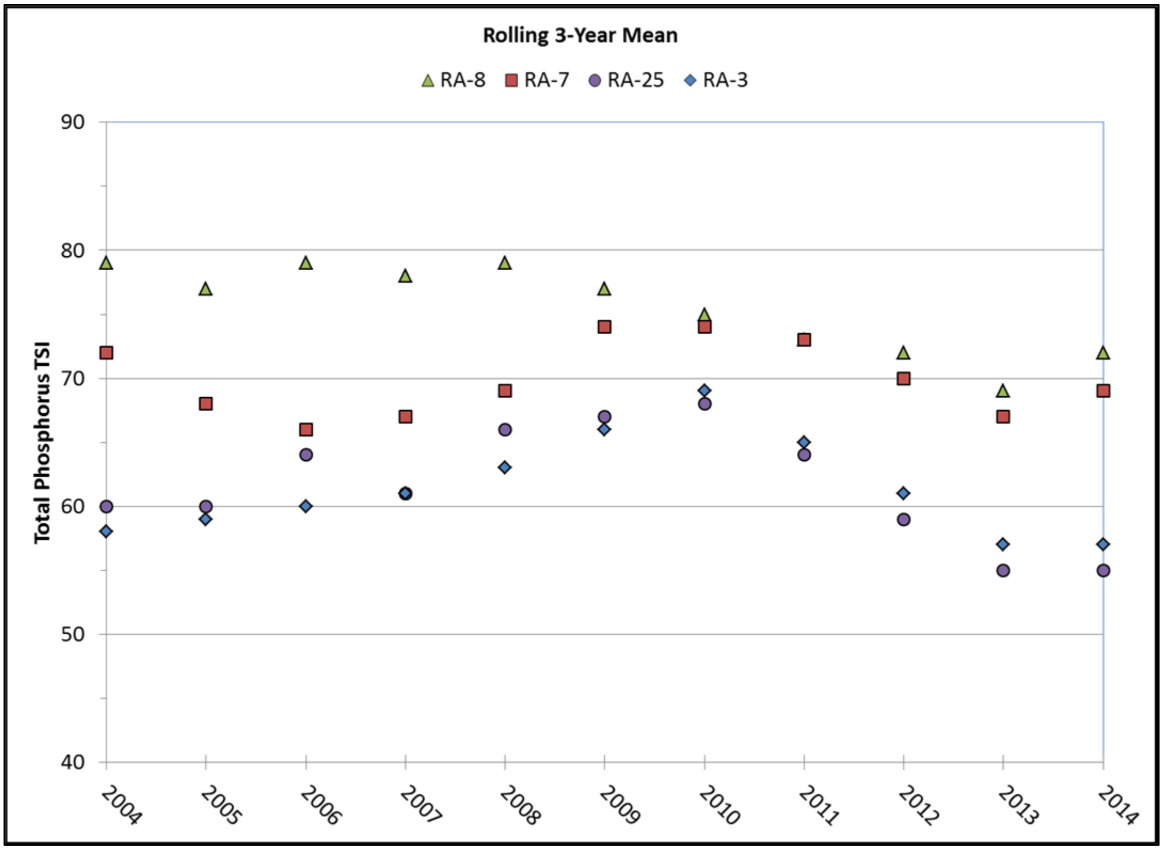


Figure 3-2. Rolling 3-year mean TP TSI for Rathbun Lake segments. Green triangles – S. Fork Chariton arm of the lake (Site RA-8, Segment IA 05-CHA-0020-L_2); red squares – Chariton arm of the lake (Site RA-7, Segment IA 05-CHA-0020-L_3); purple circles – Honey Creek arm (Site RA-25, Segment IA 05-CHA-0020-L_4, and blue diamonds – main body near dam (Site RA-3, Segment IA-05-CHA-0020-L_4).

The TSI data shows similar trends in TP levels over time at all monitoring sites, with the exception that the 3-year rolling average TP at RA-8 peaked in 2006-2008 and then declined, while TP at the other sites was highest from 2009-2010. The rolling average decreased from 2010 to 2013 at all sites, before leveling off or increasing in 2014. Temporal trends in TP concentration were likely due to very high flow, and hence, high watershed export of TP in 2008 and 2010, followed by dry, low export years in 2011-2012. The cause of a distinct pattern at RA-8 compared to other sites prior to 2010 is uncertain, but may be attributable to extremely shallow depth in this arm of the lake.

Figure 3-3 shows the 3-year rolling average Secchi depth TSI as well as the 303(d) listing threshold value of 65. The data reveal that turbidity was very high at RA-7 and RA-8 in 2004 (and prior) and has remained high with similar but dampened variation compared to TP TSI values at these sites (Figure 3-2). Turbidity at RA-25 and RA-3 was below the impairment threshold but increased significantly after 2009 and has exceeded the impairment threshold since 2010. Like TP TSI values, there is a notable gap between Secchi depth TSI values at RA-7 and RA-8 compared with RA-25 and RA-3. The lower TP and turbidity in Honey Creek (RA-25) and near the Rathbun dam (RA-3) are primarily products of three physical characteristics: (i) longer distances downstream from the mouth of the inflowing tributaries, (ii) greater water depths, and (iii) lower watershed-to-lake ratios (Table 3-2).

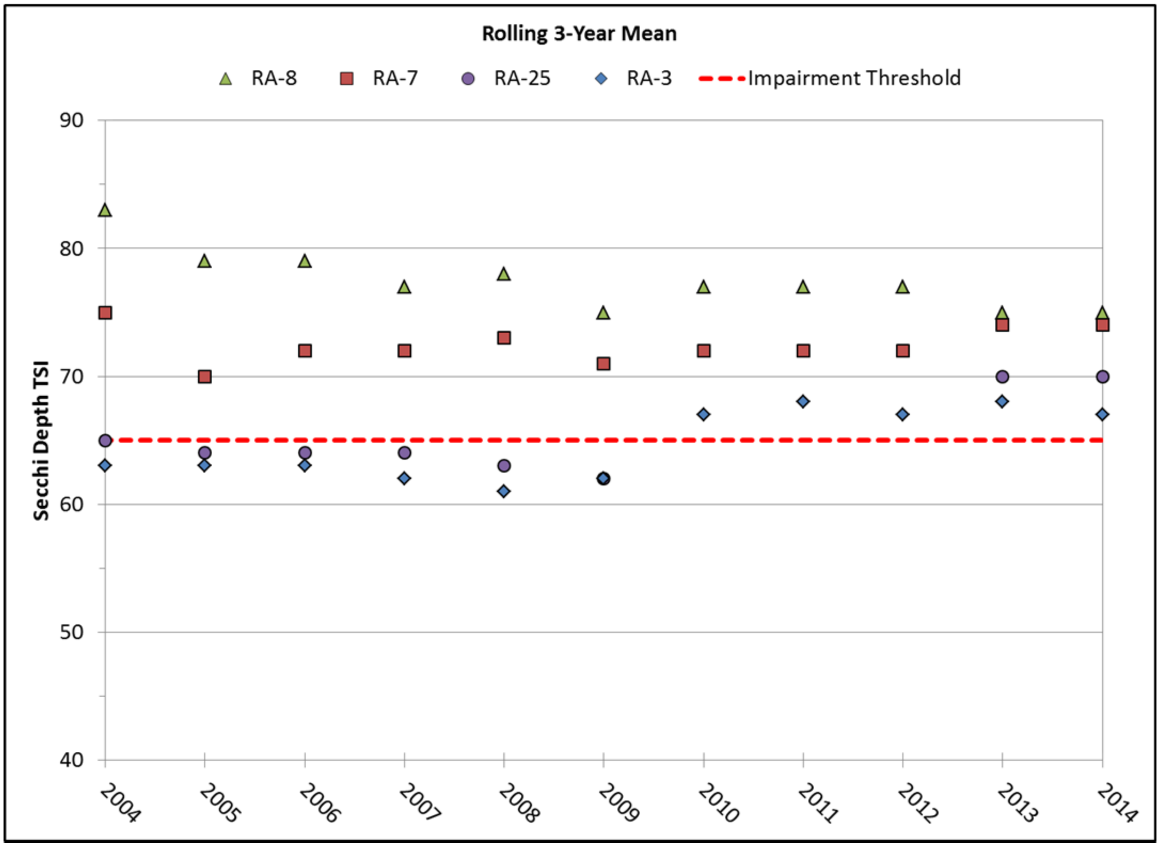


Figure 3-3. Rolling 3-year mean Secchi depth TSI for Rathbun Lake segments. Green triangles – S. Fork Chariton arm of the lake (Site RA-8, Segment IA 05-CHA-0020-L_2); red squares – Chariton arm of the lake (Site RA-7, Segment IA 05-CHA-0020-L_3); purple circles – Honey Creek arm (Site RA-25, Segment IA 05-CHA-0020-L_4, and blue diamonds – main body near dam (Site RA-3, Segment IA-05-CHA-0020-L_4). Red-dashed line illustrates the impairment TSI threshold value of 65.

Table 3-2. Distinct physical characteristics of impaired lake segments.

Segment	Monitoring Segment	Distance from mouth (mi)	Mean Segment Depth (ft)	Area ratio [a]
Near-dam segment	RA-3	16.5	32.6	29:1
S. Fork Chariton arm	RA-8	7.1	6.7	148:1
Chariton River arm	RA-7	6.0	11.2	89:1
Honey Creek arm	RA-25	2.1	22.9	11:1

[a] Effective watershed-to-lake ratio calculated using drainage area and upstream lake area.

Figure 3-4 shows the 3-year rolling average Chl-a TSI along with the 303(d) listing threshold value of 65. As indicated by the Chl-a TSI value, algal turbidity has been low relative to overall turbidity, suggesting that non-algal turbidity (i.e., from fine suspended sediment) is primarily responsible for poor water clarity in all monitored segments of the reservoir. The 3-year rolling average Chl-a TSI never exceeded the impairment threshold of 65 in either the Honey Creek arm (RA-25) or near-dam segment (RA-3) between 2004 and 2014. Both the Chariton arm (RA-7) and S. Fork Chariton arm (RA-8) were impaired for algae on the 2008 and 2010 303(d) lists, with high median Chl-a levels present in 2005 and 2006. The decrease in Chl-a levels beginning in 2009 was not accompanied by a decrease in Secchi TSI. This is because non-algal turbidity remained high and light limitation, rather than nutrient limitation, contributed to lower Chl-a TSI levels post-2009.

Relationships between TSI values for TP, algae (Chl-a), and transparency (Secchi depth) can be used to help identify / assess lake conditions (Carlson and Simpson, 1996). Table 3-3 provides an interpretation of potential lake conditions based on these relationships, and Figure 3-5 illustrates the relationships for the main body of the lake near the dam (RA-3). TSI plots for other monitored segments of the lake are provided in Figures C-11 through C-13 of Appendix C. The TSI relationships show that non-algal turbidity plays the primary role in limiting water clarity (and algal productivity) of Rathbun Lake and substantiates the cause of impairment reported in the water quality assessment and impaired waters list. Generally, Secchi depth is poor (low), phosphorus levels are high, and algal blooms are seldom present due to light limitation caused by turbidity.

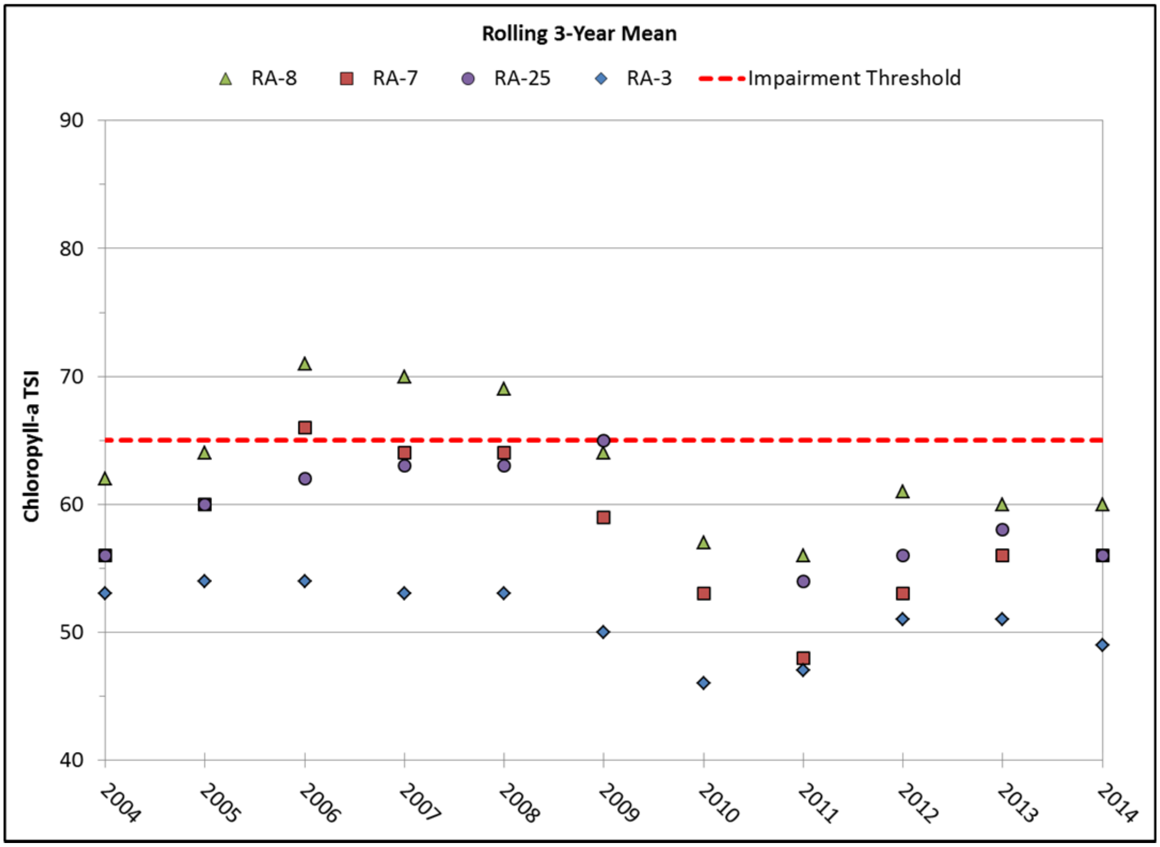


Figure 3-4. Rolling 3-year mean Chl-a TSI for Rathbun Lake segments. Green triangles – S. Fork Chariton arm of the lake (Site RA-8, Segment IA 05-CHA-0020-L_2); red squares – Chariton arm of the lake (Site RA-7, Segment IA 05-CHA-0020-L_3); purple circles – Honey Creek arm (Site RA-25, Segment IA 05-CHA-0020-L_4, and blue diamonds – main body near dam (Site RA-3, Segment IA-05-CHA-0020-L_4). Red-dashed line illustrates the impairment TSI threshold value of 65.

Table 3-3. Interpretation of relationships between TSI values.

Relationship	Plot Location (Figure 3-X)	Interpretation
TSI (TP), TSI(Secchi), and TSI(Chl-a) are similar in magnitude	Center of graph near (0,0)	Algae limits water clarity and is typically limited by phosphorus
TSI(Chl-a) is greater than TSI(Secchi)	Right of y-axis	Large algal particles limit water clarity
TSI(TP) and TSI(Secchi) are similar and both greater than TSI(Chl-a) [a]	Along diagonal in lower-left quadrant [a]	Non-algal turbidity limits water clarity [a]
TSI(Chl-a) and TSI(Secchi) are similar and both greater than TSI(TP)	Along y-axis above x-axis	Algal growth limits clarity and is driven by phosphorus
TSI(Chl-a) and TSI(Secchi) are similar but lower than TSI(TP)	Along y-axis below x-axis	Algae limits clarity; algal growth limited by something other than phosphorus
[a] Prevalent condition in all segments of Rathbun Lake during the assessment period.		

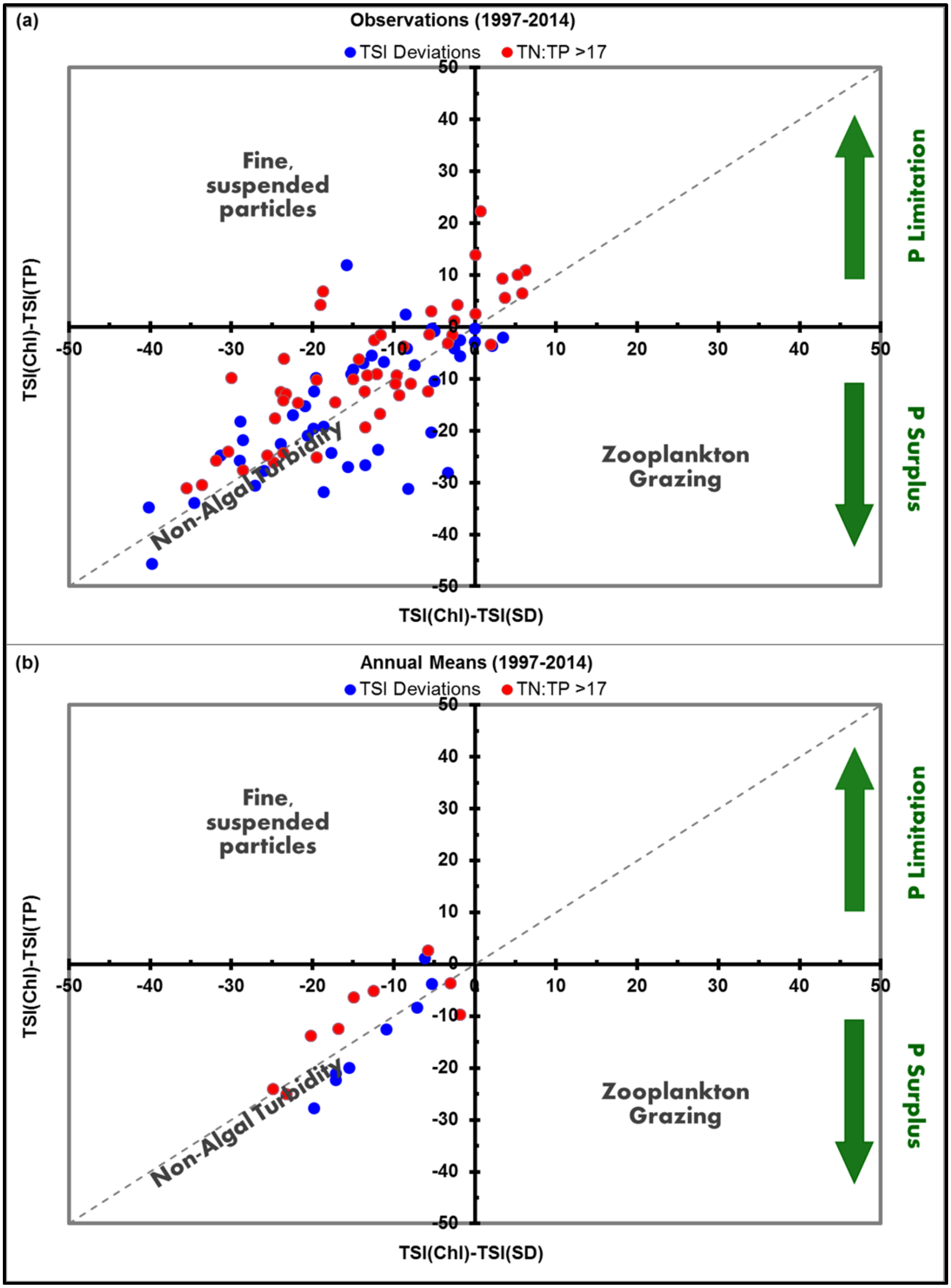


Figure 3-5. TSI relationships for near-dam area of Rathbun Lake (RA-3). Chart (a) includes individual observations and chart (b) shows annual mean values. Red dots represent observations/means with TN:TP ratio >17, indicating P-limitation (relative to N).

Weather and Water Quality

Relationships between precipitation and TP, Secchi depth, and Chl-a can provide insights to the role that hydrology plays in water quality. The correlation between annual average TP TSI and annual rainfall (Figure 3-6) has been relatively strong and positive at RA-3 and RA-25, moderately strong and positive at RA-7, and nearly nonexistent at RA-8. A positive relationship indicates the importance of watershed exports to in-lake TP levels, but the lack of correlation at RA-8 seems counter-intuitive given the relatively large watershed-to-lake ratio and other physical similarities with RA-7. Dissimilar P dynamics at RA-7 and RA-8 may stem from differences in hydrodynamics (i.e., mixing, settling, and diffusion) in these arms of the lake, which could be driven by the difference in water depth (Table 3-2).

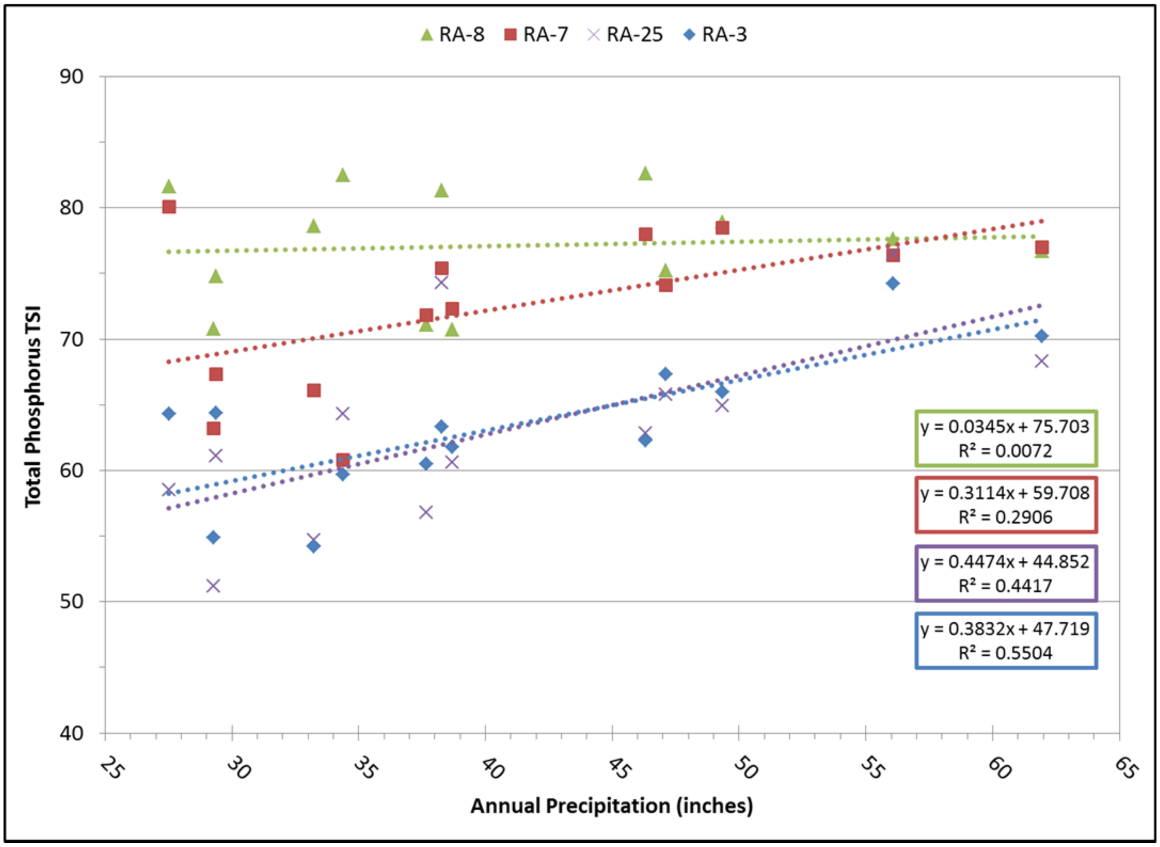


Figure 3-6. Annual mean TP TSI versus annual precipitation.

Relationships between precipitation and Secchi depth TSI illustrate a strong negative relationship at RA-8, relatively weak negative correlations for RA-7 and RA-25, and no correlation at RA-3 (Figure 3-7). The positive correlation between precipitation and water clarity often indicates the benefits of increased flushing, which reduces residence time and can lower algal turbidity, as shown in Figure 3-8. This analysis is somewhat limited because the timing of rainfall within a given year also affects water quality.

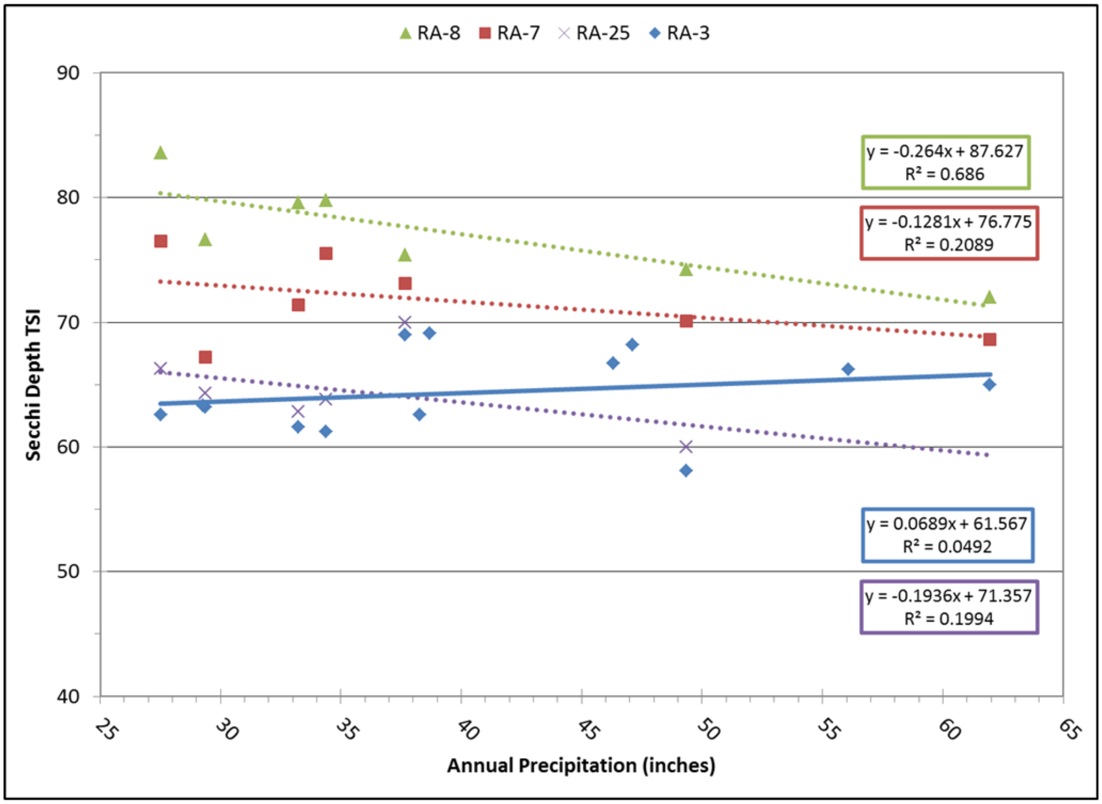


Figure 3-7. Annual mean Secchi depth TSI versus annual precipitation.

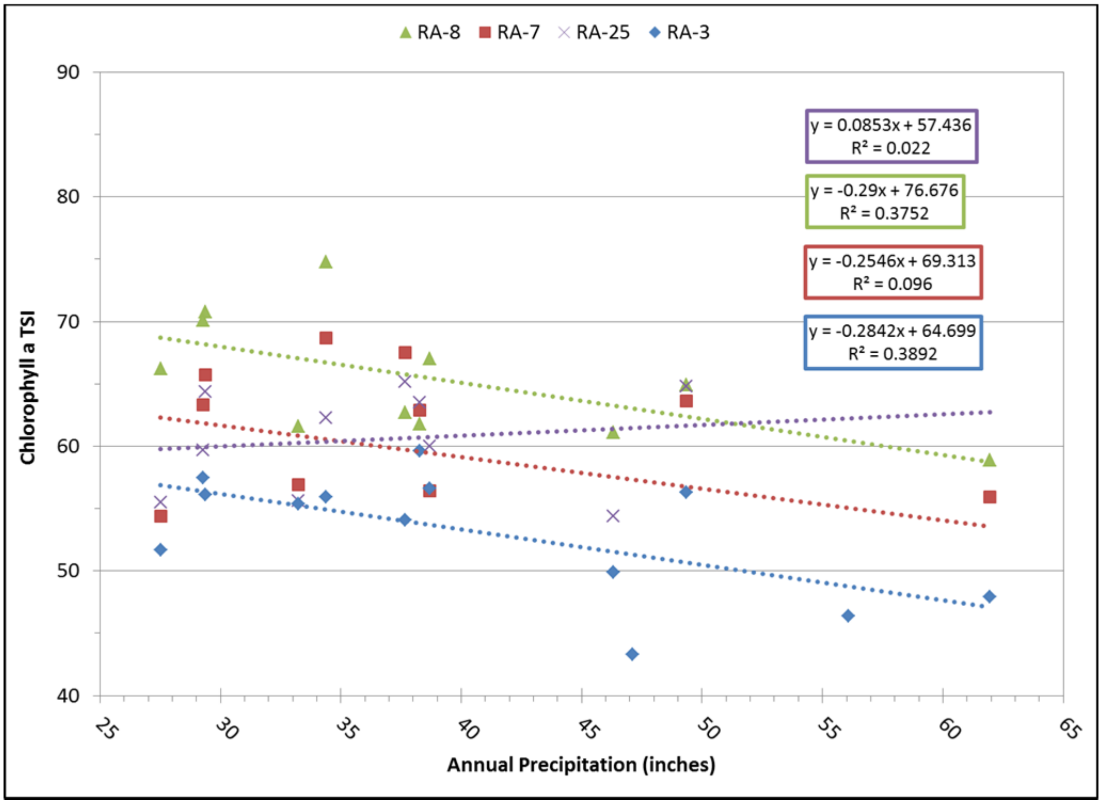


Figure 3-8. Annual mean Chl-a TSI versus annual precipitation.

To further explain unexpected differences in water quality trends between sites, potential correlations between sub-annual (daily to seasonal) precipitation and observed TSI values were evaluated. This analysis revealed weaker relationships between short-term precipitation patterns and observed TP, Secchi depth, and Chl-a than long-term patterns. This may indicate that long-term hydrology and pollutant loads have a larger effect on water quality in Rathbun Lake than short-term trends, which lends credibility to targeting average annual conditions for water quality improvement. It may also suggest unknown internal factors drive short-term variation in water quality.

Another potential short-term driver is wind and its impact on sediment settling, mixing and / or resuspension. Daily wind data was obtained from Automated Weather Observing System (AWOS) stations located at Chariton and Centerville, Iowa (IEM, 2016). Wind speed and direction data were aggregated into daily average values at both sites, with Chariton station data serving as the primary data source and data from Centerville used to fill in gaps in the data record. The wind rose for the Chariton station shows that southerly winds dominate in terms of both frequency and wind strength (Figure 3-9). The wind rose was constructed for periods when air temperature exceeded 60 degrees Fahrenheit to approximate the growing season. If winter days were included in the analysis, north and northwest winds would be more significant.

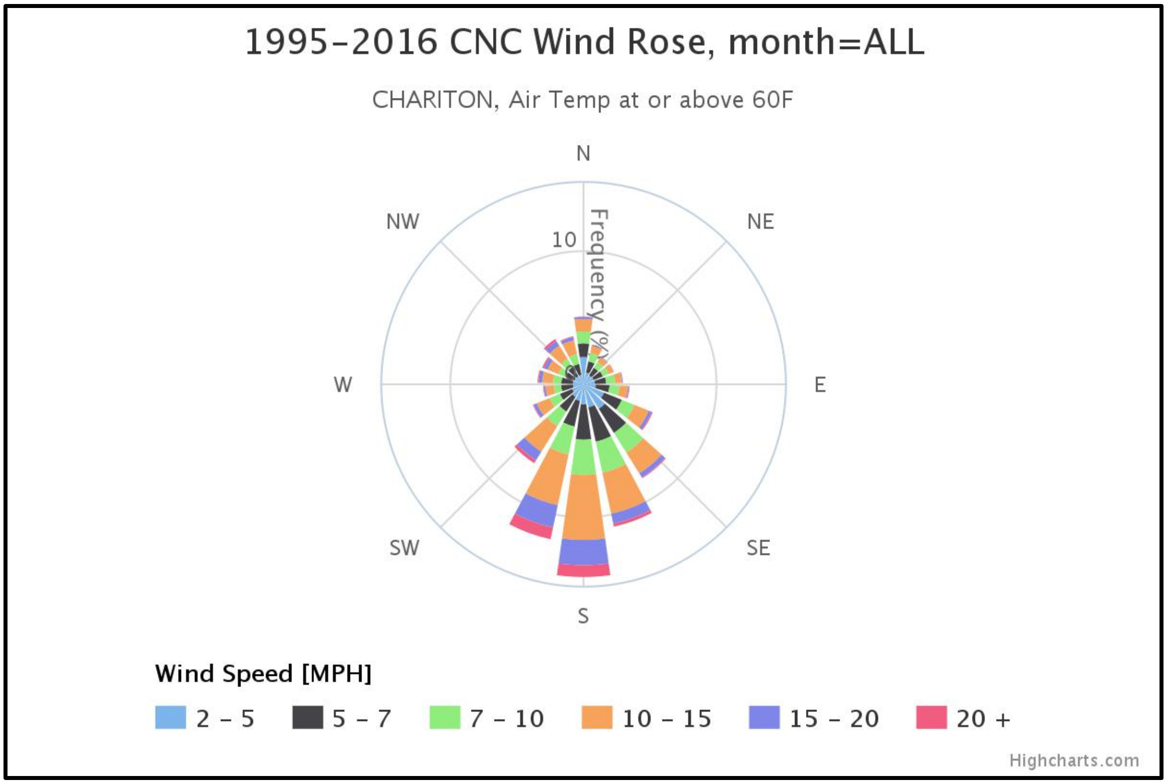


Figure 3-9. Wind rose for the Chariton AWOS weather station.

Matrix plots (Figure 3-10) reveal variation in the potential impact of wind on water quality in different areas of the lake. Wind speed appears to affect Secchi depth to some degree at all four sites, but impacts on TP are weaker. Relationships between wind speed and Chl-a are negative, which likely reflects light limitation caused by wind-induced non-algal turbidity, but may also indicate wind-induced breakup of algal blooms.

Regression analysis confirmed that wind speed contributes to turbidity, as indicated by increased Secchi depth TSI values with higher wind speeds at both RA-7 and RA-8 (Figure 3-10). The strength of the relationships is only moderate, with R^2 values of 0.29 for RA-7 and 0.21 for RA-8; however, this explains some of the variation in Secchi depth, with a multitude of other variables also affecting water transparency. The relationship between wind speed and Secchi depth at RA-3 and RA-25 are much weaker, with R^2 values near 0.10 for both sites. Because growing season wind direction is predominately from the south with few water quality samples collected during north, east, or west winds, it is difficult to determine possible impacts of wind direction. However, the data suggest that wind direction is less important than wind speed.

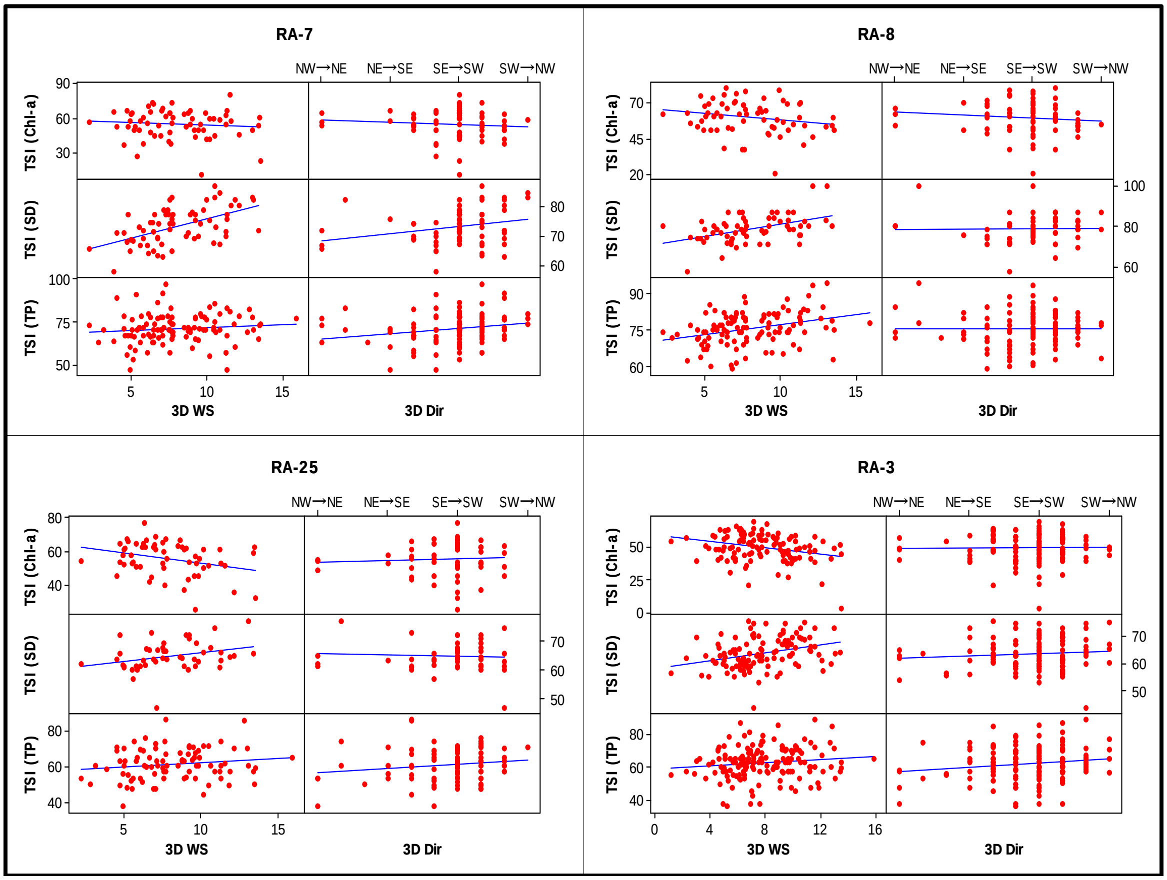


Figure 3-10. Matrix plots illustrating potential impact of wind speed and wind direction on water quality. 3D WS = average 3-day wind speed (mph). 3D Dir = 3-day average wind direction.

Watershed Exports and Water Quality

Estimated pollutant loads to the lake from the watershed were calculated using the Flux32 software program (Walker, 1999), as reported in Appendix C.3. Potential relationships between watershed loading and in-lake water quality were investigated using matrix plots and regression analysis. Both annual and multi-year trends were examined.

Algal turbidity, as indicated by annual Chl-a TSI values, decreased with increasing annual flows, TP exports, and TSS exports at all sites except RA-25 (top row of Figures 3-11 through 3-14). At RA-3 this is likely explained by increased non-algal turbidity (i.e., higher Secchi depth TSI values), which create light-limiting conditions for algal growth. However, at both main arms to the lake, Secchi depth was positively correlated with watershed flows and exports (i.e., Secchi depth TSIs decrease with increased flows / exports). This may be explained by increased algal growth in the arms of the lake in low-flow years due to decreased non-algal turbidity and increased light penetration into the water column. In-lake TP concentrations were positively correlated to high flows and exports at all sites except RA-8, where there was a very weak, negative association between in-lake TP concentration and watershed flows / exports. These spatial and temporal variations, not only in water quality, but in relationships between watershed exports and resulting water quality, illustrate the difficulty in predicting water quality response to changes in watershed and lake management, and highlight the importance of phased, flexible, and adaptive implementation of improvement strategies.

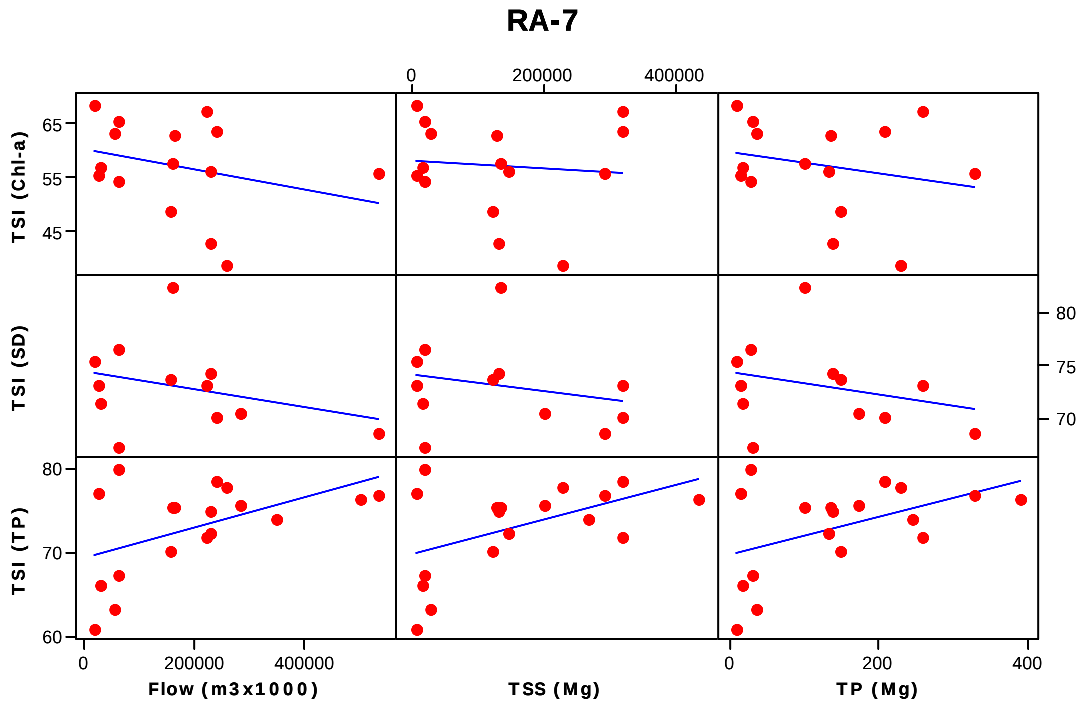


Figure 3-11. Matrix plot for Chariton River arm of lake (RA-7) illustrating potential impact of watershed exports on water quality. Trophic State Indices for TP, Secchi depth, and Chl-a on y-axis; flow, TSS export, and TP export on x-axis.

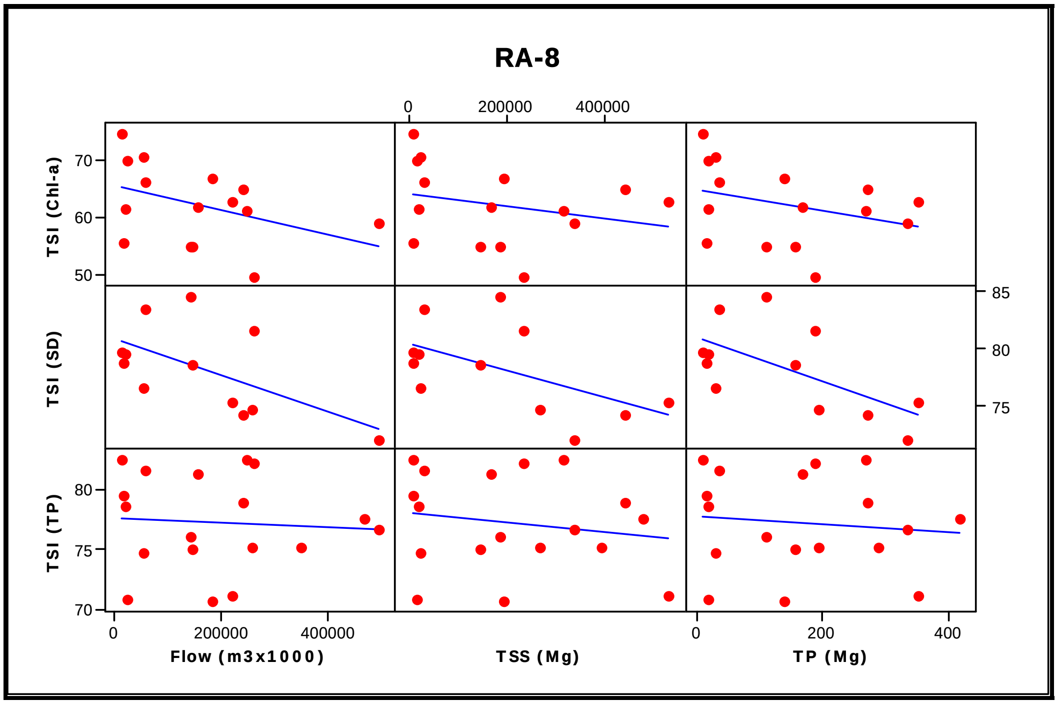


Figure 3-12. Matrix plot for S. Fork Chariton arm of lake (RA-8) illustrating potential impact of watershed exports on water quality. Trophic State Indices for TP, Secchi depth, and Chl-a on y-axis; flow, TSS export, and TP export on x-axis.

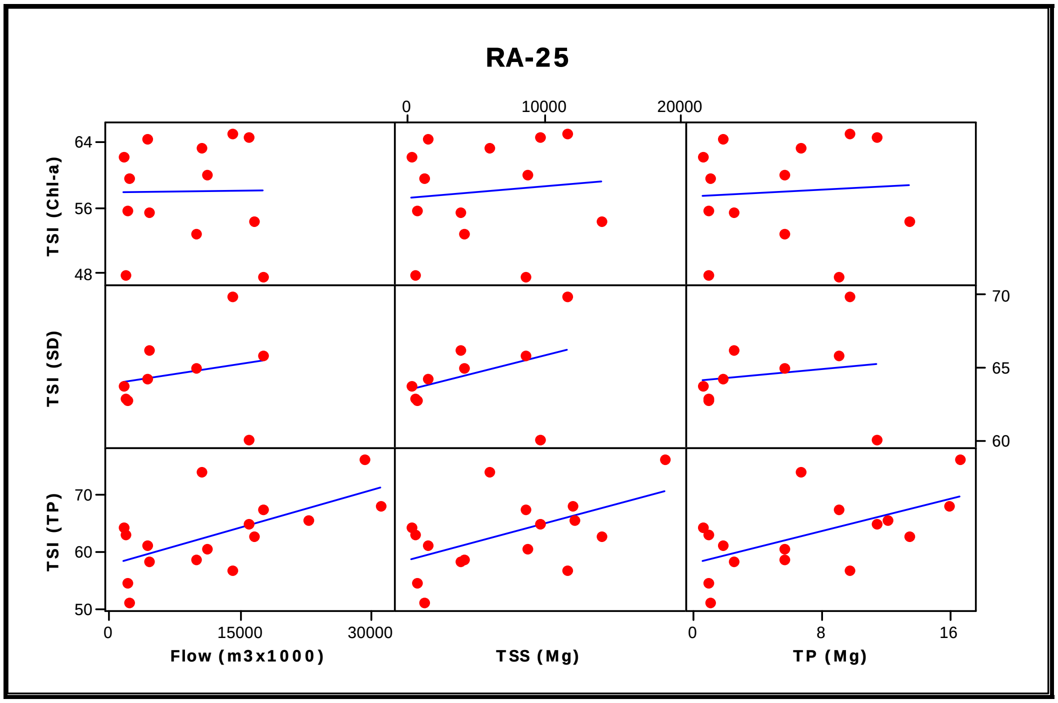


Figure 3-13. Matrix plot for Honey Creek segment of lake (RA-25) illustrating potential impact of watershed exports on water quality. Trophic State Indices for TP, Secchi depth, and Chl-a on y-axis; flow, TSS export, and TP export on x-axis.

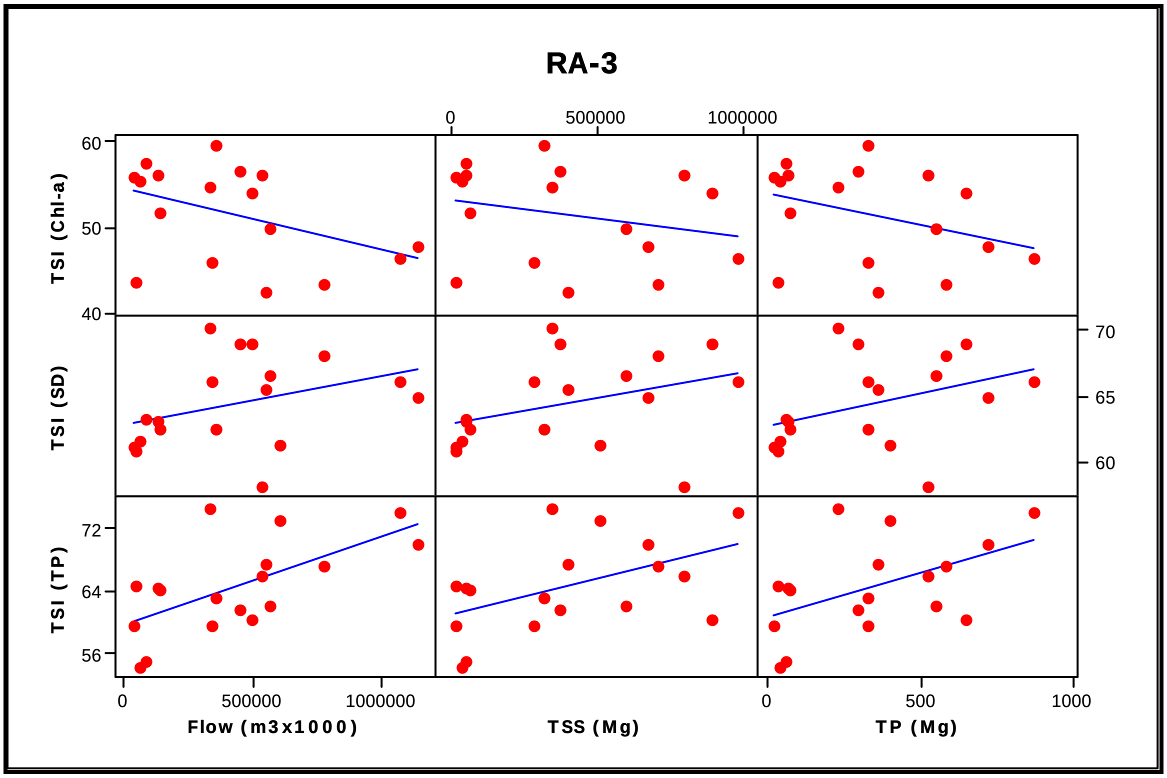


Figure 3-14. Matrix plot for near-dam segment of lake (RA-3) illustrating potential impact of watershed exports on water quality. Trophic State Indices for TP, Secchi depth, and Chl-a on y-axis; flow, TSS export, and TP export on x-axis.

3.3. TMDL Target

General Description of the Pollutant
The 2014 and draft 2016 305(b) assessments and 303(d) lists attribute poor water quality in all four assessed segments of Rathbun Lake to non-algal turbidity. The data interpretation described in Section 3.2 of this WQIP indicates TP load reductions will best address the impairments. Reduction of TP (and associated sediment) will address poor water clarity and also reduce the potential for increased algal blooms as light limitation decreases with decreased turbidity.

Seasonal Variation and Critical Conditions
The critical period for poor water clarity is the growing season (April through September); however, long-term sediment and TP loads drive water clarity problems over time. Therefore, both existing and allowable TP loads to Rathbun Lake are expressed as aggregate annual averages (for the 2008-2013 period) for the purposes of TMDL development and for tracking future changes in water quality.

Existing Load
The existing TP load to the lake was estimated using observed streamflow and water quality data, load / flux calculations developed in the Flux32 software program (Walker, 1999), observed in-lake water quality data, and the BATHTUB model. Flow and water quality data and the load / flux estimates are documented in Appendix C and the

BATHTUB model is described in detail in Appendix F. The evaluation period for load estimates was the 12-year period from 2002-2013. This includes a relatively dry 6-year period (2002-2007) and a relatively wet 6-year period (2008-2013). The long-term (i.e., 12-year) average annual aggregate TP load to the lake is an estimated 387.0 tons per year (tons/yr), with averages of 190.2 tons/yr from 2002-2007 and 583.7 tons/yr from 2008-2013. The 2008-2013 period was used to develop existing loads and the loading capacity for TMDL development.

Loading Capacity (TMDL)

This TMDL establishes a Secchi depth TSI target of 63, based on Carlson's trophic state index approach utilized in Iowa DNR's assessment methodology. The allowable TP loading capacity was developed by performing water quality simulations using the BATHTUB model (Appendix F). The annual TP loading capacity was obtained by reducing the average annual TP loads in the 2008-2013 BATHTUB model until the target Secchi depth TSI of no greater than 63 was attained for each impaired lake segment. This period was selected for determination of the loading capacities / TMDLs for Rathbun Lake because it is most representative of current water quality and recent DNR assessments. For this reason, the loading capacities expressed in Table 3-4 and load response curves illustrated in Figures 3-15 through 3-18 reflect 2008-2013 conditions. For planning purposes, the full 12-year period (2002-2013) is more reflective of an appropriate time-scale for implementation and observing water quality improvements. For that reason, per-acre loads reported in Section 4 of this WQIP are based on the 2002-2013 time frame.

Table 3-4. Annual average TP loading capacity of each lake segment.

303(d) Segment	Description	Monitoring ID	TP Loading Capacity (tons/yr)
IA 05-CHA-0020-L_3	Chariton River arm	RA-7	149.9
IA 05-CHA-0020-L_2	S. Fork Chariton arm	RA-8	94.5
IA 05-CHA-0020-L_4	Honey Creek arm	RA-25	405.3
IA 05-CHA-0020-L_1	Main lake near dam	RA-3	458.3

Although the annual loading capacity of each segment is unique, all allowable loads are based on the aggregate total for Rathbun Lake. The practical ramification of this is that simulated reductions are uniform across tributaries to the lake. This is necessary oversimplification because water quality of individual lake segments is inter-related through dispersion processes and because it is not possible to predict the spatial distribution of future TP reductions.

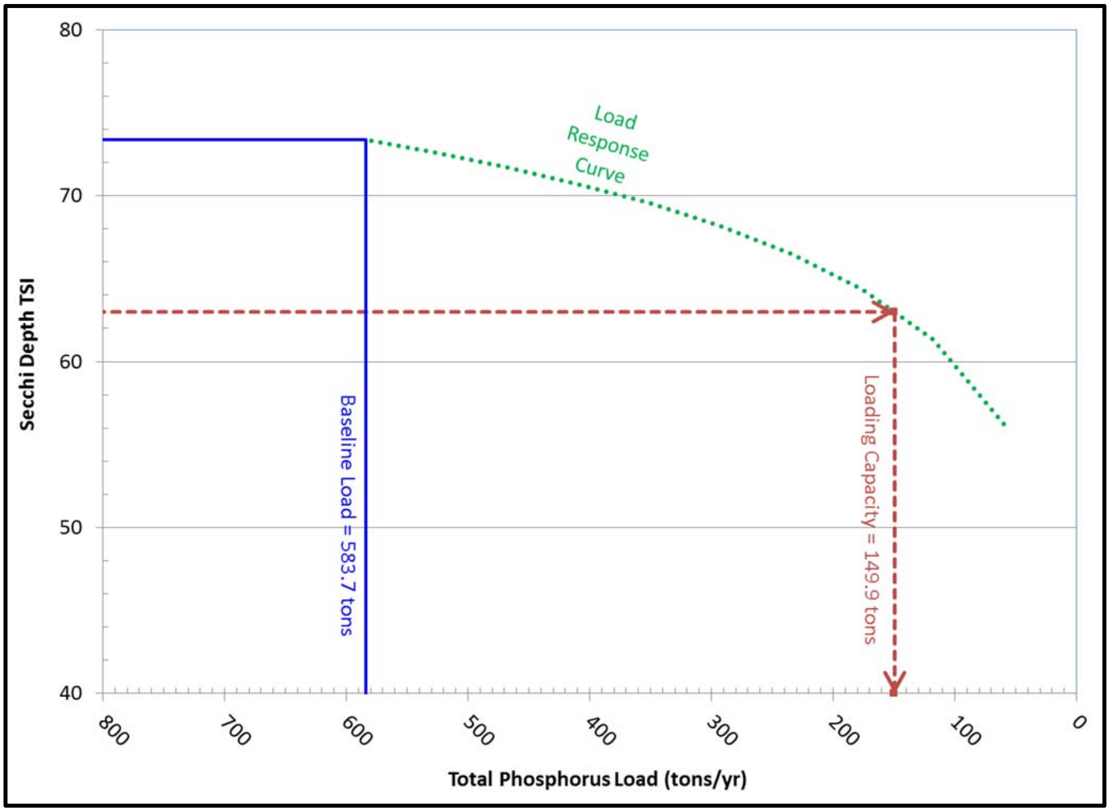


Figure 3-15. Load response curve for the Chariton River arm (RA-7).

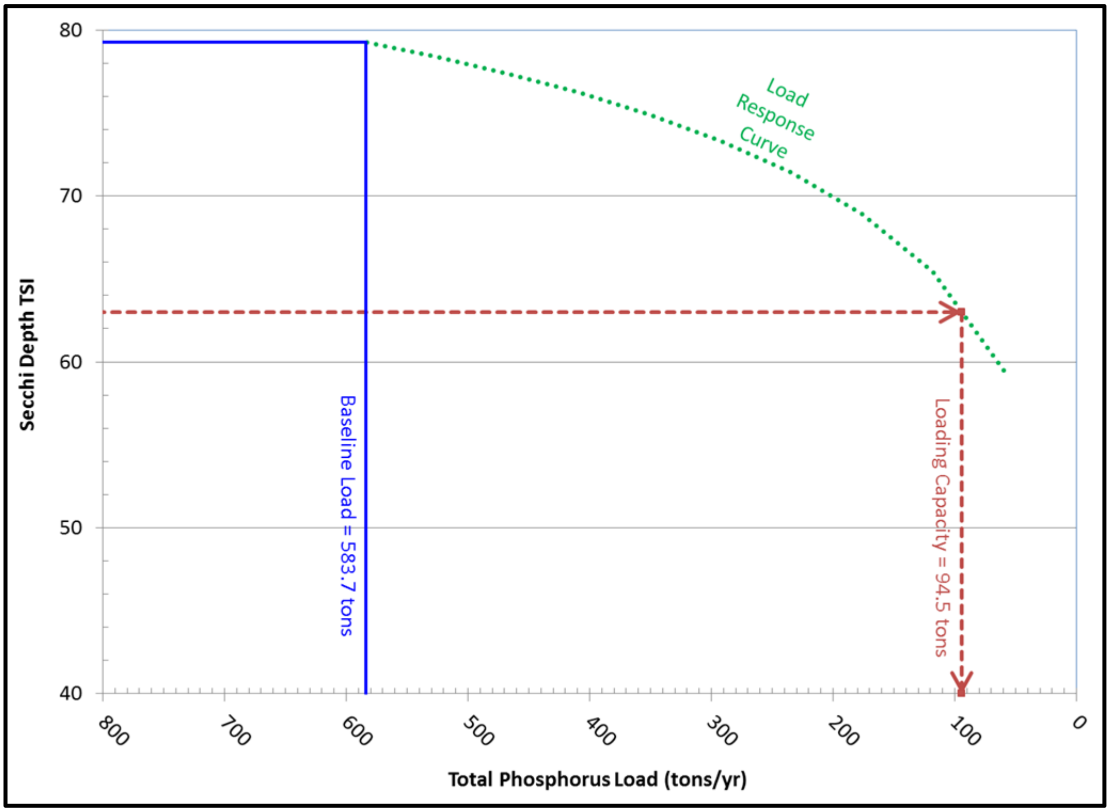


Figure 3-16. Load response curve for the S. Fork Chariton arm (RA-8).

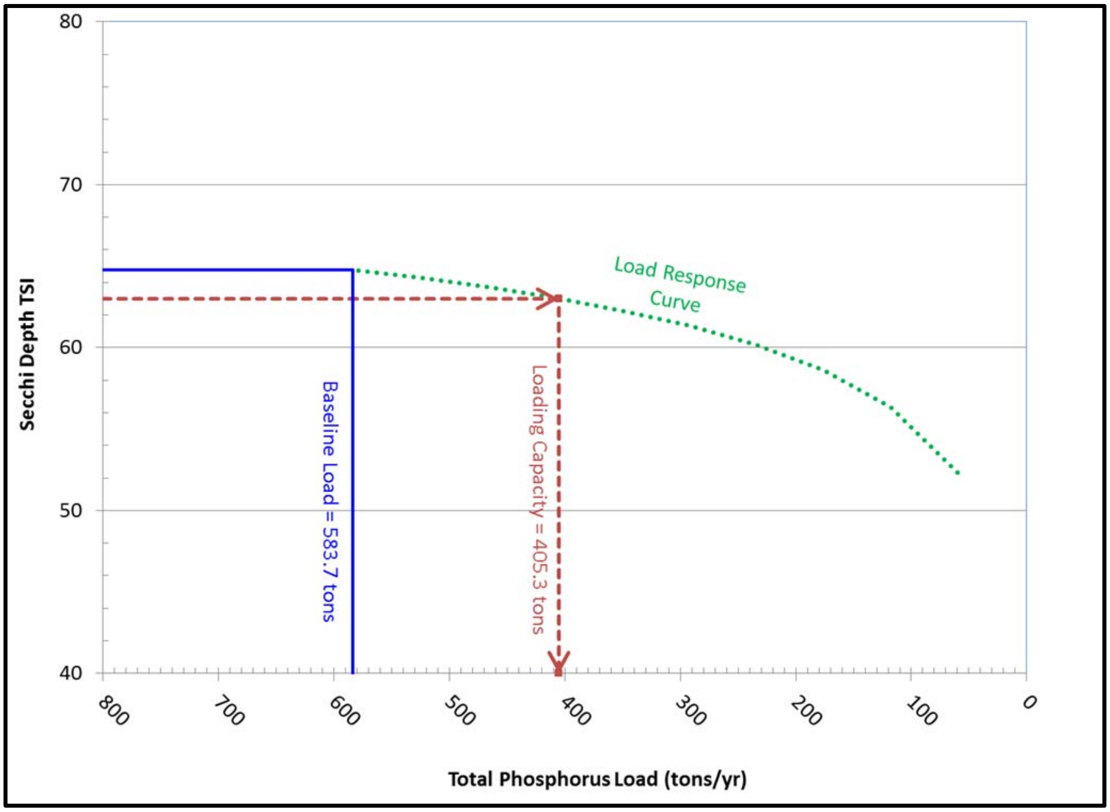


Figure 3-17. Load response curve for the Honey Creek arm (RA-25).

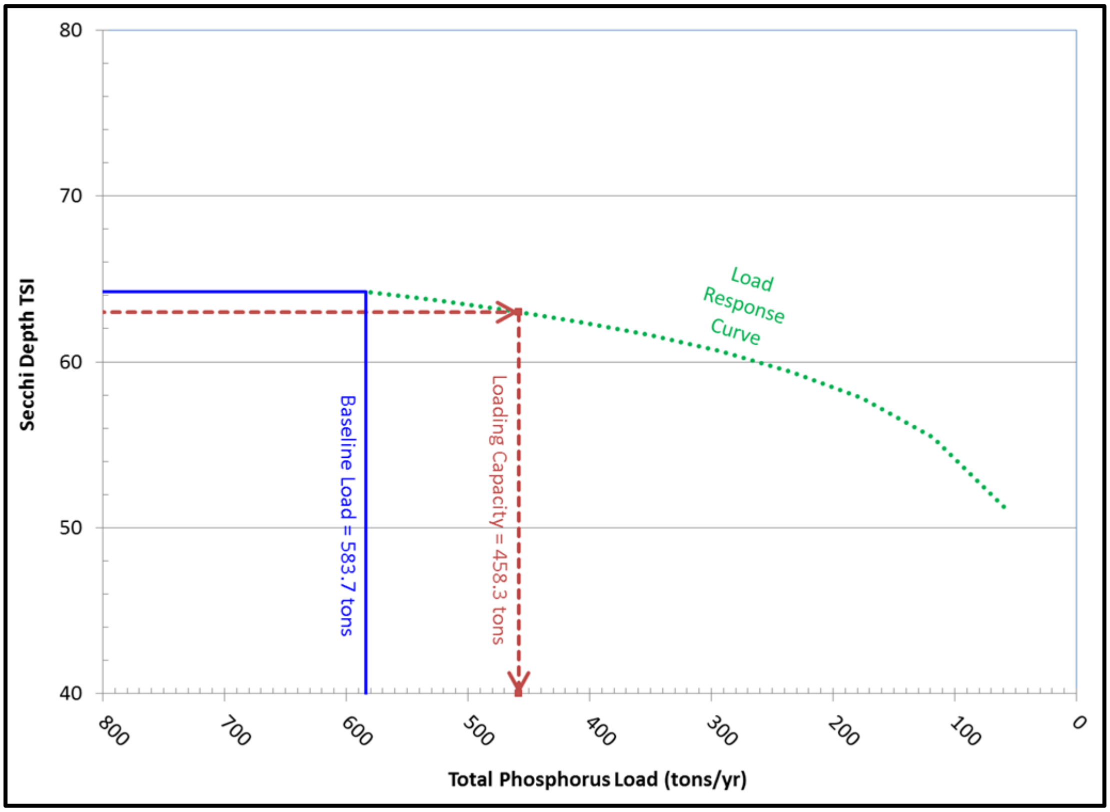


Figure 3-18. Load response curve for the near-dam segment (RA-3).

Decision Criteria for WQS Attainment

The narrative criteria in the water quality standards require that each of the monitored / assessed segments of Rathbun Lake be free from "aesthetically objectionable conditions." The metric for WQS attainment for de-listing the impairment is a median Secchi depth TSI of 63 or less in two consecutive 303(d) listing cycles. This TSI target corresponds to a measured Secchi depth of not less than 0.8 m.

Compliance Point for WQS Attainment

The TSI target for listing and delisting of each assessed segment of Rathbun Lake is measured at the monitoring locations shown in Figure 3-1, consistent with 305(b) assessment and 303(d) listing protocols administered by the Iowa DNR-Water Quality Monitoring & Assessment Section.

3.4. Pollution Source Assessment

Load Assessment Methodology

The existing TP load to the lake was calculated using monitoring data and flux calculations described in Section 3.3. In order to quantify individual sources of TP loads, watershed hydrology and pollutant loading were also simulated using the Soil and Water Assessment Tool (SWAT). The SWAT model is a well-established and widely utilized model for simulation of hydrology and pollutant transport in predominantly agricultural watersheds, and is described in detail in Appendix D.

The SWAT model was calibrated to observed streamflow and estimated sediment and TP loads. Land use specific loads were derived from the model, with other sources quantified as part of a watershed-wide estimate developed outside of SWAT. Model development / and TP source estimation are described in detail in Appendix D, and model performance is documented in Appendix E. Although SWAT was utilized supplemental to monitoring data to quantify individual source loads, it was not utilized in the development of TP load targets (i.e., the TMDLs).

Departure from Load Capacity

The departure from loading capacity is the load reduction required to meet the WQS and support the designated uses. Meeting the target in-lake Secchi depth TSI of 63 and corresponding Secchi depth (not less than 0.8 m) in all monitored segments of the lake will require a TP load reduction of 489.2 tons/yr, an overall reduction of 83.8% from baseline (2008-2013) conditions. Conversely, a reduction of only 125.4 lbs/yr (21.5%) is required to meet the target in the main body of the lake near the dam (Table 3-5).

Table 3-5. Required TP load reductions to meet WQS in each segment.

Description	Monitoring ID	Departure (tons/yr)	Reduction (%)
Chariton River arm	RA-7	433.8	74.3
S. Fork Chariton arm	RA-8	489.2	83.8
Honey Creek arm	RA-25	178.4	30.6
Main lake near dam	RA-3	125.4	21.5

Identification of Pollutant Sources

The existing TP load to Rathbun Lake is predominantly from nonpoint sources of pollution, with several relatively minor point sources of phosphorous (Table 3-6). The point sources are quantified and given WLAs; however, the vast majority of their contributions are in the form of dissolved phosphorus, and current turbidity problems in Rathbun Lake are more directly related to phosphorus attached to sediment. Sediment and TP loads from nonpoint sources, not point sources, are the primary drivers of current water quality issues in the lake. Developing TP WLAs for point sources is protective and maintains consistency with the methodology used in this TMDL.

Table 3-6. Inventory of TP sources and estimated loads (2008-2013).

Source	Descriptions and Assumptions	TP Load (tons/yr)	Percent (%)
Row Crops (conventional)	Includes land in corn and soybean rotations and continuous corn	240.9	41.3
Streambank Erosion	Streambank and channel erosion	114.3	19.6
Pasture/Grass	Includes grazed and ungrazed grassland. Does not include direct deposition of manure in streams	117.8	20.2
Row Crops (Extended)	Includes land in extended rotations that include small grains and/or hay in addition to row crops	56.5	9.7
Gully Erosion	Classic gullies, not in-field ephemeral gullies	17.9	3.1
Developed Areas	Includes roads, urban areas, and rural homesteads	12.4	2.1
Instream Deposition	Direct deposition of manure into streams (primarily by beef cattle)	7.3	1.3
Alfalfa/Hay	Includes all forms of perennial hay	5.5	0.9
Timber/Forest	Includes both grazed and ungrazed timber and shrub/scrub. Does not include direct deposition of manure in streams	4.7	0.8
Point Sources	Includes public, semi-public, and private wastewater treatment systems	2.7	0.5
Atmospheric	Deposition on the lake from wind, rain, etc.	1.6	0.3
Wildlife	Includes direct deposition by deer and other wildlife into streams	1.3	0.2
Septic Systems	Private on-site wastewater systems (does not include discharging systems permitted under GP#4)	0.6	0.1
Geese	Geese, primarily at the lake	0.2	< 0.1
Total		**583.7**	**100**

TP loads reported in Table 3-6 reflect loads to the lake from known sources within the 2008-2013 period. This quantitative inventory is based on watershed / source characteristics calculated outside of the SWAT model in combination with SWAT model output. The predominant sources of TP to Rathbun Lake include erosion from land in agricultural production and streambank and gully erosion. Row crops in conventional and extended rotations comprise 37% of the land area of the watershed (Table 2-1) and

51% of the estimated TP load to the lake (Table 3-6 and Figure 3-19). Streambank and gully erosion account for another 23%, and runoff and erosion from pasture contributes an estimated 20% of the TP load. Relatively minor sources include developed areas such as roads, farmsteads, and small urban areas, direct deposition of manure in streams by cattle and wildlife, perennial hay / alfalfa fields, timber land, discharges from wastewater treatment plants (WWTPs), atmospheric deposition by wind and rain, potential impacts from failing / faulty septic systems, and defecation by geese directly into the lake. Collectively, these minor sources account for only 6% of the estimated TP loads to Rathbun Lake.

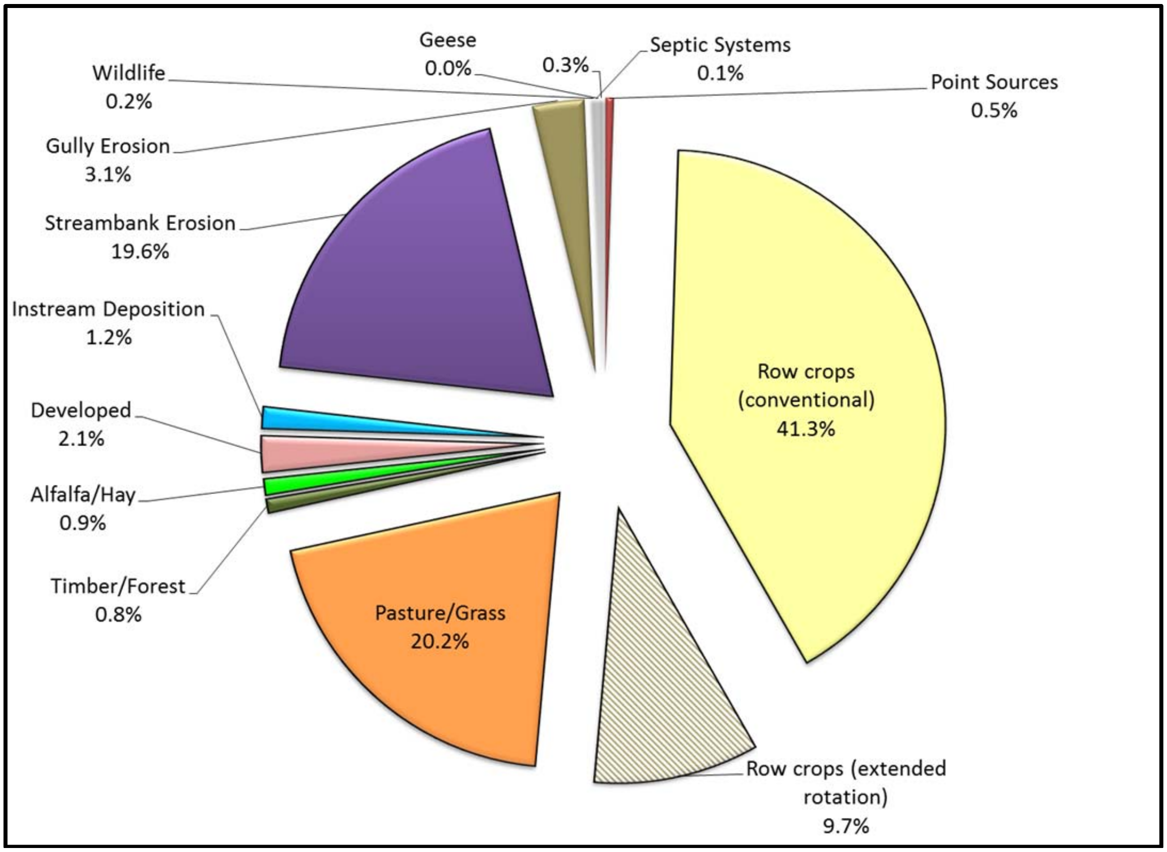


Figure 3-19. Relative TP loads by source.

There are several hog confinements within the Rathbun Lake watershed, the five largest of which are classified as large Concentrated Animal Feeding Operations (CAFOs). None of the animal feeding operations (AFOs) are allowed to discharge. Potential impacts of swine manure application on phosphorus transport are simulated as fertilizer application using the SWAT model. As a result, TP loads from swine manure application are integrated with TP loads from row crops.

Internal recycling of phosphorus in the lake was not explicitly simulated or calculated, because predicted phosphorus loads to the lake from the watershed were large enough to fully account for observed TP concentrations in the lake. The lack of internal load in the deeper areas of the lake seems reasonable given the absence of stratification and measurable dissolved oxygen (DO) in the hypolimnion of the lake during collection of water column profile data. There is some evidence that the shallow areas of the lake, particularly the S. Fork Chariton arm near RA-8, may experience mixing and / or resuspension of sediment at times, based on trend analyses presented in Section 3.2 However, the data may indicate reduced settling of incoming sediment, rather than resuspension of bottom sediments. Further, the sediment entering the lake from the watershed will only exacerbate this problem. For those reasons, internal loading was assumed to be minor.

Allowance for Increases in Pollutant Loads
There are no allowances for increased TP loads from nonpoint sources included in the TMDLs for Rathbun Lake. A majority of the watershed is grassland or in agricultural production, and is unlikely to develop significantly due to population growth. Commodity price fluctuations have driven changes in the balance of row crop and grass / hay acres the past 10 to 20 years, and those shifts will likely continue (potentially in both directions) into the future. However, TP loads resulting from increases in agricultural production should be offset by improved management practices and conservation technologies.

There are several allowances for increased TP loads from point sources. As communities grow and expand, wastewater discharges will likely increase. There are several unsewered communities in the watershed in which residents are currently on private septic systems that could eventually be centralized into public or semi-public treatment facilities that discharge under an NPDES permit. There is also the potential for an increase in the number of private onsite wastewater systems that discharge under General Permit #4 (GP4). Allowances are provided in two forms, including: (i) an over-estimate of existing loads from point sources, which will likely provide room for new and expanded discharges, and (ii) the inclusion of Reserve WLAs (described subsequently in Section 3.5).

3.5. Pollutant Allocation

Wasteload Allocation
Wastewater facilities with NPDES-permitted discharges are described in Table 3-7. Existing average annual loads were estimated using facility-specific design data (i.e., population equivalent) and a per-capita TP load of 0.005 lb per day (Metcalf & Eddy, 2013). These likely over-estimate point source contributions because potential reductions by the treatment plants are ignored. Even with these over-estimates, wastewater is less than one percent of the TP load to Rathbun Lake. Further, turbidity impairments to the lake are primarily driven by sediment that carries a great majority of the phosphorus load to the lake. Therefore, inclusion of phosphorus WLAs is a protective approach and future WLAs are left at the existing load estimates. The annual average loads used to calculate the WLAs reported Table 3-7 are equivalent to long-term averages utilized for developing water quality-based effluent limits.

Table 3-7. Existing point source loads and future WLAs.

Source Location	Facility Type	Facility/ Permit ID	Pop. Equiv.	Existing Load (lb/yr)	WLA_{AA}[a] (lb/yr)	WLA_{30d}[b] (lb/day)	WLA_{DM}[c] (lb/day)
Chariton River: Discharges to Segments IA 05-CHA-0020-L_3 & IA 05-CHA-0020-L_1							
City of Derby	WSL[d]	5909001	135	246	246	n/a	6.8
City of Humeston	AL[e]	9348001	1,048	1,913	1,913	10.0	16.3
City of Russell	AL[e]	5939001	671	1,225	1,225	6.4	10.4
Indian Ridge HOA	WWTF[f]	9300601	118	215	215	1.1	1.8
Onsite WW	GP4[g]	n/a	n/a	60	60	n/a	0.5
Reserve (UC[i])	UC[h]	n/a	n/a	0	528	n/a	4.5
Reserve (GP4[g])	GP4[g]	n/a	n/a	0	441[i]	n/a	3.8[i]
NE of Weldon	CAFO[j] (swine)	310681395	n/a	0	0	0	0
SE of Derby	CAFO[j] (swine)	310699011	n/a	0	0	0	0
S of Russell	CAFO[j] (swine)	310722288	n/a	0	0	0	0
Totals				3,659	4,628		44.1
S. Fork Chariton: Discharges to Segments IA 05-CHA-0020-L_2 & IA 05-CHA-0020-L_1							
Source Location	**Facility Type**	**Facility/ Permit ID**	**Pop. Equiv.**	**Existing Load (lb/yr)**	**WLA_{AA}[a] (lb/yr)**	**WLA_{30d}[b] (lb/day)**	**WLA_{DM}[c] (lb/day)**
City of Allerton	WSL[d]	9303003	171	312	312	n/a	8.7
City of Corydon	AL[e]	9334004	2,335	4,261	4,261	22.2	36.3
Reserve (UC[i])	UC[h]	n/a	n/a	0	192	n/a	1.6
Reserve (GP4[g])	GP4[g]	n/a	n/a	0	252	n/a	2.1
N of Promise City	CAFO[j] (swine)	310719918	n/a	0	0	0	0
NW of Promise City	CAFO[j] (swine)	310740839	n/a	0	0	0	0
Totals				4,573	5,017		48.7

[a] WLA_{AA} = wasteload allocation (annual average) equivalent to long-term average used for development of water quality-based effluent limits.

[b] WLA_{30d} = wasteload allocation (30-day average) applicable to water quality-based effluent limits. Not applicable to controlled discharge lagoons or calculation of reserves.

[c] WLA_{DM} = wasteload allocation (daily maximum) applicable to water quality-based effluent limits.

[d] WSL = municipal waste stabilization lagoon (controlled discharge lagoon, CDL). Daily maximum is shown for consistency with the TMDLs but is not applicable to NPDES permit limits. Daily maximum is the annual average divided by 36 days of allowable discharge.

[e] AL = municipal aerated lagoon

[f] WWTF = homeowners association wastewater treatment facility

[g] GP4 = onsite wastewater disposal facilities that discharge under General Permit #4. Reserve is transferable to other point sources.

[h] UC = unsewered community. Reserve is transferrable to other point sources.

[i] 9 lbs/yr of the Reserve WLA_{AA} (<0.1 lb/day WLA_{DM}) for Onsite WW facilities is designated for the Honey Creek arm (IA 05-CHA-0020-L_4)

[j] Concentrated Animal Feeding Operation

Reserve WLAs for unsewered communities were calculated by multiplying population of known unsewered communities by the same per-capita load used for existing dischargers. Reserve WLAs for future increases in the number of private, onsite wastewater systems that discharge under GP4 were based on an assumed 10% increase in permitted systems and per-capita loading rates (see Appendix D). Although calculated using specific source types, these Reserve WLAs may be utilized for non-specified, new, and / or expanded discharges. Daily maximum wasteloads for all point sources except controlled discharge lagoons (CDLs) were calculated by applying a statistical multiplier of 3.11 to average wasteloads, consistent with Iowa NPDES WLA development protocols (see Appendix G). Daily maximum loads were calculated for CDLs by dividing the annual average load by 36 days, the peak discharge period for CDLs. Calculation of daily maximum CDL limits was included for consistency with TMDL calculations; however, they are not applicable to NPDES permit requirements. Location of existing point sources (not including GP4 systems) is shown in Figure 3-20.

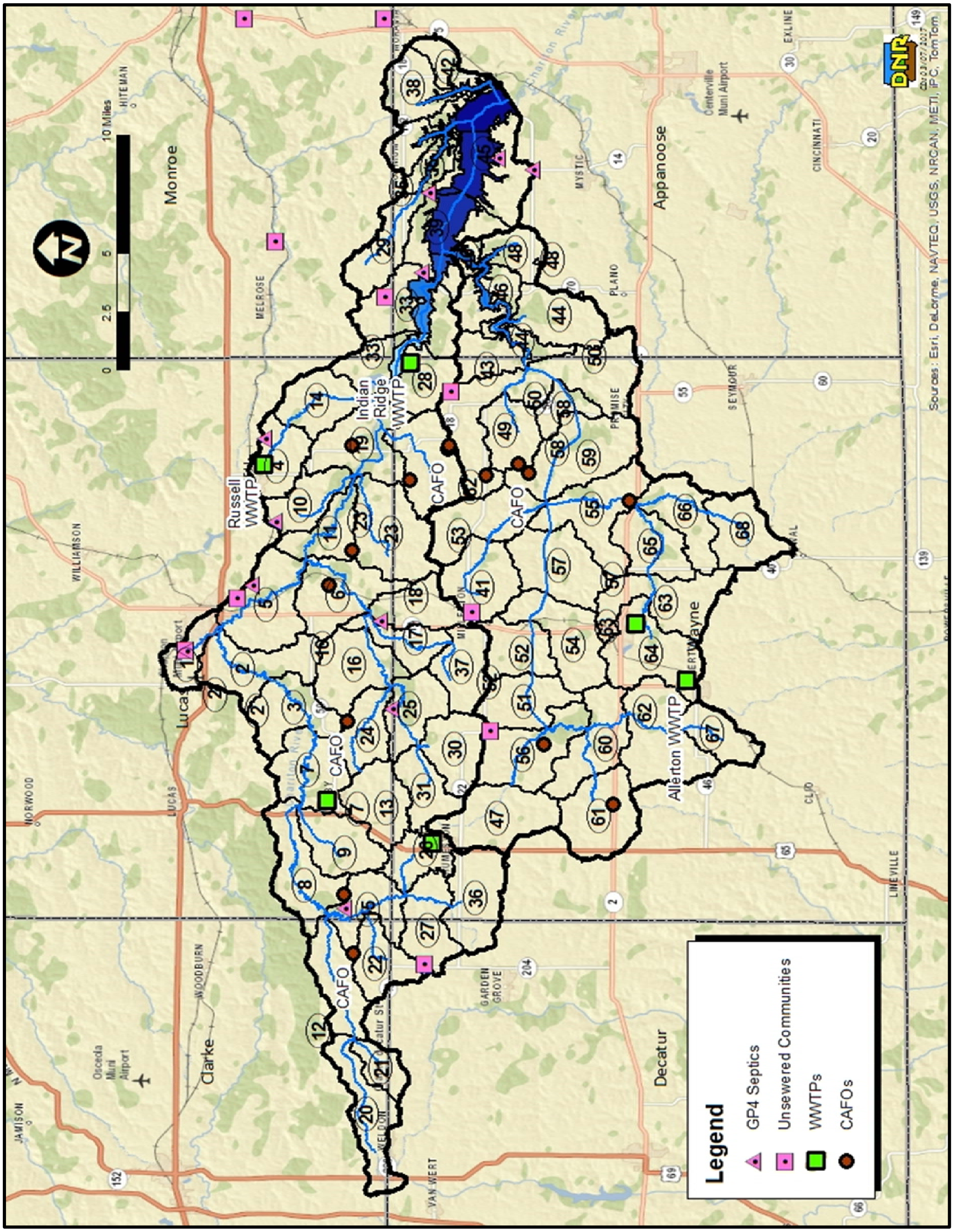


Figure 3-20. Point source location map.

Load Allocation
Nonpoint sources of phosphorus to Rathbun Lake include erosion and loss of manure and fertilizer from land in row crop production, erosion and manure from pasture and other grasslands, stream and gully erosion, erosion from timber / wooded areas, wildlife defecation, and atmospheric deposition (from dust and rain). Septic systems can fail or drain illegally to ditches, contributing relatively small amounts of phosphorus to the lake. Changes in agricultural land management, implementation of structural best management practices (BMPs), repair or replacement of failing septic systems, and in-lake restoration techniques can reduce phosphorus loads and improve water quality. Based on the inventory of sources, erosion prevention strategies, land management, and structural practices targeting land in row crop production offer the largest potential reductions in TP loads. Mitigation of streambank and gully erosion will also be required to meet all of the water quality goals set forth in the TMDLs for Rathbun Lake.

Table 3-8 shows an example load allocation scenario that meets the TP TMDL at the compliance point near the dam (i.e., monitoring site RA-3 located in Segment 05-CHA-0020-L_1) for 2008-2013 conditions. The LA for this TMDL is 407.7 tons/year. The individual source reductions shown in Table 3-8 are not required, but provide one of many possible combinations of reductions that would achieve water quality goals at RA-3. This example allocation would not result in attainment of WQS in other segments of the lake, but serves as an example for developing similar allocation schemes to achieve WQS in other impaired segments of Rathbun Lake.

Table 3-8. Example load allocation scheme to meet target TP load.

TP Source	Existing Contribution (ton/yr)	Reduction (%)	Load Allocation (tons/yr)
Row Crops (conventional)	240.9	45	132.5
Streambank Erosion	114.3	10	102.8
Pasture/Grass	117.8	20	94.2
Row Crops (Extended)	56.5	15	48.0
Gully Erosion	17.9	60	7.2
Developed Areas	12.4	25	9.3
Instream Deposition	7.3	85	1.1
Alfalfa/Hay	5.5	10	4.9
Timber/Forest	4.7	10	4.2
Atmospheric	1.6	0	1.6
Wildlife	1.3	0	1.3
Septic Systems	0.6	75	0.1
Geese	0.2	0	0.2
Total	**581.0**	**29.8**	**< 407.7**

Margin of Safety
To account for uncertainties in data and modeling, a margin of safety (MOS) is a required component of all TMDLs. An explicit MOS of 10% was utilized in the development of TMDLs for Rathbun Lake.

Reasonable Assurance

Under current EPA guidance, 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, the TMDL should provide reasonable assurance that nonpoint source control measures will achieve expected load reductions. The point sources in the Rathbun watershed are contributing primarily dissolved phosphorus and little to no sediment and turbidity. Nonetheless, WLAs are included for consistency and to provide protection against potential / future algal blooms. Reasonable assurance for nonpoint source reductions is provided by the active engagement and implementation efforts lead by the Rathbun Land and Water Alliance (RLWA) and other soil and water conservation partners. An EPA-approved watershed management plan (Protect Rathbun Lake: Interim Watershed Management Plan, 2014-2019) is already being implemented, and will be updated with information provided by this Water Quality Improvement Plan and associated TMDLs.

3.6. TMDL Summary

The following general equation represents the total maximum daily load (TMDL) calculation and its components:

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

Where: TMDL = total maximum daily load
LC = loading capacity
Σ WLA = sum of wasteload allocations (point sources)
Σ LA = sum of load allocations (nonpoint sources)
MOS = margin of safety (to account for uncertainty)

Once the loading capacity, wasteload allocations, load allocations, and margin of safety have all been determined for Rathbun Lake, the general equation above can be expressed for all four assessed segments of the lake. The loads are expressed as allowable annual averages (Table 3-9) and equivalent daily maximum values (Table 3-10). Annual allowable loads are most relevant to water quality assessment, watershed management, and CWA program implementation, while daily maximum loads are provided according to EPA recommendations.

Table 3-9. TMDLs expressed as annual average TP loads.

Waterbody ID	Monitoring Segment	TMDL (tons/yr)	Σ WLA (tons/yr)	Σ LA (tons/yr)	MOS (tons/yr)
05-CHA-0020-L_1	RA-3	458.3	4.8	407.7	45.8
05-CHA-0020-L_2	RA-8	94.5	2.5	82.5	9.5
05-CHA-0020-L_3	RA-7	149.9	2.3	132.6	15.0
05-CHA-0020-L_4	RA-25	405.3	0.005[a]	364.8	40.5

[a] Reserve WLA of 9 lbs/yr for onsite wastewater systems covered under GP4.

In November of 2006, The U.S. Environmental Protection Agency (EPA) issued a memorandum (EPA, 2006) entitled *Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits.* In the context of the memorandum, EPA

> *"…recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increment. In addition, TMDL submissions may include alternative, non-daily pollutant load expressions in order to facilitate implementation of the applicable water quality standards…"*

In order to follow EPA guidance, loading capacities are expressed as a daily maximum loads in addition to the annual loading capacities. The maximum daily load was estimated from the growing season average load using a statistical approach that is outlined in more detail in Appendix G. This approach uses a log-normal distribution to calculate the daily maximum from the long-term (e.g., annual average) load. The methodology for this approach is taken directly from a follow-up guidance document entitled *Options for Expressing Daily Loads in TMDLs* (EPA, 2007), and was issued shortly after the November 2006 memorandum cited previously. This methodology can also be found in EPA's 1991 *Technical Support Document for Water Quality Based Toxics Control* (EPA, 1991).

Table 3-10. TMDLs expressed as daily maximum TP loads.

Waterbody ID	Monitoring Segment	TMDL (lbs/day)	Σ WLA (lbs/day)	Σ LA (lbs/day)	MOS (lbs/day)
05-CHA-0020-L_1	RA-3	31,786	93	28,514	3,179
05-CHA-0020-L_2	RA-8	6,554	49	5,850	655
05-CHA-0020-L_3	RA-7	10,396	44	9,312	1,040
05-CHA-0020-L_4	RA-25	28,110	0.1	25,299	2,811

3.7. References

Carlson, R, and J. Simpson. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society. 96 pp.

Iowa Environmental Mesonet (IEM). 2015. Iowa State University Department of Agronomy. Iowa Ag Climate Network. Download available at http://mesonet.agron.iastate.edu/request/coop/fe.phtml. Last accessed in February 2015.

Iowa Environmental Mesonet (IEM). 2016. Iowa State University Department of Agronomy. Iowa Automated Weather Observing System (AWOS). Download available at http://mesonet.agron.iastate.edu/AWOS/. Last accessed in August 2016.

Metcalf & Eddy. 2013. Wastewater Engineering: Treatment and Resource Recovery. pp 216-219. McGraw-Hill. New York, NY.

National Oceanic and Atmospheric Administration (NOAA). 2015. National Climatic Data Center (NCDC). Download available at http://www.ncdc.noaa.gov/. Last accessed in February 2015.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 30 Aug 2016

Tomer, M.D., S.A. Porter, D.E. James, K.M.B. Boomer, J.A. Kostel, and E. McLellan. 2013. Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning. J. Soil Water Conserv. 68(5):113A-120A.

U.S. Department of Agriculture – National Agricultural Statistical Summary (USDA-NASS). 2013. http://nassgeodata.gmu.edu/CropScape/. Accessed August 2014.

U.S. Environmental Protection Agency (EPA). 1991. Technical Support Document for Water Quality-based Toxics Control. EPA/505/2-90-001. EPA Office of Water, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2006. Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits. Memorandum from Benjamin Grumbles, Assistant Administrator, EPA Office of Water, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2007. Options for Expressing Daily Loads in TMDLs (Draft). EPA Office of Wetlands, Oceans & Watersheds, Washington, DC.

U.S. Geological Survey (USGS). 2015. Surface Water Data for the Nation. http://waterdata.usgs.gov/nwis/sw. Last accessed August 2015.

Walker, W. 1999. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. US Army Corps of Engineers Waterways Experiment Station. Instruction Report W-96-2.

4. Implementation Planning

This implementation plan is not a required component of Total Maximum Daily Loads (TMDLs) as articulated by the Federal Clean Water Act. However, the Iowa Department of Natural Resources (DNR) recognizes that technical guidance and support are critical to achieving the goals outlined in this Water Quality Improvement Plan (WQIP). Therefore, this implementation plan is included for use by local agencies, watershed managers, and citizens for decision-making support and planning purposes. The analysis and predictive tools described are provided to the watershed partners to (i) assist in the estimation of load reductions from implementation of best management practices (BMPs) and (ii) provide a menu of potential tools (i.e., BMPs) to achieve water quality goals. It is possible that only a portion of BMPs included in this plan will be feasible for implementation in the Rathbun Lake watershed. Additionally, there may be potential BMPs not discussed in this implementation plan that should be considered. This implementation plan should be used as a guide and starting point for more detailed and comprehensive planning by local stakeholders.

4.1. Historical Planning and Implementation

There is a long history of watershed conservation and in-lake management efforts for protection and improvement of water quality in Rathbun Lake. The first comprehensive watershed management plan, titled *Assessment and Management Strategies for the Rathbun Lake Watershed*, was developed in 2001, and was a cooperative effort by the members and partners of the Rathbun Land and Water Alliance (RLWA, 2001). The original plan enabled RLWA partners to identify priority land and implement BMPs in a strategic manner. An Interim Plan: *Protect Rathbun Lake: Interim Watershed Management Plan 2014-2019*, was developed in 2014 and serves as an update (RWLA, 2014). The goal of the Interim Plan was to provide planning and implementation guidance for watershed managers to build on prior efforts until completion of this WQIP and the associated TMDLs for total phosphorus (TP). As of March, 2017, an estimated 51,000 tons of sediment and 220,000 lbs (110 tons) of phosphorus have been prevented from entering the lake (RLWA, 2017). Incorporation of information from this WQIP into long-term planning efforts will help satisfy evolving programmatic requirements (e.g., development of a nine-element watershed management plan) by relating watershed load reductions to improvement in in-lake water quality.

4.2. Updated Information for Implementation Planning

Pollutant Exports and Prioritization by Subwatershed

A combination of instream monitoring and watershed modeling was utilized to develop per-acre estimates of both sediment (Figure 4-1) and TP (Figure 4-2) yields transported from the 68 SWAT subbasins (representative of the 61 HUC-14 RLWA planning-scale subwatersheds) to tributary streams. Although the numeric TMDLs were developed based on 2008-2013 conditions, the 12-year period (2002-2013) may provide better baseline information for long-term planning and implementation. All information provided in this Section of the WQIP is therefore based on 2002-2013 conditions.

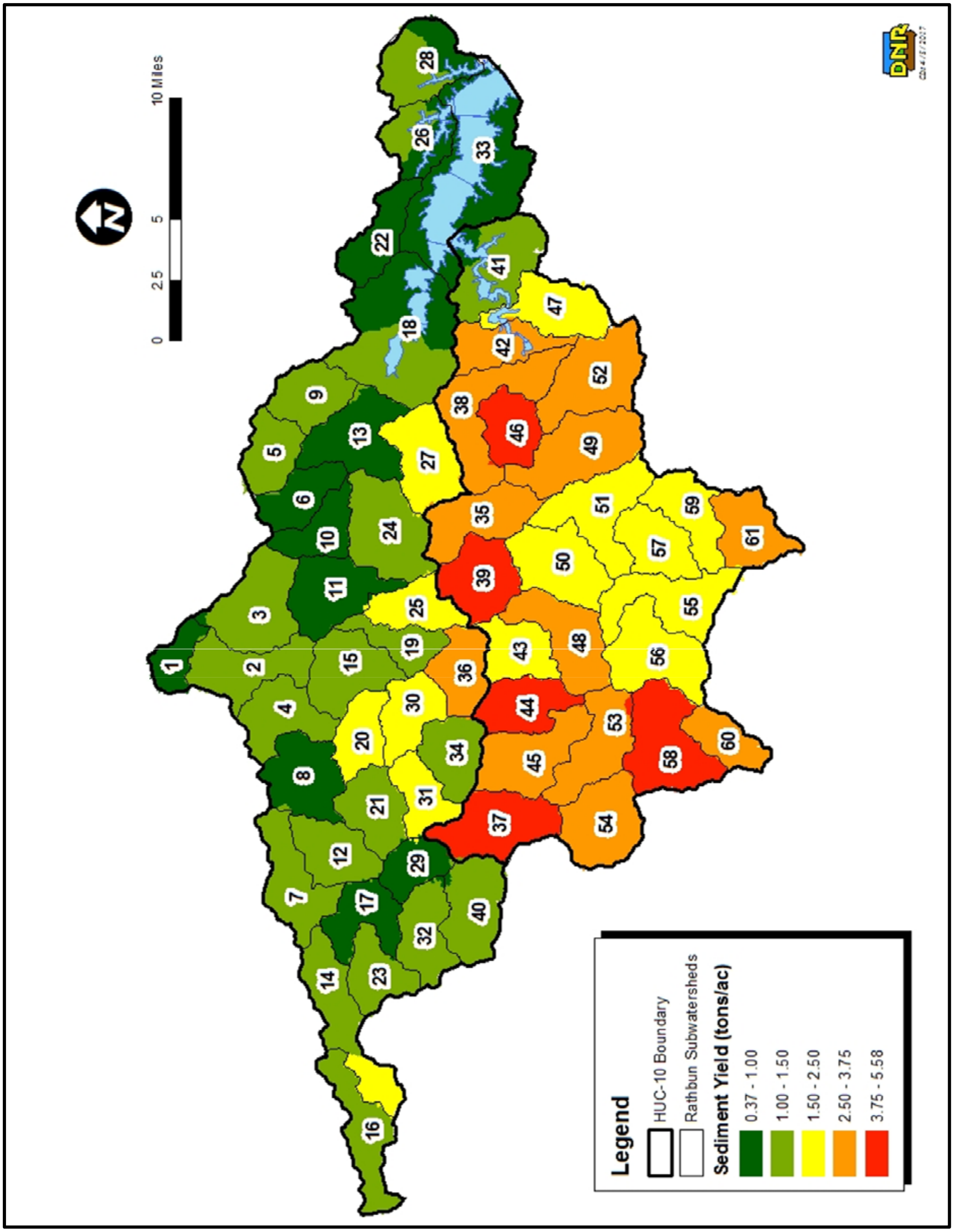


Figure 4-1. Estimated annual average sediment yields by RLWQ planning subwatersheds. Yield estimates reflect the amount of sediment delivered to the stream on a per-acre basis (2002-2013).

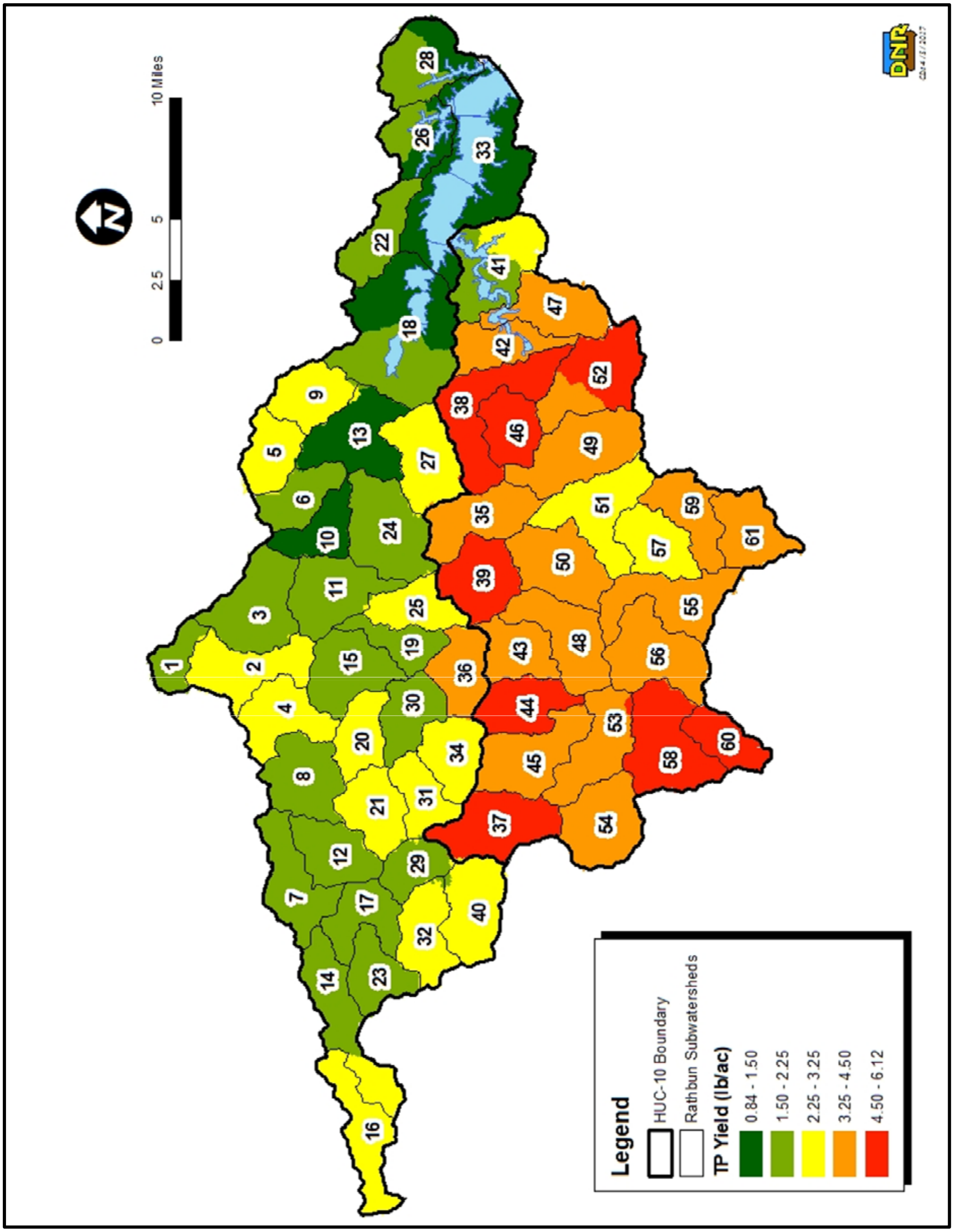


Figure 4-2. Estimated annual average TP yields by RLWQ planning subwatersheds. Yield estimates reflect the amount of sediment delivered to the stream on a per-acre basis (2002-2013).

The subwatershed analysis shows that the southern half of the watershed (i.e., the S. Fork Chariton River basin) exhibits higher sediment and TP yields than the north half (i.e., the Chariton River basin), and that yields from individual subwatersheds vary widely. Sediment and TP yields are high throughout both basins and a watershed-wide approach to water quality improvement will be needed to attain water quality goals set forth in these TMDLs. However, significant spatial variation in sediment and TP contributions from upland areas reveals the importance of prioritizing / targeting efforts, given limited resources available for implementation of conservation practices and strategies. In fact, of the 68 SWAT subbasins, the 10 that contribute the highest per-acre sediment yields contribute 38% of the upland sediment (Figure 4-3). Conversely, the 40 lowest-contributing SWAT subbasins account for only 37% of the upland sediment yield. Similarly, the 20 highest-contributing subbasins generate 58% of the upland sediment load; whereas the lowest 50 contributing subbasins contribute only 57%.

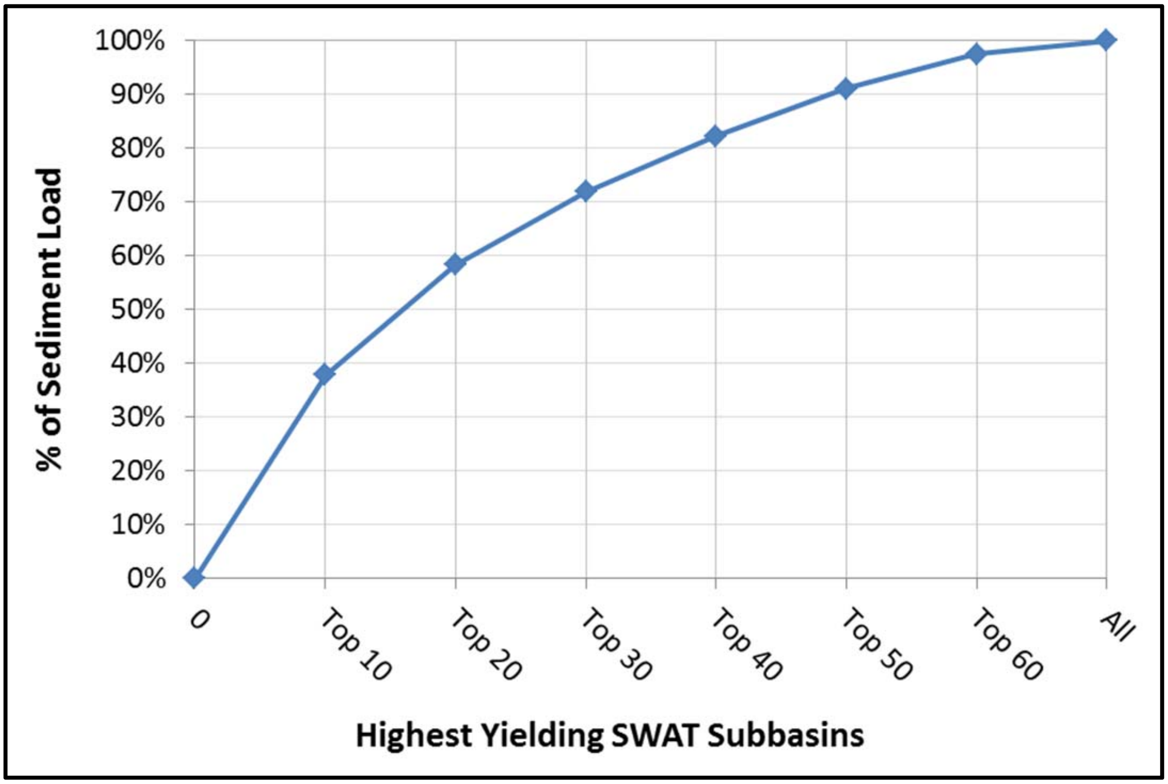


Figure 4-3. The percent of upland sediment load contributed by the highest-contributing SWAT subbasins.

Estimation of Load Reductions by Subwatershed

The subwatershed-scale sediment and TP yields were also utilized to estimate sediment-phosphorus ratios. This information may be used to calculate TP load reductions associated with erosion prevention / control practices, for which the RLWA has established procedures for estimating reductions. The ratios are provided in Table E-9 of Appendix E as a supplement to this WQIP. Overall, sediment-phosphorus ratios are generally higher in the Chariton River basin compared with the S. Fork (Figure 4-4), but there is significant variability between subwatersheds within both HUC-10s.

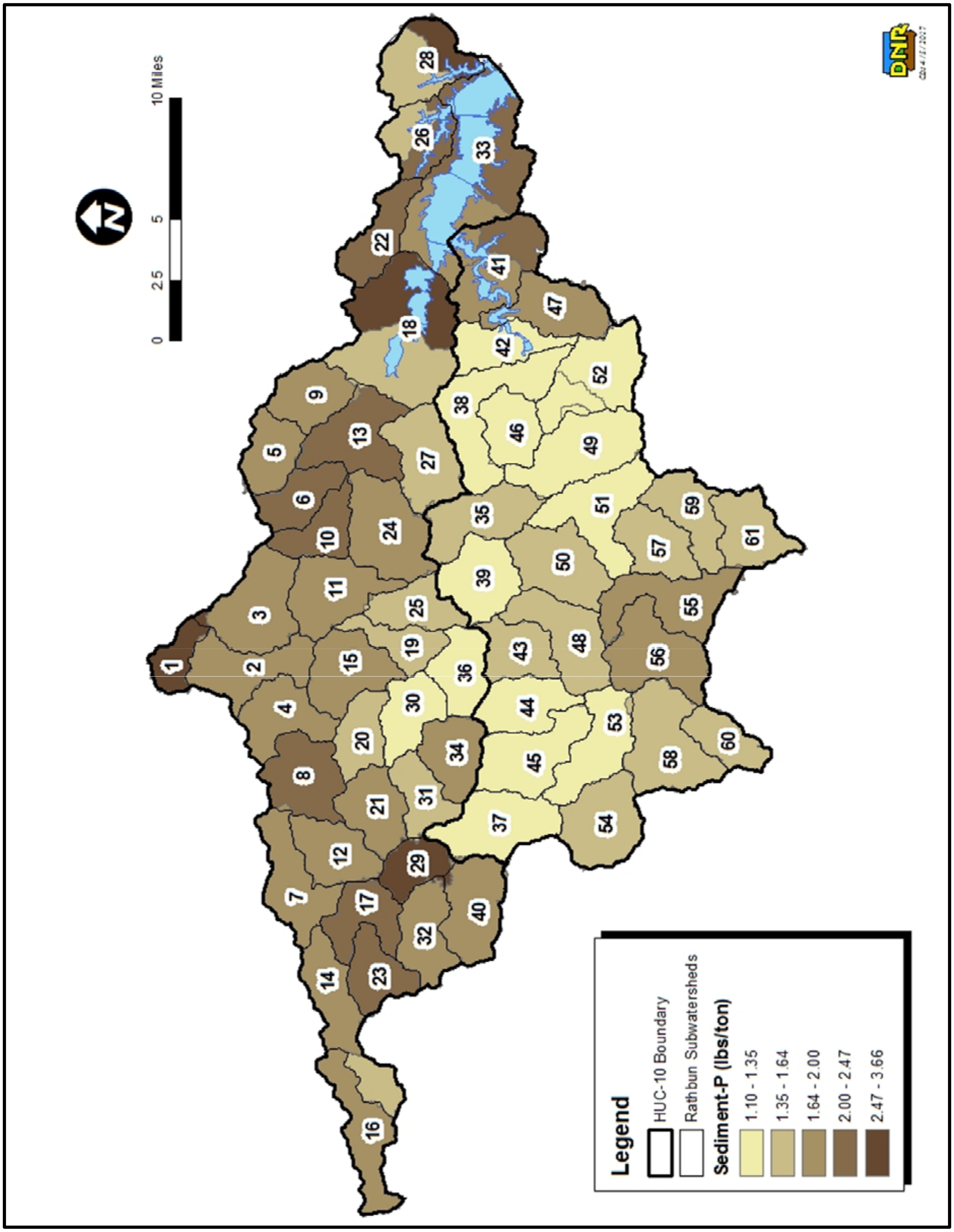


Figure 4-4. Sediment-phosphorus (lbs-P/ton-sediment) by SWAT subbasin.

4.3. Prioritization by Land Use, Soil, and Slope

Identification of Priority Areas within Subwatersheds
Spatial definition of areas having the same land use, soil type, and slope classification is a foundational component of watershed model development. These areas, called hydrologic response units (HRUs), will share similar hydrologic and pollutant transport behaviors. This information is also useful for targeting priority areas that exhibit high rates of erosion or TP loss. The RLWA already considers these characteristics in the identification of priority areas, and targets implementation to areas that have the least amount of vegetative cover, the most erodible soils, and the steepest slopes. The analysis included in development of this WQIP plan confirms this strategy, and DNR supports RLWA's current approach.

Relative Sediment and TP Yields by Land Cover
One potentially useful output from the SWAT model is the quantification of sediment and TP yields by land use category (Table 4-1). The model estimated that row crops in extended rotations may result in 35% lower sediment yields and 30% lower TP yields than conventional rotations. Perennial land uses (e.g., pasture and hay / alfalfa) provide even greater water quality benefits than diversifying corn and soybean rotations with small grains and hay. Many studies have shown that cover crops offer similar reductions in sediment and nutrient losses, as cover crops attempt to mimic perennial cover. The DNR recognizes that these types of land management strategies pose challenges for landowners and producers, and therefore implementation of structural practices is often preferred by owners / operators as well as watershed management agencies. However, ultimate attainment of water quality goals in Rathbun Lake may require encouragement of more diversity in the landscape, while maintaining agricultural productivity and use. To promote this change, benefits of increased perennial crops, such as increased organic matter, improved soil health, and improved wildlife habitat should also be encouraged.

Table 4-1. Estimated annual upland sediment and TP yields by land use.

Source	Descriptions and Assumptions	Sed Yield (tons/ac)	TP Yield (lbs/ac)
Row Crops (conventional)	Includes land in corn and soybean rotations and continuous corn	4.7	5.8
Row Crops (Extended)	Includes land in extended rotations that include small grains and/or hay in addition to row crops	3.0	4.1
Pasture/Grass	Includes grazed and ungrazed grassland. Does not include direct deposition of manure in streams	0.9	2.2
Developed Areas	Includes roads, urban areas, and rural homesteads	0.1	1.8
Alfalfa/Hay	Includes all forms of perennial hay	0.4	1.3
Timber/Forest	Includes both grazed and ungrazed timber and shrub/scrub. Does not include direct deposition of manure in streams	< 0.1	0.2

Erosion Rates by Land Use and Slope

Sorting the HRUs from highest to lowest with respect to simulated erosion rates reveals that nearly 75% of the erosion exported from the upland areas comes from only 20% of the watershed area (Figure 4-5). These high-erosion areas tend to have steep slopes and be in some kind of row crop rotation. The average erosion rate on slopes steeper than nine percent is 14.1 tons/ac for conventional rotations, 7.1 tons/ac for extended rotations, and less than 1 ton/ac from areas in some kind of perennial cover (i.e., grass, hay, or timber).

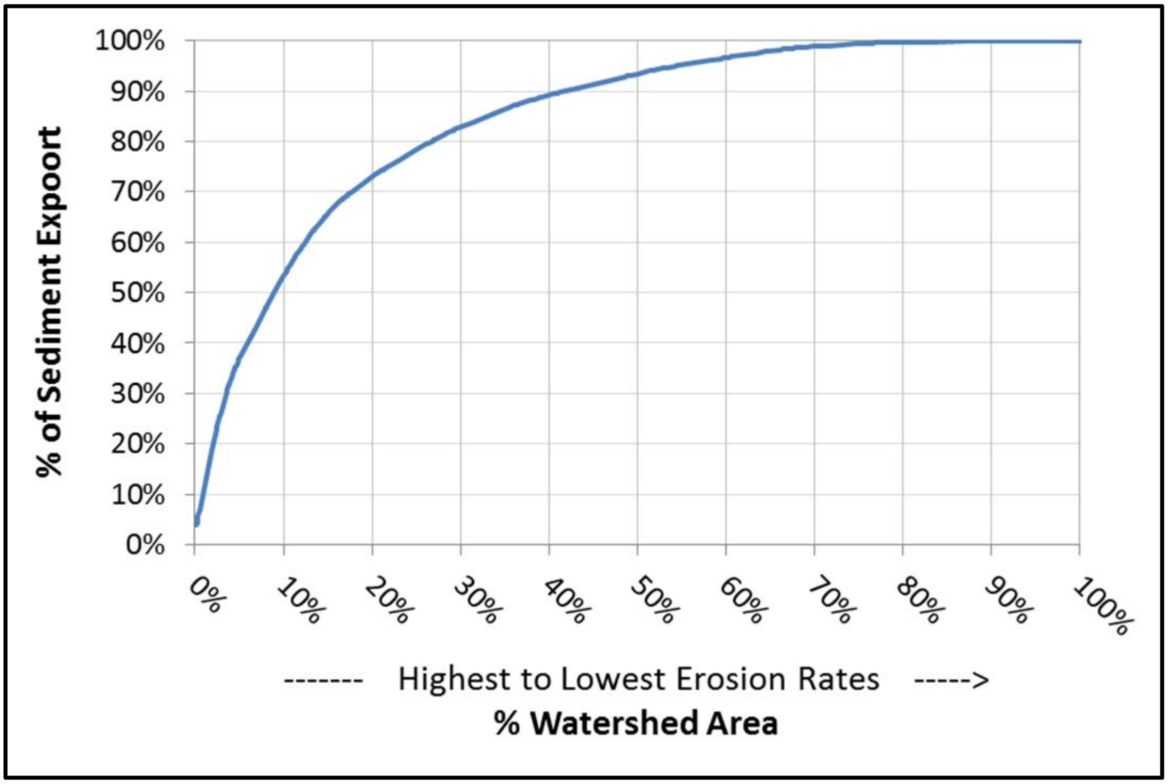


Figure 4-5. Sediment originating from watershed areas arranged from highest to lowest erosion rates.

4.4. Future Planning and Implementation

General Approach

Future watershed management and BMP implementation efforts in the Rathbun Lake watershed should utilize a phased approach. Given the large watershed-to-lake ratios and the morphology of the upper-arms of this reservoir, attainment of existing WQS at RA-7 and RA-8 will be challenging. Water quality improvement and enhancement of Rathbun Lake as a recreational resource and attainment of WQS at RA-25 and RA-3, however, are certainly attainable goals. Efforts should be targeted to maximize benefits and minimize costs using the information provided in Sections 4.2 and 4.3.

Emphasis should be placed on continued construction of structural BMPs in the watershed, based on the success RLWA has had in gaining landowner acceptance of these strategies, and their more immediate and quantifiable water quality benefits. Long-term improvement and protection may require increased promotion and adoption of non-structural (i.e., land management) practices that increase infiltration (thereby reducing runoff and erosion), keep the soil covered with vegetation, and minimize direct inputs by livestock or other sources. The added benefit of increased soil organic matter should be emphasized when encouraging adoption of land management practices. Projects with multiple benefits (e.g., wildlife habitat, soil conservation, and water quality) may have increased landowner and public buy-in than practices focused solely on water quality.

Timeline

Planning and implementation of specific improvement projects may take several years, depending on stakeholder interest, availability of funds, landowner participation, and time needed for design and construction of structural BMPs. On a watershed-wide scale, implementation must be an on-going process that is never truly complete. Realization and documentation of significant water quality benefits may take 10 years or longer, depending on weather patterns, amount of water quality data collected, and the degree of success with selection, location, design, construction, and maintenance of BMPs. It may be appropriate to set shorter-term goals of WQS attainment at RA-3 and RA-25, while viewing attainment of goals in the upper arms of the lake as long-term (i.e., generational) goals.

Tracking Milestones and Progress

A monitoring plan, based on the one outlined in Section 5 of this WQIP, would address several requirements of an EPA-approved nine-element plan. An approved nine-element plan will be needed to obtain additional 319 funds. Establishment of specific short, intermediate, and long-term water quality goals and milestones would also be needed to acquire 319 funding. A path to full attainment of water quality standards and designated uses must be included, but efforts should first focus on documenting water quality improvement resulting from BMPs and elimination of any sediment and phosphorus "hot spots" that may exist.

Connecting Implementation and In-Lake Water Quality

Ideally, flow and water quality monitoring data will be collected at a level of detail sufficient for documenting sediment and TP loads and in-lake water quality trends (see Section 5 of this WQIP). In practice, however, this is challenging. Often, the frequency and scale of data required to document a statistically-significant outcome or trend is cost-prohibitive. Further, variations in rainfall and streamflow and / or evolving land use patterns are the primary driver of short-term changes in pollutant transport and water quality. As a result, it can take many years of data to provide statistical evidence of "real" change in water quality. In the absence of sufficient tributary and in-lake data, potential water quality impacts of TP load reductions can be estimated using: (i) current load reduction estimate procedures, (ii) updated source information provided in Section 4 WQIP, and (iii) the in-lake water quality mode (BATHTUB) described in Appendix F.

4.5. Best Management Practices

No stand-alone conservation practice will be able to sufficiently reduce phosphorus loads to Rathbun Lake. Rather, a comprehensive package of BMPs will be required to adequately reduce sediment and phosphorus transport to the lake. The majority of phosphorus that enters the lake is from both upland erosion and streambank / channel erosion in the many tributary streams that drain to the lake. However, losses from developed areas, septic systems, and even grass and timber areas occur. Each of these sources has distinct phosphorus transport pathways and processes; therefore, each requires a different set of BMPs and strategies. Potential BMPs are grouped into three types: land management (prevention), structural (mitigation), and in-lake alternatives (remediation).

Land Management (Prevention Strategies)
Many agricultural BMPs are designed to reduce erosion and nutrient loss from the landscape. These BMPs provide a combination of water quality, soil conservation, and soil health benefits, because they prevent erosion and nutrient loss from occurring. Land management alternatives implemented in row crop areas should include conservation practices such as contour or cross-slope farming, no-till and strip-till farming, diversified crop rotation methods, utilization of in-field perennial strips / buffers, planting cover crops, and nutrient / manure management strategies. Potential TP reductions associated with these practices are listed in Table 4-2.

Table 4-2. Potential land management BMPs (prevention strategies).

BMP or Activity	[1] Potential TP Reduction
Conservation Tillage:	
Moderate vs. Intensive Tillage	50%
No-Till vs. Intensive Tillage	70%
No-Till vs. Moderate Tillage	45%
Cover Crops	50%
Diversified Cropping Systems (i.e., extended rotations)	50%
In-Field Vegetative Buffers	50%
Pasture/Grassland Management:	
Livestock Exclusion from Streams	75%
Rotational Grazing vs. Constant Intensive Grazing	25%
Seasonal Grazing vs. Constant Intensive Grazing	50%
Phosphorus Nutrient Application Techniques	
[2]Deep Tillage Incorporation vs. Surface Broadcast	-15%
[2]Shallow Tillage Incorporation vs. Surface Broadcast	-10%
Knife/Injection Incorporation vs. Surface Broadcast	35%
Phosphorus Nutrient Application Timing and Rates:	
Spring vs. Fall Application	30%
Soil-Test P Rate vs. Over-Application Rates	40%
Application: 1-month prior to runoff event vs. 1-day	30%

[1] Adopted from Dinnes (2004) with professional judgment. Actual reduction percentages may vary widely across sites and runoff events.

[2] Note: Tillage incorporation can increase TP in runoff in some cases.

The Rathbun Lake watershed has extensive grazed pastures, and many are adjacent to tributary streams. Though not suspected to be a large source of sediment and phosphorus, even a few acres of pasture with direct access to the stream affects instream conditions and could eventually impact water quality in the lake. Well-managed pastures, however, have very little negative impact and can even improve water quality, since the soil is covered with vegetation year-round. Stable and diverse pasture forages hold soil in place, filter runoff, and uptake nutrients throughout a long growing season compared to annual row crops. Exclusion of livestock from streams and riparian areas can provide additional water quality benefits. Rotational grazing systems can improve water quality in adjacent waterbodies compared with continuously grazed systems. There is evidence that forage diversity, degree of vegetation coverage / residue, and regrowth rates are higher in rotationally-grazed pastures (Dinnes, 2004). These characteristics increase erosion protection, reduce and filter runoff, and provide increased nutrient uptake compared with continually grazed grasses and forages.

Structural BMPs (Mitigation Strategies)

Although they do not address the underlying generation of sediment or nutrients, structural BMPs such as sediment control basins, terraces, grass waterways, riparian buffers, and wetlands can play an essential role in reduction of sediment and nutrient transport to Rathbun Lake. These BMPs attempt to mitigate the impacts of soil erosion and nutrient loss by intercepting them before they reach a stream or lake. Structural BMPs should be targeted to priority areas to increase their cost effectiveness and maximize pollutant reductions. Landowner willingness and the physical features of potential sites must also be considered when targeting structural practices. These practices may offer additional benefits not directly related to water quality improvement. These secondary benefits are important to emphasize to increase landowner and public interest and adoption. Potential structural BMPs are listed in Table 4-3, which includes secondary benefits and potential TP reductions.

Landowner buy-in, ease of construction, and difficulty implementing preventative land management measures all contribute to the popularity of sediment control structures as a sediment and phosphorus mitigation strategy. This is a proven practice, if properly located, designed, constructed, and maintained. However, if not properly designed and constructed, sediment control basins may trap substantially less sediment and phosphorus than widely-used rules-of-thumb that are often assumed when quantifying reductions in the context of a watershed management plan. There are at least three general criteria that should be considered when designing sediment control basins. First, the size of the basin should be appropriate relative to the size of the drainage area. Effective sediment control basins require a minimum size of at least one percent of the total drainage area to the basin. Second, drawdown times (i.e., the time it takes for runoff from a storm event to drain from the basin) should be no less than 24 hours, and preferably 40 hours. Shorter drawdown periods do not adequately settle fine sediments, which carry a large portion of attached phosphorus. Third, sediment basins should be shaped such that the length-to-width ratio is maximized to prevent short-circuiting across a short flow-path through the basin. A minimum length to width ratio of 3:1 is commonly cited in the literature.

To obtain reductions in TP load necessary to meet water quality targets, land management strategies and structural BMPs should be implemented to obtain the largest and most cost-effective water quality benefit. Targeting efforts should consider areas with the highest potential phosphorus loads to the lake (refer to Sections 4.2 and 4.3).

Table 4-3. Potential structural BMPs (mitigation strategies).

BMP or Activity	Secondary Benefits	[1] Potential TP Reduction
Terraces	Soil conservation, prevent in-field gullies, prevent wash-outs	50%
Grass Waterways	Prevent in-field gullies, prevent washouts, some ecological services	50%
[2]Sediment Control Structures	Some ecological services, gully prevention	Varies
[3]Wetlands	Ecological services, potential flood mitigation, aesthetic value	15%
[4]Sediment Forebay	Ecological services, aesthetic value	55%
Riparian Buffers	Ecological services, aesthetic value, alternative agriculture	45%

[1] Adopted from Dinnes (2004) with professional judgment. Actual reduction percentages may vary widely across sites and runoff events.

[2] Not discussed in Dinnes (2004). Phosphorus removal in sediment basins varies widely and is dependent upon the size of the structure relative to the drainage area, the length:width ratio, and drawdown time of a specified rainfall/runoff event.

[3] Note: TP reductions in wetlands vary greatly depending on site-specific conditions, such as those listed for sediment control structures. Generally, removal of phosphorus is lower in wetlands than in sediment control structures. Wetland can sometimes be sources, rather than sinks, of phosphorus

[4] Average of removal efficiencies from EPA Wet Pond Fact Sheet (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=68)

In-Lake BMPs (Remediation Strategies)

Phosphorus recycled between the bottom sediment and water column of the lake is, at times, an important contributor of bioavailable phosphorus in some lakes. The average annual contribution of TP to the system from internal loading appears to be relatively small in Rathbun Lake. The reservoir has very large watershed-to-lake ratios in the upper arms of the lake, so external inputs typically dwarf internal recycling. However, certain conditions, such as extended high wind speeds, may reduce sediment settling in the lake or even cause bottom sediments in shallow areas to be temporarily resuspended, which decreases water clarity (refer to Section 3.2 for more detail)

Even in lakes with significant potential for internal loading, which does not appear to be the case in Rathbun Lake, external loads from wet weather supply the build-up of sediment and phosphorus. Additionally, the sheer size and depth of Rathbun Lake likely makes many of the in-lake alternatives cost-prohibitive. Therefore, reductions from watershed sources of sediment and TP should be given implementation priority. Despite being a lower priority in terms of water quality impact, descriptions of potential in-lake restoration methods are included in Table 4-4. Phosphorus reduction percentages of each alternative will vary and depend on a number of site-specific factors.

Table 4-4. Potential in-lake BMPs for water quality improvement.

In-Lake BMPs	Comments
Fisheries management	Moderate reductions in internal phosphorus load may be attained via fisheries improvement. The potential reduction of in-lake phosphorus as a result of this practice is uncertain, but the overall health of the aquatic ecosystem may be improved, which typically improves overall water quality as well. The size and depth of the reservoir may make a full fish renovation impractical in Rathbun Lake.
Targeted dredging and sediment forebay improvement	Targeted dredging in shallow inlet areas would create pockets of habitat for predatory fish that would help control rough fish populations. Strategic dredging would also increase the sediment capacity of the inlet areas, thereby reducing sediment and phosphorus loads to the larger, open water area of the lake. Sediment and phosphorus capture via construction of forebays in the upper reaches of the lake may be challenging, given the size of the watershed and peak flows experienced in the major tributaries to Rathbun Lake.
Shoreline stabilization	Helps establish and sustain vegetation, which provides erosion protection and competes with algae for nutrients. Lake-wide water quality impacts of individual projects may be small, but can improve water clarity near the affected shoreline. Cumulative effects of widespread stabilization projects can be an important part of overall water quality improvement as well. The entire shoreline of Rathbun Lake is publicly owned, making this alternative feasible from an access and permission standpoint. Because of rapid and significant changes in water level in this reservoir, shoreline erosion is a documented problem.

4.6. References

Rathbun Land and Water Alliance (RLWA). 2001. Assessment and Management Strategies for the Rathbun Lake Watershed. A cooperative effort by the members and partners of the Rathbun Land and Water Alliance. December 2001.

Rathbun Land and Water Alliance (RLWA). 2014. Protect Rathbun Lake: Interim Watershed Management Plan (2014-2019).

Rathbun Land and Water Alliance (RLWA). 2017. Board Briefs: A Newsletter for Rathbun Land and Water Alliance. Volume 13, Issue 2. Published March, 2017.

5. Future Monitoring

Monitoring is critical for assessing the current status of water quality as well as historical and future trends. Furthermore, monitoring is necessary to track the effectiveness of best management practice (BMP) implementation and to document attainment of total maximum daily loads (TMDLs) and progress towards water quality standards (WQS).

Past monitoring efforts in the Rathbun Lake and its watershed are described in detail in Appendix C of this Water Quality Improvement Plan (WQIP). Future monitoring will depend on continued financial resources, commitment, and collaboration of local partners such as the Rathbun Land & Water Alliance (RLWA), the Iowa Department of Natural Resources (DNR), and the U.S. Army Corps of Engineers (USACE). Ideally, monitoring efforts should include an approved Quality Assurance Project Plan (QAPP), in accordance with Iowa Administrative Code (IAC) 567-61.10(455B) through 567-61.13(455B). Failure to prepare an approved QAPP will prevent data collected from being used to evaluate waterbody in the 305(b) Integrated Report – the biannual assessment of water quality in the state, and the 303(d) list – the list that identifies impaired waterbodies.

5.1. Basic Monitoring for Water Quality Assessment

Without continued support from local partners, future data collection in Rathbun Lake will likely be limited to in-lake grab samples at RA-7, RA-8, RA-3, and RA-25 (Figure 5-1). The DNR will continue to collect data at RA-3 as part of the ambient monitoring program, and USACE will continue to collect grab samples at the other three locations (barring unforeseen changes in funding / resources). These data will be utilized primarily to assess water quality trends in the lake, compliance / exceedance of water quality standards (WQS), and will be used for 303(d) listing and delisting purposes.

Sampling parameters will includes those listed in Tables C-11 through C-14 of Section C.4 and water column profile data illustrated in Figures C-3 through C-6 of Section C.5. The DNR ambient monitoring includes at least three sampling events every summer between Memorial Day and Labor Day. USACE in-lake data will be collected once a month from April through September. While the DNR and USACE in-lake grab sampling can be used to identify long-term trends in water quality, it does not lend itself to assessment of short-term trends or phenomena (such as resuspension or mixing), calculation of watershed loads, identification of individual pollutant sources, or the evaluation of BMP implementation.

5.2. Recommended Watershed Monitoring for Tracking Loads

If the goal of monitoring is to evaluate spatial and temporal trends in sediment and phosphorus exports to the lake from the watershed and the impacts of BMP implementation on water quality, continued watershed / tributary monitoring, in addition to basic in-lake monitoring, is recommended. Pre-TMDL monitoring included regularly-scheduled grab sampling and automated, event-based monitoring at four locations in the

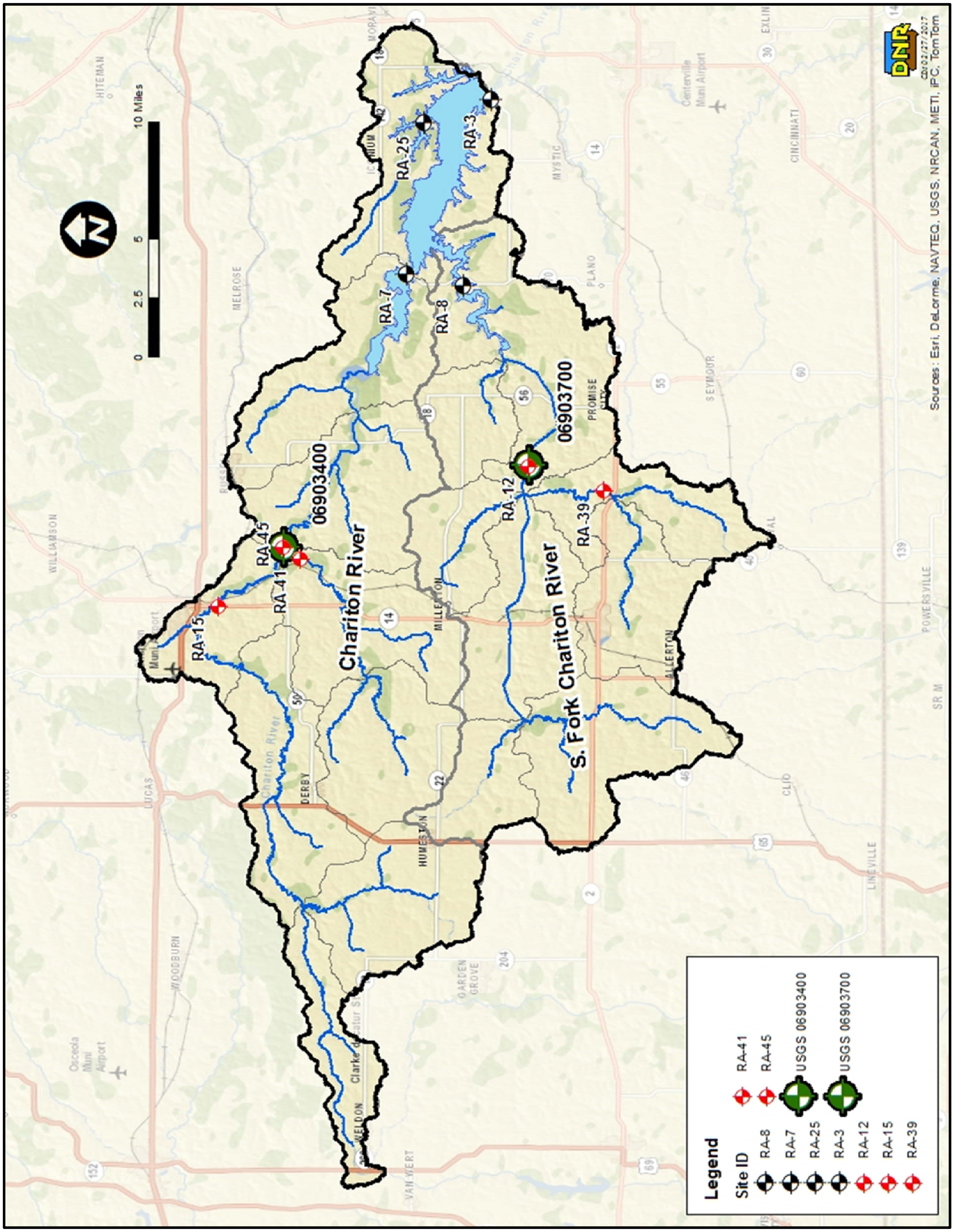


Figure 5-1. Monitoring location map.

watershed: RA-15 on the Chariton River, RA-41 on Wolf Creek, RA-12 on the South Fork Chariton (at USGS gaging station 06903700), and RA-39 on Jackson Creek (Figure 5-1). Since 2014, event-based monitoring has continued at RA-12 and at the USGS gaging station 06903400 located immediately downstream of the confluence of Wolf Creek (RA-41) and the Chariton River (RA-15). Flow, event-based, and occasional grab sampling at RA-12 and RA-45 on an on-going basis will allow reasonable estimates of annual (and perhaps monthly) sediment and TP loads entering the lake from the watershed, and will allow watershed and lake managers to relate spatial and temporal trends in watershed loads to observed water quality in the lake. However, this recommended monitoring lacks the resolution necessary to quantify the impacts of watershed / water quality improvement practices implemented in priority areas (at either the subwatershed or field scale).

5.3. Potential Expanded Monitoring for Assessing Implementation

If the evaluation of spatial patterns of sediment and phosphorus transport and / or the impacts of BMP adoption on sediment and nutrient loss is desired, then an expanded watershed monitoring plan that includes higher resolution of data collection is recommended. This monitoring should include collection of flow, grab samples, and potentially event-based samples at smaller scales than past and present watershed monitoring. At a minimum, water quality parameters should include sediment and TP, but collection of dissolved phosphorus and nitrogen-related data may also be of interest to stakeholders, even though they are not causing the current impairments.

To assess the impact of BMP implementation in RLWA planning subbasins, the type of monitoring at RA-12 could be conducted at several small subwatershed outlets. Additionally, a paired watershed sampling approach could be taken that collects similar data at two locations: (i) the outlet of a subwatershed with relatively little implementation (i.e., the control subwatershed) and (ii) the outlet of a subwatershed with a high degree of implementation. Targeted monitoring of this nature would either provide confidence that implementation efforts are improving water quality, or supply evidence that practices are not having the desired effect and that implementation strategies need refinement / adaptation. If more information about the performance of individual practices is desired, edge-of-field scale monitoring could be conducted, as well as inflow / outflow monitoring of structural BMPs.

5.4. Potential Expanded Monitoring for Advanced In-Lake Assessment

Although the historical in-lake grab sampling is adequate for assessing long-term, average conditions in four areas of the lake, it cannot be utilized to explain the dynamic nature of water quality based on weather phenomena, seasonal trends, or internal processes (i.e., mixing, resuspension, and anoxia). To provide insight into the short-term behavior of the lake, more advanced in-lake monitoring would be necessary. This could include higher frequency of grab samples, deployment of continuous data loggers, and evaluation of the hypolimnion and sediment-water interface at the bottom of the lake.

To determine what type of additional data collect may be desired and warranted, lake and watershed stakeholders need to develop a list of goals and objective and ask themselves what current questions cannot be answered with existing information. Table 5-1 provides a summary of varies types of monitoring, listed in order of most basic to most complex / detailed (within each location).

Table 5-1. Potential monitoring and data collection.

Location / Scale	Type	Parameters	Purpose(s)
In-Lake	Monthly grab samples	Historical DNR and USACE parameters (Appendix C)	Detect in-lake WQ trends and evaluate impairment status.
	Weekly to biweekly grab samples throughout the year	Same as above	Evaluate short-term trends and potential impacts of weather events, seasons, etc. Potentially useful for more advanced in-lake modeling.
	Continuous data loggers	Temperature, DO, pH, and Chl-a	Evaluate the diurnal nature of algal blooms. Potentially useful for evaluation of internal/mixing dynamics. Potentially useful for more advanced in-lake modeling.
Watershed (vary spatial scale with needs / goals)	Monthly or semi-monthly grab samples	Flow, sediment, phosphorus[1]	Detect changes in baseflow concentrations. Helpful for development of load estimates.
	Runoff events with automated samplers [2]	Flow, sediment, phosphorus[1]	Essential for development of load estimates. Potentially useful for watershed model refinement.
Edge of Field	Runoff events with automated samplers	Flow, sediment, phosphorus[1]	Calculate pollutant loads and improvement after BMP implementation; especially useful in a paired field/catchment study.
BMP Inflow / Outflow	Grab samples or event samples	Flow, sediment, phosphorus[1]	Evaluate the pollutant removal associated with specific BMPs or BMP types.

[1] Sediment and TP are most relevant to current impairments. Other parameters (e.g., nitrogen, atrazine, etc.) could be added for developing baseline information for potential/future issues.
[2] Event-based sampling is more important for estimating sediment and TP loads, which cause the current impairments. Therefore, this should be given priority over grab samples.

6. Public and Stakeholder Participation

Public involvement is important in the Total Maximum Daily Load (TMDL) process since it is the land owners, tenants, and citizens who directly manage land and live in the watershed that determine the water quality in Rathbun Lake.

6.1. Stakeholder Meetings

August 5, 2014
A stakeholder meeting with the Rathbun Regional Water Association (RRWA) was held at the RRWA office in Centerville, Iowa, to introduce the TMDL development process and talk about relevant data collection, modeling, and planning efforts. Attendees included RRWA staff, personnel from local Soil and Water Conservation Districts (SWCDs) that are actively engaged with watershed improvement activities of the Rathbun Land & Water Alliance (RLWA), and a beef cattle specialist from Iowa State University-Extension and Outreach. The discussion included modeling needs, potential model selection, and stakeholder planning and technical support needs.

September 29, 2015
A second stakeholder meeting with the Rathbun Regional Water Association (RRWA) was held at the RRWA office in Centerville, Iowa, to present initial findings / simulations of in-lake response to pollutant load reductions. The final selection of the watershed model methodology was discussed to ensure maximum utility of the model for long-term planning and assessment efforts by stakeholders.

April 1, 2016 and April 7, 2017
Iowa DNR Watershed Improvement Section staff provided TMDL and monitoring updates at the annual Rathbun Land and Water Alliance (RLWA) board meetings. Attendees included staff from RRWA/RLWA, The U.S. Army Corps of Engineers (USACE), DNR Lakes Restoration, Iowa Department of Agriculture and Land Stewardship (IDALS), Natural Resources Conservation Service (NRCS), other soil and water related agencies, and local residents, agricultural producers, and land owners.

6.2. Public Meetings

July, 6, 2017
A public meeting to present the results of the TMDL study, obtain stakeholder input, and discuss next steps for water quality improvement was held at the Pin Oak Lodge in Chariton, Iowa from 6:00 to 7:30 on July 6, 2017.

6.3. Written Comments

The public comment period began June 22 and ended July 24, 2017. No public comments were received during the public comment period.

Appendix A --- Glossary of Terms, Abbreviations, and Acronyms

303(d) list:	Refers to section 303(d) of the Federal Clean Water Act, which requires a listing of all public surface waterbodies (creeks, rivers, wetlands, and lakes) that do not support their general and/or designated uses. Also called the state's "Impaired Waters List."
305(b) assessment:	Refers to section 305(b) of the Federal Clean Water Act, it is a comprehensive assessment of the state's public waterbodies' ability to support their general and designated uses. Those bodies of water which are found to be not supporting or only partially supporting their uses are placed on the 303(d) list.
319:	Refers to Section 319 of the Federal Clean Water Act, the Nonpoint Source Management Program. Under this amendment, States receive grant money from EPA to provide technical & financial assistance, education, & monitoring to implement local nonpoint source water quality projects.
AFO:	Animal Feeding Operation. A lot, yard, corral, building, or other area in which animals are confined and fed and maintained for 45 days or more in any 12-month period, and all structures used for the storage of manure from animals in the operation. Open feedlots and confinement feeding operations are considered to be separate animal feeding operations.
AU:	Animal Unit. A unit of measure used to compare manure production between animal types or varying sizes of the same animal. For example, one 1,000 pound steer constitutes one AU, a butcher or breeding swine weighing more than 55 pounds constitutes 0.4 AU.
Benthic:	Associated with or located at the bottom (in this context, "bottom" refers to the bottom of streams, lakes, or wetlands). Usually refers to algae or other aquatic organisms that reside at the bottom of a wetland, lake, or stream (see periphyton).
Benthic macroinvertebrates:	Animals larger than 0.5 mm that do not have backbones. These animals live on rocks, logs, sediment, debris and aquatic plants during some period in their life. They include crayfish, mussels, snails, aquatic worms, and the immature forms of aquatic insects such as stonefly and mayfly nymphs.
Base flow:	Sustained flow of a stream in the absence of direct runoff. It can

	include natural and human-induced stream flows. Natural base flow is sustained largely by groundwater discharges.
Biological impairment:	A stream segment is classified as biologically impaired if one or more of the following occurs, the FIBI and or BMIBI scores fall below biological reference conditions, a fish kill has occurred on the segment, or the segment has seen a > 50% reduction in mussel species.
Biological reference condition:	Biological reference sites represent the least disturbed (i.e. most natural) streams in the ecoregion. The biological data from these sites are used to derive least impacted BMIBI and FIBI scores for each ecoregion. These scores are used to develop Biological Impairment Criteria (BIC) scores for each ecoregion. The BIC is used to determine the impairment status for other stream segments within an ecoregion.
BMIBI:	Benthic Macroinvertebrate Index of Biotic Integrity. An index-based scoring method for assessing the biological health of streams and rivers (scale of 0-100) based on characteristics of bottom-dwelling invertebrates.
BMP:	Best Management Practice. A general term for any structural or upland soil or water conservation practice. For example terraces, grass waterways, sediment retention ponds, reduced tillage systems, etc.
CAFO:	Concentrated Animal Feeding Operation. A federal term defined as any animal feeding operation (AFO) with more than 1000 animal units confined on site, or an AFO of any size that discharges pollutants (e.g. manure, wastewater) into waters of the United States through a manmade ditch, flushing system, or other similar man-made device
CBOD5:	5-day Carbonaceous Biochemical Oxygen Demand. Measures the amount of oxygen used by microorganisms to oxidize hydrocarbons in a sample of water at a temperature of 20°C and over an elapsed period of five days in the dark.
CFU:	A Colony Forming Unit is a cell or cluster of cells capable of multiplying to form a colony of cells. Used as a unit of bacteria concentration when a traditional membrane filter method of analysis is used. Though not necessarily equivalent to most probably number (MPN), the two terms are often used interchangeably.
Confinement	An animal feeding operation (AFO) in which animals are

feeding operation:	confined to areas which are totally roofed.
Credible data law:	Refers to 455B.193 of the Iowa Administrative Code, which ensures that water quality data used for all purposes of the Federal Clean Water Act are sufficiently up-to-date and accurate. To be considered “credible,” data must be collected and analyzed using methods and protocols outlined in an approved Quality Assurance Project Plan (QAPP).
Cyanobacteria (blue-green algae):	Members of the phytoplankton community that are not true algae but are capable of photosynthesis. Some species produce toxic substances that can be harmful to humans and pets.
Designated use(s):	Refer to the type of economic, social, or ecological activities that a specific waterbody is intended to support. See Appendix B for a description of all general and designated uses.
DNR:	Iowa Department of Natural Resources.
Ecoregion:	Areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources based on geology, vegetation, climate, soils, land use, wildlife, and hydrology.
EPA (or USEPA):	United States Environmental Protection Agency.
Ephemeral gully erosion:	Ephemeral gullies occur where runoff from adjacent slopes forms concentrated flow in drainage ways. Ephemerals are void of vegetation and occur in the same location every year. They are crossable with farm equipment and are often partially filled in by tillage.
FIBI:	Fish Index of Biotic Integrity. An index-based scoring method for assessing the biological health of streams and rivers (scale of 0-100) based on characteristics of fish species.
FSA:	Farm Service Agency (United States Department of Agriculture). Federal agency responsible for implementing farm policy, commodity, and conservation programs.
General use(s):	Refer to narrative water quality criteria that all public waterbodies must meet to satisfy public needs and expectations. See Appendix B for a description of all general and designated uses.
Geometric Mean	A statistic that is a type of mean or average (different from

(GM):	arithmetic mean or average) that measures central tendency of data. It is often used to summarize highly skewed data or data with extreme values such as wastewater discharges and bacteria concentrations in surface waters. In Iowa's water quality standards and assessment procedures, the geometric mean criterion for *E. coli* is measured using at least five samples collected over a 30-day period.
GIS:	Geographic Information System(s). A collection of map-based data and tools for creating, managing, and analyzing spatial information.
Groundwater:	Subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated.
Gully erosion:	Soil movement (loss) that occurs in defined upland channels and ravines that are typically too wide and deep to fill in with traditional tillage methods.
HEL:	Highly Erodible Land. Defined by the USDA Natural Resources Conservation Service (NRCS), it is land, which has the potential for long-term annual soil losses to exceed the tolerable amount by eight times for a given agricultural field.
IDALS:	Iowa Department of Agriculture and Land Stewardship
Integrated report:	Refers to a comprehensive document that combines the 305(b) assessment with the 303(d) list, as well as narratives and discussion of overall water quality trends in the state's public waterbodies. The Iowa Department of Natural Resources submits an integrated report to the EPA biennially in even numbered years.
LA:	Load Allocation. The portion of the loading capacity attributed to (1) the existing or future nonpoint sources of pollution and (2) natural background sources. Wherever possible, nonpoint source loads and natural loads should be distinguished. (The total pollutant load is the sum of the wasteload and load allocations.)
LiDAR:	Light Detection and Ranging. Remote sensing technology that uses laser scanning to collect height or elevation data for the earth's surface.
Load:	The total amount of pollutants entering a waterbody from one or

	multiple sources, measured as a rate, as in weight per unit time or per unit area.
Macrophyte:	An aquatic plant that is large enough to be seen with the naked eye and grows either in or near water. It can be floating, completely submerged (underwater), or partially submerged.
MOS:	Margin of Safety. A required component of the TMDL that accounts for the uncertainty in the response of the water quality of a waterbody to pollutant loads.
MPN:	Most Probable Number. Used as a unit of bacteria concentration when a more rapid method of analysis (such as Colisure or Colilert) is utilized. Though not necessarily equivalent to colony forming units (CFU), the two terms are often used interchangeably.
MS4:	Municipal Separate Storm Sewer System. A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) owned and operated by a state, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to state law) having jurisdiction over disposal of sewage, industrial wastes, stormwater, or other wastes, including special districts under state law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the Clean Water Act (CWA) that discharges to waters of the United States.
Nonpoint source pollution:	Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related either to land or water use including failing septic tanks, improper animal-keeping practices, forestry practices, and urban and rural runoff.
NPDES:	National Pollution Discharge Elimination System. The national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under Section 307, 402, 318, and 405 of the Clean Water Act. Facilities subjected to NPDES permitting regulations include operations such as municipal wastewater treatment plants and industrial waste treatment facilities, as well as some MS4s.
NRCS:	Natural Resources Conservation Service (United States

	Department of Agriculture). Federal agency that provides technical assistance for the conservation and enhancement of natural resources.
Open feedlot:	An unroofed or partially roofed animal feeding operation (AFO) in which no crop, vegetation, or forage growth or residue cover is maintained during the period that animals are confined in the operation.
Periphyton:	Algae that are attached to substrates (rocks, sediment, wood, and other living organisms). Are often located at the bottom of a wetland, lake, or stream.
Phytoplankton:	Collective term for all photosynthetic organisms suspended in the water column. Includes many types of algae and cyanobacteria.
Point source pollution:	Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources are generally regulated by a federal NPDES permit.
Pollutant:	As defined in Clean Water Act section 502(6), a pollutant means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water.
Pollution:	The man-made or man-induced alteration of the chemical, physical, biological, and/or radiological integrity of water.
PPB:	Parts per Billion. A measure of concentration that is the same as micrograms per liter (µg/L).
PPM:	Parts per Million. A measure of concentration that is the same as milligrams per liter (mg/L).
RASCAL:	Rapid Assessment of Stream Conditions Along Length. RASCAL is a global positioning system (GPS) based assessment procedure designed to provide continuous stream and riparian condition data at a watershed scale.
Riparian:	Refers to areas near the banks of natural courses of water.

	Features of riparian areas include specific physical, chemical, and biological characteristics that differ from upland (dry) sites. Usually refers to the area near a bank of a stream or river.
RUSLE:	Revised Universal Soil Loss Equation. An empirical model for estimating long term, average annual soil losses due to sheet and rill erosion.
Scientific notation:	See explanation on page 107.
Secchi disk:	A device used to measure transparency in waterbodies. The greater the Secchi depth (typically measured in meters), the more transparent the water.
Sediment delivery ratio:	A value, expressed as a percent, which is used to describe the fraction of gross soil erosion that is delivered to the waterbody of concern.
Seston:	All particulate matter (organic and inorganic) suspended in the water column.
SHL:	State Hygienic Laboratory (University of Iowa). Provides physical, biological, and chemical sampling for water quality purposes in support of beach monitoring, ambient monitoring, biological reference monitoring, and impaired water assessments.
Sheet & rill erosion:	Sheet and rill erosion is the detachment and removal of soil from the land surface by raindrop impact, and/or overland runoff. It occurs on slopes with overland flow and where runoff is not concentrated.
Single-Sample Maximum (SSM):	A water quality standard criterion used to quantify *E. coli* levels. The single-sample maximum is the maximum allowable concentration measured at a specific point in time in a waterbody.
SI:	Stressor Identification. A process by which the specific cause(s) of a biological impairment to a waterbody can be determined from cause-and-effect relationships.
Storm flow (or stormwater):	The discharge (flow) from surface runoff generated by a precipitation event. *Stormwater* generally refers to runoff that is routed through some artificial channel or structure, often in urban areas.
STP:	Sewage Treatment Plant. General term for a facility that treats

	municipal sewage prior to discharge to a waterbody according to the conditions of an NPDES permit.
SWCD:	Soil and Water Conservation District. Agency that provides local assistance for soil conservation and water quality project implementation, with support from the Iowa Department of Agriculture and Land Stewardship.
TDS:	Total Dissolved Solids: The quantitative measure of matter (organic and inorganic material) dissolved, rather than suspended, in the water column. TDS is analyzed in a laboratory and quantifies the material passing through a filter and dried at 180 degrees Celsius.
TMDL:	Total Maximum Daily Load. As required by the Federal Clean Water Act, a comprehensive analysis and quantification of the maximum amount of a particular pollutant that a waterbody can tolerate while still meeting its general and designated uses. A TMDL is mathematically defined as the sum of all individual wasteload allocations (WLAs), load allocations (LAs), and a margin of safety (MOS).
Trophic state:	The level of ecosystem productivity, typically measured in terms of algal biomass.
TSI (or Carlson's TSI):	Trophic State Index. A standardized scoring system developed by Carlson (1977) that places trophic state on an exponential scale of Secchi depth, chlorophyll, and total phosphorus. TSI ranges between 0 and 100, with 10 scale units representing a doubling of algal biomass.
TSS:	Total Suspended Solids. The quantitative measure of matter (organic and inorganic material) suspended, rather than dissolved, in the water column. TSS is analyzed in a laboratory and quantifies the material retained by a filter and dried at 103 to 105 degrees Celsius.
Turbidity:	A term used to indicate water transparency (or lack thereof). Turbidity is the degree to which light is scattered or absorbed by a fluid. In practical terms, highly turbid waters have a high degree of cloudiness or murkiness caused by suspended particles.
UAA:	Use Attainability Analysis. A protocol used to determine which (if any) designated uses apply to a particular waterbody. (See Appendix B for a description of all general and designated uses.)
USDA:	United States Department of Agriculture

USGS:	United States Geologic Survey (United States Department of the Interior). Federal agency responsible for implementation and maintenance of discharge (flow) gauging stations on the nation's waterbodies.
Watershed:	The land area that drains water (usually surface water) to a particular waterbody or outlet.
WLA:	Wasteload Allocation. The portion of a receiving waterbody's loading capacity that is allocated to one of its existing or future point sources of pollution (e.g., permitted waste treatment facilities).
WQS:	Water Quality Standards. Defined in Chapter 61 of Environmental Protection Commission [567] of the Iowa Administrative Code, they are the specific criteria by which water quality is gauged in Iowa.
WWTF:	Wastewater Treatment Facility. General term for a facility that treats municipal, industrial, or agricultural wastewater for discharge to public waters according to the conditions of the facility's NPDES permit. Used interchangeably with wastewater treatment plant (WWTP).
Zooplankton:	Collective term for all animal plankton suspended in the water column which serve as secondary producers in the aquatic food chain and the primary food source for larger aquatic organisms.

Appendix B --- General and Designated Uses of Iowa's Waters

Introduction

Iowa's water quality standards (Environmental Protection Commission [567], Chapter 61 of the Iowa Administrative Code) provide the narrative and numerical criteria by which waterbodies are judged when determining the health and quality of our aquatic ecosystems. These standards vary depending on the type of waterbody (lakes vs. rivers) and the assigned uses (general use vs. designated uses) of the waterbody that is being dealt with. This appendix is intended to provide information about how Iowa's waterbodies are classified and what the use designations mean, hopefully providing a better general understanding for the reader.

All public surface waters in the state are protected for certain beneficial uses, such as livestock and wildlife watering, aquatic life, non-contact recreation, crop irrigation, and other incidental uses (e.g. withdrawal for industry and agriculture). However, certain rivers and lakes warrant a greater degree of protection because they provide enhanced recreational, economical, or ecological opportunities. Thus, all public bodies of surface water in Iowa are divided into two main categories: *general* use segments and *designated* use segments. This is an important classification because it means that not all of the criteria in the state's water quality standards apply to all water ways; rather, the criteria which apply depend on the use designation & classification of the waterbody.

General Use Segments

A general use segment waterbody is one that does not maintain perennial (year-round) flow of water or pools of water in most years (i.e. ephemeral or intermittent waterways). In other words, stream channels or basins that consistently dry up year after year would be classified as general use segments. Exceptions are made for years of extreme drought or floods. For the full definition of a general use waterbody, consult section 61.3(1) in the state's published water quality standards, which became effective on March 22, 2006 (Environmental Protection Commission [567], Chapter 61 of the Iowa Administrative Code).

General use waters are protected for the beneficial uses listed above, which are: livestock and wildlife watering, aquatic life, non-contact recreation, crop irrigation, and industrial, agricultural, domestic and other incidental water withdrawal uses. The criteria used to ensure protection of these uses are described in section 61.3(2) in the state's published water quality standards, which became effective on March 22, 2006 (Environmental Protection Commission [567], Chapter 61 of the Iowa Administrative Code).

Designated Use Segments

Designated use segments are waterbodies that maintain flow throughout the year, or at least hold pools of water that are sufficient to support a viable aquatic community (i.e. perennial waterways). In addition to being protected for the same beneficial uses as the general use segments, these perennial waters are protected for more specific activities such as primary contact recreation, drinking water sources, or cold-water fisheries. There are thirteen different designated use classes (Table B-1) that may apply, and a waterbody may have more than one designated use. For definitions of the use classes and more detailed descriptions, consult section 61.3(1) in the state's published water quality standards, which became effective on March 22, 2006 (Environmental Protection Commission [567], Chapter 61 of the Iowa Administrative Code).

Table B-1. Designated use classes for Iowa waterbodies.

Class prefix	Class	Designated use	Brief comments
A	A1	Primary contact recreation	Supports swimming, water skiing, etc.
	A2	Secondary contact recreation	Limited/incidental contact occurs, such as boating
	A3	Children's contact recreation	Urban/residential waters that are attractive to children
B	B(CW1)	Cold water aquatic life – Type 2	Able to support coldwater fish (e.g. trout) populations
	B(CW2)	Cold water aquatic life – Type 2	Typically unable to support consistent trout populations
	B(WW-1)	Warm water aquatic life – Type 1	Suitable for game and nongame fish populations
	B(WW-2)	Warm water aquatic life – Type 2	Smaller streams where game fish populations are limited by physical conditions & flow
	B(WW-3)	Warm water aquatic life – Type 3	Streams that only hold small perennial pools which extremely limit aquatic life
	B(LW)	Warm water aquatic life – Lakes and Wetlands	Artificial and natural impoundments with "lake-like" conditions
C	C	Drinking water supply	Used for raw potable water
Other	HQ	High quality water	Waters with exceptional water quality
	HQR	High quality resource	Waters with unique or outstanding features
	HH	Human health	Fish are routinely harvested for human consumption

Designated use classes are determined based on a Use Attainability Analysis, or UAA. This is a procedure in which the waterbody is thoroughly scrutinized, using existing knowledge, historical documents, and visual evidence of existing uses, in order to determine what its designated use(s) should be. This can be a challenging endeavor, and as such, conservative judgment is applied to ensure that any potential uses of a waterbody are allowed for. Changes to a waterbody's designated uses may only occur based on a new UAA, which depending on resources and personnel, can be quite time consuming.

It is relevant to note that on March 22, 2006, a revised edition of Iowa's water quality standards became effective which significantly changed the use designations of the state's surface waters. Essentially, the changes that were made consisted of implementing a "top down" approach to use designations, meaning that all waterbodies should receive the highest degree of protection applicable until a UAA could be performed to ensure that a particular waterbody did not warrant elevated protection. For more information about Iowa's water quality standards and UAAs, contact the Iowa DNR's Water Quality Bureau.

Appendix C --- Watershed & Lake Monitoring

C.1. Monitoring Summary

Rathbun Lake and its watershed have been one of the most intensively monitored water resources in the State of Iowa since the late 1990s. Monitoring information has been funded and collected by a collaboration of partners, including the U.S. Army Corps of Engineers (USACE), U.S. Geological Survey (USGS), Iowa Department of Natural Resources (DNR), the Rathbun Regional Water Association (RRWA), and the Rathbun Land and Water Alliance (RLWA). Tributary monitoring has included both grab and event sampling for water quality constituents, several USGS flow gaging stations, a USGS lake stage recorder, and several DNR automated sampling stations where continuous water level measurements enable daily flow estimation in smaller subwatersheds. In-lake data has included water quality grab samples and temperature / dissolved oxygen / pH profiles at multiple locations in the lake and a USGS water level recorder. Table C-1 lists monitoring sites utilized for water quality analysis, development of load estimates, and model calibration. A map of monitoring sites is provided in Figure C-1.

Table C-1. Watershed and lake monitoring site summary.

Site ID[a]	Model Reach/Segment	Tributary / Lake Segment	Date Type	Collecting Agency
RA-12 USGS 06903700	Reach 59	S. Fork Chariton River County Rd. S50 / 200th St.	Flow Grab Event	USGS, DNR/SHL DNR/ISULL/SHL, USACE DNR/SHL
RA-15	Reach 5	Chariton River Hwy 14	Flow Grab Event	USGS, DNR/SHL DNR/ISULL/SHL, USACE DNR/SHL
RA-39	Reach 65+66	Jackson Creek Liberty Rd.	Flow Grab Event	USGS, DNR/SHL DNR/ISULL/SHL, USACE DNR/SHL
RA-41	Reach 6	Wolf Creek 430th St.	Flow Grab Event	USGS, DNR/SHL DNR/ISULL/SHL, USACE DNR/SHL
RA-45 USGS 06903400	Reach 11	Chariton River County Rd. S43 / 255th St.	Flow	USGS
RA-3	Segment A	Ambient (near dam) IA 05-CHA-0020-L_1	WQ[b]	USACE, DNR/ISULL/SHL
RA-7	Segment C1	Ambient (Chariton arm) IA 05-CHA-0020-L_3	WQ[b]	USACE
RA-8	Segment D2	Ambient (S. Fork arm) IA 05-CHA-0020-L_2	WQ[b]	USACE
RA-25	Segment E	Ambient (Honey Creek) IA 05-CHA-0020-L_4	WQ[b]	USACE

[a] Sites RA-12, 15, 39, 41, and 45 are stream/tributary sampling locations. Sites RA-3, 7, 8, and 25 are in-lake sampling locations.

[b] In-lake WQ samples include grab sample chemical analysis and water column profiles.

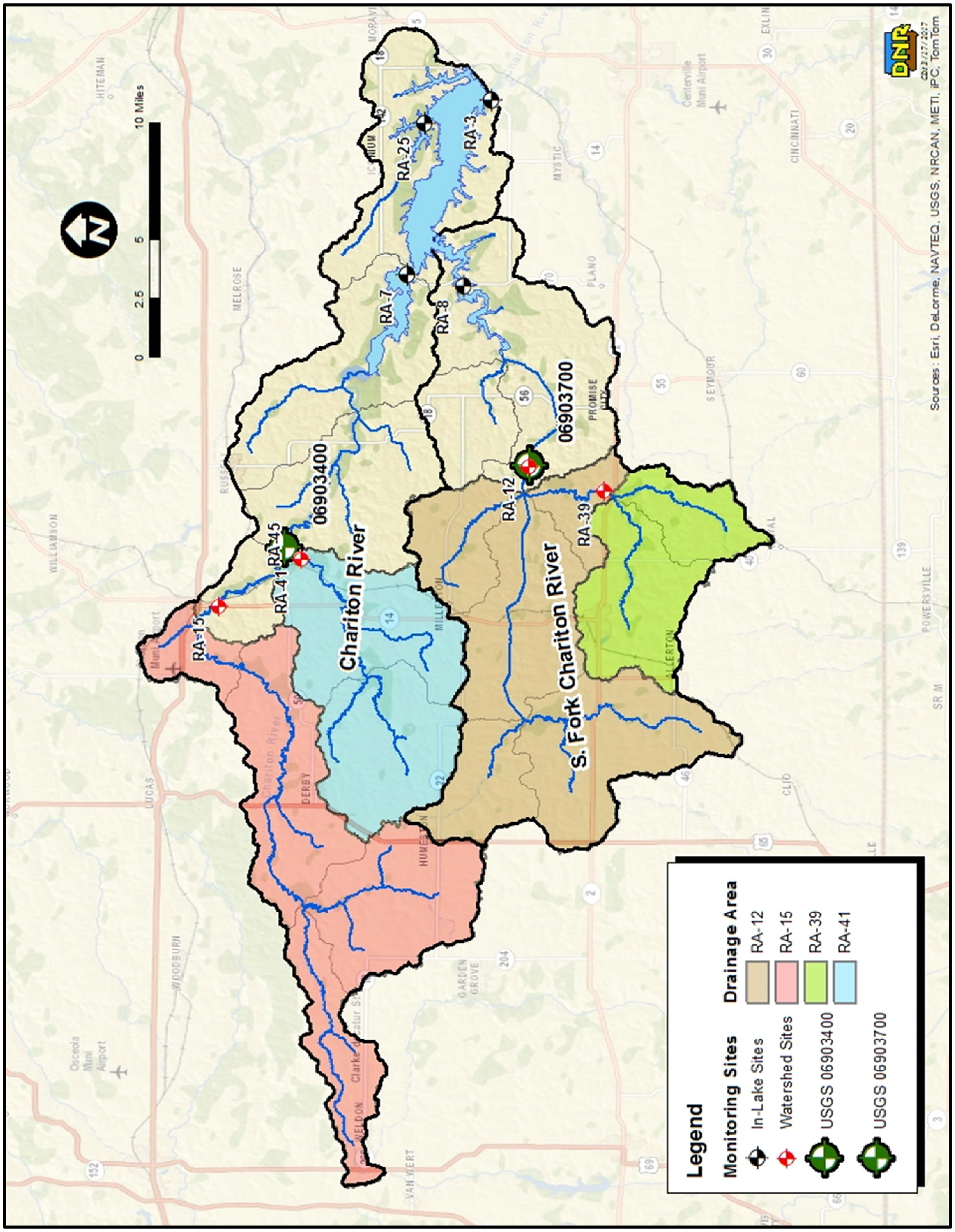


Figure C-1. Monitoring location map.

C.2. Watershed / Tributary Water Quality Data

Table C-2. Tributary water quality data for S. Fork Chariton River (RA-12)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO$_x$ (ppm)	NH$_x$ (ppm)
4/30/1997	0.34		1363	2.66	0.16	
5/12/1997	0.11		36	1.31	0.51	
5/27/1997	0.21		79	1.18	0.08	
6/8/1997	0.18		187	4.49	2.39	
6/23/1997	0.86		982	10.3	6.00	
7/7/1997	0.22		22	0.47	0.07	
7/21/1997	0.18		26	0.91	0.11	
8/4/1997	0.45		42	0.46	0.06	
9/2/1997	0.16		22	1.32	0.12	
9/15/1997	0.18		19	0.97	0.07	
4/14/1998	0.20		265	1.83	0.43	
5/4/1998	0.14		18	0.64	0.04	
5/22/1998	1.03		1920	10.02	2.92	
6/9/1998	0.15		140	3.56	2.26	
6/24/1998	0.22		400	2.12	0.72	
7/6/1998	0.13		158	1.41	0.61	
7/22/1998	0.08		24	0.69	0.09	
8/3/1998	0.14		18	0.93	0.43	
8/18/1998	0.15		22	0.6	0.10	
8/31/1998	0.12		31	0.48	0.08	
9/14/1998	0.76			1.59	0.49	
10/14/1998	0.19			1.62	0.62	
11/10/1998	0.49		658	3.16	1.16	
3/17/1999	0.90		785	4.71	2.81	
4/13/1999	0.12		25	0.89	0.56	
5/11/1999	0.41		26	0.68	0.17	
6/11/1999	1.35		1492	5.27	1.34	
6/15/1999	0.26		109	1.81	0.78	
7/13/1999	0.11		22	0.68		
8/18/1999	0.13		51	0.44	0.06	
9/13/1999	0.10		28	0.48		
10/13/1999	0.23		16	0.54		
11/15/1999	0.10		2.6	0.2		
3/28/2000	0.14		6.5	0.65		
4/18/2000	0.11		13	0.73		
5/16/2000	0.18		36	0.95		
6/13/2000	0.21		45	2.00	1.00	
6/27/2000	0.52		183	3.36	1.36	
7/19/2000	0.27		86	1.26	0.10	
8/15/2000	0.46		42	1.14	0.14	
9/12/2000	0.10		15	0.60		
10/17/2000	0.20		13	0.40		
11/14/2000	0.23		16	1.43	0.33	
3/20/2001	0.44		275	4.00	3.00	
4/17/2001	0.19		46	1.74	1.00	
5/15/2001	0.09		314	2.50	1.30	

Table C-2. Tributary water quality data for S. Fork Chariton River (RA-12)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
6/1/2001	0.50		518	4.20	2.70	
6/12/2001	0.21		35	0.87	0.65	
7/11/2001	0.18		23	0.59	0.01	
8/14/2001	0.14		30	0.25	0.01	
9/27/2001	0.34		59	1.28	0.33	
10/16/2001	0.28		22	0.57	0.29	
11/13/2001	0.08		9.6	0.06	0.01	
2/19/2002	0.16		26	0.81	0.76	
3/6/2002	0.10		8	0.21	0.10	
3/26/2002	0.12		7	0.06	0.01	
4/16/2002	0.11		16	0.42	0.09	
5/14/2002	0.31		156	3.13	2.30	
6/11/2002	0.18		67	0.55	0.21	
7/23/2002	0.12		35	0.15	0.10	
8/13/2002	0.09		41	0.27	0.04	
9/17/2002	0.11		29	0.27	0.01	
10/24/2002	0.14		13	0.43	0.01	
11/12/2002	0.12		7	0.25	0.01	
12/11/2002	0.09		10	0.06	0.01	
3/13/2003	0.76		43	3.40	1.00	
4/15/2003	0.20		9	0.36	0.01	
5/14/2003	0.20		57	1.76	1.30	
6/17/2003	0.16		24	2.86	2.40	
7/15/2003	0.35		36	0.87	0.39	
7/29/2003			40			
8/12/2003	0.11		24	0.57	0.01	
9/16/2003	0.24		22	1.00	0.38	
10/16/2003	0.20		25	0.34	0.01	
11/20/2003	0.15		10	1.34	1.10	
12/18/2003	0.24		32	2.83	2.00	
2/25/2004			22			
4/21/2004			11			
5/26/2004			134			
6/22/2004			67			
7/13/2004			206			
7/20/2004			18			
8/17/2004			16			
9/21/2004			10			
10/19/2004			4			
11/16/2004			6			
12/14/2004			12			
1/19/2005	0.07	0.01	2	1.14	0.47	0.47
2/15/2005	0.37	0.09	205	5.20	3.30	0.27
3/16/2005	0.11	0.01	8	0.61	0.01	0.18
4/13/2005	0.57	0.01	423	6.40	3.80	0.71
5/10/2005	0.09	0.01	14	0.82	0.02	0.01
6/15/2005	0.20	0.09	75	5.90	3.00	0.01
6/29/2005	0.50	0.20	220	3.00	1.00	0.20

Table C-2. Tributary water quality data for S. Fork Chariton River (RA-12)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
7/20/2005	0.10	0.06	46	1.04	0.04	0.10
7/28/2005	0.30	0.10	49	1.40	0.20	0.10
8/25/2005	0.59	0.01	19	0.94	0.09	0.10
9/13/2005	0.11	0.01	29	0.92	0.01	0.01
1/13/2006	0.10	0.01	5	0.83	0.13	0.24
3/16/2006	0.16	0.05	11	4.11	0.01	0.23
4/12/2006	0.34	0.09	10	0.79	0.01	0.10
4/27/2006	0.14	0.04	7	0.76	0.01	0.21
5/25/2006	0.65	0.19	370	5.00	2.30	0.17
6/7/2006	0.23	0.08	47	1.60	0.20	0.12
6/21/2006	0.14	0.05	33	1.22	0.02	0.06
7/27/2006	0.20	0.19	24	0.91	0.03	0.08
8/28/2006	0.14	0.13	22	0.99	0.10	0.04
9/13/2006	0.10	0.08	7	0.58	0.04	0.06
10/12/2006	0.14	0.10	6	0.66	0.01	0.01
4/25/2007	0.58	0.51	1204	2.87	2.87	0.40
5/23/2007	0.15	0.02	9	0.69	0.29	0.04
6/5/2007	0.27	0.10	29	2.45	1.70	0.04
6/21/2007	0.17	0.04	25	0.69	0.29	0.04
7/17/2007	0.14	0.05		0.69	0.29	0.04
7/26/2007	0.11	0.06	17	0.69	0.29	0.04
8/8/2007	0.62	0.11	1683	2.09	0.87	0.08
8/21/2007	0.29	0.10	45	0.69	0.29	0.04
9/11/2007	0.18	0.04	19	0.69	0.29	0.04
9/27/2007	0.17	0.03	17	0.69	0.29	0.04
10/4/2007	0.25	0.09	39	0.69	0.29	0.04
10/18/2007	0.62	0.23	554	2.17	0.79	0.04
11/13/2007	0.12	0.03	3	0.69	0.29	0.04
5/29/2008	0.22	0.05	66	1.81	1.03	0.10
6/3/2008	0.61	0.11	1112	6.88	0.96	0.65
6/16/2008	0.48	0.12	265	2.18	1.02	0.24
7/1/2008	0.21	0.07	43	1.58	0.64	0.04
7/15/2008	0.15	0.06	18	0.69	0.29	0.04
8/12/2008	0.15	0.04	13	0.69	0.29	0.04
9/8/2008	0.12	0.02	22	0.69	0.29	0.04
10/27/2008	0.21	0.08	37	0.69	0.29	0.04
11/4/2008	0.15	0.07	3	0.69	0.29	0.04
5/14/2009			316			
5/28/2009	0.28	0.06	314	4.13	3.00	0.16
6/18/2009	0.16	0.07	23	1.12	0.52	0.07
6/25/2009	0.24	0.07	200	3.70	1.10	0.02
7/16/2009	0.15	0.07	61	0.57	0.24	0.02
8/11/2009	0.32	0.07	199	2.80	1.10	0.08
8/17/2009	0.53	0.08	1404	1.90	0.25	0.07
9/23/2009	0.09	0.07	10	0.36	0.06	0.02
10/27/2009	0.21	0.06	89	0.37	0.25	0.07
11/23/2009	0.12	0.02	29	1.01	0.25	0.07
3/6/2010	0.19	0.03	34	1.76	0.48	0.69

Table C-2. Tributary water quality data for S. Fork Chariton River (RA-12)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
3/22/2010			477			
4/19/2010	0.08	0.00	11	0.49	0.01	0.03
4/24/2010	0.48	0.09	562	3.30	3.30	0.46
5/11/2010	0.34	0.08	137	5.63	5.15	0.17
5/26/2010	0.57	0.08	618	4.90	1.90	0.03
6/22/2010	0.60	0.08	638	5.53	0.33	0.03
7/13/2010	0.23	0.08	51	0.81	0.42	0.03
8/11/2010	0.42	0.12	153	2.06	0.46	0.06
9/21/2010	0.32	0.08	202	2.22	0.32	0.06
10/9/2010	0.11	0.03	14	0.28	0.17	0.07
11/20/2010	0.10	0.03	13	1.15	0.70	0.07
3/15/2011	0.10	0.01	37	2.08	0.78	0.18
3/28/2011	0.09	0.00	29	0.75	0.34	0.01
4/12/2011	0.13	0.02	34	0.82	0.16	0.01
4/16/2011	1.60	0.09	2900	8.80	3.10	0.54
4/27/2011	0.12	0.05	120	2.90	1.30	0.10
5/9/2011	0.07	0.00	15	0.62	0.03	0.01
5/12/2011	0.49	0.05	550	4.40	2.10	0.03
5/24/2011	0.24	0.06	97	4.90	2.90	0.06
6/7/2011	0.16	0.06	60	1.95	0.85	0.01
6/21/2011	1.85	0.08	3100	10.60	2.20	0.03
6/27/2011	0.74	0.06	1100	4.58	0.88	0.03
7/18/2011	0.08	0.03	11	0.03	0.03	0.01
7/25/2011	0.63	0.03	530	2.89	0.19	0.03
8/15/2011	0.10	0.03	30	0.65	0.05	0.03
9/19/2011	0.09	0.01	16	0.65	0.05	0.03
10/17/2011	0.58	0.10	16	1.95	0.05	0.03
5/3/2012	1.40	0.05	1400	9.00	4.40	0.23
6/26/2012	0.19	0.05	17	1.12	0.42	0.03
7/11/2012	0.15	0.04	10	0.55	0.05	0.03
10/22/2012	0.17	0.06	7	0.45	0.05	0.03
5/5/2013	0.90	0.10	1200	7.40	3.60	0.20
5/22/2013	1.00	0.03	1080	5.70	1.60	0.03
5/27/2013	2.00	0.07	2710	9.00	3.20	0.14
5/29/2013	2.20	0.07	3620	7.90	1.50	0.11
5/31/2013	2.80	0.08	3440	6.70	1.00	0.22
6/16/2013	3.40	0.03	6000	8.75	0.05	0.56
6/24/2013	1.00	0.04	1070	5.00	1.00	0.03
6/25/2013	0.44					
7/22/2013	0.17	0.04	28	0.65	0.05	0.03
8/12/2013	0.13	0.02	14	0.10	0.05	0.11
8/26/2013	0.07	0.02	12	0.65	0.05	0.03
9/26/2013	0.07	0.01	12	0.55	0.05	0.03
10/7/2013	0.08	0.02	11	0.65	0.05	0.03
10/22/2013	0.08	0.01	11	0.10	0.05	0.03
11/6/2013	0.27	0.10	10	0.55	0.05	0.03
11/18/2013	0.19	0.01	8	0.45	0.05	0.03
3/10/2014	0.80	0.63	83	3.58	0.78	0.98

Table C-2. Tributary water quality data for S. Fork Chariton River (RA-12)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO$_x$ (ppm)	NH$_x$ (ppm)
3/24/2014	0.15	▨	20	1.98	1.00	0.19
4/9/2014	0.10	0.05	15	0.49	0.04	0.02
4/13/2014	2.00	0.12	1800	▨	▨	▨
4/14/2014	1.70	0.07	1980	10.90	3.10	0.36
4/21/2014	0.09	0.05	35	1.33	0.59	0.02
4/25/2014	2.00	0.05	4280	6.40	2.60	0.22
4/29/2014	2.30	0.06	3610	7.70	1.90	0.16
5/12/2014	2.00	0.16	2500	11.65	0.65	0.17
5/13/2014	3.20	0.07	4100	12.40	2.50	0.19
5/27/2014	0.20	0.09	180	1.53	0.99	0.02
5/29/2014	2.50	0.05	3700	10.20	0.70	0.03
6/4/2014	1.10	0.10	890	▨	▨	▨
6/5/2014	0.88	0.08	880	▨	▨	▨
6/8/2014	1.60	0.08	3120	6.00	1.30	0.03
6/9/2014	0.50	0.07	350	2.50	1.40	0.06
6/23/2014	0.35	0.08	210	2.08	0.98	0.10
6/30/2014	1.70	0.06	1920	6.01	0.41	0.03
7/10/2014	0.26	0.08	66	1.54	0.64	0.03
7/14/2014	1.50	0.06	1690	4.85	0.05	0.03
7/21/2014	0.10	0.04	11	0.65	0.05	0.03
8/4/2014	0.09	0.04	11	0.55	0.05	0.03
8/16/2014	1.20	0.15	1070	▨	▨	▨
8/20/2014	0.62	0.08	590	3.45	0.05	0.03
8/23/2014	1.50	0.10	2450	4.35	0.05	0.07
8/24/2014	0.70	0.11	740	▨	▨	▨
8/29/2014	1.80	0.09	2770	3.65	0.05	0.03
8/30/2014	1.00	0.14	1040			
8/31/2014	1.40	0.20	2120	3.65	0.05	0.03
9/2/2014	0.36	0.11	170	1.36	0.16	0.03
9/15/2014	1.60	0.09	2130	4.72	0.12	0.17
10/2/2014	0.30	0.06	98	0.65	0.05	0.03
10/21/2014	0.16	0.04	14	0.80	0.20	0.03

NOTE: Cross-hatching indicates no data available for a given parameter and date.

Table C-3. Tributary water quality data for Chariton River (RA-15)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO$_x$-N (ppm)	NH$_x$-N (ppm)
4/30/1997	0.25	▨	292	2.86	1.06	▨
5/12/1997	0.25	▨	100	3.38	1.78	▨
5/27/1997	0.23	▨	64	1.27	0.07	▨
6/8/1997	0.29	▨	154	3.62	1.72	▨
6/23/1997	0.24	▨	179	2.41	0.81	▨
7/7/1997	0.09	▨	48	2.50	1.50	▨
7/21/1997	0.10	▨	80	1.34	0.14	▨
8/4/1997	0.28	▨	37	1.55	0.25	▨
9/2/1997	0.31	▨	14	1.25	0.05	▨
9/15/1997	0.16	▨	17	1.24	0.24	▨
4/14/1998	0.13	▨	92	1.83	0.63	▨

Table C-3. Tributary water quality data for Chariton River (RA-15)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x-N (ppm)	NH_x-N (ppm)
5/4/1998	0.09		61	0.43	0.03	
5/22/1998	0.82			8.19	2.79	
6/9/1998	0.15		145	2.99	1.39	
6/23/1998	0.14			2.73	1.13	
7/6/1998	0.18		105	2.04	1.24	
7/21/1998	0.24			1.38	0.28	
8/3/1998	0.18		12	0.73	0.03	
8/17/1998	0.35			1.63	0.03	
8/31/1998	0.11		15	0.50	0.10	
9/15/1998	0.16			1.34	0.24	
10/13/1998	0.36			1.76	0.76	
11/10/1998	0.53		228	2.59	1.29	
3/17/1999	0.98		685	4.59	2.86	
4/13/1999	0.40		118	5.50	4.02	
5/11/1999	0.51		92	1.58	0.43	
6/11/1999	1.18		1219	5.98	2.02	
6/15/1999	0.67		444	3.68	1.13	
7/13/1999	0.26		102	2.61	1.23	
8/18/1999	0.20		61	0.95	0.42	
9/13/1999	0.11		104	0.72		
10/13/1999	0.17		41	0.76		
11/15/1999	0.29		21	0.80		
3/28/2000	0.14		7	0.78		
4/18/2000	0.16		17	0.78		
5/16/2000	0.28		35	0.99		
6/13/2000	0.26		29	1.00		
6/27/2000	0.73		400	3.64	1.64	
7/19/2000	0.42		103	2.21	0.26	
8/15/2000	0.38		18	1.08	0.08	
9/12/2000	0.20		24	0.90		
10/17/2000	0.10		16	0.30		
11/14/2000	0.22		11	1.30	0.32	
3/20/2001	0.39		71	4.10	3.00	
4/17/2001	0.34		127	2.00	1.00	
5/15/2001	0.53		189	6.60	4.90	
6/1/2001	0.41		161	6.40	5.00	
6/12/2001	0.23		32	1.24	0.72	
7/11/2001	0.27		30	2.35	1.70	
8/14/2001	0.20		76	0.38	0.05	
9/27/2001	0.21		25	0.47	0.25	
10/16/2001	0.39		43	0.99	0.41	
11/13/2001	0.26		21	0.47	0.13	
2/19/2002	0.07		12	0.43	0.38	
3/6/2002	0.06		12	0.38	0.06	
3/26/2002	0.17		18	0.59	0.01	
4/16/2002	0.22		43	1.59	0.68	
5/14/2002	0.48		98	7.70	5.60	
6/11/2002	0.44		214	4.00	2.70	

Table C-3. Tributary water quality data for Chariton River (RA-15)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x-N (ppm)	NH_x-N (ppm)
7/23/2002	0.36		48	0.64	0.12	
8/13/2002	0.22		53	0.67	0.01	
9/17/2002	0.13		21	0.64	0.01	
10/24/2002	0.21		56	0.62	0.01	
11/12/2002	1.10		27	1.13	0.03	
12/11/2002	0.35		64	1.41	0.01	
3/13/2003	0.70		26	1.70	0.10	
4/15/2003	0.15		6	0.36	0.01	
5/14/2003	0.37		66	4.40	3.20	
6/17/2003	0.30		98	4.50	3.40	
7/15/2003	0.29		33	0.99	0.57	
7/29/2003			53			
8/12/2003	0.30		13	0.40	0.01	
9/16/2003	0.43		42	1.84	1.20	
10/16/2003	0.22		10	0.39	0.01	
11/20/2003	0.19		5	2.42	2.10	
12/18/2003	0.68		140	4.70	3.40	
2/25/2004			51			
4/21/2004			48			
6/22/2004			68			
7/13/2004			556			
7/20/2004			28			
8/17/2004			10			
9/21/2004			11			
10/19/2004			13			
11/16/2004			7			
12/14/2004			7			
1/19/2005	0.07	0.01	2	0.75	0.06	0.14
2/15/2005	0.73	0.25	366	8.00	4.90	0.38
3/16/2005	0.16	0.01	20	1.11	0.01	0.16
4/13/2005	0.62	0.28	298	9.60	6.40	0.72
5/10/2005	0.20	0.01	76	1.30	0.30	0.01
6/15/2005	0.30	0.10	163	7.00	4.00	0.10
6/29/2005	0.60	0.20	240	6.00	4.00	0.20
7/20/2005	0.30	0.07	80	1.60	0.10	0.20
7/28/2005	0.20	0.09	42	1.20	0.20	0.20
8/25/2005	0.23	0.01	34	1.28	0.30	0.09
1/13/2006	0.89	0.01	36	4.71	0.01	1.00
3/16/2006	0.09	0.01	2	1.41	0.01	0.08
4/12/2006	0.19	0.09	6	0.92	0.01	0.13
4/27/2006	0.24	0.10	7	1.41	0.01	0.25
5/25/2006	0.17	0.10	27	1.72	0.42	0.08
6/7/2006	0.44	0.16	67	4.80	2.90	0.23
6/21/2006	0.26	0.10	39	1.52	0.02	0.14
7/27/2006	0.12	0.04	140	2.11	0.01	0.07
8/28/2006	0.33	0.24	24	1.80	0.50	0.06
9/13/2006	0.20	0.08	15	1.06	0.23	0.11
10/12/2006	0.13	0.10	19	1.01	0.01	0.01

Table C-3. Tributary water quality data for Chariton River (RA-15)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x-N (ppm)	NH_x-N (ppm)
4/25/2007	0.57	0.51	935	7.80	6.18	0.86
5/23/2007	0.27	0.06	49	2.21	1.20	0.04
6/5/2007	0.45	0.18	100	7.03	5.98	0.04
6/21/2007	0.22	0.09	52	2.14	1.53	0.12
7/17/2007	0.20	0.05		0.69	0.29	0.04
7/26/2007	0.17	0.06	152	0.69	0.29	0.04
8/8/2007	0.21	0.07	72	1.39	0.29	0.14
8/21/2007	0.55	0.15	248	0.69	0.29	0.10
9/11/2007	0.24	0.10	29	0.69	0.29	0.04
9/27/2007	0.28	0.11	39	0.69	0.29	0.04
10/4/2007	0.30	0.12	36	0.69	0.29	0.04
10/18/2007	0.63	0.35	230	3.05	1.90	0.04
11/13/2007	0.22	0.12	23	0.69	0.29	0.08
5/29/2008	0.32	0.09	83	4.40	3.43	0.24
6/3/2008	0.60	0.09	990	8.27	2.14	0.57
6/16/2008	0.52	0.27	56	2.04	0.87	0.20
7/1/2008	0.34	0.12	85	3.58	2.17	0.09
7/15/2008	0.29	0.10	78	1.82	0.84	0.13
8/12/2008	0.21	0.10	38	0.69	0.29	0.04
9/8/2008	0.14	0.03	44	0.69	0.29	0.04
10/27/2008	0.29	0.15	45	1.40	0.29	0.04
11/4/2008	0.22	0.09	24	0.69	0.29	0.04
5/14/2009			57			
5/28/2009	0.54	0.08	657	10.43	9.71	0.29
6/18/2009	0.28	0.09	56	2.25	1.32	0.07
6/25/2009	1.20	0.07	267	5.70	2.80	0.05
7/16/2009	0.19	0.07	37	0.77	0.43	0.02
8/11/2009	0.72	0.07	835	3.80	1.10	0.22
8/17/2009	0.40	0.12	263	1.33	0.25	0.07
9/23/2009	0.12	0.07	18	0.77	0.12	0.02
10/27/2009	0.25	0.11	39	0.37	0.67	0.07
11/23/2009	0.28	0.10	25	2.17	1.03	0.37
3/6/2010	0.11	0.02	10	1.32	0.70	0.31
3/22/2010			192			
4/19/2010	0.12	0.03	30	0.52	0.01	0.03
4/24/2010	0.55	0.30	217	2.20	1.92	0.44
5/11/2010	0.47	0.18	972	4.08	3.21	0.07
5/26/2010	0.49	0.17	200	3.50	2.10	0.03
6/22/2010	0.53	0.17	165	3.17	0.27	0.06
7/13/2010	0.23	0.07	35	1.57	0.57	0.03
8/11/2010	0.46	0.19	143	2.92	0.52	0.03
9/21/2010	0.51	0.30	186	2.78	0.48	0.05
10/9/2010	0.19	0.07	18	1.19	0.17	0.07
11/20/2010	0.33	0.10	20	3.88	2.42	0.90
3/16/2011	0.12	0.01	22	3.90	2.70	0.15
3/28/2011	0.17	0.00	34	2.08	1.20	0.06
4/12/2011	0.26	0.11	51	5.80	4.20	0.14
4/16/2011	1.20	0.10	1300	6.30	2.50	0.32

Table C-3. Tributary water quality data for Chariton River (RA-15)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x-N (ppm)	NH_x-N (ppm)
4/26/2011	0.11	0.03	53	3.49	2.50	0.06
5/9/2011	0.07	0.00	20	1.05	0.11	0.01
5/13/2011	0.38	0.06	260	3.10	1.30	0.07
5/23/2011	0.67	0.12	540	9.40	4.80	0.13
5/26/2011	0.84	0.10	930	5.80	2.60	0.03
6/6/2011	0.20	0.05	78	2.80	1.50	0.01
6/28/2011	0.27	0.11	52	1.32	0.70	0.01
7/18/2011	0.14	0.07	29	1.36	0.62	0.01
8/16/2011	0.22	0.08	32	1.66	0.46	0.03
9/19/2011	0.12	0.05	12	0.10	0.05	0.03
10/17/2011	0.25	0.11	30	0.65	0.05	0.03
4/16/2012	1.10	0.22	1100	6.40	2.20	0.11
5/3/2012	1.10	0.14	1100	7.80	2.90	0.03
6/18/2012	0.77	0.09	660	7.50	5.10	0.13
6/26/2012	0.60	0.15	290	8.20	6.10	0.21
7/11/2012	0.26	0.08	37	1.69	0.29	0.03
10/22/2012	0.43	0.22	17	0.85	0.05	0.03
5/5/2013	0.68	0.18	670	8.10	4.70	0.25
5/17/2013	6.80	0.20	1270	7.40	3.40	0.12
5/22/2013	0.90	0.14	790	5.10	1.80	0.03
6/16/2013	0.90	0.10	880	4.50	1.50	0.03
6/25/2013	0.46	0.03	240	2.80	1.20	0.03
7/22/2013	0.48	0.04	170	2.15	0.05	0.03
7/22/2013	0.27	0.13	50	0.85	0.05	0.03
8/12/2013	0.21	0.06	25	0.65	0.05	0.03
9/26/2013	0.09	0.04	13	0.75	0.05	0.03
10/7/2013	0.10	0.04	16	0.65	0.05	0.03
10/22/2013	0.09	0.04	15	0.85	0.05	0.03
11/6/2013	0.37	0.27	12	0.75	0.05	0.03
11/18/2013	1.00	0.14	40	1.25	0.05	0.03
3/10/2014	0.64	0.41	33	3.22	0.72	0.69
3/24/2014	0.21		8	1.88	0.48	0.52
4/9/2014	0.18	0.11	9	0.72	0.04	0.02
4/15/2014	1.60	0.15	1560	5.50	2.10	0.32
4/21/2014	0.16	0.12	64	3.38	2.70	0.02
4/25/2014	0.93	0.12	980	5.80	3.00	0.11
4/28/2014	1.10	0.15	1320	3.80	1.60	0.05
4/29/2014	0.61	0.17	360	3.30	1.30	0.03
5/12/2014	0.72	0.27	290	7.40	1.50	0.17
5/13/2014	2.00	0.11	1930	8.30	1.20	0.03
5/14/2014	1.00	0.19	810	5.40	1.50	0.07
5/27/2014	0.12	0.06	39	1.48	1.00	0.03
5/28/2014	0.76	0.04	610	4.00	0.70	0.03
5/29/2014	0.92	0.13	347	▨	▨	▨
6/4/2014	1.10	0.18	920	▨	▨	▨
6/5/2014	1.30	0.14	1080	7.00	2.30	0.03
6/6/2014	0.94	0.20	430	▨	▨	▨
6/9/2014	0.68	0.24	240	3.50	2.00	0.08

Table C-3. Tributary water quality data for Chariton River (RA-15)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x-N (ppm)	NH_x-N (ppm)
6/10/2014	0.83	0.18	460	4.50	1.90	0.03
6/11/2014	0.52	0.20	120	▨	▨	▨
6/23/2014	0.36	0.13	68	4.40	2.80	0.20
6/30/2014	0.89	0.05	620	3.95	0.75	0.03
7/7/2014	0.78	0.03	430	3.31	0.61	0.03
7/10/2014	0.44	0.18	60	1.90	1.00	0.03
7/21/2014	0.16	0.06	18	1.11	0.21	0.03
8/4/2014	0.15	0.08	12	0.85	0.05	0.03
8/16/2014	1.00	0.19	730	▨	▨	▨
8/18/2014	0.91	0.17	710	3.08	0.48	0.03
8/20/2014	0.74	0.23	280	2.33	0.43	0.06
8/24/2014	0.62	0.20	400	2.25	0.05	0.03
8/25/2014	0.59	0.26	150	▨	▨	▨
8/29/2014	0.97	0.17	490	▨	▨	▨
8/30/2014	0.66	0.28	170	▨	▨	▨
8/31/2014	0.44	0.12	360	1.85	0.05	0.03
9/1/2014	0.54	0.26	110	1.45	0.05	0.03
9/2/2014	0.59	0.26	150	1.87	0.17	0.07
9/10/2014	0.65	0.21	77	▨	▨	▨
9/12/2014	0.58	0.18	140	1.45	0.05	0.03
9/14/2014	0.36	0.19	25	1.00	0.10	0.03
9/15/2014	0.30	0.13	35	0.91	0.21	0.08
10/2/2014	0.18	0.08	12	0.85	0.05	0.03
10/5/2014	0.51	0.09	210	2.06	0.16	0.03
10/16/2014	0.61	0.18	330	3.34	0.84	0.09
10/21/2014	0.26	0.10	27	1.59	0.39	0.03

NOTE: Cross-hatching indicates no data available for a given parameter and date.

Table C-4. Tributary water quality data for Jackson Creek (RA-39)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
5/13/1997	0.16	▨	64	1.17	0.27	▨
6/10/1997	0.24	▨	76	2.02	1.42	▨
6/24/1997	0.21	▨	327	4.11	2.31	▨
7/22/1997	0.10	▨	132	1.56	0.16	▨
8/17/1997	0.70	▨	712	4.98	2.08	▨
8/20/1997	0.23	▨	63	2.12	0.32	▨
9/15/1997	0.19	▨	28	1.87	0.07	▨
10/16/1997	0.34	▨	76	2.42	0.72	▨
11/13/1997	0.17	▨	14	1.29	0.49	▨
3/9/1998	0.15	▨	320	2.85	1.45	▨
4/14/1998	0.12	▨	144	1.49	0.39	▨
5/13/1998	0.22	▨	47	1.26	0.46	▨
5/22/1998	0.81	▨	1170	9.12	3.42	▨
6/25/1998	0.89	▨	1810	4.73	0.73	▨
7/8/1998	0.41	▨	157	1.64	0.74	▨
7/22/1998	0.82	▨	1000	4.02	0.12	▨
8/18/1998	0.25	▨	48	1.12	0.12	▨
9/14/1998	0.22	▨		1.47	0.47	▨

Table C-4. Tributary water quality data for Jackson Creek (RA-39)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO$_x$ (ppm)	NH$_x$ (ppm)
10/14/1998	0.12			1.19	0.39	
11/10/1998	0.43		294	2.30	0.90	
3/17/1999	0.52		330	3.15	1.79	
4/13/1999	0.10		24	0.62	0.23	
5/11/1999	0.40		18	0.98	0.06	
6/11/1999	0.57		452	3.47	0.86	
6/15/1999	0.22		87	1.32	0.42	
7/13/1999	0.13		47	0.91	0.04	
8/18/1999	0.17		120	0.61	0.14	
9/13/1999	0.28		76	1.91	0.04	
10/13/1999	0.54		44	1.98		
11/15/1999	0.36		23	1.45		
3/28/2000	0.41		5	1.72	0.42	
4/18/2000	0.61		15	3.00		
5/16/2000	0.25		43	1.00		
6/13/2000	0.36		66	2.86	0.86	
6/27/2000	0.42		141	2.92	0.92	
7/19/2000	0.59		110	1.80	0.37	
8/15/2000	0.43		99	2.11	0.01	
9/12/2000	0.20		33	1.20		
10/17/2000	0.50		15	0.94	0.04	
11/14/2000	0.30		8	1.90	0.80	
3/20/2001	0.34		167	4.00	3.00	
4/17/2001	0.19		44	2.00	1.00	
5/15/2001	0.35		94	2.40	1.30	
6/1/2001	0.38		204	3.00	1.80	
6/12/2001	0.15		37	1.30	1.10	
7/11/2001	0.19		103	0.77	0.03	
8/14/2001	0.15		18	0.12	0.07	
9/27/2001	0.29		34	0.79	0.29	
10/16/2001	0.47		15	0.61	0.01	
11/13/2001	0.27		20	0.44	0.01	
2/19/2002	0.10		2	0.67	0.55	
3/6/2002	0.07		9	0.34	0.16	
3/26/2002	0.04		10	0.15	0.01	
4/16/2002	0.22		18	0.85	0.37	
5/14/2002	0.28		107	2.23	1.40	
6/11/2002	0.24		79	0.83	0.33	
7/23/2002	0.45		108	2.40	0.10	
8/13/2002	0.47		79	1.35	0.05	
9/17/2002	0.24		21	1.49	0.09	
10/24/2002	0.54		7	1.02	0.06	
11/12/2002	0.58		6	0.89	0.01	
12/11/2002	0.44		6	1.11	0.01	
3/13/2003	1.30		32	4.70	1.40	
4/15/2003	0.63		19	1.11	0.01	
5/14/2003	0.22		27	1.52	1.30	
6/17/2003	0.19		22	0.87	0.40	
7/15/2003	0.27		99	1.54	0.79	

Table C-4. Tributary water quality data for Jackson Creek (RA-39)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
7/29/2003			63			
8/12/2003	0.23		30	0.94	0.01	
9/16/2003	0.48		41	1.39	0.73	
10/16/2003	0.72		15	0.99	0.01	
11/20/2003	0.26		16	1.57	1.10	
12/18/2003	0.23		48	2.94	2.30	
2/25/2004			26			
4/21/2004			16			
5/26/2004			70			
6/22/2004			45			
7/13/2004			66			
7/20/2004			39			
8/17/2004			20			
9/21/2004			21			
10/19/2004			8			
11/16/2004			3			
12/14/2004			17			
1/19/2005	0.10	0.06	2	2.43	0.83	0.53
2/15/2005	0.39	0.06	110	4.40	2.40	0.33
3/16/2005	0.17	0.01	12	0.92	0.01	0.27
4/13/2005	0.40	0.01	393	5.20	2.90	0.81
5/10/2005	0.10	0.10	11	1.01	0.01	0.01
6/15/2005	0.20	0.20	60	4.00	2.00	0.09
6/29/2005	0.50	0.01	186	2.80	0.80	0.20
7/28/2005	0.40	0.01	47	2.10	0.30	0.20
8/25/2005	0.28	0.13	35	1.25	0.15	0.16
1/13/2006	0.56	0.01	5	5.62	0.62	2.70
3/16/2006	0.29	0.17	10	2.01	0.01	0.05
4/12/2006	0.25	0.13	6	1.06	0.18	0.12
4/27/2006	0.24	0.10	8	1.09	0.16	0.24
5/25/2006	0.35	0.20	57	1.70	0.30	0.27
6/7/2006	0.47	0.25	32	1.80	0.20	0.26
6/21/2006	0.22	0.20	17	1.59	0.09	0.29
7/27/2006	0.20	0.03	41	1.51	0.01	0.20
8/28/2006	0.46		42	1.60	0.30	0.02
9/13/2006	0.27	0.25	11	1.43	0.23	0.11
4/25/2007	0.64	0.46	496	3.21	2.07	0.28
5/23/2007	0.18	0.05	17	0.69	0.29	0.04
6/5/2007	0.27	0.10	29	2.25	1.38	0.04
6/21/2007	0.29	0.14	43	0.69	0.87	0.04
7/17/2007	0.25	0.11		0.69	0.29	0.04
7/26/2007	0.18	0.09	10	0.69	0.29	0.04
8/8/2007	0.67	0.24	480	2.67	1.41	0.04
8/21/2007	0.44	0.29	30	0.69	0.29	0.04
9/11/2007	0.28	0.11	18	0.69	0.29	0.04
10/4/2007	0.37	0.22	17	0.69	0.29	0.04
10/18/2007	0.64	0.33	268	2.20	1.09	0.12
11/13/2007	0.14	0.06	3	0.69	0.29	0.15
5/29/2008	0.17	0.05	46	1.54	0.75	0.04

Table C-4. Tributary water quality data for Jackson Creek (RA-39)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
6/3/2008	0.48	0.11	350	4.88	0.71	0.36
6/16/2008	0.35	0.12	108	1.82	0.65	0.13
7/1/2008	0.12	0.05	70	2.44	1.69	0.04
7/15/2008	0.13	0.05	27	0.69	0.29	0.04
8/12/2008	0.18	0.05	72	0.69	0.29	0.04
9/8/2008	0.24	0.06	102	0.69	0.29	0.04
10/27/2008	0.22	0.09	28	0.69	0.29	0.04
11/4/2008	0.17	0.07	8	0.69	0.29	0.04
5/14/2009	▨	▨	93	▨	▨	▨
5/28/2009	0.27	0.08	145	2.67	1.56	0.17
6/18/2009	0.19	0.08	32	1.03	0.25	0.07
6/25/2009	0.30	0.07	110	2.52	0.92	0.02
7/16/2009	0.19	0.07	29	0.92	0.36	0.02
8/11/2009	0.22	0.07	72	1.35	0.35	0.05
8/17/2009	0.55	0.13	1077	1.90	0.50	0.07
9/23/2009	0.18	0.07	11	0.63	0.06	0.02
10/27/2009	0.19	0.07	38	0.37	0.25	0.07
11/23/2009	0.13	0.03	19	0.99	0.25	0.07
3/6/2010	0.25	0.07	3	1.85	0.47	0.75
3/22/2010	▨	▨	240	▨	▨	▨
4/19/2010	0.11	0.02	22	0.62	0.01	0.03
4/24/2010	0.55	0.01	740	1.82	1.11	0.07
5/11/2010	0.43	0.12	425	4.44	3.68	0.19
5/26/2010	0.39	0.10	364	4.00	2.10	0.03
6/22/2010	0.48	0.09	438	3.28	0.28	0.03
7/13/2010	0.22	0.08	28	1.16	0.30	0.03
8/11/2010	0.18	0.10	38	1.72	0.42	0.03
9/21/2010	0.29	0.11	87	0.95	0.35	0.03
10/9/2010	0.11	0.03	8	0.65	0.17	0.07
11/20/2010	0.10	0.03	6	1.41	0.75	0.35
3/15/2011	0.11	0.01	28	1.83	0.63	0.37
3/28/2011	0.09	0.00	15	0.85	0.24	0.01
4/12/2011	0.19	0.05	26	1.37	0.27	0.01
4/16/2011	1.20	0.18	2300	6.50	1.80	0.25
4/27/2011	0.12	0.04	75	2.80	1.20	0.12
5/9/2011	0.06	0.00	12	0.95	0.03	0.01
5/13/2011	0.31	0.06	110	2.10	0.30	0.03
5/21/2011	0.66	0.11	740	6.00	2.90	0.12
5/24/2011	0.16	0.05	70	3.70	2.20	0.08
6/7/2011	0.16	0.04	70	1.80	0.70	0.01
6/27/2011	0.38	0.09	240	2.91	0.61	0.03
7/18/2011	0.08	0.04	15	0.60	0.11	0.02
8/15/2011	0.09	0.01	28	0.95	0.05	0.03
9/19/2011	0.11	0.01	19	0.65	0.05	0.03
10/17/2011	0.14	0.04	10	1.05	0.05	0.03
4/14/2012	0.50	0.09	360	4.80	1.80	0.20
5/7/2012	1.20	0.07	2500	7.40	3.10	0.06
6/26/2012	0.18	0.04	58	1.45	0.05	0.19
7/11/2012	0.21	0.03	44	2.05	0.05	0.22

Table C-4. Tributary water quality data for Jackson Creek (RA-39)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
8/27/2012	0.25	0.05	82	2.45	0.05	0.03
10/22/2012	0.53	0.34	11	1.35	0.05	0.03
5/5/2013	0.70	0.13	890	6.40	3.00	0.11
5/28/2013	0.94	0.08	1070	8.60	3.80	0.12
5/29/2013	0.69	0.12	680	4.70	1.50	0.03
6/16/2013	0.59	0.07	530	4.10	1.20	0.03
6/24/2013	1.30	0.10	1500	5.50	1.90	0.03
7/22/2013	0.33	0.08	58	1.56	0.16	0.03
8/12/2013	0.12	0.03	12	0.25	0.05	0.03
8/26/2013	0.08	0.01	14	0.95	0.05	0.03
9/26/2013	0.09	0.03	9	0.95	0.05	0.03
10/7/2013	0.17	0.08	18	1.15	0.05	0.07
10/22/2013	0.10	0.01	15	0.75	0.05	0.03
10/31/2013	1.20	0.54	280	2.25	0.05	0.12
11/6/2013	0.42	0.31	10	0.65	0.05	0.03
11/18/2013	0.49	0.22	7	0.65	0.05	0.03
3/10/2014	1.10	0.90	81	3.68	0.78	1.20
3/24/2014	0.31	0.23	23	2.80	1.70	0.83
4/9/2014	0.18	0.13	13	0.65	0.04	0.02
4/15/2014	1.20	0.12	950	8.00	2.60	0.34
4/21/2014	0.28	0.17	46	1.79	0.79	0.08
4/25/2014	1.00	0.11	1050	3.60	1.80	0.13
4/28/2014	1.00	0.10	1100	3.80	1.50	0.03
5/12/2014	0.25	0.07	190	2.29	0.29	0.02
5/13/2014	2.10	0.08	2370	9.00	1.90	0.22
5/27/2014	0.18	0.16	20	1.68	0.93	0.17
5/29/2014	0.19	0.04	530	3.80	1.30	0.06
6/5/2014	1.20	0.12	1240	7.20	2.70	0.03
6/9/2014	0.25	0.12	140	1.95	1.30	0.07
6/23/2014	0.24	0.09	52	1.48	0.78	0.10
7/7/2014	0.84	0.02	720	2.95	0.05	0.03
7/10/2014	0.22	0.10	30	1.31	0.51	0.03
7/14/2014	1.10	0.07	1190	4.15	0.05	0.06
7/21/2014	0.14	0.04	21	0.95	0.05	0.03
8/4/2014	0.10	0.01	14	0.65	0.05	0.03
8/16/2014	1.50	0.15	2230	4.15	0.05	0.03
8/20/2014	0.47	0.13	300	2.00	0.20	0.03
8/24/2014	1.20	0.10	1390	4.35	0.05	0.03
8/31/2014	0.88	0.12	760	1.95	0.05	0.05
9/2/2014	0.33	0.15	57	1.21	0.21	0.03
9/15/2014	1.60	0.10	2840	4.95	0.05	0.13
10/2/2014	0.34	0.10	56	0.88	0.18	0.03
10/3/2014	1.00	0.18	1030	13.20	10.00	0.03
10/21/2014	0.17	0.05	8	0.90	0.30	0.03

NOTE: Cross-hatching indicates no data available for a given parameter and date.

Table C-5. Tributary water quality data for Wolf Creek (RA-41)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
5/12/1997	0.05			1.46	0.46	
6/9/1997	0.20		259	3.73	1.13	
6/23/1997	0.12		75	2.03	0.63	
7/21/1997	0.13		202	2.04	0.14	
8/19/1997	0.34		160	2.40	0.60	
9/15/1997	0.37		15	0.59	0.09	
10/14/1997	0.46		164	3.50	1.10	
11/12/1997	0.19		17	0.84	0.34	
3/16/1998	0.24		60	1.59	0.79	
4/16/1998	0.13		266	1.46	0.46	
5/14/1998	0.07		31	0.89	0.29	
5/23/1998	0.34		531	5.96	2.66	
6/23/1998	0.10		40	1.55	0.85	
7/8/1998	0.36		264	2.57	1.57	
7/21/1998	0.11		13	0.63	0.23	
8/17/1998	0.18		8	0.41	0.01	
9/15/1998	0.20			1.29	0.19	
10/13/1998	0.21			1.75	0.75	
11/10/1998	0.46		802	2.98	0.88	
3/17/1999	1.10		952	6.11	3.52	
4/13/1999	0.11		48	1.42	0.96	
5/11/1999	0.38		30	0.67		
6/11/1999	2.19		2508	8.26	1.91	
6/15/1999	0.22		93	2.05	0.92	
7/13/1999	0.11		55	1.18	0.38	
8/18/1999	0.23		90	1.54	0.51	
9/13/1999	0.19		68	0.96		
10/13/1999	0.16		78	1.00		
11/15/1999	0.20		62	0.95		
3/28/2000	0.10		9	0.73		
4/18/2000	0.10		14	0.86		
5/16/2000	0.09		11	1.00		
6/13/2000	0.13		19	0.91		
6/27/2000	0.46		161	5.30	3.30	
7/19/2000	0.44		38	1.39		
8/15/2000	0.27		67	1.00		
9/12/2000	0.20		176	0.95		
10/17/2000	0.07		10	0.54	0.04	
11/14/2000	0.21		14	1.37	0.41	
3/20/2001	0.49		333	5.00	3.00	
4/17/2001	0.21		43	1.80	1.00	
5/15/2001	0.41		212	4.20	2.80	
6/1/2001	0.46		208	5.30	3.70	
6/12/2001	0.14		27	1.14	0.90	
7/11/2001	0.17		37	1.50	0.81	
8/14/2001	0.12		51	0.09	0.04	
9/27/2001	0.11		42	0.23	0.07	
10/16/2001	0.36		65	0.89	0.06	
11/13/2001	0.15		17	0.35	0.06	

Table C-5. Tributary water quality data for Wolf Creek (RA-41)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO$_x$ (ppm)	NH$_x$ (ppm)
2/19/2002	0.08		19	1.05	1.00	
3/6/2002	0.09		7	0.09	0.04	
3/26/2002	0.07		14	0.17	0.01	
4/16/2002	0.06		14	0.26	0.01	
5/14/2002	0.27		111	4.80	3.80	
6/11/2002	0.28		157	1.54	0.96	
7/23/2002	0.16		75	0.52	0.10	
8/13/2002	0.11		75	0.45	0.01	
12/11/2002	1.40		63	2.21	0.01	
3/13/2003	0.73		29	3.15	0.95	
4/15/2003	0.14		6	0.25	0.01	
5/14/2003	0.18			2.13	1.60	
6/17/2003	0.35		148	3.50	2.40	
7/15/2003	0.16		22	0.98	0.61	
7/29/2003			41			
8/12/2003	0.12			0.90	0.01	
9/16/2003	0.10		28	0.47	0.04	
11/20/2003	0.19		23	2.63	2.30	
12/18/2003	0.21		22	3.41	2.80	
2/25/2004			26			
4/21/2004			30			
5/26/2004			322			
6/22/2004			34			
7/13/2004			123			
7/20/2004			35			
8/17/2004			133			
9/21/2004			20			
10/19/2004			8			
11/16/2004			6			
12/14/2004			11			
1/19/2005	0.04	0.01	2	0.66	0.15	0.12
2/15/2005	0.43	0.01	179	6.80	4.80	0.32
3/16/2005	0.08	0.01	9	0.46	0.01	0.21
4/13/2005	0.59	0.10	394	8.70	6.00	0.73
5/10/2005	0.07	0.13	13	0.81	0.01	0.01
6/15/2005	0.40	0.13	122	7.00	5.00	0.10
6/29/2005	0.50	0.01	220	4.00	2.00	0.20
7/28/2005	0.20	0.01	56	1.50	0.20	0.40
3/16/2006	0.16	0.01	2	1.51	0.01	0.06
4/12/2006	0.16	0.06	26	1.15	0.17	0.13
4/27/2006	0.13	0.03	13	1.31	0.01	0.24
5/25/2006	0.78	0.20	540	11.30	7.50	0.30
6/7/2006	0.30	0.03	43	1.98	0.18	0.87
6/21/2006	0.20	0.02	32	1.71	0.01	0.22
4/25/2007	0.54	0.47	1595	2.15	3.27	0.33
5/23/2007	0.14	0.02	48	0.69	0.29	0.04
6/21/2007	0.14	0.02	32	0.69	0.61	0.09
8/8/2007	0.21	0.02	58	0.69	0.29	0.26
8/21/2007	0.19	0.06	72	0.69	0.29	0.09

Table C-5. Tributary water quality data for Wolf Creek (RA-41)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
9/11/2007	0.14	0.03	35	0.69	0.29	0.04
9/27/2007	0.20	0.04	37	0.69	0.29	0.09
10/4/2007	0.16	0.03	10	0.69	0.29	0.04
10/18/2007	0.60	0.19	660	2.85	2.08	0.04
11/13/2007	0.12	0.03	9	0.69	0.29	0.09
5/29/2008	0.14	0.03	72	2.30	1.32	0.25
6/3/2008	0.57	0.05	638	6.46	0.93	0.48
6/16/2008	0.22	0.06	84	2.08	1.04	0.17
7/1/2008	0.15	0.03	52	2.23	1.43	0.12
7/15/2008	0.16	0.04	61	1.76	0.77	0.13
8/12/2008	0.12	0.05	40	0.69	0.29	0.04
9/8/2008	0.08	0.01	23	0.69	0.29	0.04
10/27/2008	0.21	0.07	39	0.69	0.29	0.04
11/4/2008	0.11	0.03	3	0.69	0.29	0.04
5/14/2009	▨	▨	34	▨	▨	▨
5/28/2009	0.27	0.06	166	7.48	6.19	0.18
6/18/2009	0.13	0.04	25	1.06	0.25	0.07
6/25/2009	0.45	0.07	106	4.50	2.00	0.08
7/16/2009	0.13	0.07	61	0.80	0.39	0.02
8/11/2009	0.37	0.07	234	2.38	0.78	0.08
8/17/2009	0.55	0.13	541	1.53	0.64	0.07
9/23/2009	0.17	0.07	68	0.95	0.12	0.02
10/27/2009	0.18	0.03	75	0.37	0.25	0.07
11/23/2009	0.11	0.01	19	0.82	0.25	0.07
3/22/2010	▨	▨	418	▨	▨	▨
4/19/2010	0.07	0.01	11	0.51	0.01	0.03
4/24/2010	0.73	0.34	294	5.28	3.83	0.97
5/11/2010	0.54	0.12	1223	7.35	7.35	0.24
5/26/2010	0.22	0.09	270	2.06	1.20	0.03
6/22/2010	0.47	0.09	350	3.96	0.26	0.03
7/13/2010	0.16	0.04	41	1.27	0.41	0.03
8/11/2010	0.60	0.20	289	3.49	0.39	0.05
9/21/2010	0.27	0.09	78	0.99	0.29	0.03
10/9/2010	0.08	0.02	16	0.28	0.17	0.07
11/20/2010	0.10	0.02	9	1.47	0.85	0.31
3/16/2011	0.01	0.01	16	1.45	0.84	0.08
3/28/2011	0.08	0.00	26	1.27	0.58	0.03
4/12/2011	0.10	0.02	20	1.49	0.79	0.03
4/16/2011	0.82	0.09	1000	6.70	2.30	0.34
4/26/2011	0.09	0.01	91	1.44	0.58	0.05
5/9/2011	0.05	0.00	11	0.78	0.03	0.01
5/12/2011	0.90	0.05	680	6.30	1.40	0.09
5/21/2011	0.67	0.07	1000	5.80	3.40	0.16
5/23/2011	0.30	0.05	210	8.60	5.40	0.20
6/6/2011	0.14	0.03	61	1.72	0.73	0.03
6/28/2011	0.29	0.05	200	1.37	0.66	0.04
7/18/2011	0.11	0.02	40	1.09	0.09	0.01
8/6/2011	0.53	0.08	400	2.70	0.70	0.07
8/16/2011	0.15	0.04	62	1.61	0.11	0.03

Table C-5. Tributary water quality data for Wolf Creek (RA-41)

Date	TP (ppm)	Ortho-P (ppm)	TSS (ppm)	TN (ppm)	NO_x (ppm)	NH_x (ppm)
9/19/2011	0.07	0.02	13	0.75	0.05	0.03
10/17/2011	0.14	0.06	8	1.25	0.05	0.03
4/14/2012	0.52	0.15	250	4.00	1.20	0.09
5/3/2012	1.50	0.07	1800	9.60	3.40	0.14
6/18/2012	0.73	0.04	690	10.30	7.50	0.14
6/26/2012	0.15	0.04	20	5.90	5.10	0.08
7/12/2012	0.14	0.03	25	1.80	0.10	0.30
10/22/2012	0.55	0.41	14	1.25	0.05	0.03
5/5/2013	0.82	0.14	960	7.40	4.20	0.18
5/17/2013	0.32	0.11	910	4.60	1.90	0.10
5/22/2013	0.68	0.09	620	5.40	1.90	0.09
5/28/2013	1.10	0.11	1120	8.20	3.60	0.14
6/16/2013	1.30	0.09	1640	6.30	1.80	0.03
6/25/2013	1.10	0.05	1100	4.70	1.30	0.03
7/22/2013	0.11	0.03	20	1.35	0.55	0.03
8/12/2013	0.07	0.05	12	0.25	0.05	0.03
10/7/2013	0.09	0.02	19	0.55	0.05	0.03
10/22/2013	0.08	0.05	10	0.35	0.05	0.03
11/6/2013	0.36	0.32	6	0.55	0.05	0.03
3/10/2014	1.10	0.96	62	3.46	0.66	0.98
3/24/2014	0.16	0.08	12	0.75	0.55	0.22
4/9/2014	0.10	0.05	12	0.59	0.04	0.02
4/14/2014	1.80	0.11	1580	8.60	3.50	0.41
4/21/2014	0.10	0.03	67	3.19	2.60	0.02
4/25/2014	1.40	0.07	2340	6.10	3.00	0.19
4/29/2014	1.20	0.11	1880	4.10	2.30	0.12
5/12/2014	0.88	0.22	1400	10.30	2.20	0.24
5/14/2014	1.40	0.10	1620	6.10	2.40	0.09
5/27/2014	0.07	0.05	14	1.11	0.63	0.02
6/5/2014	1.30	0.11	1240	8.30	3.80	0.03
6/8/2014	1.20	0.07	1380	6.90	2.50	0.07
6/9/2014	0.18	0.09	91	3.07	2.10	0.07
6/23/2014	0.14	0.04	20	1.10	0.60	0.03
7/10/2014	0.20	0.06	32	1.72	0.92	0.03
7/21/2014	0.08	0.01	21	0.75	0.05	0.03
8/4/2014	0.08	0.02	18	0.75	0.05	0.03
8/17/2014	1.10	0.15	1250	3.99	0.59	0.03
8/20/2014	0.62	0.10	400	2.47	0.27	0.09
9/2/2014	0.41	0.14	110	1.79	0.19	0.10
9/15/2014	0.20	0.04	34	1.14	0.24	0.10
10/2/2014	0.13	0.04	15	0.65	0.05	0.03
10/21/2014	0.15	0.03	8	0.78	0.18	0.03

NOTE: Cross-hatching indicates no data available for a given parameter and date.

C.3. Watershed Load Estimates

Sediment and nutrient loads (i.e., fluxes) exported from the watershed to the lake were calculated using tributary monitoring data at RA-12, RA-15, RA-39, and RA-41 and the Flux32 software program (Walker, 1999). Flux input includes a file of average daily flows and a file containing water quality sampling data for a given monitoring location (i.e., Tables C-2 through C-5). For both sediment (TSS) and TP, flux calculations utilized Method 6 with flow stratification, which is documented in the Flux32 user manual.

Calculated / observed loads were extrapolated to un-monitored drainage areas to the lake based on similarity of drainage area characteristics, which enabled estimation of total watershed loads exported to the lake. Figure C-2 illustrates the monitored drainage areas and areas that required load projections. Sediment and TP fluxes for SWAT model calibration (Appendix E) were calculated at RA-12, which coincides with USGS Gaging Station 06903700 and includes water quality monitoring data. Fluxes at RA-41 and RA-15 were calculated using flows measuring using an automated ISCO sampler that were refined using relationships with nearby USGS gages and WQ data collected at each site. Fluxes at RA-41 and RA-15 were added together to get fluxes at RA-45, which coincides with USGS Gaging Station 06903400.

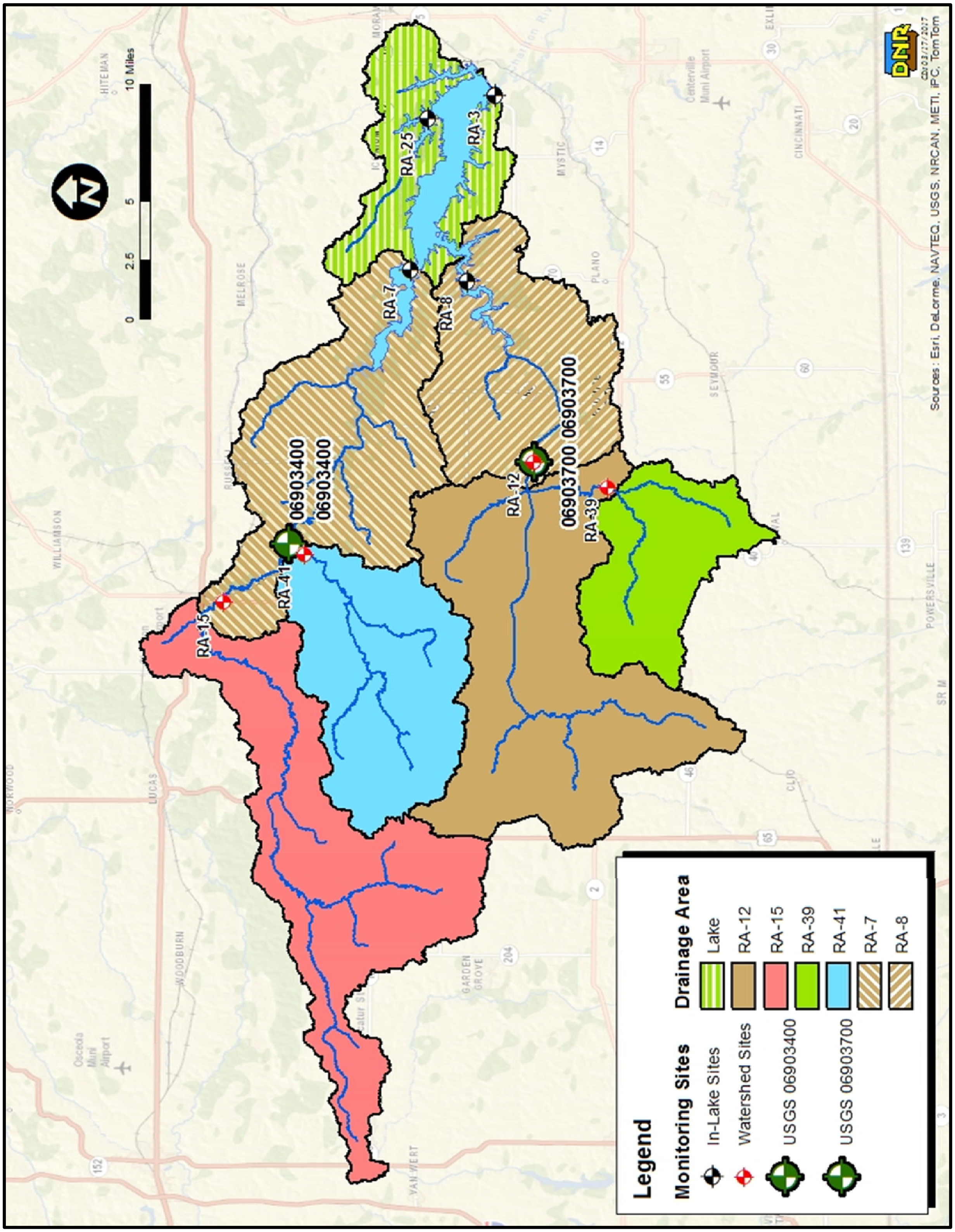


Figure C-2. Watershed loading map. Loads for watersheds lacking monitoring data (cross-hatched areas) were projected from loads estimated using monitoring data (solid-shaded areas).

Per-area loads measured at RA-12 were projected to the drainage areas (i.e., watersheds) for RA-7 and RA-8, and per area loads at RA-39 were projected to the drainage area adjacent to the lake (Table C-6). Estimated monthly loads are reported in Tables C-7 through C-10.

Table C-6. Monitored drainage areas for watershed load estimates.

Monitored DA[a]	Projected DA[a]	Notes	Area (ha)
RA-12		Measured at Site RA-12	31,493[b]
	RA-7	Projected from RA-12	23,774
	RA-8	Projected from RA-12	17,933
RA-15		Measured at Site RA-15	27,052
RA-39		Measured at Site RA-39	11,550
	Adjacent to Lake	Projected from RA-39	13,324
RA-41		Measured at Site RA-41	18,148

[a] DA = drainage area (i.e., watershed) upstream of monitoring sites.

[b] The drainage area reported for RA-12 excludes 11,550 ha upstream of RA-39.

Table C-7. Monthly load estimates for RA-12.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
1997	1	0.14	9.9	77.4	19.5	406.2	122.5	23.8
1997	2	10.19	42856.7	28927.0	2775.8	148252.0	67330.0	4660.3
1997	3	3.37	8899.1	6955.8	847.0	40360.0	16088.0	1277.7
1997	4	9.06	33165.5	10583.0	2517.6	80075.0	11364.0	4219.7
1997	5	4.07	12416.7	3955.4	932.7	31617.0	3184.4	1971.6
1997	6	1.60	5023.0	3996.6	309.4	36495.0	17292.0	593.7
1997	7	0.13	11.3	90.1	18.4	312.7	86.6	20.5
1997	8	1.09	4269.3	3408.9	255.9	11580.0	4794.1	550.2
1997	9	0.17	16.4	82.6	23.8	547.0	188.5	23.0
1997	10	4.68	17345.9	12504.0	1261.0	63314.0	25694.0	2341.1
1997	11	1.10	938.6	1159.7	191.0	6801.0	3558.8	266.3
1997	12	2.91	4162.4	4244.5	527.8	28426.0	12551.0	1039.2
1998	1	3.47	9869.0	7550.0	771.5	37569.0	17236.0	1562.8
1998	2	4.40	10050.5	8500.7	878.3	44989.0	20370.0	1852.2
1998	3	16.38	69116.9	45923.0	4843.2	242527.0	100347.0	8240.9
1998	4	8.85	22557.4	8671.3	2317.0	64021.0	18133.0	4243.7
1998	5	12.14	46210.6	28615.0	3709.5	179575.0	40165.0	5819.5
1998	6	8.92	21413.0	5790.9	2538.4	79547.0	31512.0	4029.2
1998	7	1.07	1033.7	384.9	204.3	3528.7	1533.5	367.7
1998	8	0.07	4.6	28.8	10.0	148.1	51.5	12.2
1998	9	0.10	8.0	130.7	13.7	301.2	77.1	13.9
1998	10	7.21	32547.5	22143.0	2270.1	170785.0	99409.0	3343.4
1998	11	5.69	15514.2	7903.2	1306.6	48127.0	19005.0	2814.2
1998	12	0.81	173.6	494.0	126.4	3386.8	2053.2	124.6
1999	1	0.82	303.4	601.9	131.3	4128.2	2237.7	157.7
1999	2	3.09	5792.0	5189.4	582.4	28702.0	13394.0	1177.0
1999	3	4.57	10201.8	8565.4	1139.3	54489.0	28232.0	1954.1
1999	4	12.13	36773.7	26573.0	3416.5	118407.0	34094.0	5736.9
1999	5	10.59	40875.6	45707.0	3257.2	126496.0	35936.0	4962.4

Table C-7. Monthly load estimates for RA-12.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
1999	6	7.63	28127.0	22528.0	2128.7	107306.0	31828.0	3559.2
1999	7	0.21	17.9	85.9	31.3	562.7	289.9	30.6
1999	8	0.15	15.0	71.2	22.1	359.6	127.0	23.0
1999	9	0.04	2.7	14.1	5.4	66.0	16.5	6.5
1999	10	0.04	2.3	21.6	5.3	75.4	16.9	6.4
1999	11	0.06	2.7	23.1	8.0	78.2	40.5	9.7
1999	12	0.03	1.6	10.9	3.4	53.0	8.2	4.1
2000	1	0.03	1.9	13.1	4.1	64.4	10.4	4.9
2000	2	0.25	65.5	153.4	35.4	1013.5	545.9	42.6
2000	3	0.08	4.5	36.1	10.5	181.2	46.2	12.7
2000	4	0.16	41.8	78.1	23.6	626.1	314.5	32.2
2000	5	0.05	4.0	27.7	7.5	160.9	33.4	8.3
2000	6	3.21	8022.8	7665.1	916.6	41013.0	17533.0	1451.5
2000	7	0.30	96.3	232.5	45.6	1325.6	307.9	61.1
2000	8	0.09	7.0	77.2	11.9	253.3	40.4	13.7
2000	9	0.01	0.7	4.3	1.7	23.2	3.0	2.0
2000	10	0.02	0.9	7.8	2.1	26.1	4.7	2.6
2000	11	0.17	15.9	102.9	25.2	732.4	451.4	23.2
2000	12	0.02	1.5	10.6	3.3	51.7	7.9	4.1
2001	1	0.51	486.2	576.6	85.9	3964.2	1759.8	146.8
2001	2	15.12	64406.7	42696.0	4264.8	226224.0	99812.0	6500.0
2001	3	14.67	43471.8	26788.0	3895.6	178833.0	103250.0	8103.4
2001	4	5.17	9375.9	6338.2	1119.9	38309.0	20292.0	2380.9
2001	5	15.26	46349.0	11031.0	4866.5	152957.0	86628.0	7196.3
2001	6	17.68	60833.3	40803.0	5288.4	190793.0	93513.0	8380.9
2001	7	0.43	209.8	327.0	67.3	1664.1	168.8	86.4
2001	8	0.11	10.2	51.1	15.8	203.7	54.1	15.9
2001	9	0.09	8.1	60.4	11.7	287.3	109.8	13.0
2001	10	0.95	1987.6	2250.6	196.5	6987.1	4964.3	378.7
2001	11	0.17	10.8	61.4	23.4	182.0	60.5	25.9
2001	12	0.26	24.3	139.8	37.9	848.4	413.1	37.5
2002	1	0.09	6.0	45.6	12.2	235.1	60.6	14.8
2002	2	0.72	142.6	351.3	103.5	1635.8	823.0	113.3
2002	3	0.91	328.5	475.1	149.2	773.4	283.0	199.0
2002	4	3.22	7826.3	5280.0	697.4	18855.0	5940.2	1426.3
2002	5	9.42	26130.0	16381.0	2842.0	117232.0	76185.0	4331.8
2002	6	0.57	505.8	516.3	90.5	2292.9	874.5	133.8
2002	7	0.06	4.3	25.8	8.2	87.9	30.3	9.9
2002	8	0.06	4.8	21.4	8.4	86.8	21.6	9.4
2002	9	0.03	1.8	9.4	3.6	32.8	2.9	4.3
2002	10	0.02	1.3	9.6	3.1	39.8	4.9	3.8
2002	11	0.02	1.0	7.8	3.0	20.5	1.2	3.6
2002	12	0.02	0.9	5.6	2.3	13.8	2.0	2.8
2003	1	0.02	1.1	7.7	2.5	37.2	5.3	3.0
2003	2	0.06	3.9	30.7	7.8	160.3	48.4	9.5
2003	3	0.08	6.3	111.3	11.1	457.1	110.2	12.5
2003	4	0.28	71.4	201.1	42.1	873.2	214.3	51.4
2003	5	1.55	4318.6	3168.8	340.7	19183.0	12512.0	697.8

Table C-7. Monthly load estimates for RA-12.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2003	6	1.02	2660.2	2062.3	225.9	17886.0	14801.0	465.0
2003	7	0.22	160.8	326.6	35.3	1422.1	1187.5	57.6
2003	8	0.01	1.0	5.2	2.0	26.2	1.8	2.4
2003	9	0.10	7.2	55.9	13.4	273.2	130.6	13.8
2003	10	0.05	3.5	26.3	7.3	72.1	6.1	8.8
2003	11	1.40	4669.0	3309.1	317.2	15587.0	7322.8	674.6
2003	12	0.54	707.3	797.8	101.2	6693.3	4607.7	172.5
2004	1	0.28	27.4	151.5	40.4	912.5	490.8	41.5
2004	2	3.02	4619.2	6684.1	650.1	33417.0	14869.0	1399.6
2004	3	7.66	21348.3	20995.0	2141.7	110901.0	48479.0	3556.6
2004	4	0.56	98.5	333.2	84.8	2206.1	1123.1	83.8
2004	5	3.60	9604.5	9811.5	1035.8	51414.0	20340.0	1699.8
2004	6	4.74	19027.0	12201.0	1286.2	64006.0	26072.0	2085.7
2004	7	1.87	4134.1	4110.0	415.0	19890.0	8889.9	844.6
2004	8	18.23	85870.4	62242.0	6087.0	334046.0	155827.0	8599.7
2004	9	0.31	27.7	160.1	44.2	1001.5	522.6	41.7
2004	10	0.15	7.6	77.6	20.9	432.1	131.9	22.7
2004	11	0.31	18.2	162.2	42.6	958.9	441.9	44.1
2004	12	0.33	115.0	260.0	51.8	1692.4	721.4	73.0
2005	1	1.09	1200.2	1024.9	62.1	10983.0	5994.6	1309.5
2005	2	5.52	9716.8	5597.9	1146.0	66325.0	35558.0	3090.3
2005	3	0.66	50.9	240.9	28.2	1646.3	240.5	196.2
2005	4	3.91	7936.2	5122.3	94.5	61820.0	30979.0	4198.8
2005	5	0.64	281.9	317.3	26.3	2703.2	258.4	34.4
2005	6	2.80	8102.1	6539.1	1881.5	44695.0	17779.0	1348.8
2005	7	0.31	99.3	217.6	108.1	1368.6	423.5	94.2
2005	8	0.06	3.7	53.0	4.0	150.6	20.3	11.5
2005	9	0.02	1.3	9.2	0.9	45.7	2.4	1.3
2005	10	0.03	2.0	14.1	4.2	69.9	13.0	5.1
2005	11	0.05	3.3	24.0	6.9	121.0	24.9	8.4
2005	12	0.02	1.1	7.7	2.4	37.2	5.2	3.1
2006	1	0.02	1.2	9.0	1.9	51.3	10.2	6.0
2006	2	0.04	2.4	17.1	5.1	84.8	15.4	6.2
2006	3	0.23	43.2	163.2	39.1	1993.8	47.6	103.9
2006	4	0.43	187.6	373.8	73.5	2148.0	148.9	204.3
2006	5	0.81	1020.7	1277.1	188.3	7635.5	1194.7	730.6
2006	6	0.05	4.6	30.2	8.6	221.4	31.4	11.7
2006	7	0.02	1.1	8.8	3.5	44.8	7.4	3.1
2006	8	0.12	11.1	53.0	35.1	408.5	125.9	13.6
2006	9	0.05	2.5	17.0	12.0	107.3	12.8	6.6
2006	10	0.06	3.8	30.4	9.2	167.4	43.5	6.6
2006	11	0.37	712.9	683.9	76.1	3643.2	1611.2	155.5
2006	12	0.70	1628.0	1376.3	149.9	6901.5	3071.9	300.6
2007	1	0.42	812.0	762.7	89.0	3837.2	1791.2	166.5
2007	2	4.60	17306.9	12040.0	1221.7	61702.0	24911.0	2097.0
2007	3	3.77	10408.3	8321.8	846.8	42293.0	19227.0	1765.0
2007	4	12.08	44114.2	20136.0	11166.0	101850.0	76636.0	10248.0
2007	5	13.71	60617.1	34606.0	6136.6	179961.0	103879.0	7668.6

Table C-7. Monthly load estimates for RA-12.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2007	6	1.55	3259.8	3639.3	366.1	20454.0	10478.0	550.1
2007	7	0.07	4.2	26.3	9.0	130.7	53.4	7.7
2007	8	20.88	146567.2	99004.0	12510.0	286739.0	189545.0	7003.1
2007	9	0.40	123.7	256.7	46.0	1188.8	666.8	50.8
2007	10	2.43	5194.2	3284.6	1159.2	11495.0	4716.3	267.2
2007	11	0.24	11.0	95.4	26.0	516.8	194.6	29.5
2007	12	3.68	11209.5	8431.2	836.5	41680.0	18822.0	1767.9
2008	1	4.13	13281.3	9854.0	958.8	47789.0	21491.0	2023.3
2008	2	3.15	4453.0	4384.1	533.9	28920.0	12838.0	1023.1
2008	3	9.54	38066.7	27280.0	2811.0	144836.0	61298.0	4604.4
2008	4	16.38	69823.3	47668.0	4952.1	254281.0	103330.0	7633.9
2008	5	11.76	36849.3	23762.0	3185.0	141658.0	59392.0	5337.8
2008	6	19.55	56412.0	27433.0	5956.6	208694.0	49861.0	17496.0
2008	7	37.12	148784.7	104999.0	11640.0	436472.0	149067.0	15583.0
2008	8	0.84	211.4	476.5	105.0	2723.1	1279.0	129.3
2008	9	7.51	27829.5	15594.0	1227.5	73437.0	29740.0	3114.7
2008	10	3.85	11091.6	9469.5	1089.5	29540.0	9674.3	1708.4
2008	11	4.07	7736.3	7006.0	1307.7	35304.0	15585.0	1215.4
2008	12	6.70	27578.8	19137.0	1950.1	100459.0	43655.0	3156.7
2009	1	1.06	523.0	859.0	172.2	5956.4	3103.8	217.2
2009	2	1.35	1141.0	1401.4	219.1	8726.8	4402.8	352.8
2009	3	16.12	73129.4	49548.0	5214.9	270626.0	111060.0	7462.1
2009	4	10.11	45144.1	29881.0	2904.9	155719.0	72709.0	4632.7
2009	5	10.60	30326.1	24234.0	3046.5	161911.0	83067.0	5552.7
2009	6	8.40	22482.0	13017.0	2292.3	100392.0	41679.0	3889.6
2009	7	8.19	31587.9	14465.0	3076.9	91796.0	24675.0	700.1
2009	8	15.84	77370.0	38972.0	4736.2	194045.0	56838.0	4580.8
2009	9	0.47	82.9	232.7	74.9	1451.2	691.7	54.9
2009	10	10.82	31225.4	15363.0	3206.3	28097.0	17248.0	3051.5
2009	11	4.47	7600.7	4110.5	614.3	23459.0	6778.8	1157.3
2009	12	4.82	17824.9	12645.0	1350.0	67302.0	27722.0	2133.7
2010	1	7.12	28167.4	19693.0	2122.1	105346.0	43403.0	3218.2
2010	2	0.81	80.1	361.5	106.4	2533.7	1556.8	116.4
2010	3	18.39	47907.4	34580.0	3891.8	207859.0	65845.0	25786.0
2010	4	12.95	39571.5	17871.0	3513.0	144351.0	134682.0	11208.0
2010	5	17.45	45436.8	17658.0	3572.9	239435.0	184742.0	5418.3
2010	6	28.20	105460.1	63239.0	8122.1	479687.0	100400.0	4310.1
2010	7	14.27	59708.8	44682.0	5371.2	165883.0	40412.0	3831.5
2010	8	6.49	14361.0	9362.6	1953.7	47867.0	13699.0	1472.3
2010	9	23.91	66096.6	26158.0	5090.2	160981.0	35049.0	4697.5
2010	10	0.86	160.1	375.0	97.0	1902.3	970.0	142.3
2010	11	1.86	3254.1	2253.3	238.6	15063.0	6155.6	891.0
2010	12	0.48	133.9	322.7	71.1	2090.5	861.1	84.4
2011	1	0.38	83.0	248.4	56.3	1530.9	680.1	68.6
2011	2	7.42	27141.2	18557.0	1809.4	91361.0	37952.0	3439.6
2011	3	3.72	5202.7	2671.7	184.1	26419.0	10694.0	1442.4
2011	4	8.34	29798.6	18519.0	1638.5	136756.0	45765.0	6114.3
2011	5	13.46	39107.0	21020.0	3733.4	298817.0	164590.0	2612.3

Table C-7. Monthly load estimates for RA-12.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2011	6	14.65	63548.9	36087.0	2659.3	237298.0	49926.0	1245.7
2011	7	0.39	127.8	237.6	33.5	1116.9	282.0	18.2
2011	8	0.14	17.8	65.3	12.7	405.1	42.7	10.6
2011	9	0.04	2.3	13.7	2.8	79.8	10.9	4.4
2011	10	0.04	2.3	38.8	7.9	150.6	8.1	3.8
2011	11	0.07	4.4	33.6	8.9	174.0	49.1	10.8
2011	12	0.37	225.3	330.0	59.2	2216.3	1044.8	86.2
2012	1	0.06	4.0	29.4	8.2	149.0	32.9	10.0
2012	2	0.33	28.4	164.1	45.2	1016.2	481.4	42.4
2012	3	1.27	989.9	1260.8	211.1	8739.8	4302.9	306.7
2012	4	0.97	1155.9	1290.2	163.1	8058.0	3682.5	298.6
2012	5	2.38	6875.3	6754.3	318.5	43661.0	21260.0	1164.9
2012	6	0.50	778.2	799.9	97.1	4186.2	2070.8	125.4
2012	7	0.02	0.8	6.7	1.9	29.3	4.4	1.3
2012	8	0.02	1.3	9.1	2.7	45.3	8.6	3.3
2012	9	0.00	0.1	0.5	0.2	2.3	0.2	0.2
2012	10	0.21	11.2	98.0	31.0	306.0	51.8	18.0
2012	11	0.09	6.4	44.6	12.3	239.0	75.6	13.4
2012	12	0.09	5.7	43.5	11.6	223.7	56.6	14.1
2013	1	0.04	2.7	20.7	5.6	106.8	29.0	6.8
2013	2	0.39	449.0	458.5	59.2	3120.3	1306.5	106.9
2013	3	4.89	18970.8	13302.0	1398.1	70435.0	29222.0	2255.1
2013	4	31.66	161078.7	104257.0	10317.0	561731.0	256907.0	14312.0
2013	5	15.48	92485.2	76336.0	2960.0	310995.0	85705.0	5508.3
2013	6	6.25	52814.7	54635.0	917.0	122301.0	6695.5	6256.9
2013	7	0.07	5.2	33.9	7.1	170.6	37.0	5.3
2013	8	0.04	2.1	13.0	2.5	26.9	5.4	7.4
2013	9	0.03	1.5	10.0	2.3	59.0	15.4	3.2
2013	10	0.06	4.7	28.3	6.1	68.5	36.5	3.7
2013	11	0.17	9.6	91.5	14.9	253.3	49.5	11.6
2013	12	0.04	2.2	16.1	4.7	78.4	13.8	5.8
2014	1	0.04	2.8	20.4	6.0	102.1	19.5	7.3
2014	2	5.21	19373.8	13373.0	1378.1	67925.0	27490.0	2401.1
2014	3	2.20	2444.1	3130.8	2215.3	17381.0	4841.0	3557.6
2014	4	3.81	21137.5	16765.0	574.4	68621.0	20611.0	1917.9
2014	5	4.50	22156.6	24139.0	1087.2	110621.0	17938.0	1691.2
2014	6	15.05	58302.5	41409.0	3330.4	309244.0	56953.0	1500.6
2014	7	1.89	5806.8	6133.3	389.7	22745.0	2590.4	220.3
2014	8	13.92	59021.2	44145.0	4649.3	171903.0	2903.8	1592.5
2014	9	9.59	35207.6	28880.0	3057.1	92943.0	4219.1	2030.5
2014	10	8.42	20318.9	11610.0	1595.7	36728.0	3807.4	1027.7
2014	11	0.55	49.5	279.5	78.8	1781.5	819.9	63.9
2014	12	0.73	83.8	392.6	113.5	2667.1	1604.8	92.1

[a] Average monthly flow
[b] Total suspended solids is equivalent to suspended sediment in mega grams (metric tons)

Table C-8. Monthly load estimates for RA-15.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
1997	1	0.19	18.2	133.7	47.4	722.6	393.3	50.9
1997	2	6.14	12824.1	13132.0	2666.8	98660.0	82267.0	1896.5
1997	3	3.10	3187.4	5057.8	1306.2	33080.0	22500.0	1140.2
1997	4	4.39	5576.0	5080.4	1919.8	41663.0	21691.0	1620.9
1997	5	4.22	5586.4	5312.4	2054.7	45185.0	24211.0	1649.6
1997	6	1.66	2207.2	1956.9	635.4	19557.0	8473.3	573.0
1997	7	0.78	1123.5	616.4	332.9	8080.5	1503.4	283.8
1997	8	0.34	178.1	387.5	93.1	2511.2	759.0	103.4
1997	9	0.14	12.3	79.8	35.0	527.5	151.9	38.1
1997	10	1.48	1091.5	2186.2	566.7	12563.0	6050.8	525.6
1997	11	0.99	376.0	889.8	254.7	6786.0	4272.6	290.8
1997	12	2.32	1293.3	2584.4	673.3	21179.0	13557.0	758.7
1998	1	2.44	2302.6	4058.3	1077.7	23836.0	14139.0	910.6
1998	2	3.63	3074.7	5375.3	1232.4	31487.0	15807.0	1173.3
1998	3	9.30	17157.5	19637.0	4502.6	141005.0	105626.0	3370.7
1998	4	9.08	11837.4	8019.8	3931.8	88554.0	42117.0	2832.7
1998	5	7.89	16015.6	12529.0	3744.9	134422.0	60161.0	2682.9
1998	6	3.27	3430.5	2560.1	1426.7	34572.0	14053.0	1201.8
1998	7	1.80	1904.0	1928.3	846.3	12903.0	7413.1	689.3
1998	8	0.15	13.1	94.5	38.1	486.5	26.8	41.4
1998	9	0.21	20.1	90.5	50.7	552.4	136.8	55.3
1998	10	2.49	3214.3	5527.1	1178.3	34175.0	23036.0	959.3
1998	11	3.29	2436.9	4037.3	1466.0	20177.0	9577.8	1216.6
1998	12	0.73	127.6	508.8	183.7	4380.9	3496.4	211.6
1999	1	0.87	202.5	658.1	227.7	5996.4	5028.6	260.2
1999	2	2.34	1332.2	2816.6	817.0	18916.0	11849.0	752.9
1999	3	2.64	2460.3	4588.8	1065.3	24417.0	15185.0	951.9
1999	4	8.63	19787.7	26058.0	3875.1	196080.0	93226.0	2863.4
1999	5	5.40	8837.8	16513.0	2569.3	46843.0	21111.0	2017.6
1999	6	2.82	3520.2	5815.2	1096.9	29900.0	10302.0	991.0
1999	7	0.36	66.5	254.0	91.6	2267.0	1518.1	103.5
1999	8	1.07	873.3	1402.7	425.3	8365.1	5135.6	381.4
1999	9	0.05	6.1	19.4	10.9	108.4	42.0	11.7
1999	10	0.03	3.5	18.6	8.5	84.8	27.3	9.1
1999	11	0.02	1.8	15.1	5.2	60.8	20.4	5.5
1999	12	0.01	0.9	6.0	2.2	25.7	3.5	2.4
2000	1	0.03	3.0	20.2	7.4	96.0	24.5	8.0
2000	2	0.12	14.6	75.3	27.1	509.0	296.5	30.3
2000	3	0.03	2.9	19.7	8.7	99.0	29.1	9.3
2000	4	0.10	9.9	48.9	25.4	316.3	209.3	28.2
2000	5	0.06	5.4	40.6	15.1	161.6	69.6	16.2
2000	6	2.23	2039.1	3318.5	996.5	16242.0	9309.4	828.8
2000	7	1.13	917.3	1854.5	385.8	9535.7	2629.3	382.7
2000	8	0.15	18.8	133.7	37.6	676.2	188.4	42.1
2000	9	0.03	2.3	15.6	6.3	73.1	20.1	6.7
2000	10	0.03	2.6	14.3	7.9	59.2	29.1	8.4
2000	11	0.07	5.1	43.3	17.1	250.3	106.0	18.3
2000	12	0.03	3.0	20.6	7.6	96.7	22.5	8.1
2001	1	0.19	20.4	133.4	47.5	760.3	370.8	51.9

Table C-8. Monthly load estimates for RA-15.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2001	2	1.00	302.7	785.0	245.2	6852.1	5043.5	278.3
2001	3	7.16	6182.1	8787.1	3538.4	87339.0	73126.0	2844.5
2001	4	3.53	2559.9	4155.3	1478.0	24489.0	15144.0	1278.9
2001	5	4.97	5715.4	6202.0	2113.0	81179.0	61592.0	1660.6
2001	6	9.24	12278.4	13581.0	4434.3	118691.0	120828.0	3278.7
2001	7	0.60	341.7	801.7	221.5	6185.3	3369.4	205.9
2001	8	0.06	7.5	34.8	13.9	141.7	55.1	15.2
2001	9	0.20	94.0	206.2	54.4	1363.8	702.8	61.0
2001	10	1.16	1380.6	2426.6	471.3	10213.0	6266.4	419.6
2001	11	0.16	15.4	111.5	39.9	404.0	158.8	43.6
2001	12	0.14	13.8	100.4	35.7	536.1	275.8	38.3
2002	1	0.03	2.9	19.7	7.2	92.9	22.9	7.7
2002	2	0.25	20.2	51.8	56.7	283.4	187.3	63.9
2002	3	0.94	303.4	374.8	257.7	2421.9	316.1	292.3
2002	4	1.75	909.2	1847.8	587.7	11118.0	4376.9	574.7
2002	5	4.95	4456.5	6260.7	2201.8	86673.0	52872.0	1779.8
2002	6	0.87	660.5	1240.3	232.6	9106.9	5154.6	263.1
2002	7	0.36	86.9	305.4	96.6	2075.6	1386.2	108.7
2002	8	0.02	1.8	10.5	4.0	35.4	2.5	4.3
2002	9	0.01	0.9	4.7	2.5	22.1	1.2	2.7
2002	10	0.01	1.0	6.7	2.5	28.4	5.2	2.7
2002	11	0.00	0.4	7.0	1.0	10.4	0.3	1.0
2002	12	0.00	0.3	1.6	0.5	6.5	0.2	0.6
2003	1	0.00	0.0	0.3	0.1	0.9	0.0	0.1
2003	2	0.05	4.0	29.6	10.4	154.6	77.5	11.1
2003	3	0.22	24.7	299.9	55.1	1030.7	176.8	62.1
2003	4	0.24	20.7	127.0	57.9	596.4	107.0	64.3
2003	5	1.49	1455.8	2935.7	572.2	22187.0	15026.0	528.6
2003	6	0.66	423.9	713.6	174.6	9146.3	7870.9	197.1
2003	7	0.23	100.9	253.2	63.7	1584.2	1597.3	71.6
2003	8	0.00	0.1	0.8	0.3	1.8	0.1	0.3
2003	9	0.06	8.3	59.5	14.2	333.7	218.4	16.0
2003	10	0.01	1.0	7.7	3.1	22.0	1.8	3.3
2003	11	1.53	1638.9	2662.7	710.7	16389.0	10028.0	572.2
2003	12	0.57	455.3	1060.9	158.4	8616.2	5626.2	177.7
2004	1	0.19	22.5	132.0	47.0	823.7	475.6	51.7
2004	2	1.66	882.0	2686.3	640.2	14931.0	7403.4	570.8
2004	3	5.30	6127.8	10218.0	2369.2	70003.0	47755.0	1920.7
2004	4	0.70	129.6	495.3	175.6	4325.4	3167.8	200.8
2004	5	2.70	3771.3	5291.9	1371.9	33982.0	25054.0	1075.4
2004	6	4.12	6519.8	8193.8	1864.7	55156.0	37447.0	1446.7
2004	7	0.77	597.3	1012.6	259.8	6113.7	3403.1	256.4
2004	8	7.09	11273.0	15537.0	3333.8	104762.0	61133.0	2308.0
2004	9	0.64	296.8	650.1	170.7	4684.8	2948.0	192.5
2004	10	0.15	11.1	104.0	37.0	554.1	280.1	39.7
2004	11	0.18	13.3	121.1	43.2	712.9	353.6	47.4
2004	12	0.21	20.6	149.8	53.8	1055.1	663.9	60.3
2005	1	0.22	21.3	85.4	13.6	962.6	373.9	82.5
2005	2	2.11	1267.9	2401.8	813.5	29883.0	19874.0	1378.1

Table C-8. Monthly load estimates for RA-15.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2005	3	0.55	69.3	290.7	35.7	2479.7	330.0	236.7
2005	4	5.12	5538.9	6484.3	3268.9	67316.0	31690.0	7753.6
2005	5	0.66	311.2	542.1	37.8	3967.3	1752.3	39.9
2005	6	1.38	1329.8	2121.0	475.0	20162.0	10588.0	435.1
2005	7	0.08	15.2	89.1	29.0	531.3	116.0	36.8
2005	8	0.05	4.6	31.0	4.1	175.0	80.5	13.0
2005	9	0.00	0.3	1.9	0.5	8.4	1.0	0.8
2005	10	0.00	0.2	1.0	0.4	3.7	0.3	0.4
2005	11	0.01	0.6	3.8	1.4	16.6	3.0	1.5
2005	12	0.00	0.4	2.8	1.0	11.7	1.0	1.2
2006	1	0.00	0.5	5.7	0.6	26.6	1.0	4.1
2006	2	0.01	0.5	3.0	1.1	12.7	1.6	1.2
2006	3	0.07	4.3	24.3	3.5	256.5	6.3	17.4
2006	4	0.24	45.3	182.0	62.3	1500.5	81.7	111.6
2006	5	1.28	709.9	2000.8	609.8	12161.0	1029.9	792.8
2006	6	0.08	11.7	68.0	28.6	783.8	405.8	34.8
2006	7	0.01	0.9	3.2	1.1	24.0	2.0	1.4
2006	8	0.34	130.7	417.6	187.7	3434.0	1829.3	74.6
2006	9	0.06	5.8	44.5	24.7	310.4	153.3	13.3
2006	10	0.01	1.1	7.4	3.0	38.3	8.2	2.5
2006	11	0.14	61.0	140.5	38.9	1082.2	586.0	43.6
2006	12	0.36	141.0	351.9	99.8	2569.7	1367.2	111.6
2007	1	0.54	475.1	861.3	207.3	4680.2	2226.7	191.3
2007	2	4.07	9473.0	9115.3	1825.7	71724.0	66919.0	1293.1
2007	3	2.43	1953.5	3575.5	892.3	22700.0	12669.0	854.0
2007	4	7.35	12673.7	11592.0	6013.0	119576.0	60628.0	7714.7
2007	5	9.08	12615.0	15016.0	5200.9	131256.0	67060.0	3895.3
2007	6	1.47	1580.0	3316.5	795.1	28766.0	22564.0	210.9
2007	7	0.06	7.0	32.5	10.4	200.1	146.3	10.7
2007	8	4.61	15760.8	15235.0	2909.8	29522.0	7235.0	1245.3
2007	9	0.08	8.2	58.3	21.3	153.9	115.0	9.5
2007	10	1.33	947.5	1819.2	943.7	10357.0	7481.6	152.0
2007	11	0.18	15.2	112.8	52.5	467.0	224.0	42.2
2007	12	2.50	2315.6	4139.8	1040.0	24019.0	12752.0	921.0
2008	1	2.77	2987.6	4985.2	1274.9	28854.0	16154.0	1061.5
2008	2	1.61	591.8	1408.3	430.1	12877.0	8515.7	486.2
2008	3	10.28	14994.3	21000.0	4906.5	124140.0	66617.0	3508.0
2008	4	10.82	22741.7	23869.0	4956.5	181056.0	139430.0	3619.0
2008	5	3.96	5127.9	7896.5	1666.4	60190.0	33102.0	2389.9
2008	6	12.22	28953.0	29368.0	6386.8	223802.0	79850.0	8621.0
2008	7	13.35	20505.1	27300.0	6590.8	137859.0	87373.0	3960.0
2008	8	1.11	723.0	1348.6	404.6	5916.9	2972.3	241.6
2008	9	4.57	12896.5	7632.6	1023.5	58823.0	35772.0	785.0
2008	10	3.47	2793.8	4730.6	1947.6	23148.0	9491.6	789.2
2008	11	4.18	5011.2	6992.5	1755.3	27635.0	15417.0	843.8
2008	12	6.56	11722.2	13732.0	2821.8	95904.0	53184.0	2023.3
2009	1	1.30	655.2	1459.1	410.9	10372.0	6286.6	425.6
2009	2	1.54	559.2	1317.4	388.1	11476.0	8052.9	440.1
2009	3	9.76	18438.3	21206.0	4469.0	150390.0	89227.0	3227.8

Table C-8. Monthly load estimates for RA-15.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2009	4	5.78	11214.4	11763.0	2323.7	92159.0	64205.0	1657.1
2009	5	4.93	6825.7	8231.2	1652.1	95431.0	85909.0	2285.9
2009	6	4.35	4730.8	7745.7	1241.1	68751.0	44299.0	1452.9
2009	7	3.49	4353.6	7684.3	1130.0	29132.0	13100.0	278.8
2009	8	6.53	9304.0	10594.0	2406.3	55792.0	17791.0	1637.8
2009	9	0.59	160.9	428.0	143.2	3472.7	2202.7	134.3
2009	10	4.82	6684.7	6948.5	2163.4	15084.0	26541.0	932.6
2009	11	3.81	2284.6	4401.2	1483.7	20178.0	14535.0	2251.2
2009	12	2.54	4625.1	4670.5	965.0	39504.0	36744.0	861.1
2010	1	4.98	8228.5	10066.0	2214.0	69501.0	42922.0	1672.9
2010	2	1.04	166.8	588.2	203.3	5684.9	5251.7	317.6
2010	3	13.16	13396.3	16937.0	3133.6	115961.0	66632.0	6849.5
2010	4	8.23	8053.5	10258.0	4462.0	42232.0	22641.0	4998.6
2010	5	9.52	17036.6	14918.0	4651.3	94025.0	49451.0	1322.4
2010	6	12.76	17040.3	23032.0	6327.7	136497.0	45627.0	2439.5
2010	7	14.00	17101.3	24741.0	5114.3	117191.0	43050.0	1850.6
2010	8	5.24	5834.8	7007.4	2176.1	59536.0	20281.0	562.6
2010	9	8.85	13066.9	13389.0	5166.1	89934.0	19315.0	1086.6
2010	10	0.57	81.7	349.0	138.8	2723.4	1307.4	128.3
2010	11	1.46	981.1	2563.6	606.6	18807.0	10146.0	1996.8
2010	12	0.47	71.5	332.9	119.2	2494.0	1405.8	150.9
2011	1	0.39	51.1	276.6	98.5	1880.9	1246.7	109.6
2011	2	5.21	8966.7	10276.0	2210.2	73062.0	47739.0	1632.7
2011	3	3.21	1719.8	2450.6	224.1	30541.0	18038.0	1076.7
2011	4	4.35	4710.4	5905.4	778.7	56876.0	33568.0	1874.8
2011	5	8.28	17056.1	16082.0	2163.0	146483.0	87841.0	1037.9
2011	6	14.46	15786.1	14705.0	4271.9	106486.0	92021.0	579.0
2011	7	1.30	485.6	780.5	338.7	5587.2	5189.4	60.4
2011	8	0.56	176.1	446.2	140.5	4219.3	1609.7	81.9
2011	9	0.06	4.8	32.6	12.0	130.8	67.8	11.1
2011	10	0.00	0.3	2.0	0.8	5.8	0.5	0.4
2011	11	0.28	38.2	191.0	68.4	1370.7	1018.0	76.5
2011	12	1.27	949.7	1737.5	413.7	10652.0	5856.6	423.3
2012	1	0.28	30.3	197.7	70.1	1156.7	631.3	76.7
2012	2	1.23	653.7	1311.6	322.4	9270.2	4980.8	365.5
2012	3	2.77	2137.2	3920.8	979.4	25991.0	15230.0	964.3
2012	4	2.72	3663.5	5526.8	1150.1	33061.0	11454.0	682.4
2012	5	3.66	6296.5	8116.0	1471.2	46223.0	15625.0	406.6
2012	6	0.47	360.1	711.7	123.6	7871.6	5633.0	172.2
2012	7	0.00	0.5	3.8	1.1	23.5	6.0	0.8
2012	8	0.00	0.1	0.8	0.3	3.1	0.2	0.3
2012	9	0.00	0.0	0.2	0.1	0.8	0.0	0.1
2012	10	0.05	3.5	45.8	21.5	114.9	11.0	4.5
2012	11	0.06	6.3	42.7	15.7	219.7	79.7	15.5
2012	12	0.03	3.4	23.3	8.5	111.4	29.0	9.2
2013	1	0.03	3.4	23.1	8.4	109.8	27.8	9.1
2013	2	0.22	33.8	136.7	49.3	1192.7	1229.8	56.1
2013	3	2.28	3218.4	4364.0	1109.7	29216.0	21888.0	893.0
2013	4	11.75	11860.2	20616.0	5214.9	103973.0	32422.0	3739.5

Table C-8. Monthly load estimates for RA-15.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2013	5	13.01	21067.3	42101.0	6661.3	202162.0	106458.0	3854.6
2013	6	4.09	5328.7	7277.4	1035.7	46027.0	20731.0	297.9
2013	7	0.31	68.4	267.6	63.9	1116.3	127.0	25.7
2013	8	0.02	2.1	16.4	4.3	50.7	6.7	1.7
2013	9	0.00	0.3	1.6	0.7	10.2	1.1	0.5
2013	10	0.00	0.1	0.5	0.2	2.8	0.2	0.1
2013	11	0.02	1.7	29.5	8.1	57.8	5.4	1.8
2013	12	0.00	0.5	3.0	1.1	11.9	1.2	1.1
2014	1	0.01	0.8	5.5	2.1	23.4	3.1	2.2
2014	2	2.49	5005.4	5033.0	1060.7	40039.0	38503.0	838.7
2014	3	1.06	300.3	1269.0	843.2	8436.9	2263.5	1702.9
2014	4	4.78	9326.1	12094.0	1743.2	52638.0	20922.0	1436.0
2014	5	4.90	8316.4	13272.0	1836.6	70647.0	14056.0	771.1
2014	6	5.45	8857.5	12744.0	2367.3	73902.0	31685.0	639.4
2014	7	0.89	630.1	1286.8	111.4	7320.7	1908.3	55.8
2014	8	8.47	12725.7	17011.0	4927.1	76444.0	8616.0	609.1
2014	9	4.45	2739.5	6189.0	2188.9	16027.0	1012.1	401.2
2014	10	4.01	6230.1	6901.4	1548.5	39266.0	7838.7	613.9
2014	11	0.45	60.2	304.6	110.0	2040.0	950.7	111.6
2014	12	0.52	82.0	363.9	131.1	2750.3	1486.4	151.0

[a] Average monthly flow
[b] Total suspended solids is equivalent to suspended sediment in mega grams (metric tons)

Table C-9. Monthly load estimates for RA-39.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
1997	1	0.12	13.0	92.8	32.8	449.4	109.3	41.0
1997	2	2.92	6211.7	4991.3	1030.9	35609.0	17238.0	823.9
1997	3	0.97	1223.1	1315.3	318.3	7856.8	3740.3	339.1
1997	4	2.73	5388.4	4610.6	969.9	28211.0	13053.0	854.4
1997	5	1.09	2588.6	1312.8	341.7	8530.9	1683.5	322.4
1997	6	0.51	2580.8	427.9	133.6	7497.1	12419.0	171.7
1997	7	0.10	23.7	42.7	26.4	435.6	117.2	33.1
1997	8	0.42	557.9	621.9	133.0	4513.6	1676.7	124.4
1997	9	0.13	13.6	75.4	33.1	597.8	79.3	43.9
1997	10	1.53	3248.1	3270.6	558.6	20346.0	5579.6	442.9
1997	11	0.40	122.3	271.1	101.1	1825.7	694.0	124.1
1997	12	0.92	678.9	975.7	225.3	6482.9	2468.8	355.8
1998	1	1.05	1903.2	1709.5	325.4	9480.2	5143.3	313.3
1998	2	1.30	1495.3	1517.6	342.0	9651.1	4358.4	381.7
1998	3	4.67	7887.0	5482.7	1776.6	50530.0	25565.0	1483.9
1998	4	2.25	1762.8	1363.2	756.7	14053.0	5559.0	715.3
1998	5	3.39	7471.0	6432.9	1321.3	52604.0	22572.0	1124.7
1998	6	2.78	8536.7	5464.3	1005.9	32576.0	8639.7	893.4
1998	7	0.32	751.5	474.3	88.8	2784.4	373.9	109.4
1998	8	0.10	20.5	81.9	26.9	377.2	45.0	33.8
1998	9	0.10	13.2	78.2	27.2	400.3	74.1	33.5
1998	10	2.25	5302.7	2209.2	887.4	24405.0	16651.0	745.3
1998	11	1.71	1290.9	1792.0	565.1	10074.0	3896.5	509.9

Table C-9. Monthly load estimates for RA-39.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
1998	12	0.31	48.6	198.9	77.7	1303.5	701.1	104.8
1999	1	0.31	52.7	197.4	74.5	1333.8	628.9	110.6
1999	2	0.96	931.5	1051.7	237.8	6441.9	2694.0	306.3
1999	3	1.41	699.6	1371.7	439.1	9382.7	4276.7	504.3
1999	4	3.35	3595.3	4217.7	1215.8	18770.0	8119.0	1054.1
1999	5	3.14	4108.8	7075.6	1234.5	31710.0	7990.2	1036.9
1999	6	2.40	3690.1	3752.9	872.5	23592.0	8003.6	725.4
1999	7	0.13	17.0	68.3	36.3	419.4	77.1	43.7
1999	8	0.09	21.0	56.2	24.2	235.6	50.8	30.1
1999	9	0.09	15.4	72.9	24.7	412.1	29.6	30.9
1999	10	0.09	11.2	105.2	25.5	430.8	78.0	31.9
1999	11	0.10	8.6	87.5	26.7	387.3	87.9	33.0
1999	12	0.09	11.7	81.6	24.6	372.5	74.4	30.8
2000	1	0.09	11.7	81.8	24.7	373.8	74.9	31.0
2000	2	0.16	21.8	108.8	37.5	614.7	219.3	52.5
2000	3	0.11	7.4	95.5	29.0	432.9	102.0	36.3
2000	4	0.13	6.5	150.2	32.7	814.8	167.9	43.7
2000	5	0.10	10.8	73.1	26.4	322.8	84.6	32.8
2000	6	0.97	1292.6	1919.0	358.6	10785.0	4019.8	302.3
2000	7	0.12	28.5	157.8	30.5	590.8	116.6	41.7
2000	8	0.10	21.3	108.2	28.1	509.5	18.9	35.2
2000	9	0.09	9.0	58.3	22.4	302.2	66.9	28.1
2000	10	0.09	6.1	96.6	23.4	277.9	28.3	29.3
2000	11	0.14	7.6	99.1	34.6	621.6	304.4	45.2
2000	12	0.09	11.7	81.0	24.2	369.1	73.0	30.3
2001	1	0.24	127.0	239.9	55.4	1517.8	586.6	96.3
2001	2	5.02	11100.0	8696.0	1766.2	61254.0	31157.0	1509.6
2001	3	4.33	5301.2	5879.2	1537.1	46535.0	29493.0	1217.9
2001	4	1.55	1392.9	1868.7	453.8	12906.0	7766.6	469.9
2001	5	4.70	3089.4	5756.0	1878.1	49237.0	34927.0	1559.2
2001	6	5.11	6474.4	6005.6	1981.5	50064.0	25836.0	1621.6
2001	7	0.19	97.1	130.0	47.3	693.0	104.6	68.1
2001	8	0.12	9.6	65.9	31.4	167.8	75.7	38.6
2001	9	0.10	11.1	79.8	26.9	315.7	93.9	33.2
2001	10	0.31	136.3	428.1	87.2	1139.0	137.0	104.7
2001	11	0.13	10.1	91.6	34.5	282.3	40.9	42.6
2001	12	0.16	19.0	110.7	41.7	615.7	197.7	56.4
2002	1	0.11	12.5	89.4	30.2	423.3	96.9	37.9
2002	2	0.31	6.2	106.9	69.6	584.7	429.4	95.8
2002	3	0.33	21.4	64.5	79.6	330.6	82.9	118.4
2002	4	1.04	1546.0	1587.3	305.7	7239.2	4119.8	305.9
2002	5	2.79	10300.0	5424.7	1072.2	45665.0	28375.0	925.7
2002	6	0.22	95.5	179.2	60.2	757.8	230.0	70.3
2002	7	0.08	17.7	91.4	22.6	439.8	40.2	28.4
2002	8	0.10	18.4	107.7	27.6	402.0	37.0	34.1
2002	9	0.09	7.5	66.3	23.9	355.2	40.2	30.0
2002	10	0.09	5.9	103.5	24.4	305.1	39.6	30.6
2002	11	0.09	3.1	114.4	23.6	249.5	10.9	29.6
2002	12	0.09	5.3	91.2	23.9	312.3	24.0	30.0

Table C-9. Monthly load estimates for RA-39.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2003	1	0.09	11.6	80.8	24.1	367.8	72.5	30.2
2003	2	0.10	10.9	79.0	24.9	364.9	79.2	31.2
2003	3	0.10	9.9	228.1	26.5	772.9	142.1	32.9
2003	4	0.16	16.3	164.5	40.3	572.2	58.0	56.4
2003	5	0.49	368.7	575.2	147.0	3526.3	2241.2	154.2
2003	6	0.38	374.6	430.4	117.6	2302.5	1455.6	107.9
2003	7	0.15	51.8	103.4	36.0	672.3	428.3	53.4
2003	8	0.09	10.0	66.1	23.7	286.3	22.3	29.7
2003	9	0.11	14.0	121.5	29.2	438.6	193.9	35.8
2003	10	0.10	7.5	144.3	27.1	331.9	19.6	34.0
2003	11	0.42	947.2	751.1	129.3	4015.9	2647.3	121.6
2003	12	0.23	112.9	193.6	64.7	1840.1	1239.1	72.4
2004	1	0.17	19.7	115.9	43.9	627.0	231.3	57.2
2004	2	0.97	210.3	1554.3	278.0	8656.9	4408.2	279.8
2004	3	2.19	2452.6	3918.5	800.4	25723.0	13167.0	708.2
2004	4	0.23	22.7	147.7	58.3	905.2	407.3	73.9
2004	5	1.05	2434.0	1844.4	395.5	10752.0	5140.5	328.4
2004	6	1.33	2490.6	2356.8	479.3	14301.0	7761.6	408.2
2004	7	0.65	795.0	1152.9	198.9	6254.0	3862.4	198.5
2004	8	5.54	10500.0	10213.0	2321.1	85379.0	40073.0	1863.1
2004	9	0.15	13.4	104.7	38.9	552.1	179.6	46.6
2004	10	0.12	6.3	96.1	33.6	479.0	126.9	41.1
2004	11	0.18	4.8	113.7	45.0	620.7	218.9	57.6
2004	12	0.18	18.1	131.7	46.3	768.9	272.2	64.2
2005	1	0.44	82.0	297.7	88.6	4109.1	1977.1	372.3
2005	2	1.78	954.1	2017.6	462.5	18073.0	10086.0	921.3
2005	3	0.28	18.5	145.6	15.3	900.3	100.5	165.5
2005	4	0.97	1998.0	1365.9	45.0	14077.0	8316.5	1157.9
2005	5	0.26	31.3	124.1	64.2	1030.2	73.1	23.4
2005	6	0.92	1170.9	1420.5	146.2	9766.1	4697.4	308.9
2005	7	0.18	25.8	158.3	8.8	847.4	201.1	80.3
2005	8	0.10	11.4	87.6	22.3	404.8	58.8	40.8
2005	9	0.09	11.0	77.2	24.0	350.6	66.2	30.0
2005	10	0.09	11.8	82.5	25.2	378.4	76.9	31.6
2005	11	0.10	11.7	82.5	26.2	383.4	81.6	32.9
2005	12	0.09	11.4	81.2	23.3	373.5	73.0	31.5
2006	1	0.09	4.7	103.9	8.4	745.7	106.3	199.8
2006	2	0.10	10.8	75.8	23.6	349.6	72.6	29.6
2006	3	0.16	7.9	108.5	55.2	727.2	31.3	33.8
2006	4	0.21	19.5	152.9	65.0	794.3	238.1	80.4
2006	5	0.27	59.5	268.0	101.0	1365.7	352.8	143.6
2006	6	0.09	6.0	77.4	49.8	392.1	34.3	62.4
2006	7	0.09	10.3	64.9	17.3	359.3	32.7	37.1
2006	8	0.10	11.9	95.1	25.9	425.8	84.4	22.7
2006	9	0.10	5.8	78.2	41.4	367.2	66.0	22.9
2006	10	0.10	12.8	86.3	27.5	410.0	93.9	34.0
2006	11	0.20	121.7	210.5	55.5	1151.8	370.8	62.5
2006	12	0.29	321.7	377.5	86.7	2076.5	893.5	92.4
2007	1	0.19	113.0	199.3	55.9	1056.3	329.2	56.5

Table C-9. Monthly load estimates for RA-39.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2007	2	1.28	2817.7	2291.1	440.5	13143.0	6969.1	356.2
2007	3	1.18	2053.1	1890.8	356.5	10667.0	5453.9	363.9
2007	4	3.44	4709.9	5588.5	3052.6	27964.0	16878.0	2077.3
2007	5	3.87	6761.4	6700.4	2025.1	44847.0	24056.0	1490.9
2007	6	0.49	361.4	671.2	145.9	3769.2	2315.5	53.4
2007	7	0.10	7.6	65.8	29.1	212.6	93.4	13.5
2007	8	6.63	11800.0	16354.0	6461.0	57338.0	43604.0	899.6
2007	9	0.21	23.5	187.5	68.6	516.7	254.4	26.8
2007	10	0.79	373.2	1068.0	572.4	3644.0	1719.3	235.2
2007	11	0.15	4.7	74.1	30.6	368.1	126.4	53.4
2007	12	1.13	2370.9	1957.5	336.0	10908.0	6289.4	357.6
2008	1	1.24	2630.7	2209.5	392.1	12087.0	6810.6	362.5
2008	2	1.05	924.4	1206.0	247.1	7704.9	3129.7	364.3
2008	3	2.41	4722.9	4188.7	920.6	27584.0	12701.0	787.9
2008	4	4.54	9962.7	8267.5	1742.6	53988.0	26506.0	1466.6
2008	5	3.64	4935.1	5339.4	1098.1	36818.0	18200.0	711.5
2008	6	5.45	4292.6	6136.6	1604.1	55001.0	22209.0	2820.2
2008	7	11.08	20000.0	16500.0	3275.0	105192.0	49555.0	1681.9
2008	8	0.29	53.5	160.3	48.3	712.4	373.7	46.0
2008	9	2.17	7569.6	3741.7	574.1	16388.0	7045.3	368.5
2008	10	1.09	1696.0	1888.8	340.4	7181.6	3271.5	197.2
2008	11	1.11	542.0	1249.2	284.8	6653.1	4396.2	182.8
2008	12	1.75	3562.0	3032.0	665.5	20751.0	10071.0	565.6
2009	1	0.36	71.6	246.6	89.1	1623.9	905.2	122.0
2009	2	0.45	152.8	309.8	101.3	2052.8	943.5	144.8
2009	3	4.56	9732.7	8249.9	1845.3	58008.0	27246.0	1565.9
2009	4	2.95	6653.8	5311.7	1086.3	39354.0	20504.0	937.3
2009	5	3.19	1964.6	4764.6	1231.7	35367.0	20999.0	1040.5
2009	6	2.52	2213.6	2915.9	806.7	19345.0	7687.0	448.4
2009	7	2.58	1908.3	2982.0	884.5	23937.0	7351.2	101.8
2009	8	4.79	12100.0	7674.6	1836.5	51523.0	19039.0	1205.1
2009	9	0.21	18.0	118.0	46.5	597.0	233.5	38.5
2009	10	3.22	1099.7	2698.8	1234.5	7369.0	5355.6	505.1
2009	11	1.29	593.8	1181.3	254.0	6704.0	2432.9	235.3
2009	12	1.48	2822.6	2508.5	536.5	15558.0	7589.7	464.8
2010	1	2.02	3909.3	3452.2	764.6	21988.0	10672.0	669.5
2010	2	0.30	31.5	174.4	69.4	1087.2	576.9	102.1
2010	3	4.96	1058.0	9475.8	1966.0	57316.0	21365.0	4280.5
2010	4	3.63	4531.0	3909.4	157.0	20532.0	8850.9	845.1
2010	5	5.05	5236.4	5490.1	1440.2	55448.0	41136.0	1728.4
2010	6	8.21	14900.0	12815.0	2707.2	100484.0	30174.0	1301.2
2010	7	3.74	5794.2	7951.7	1421.6	40507.0	13686.0	332.8
2010	8	1.80	813.5	1577.8	482.9	11874.0	5009.9	242.0
2010	9	7.15	2519.8	5998.3	2007.6	28246.0	10727.0	643.3
2010	10	0.34	25.5	142.4	47.5	904.9	345.6	80.1
2010	11	0.59	262.4	486.7	84.1	4402.9	2033.6	373.1
2010	12	0.22	36.5	146.8	54.0	914.5	348.3	72.9
2011	1	0.19	23.0	124.1	48.8	710.2	240.5	66.5
2011	2	2.09	5040.8	3842.9	656.5	21240.0	12671.0	580.3

Table C-9. Monthly load estimates for RA-39.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2011	3	1.12	882.5	1024.1	70.2	8911.5	3965.4	437.6
2011	4	2.00	7854.8	4127.3	694.9	32040.0	10653.0	858.6
2011	5	3.61	10600.0	4712.6	772.5	108809.0	49988.0	759.7
2011	6	3.87	3792.0	4066.7	866.7	32595.0	9010.7	335.1
2011	7	0.17	10.6	55.7	23.2	395.7	114.4	18.9
2011	8	0.20	8.0	53.9	12.0	421.7	42.9	26.2
2011	9	0.11	7.8	51.0	10.6	267.6	39.9	17.0
2011	10	0.13	6.4	64.2	19.6	396.5	40.8	17.8
2011	11	0.09	11.4	78.1	23.6	360.6	73.5	29.3
2011	12	0.13	32.0	112.5	32.3	638.0	210.7	48.9
2012	1	0.09	11.6	80.5	23.9	365.8	71.9	29.9
2012	2	0.12	14.2	90.3	30.9	451.2	131.6	37.6
2012	3	0.32	133.6	277.1	84.9	1726.3	733.6	108.7
2012	4	0.27	166.4	302.9	65.5	2373.9	814.5	107.1
2012	5	0.71	2930.3	1670.2	144.0	10263.0	3996.3	140.5
2012	6	0.15	17.5	88.2	27.9	539.1	74.6	60.0
2012	7	0.19	23.7	112.8	29.0	869.7	108.4	87.2
2012	8	0.19	32.3	124.0	40.9	954.2	164.5	37.1
2012	9	0.19	25.2	120.9	45.8	786.5	215.4	47.6
2012	10	0.17	13.0	162.9	85.6	650.5	117.9	30.4
2012	11	0.11	12.2	90.7	31.4	420.3	96.9	34.1
2012	12	0.11	12.4	88.8	29.8	419.4	95.1	37.3
2013	1	0.09	12.1	82.9	25.6	385.3	80.5	32.0
2013	2	0.20	116.5	201.8	52.1	1117.8	353.1	60.2
2013	3	1.51	2975.6	2588.8	535.6	16432.0	8186.2	507.7
2013	4	9.47	21900.0	17135.0	3831.4	137268.0	65777.0	3104.6
2013	5	4.39	10200.0	9031.1	1215.5	72967.0	31340.0	847.5
2013	6	0.80	2460.3	1909.6	182.8	9084.6	3833.0	52.8
2013	7	0.15	20.0	134.4	33.2	564.3	142.3	19.7
2013	8	0.14	5.7	45.2	9.6	210.3	22.6	10.4
2013	9	0.14	7.2	56.3	18.4	397.7	51.7	21.8
2013	10	0.14	18.8	113.9	38.9	442.2	17.3	21.8
2013	11	0.14	7.0	175.6	87.4	308.7	34.2	14.3
2013	12	0.09	11.6	83.7	25.9	378.7	76.6	31.5
2014	1	0.10	12.0	84.2	26.3	388.9	81.2	33.0
2014	2	1.60	3554.2	2865.1	538.1	16309.0	8923.0	487.3
2014	3	0.76	131.1	1516.6	1111.0	6339.4	1933.5	2213.2
2014	4	1.21	2664.6	2785.4	411.9	12530.0	4404.5	311.0
2014	5	1.66	3848.4	3966.6	321.6	20045.0	4071.4	502.8
2014	6	5.21	12000.0	10282.0	2023.3	88187.0	32117.0	594.4
2014	7	0.71	3913.9	2387.8	128.9	7600.9	281.5	56.5
2014	8	2.61	10100.0	8018.3	929.7	25871.0	575.3	249.6
2014	9	2.89	6769.6	6720.0	1084.5	27034.0	741.1	572.9
2014	10	3.02	2895.3	4546.9	940.4	51005.0	32130.0	212.9
2014	11	0.24	29.4	146.3	57.4	914.2	417.0	64.5
2014	12	0.30	43.1	188.7	75.8	1212.8	654.6	96.9

[a] Average monthly flow

[b] Total suspended solids is equivalent to suspended sediment in mega grams (metric tons)

Table C-10. Monthly load estimates for RA-41.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
1997	1	0.05	5.2	20.5	5.1	146.5	69.0	9.6
1997	2	3.81	9370.3	6600.8	1303.4	54577.0	34095.0	1825.9
1997	3	1.42	2613.0	2403.1	442.1	16948.0	9179.4	749.1
1997	4	2.71	3746.2	4296.2	1000.2	31528.0	16849.0	1302.5
1997	5	2.03	4538.0	1150.3	632.3	17865.0	5845.6	1180.5
1997	6	0.67	639.0	534.6	192.7	7539.2	1847.1	312.8
1997	7	0.25	626.8	233.8	71.0	3572.4	437.9	130.5
1997	8	0.22	499.8	481.0	65.8	3624.0	846.1	121.7
1997	9	0.04	3.2	25.4	5.3	83.8	25.4	7.5
1997	10	1.06	1219.9	1843.9	329.8	11894.0	4526.1	594.3
1997	11	0.36	109.8	349.4	92.7	1849.2	795.1	103.5
1997	12	0.91	459.0	1015.2	330.8	7368.9	3565.6	392.7
1998	1	1.22	1500.6	1678.8	367.1	13178.0	7047.7	652.7
1998	2	1.63	1113.5	1915.6	504.0	14242.0	6659.8	773.7
1998	3	5.80	12497.9	9123.2	2170.7	66252.0	42498.0	3104.7
1998	4	4.61	10012.0	5189.1	1709.2	41324.0	20081.0	2292.7
1998	5	4.73	10347.7	4621.8	1863.7	60504.0	26279.0	2336.0
1998	6	2.28	3730.6	2732.1	714.5	22529.0	12326.0	1270.1
1998	7	0.72	703.6	632.7	217.7	4476.8	2741.4	397.0
1998	8	0.03	2.2	13.6	3.8	50.2	6.0	6.2
1998	9	0.05	4.7	22.7	5.9	152.2	32.0	9.2
1998	10	1.88	5400.9	4127.2	695.2	38496.0	23709.0	952.6
1998	11	1.84	2725.5	1754.8	556.3	12827.0	4436.1	1016.5
1998	12	0.25	31.8	119.2	47.3	998.7	735.8	50.1
1999	1	0.28	54.4	147.0	67.0	1361.9	981.6	74.7
1999	2	1.01	553.9	992.7	292.6	7810.6	4199.7	428.5
1999	3	1.39	2248.7	2715.5	443.6	16549.0	9459.7	731.6
1999	4	4.90	9722.6	7593.3	1770.3	48038.0	25661.0	2523.2
1999	5	3.35	7896.3	11426.0	1129.3	27046.0	26801.0	1896.5
1999	6	1.90	4116.3	5360.0	582.8	26733.0	8555.3	1043.8
1999	7	0.10	13.3	34.9	16.2	365.9	192.9	19.6
1999	8	0.31	194.4	340.7	91.8	2622.1	1267.2	134.3
1999	9	0.00	0.2	1.1	0.2	7.4	2.5	0.4
1999	10	0.00	0.1	0.4	0.1	2.5	0.8	0.1
1999	11	0.00	0.4	1.6	0.4	11.2	5.0	0.7
1999	12	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2000	1	0.00	0.1	0.4	0.1	2.4	0.8	0.1
2000	2	0.04	4.8	18.6	6.7	148.0	95.1	8.1
2000	3	0.00	0.3	1.8	0.4	12.7	4.6	0.7
2000	4	0.03	3.0	12.9	4.9	97.0	55.4	5.6
2000	5	0.01	0.6	3.3	0.7	22.6	9.3	1.4
2000	6	1.18	1757.2	1996.1	376.0	15950.0	10624.0	639.7
2000	7	0.33	118.8	461.4	101.1	3011.1	1387.9	145.0
2000	8	0.03	4.6	21.3	5.2	109.7	80.4	6.5
2000	9	0.00	0.0	0.2	0.0	1.6	0.5	0.1
2000	10	0.00	0.1	0.7	0.2	4.9	1.9	0.3
2000	11	0.02	1.9	8.8	3.3	59.5	29.2	4.5
2000	12	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2001	1	0.09	11.6	41.3	14.2	354.1	276.6	17.5

Table C-10. Monthly load estimates for RA-41.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2001	2	2.24	4939.6	3330.7	739.8	29869.0	19449.0	1017.4
2001	3	4.59	7096.7	7402.4	1556.1	61269.0	34617.0	2677.1
2001	4	1.77	1469.4	1532.7	565.8	13051.0	7829.6	947.0
2001	5	3.90	7280.7	4076.4	1509.9	50808.0	39226.0	1949.0
2001	6	6.00	11375.1	8991.5	2201.6	72428.0	43181.0	3054.8
2001	7	0.20	95.2	277.5	60.5	1751.1	737.7	74.2
2001	8	0.01	1.3	6.3	2.5	42.1	17.6	2.9
2001	9	0.05	12.6	27.4	12.9	242.8	115.0	15.9
2001	10	0.48	889.3	1187.5	148.8	4604.9	854.3	247.1
2001	11	0.04	3.9	17.3	5.2	78.4	26.9	8.7
2001	12	0.05	5.1	20.9	6.2	146.8	68.2	9.8
2002	1	0.00	0.4	2.0	0.4	14.0	5.5	0.8
2002	2	0.12	9.5	26.1	19.1	234.0	199.4	22.6
2002	3	0.32	65.0	152.6	89.3	291.5	82.1	102.2
2002	4	0.89	600.3	585.1	258.8	3677.8	728.7	415.9
2002	5	3.02	3939.5	2386.3	1157.2	38740.0	32487.0	1474.8
2002	6	0.28	170.1	396.6	78.6	1927.8	884.3	92.7
2002	7	0.08	11.0	38.9	14.2	343.1	286.5	16.1
2002	8	0.00	0.2	1.0	0.2	7.0	2.9	0.4
2002	9	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2002	10	0.00	0.0	0.0	0.0	0.3	0.1	0.0
2002	11	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2002	12	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2003	1	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2003	2	0.01	1.2	4.6	1.2	33.1	15.8	2.2
2003	3	0.05	5.1	67.1	7.6	363.1	154.7	10.1
2003	4	0.07	6.0	28.2	10.9	120.7	29.4	14.5
2003	5	0.64	575.2	943.8	203.9	9139.4	6103.2	320.2
2003	6	0.28	205.9	312.4	78.5	3365.1	2237.2	122.0
2003	7	0.07	15.7	39.6	18.2	347.7	189.7	20.7
2003	8	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2003	9	0.02	1.3	4.5	2.8	22.0	2.5	3.2
2003	10	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2003	11	0.70	1152.8	1085.9	202.9	8410.8	4559.5	389.4
2003	12	0.19	72.0	248.9	57.8	2473.9	1461.0	70.5
2004	1	0.06	6.9	27.9	8.9	210.7	117.1	12.4
2004	2	0.89	390.3	1055.8	271.9	8323.0	3928.8	471.4
2004	3	2.87	4888.9	5008.3	1035.4	41512.0	25818.0	1483.0
2004	4	0.21	29.4	99.5	41.7	858.5	602.7	47.5
2004	5	1.47	4313.6	3420.7	457.8	22348.0	12182.0	867.7
2004	6	2.11	3824.3	3867.7	713.6	26874.0	14529.0	1096.9
2004	7	0.43	292.1	588.4	129.9	4138.9	2058.1	203.0
2004	8	5.42	21488.3	10834.0	2267.9	94684.0	63740.0	2574.1
2004	9	0.18	57.2	147.8	46.8	1061.9	566.8	55.1
2004	10	0.04	2.9	16.4	4.1	117.2	54.3	7.6
2004	11	0.06	4.3	26.3	8.2	189.0	93.2	12.1
2004	12	0.07	7.0	34.3	12.4	274.7	185.9	14.8
2005	1	0.15	27.8	49.9	12.7	670.7	362.0	61.4
2005	2	1.28	937.2	1316.6	42.4	17316.0	11895.0	781.0

Table C-10. Monthly load estimates for RA-41.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2005	3	0.19	15.3	59.0	9.1	469.5	85.8	73.5
2005	4	2.36	3483.3	2844.7	739.7	42645.0	30249.0	3024.5
2005	5	0.22	48.3	98.8	132.5	1001.1	55.5	13.4
2005	6	0.76	904.9	1510.2	212.0	13846.0	6216.8	461.8
2005	7	0.04	5.5	27.5	0.5	196.0	136.4	11.7
2005	8	0.01	0.7	2.9	0.7	20.6	9.2	1.3
2005	9	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2005	10	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2005	11	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2005	12	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2006	1	0.00	0.0	0.1	0.0	0.4	0.1	0.0
2006	2	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2006	3	0.03	1.8	11.2	1.6	96.1	4.6	5.7
2006	4	0.09	27.1	67.9	24.3	491.4	193.7	30.9
2006	5	0.47	376.3	838.7	165.2	5434.0	2381.6	268.1
2006	6	0.02	4.0	13.7	3.2	122.3	34.0	23.0
2006	7	0.00	0.0	0.3	0.1	1.8	0.7	0.1
2006	8	0.09	27.3	58.7	26.6	508.7	243.5	31.4
2006	9	0.01	1.1	5.1	1.7	34.8	15.5	2.3
2006	10	0.00	0.3	1.6	0.4	10.9	4.6	0.7
2006	11	0.06	26.1	49.1	22.4	443.4	209.2	27.0
2006	12	0.16	96.7	287.8	49.6	1363.6	529.3	60.1
2007	1	0.20	124.6	223.1	60.3	1735.7	872.6	97.3
2007	2	2.21	4591.7	3920.5	718.2	29244.0	16513.0	1120.5
2007	3	1.16	944.0	1719.2	388.1	11336.0	5324.9	565.7
2007	4	4.48	15082.7	6971.1	3753.9	34068.0	36562.0	3460.0
2007	5	5.55	22946.7	9970.9	2749.1	62567.0	55084.0	2847.8
2007	6	0.67	1086.7	999.3	147.6	6247.2	3065.9	278.9
2007	7	0.01	1.1	4.1	1.0	27.1	15.2	2.1
2007	8	4.81	20779.6	10800.0	2578.6	59036.0	36503.0	2364.9
2007	9	0.05	5.3	18.4	5.4	84.5	49.5	7.0
2007	10	0.72	891.3	911.9	357.4	4333.8	2907.4	75.8
2007	11	0.05	4.4	19.9	4.7	124.7	56.4	11.6
2007	12	1.24	1438.6	1906.6	406.2	13328.0	6541.3	652.8
2008	1	1.45	2234.0	2499.1	464.0	17277.0	8682.0	802.4
2008	2	0.72	292.3	608.6	237.8	4987.9	2465.8	280.7
2008	3	5.26	14076.7	10360.0	2000.7	81875.0	50162.0	2745.7
2008	4	6.44	17971.7	13239.0	2360.7	98793.0	59199.0	3319.2
2008	5	2.97	7381.9	5345.5	647.7	45639.0	18080.0	3206.1
2008	6	7.56	15693.8	8597.1	1213.0	92793.0	28775.0	5286.6
2008	7	10.77	45270.7	19675.0	3097.5	206936.0	125066.0	6152.8
2008	8	0.40	254.9	308.6	84.2	2314.4	1101.6	127.6
2008	9	2.82	7256.4	3949.4	493.3	34255.0	18715.0	919.6
2008	10	1.67	1850.5	2206.5	359.1	9569.0	4620.5	464.8
2008	11	1.97	2989.2	3091.5	365.1	17319.0	7915.7	689.0
2008	12	3.37	8862.2	6477.2	1345.6	52060.0	33083.0	1588.7
2009	1	0.44	173.5	462.9	129.6	2967.7	1489.2	148.0
2009	2	0.50	140.0	300.7	138.9	2805.3	1684.7	159.8
2009	3	6.03	15942.7	11907.0	2569.0	96458.0	61493.0	2784.6

Table C-10. Monthly load estimates for RA-41.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2009	4	3.53	8574.8	6297.6	1470.8	53028.0	34967.0	1488.9
2009	5	3.16	4396.6	4810.9	970.0	57761.0	42861.0	1453.2
2009	6	2.58	2881.8	2944.6	485.1	32916.0	12901.0	987.5
2009	7	2.37	4767.2	3096.3	617.4	24398.0	11535.0	361.4
2009	8	4.77	14246.8	8010.6	1965.2	51119.0	31623.0	1418.3
2009	9	0.18	37.3	95.7	42.7	771.9	400.5	40.1
2009	10	3.38	7712.6	3199.8	347.0	10441.0	9768.1	803.2
2009	11	1.76	1675.2	1434.3	97.3	7469.6	3292.2	472.3
2009	12	1.47	2671.4	2446.2	533.0	18989.0	11262.0	660.8
2010	1	2.79	7097.3	5492.5	1064.1	42056.0	26223.0	1332.7
2010	2	0.32	43.1	145.2	61.3	1297.7	968.6	64.0
2010	3	7.77	22887.1	15850.0	3214.8	130513.0	84734.0	3734.7
2010	4	4.95	9809.2	6665.9	4576.5	67104.0	57320.0	7720.8
2010	5	6.08	16186.6	7761.8	1861.0	86149.0	75584.0	2577.6
2010	6	9.01	18628.6	12646.0	2900.5	104177.0	30369.0	1249.0
2010	7	7.56	19245.8	13102.0	2134.3	91500.0	28320.0	1833.0
2010	8	2.73	6237.7	6601.7	1422.4	36091.0	7476.1	528.5
2010	9	6.86	11396.1	4911.6	1912.1	21884.0	8476.7	564.5
2010	10	0.21	22.1	70.1	23.8	465.0	372.6	35.4
2010	11	0.69	574.5	628.1	77.8	6688.9	3123.1	783.8
2010	12	0.15	21.0	64.3	26.0	509.8	252.5	37.8
2011	1	0.12	14.6	53.6	18.0	411.4	254.1	24.8
2011	2	2.97	5667.4	5173.6	1010.3	37717.0	21283.0	1395.7
2011	3	1.35	806.3	368.9	90.3	9390.9	4650.0	353.9
2011	4	2.00	2351.4	1904.7	225.0	18391.0	6295.7	799.5
2011	5	5.07	15161.4	8347.9	842.9	149986.0	97503.0	1725.9
2011	6	7.73	13725.6	7133.2	1049.5	39681.0	16316.0	1113.6
2011	7	0.36	136.4	298.8	43.1	1397.1	221.2	28.1
2011	8	0.09	25.2	77.6	11.4	423.5	86.6	9.6
2011	9	0.02	2.0	8.8	2.1	62.3	27.8	4.0
2011	10	0.20	19.8	84.5	30.6	855.5	180.1	21.2
2011	11	0.06	6.6	26.8	9.0	198.0	106.9	12.1
2011	12	0.38	200.9	531.2	120.3	3016.3	1291.8	144.9
2012	1	0.06	6.8	25.4	6.5	182.9	89.7	12.3
2012	2	0.33	103.4	233.8	94.6	1857.9	854.1	111.0
2012	3	0.91	527.8	1200.8	301.5	7816.9	3832.9	380.5
2012	4	0.77	856.4	898.9	223.0	8350.1	3473.2	208.2
2012	5	1.68	5025.4	4755.7	340.8	32256.0	12205.0	602.4
2012	6	0.64	371.6	790.9	103.2	10259.0	8658.7	204.7
2012	7	0.13	11.3	51.3	12.4	809.6	236.6	49.4
2012	8	0.04	5.0	20.6	8.4	162.3	99.2	8.7
2012	9	0.08	8.6	36.4	14.0	259.5	130.3	16.6
2012	10	0.18	16.5	198.7	129.5	609.9	52.6	16.1
2012	11	0.02	2.0	12.1	5.1	67.9	21.2	3.7
2012	12	0.00	0.4	2.1	0.4	14.5	5.3	0.8
2013	1	0.00	0.2	1.2	0.3	8.1	3.2	0.5
2013	2	0.08	19.1	46.5	19.6	409.8	246.6	22.6
2013	3	1.48	3222.6	2931.4	548.9	20650.0	11629.0	744.7
2013	4	9.34	33921.9	18830.0	3793.8	171019.0	119481.0	4272.9

Table C-10. Monthly load estimates for RA-41.

Year	Month	Flow[a] (cms)	TSS[b] (Mg)	TP (kg)	Ortho-P (kg)	TN (kg)	NO_x (kg)	NH_x (kg)
2013	5	6.24	19959.2	17361.0	1782.6	123741.0	55365.0	2651.8
2013	6	1.61	5612.8	6630.0	355.0	25695.0	7728.0	199.8
2013	7	0.04	4.7	21.6	3.7	125.5	44.4	2.7
2013	8	0.01	1.1	4.2	1.1	34.6	16.0	1.6
2013	9	0.05	5.4	21.8	7.0	145.3	61.2	10.4
2013	10	0.18	13.6	48.0	20.7	228.6	27.5	12.3
2013	11	0.10	8.1	72.6	58.5	150.5	23.7	7.4
2013	12	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2014	1	0.00	0.0	0.0	0.0	0.0	0.0	0.0
2014	2	1.60	2821.5	2669.0	570.8	19829.0	11088.0	776.3
2014	3	0.52	176.4	883.0	908.0	3469.2	953.5	982.1
2014	4	2.59	9987.0	7630.0	756.6	36059.0	20387.0	1056.1
2014	5	2.23	7942.6	5209.1	1042.4	47644.0	16348.0	727.3
2014	6	2.90	9809.3	8337.4	696.3	61134.0	29839.0	296.1
2014	7	0.40	221.9	752.0	98.0	4073.9	1450.5	54.3
2014	8	6.78	17448.2	14728.0	2814.8	63412.0	9311.2	1329.3
2014	9	3.46	5049.2	3689.8	821.0	17222.0	3220.5	706.6
2014	10	2.59	4199.2	2723.7	360.1	11609.0	1447.1	296.6
2014	11	0.15	14.3	62.7	23.7	417.6	202.6	27.4
2014	12	0.19	20.7	85.9	35.0	636.3	360.2	38.4

[a] Average monthly flow
[b] Total suspended solids is equivalent to suspended sediment in mega grams (metric tons)

C.4. Lake Water Quality Data

Table C-11. Lake water quality data for IA 05-CHA-0020-L_1 (RA-3).

Date	NH_x (ppm)	NO_x (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
4/30/1997	0.15	1.00	1.00	2.00	370		17	0.6
5/13/1997	0.01	0.80	0.90	1.70	160		7	0.3
5/27/1997	0.10	0.85	1.10	1.95	140	30		
6/8/1997	0.30	0.81	1.20	2.01	90	70		
6/23/1997	0.02	0.91	0.90	1.81	150	30		
7/7/1997	0.02	0.73	0.50	1.23	50	50		
7/21/1997	0.02	0.56	0.60	1.16	80	20		
8/4/1997	0.07	0.27	0.90	1.17	180	20		
9/2/1997	0.01	0.24	1.20	1.44	50	30		
9/15/1997	0.11	0.22	0.70	0.92	70	40		
4/14/1998	0.03	0.50	0.90	1.40	60	50		0.4
5/4/1998	0.04	0.61	0.40	1.01	70	10		0.7
5/18/1998	0.09	0.62	0.60	1.22	70	30		1.1
6/9/1998	0.14	0.73	0.60	1.33	190	40		0.6
6/22/1998	0.05	0.70	0.80	1.50	100	30		0.8
7/6/1998	0.46	0.81	0.50	1.31	190	10		1.0
7/20/1998	0.05	0.49	0.50	0.99	330	30		1.2
8/3/1998	0.01	0.57	0.30	0.87	60	30		1.1
8/17/1998	0.04	0.45	0.60	1.05	110	20		1.1
8/31/1998	0.05	0.26	0.90	1.16	40	30		1.1
9/13/1998	0.06	0.26	0.60	0.86	90	30		1.1
4/14/1999	0.01	0.46	0.39	0.85	60	30		0.5
5/11/1999	0.19	0.81	0.50	1.31	40	20	4	0.6
6/15/1999	0.01	1.23	0.62	1.85	60	30	6	0.5
7/13/1999	0.01	1.01	0.68	1.69	70	10	2	0.8
8/18/1999	0.01	0.96	0.39	1.35	50	30	6	0.9
9/14/1999	0.01	0.68	0.42	1.10	10	10	4	0.8

Table C-11. Lake water quality data for IA 05-CHA-0020-L_1 (RA-3).

Date	NH_x (ppm)	NO_x (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
10/13/1999	0.07	0.01	0.32	0.33	40	10	6	0.6
4/18/2000	0.01	0.14	0.53	0.67	120	10	5	0.9
5/16/2000	0.04	0.01	0.45	0.46	60	10	1	0.6
6/13/2000	0.20	0.08	0.50	0.58	60	10	2	0.6
6/29/2000	▨	0.17	2.92	3.09	▨	▨	6	0.9
7/20/2000	0.01	0.01	0.41	0.42	120	10	7	0.9
7/25/2000	▨	0.05	0.71	0.76	▨	▨	5	1.4
8/15/2000	0.01	0.01	0.27	0.28	20	10	3	1.5
8/24/2000	▨	0.19	0.45	0.65	▨	▨	▨	1.4
9/12/2000	0.01	0.03	0.40	0.43	40	10	3	0.8
10/17/2000	0.01	0.30	0.20	0.50	50	30	3	0.5
5/15/2001	0.08	0.94	0.36	1.30	80	30	0	0.9
5/31/2001	▨	1.39	0.44	1.83	115	▨	2	0.4
6/12/2001	0.02	1.20	0.27	1.47	110	20	9	0.4
6/27/2001	▨	1.72	0.72	2.45	95	▨	4	0.8
7/11/2001	0.01	1.20	0.47	1.67	100	30	3	0.6
7/31/2001	▨	1.38	0.23	1.61	46	▨	1	1.0
8/14/2001	0.09	0.69	0.58	1.27	60	10	▨	0.7
9/24/2001	0.16	0.53	0.22	0.75	40	20	▨	0.6
4/15/2002	0.13	0.37	0.54	0.91	50	10	▨	0.6
5/13/2002	0.24	0.12	0.46	0.58	30	10	▨	0.8
6/5/2002	▨	0.52	0.67	1.19	67	4	13	0.7
6/10/2002	0.10	0.71	0.17	0.88	90	10		0.5
7/9/2002	▨	0.78	0.33	1.10	34	7	3	0.7
7/23/2002	0.01	0.38	0.24	0.62	220	10	11	1.2
8/7/2002	▨	0.46	0.55	1.01	30		4	1.3
8/13/2002	0.01	0.19	0.07	0.26	10	10	19	1.1
9/18/2002	0.16	0.01	0.18	0.19	50	10	2	0.6
4/14/2003	0.22	0.12	0.34	0.46	20	10		0.8
5/13/2003	0.07	0.08	0.14	0.22	40	10	9	0.7
6/4/2003	▨	0.19	0.50	0.69	36	3	11	1.3
6/19/2003	0.01	0.01	0.10	0.11	20	10	7	1.1
7/16/2003	0.08	0.01	0.39	0.40	60	10	27	0.8
8/12/2003	0.16	0.01	0.35	0.36	40	10	15	0.9
9/16/2003	0.35	0.12	0.68	0.80	10	20	7	0.7
4/19/2004	0.20	0.64	0.86	1.50	70	10	▨	▨
5/20/2004	0.08	0.77	0.63	1.40	90	10	▨	▨
6/3/2004	0.12	0.68	0.90	1.58	39	1	4	0.6
6/22/2004	0.26	0.61	0.70	1.31	60	10	▨	▨
6/30/2004	0.03	0.67	0.72	1.38	39	1	17	0.9
7/19/2004	0.31	0.30	1.00	1.30	40	20	25	▨
8/5/2004	0.01	0.39	0.40	0.79	44	2	31	0.9
9/21/2004	0.27	0.30	0.84	1.14	100	10	▨	▨
4/19/2005	0.03	0.31	0.73	1.04	40	20	11	1.2
5/16/2005	0.20	0.50	0.90	1.40	60	20		0.5
5/17/2005	0.07	0.42	0.73	1.15	50	20	5	0.5
6/8/2005	0.12	0.71	0.33	1.04	39	11	2	0.8
6/13/2005	0.03	0.65	0.62	1.27	20	20	2	0.6
6/20/2005	0.20	0.60	0.80	1.40	10	10		1.0
7/11/2005	0.03	0.03	0.64	0.64	70	10	12	1.0
7/12/2005	0.01	0.41	0.67	1.07	33	1	35	1.0
7/25/2005	0.07	0.03	0.94	0.97	300	10	21	▨
8/3/2005	0.01	0.27	0.54	0.81	39	1	19	1.0
8/22/2005	0.02	0.01	0.88	0.89	70	10	26	0.8
9/8/2005	0.03	0.03	0.70	0.70	60	10	18	0.9
9/19/2005	0.05	0.09	0.72	0.81	60	10	8	0.5
10/17/2005	0.03	0.24	0.40	0.64	60	10	3	0.5
4/10/2006	0.14	0.12	0.64	0.76	40	10	8	0.7
5/1/2006	0.03	0.03	0.60	0.60	50	10	3	1.0
5/16/2006	0.10	0.05	0.64	0.69	20	10	3	0.7
6/5/2006	0.03	0.03	0.70	0.70	40	10	5	1.3
6/6/2006	0.05	0.05	0.62	0.68	27	1	6	1.3
6/26/2006	0.04	0.01	0.77	0.78	40	10	13	0.9

Table C-11. Lake water quality data for IA 05-CHA-0020-L_1 (RA-3).

Date	NH_x (ppm)	NO_x (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
7/10/2006	0.18	0.01	0.93	0.94	60	10	23	1.2
7/10/2006	0.03	0.03	0.60	0.60	40	10	14	0.9
7/11/2006	0.01	0.05	0.60	0.65	31		27	1.0
8/8/2006	0.01	0.05	0.68	0.73	47	1	13	0.8
8/14/2006	0.12	0.03	0.75	0.78	70	10	19	0.9
8/28/2006	0.09	0.03	0.80	0.80	60	10	12	0.5
9/11/2006	0.06	0.07	0.79	0.86	75	10	27	1.0
10/2/2006	0.03	0.08	0.90	0.98	60	10	13	0.8
4/16/2007	0.01	0.70	4.48	5.18	70	10		3.1
5/21/2007	0.17	1.21	0.86	2.07	105	60	11	0.7
5/21/2007	0.16	1.20	0.70	1.90	120	50	3	1.0
6/4/2007	0.04	1.55	0.56	2.11	112	58	6	0.4
6/18/2007	0.05	1.75	0.89	2.64	158	87	14	0.9
7/10/2007	0.04	0.87	1.05	1.92	52	3	44	0.9
7/16/2007	0.03	1.00	0.70	1.70	70	10	9	0.9
7/23/2007	0.02	0.90	0.55	1.45	34	23	19	0.9
8/1/2007	0.04	0.75	0.74	1.49	32	3	3	1.3
8/20/2007	0.01	0.45	0.57	1.02	22	3	17	1.6
8/23/2007	0.03	0.32	0.70	1.02	50	10	15	1.4
9/17/2007	0.03	0.22	0.52	0.74	49	22	10	0.7
5/27/2008	0.03	1.20	0.80	2.00	90	50	3	0.5
6/9/2008	0.04	1.30	0.59	1.89	280			
7/14/2008	0.04	1.30	1.10	2.40	105			
7/21/2008	0.03	1.00	0.70	1.70	90	40	7	0.8
8/18/2008	0.04	0.40	1.40	1.80	105			
9/15/2008	0.04	0.59	0.68	1.27	105			
4/20/2009	0.02	1.20	1.00	2.20	140			
6/15/2009	0.02	1.50	1.20	2.70	130			
6/17/2009	0.05	1.50	0.60	2.10	97	22	3	0.4
7/13/2009	0.02	1.90	0.72	2.62	37			
7/21/2009	0.05	1.60	0.90	2.50	62	18	3	0.5
8/10/2009	0.02	1.30	0.96	2.26	59			
8/17/2009	0.05	1.20	0.90	2.10	43	5	6	0.8
9/21/2009	0.02	0.91	0.58	1.49	70			
4/8/2010	0.03	0.94	0.49	1.43	110	70	7	0.4
5/4/2010	0.03	1.10	0.36	1.46	99	46	7	0.5
5/25/2010	0.07	1.41	0.25	1.73	101	53	3	0.4
6/8/2010	0.03	1.50	0.75	2.25	130	48		
7/13/2010	0.07	0.95	0.25	1.26	117	43	6	0.7
7/20/2010	0.03	1.10	0.42	1.52	150	55	7	0.8
8/23/2010	0.03	0.40	1.40	1.80	55	10	7	1.4
8/26/2010	0.07	0.25	0.25	0.57	53	18		1.0
9/21/2010	0.03	0.44	0.57	1.01	60	25	5	0.6
4/7/2011	0.06	1.00	1.60	2.60	68	12	16	
5/24/2011	0.07	1.58	0.25	1.90	70	16	3	0.5
6/16/2011	0.01	1.80	0.87	2.67	70	15	1	
7/11/2011	0.07	1.48	0.83	2.38	76	25	54	0.4
7/28/2011	0.01	1.60	0.90	2.50	68	24	1	
8/18/2011	0.01	0.97	0.67	1.64	9		16	
8/22/2011	0.07	1.05	1.19	2.31	31	6	8	0.8
9/22/2011	0.01	0.53	0.95	1.48	45	7	16	
4/5/2012	0.03	0.30	0.74	1.04	17	3	17	
5/3/2012	0.02	0.37	0.00	0.37	30	3	3	
5/22/2012	0.04	0.13	0.92	1.10	50	5	8	0.7
6/7/2012	0.02	0.30	0.43	0.73	27	3	28	
7/5/2012	0.02	0.02	0.00	0.00	14	3	22	
7/9/2012	0.01	0.03	0.87	0.91	55	5	18	0.9
8/2/2012	0.02	0.02	0.64	0.64	40	3	6	
8/22/2012	0.01	0.15	0.46	0.62	43	16	7	0.7
9/6/2012	0.02	0.03	0.00	0.00	28	3	30	
4/25/2013	0.09	0.70	0.00	0.70	48	14	5	
5/21/2013	0.07	1.10	1.20	2.30	61	12	4	
6/17/2013	0.02	1.30	1.30	2.60	78	25	20	

Table C-11. Lake water quality data for IA 05-CHA-0020-L_1 (RA-3).

Date	NH_x (ppm)	NO_x (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
7/16/2013	0.02	1.50	0.88	2.38	69	3	0	0.3
8/6/2013	0.02	0.77	0.41	1.18	23	3	28	0.8
9/24/2013	0.02	0.49	0.00	0.49	20	9	9	0.5
4/30/2014	0.02	0.04	0.71	0.71	24	3	▨	▨
5/27/2014	0.06	0.30	0.46	0.76	17	22	5	▨
5/28/2014	0.07	0.53	0.84	1.37	70	14	11	0.9
6/18/2014	0.04	0.83	0.57	1.40	47	41	0	▨
7/14/2014	0.01	0.97	0.71	1.68	72	19	13	0.4
7/16/2014	0.03	0.87	0.56	1.43	130	79	3	▨
8/27/2014	0.02	0.51	0.55	1.06	36	3	11	0.7

NOTE: Cross-hatching indicates no data available for a given parameter and date.

Table C-12. Lake water quality data for IA 05-CHA-0020-L_3 (RA-7).

Date	NHx (ppm)	NOx (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
4/30/1997	▨	▨	▨	▨	▨	▨	16	0.2
5/13/1997	0.04	1.62	1.30	2.92	190	▨	17	0.2
5/27/1997	0.08	1.31	1.20	2.51	90	50	▨	▨
6/8/1997	0.23	1.33	1.30	2.63	100	80	▨	▨
6/23/1997	0.01	1.36	0.80	2.16	90	50	▨	▨
7/7/1997	1.02	0.86	1.10	1.96	80	50	▨	▨
7/21/1997	0.03	0.49	0.80	1.29	150	30	▨	▨
8/4/1997	0.08	0.17	1.30	1.47	420	30	▨	▨
9/2/1997	0.01	0.17	1.20	1.37	60	30	▨	▨
9/15/1997	0.10	0.08	1.30	1.38	80	40	▨	▨
4/14/1998	0.18	0.84	1.30	2.14	140	80	▨	0.2
5/4/1998	0.09	0.72	0.70	1.42	130	50	▨	0.2
5/18/1998	0.12	0.63	0.60	1.23	110	60	▨	0.6
6/9/1998	0.01	0.98	0.40	1.38	130	90	▨	0.3
6/22/1998	0.06	1.32	1.20	2.52	180	90	▨	0.3
7/6/1998	0.06	0.97	1.00	1.97	100	20	▨	0.7
7/20/1998	0.07	0.69	0.90	1.59	190	30	▨	0.7
8/3/1998	0.03	0.57	0.50	1.07	310	20	▨	0.5
8/17/1998	0.02	0.39	0.60	0.99	160	20	▨	0.8
8/31/1998	0.02	0.18	0.80	0.98	30	30	▨	0.6
9/13/1998	0.06	0.12	0.60	0.72	100	30	▨	0.5
4/14/1999	0.01	0.88	0.52	1.40	110	50	▨	0.3
5/12/1999	0.03	2.28	0.90	3.18	150	80	3	0.2
6/15/1999	0.01	1.82	0.44	2.26	100	70	3	0.3
7/13/1999	0.01	1.07	1.06	2.13	110	10	2	0.4
8/18/1999	0.01	0.73	0.51	1.24	40	20	12	0.6
9/14/1999	0.01	0.41	0.53	0.94	140	20	6	0.4
10/14/1999	0.01	0.36	0.54	0.90	40	10	12	0.5
4/18/2000	0.01	0.01	0.66	0.67	110	10	7	0.5
5/16/2000	0.04	0.01	0.71	0.72	90	20	12	0.3
6/13/2000	0.21	0.03	0.61	0.64	190	10	12	0.4
7/21/2000	0.01	0.13	0.62	0.75	380	10	10	0.5
8/16/2000	0.01	0.01	1.00	1.01	160	50	32	0.6
9/13/2000	0.01	0.01	0.60	0.61	100	40	7	0.3
10/17/2000	0.01	0.40	0.30	0.70	80	40	9	0.3
5/15/2001	0.01	1.30	0.54	1.84	180	50	5	0.2
6/12/2001	0.03	2.00	0.38	2.38	170	70	4	0.3
7/11/2001	0.01	1.50	0.55	2.05	180	50	2	0.5
8/14/2001	0.03	0.56	0.29	0.85	80	10	▨	0.5
9/24/2001	0.26	0.45	0.52	0.97	70	40	▨	0.3
4/15/2002	0.07	0.01	0.51	0.52	80	10	▨	0.3
5/13/2002	0.82	0.34	0.64	0.98	100	20	▨	0.2
6/10/2002	0.22	0.90	0.39	1.29	90	20	▨	0.4
7/24/2002	0.01	0.19	0.37	0.56	110	10	7	0.4
8/14/2002	0.01	0.04	0.45	0.49	650	20	23	0.3
9/19/2002	0.09	0.02	0.30	0.32	130	10	4	0.3
4/14/2003	0.04	0.01	0.07	0.08	50	10		0.2

Table C-12. Lake water quality data for IA 05-CHA-0020-L_3 (RA-7).

Date	NHx (ppm)	NOx (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
5/13/2003	0.20	0.16	0.25	0.41	70	40	11	0.4
6/19/2003	0.26	0.01	0.42	0.43	60	10	15	0.6
7/16/2003	0.11	0.01	0.49	0.50	80	10	22	0.4
8/12/2003	0.16	0.01	0.37	0.38	120	10	15	0.7
9/16/2003	0.83	0.33	0.42	0.75	60	40	11	0.4
4/19/2004	0.25	0.01	1.30	1.31	160	70	▨	▨
5/20/2004	0.12	1.10	0.81	1.91	90	70	▨	▨
6/22/2004	0.19	2.10	1.40	3.50	180	20	▨	▨
7/19/2004	0.27	0.55	1.30	1.85	100	10	33	▨
8/1/2004	▨	▨	▨	▨	▨	▨	21	▨
9/21/2004	0.22	0.19	0.98	1.17	170	120	▨	▨
4/1/2005	▨	▨	▨	▨	▨	▨	▨	▨
5/16/2005	0.30	2.00	1.00	3.00	100	50	▨	0.6
6/20/2005	0.20	0.40	1.00	1.40	20	10	▨	0.7
7/25/2005	0.09	0.01	1.40	1.41	100	10	38	▨
8/22/2005	0.03	0.04	0.89	0.93	80	10	29	0.5
9/19/2005	0.01	0.01	0.99	1.00	100	10	41	0.6
4/10/2006	0.07	0.01	0.82	0.83	40	10	27	0.5
5/16/2006	0.02	0.01	0.86	0.87	20	10	39	0.3
6/26/2006	0.07	0.08	1.10	1.18	40	30	31	0.2
7/10/2006	0.20	0.01	1.10	1.11	60	40	76	0.4
8/14/2006	0.05	0.01	1.10	1.11	70	10	81	0.3
9/11/2006	0.07	0.01	0.84	0.85	75	50	36	0.4
4/16/2007	0.01	2.20	2.04	4.24	440	50	▨	0.8
5/21/2007	0.31	2.24	0.99	3.23	252	157	3	0.3
6/18/2007	0.04	1.40	0.76	2.16	75	33	9	0.5
7/23/2007	0.02	0.52	0.83	1.35	78	3	69	0.5
8/20/2007	0.10	0.13	0.83	0.96	98	40	33	0.4
9/17/2007	0.01	0.18	0.63	0.81	95	32	31	0.5
6/9/2008	0.04	1.60	0.86	2.46	230	▨	▨	▨
7/14/2008	0.04	1.30	1.40	2.70	160	160	▨	▨
8/18/2008	0.04	0.06	1.30	1.36	105	▨	▨	▨
9/15/2008	0.04	0.38	0.88	1.26	105	▨	▨	▨
4/20/2009	0.12	1.50	1.60	3.10	240	▨	▨	▨
7/13/2009	0.02	1.70	1.20	2.90	61	▨	▨	▨
8/10/2009	0.02	0.75	1.40	2.15	110	▨	▨	▨
6/15/2009	0.02	2.00	1.00	3.00	130	▨	▨	▨
9/21/2009	0.02	0.77	0.50	1.27	100	▨	▨	▨
4/8/2010	0.16	0.89	0.91	1.80	170	74	7	0.2
5/4/2010	0.33	1.50	0.93	2.43	300	140	4	0.2
6/8/2010	0.03	1.90	0.70	2.60	170	58		▨
7/20/2010	0.03	0.54	1.10	1.64	170	77	13	0.7
8/23/2010	0.03	0.27	1.40	1.67	63	2.5	34	1.2
9/21/2010	0.03	0.37	0.00	0.37	67	12	7	0.5
4/7/2011	0.13	1.40	1.40	2.80	100	8	32	▨
6/16/2011	0.01	2.10	0.68	2.78	180	41	0	▨
7/28/2011	0.01	1.30	0.73	2.03	98	39	1	▨
8/18/2011	0.01	0.70	0.81	1.51	75	29	7	▨
9/22/2011	0.01	0.33	1.10	1.43	110	13	29	▨
4/5/2012	0.03	0.29	0.86	1.15	35	3	19	▨
5/3/2012	0.02	0.84	0.95	1.79	98	3	19	▨
6/7/2012	0.02	0.12	0.70	0.82	43	3	10	▨
7/5/2012	0.02	0.02	0.34	0.34	54	17	48	▨
8/2/2012	0.02	0.02	0.00	0.00	49	3	15	▨
9/6/2012	0.02	0.03	0.54	0.54	82	17	57	▨
4/25/2013	0.19	1.90	0.46	2.36	210	87	160	▨
5/21/2013	0.07	1.40	1.60	3.00	120	49	21	▨
6/17/2013	0.02	1.80	1.60	3.40	170	74	6	▨
7/16/2013	0.02	1.40	0.66	2.06	72	3	11	0.4
8/6/2013	0.02	0.51	0.61	1.12	36	3	41	0.6
9/24/2013	0.04	0.33	0.00	0.33	48	14	20	0.3
4/30/2014	0.26	1.40	1.10	2.50	130	56		▨
5/27/2014	0.04	1.80	0.89	2.69	170	170	4	▨

Table C-12. Lake water quality data for IA 05-CHA-0020-L_3 (RA-7).

Date	NHx (ppm)	NOx (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
6/18/2014	0.04	1.60	0.57	2.17	130	82	0	▨
7/16/2014	0.03	1.10	0.61	1.71	240	220	2	▨

NOTE: Cross-hatching indicates no data available for a given parameter and date.

Table C-13. Lake water quality data for IA 05-CHA-0020-L_2 (RA-8).

Date	NHx (ppm)	NOx (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
4/30/1997	0.21	1.33	1.10	2.43	130	▨	11	0.2
5/13/1997	0.30	1.25	1.50	2.75	160	▨	12	0.2
5/27/1997	0.22	0.90	1.60	2.50	190	80	▨	▨
6/8/1997	0.03	0.54	0.14	0.68	100	80	▨	▨
6/23/1997	0.04	0.84	1.40	2.24	150	40	▨	▨
7/7/1997	0.29	1.45	1.60	3.05	80	70	▨	▨
7/21/1997	0.06	0.63	1.00	1.63	130	30	▨	▨
8/4/1997	0.12	0.09	1.80	1.89	290	40	▨	▨
9/2/1997	0.01	0.68	1.30	1.98	130	50	▨	▨
9/15/1997	0.06	0.26	1.00	1.26	110	60	▨	▨
4/14/1998	0.18	0.49	1.50	1.99	130	90	▨	0.2
5/4/1998	0.14	0.53	0.60	1.13	60	50	▨	0.3
5/18/1998	0.20	0.86	1.20	2.06	340	100	▨	0.2
6/9/1998	0.04	1.06	1.10	2.16	110	100	▨	0.2
6/22/1998	0.07	1.65	1.60	3.25	130	100	▨	0.3
7/6/1998	0.09	1.25	0.60	1.85	90	60	▨	0.4
7/20/1998	0.06	0.26	0.70	0.96	160	30	▨	0.7
8/3/1998	0.11	0.16	0.60	0.76	50	30	▨	0.4
8/17/1998	0.05	0.06	0.90	0.96	200	20	▨	0.5
8/31/1998	0.08	0.12	0.80	0.92	80	30	▨	0.4
9/13/1998	0.09	0.07	1.00	1.07	170	40	▨	0.4
4/14/1999	0.05	0.84	0.89	1.73	150	80	▨	0.2
5/12/1999	0.32	1.62	1.08	2.70	150	80	5	0.2
6/15/1999	0.01	1.07	0.15	1.22	230	60	2	0.2
7/13/1999	0.01	0.89	0.94	1.83	150	10	8	0.3
8/18/1999	0.01	0.59	0.65	1.24	100	40	21	0.3
9/14/1999	0.01	0.18	0.84	1.02	90	20	16	0.3
10/14/1999	0.01	0.01	0.71	0.72	80	10	19	0.5
4/18/2000	0.01	0.01	1.00	1.01	150	10	6	0.5
5/16/2000	0.01	0.01	2.00	2.01	210	30	16	0.3
6/13/2000	0.42	0.03	1.00	1.03	220	60	10	0.2
7/21/2000	0.09	0.28	0.70	0.98	160	20	13	0.4
8/16/2000	0.18	0.01	1.00	1.01	270	110	11	0.2
9/13/2000	0.03	0.01	1.00	1.01	200	70	17	0.2
10/17/2000	0.01	0.50	0.40	0.90	90	40	15	0.2
5/15/2001	0.12	1.20	1.50	2.70	500	50	5	0.1
6/12/2001	0.05	1.10	0.67	1.77	220	70	6	0.2
7/11/2001	0.01	1.00	0.47	1.47	140	30	10	0.4
8/14/2001	0.06	0.02	0.35	0.37	140	30	▨	0.3
9/24/2001	0.21	0.62	0.57	1.19	120	70	▨	0.2
4/15/2002	0.25	0.54	1.20	1.74	180	10	▨	0.2
5/13/2002	0.41	2.90	1.90	4.80	530	160	▨	0.1
6/10/2002	0.10	1.20	0.45	1.65	140	10	▨	0.3
7/24/2002	0.01	0.03	0.38	0.41	140	10	79	0.3
8/14/2002	0.16	0.10	0.85	0.95	130	40	25	0.2
9/19/2002	0.12	0.01	0.48	0.49	170	20	9	0.2
4/14/2003	0.07	0.01	0.73	0.74	370	10	▨	0.2
5/13/2003	0.44	1.70	0.94	2.64	180	40	11	0.2
6/19/2003	0.09	0.01	0.51	0.52	160	40	22	0.2
7/16/2003	0.22	0.67	0.63	1.30	100	10	25	0.3
8/12/2003	0.28	0.01	0.68	0.69	130	20	24	0.2
9/16/2003	0.25	0.03	0.77	0.80	110	20	36	0.2
4/19/2004	0.29	1.50	1.60	3.10	170	10	▨	▨
5/20/2004	0.12	0.10	1.50	1.60	190	10	▨	▨
6/22/2004	0.38	1.90	1.40	3.30	240	90	▨	▨

Table C-13. Lake water quality data for IA 05-CHA-0020-L_2 (RA-8).

Date	NHx (ppm)	NOx (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
7/19/2004	0.24	0.35	1.50	1.85	230	70	21	▨
8/1/2004	▨	▨	▨	▨	▨	▨	27	▨
9/21/2004	0.32	0.31	1.10	1.41	220	140	▨	▨
4/1/2005	▨	▨	▨	▨	▨	▨	▨	▨
5/16/2005	0.30	0.40	2.00	2.40	90	10	▨	0.3
6/20/2005	0.20	4.00	2.00	6.00	80	10	▨	0.4
7/25/2005	0.09	0.20	1.80	2.00	200	10	75	▨
8/22/2005	0.10	0.03	1.20	1.23	100	20	45	0.3
9/19/2005	0.01	0.03	1.50	1.53	200	30	61	0.3
4/10/2006	0.07	0.01	1.30	1.31	200	30	52	0.3
5/16/2006	0.20	1.80	2.00	3.80	230	10	54	0.3
6/26/2006	0.18	0.01	1.40	1.41	200	20	47	0.2
7/10/2006	0.28	0.01	1.10	1.11	200	180	166	0.2
8/14/2006	0.13	0.10	1.40	1.50	310	10	122	0.2
9/11/2006	0.12	0.01	1.50	1.51	230	80	103	0.2
4/16/2007	0.01	2.90	4.19	7.09	230	130	▨	0.5
5/21/2007	0.38	1.49	1.14	2.63	272	155	15	▨
6/18/2007	0.05	1.97	1.08	3.05	121	34	37	0.5
7/23/2007	0.19	0.30	1.07	1.37	113	25	38	0.4
8/20/2007	0.28	0.18	1.32	1.50	150	43	46	0.3
9/17/2007	0.09	0.10	0.73	0.83	181	53	30	0.3
6/9/2008	0.14	1.40	1.50	2.90	270	▨	▨	▨
7/14/2008	0.04	0.79	1.50	2.29	170	170	▨	▨
8/18/2008	0.04	0.06	0.91	0.97	105	▨	▨	▨
9/15/2008	0.11	0.16	0.95	1.11	105	▨	▨	▨
4/20/2009	0.02	0.42	1.40	1.82	170	▨	▨	▨
6/15/2009	0.02	2.60	1.50	4.10	160	▨	▨	▨
7/13/2009	0.02	1.10	1.20	2.30	110	▨	▨	▨
8/10/2009	0.04	0.25	1.20	1.45	130	▨	▨	▨
9/21/2009	0.02	0.38	0.80	1.18	120	▨	▨	▨
4/8/2010	0.17	0.69	0.52	1.21	150	47	10	0.2
5/4/2010	0.39	2.00	1.60	3.60	240	97	8	0.2
6/8/2010	0.03	1.80	1.60	3.40	220	62	▨	▨
7/20/2010	0.03	0.10	1.10	1.20	180	34	35	0.5
8/23/2010	0.03	0.00	0.75	0.75	57	3	27	1.2
9/21/2010	0.03	0.38	0.52	0.90	71	43	10	0.2
4/7/2011	0.01	0.06	1.90	1.96	130	3	140	▨
6/16/2011	0.01	2.00	0.59	2.59	130	21	0	▨
7/28/2011	0.01	0.49	1.20	1.69	48	3	8	▨
8/18/2011	0.11	0.09	1.40	1.49	87	10	28	▨
9/22/2011	0.01	0.31	1.30	1.61	110	17	27	▨
4/5/2012	0.26	0.47	1.60	2.07	69	3	65	▨
5/3/2012	0.06	0.68	1.40	2.08	130	3	51	▨
6/7/2012	0.02	0.79	1.30	2.09	110	3	50	▨
7/5/2012	0.02	0.31	0.78	1.09	53	3	110	▨
8/2/2012	0.02	0.02	0.75	0.75	130	12	8	▨
9/6/2012	0.02	0.03	1.30	1.30	120	22	53	▨
4/25/2013	0.17	1.70	0.45	2.15	250	100	3	▨
5/21/2013	0.02	1.40	1.50	2.90	58	3	20	▨
6/17/2013	0.02	1.50	1.70	3.20	140	49	2	▨
7/16/2013	0.02	0.98	0.64	1.62	44	2.5	9	0.4
8/6/2013	0.12	0.08	0.82	0.90	62	17	93	0.4
9/24/2013	0.02	0.57	0.48	1.05	71	7.1	31	0.3
4/30/2014	0.32	1.80	1.80	3.60	240	83	▨	▨
5/27/2014	0.04	1.70	0.72	2.42	180	110	57	▨
6/18/2014	0.04	1.50	0.67	2.17	140	77	8	▨
7/16/2014	0.03	0.02	0.80	0.80	360	190	2	▨

NOTE: Cross-hatching indicates no data available for a given parameter and date.

Table C-14. Lake water quality data for IA 05-CHA-0020-L_4 (RA-25).

Date	NHx (ppm)	NOx (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
4/14/1999	0.01	0.46	0.87	1.33	140	77		0.6
5/11/1999	0.16	0.81	0.48	1.29	360	190	10	0.5
6/15/1999	0.01	1.19	0.64	1.83	50	20	10	0.6
7/13/1999	0.25	1.14	0.65	1.79	50	30	8	0.9
8/18/1999	0.01	0.82	0.39	1.21	60	20	8	0.9
9/14/1999	0.01	0.66	0.51	1.17	60	10	8	0.5
10/13/1999	0.01	0.01	0.48	0.49	30	30	15	0.9
4/18/2000	0.01	0.08	0.62	0.70	30	10	4	1.0
5/16/2000	0.01	0.01	0.40	0.41	30	10	2	0.9
6/13/2000	0.37	0.01	0.90	0.91	80	10	5	0.8
7/20/2000	0.01	0.01	0.22	0.23	30	10	9	0.9
8/15/2000	0.01	0.01	0.45	0.46	70	10	6	0.9
9/12/2000	0.01	0.01	0.50	0.51	100	10	5	0.8
10/17/2000	0.01	0.20	0.30	0.50	30	10	10	0.4
5/15/2001	0.01	0.92	0.38	1.30	50	10	2	0.7
6/12/2001	0.01	1.10	0.33	1.43	60	10	11	0.4
7/11/2001	0.01	0.95	0.57	1.52	100	10	4	0.8
8/14/2001	0.10	0.61	0.21	0.82	110	10		1.0
9/24/2001	0.20	0.46	0.35	0.81	90	10		0.5
4/15/2002	0.08	0.33	0.44	0.77	70	10		0.6
5/13/2002	0.27	0.30	0.45	0.75	40	20		0.3
6/10/2002	0.39	0.39	0.46	0.85	50	10		0.6
7/24/2002	0.01	0.37	0.07	0.44	50	10	10	1.0
8/13/2002	0.01	0.06	0.22	0.28	50	10	25	0.8
9/18/2002	0.15	0.01	0.33	0.34	20	10	3	0.6
4/14/2003	0.05	0.09	0.15	0.24	20	10		0.7
5/13/2003	0.09	0.15	0.12	0.27	70	10	18	0.7
6/19/2003	0.01	0.01	0.10	0.11	40	10	11	1.2
7/16/2003	0.18	0.01	0.41	0.42	40	10	13	0.8
8/12/2003	0.30	0.01	0.40	0.41	30	10	11	0.9
9/16/2003	0.30	0.10	0.33	0.43	50	10	12	0.7
4/19/2004	0.15	0.45	1.00	1.45	30	10		
5/20/2004	0.09	0.64	0.75	1.39	10	10		
6/22/2004	0.58	0.51	1.20	1.71	70	10		
7/19/2004	0.22	0.22	1.10	1.32	300	10	24	
8/1/2004					130	10	33	
9/21/2004	0.25	0.23	0.84	1.07	60	20		
4/1/2005								
5/16/2005	0.30	0.40	1.00	1.40	90	10		0.4
6/20/2005	0.20	0.40	1.00	1.40				0.9
7/25/2005	0.08	0.01	1.20	1.21	40	10	23	
8/22/2005	0.03	0.01	0.72	0.73	10	10	23	0.9
9/19/2005	0.01	0.01	0.99	1.00	60	10	48	0.8
4/10/2006	0.08	0.10	1.00	1.10	50	10	22	0.9
5/16/2006	0.07	0.05	0.64	0.69	100	10	10	0.8
6/26/2006	0.05	0.01	0.80	0.81	40	10	19	0.6
7/10/2006	0.19	0.01	0.72	0.73	30	10	26	0.9
8/14/2006	0.02	0.01	0.76	0.77	40	10	41	0.6
9/11/2006	0.05	0.01	0.72	0.73	150	90	33	0.8
4/16/2007	0.01	0.40	1.95	2.35	40	70		2.5
5/21/2007	0.15	1.16	0.84	2.00	90	10	23	0.7
6/18/2007	0.07	1.17	0.77	1.94	60	10	41	0.7
7/23/2007	0.02	0.68	0.68	1.36	106	42	39	0.6
8/20/2007	0.05	0.24	0.88	1.12	81	17	34	0.8
9/17/2007	0.02	0.15	0.76	0.91	48	3	27	0.8
6/9/2008	0.04	1.50	0.66	2.16	47	4		
7/14/2008	0.04	1.10	1.10	2.20	63	14		
8/18/2008	0.04	0.28	0.98	1.26	290			
9/15/2008	0.04	0.60	0.72	1.32	105			
4/20/2009	0.02	1.10	1.20	2.30	105			
6/15/2009	0.02	1.50	0.85	2.35	105			

Table C-14. Lake water quality data for IA 05-CHA-0020-L_4 (RA-25).

Date	NHx (ppm)	NOx (ppm)	TKN (ppm)	TN (ppm)	TP (ppb)	Ortho-P (ppb)	Chl-a (ppb)	Secchi depth (m)
7/13/2009	0.02	1.50	0.80	2.30	130	▨	▨	▨
8/10/2009	0.02	1.10	1.00	2.10	94	▨	▨	▨
9/21/2009	0.02	0.83	0.51	1.34	24	▨	▨	▨
4/8/2010	0.03	0.97	0.44	1.41	61	▨	▨	▨
5/4/2010	0.03	1.30	0.39	1.69	50	▨	▨	▨
6/8/2010	0.03	1.30	0.92	2.22	100	51	▨	▨
7/20/2010	0.03	0.77	0.64	1.41	110	34	▨	▨
8/23/2010	0.03	0.26	0.91	1.17	120	39	▨	▨
9/21/2010	0.03	0.43	0.00	0.43	79	10	▨	▨
4/7/2011	0.01	0.96	1.20	2.16	43	3	13	▨
6/16/2011	0.01	1.80	0.53	2.33	62	22	1	▨
7/28/2011	0.01	1.00	1.10	2.10	70	3	16	▨
8/18/2011	0.01	0.74	1.30	2.04	81	11	43	▨
9/22/2011	0.01	0.45	0.84	1.29	28	3	28	▨
4/5/2012	0.03	0.36	0.38	0.74	21	3	7	▨
5/3/2012	0.02	0.33	0.32	0.65	50	3	9	▨
6/7/2012	0.02	0.02	0.66	0.66	16	3	38	▨
7/5/2012	0.02	0.02	0.30	0.30	23	3	22	▨
8/2/2012	0.02	0.02	0.00	0.00	35	3	16	▨
9/6/2012	0.02	0.03	0.38	0.38	20	3	25	▨
4/25/2013	0.09	0.67	0.00	0.67	36	70	9	▨
5/21/2013	0.02	0.70	1.60	2.30	27	3	26	▨
6/17/2013	0.02	1.20	1.00	2.20	56	20	110	▨
7/16/2013	0.02	1.40	0.57	1.97	24	3	4	0.4
8/6/2013	0.02	0.66	0.96	1.62	49	13	31	0.7
9/24/2013	0.02	0.34	0.49	0.83	47	3	24	0.4
4/30/2014	0.02	0.04	0.52	0.52	23	3	▨	▨
5/27/2014	0.02	0.16	0.47	0.63	32	3	30	▨
6/18/2014	0.02	0.81	0.54	1.35	23	0	1	▨
7/16/2014	0.02	0.77	0.56	1.33	36	7	3	▨

NOTE: Cross-hatching indicates no data available for a given parameter and date.

C.5. Lake Profile Data

The following figures illustrate temperature and DO profiles, which were used primarily for assessment of potential stratification.

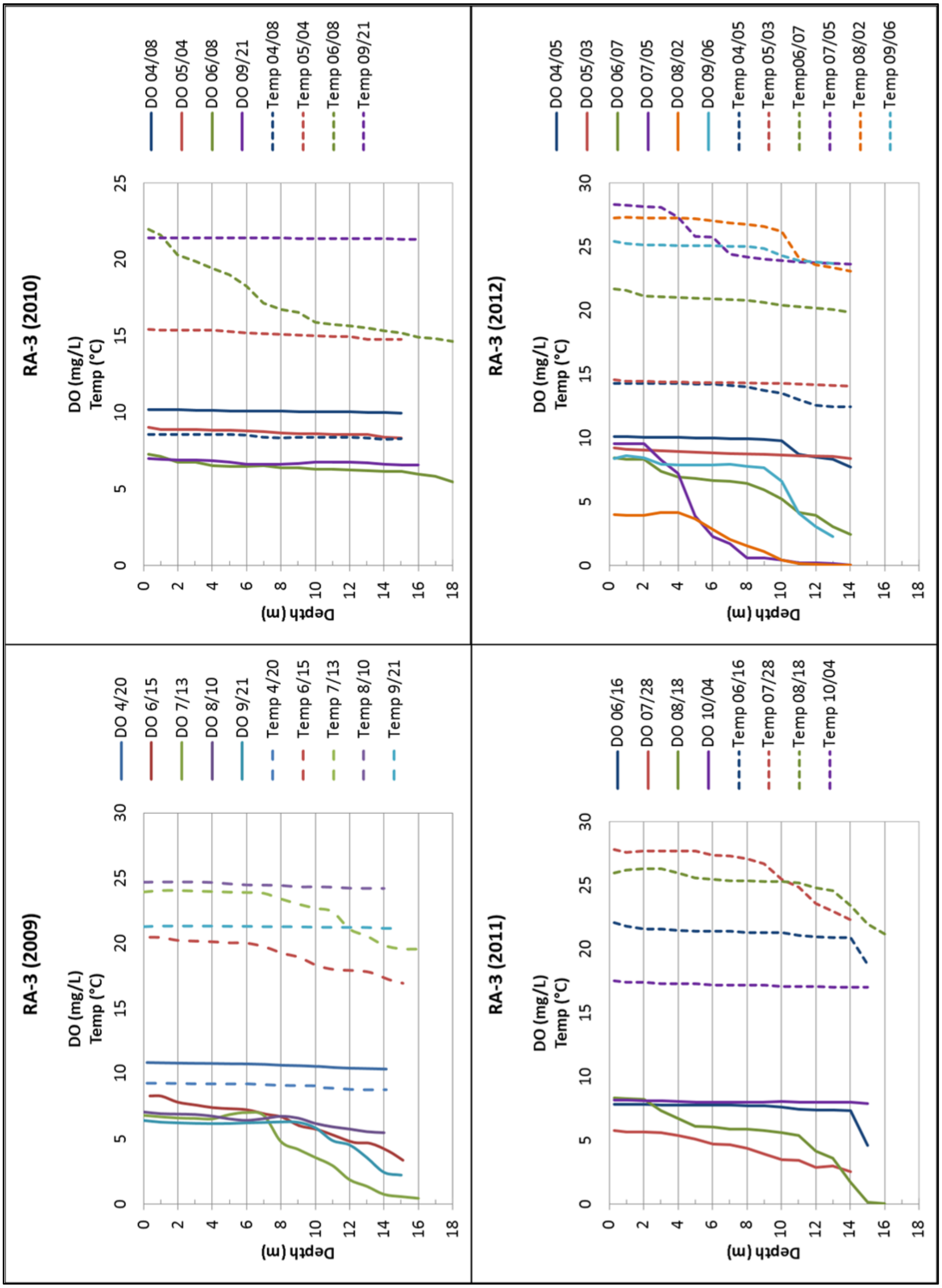


Figure C-3. Temperature and DO profiles for IA 05-CHA-0020-L_1 (RA-3).

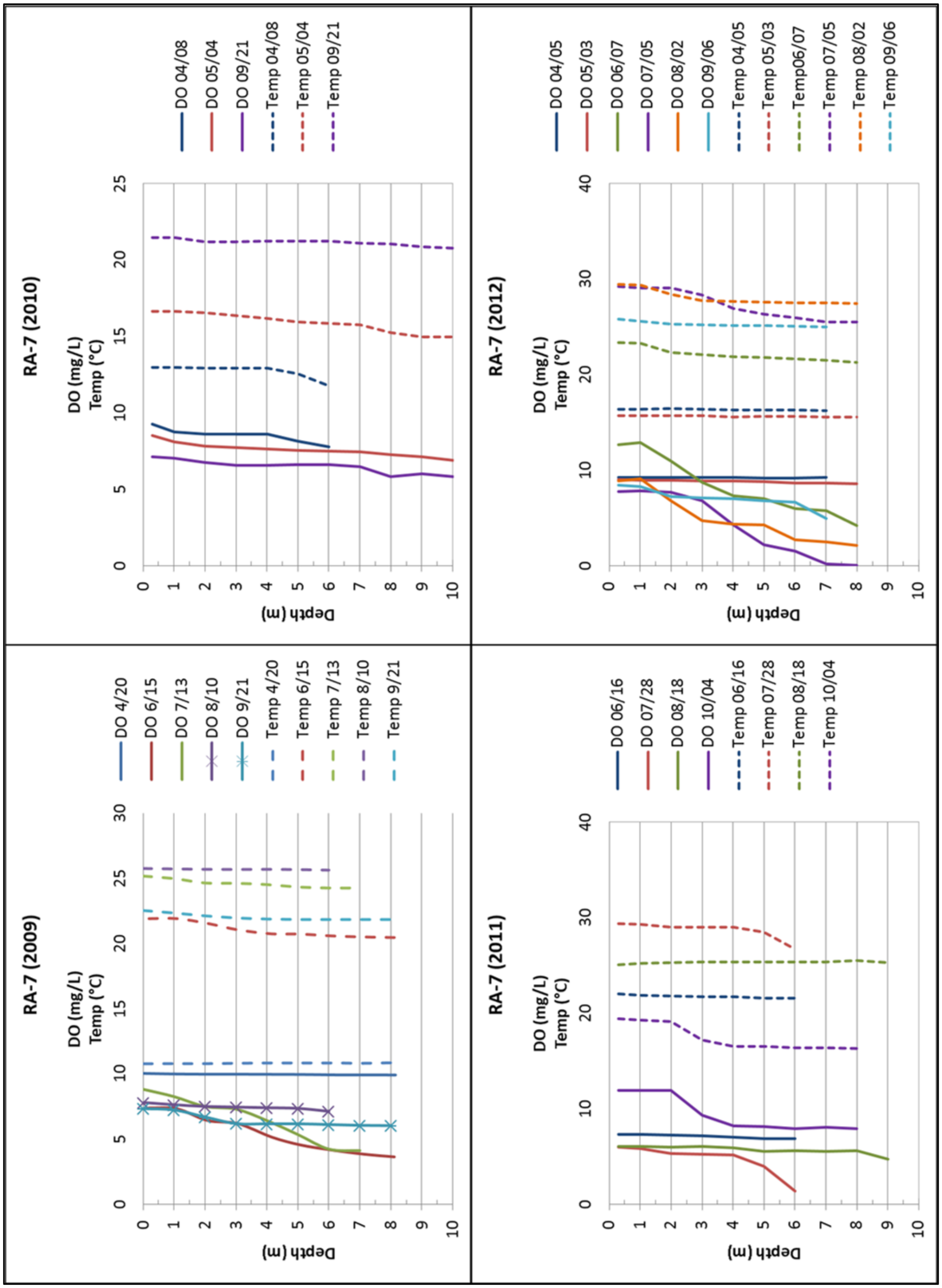


Figure C-4. Temperature and DO profiles for IA 05-CHA-0020-L_3 (RA-7).

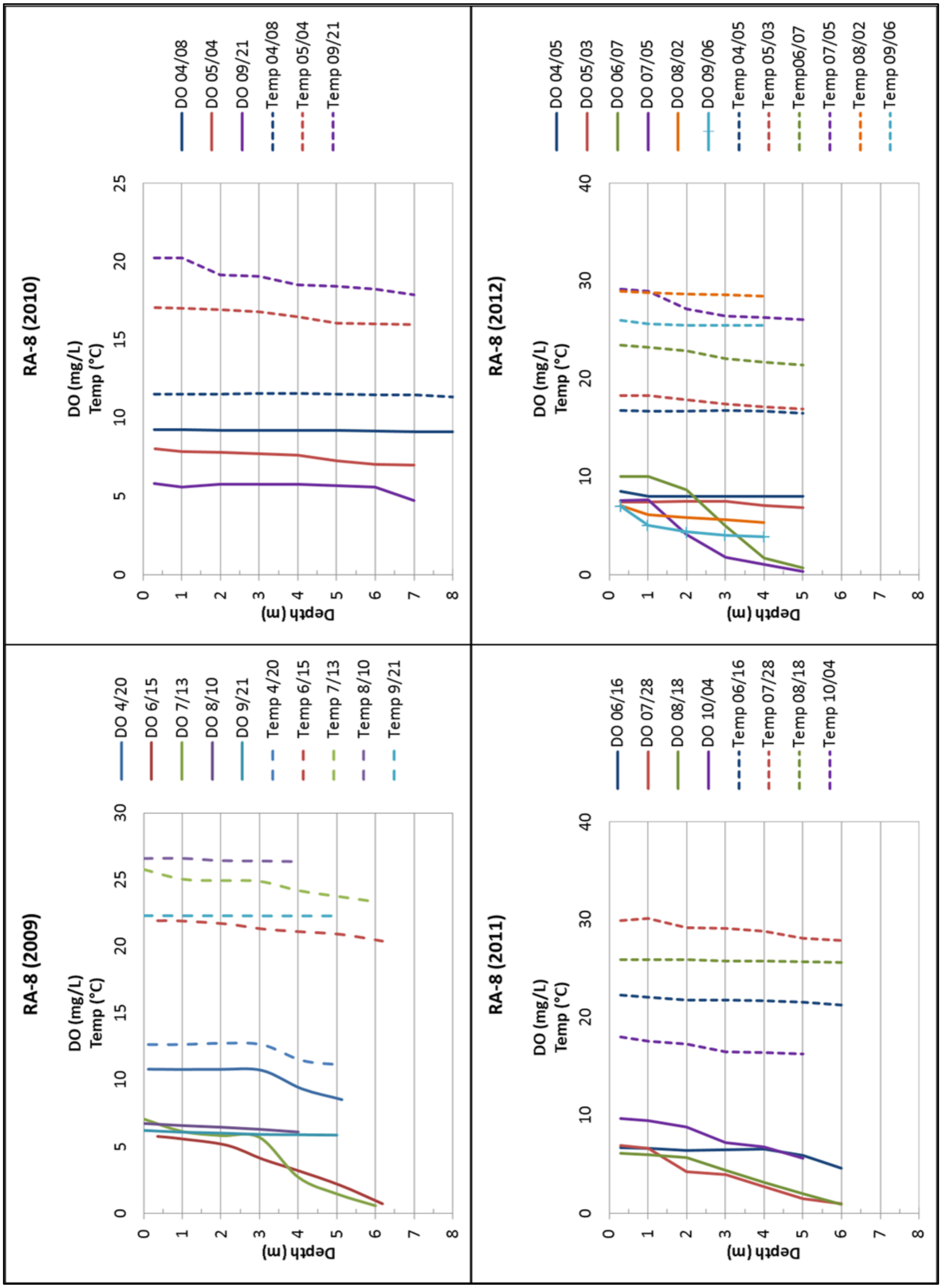


Figure C-5. Temperature and DO profiles for IA 05-CHA-0020-L_2 (RA-8).

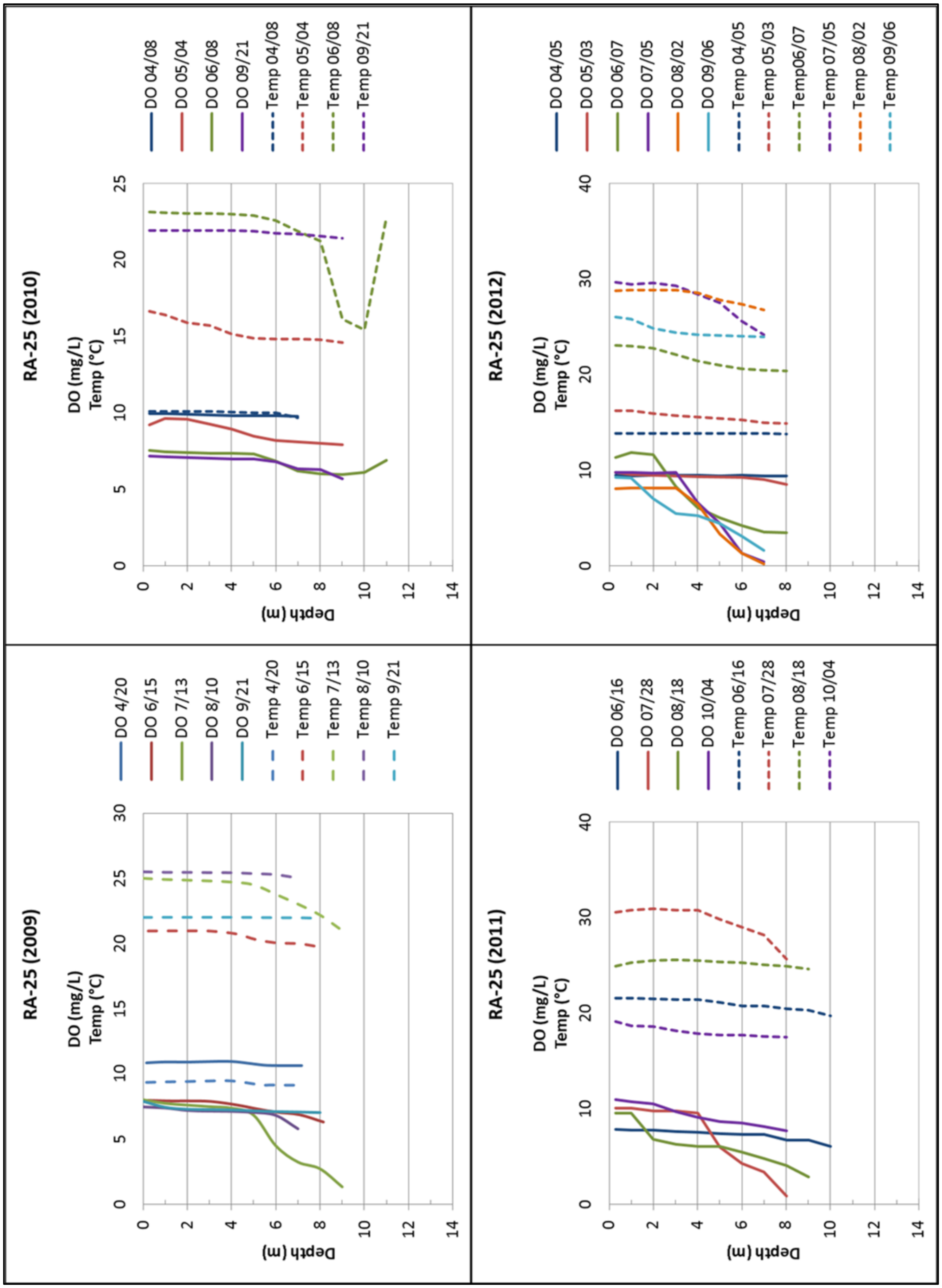


Figure C-6. Temperature and DO profiles for IA 05-CHA-0020-L_4 (RA-25).

C.6. Lake Trophic State Indices

The following figures illustrate annual average Trophic State Index (TSI) values and potential relationships between total phosphorus (TP), Secchi depth, and chlorophyll *a* (Chl-a) TSIs. These analyses were all used to interpret water quality data discussed in Section 3.1 of this WQIP.

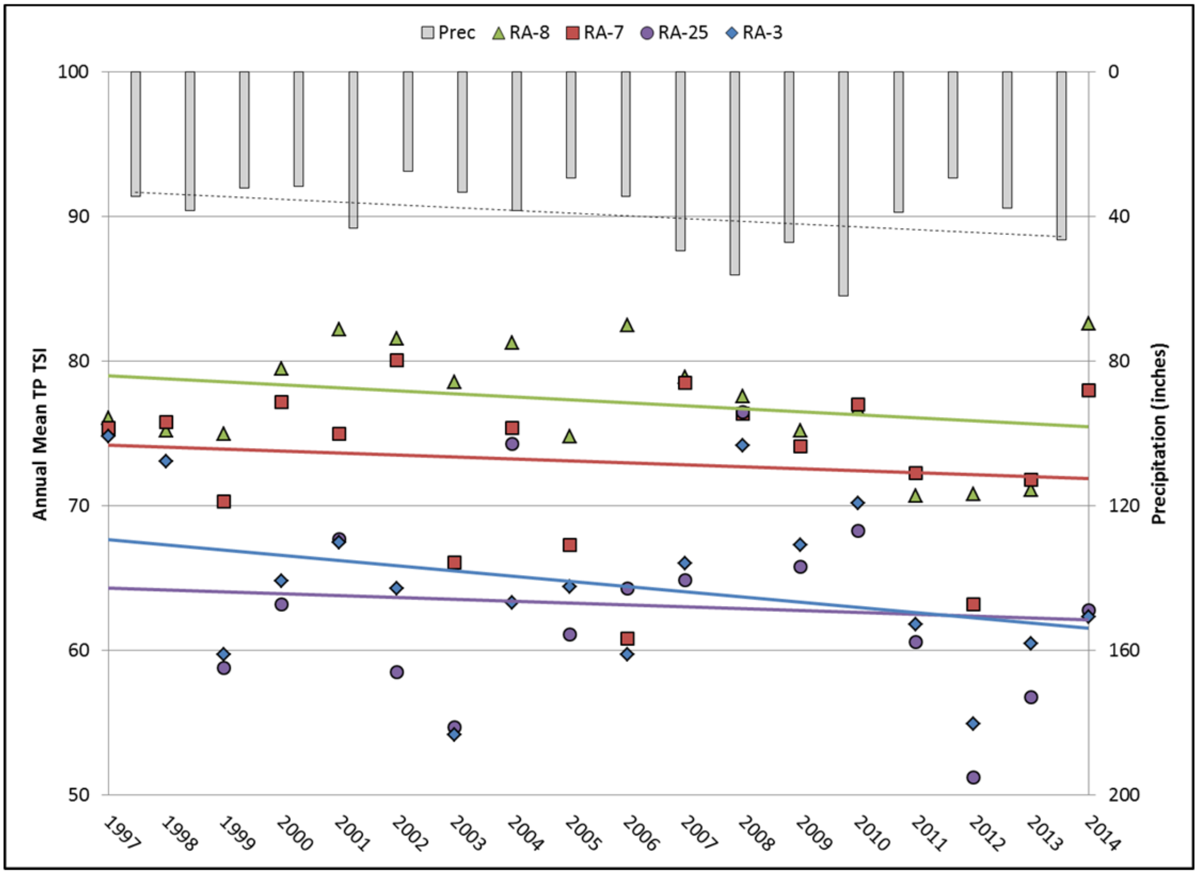


Figure C-7. Annual average TP TSI values for Rathbun Lake segments (1997-2014). Linear regression indicated overall decrease in TP levels since 1997 with a high degree of year-to-year annual variation. Note that annual average precipitation (secondary y-axis) increased over the same period. Generally, lower annual precipitation was associated with lower TP TSI values.

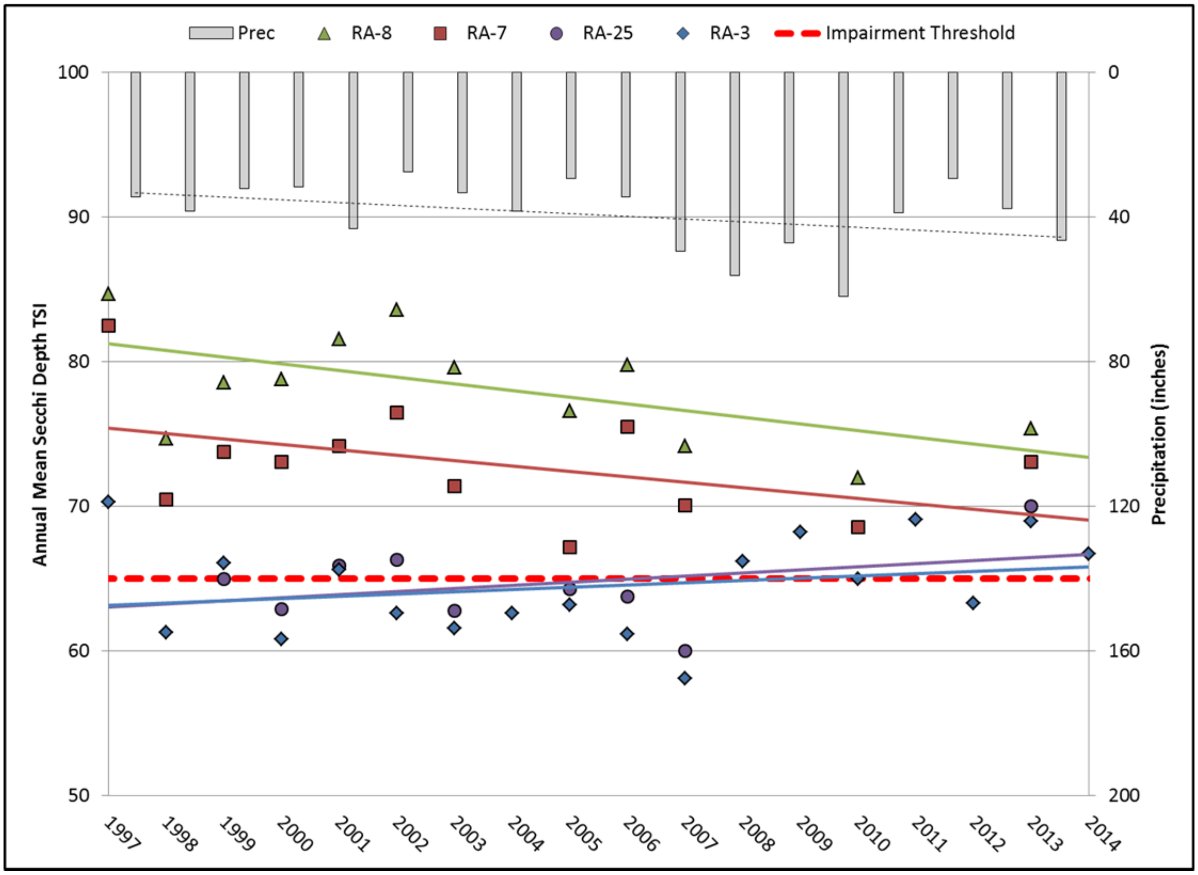


Figure C-8. Annual average Secchi depth TSI values for Rathbun Lake segments (1997-2014). Linear regression indicated overall decrease in Secchi depth TSI (i.e., increased water clarity) at RA-7 and RA-8, but an increased in TSI (i.e., decreased water clarity) at RA-25 and RA-3 since 1997.
Since 2008, the annual average TSI value has met or exceeded the impairment threshold at all sites with the exception of RA-3 in 2012.

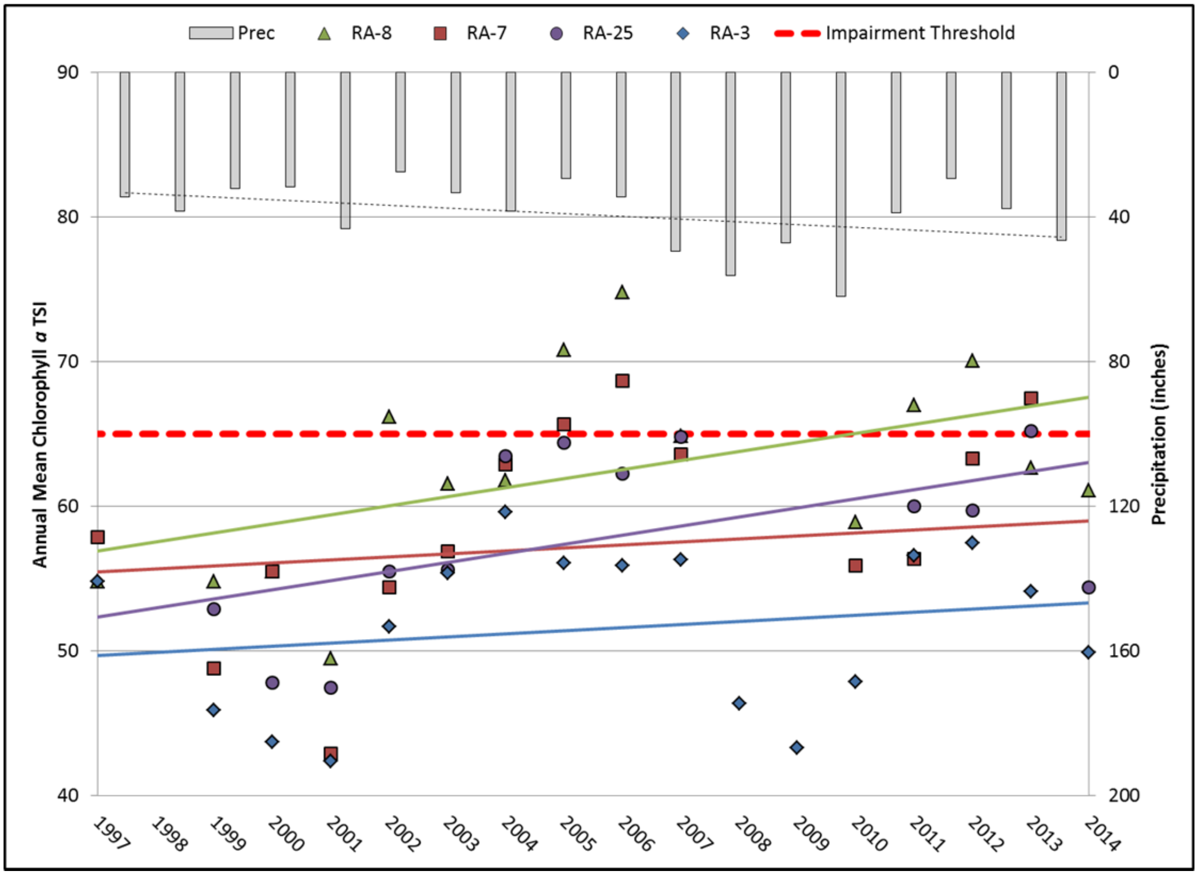


Figure C-9. Annual average Chl-a TSI values for Rathbun Lake segments (1997-2014). Linear regression indicated overall increase in Chl-a TSIs (increased algal production) at all sites since 1997, with steeper increases in the Honey Creek and Chariton River arms of the lake. Overall, Chl-a TSI values are notably lower than TP and Secchi depth TSIs, with relatively few exceedances of the impairment threshold of 65, indicated by the red, dashed line.

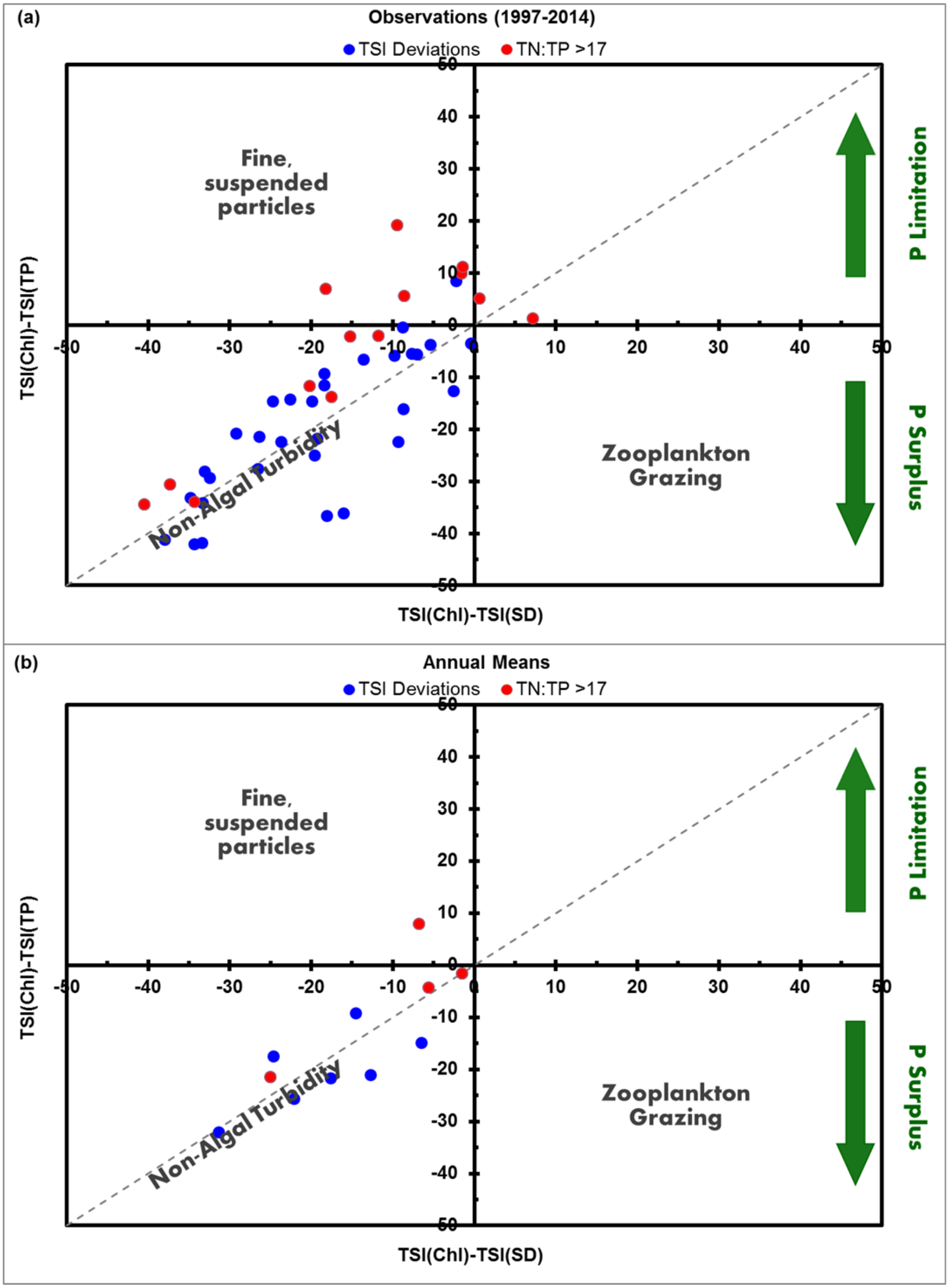


Figure C-10. TSI relationships for Chariton River arm of Rathbun Lake (RA-7). Chart (a) includes individual observations and chart (b) shows annual mean values. Red dots represent observations / means with TN:TP ratio >17, indicating P-limitation.

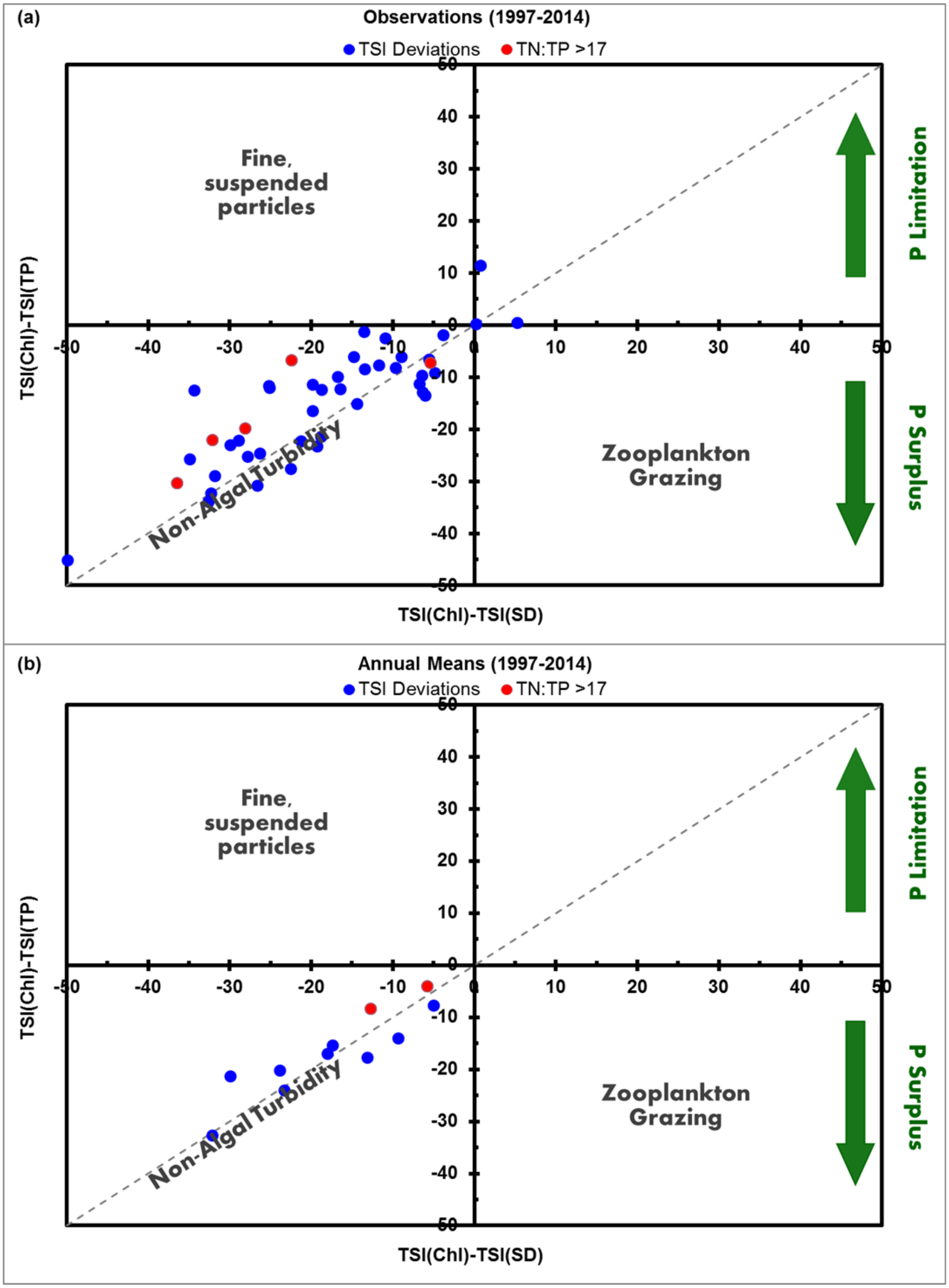


Figure C-11. TSI relationships for S. Fork Chariton arm of Rathbun Lake (RA-8). Chart (a) includes individual observations and chart (b) shows annual mean values. Red dots represent observations / means with TN:TP ratio >17, indicating P-limitation.

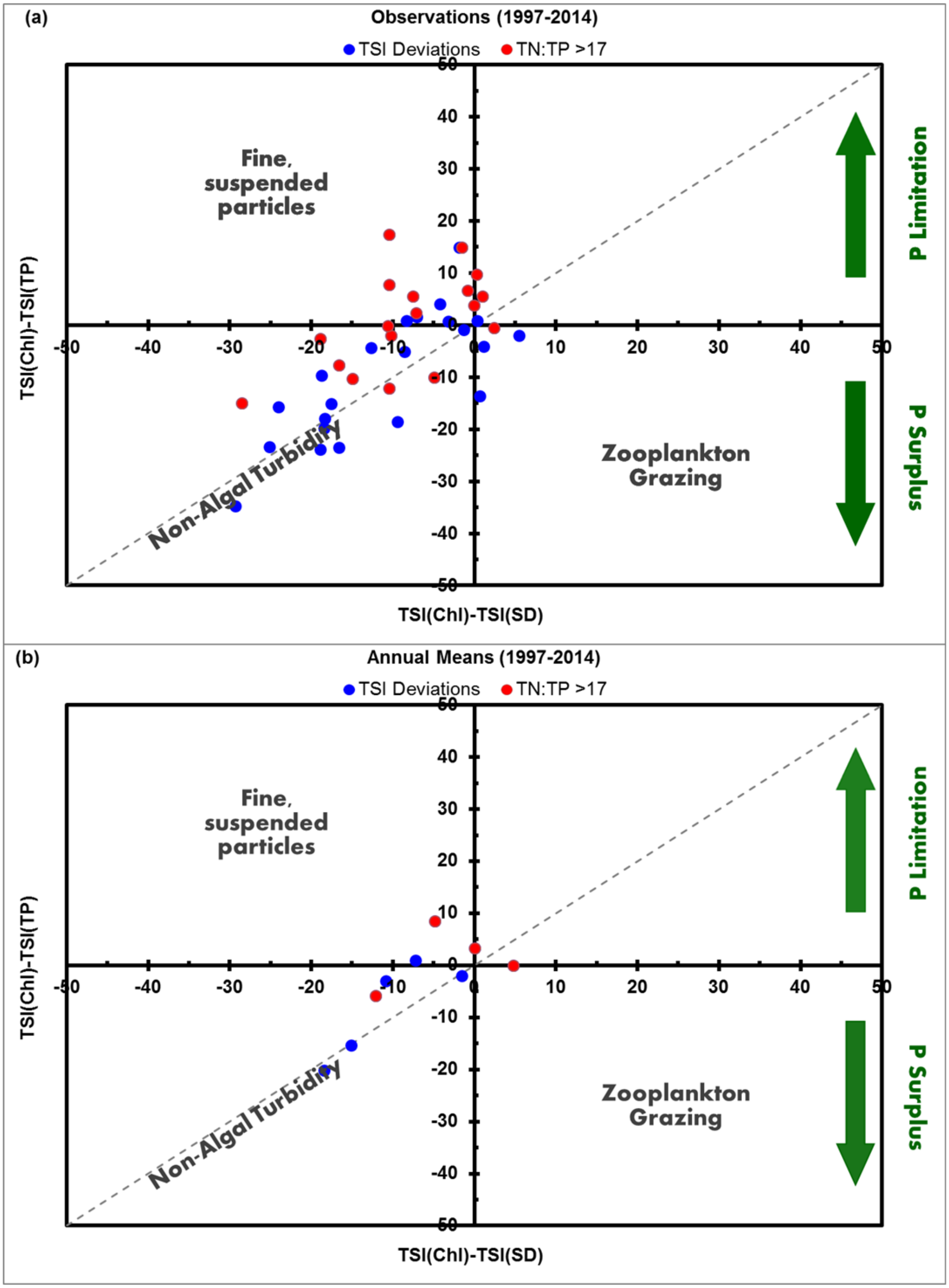


Figure C-12. TSI relationships for Honey Creek arm of Rathbun Lake (RA-25). Chart (a) includes individual observations and chart (b) shows annual mean values. Red dots represent observations / means with TN:TP ratio >17, indicating P-limitation.

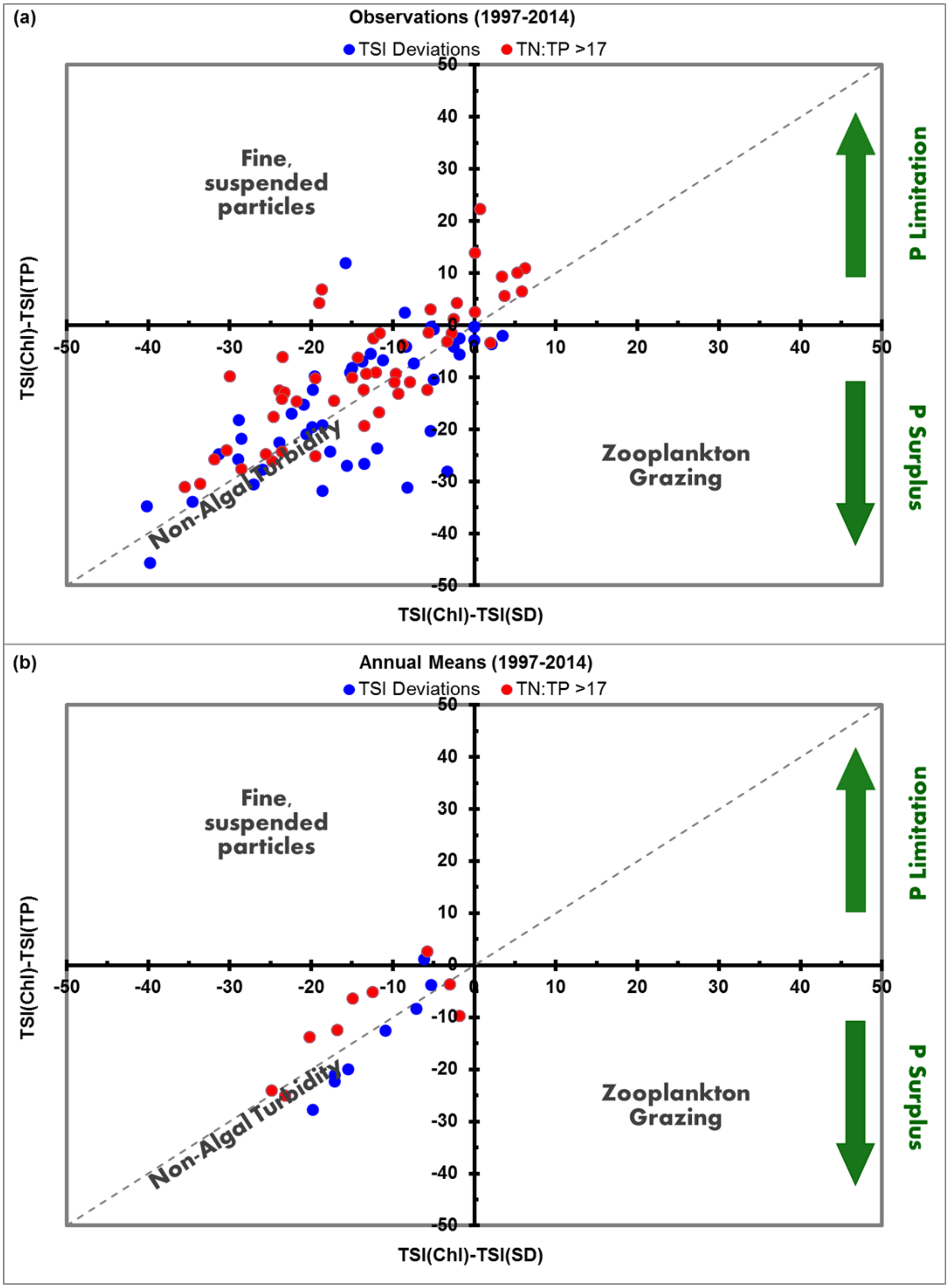


Figure C-13. TSI relationships for near-dam area of Rathbun Lake (RA-3). Chart (a) includes individual observations and chart (b) shows annual mean values. Red dots represent observations / means with TN:TP ratio >17, indicating P-limitation.

Appendix D --- Watershed Sources & Model Development

Watershed and in-lake water quality modeling were used in conjunction with observed flow and water quality data to develop the Total Maximum Daily Loads (TMDLs) for turbidity impairments to Rathbun Lake in south-central Iowa. The Soil & Water Assessment Tool (SWAT2012), Revision 637, was used to simulate hydrology and nonpoint source pollutant loads to the lake from the watershed. Several land-derived nonpoint and point source pollutant loads were calculated outside of the SWAT model but summarized for each SWAT model subbasin. This section of the Water Quality Improvement Plan (WQIP) documents quantification of watershed pollutant sources, development of the SWAT model, and parameterization of model inputs.

D.1. SWAT Model Description

SWAT is a watershed-scale hydrology and water quality model developed by the U.S. Department of Agriculture – Agricultural Research Service (USDA-ARS). SWAT is a long-term continuous-simulation model that operates on a daily time step, and was developed to assess the impacts of land use and management practices on hydrology and water quality (Gassman et al., 2007; Schilling et al., 2008). SWAT has been applied worldwide for many types of water resource problems across a wide spectrum of watershed scales and conditions (Gassman et al., 2014; Krysanova and White, 2015; Bressiani et al., 2015). The model is capable of simulating a variety of pollutants, including sediment, nutrients, pesticides, and bacteria. The model also simulates crop growth and soil nutrient cycling and is under continuous development / improvement by USDA-ARS.

Primary inputs include spatial coverage of soil types and land uses. Climatic data includes daily precipitation, temperature, solar radiation, relative humidity, and wind speed. Land management considerations that affect hydrology and water quality, such as crop rotation, tillage practices, best management practices, manure application, tile drainage characteristics, livestock grazing, and point source pollution loads, are also important model inputs.

Watersheds are delineated into subbasins based on a desired area threshold. Subbasins are further divided into hydrologic response units (HRUs) that consist of homogeneous soil, land use, and slope characteristics. Because each HRU represents the portion of a subbasin with the same soil, land use, and slope classification, HRUs are not spatially contiguous. The water balance and pollutant yields are simulated for each HRU and summarized at the subbasin level before being routed through the stream network (i.e., SWAT reach files). In this regard, SWAT is considered a semi-distributed model, because HRUs are lumped, but subbasin / reach routing is distributed.

Like all models, SWAT has limitations and should be applied cautiously, with its limitations fully considered. There is a long history of the use of SWAT for hydrologic and water quality simulations and its utilization for the development of TMDLs is increasingly popular. Recognizing its extensive use, Arnold et al. (2012) published guidance on the use, calibration, and validation of SWAT models and detailed performance measures and evaluation criteria have been set forth by Moriasi et al. (2015). Watershed management decisions made based on model output must be thoroughly vetted to ensure that model algorithms, assumptions, and parameterization / calibration methods appropriately support the model's use (Arnold et al., 2015; Baffaut et al., 2015). Model calibration and the limitations of model performance for watershed planning are discussed in Section E.

D.2. Watershed Delineation

Topographic Data
Although a 3-meter DEM based on LiDAR was available for use in model development, this highly resolute data source creates several problems for large-scale SWAT application. First, LiDAR-based DEMs require manual hydraulic reinforcement to prevent roadways and other embankments with culverts / bridges from damming up water. Second, LiDAR has been shown to result in average slope calculations that are inconsistent with the underlying soil erosion algorithms in SWAT. Finally, the Rathbun Lake watershed is very large, and the increased resolution would add to the computational complexity of the model and may create instability and / or slow run times. For these reasons, the Rathbun Lake watershed boundary was delineated in ArcSWAT 2012 (Version 10_1.14, released 3/5/2014) using a 10-meter resolution digital elevation model (DEM) developed by the Iowa Department of Natural Resources (IDNR). In addition to providing the basis for watershed and subbasin delineation, the DEM allows calculation of average slopes for each HRU and stream reach, which are important inputs for hydrologic and water quality simulation.

Watershed and Subwatershed Delineation
During the delineation process, a stream definition threshold of 518 hectares (1,280 acres) was entered to define the drainage area at which stream formation is initiated. This value was obtained through an iterative process in order to develop subbasins that resemble the HUC-14 level planning watersheds utilized by the Rathbun Land & Water Alliance (RLWA). Subbasin outlets were adjusted manually as part of the delineation process to establish outlets at key locations for linkage to the in-lake model and for calibration purposes. Manual outlet definition was also helpful to ensure that the range of subbasin areas was roughly within an order of magnitude, as recommended by SWAT model developers (R. Srinivasan, March 16, 2009, personal communication).

The delineation resulted in a total watershed area of 143,273 hectares (354,035 acres) consisting of 68 subbasins. The subbasins have areas ranging from 413 to 5,343 hectares (1,021 to 13,203 acres), approximately an order of magnitude of variation. There are only 61 HUC-14 level planning subwatersheds utilized by RLWA (versus 68 subwatersheds developed in the SWAT model for the TMDL). Several RWLA planning subwatersheds were subdivided into multiple basins during watershed delineation to facilitate linkage subwatersheds to in-lake model (BATHTUB) tributaries. Figure D-1 illustrates the watershed, reach, and subbasin delineation for the Rathbun watershed SWAT model.

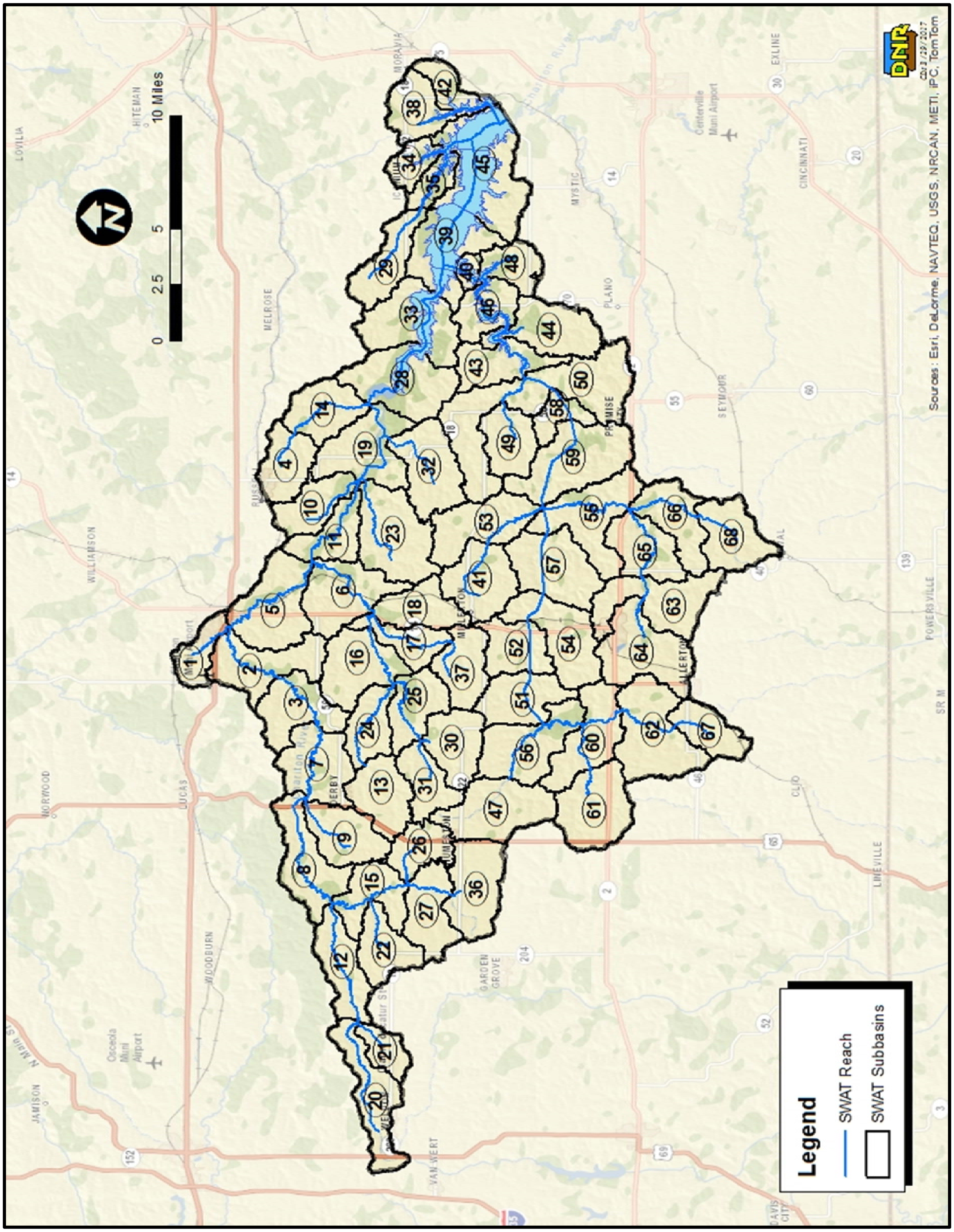


Figure D-1. SWAT watershed, reach, and subbasin delineation.

An inventory of subwatersheds is provided in Table D-1, which compares the HUC-14 planning subwatersheds used by RLWA and corresponding SWAT subbasins. The SWAT IDs apply to SWAT subbasins and stream / river reaches, and are critical for identifying SWAT output relative to monitoring locations with observed data.

Table D-1. SWAT subbasins and corresponding RLWA (HUC-14) subwatersheds used for watershed planning.

SWAT Sub ID	SWAT Sub Area		HUC-14 ID	HUC-14 Name	HUC-14 Sub Area	
	(ha)	(ac)			(ha)	(ac)
1	1,117	2,759	1	West Lake	1,048	2,590
2	2,477	6,121	2	Chariton River #7	2,464	6,089
3	2,126	5,252	4	Chariton River #6	2,127	5,257
4	1,702	4,206	5	Upper Honey Creek Lucas	1,672	4,131
5	2,933	7,248	3	Chariton River #8	2,983	7,370
6	2,529	6,248	11	Lower Wolf Creek	2,522	6,233
7	2,385	5,894	8	Chariton River #5	2,426	5,995
8	2,501	6,179	7	Chariton River #4	2,452	6,059
9	1,955	4,831	12	Hamilton Creek	1,973	4,875
10	1,590	3,928	6	Ragtown Branch	1,600	3,953
11	1,541	3,807	10	Chariton River #9	1,542	3,811
12[a]	1,987	4,910	14[b]	Lower Chariton Creek	2,894	7,150
13	1,940	4,793	21	Upper Fivemile Creek	1,943	4,802
14	1,864	4,605	9	Lower Honey Creek Lucas	1,851	4,574
15	1,790	4,424	17	Chariton River #3	1,810	4,473
16	2,392	5,911	15	Middle Wolf Creek #2	2,375	5,868
17	1,316	3,252	19	Lower Brush Creek	1,313	3,244
18	1,623	4,010	25	Sugar Creek	1,624	4,014
19	2,651	6,551	13	Chariton River #10	2,704	6,682
20	2,382	5,887	16	Upper Chariton Creek	2,399	5,927
21[a]	905	2,236	14[b]	Lower Chariton Creek	--[b]	--[b]
22	1,655	4,090	23	Brush Creek	1,645	4,066
23	3,069	7,583	24	Lost Branch	3,082	7,616
24	1,527	3,774	20	Lower Fivemile Creek	1,532	3,786
25	1,738	4,293	30	Middle Wolf Creek #1	1,745	4,311
26	1,388	3,430	29	Humeston Reservoir	1,328	3,282
27	1,942	4,799	32	Chariton River #2	1,949	4,816
28[a]	3,028	7,481	18[b]	Chariton River #11	5,930	14,653
29	1,815	4,484	22	Upper Honey Creek Monroe	1,830	4,523
30	1,847	4,563	34	Upper Wolf Creek	1,848	4,566
31	1,480	3,658	31	Upper Wolf Creek #2	1,471	3,635
32	2,471	6,105	27	Goodwater Creek	2,493	6,160
33	2,927	7,233	18[b]	Chariton River #11	--[b]	--[b]
34[a]	910	2,249	26[b]	Lower Honey Creek Appanoose	1,898	4,689
35[a]	849	2,097	26[b]	Lower Honey Creek Appanoose	--[b]	--[b]
36	2,443	6,036	40	Chariton River #1	2,421	5,983
37	1,756	4,340	36	Upper Brush Creek	1,754	4,335
38[a]	1,626	4,019	28[b]	Buck Creek	2,631	6,502
39[a]	2,615	6,462	33[b]	Chariton River #12	6,649	16,430
40[a]	413	1,021	41[b]	South Fork Chariton River #8	3,126	7,724

Table D-1. SWAT subbasins and corresponding RLWA (HUC-14) subwatersheds used for watershed planning.

SWAT Sub ID	SWAT Sub Area		HUC-14 ID	HUC-14 Name	HUC-14 Sub Area	
	(ha)	(ac)			(ha)	(ac)
41	2,267	5,601	39	Upper Jordan Creek	2,257	5,577
42[a]	999	2,467	28[b]	Buck Creek	--[b]	--[b]
43	1,777	4,391	42	South Fork Chariton River #7	1,749	4,321
44	2,305	5,695	47	Sandy Branch	2,316	5,722
45[a]	4,097	10,124	33[b]	Chariton River #12	--[b]	--[b]
46[a]	1,526	3,770	41[b]	South Fork Chariton River #8	--[b]	--[b]
47	2,737	6,763	37	Upper Ninemile Creek	2,785	6,883
48[a]	1,185	2,927	41[b]	South Fork Chariton River #8	--[b]	--[b]
49	1,663	4,109	46	South Fork Walker Branch	1,662	4,108
50	5,343	13,203	38[c] 52[c]	Walker Branch & South Fork Chariton River #6	3,201 3,081	7,910 7,613
51	1,960	4,842	44	South Fork Chariton River #2	1,946	4,809
52	1,693	4,184	43	South Fork Chariton River #3	1,686	4,167
53	2,408	5,950	35	Lower Jordan Creek	2,402	5,935
54	2,581	6,377	48	Wildcat Creek	2,583	6,383
55	2,852	7,048	51	Lower Jackson Creek	2,843	7,024
56	2,670	6,597	45	Lower Ninemile Creek	2,678	6,617
57	2,680	6,622	50	South Fork Chariton River #4	2,666	6,588
58	856	2,114	52	South Fork Chariton River #6	3,081	7,613
59	3,279	8,103	49	South Fork Chariton River #5	3,201	7,910
60	2,351	5,809	53	Lower Dick Creek	2,410	5,955
61	2,613	6,457	54	Upper Dick Creek	2,630	6,500
62	3,257	8,049	58	South Fork Chariton River #1	3,196	7,898
63	2,710	6,697	55	Middle West Jackson Creek	2,682	6,628
64	2,922	7,221	56	Upper West Jackson Creek	2,905	7,179
65	1,909	4,718	57	Lower West Jackson Creek	1,915	4,732
66	1,971	4,870	59	Middle Jackson Creek	1,959	4,841
67	1,425	3,522	60	Bob White Lake	1,429	3,531
68	2,039	5,037	61	Upper Jackson Creek	2,046	5,056
Totals	143,273	354,035			143,282	354,061

[a] More than one SWAT subbasin comprises the corresponding HUC-14 subwatershed.
[b] The HUC-14 subwatershed overlaps more than one SWAT subbasin. HUC-14 area reported only once.
[c] More than one HUC-14 subwatershed comprises the corresponding SWAT subbasin.

D.3. Hydrologic Response Unit (HRU) Input

Land Use
The land cover data layer utilized in the development of the SWAT model was the U.S. Department of Agriculture National Agricultural Statistics Service Cropland Data Layer (CDL) reflecting 2006 conditions (USDA-NASS, 2013). This grid coverage is comprised of 30-meter by 30-meter pixels each having a unique value assigned to it using satellite imagery combined with field assessments conducted by NASS. Each unique pixel value represents a specific land cover, such as corn, soybeans, alfalfa, pasture, and various other categories. The NASS grid was recoded by Iowa DNR to simplify the land cover classifications and make it more suitable for SWAT model development.

In addition to 2006 land cover data, crop rotation data for the Rathbun watershed was obtained from the USDA Agricultural Research Service (ARS) National Laboratory for Agriculture and the Environment (NLAE) in Ames, Iowa. The crop rotation coverage was created by NLAE, which utilized field boundaries and 2008-2013 CDL coverages to develop a 6-year crop rotation database (Tomer et al., 2013). Crop rotations were combined with the modified CDL coverage and used to distinguish fields that were in two-year corn and soybean rotations from those fields that contained continuous corn or some type of extended rotation with corn, soybeans, and alfalfa or grass. The SWAT land use (i.e., the crop / plant) database does not include rotation data; therefore the SWAT database was appended with new land use codes to distinguish between rotations. For example, a continuous corn category was created by copying the corn land use in the SWAT database. The crop parameters are identical to corn in other rotations, but the unique category allows distinct management operations (e.g., fertilizer application and crop rotation) to be simulated. Crop rotations were incorporated into the model because they impact hydrology and nutrient transport. Also, extended crop rotations are recognized agricultural best management practices (BMPs), and stakeholders may wish to evaluate scenarios that increase or decrease acres in extended rotations.

The CDL coverage includes 30-meter pixels and is generated using satellite imagery. Consequently, many fields contain fragmented land use categories. As an example, it is common to observe fields in which pasture or forest pixels are present in the middle of row crops in the CDL coverage, but not in reality. This can arise from image sampling method limitations or natural variation in plant pigmentation. Furthermore, the field boundary coverage that contains the crop rotation data is full of irregularities, including: gaps in non-agricultural land; inconsistent treatment of features such waterways, ditches, terraces, and streams; and oddly-shaped field boundaries. The land use fragments and field boundary irregularities would result in a much more complex spatial data set, and unnecessarily increase the number of unique combinations of land cover and crop rotation. To address this, a 1-ha fishnet shapefile was created, and the majority land cover and crop rotation IDs were assigned to each 1-ha grid of the fishnet. This simplified, but also preserved the spatial integrity and accuracy of the data, and resulted in two coverages: one with 1-ha grids containing a unique land cover, and another with generalized crop rotations. Table D-2 explains the land use codes created to reflect crop rotations.

The land cover and crop rotations were integrated using a zonal statistics command within ESRI ArcGIS. This step calculated the majority crop rotation for each 1-ha grid with a specified land cover. Within the land use shapefile, the numeric ID values for the land cover and crop rotation were then combined to create numeric values representing both land cover and crop rotation. Finally, a lookup table was created that associates the merged land cover and crop rotation with a land use code recognized by SWAT. These associations are reported along with their respective areas in Table D-3.

Table D-2. Possible land use and crop rotation combinations and SWAT model land use identifiers.

SWAT Land Use	Crop Rotation (Crop listed for each year of 6-year rotation)					
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
ACSC	ALFA	ALFA	ALFA	CORN	SOYB	CORN
CSCS	CORN	SOYB	CORN	SOYB	CORN	SOYB
CCCC	CORN	CORN	CORN	CORN	CORN	CORN
CSCA	CORN	SOYB	CORN	ALFA	ALFA	ALFA
SCAC	SOYB	CORN	ALFA	ALFA	ALFA	CORN
SCSC	SOYB	CORN	SOYB	CORN	SOYB	CORN

Table D-3. Possible land use and crop rotation combinations and SWAT model land use identifiers.

Land Cover	Crop Rotation	SWAT Land Use	Area (ha)	(ac)
Water & Wetlands[a]	Not applicable[b]	WATR	6,706.9	16,573.1
Forest (all types)[a]	Not applicable[b]	FRST	19,817.4	48,969.7
Grassland	Not applicable[b]	BROM	54,058.4	133,581.0
Alfalfa, hay	Not applicable[b]	ALFA	3,784.3	9,351.2
Alfalfa, hay	Extended Rotation	ACSC[c]	3,412.5	8,432.5
Corn	Corn-Soybean	CSCS[c]	14,310.1	35,360.9
Corn	Continuous Corn	CCCC[c]	1,210.3	2,990.6
Corn	Extended Rotation	CSCA[c]	5,994.5	14,812.7
Soybeans	Soybean-Corn	SCSC[c]	24,337.4	60,139.0
Soybeans	Extended Rotation	SCAC[c]	3,690.1	9,118.5
Urban	Not applicable[b]	URBN	5,951.4	14,706.1
		Total Area	143,273.3	354,035.3

[a] Similar land cover classifications combined into one.
[b] Non-row crop area – crop rotation data does not apply.
[c] Crop rotation defined in Table D-2.

The largest land use is grassland (BROM), followed by row crops and forest. Approximately one-third of row crop land is projected to be in an extended rotation that includes alfalfa. It is possible that CRP or a type of hay other than alfalfa is sometimes utilized in extended rotations, but alfalfa was assumed for modeling purposes. The resulting land use distribution using the modified 2006 NASS data and USDA-ARS crop rotation data obtained from NLAE is illustrated in Figure D-2. Land uses were filtered during the HRU definition step of model development to reduce the number of small HRUs to decrease model run times and data intensive input / output. A one percent land use filter was utilized, which removes all land uses comprising less than one percent of any subbasin and reapportions removed uses according to remaining land use in the subbasin. The filtered land use is reported in Table D-4.

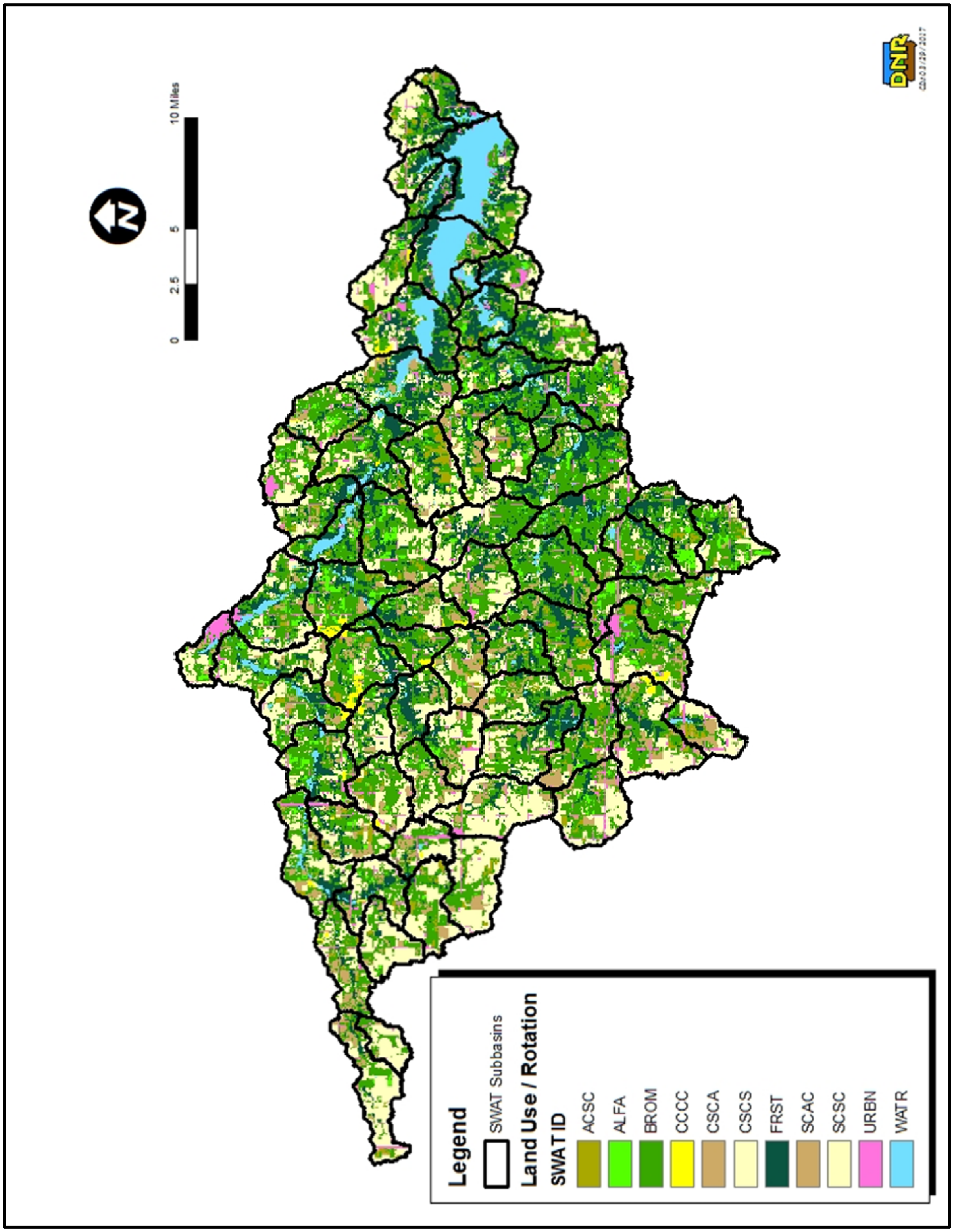


Figure D-2. SWAT model land use and crop rotation map.

Table D-4. Land use summary after HRU definition step of SWAT model setup.

General Land Use	Land Use Description	SWAT Land Use[a]	Area (ha)	(ac)	%
Grassland	Both pasture and ungrazed grassland	BROM[b]	54,367.3	134,344.3	37.9
Row Crops w/ Conventional Rotations	Corn-soybean, soybean-corn, and continuous corn	CSCS, SCSC, & CCCC	39,912.2	98,625.0	27.9
Row Crops w/ Extended Rotations	Includes areas with multiple years of non-row crop (e.g., alfalfa)	ACSC, CSCA, & SCAC	12,832.0	31,708.5	9.0
Forest/Timber	All forested areas	FRST	19,935.3	49,261.2	13.9
Water/ Wetlands	Ponds, lakes, and wetlands	WATR	6,623.4	16,366.7	4.6
Urban/ Developed	Includes all developed areas	URBN	5,988.1	14,796.9	4.2
Alfalfa/ Hay	Alfalfa and hay not in extended rotations	ALFA	3,615.0	8,932.8	2.5
		Total Area	143,273.3	354,035.4	100.0

[a] Land uses and rotations defined in Table D-2 and Table D-3.
[b] Custom land use, PMIX, replaces BROM in Operations Management input

Plant / crop Database

SWAT has a built-in plant / crop database that includes a list of 118 types of vegetation. Plant growth characteristics affect simulation of hydrology, nutrients, and erosion. Each plant type has 35 characteristics, which users can modify. The crop rotations in Table D-2 were added to the plant database so that unique rotations could be defined during model setup. Each crop included in the rotation data already exists in the database, and plant types are specified annually in the Operations Management input. A new plant type termed PMIX was also added to the plant database to simulate pasture, since existing grass types did not provide biomass yields reflective of pasture growth in the south-central Iowa. PMIX has characteristics that reflect a mix of alfalfa (ALFA) and a variety of grasses such as Timothy (TIMO), Tall Fescue (FESC), Bromegrass (BROM), and Eastern Gamagrass (GAMA). The PMIX plant type was utilized in all HRUs that had BROM listed in the land use data (see Table D-4). Simulated biomass yields of PMIX were assessed and are typically near annual production levels calculated from Iowa State University – Extension guidance on forage production (ISU, 2009.)

Soils

SWAT model development utilized the Soil Survey Geographic (SSURGO) soils coverage, developed by the United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS). Soils data are discussed in more detail in Section 2.2. The SSURGO data was filtered during HRU definition so that soils comprising less than 10% of any land use in a given subbasin would be eliminated, and the corresponding area would be reapportioned to the remaining soils (soils comprising greater than 10% of each land use in a subbasin). The soil groups comprising the largest areas of the watershed (after filtration), and their respective hydrologic soil group (HSG), are reported in Table D-5. A substantial majority of the watershed is classified as either HSG C or D and described as being somewhat poorly to very poorly-drained. SWAT uses the soil HSG in conjunction with land cover to assign NRCS runoff curve numbers (CNs), a key hydrologic parameter.

Table D-5. Predominant soils with hydrologic soil group.

Soil Name	Watershed Area (%)	Texture	Drainage Class	Hydrologic Soil Group (HSG)
Clarinda	12.8	Silty clay loam	Poorly drained	D
Seymour	11.6	Silt loam	Somewhat poorly drained	C
Shelby	11.4	Clay loam	Well drained	B
Grundy	10.2	Silt loam	Somewhat poorly drained	C
Arispe	7.7	Silty clay loam	Somewhat poorly drained	C
Olmitz	6.4	Loam	Moderately well drained	B
Gara	6.3	Loam	Well drained	C
Adair	6.1	Clay loam	Somewhat poorly drained	C
Edina	5.1	Silt loam	Very poorly drained	D
All others	22.4	Varies	Varies	Varies

Slopes

During the watershed delineation process, ArcSWAT creates a slope grid using the input DEM. To complete the definition of HRUs, the SWAT user must define the desired slope classifications. For the Rathbun Lake SWAT model, four slope classifications were defined in accordance with classifications found in the NRCS soil surveys. Note, however, that each individual HRU has a specific slope value calculated from the DEM. A 20% filter was applied to the slope classes during HRU definition. The breakdown of slope classes is reported in Table D-6 and a map of slope classifications is provided in Figure D-3. A map of the average subbasin slope is shown in Figure D-4.

The HRU definition process resulted in 4,330 HRUs. Hydrologic and water quality computations are performed in SWAT for each HRU, summed for each subbasin, then routed through the network of reaches in the watershed. Aggregating HRUs across subbasins reveals that there are 487 unique combinations of land use, soil, and slope in the entire Rathbun Lake watershed, with 244 combinations of soil and slope on land that included row crop production from 2008-2013.

Table D-6. Slope classifications in Rathbun Lake SWAT model.

Slope (%)	Description	Watershed Area (%)
0-2	Level and nearly level	19.3
2-5	Gently sloping	29.1
5-9	Moderately sloping	26.2
>9	Strongly sloping to very steep	25.4

D.4. Meteorological Input

Precipitation and Temperature Data
There are six weather stations in or within eight miles of the watershed for which daily precipitation and temperature data are available through the Iowa Environmental Mesonet (IEM, 2015) or the National Oceanic and Atmospheric Administration (NOAA, 2015). Station locations include Allerton, Chariton, Osceola, Leon, Promise City, and at the Rathbun Lake dam. During model delineation in ArcSWAT, temperature and precipitation stations are assigned to each subbasin based on geographical proximity. During hydrologic calibration, spatial variation of rainfall was determined to be a large source of error. Therefore, radar-based rainfall obtained from the PRISM Climate Group (PRISM, 2016) was incorporated into the SWAT model in place of the original six weather station data. This allowed a higher spatial resolution of rainfall data, with a point estimate of daily precipitation provided at the centroid of each HUC-12 watershed.

Solar Radiation, Wind Speed, and Relative Humidity
SWAT allows the user to simulate solar radiation, wind speed, and relative humidity input, or import data from nearby weather stations. Oftentimes, daily solar radiation, wind speed, and humidity data near the watershed of interest are not available. Simulated input is generated through algorithms within the SWAT model that draw from historical weather data stored in the SWAT database and precipitation and temperature inputs. The SWAT model used in this TMDL relied on simulated input data for solar radiation, wind speed, and relative humidity, consistent with previous SWAT applications.

D.5. Channel Routing

SWAT assumes that each stream channel (i.e., reach) has a trapezoidal cross-section with side slopes of 2:1 (run:rise). Default channel widths and depths are calculated during the automatic delineation process based on empirical relationships between drainage area and channel geometry. However; default channel widths were consistently much larger than channel widths indicated by LiDAR and aerial photography. To improve the accuracy of channel geometry, stream cross-sections were created using a DEM developed from LiDAR data and the ESRI ArcGIS 3D Analyst tool. Improved estimates of channel width (CH_W2), depth (CH_D), width-to-depth ratio (CH_WDR), and slide slope (CH_SIDE) were entered into SWAT reach input files (.rte files), which can be accessed in the Subbasin Data menu of the ArcSWAT interface. SWAT channel geometry is shown in Table D-7.

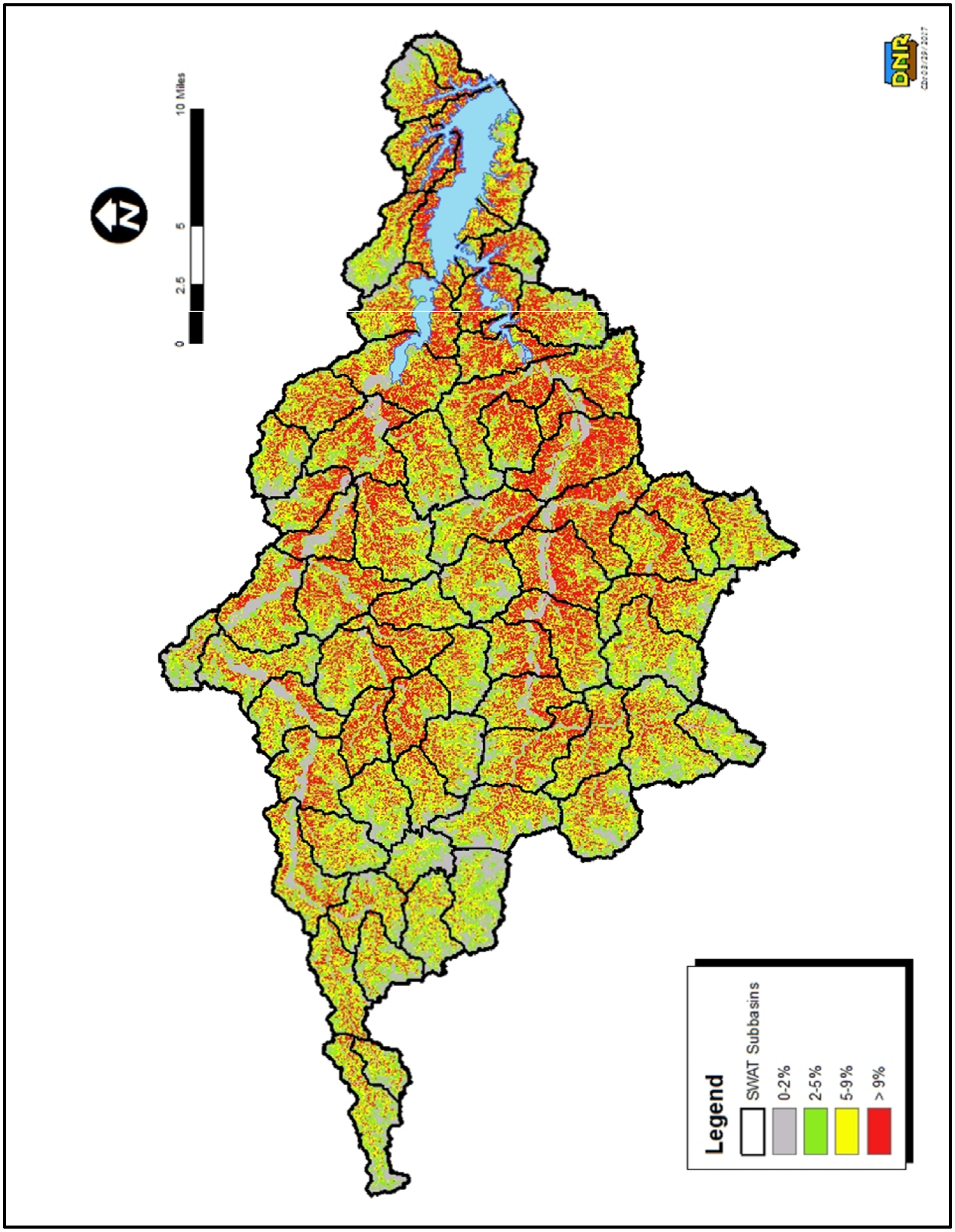


Figure D-3. SWAT model HRU slope classifications.

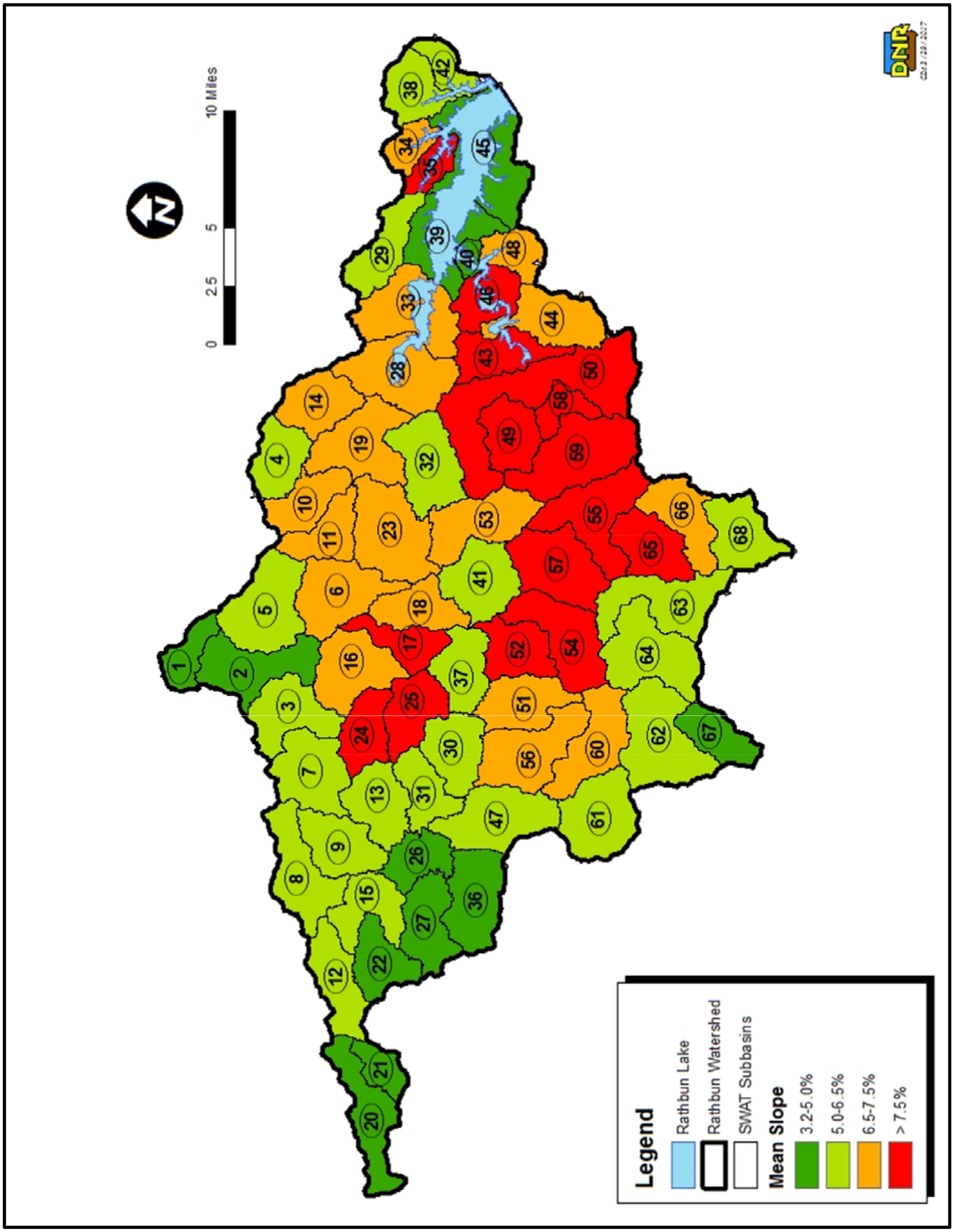


Figure D-4. SWAT model average subbasin slopes.

Table D-7. SWAT stream channel (reach) characteristics.

SWAT Reach / ID	Width (m)	Depth (m)	Width:Depth Ratio	Side Slope (m/m)	Manning's
	CH_W2	CH_D	CH_WDR	CH_SIDE	CH_N2
1	12.8	2.1	7.5	2.7	0.045
2	18.3	2.4	7.7	3.5	0.035
3	19.5	3.1	6.2	2.3	0.035
4	11.5	1.6	7.2	3.6	0.045
5	19.2	3.1	6.3	2.4	0.035
6	18.5	3.7	5.0	1.9	0.035
7	17.5	2.7	6.4	3.0	0.035
8	23.5	3.4	7.1	3.1	0.035
9	11.0	1.8	6.5	3.2	0.045
10	8.3	1.1	7.3	2.4	0.045
11	24.5	3.4	7.3	2.8	0.035
12	14.3	2.3	6.3	3.0	0.035
13	11.0	1.6	6.8	3.1	0.045
14	9.5	1.3	7.3	3.7	0.035
15	15.5	2.7	5.7	2.6	0.035
16	18.0	3.4	5.4	2.3	0.035
17	11.3	2.1	5.4	2.6	0.035
18	23.5	4.6	5.1	1.7	0.035
19	28.0	2.3	15.5	5.4	0.035
20	10.8	1.4	7.5	3.3	0.045
21	12.0	1.8	6.9	3.0	0.045
22	10.8	1.6	6.7	3.1	0.045
23	9.0	1.1	9.0	4.3	0.035
24	11.0	1.9	5.8	2.6	0.035
25	15.0	3.0	4.9	2.0	0.035
26	12.0	1.4	8.4	4.2	0.045
27	13.8	1.9	7.3	3.3	0.035
28[a]	28.0	2.3	15.5	5.4	0.035
29	12.3	2.1	6.1	2.6	0.045
30	14.0	2.4	5.9	2.7	0.045
31	11.5	2.4	4.9	2.1	0.045
32	12.0	2.1	6.0	2.5	0.045
33[a]	28.0	2.3	15.5	5.4	0.035
34[a]	12.3	2.1	6.1	2.6	0.045
35[a]	12.3	2.1	6.1	2.6	0.045
36	9.5	1.7	5.7	2.2	0.045
37	10.0	1.5	6.6	3.0	0.045
38[a]	12.3	2.1	6.1	2.6	0.045
39[a]	28.0	2.3	15.5	5.4	0.035
40[a]	34.0	4.3	8.0	2.4	0.035
41	10.0	1.6	6.8	2.7	0.045
42[a]	12.3	2.1	6.1	2.6	0.045
43[a]	34.0	4.3	8.0	2.4	0.035
44[b]	16	1.5	10.6	4.0	0.045
45[a]	28.0	2.3	15.5	5.4	0.035

Table D-7. SWAT stream channel (reach) characteristics.

SWAT Reach / ID	Width (m)	Depth (m)	Width:Depth Ratio	Side Slope (m/m)	Manning's
	CH_W2	CH_D	CH_WDR	CH_SIDE	CH_N2
46[a]	34.0	4.3	8.0	2.4	0.035
47	8.5	1.0	8.6	3.5	0.035
48[b]	22.0	2.6	8.5	4.2	0.045
49	10.3	2.3	4.6	1.8	0.045
50	23.0	2.9	7.7	2.6	0.035
51	25.8	5.0	5.2	2.2	0.035
52	22.8	4.2	5.4	2.0	0.035
53	14.0	2.9	4.9	2.2	0.035
54	23.5	4.0	6.0	2.2	0.035
55	17.3	3.0	5.7	2.1	0.035
56	17.5	3.7	4.7	1.9	0.035
57	27.0	4.9	5.5	1.9	0.035
58	34.0	4.3	8.0	2.4	0.035
59	34.0	4.1	8.9	2.2	0.035
60	14.5	2.7	5.4	2.1	0.035
61	10.0	1.8	5.5	2.3	0.035
62	11.0	1.7	6.6	3.0	0.035
63	14.3	3.0	4.8	2.2	0.035
64	13.3	2.2	6.0	2.8	0.035
65	14.8	2.7	5.4	2.1	0.035
66	9.3	1.4	6.6	3.0	0.035
67[b]	10.0	1.4	7.3	2.6	0.045
68	9.5	1.4	7.1	3.4	0.045

[a] Reach lies within a reservoir. Channel parameters are copied from adjacent reach.
[b] Reach is a short segment immediately upstream of a reservoir – reach length adjusted accordingly.

The Manning's roughness coefficient (CH_N2) was set to 0.035 for all reaches with drainage areas exceeding 10 square miles, and 0.045 for all reaches draining less than 10 square miles, consistent with HEC-RAS model inputs utilized in the Upper Chariton River floodplain mapping update (IIHR, 2014) and well-established values for natural channels (Chaudry, 1993). Reaches that lie within segments of Rathbun Lake were given channel parameter values from adjacent reaches; however, watershed model inputs to the lake are summarized upstream of these reaches. Therefore, these reach simulations are not meaningful or utilized in the development of the in-lake model or the TMDL.

D.6. Reservoir Input

Reservoirs in SWAT allow for simulation of the effects of impoundments (lakes, reservoirs, or large wetlands) on watershed hydrology and water quality. Reservoirs must be added during the watershed delineation phase of model development (i.e., they cannot be added to ArcSWAT later). Therefore, reservoir outlets were placed in all 18 subbasins in which potential significant impoundment of the main reach / channel was observed. Thirteen reservoir nodes lie within segments of the Rathbun Lake, but Rathbun Lake is simulated using the BATHTUB model and reach outputs from SWAT are summarized at the mouth of the tributaries to the lake. Therefore, reservoir nodes within Rathbun Lake are not activated / simulated in the model. The remaining 5 reservoirs include West Lake near Chariton in Subbasin 1, Bob White Lake in Subbasin 67, a large pond located in Subbasin 14, and large riparian wetlands adjacent to the Chariton River in Subbasin 10 and Subbasin 23. All reservoirs are simulated using the Simulated Target Release method, selected by setting the IRESCO parameter to 2. Table D-8 lists the location, Subbasin ID, input parameters for all reservoirs simulated in the SWAT model.

Table D-8. Parameterization of reservoirs in the Rathbun lake watershed.

Input Parameter	Parameter Description	Units	Input Value
Subbasin 1 – West Lake near Chariton (Reservoir 1[a])			
RES_PSA	Surface area of lake at principal spillway elevation	ha	31.7
RES_PVOL	Volume of lake at principal spillway elevation	10^4 m^3	76.0
RES_ESA	Surface area of lake at emergency spillway elevation	ha	39.1
RES_EVOL	Volume of lake at emergency spillway elevation	10^4 m^3	85.0
NDTARGR	Number of days to reach target storage	days	3[b]
STARG	Monthly target storage	10^4 m^3	76.0
RES_SED RES_NSED	Initial and equilibrium sediment concentration, respectively	mg/L	30[c]
RES_D50	Median particle diameter of sediment	μm	50[d]
Subbasin 10 – Riparian wetland (Reservoir 3[a])			
RES_PSA	Surface area of lake at principal spillway elevation	ha	10.2
RES_PVOL	Volume of lake at principal spillway elevation	10^4 m^3	32.4
RES_ESA	Surface area of lake at emergency spillway elevation	ha	64.1
RES_EVOL	Volume of lake at emergency spillway elevation	10^4 m^3	39.5
NDTARGR	Number of days to reach target storage	days	3[b]
STARG	Monthly target storage	10^4 m^3	32.4

Table D-8. Parameterization of reservoirs in the Rathbun lake watershed.

Input Parameter	Parameter Description	Units	Input Value
RES_SED RES_NSED	Initial and equilibrium sediment concentration, respectively	mg/L	30[c]
RES_D50	Median particle diameter of sediment	µm	50[d]
Subbasin 14 – Sediment basin upstream of Rathbun Lake (Reservoir 2[a])			
RES_PSA	Surface area of lake at principal spillway elevation	ha	13.9
RES_PVOL	Volume of lake at principal spillway elevation	$10^4\ m^3$	13.9
RES_ESA	Surface area of lake at emergency spillway elevation	ha	39.1
RES_EVOL	Volume of lake at emergency spillway elevation	$10^4\ m^3$	44.1
NDTARGR	Number of days to reach target storage	days	3[b]
STARG	Monthly target storage	$10^4\ m^3$	13.9
RES_SED RES_NSED	Initial and equilibrium sediment concentration, respectively	mg/L	30[c]
RES_D50	Median particle diameter of sediment	µm	50[d]
Subbasin 23 – Riparian wetland (Reservoir 4[a])			
RES_PSA	Surface area of lake at principal spillway elevation	ha	21.2
RES_PVOL	Volume of lake at principal spillway elevation	$10^4\ m^3$	10.0[e]
RES_ESA	Surface area of lake at emergency spillway elevation	ha	37.3
RES_EVOL	Volume of lake at emergency spillway elevation	$10^4\ m^3$	16.0
NDTARGR	Number of days to reach target storage	days	3[b]
STARG	Monthly target storage	$10^4\ m^3$	10.0[e]
RES_SED RES_NSED	Initial and equilibrium sediment concentration, respectively	mg/L	30[c]
RES_D50	Median particle diameter of sediment	µm	50[d]

Table D-8. Parameterization of reservoirs in the Rathbun lake watershed.

Input Parameter	Parameter Description	Units	Input Value
Subbasin 67 - Bob White Lake (Reservoir 10[a])			
RES_PSA	Surface area of lake at principal spillway elevation	ha	32.3
RES_PVOL	Volume of lake at principal spillway elevation	10^4 m^3	45.3
RES_ESA	Surface area of lake at emergency spillway elevation	ha	61.9
RES_EVOL	Volume of lake at emergency spillway elevation	10^4 m^3	81.3
NDTARGR	Number of days to reach target storage	days	3[b]
STARG	Monthly target storage	10^4 m^3	45.3
RES_SED RES_NSED	Initial and equilibrium sediment concentration, respectively	mg/L	30[c]
RES_D50	Median particle diameter of sediment	μm	50[d]

[a] Reservoir number in SWAT model output

[b] Initial NDTARGR value of 3 was set for all reservoirs, and was confirmed during hydrologic calibration.

[c] Reservoir sediment concentration (30 mg/L) for all upland reservoirs taken from Bob White Lake water quality data.

[d] Median particle size set to 50 microns, which is equivalent silt per SWAT user manual. Smaller clay particles will experience much less settling.

[e] Minimum allowable PVOL in ArcSWAT database parameter is $10.0\times10^{\wedge 4}$ m^3. Measured value using topographic data was $6.4\times10^{\wedge 4}$ m^3.

Required input parameters for hydrologic simulation of reservoirs in SWAT using the simulated target release method include the surface area at the principal spillway crest elevation (RES_PSA), the storage volume at the principal spillway crest (RES_PVOL), the surface area and volume at the emergency spillway crest elevation (RES_ESA and RES_EVOL, respectively), the targeted monthly storage volume (STARG), and the number of days required to reach target storage (NTARGR). Input parameters for the reservoirs in Table D-8 were estimated using available topographic data (i.e., a DEM) in ArcGIS.

The monthly target storage (STARG) was set to the principal spillway volume for all reservoirs. The number of days required to reach the target storage (NDTARGR) was initially set to 3 days, which provided the best daily flow calibration. See Appendix E for a more detailed description of hydrologic calibration procedures.

D.7. General Management Variables

Hydrologic Curve Number
Curve numbers (CNs) in SWAT are determined by land use and hydrologic soil group (HSG) for antecedent moisture condition II. The nomenclature for this input parameter in SWAT is CN2. Because the CN approach was originally developed for simulation of storm events rather than continuous hydrology, daily CN values must be calculated to account for changing soil conditions. Two methods are available in SWAT for calculating daily CN values from CN2. The first option is the Soil Moisture method, which is the default option. The second method updates CN values based on the impacts of Plant ET, and is selected by changing ICN from 0 to1. After evaluating both methods as part of the hydrologic calibration process, it was determined that model performance was better using the Soil Moisture method.

CN2 values for pervious areas of the urban landscape are based on turf grass (Bermuda grass), with a CN2 value of 98 applied to all impervious areas. A composite CN is then calculated based on built-in assumptions of the fraction of impervious (FIMP) and fraction of directly-connected impervious (FCIMP) areas associated with each type of urban land use. All urban uses in the Rathbun SWAT model are assigned to urban-residential (URBN), which has impervious characteristics representative of the span of actual urban uses present (e.g., low density residential, commercial, industrial, transportation, etc.). The URBN land use category assumes a FIMP value of 0.38 and a FCIMP value of 0.30.

Tile Drainage
Unlike most agricultural land on the Des Moines Lobe in north-central Iowa, the steeply sloped landscape of the southern Iowa Rathbun lake watershed is not heavily tile-drained. While there has been an increase in tile drain installation in the past 10 years, there are relatively small, isolated wet spots that benefit from subsurface drainage (RRWA, personal communication). The amount of soluble phosphorus transported by subsurface tile drainage is insignificant compared to phosphorus lost from steep slopes by soil erosion in this watershed. Additionally, algorithms for transport of soluble phosphorus with tile flow in SWAT are not well-developed and tested, although this feature is currently under development by USDA-ARS. For those reasons, tile drainage is not incorporated into the Rathbun Lake watershed model.

Universal Soil Loss Equation (USLE) C-Factor
The plant database also includes a key soil erosion parameter called the USLE C-factor (Table D-9). This parameter is assumed to be constant for individual plant / crop types, but can be varied to reflect agricultural practices (percent residue, tillage, etc.) if required data are available. The size and scope of the Rathbun Watershed SWAT model does not allow for convenient compilation and simulation of actual / current tillage practices; however, various tillage scenarios can be simulated to evaluate potential impacts of tillage practices on sediment and phosphorus exports to the lake. Tillage operations in SWAT can be simulated directly in the management operations scheduling or by adjusting USLE C-Factors.

Table D-9. Antecedent moisture condition II curve numbers (CN2).

Plant Type / Land Use	Curve Number (CN2)				USLE C-factor
	HSG A	HSG B	HSG C	HSG D	
ALFA	31	59	72	79	0.01
CORN	67	77	83	87	0.20
SOYB	67	78	85	89	0.20
PMIX	31	59	72	79	0.01
FRST	36	60	73	79	0.001
WATR	92	92	92	92	0.0
$\text{URBN}_{\text{perv}}$[a]	31	59	72	79	--[c]
URBN_{imp}[b]	98	98	98	98	--[c]

[a] Urban pervious area CN2 values
[b] Urban impervious area CN2 values
[c] USLE not utilized to calculate erosion urban areas

D.8. Scheduled Management Operations

Crop Rotation
As described in Section D.3, six-year crop rotations developed by USDA-NLAE were incorporated into the Rathbun Lake SWAT model. The rotations are input to the model by scheduling planting and harvesting dates. An example extended rotation (CSCA), with all its scheduled management operations, including planting, harvest, fertilizer types, rates, and dates, is shown in Table D-10.

Fertilizer Application
Nitrogen (N) and phosphorus (P) fertilizers were applied to row crops at rates and times consistent with agronomic practices in south-central Iowa and guidance provided by Iowa State University – Extension. All nutrient application assumes chemical rather than organic (i.e., manure) sources. Application rates were taken from estimates developed for Major Land Resource Area (MLRA) 109 in the Iowa Nutrient Reduction Strategy (Iowa State University, 2013). Approximately 75% of fertilizer-N was applied in the spring (before planting corn), with half of spring-applied-N being anhydrous ammonia (82-00-00). All N applied in the fall (before corn) was anhydrous ammonia. Remaining N was applied in the form of urea ammonium nitrate (33-00-00). Chemical P fertilizer was a blend of diammonium and monoammonium phosphate (16-48-00) added to the fertilizer database during model development. Fertilizer rates and associated nutrient quantities are shown in Table D-10, along with other scheduled management operations.

Manure Application
All fertilizer was in chemical form in the SWAT model because most livestock in the Rathbun Lake watershed are beef cattle grazed in pastures and confined to feedlots for only short periods of the year. There are very few hog confinements that generate significant amounts of liquid manure requiring land application.

Table D-10. Scheduled management operations for HRUs in CSCA rotation.

Year	Month	Day	Operation	Plant	Fertilizer N:P:K[a]	Fertilizer Rate (kg ha^{-1})	Nutrient Rate (kg ha^{-1})	
			SWAT IDs:	PLANT_ID	FERT_ID	FRT_KG	N	P
1	4	15	Fertilizer application		82-00-00	73	60	
1	4	15	Fertilizer application		33-00-00	85	28	
1	5	1	Plant/begin growing	CORN				
1	9	30	Harvest and kill					
2	4	15	Fertilizer application		16-48-00	198	32	95
2	5	1	Plant/begin growing	SOYB				
2	9	30	Harvest and kill					
2	10	25	Fertilizer application		82-00-00	50	41	
3	4	15	Fertilizer application		82-00-00	73	60	
3	4	15	Fertilizer application		33-00-00	85	28	
3	5	1	Plant/begin growing	CORN				
3	9	30	Harvest and kill					
4	1	1	Plant/begin growing	ALFA				
4	6	7	Harvest (cut)					
4	7	17	Harvest (cut)					
4	8	26	Harvest (cut)					
4	10	1	Fertilizer application		16-48-00	118	19	57
4	12	1	Kill					
5	1	1	Plant/begin growing	ALFA				
5	6	7	Harvest (cut)					
5	7	17	Harvest (cut)					
5	8	26	Harvest (cut)					
5	10	1	Fertilizer application		16-48-00	118	19	57
5	12	1	Kill					
6	1	1	Plant/begin growing	ALFA				
6	6	7	Harvest (cut)					
6	7	17	Harvest (cut)					
6	8	26	Harvest (cut)					
6	10	1	Fertilizer application		16-48-00	118	19	57
6	12	1	Kill					

[a] Fertilizer types: (82-00-00 = anhydrous ammonia, 33-00-00 = urea ammonium nitrate, 16-48-00 = commercial phosphorus blend)

Livestock Grazing

The number of grazing livestock (head of beef cattle) in the watershed was estimated from the NASS Cattle Inventory for 2010-2011 (USDA-NASS, 2015) and the area of each county within the Rathbun Lake watershed. Cattle density was calculated by dividing the number of head by the estimated pasture area from the land use data (BROM land use = PMIX plant type in the SWAT model). This resulted in an average cattle density of 0.77 head per hectare (head ha^{-1}) or 0.31 head ac^{-1} of pasture. While grazing densities certainly vary spatially and temporally, this is a reasonable estimate to evaluate the impacts of livestock grazing on nutrient loads to the lake. Grazing was assumed to occur between April 15 and November 15 of each year, for a total of 214 grazing days. Typical dry matter consumption of 9.0 kg head^{-1} day^{-1} (ISU, 1995; The Beef Site, 2012), an average manure production rate of 3.4 kg head^{-1} day^{-1} (ASAE, 2003; USDA, 1998) and the preceding data were used to calculate the amount of biomass (grass) consumed and manure produced by grazing cattle, which define the grazing operation as summarized in Table D-11. The manure production estimate is likely an over-estimate because it is based on a nearly fully-grown animal even though most operations in the watershed are cow-calf operations that sell feeder calves (to buyers outside the watershed) at a weight of 227-318 kg (500-700 lbs).

Table D-11. Livestock grazing input summary.

Parameter Description	SWAT ID	SWAT Input
Manure source	MANURE_ID	Beef Cattle – Fresh (Dry)
Beginning of grazing season	Month/Day	April 1
Length of grazing season	GRZ_DAYS	214 days
Biomass (dry) consumption	BIO_EAT	6.9 kg ha^{-1} day^{-1}
Manure (dry) production	MANURE_KG	2.6 kg ha^{-1} day^{-1}

Open Feedlots
There are 8 open feedlots in the watershed, all of them housing beef cattle with less than 1,000 animal units (AUs). They do not meet the criteria for a large or medium regulatory CAFO. Many of them are adjacent to pasture on which cattle are grazed for a substantial part of the year, and all are required to settle manure solids and detain rainfall runoff. For these reasons, runoff from open feedlots is not explicitly simulated in the SWAT model, although the manure generated by these cattle is accounted for in the grazing operation.

D.9. Point Source Input

There are six permitted point source discharges in the Rathbun watershed and several private onsite wastewater systems (i.e., septic systems) that discharge under General Permit #4 (GP4). Point sources were not simulated in the SWAT model, but were summarized with SWAT model subbasin output, which is input to the BATHTUB lake model tributaries.

NPDES Facilities
Wastewater facilities with NPDES-permitted discharges are described in Section 3.4 and reported in Table 3-7 of this WQIP. Existing average annual loads were estimated using facility-specific design data (i.e., population equivalent) and a per-capita TP load of 2.1 g $person^{-1}$ day^{-1} (0.005 lb $person^{-1}$ day^{-1}) (Metcalf & Eddy, 2013). The average annual loads reported in the Rathbun Lake TMDLs are equivalent to the long-term averages utilized for development of water quality-based effluent limits.

Onsite Wastewater (General Permit #4 Systems)
DNR records indicate the presence of 11 onsite wastewater systems in the Chariton River watershed that discharge under GP4. Existing loads for these facilities were determined assuming each septic serves an average of 3 people, a daily per capita flow of 284 L day^{-1} (75 gal $person^{-1}$ day^{-1}), and an assumed TP load of 2.1 g $person^{-1}$ day^{-1} (0.005 lb $person^{-1}$ day^{-1}) (Metcalf & Eddy, 2013). All onsite systems operating under GP4 were assumed to discharge to surface water (and ultimately, to Rathbun Lake). This over-estimates actual contributions because most onsite systems discharge to small ditches and drainage ways and may contribute only a small portion, if any, of the discharged load to the lake. There

are no known onsite wastewater systems operating under GP4 in the S. Fork Chariton watershed.

Confined Feeding Operations
There are 15 confined feeding operations in the watershed, with all of them housing swine. Only 5 of the 15 confinements exceed 1,000 AUs. None of the facilities are allowed to discharge, therefore the existing load from confinements is zero (Table 3-7). Manure production from these facilities is not explicitly simulated in the SWAT model, because chemical fertilizer nutrient application rates (documented earlier in Section D.8) account for potential manure application and its impact on nonpoint source loads. The 5 confinements exceeding 1,000 AUs do meet the regulatory criteria for medium or large CAFOs and are therefore given wasteload allocations (WLAs) of zero in Section 3.4 of this WQIP.

D.10 Other Watershed Sources

Onsite Wastewater (Non-Discharging Septic Systems)
A GIS coverage of the rural population expected to have private onsite wastewater treatment systems (e.g., septic systems) was utilized to estimate the number of people on septic systems and the portion of systems located within a ¼ mile buffer of a stream. The coverage was developing using Census data from the year 2000. Information about the types of systems present and the likelihood of failing systems or illicit discharges to surface water was ascertained from conversations with county sanitarians. It was assumed that the risk of septic system loads to surface water was 33% from systems within a quarter-mile of the watershed and 10% from systems outside that buffer, resulting in an effective contribution (i.e., failure) rate of 25%. This failure rate, a daily per capita flow of 284 L day^{-1} (75 gal person^{-1} day^{-1}), and an assumed TP load of 2.1 g person^{-1} day^{-1} (0.005 lb person^{-1} day^{-1}) (Metcalf & Eddy, 2013) were utilized to calculate potential TP loads from non-permitted septic systems. Septic system contributions were not simulated in SWAT, but estimated loads were summarized with SWAT model subbasin output, which is input to the BATHTUB lake model tributaries. The resulting annual TP load is 785 kg yr^{-1} (1,731 lb yr^{-1}) for the entire watershed.

Instream Deposition by Livestock
All grazing livestock were assumed to have direct stream access, since the majority of pastures in the watershed are located adjacent to streams and no stream exclusion practices were observed during field surveys. Livestock with direct access were assumed to defecate in streams a portion of the time during the grazing season (April 1 through November 1). The amount of time cattle spend in streams varies with temperature, pasture shape / size relative to streams, and the amount of shade available in the pasture (Bisinger et al., 2014; Brown et al., 2014). To estimate the amount of phosphorus deposited directly in the stream by cattle, it was assumed that cattle spend an average of 0.64 hours in the stream each day across the 214-day grazing season. This is equivalent to 2.7% of a 24-hour day. Therefore, potential TP loads to the lake from direct deposition by beef cattle were calculated by multiplying daily manure TP production of 0.042 kg head^{-1} day^{-1} (0.092 lb-p head^{-1} day^{-1}) by 2.7%. The resulting annual TP load is

9,940 kg yr^{-1} (21,913 lb yr^{-1}) for the entire watershed. This is likely an overestimate because TP production estimate is based on a fully grown animal and approximately half of the cattle in the watershed are calves raised for feeder cattle that are sold to finishing operations (outside of the watershed) at a weight of 227-318 kg (500-700 lbs) (Joe Sellers, Iowa State University – Extension specialist, March 1, 2016, personal communication). These loads were summarized with SWAT model subbasin output and input to corresponding BATHTUB model tributaries.

Upland Wildlife

The deer density in the Iowa DNR Rathbun Wildlife Unit was estimated to be 26 deer per square mile. This is based on DNR population trend models for the Wildlife Unit and the area of the Rathbun Lake watershed. Deer manure characteristics were taken from a summary of potential nutrient loads from wildlife in the Mississippi River Basin (Moffitt, 2009). Because deer have a wide browsing range and are not restricted to single land use their manure is relatively diffuse and was not assumed to significantly affect nutrient concentrations in upland runoff. However, direct deposition in / near streams by deer and other wildlife was accounted for. Because population data for other wildlife (e.g., furbearers) is unknown, a liberal estimate for direct deposition was made by assuming that 10% of manure-P generated by deer is directly deposited into surface water entering the lake. This amounts to a total deer and wildlife TP load of 1,849 kg-P yr^{-1} (4,075 lbs-P yr^{-1}). This load was not simulated in SWAT, but was distributed across SWAT subbasins based on the amount of timber (FRST) land use in each subbasin. Subbasin-level loads from this source were and input directly to the corresponding BATHTUB model tributaries.

In-Lake Deposition by Waterfowl

Nutrients are contributed to the lake by feces deposited in and near the lake by Canada geese and other waterfowl. An estimate of the goose population was provided by DNR waterfowl biologists (Orrin Jones, DNR, March 11, 2016, personal communication). The estimate considers migratory patterns, nesting season, and number of resident geese, but are summarized as the average population on an annual basis. Loading calculations consider the amount of time geese spend on land versus in the lake, the rate of defecation, and the nutrient content of goose feces (Manny et al, 1994; Unckless and Makarewicz, 2007). The TP and TN loads of 165 kg yr^{-1} (364 lbs yr^{-1}) and 529 kg yr^{-1} (1,166 lbs yr^{-1}), respectively, were assumed to be uniformly distributed across the surface area of the lake and were input directly as internal loads in the BATHTUB model segment menu (see Appendices D.10 and F.2 for waterfowl-related nutrient loads to BATHTUB segments).

Stream / Channel Erosion

Although the SWAT model simulates channel erosion, application and testing of the model's capabilities in this area are largely unknown, especially in watersheds with such significant bank erosion. To provide an estimate of the potential magnitude and relative importance of stream bank erosion, the DNR conducted a two-year bank erosion field assessment. The estimate was also utilized in the calibration of the SWAT model, which utilized a transport capacity model called the Bagnold equation (Neitsch et al., 2011; Arnold et al., 2012), to provide rough estimates of channel erosion.

The field assessment utilized the National Hydrography Dataset (NHD) coverage of the digitized stream network in the Rathbun Lake watershed. The assessment included all second through fifth-order streams; however, only segments upstream of the Rathbun inundation zone and below other impoundments in the watershed were considered. The goal was to randomly select 10% of stream segments for field assessment and apply resulting erosion rates to the unassessed stream reaches to estimate the total potential erosion.

ESRI ArcGIS was utilized to place a point every 100 meters (m) on each stream segment in the second through fifth-order stream coverage (i.e., shapefile). Points were then randomly selected (using the random selection tool within ArcGIS) until a sample size of 10% of all reaches in each stream order was achieved. Actual field assessment occurred only on reaches in the selected sample set for which access and landowner cooperation were attainable (Table D-12). Survey data included the height and length of all stream banks categorized as severely eroding. Erosion estimates were calculated using both the NRCS erosion rate of 0.50 ft/yr (NRCS, 1998) and a locally-derived rate of 0.72 ft/yr (Tufekcioglu et al., 2012). An assumed streambank sediment-phosphorus concentration of 300 mg/kg (0.6 lbs/ton) taken from three local streambank studies was used to quantify bank erosion as a source of TP (Hongthanat et al., 2011; Tufekcioglu et al., 2012; Hongthanat et al., 2016). Note that sediment and TP loads delivered to the lake from streambank erosion are lower than the source loads reported in Table D-12 due to deposition in the channel upstream of the lake.

Table D-12. Streambank assessment summary.

Stream Order	Length (miles)		Erosion (tons/yr)		TP[c] (tons/yr)
	Assessed	Total	NRCS[a]	Rathbun[b]	
2	15.4	311.3	131,779	190,289	57.1
3	10.7	167.2	63,325	91,441	27.4
4	5.6	80.8	53,240	76,879	23.1
5	6.4	73.6	63,589	91,822	27.5
Totals	38.1	632.9	311,933	450,431	**135.1**

[a] Streambank erosion estimate using NRCS recession rate of 0.5 ft/yr

[b] Streambank erosion estimate using Rathbun watershed rate of 0.72 ft/yr

[c] Calculated using the Rathbun erosion rates and a bank sediment phosphorus concentration of 300 mg/kg (0.6 lbs/ton)

Gully Erosion

Gullies were not surveyed or assessed, but gully formation is a known issue in the Rathbun Lake watershed. Based on the small suspected length of classic gullies compared to digitized stream lengths, best professional judgement was used to estimate that TP loads are approximately 20% of channel erosion, or 27 tons/yr.

D.11. References

American Society of Agricultural Engineers (ASAE). 2003. ASAE Standards. Manure Production and Characteristics. ASAE D384.1.

Arnold, J. G., , J. R. Kiniry, R. Srinivasan, J. R. Williams, E. B. Haney, and S. L. Neitsch. Input/Output Documentation Version 2012. Texas Water Resources Institute Technical Report No. 439. Texas A&M University. College Station, Texas.

Arnold, J. G., D. N. Moriasi, P. W. Gassman, K. C. Abbaspour, M. J. White, R. Srinivasan, C. Santhi, R. D. Harmel, A. van Griensven, M. W. Van Liew, N. Kannan, and M. K. Jha. 2012. SWAT: Model use, calibration, and validation. Trans. of the ASABE. 55(4): 1491-1508.

Arnold, J. G., M. A. Youssef, H. Yen, M. J. White, A. Y. Sheshukov, A. M. Sadeghi, D. N. Moriasi, J. L. Steiner, D. M. Amatya, R. W. Skaggs, E.B. Haney, J. Jeong, M. Arabi, P. H. Gowda. 2015. Hydrological processes and model representation: Impact of soft data on calibration. Trans. ASABE. 58(6):1637-1660. doi:10.13013/trans.58.10726.

Baffaut, C., S. M. Dabney, M. D. Smolen, M. A. Youssef, J. V. Bonta, M. L. Chu, J. A. Guzman, V. S. Shedekar, M. K. Jha, and J. G. Arnold. 2015. Hydrologic and water quality modeling: Spatial and temporal considerations. Trans. ASABE. 58(6):1661-1680.

Bisinger, J., J. R. Russell, D. G. Morrical, and T. M. Isenhart. 2014. Pasture size effects on the ability of off-stream water or restricted stream access to alter the spatial/temporal distribution of grazing beef cows. Journal of Animal Science 92(8). doi:10.2527/jas.2013-7405.

Bressiani, D. d. A., P. W. Gassman, J. G. Fernandes, L. H. P. Garbossa, R. Srinivasan, N. B. Bonumá and E. M. Mendiondo. 2015. A review of Soil and Water Assessment Tool (SWAT) applications in Brazil: Challenges and prospects. International Journal of Agricultural & Biological Engineering 8(3):9-35. doi: 10.3965/j.ijabe.20150803.1765.

Brown, S. B., C. D. Ikenberry, M. L. Soupir, J. Bisinger, and J. R. Russell. 2014. Predicting time cattle spend in streams to quantify direct deposition of manure. Applied Engineering in Agriculture. 30(2):187-195. doi:10.13031/aea.30.10393.

Chaudry, M. H. 1993 Open-channel flow. Prentice Hall, New Jersey.

Gassman, P., M. Reyes, C. Green, and J. Arnold. 2007. The Soil and Water Assessment Tool: historical development, applications, and future research directions. Transactions of the ASABE, 50(4):1211-1250.

Gassman, P. W., A. M. Sadeghi and R. Srinivasan. 2014. Applications of the SWAT Model Special Section: Overview and Insights. *Journal of Environmental Quality* 43(1):1-8. doi: 10.2134/jeq2013.11.0466.

Hongthanat, N., J. L. Kovar, and M. L. Thompson. 2011. Sorption indices to estimate risk of soil phosphorus loss in the Rathbun Lake watershed, Iowa. Soil Science. 175:237-244. doi:10.1097/SS.0b013e318214fa9b.

Hongthanat, N., J. L. Kovar, M. L. Thompson, J. R. Russell, and T. M. Isenhart. 2016. Phosphorus source-sink relationships of stream sediments in the Rathbun Lake watershed in southern Iowa, USA. Environ. Monit. Assess. 188:453. doi: 10.1007/s10661-016-5437-6

Iowa Department of Natural Resources (DNR). 2008. Water Quality Improvement Plan for Raccoon River, Iowa. Total Maximum Daily Load for Nitrate and E. coli. Prepared by K. Schilling and C. Wolter.

Iowa Institute of Hydraulic Research (IIHR). 2014. Hydraulic Analyses for the Update of Zone A Floodplains. Watershed report for 10280201. Case no. 11-07-XXXXS. Submitted to FEMA Region VII. IIHR-Hydroscience & Engineering, Iowa City, Iowa.

Iowa State University (ISU) Extension. 1995. Feeding The Beef Cow Herd – Part II. Managing the Feeding Program. G95-1262. Ames, Iowa.

Iowa State University (ISU) Extension. 2009. Estimating Available Pasture Forage. PM 1758. Ames, Iowa.

Iowa State University. 2013. Iowa nutrient reduction strategy. http://www.nutrientstrategy.iastate.edu (accessed January 14, 2015).

Iowa Environmental Mesonet (IEM). 2015. Iowa State University Department of Agronomy. Iowa Ag Climate Network. Download available at http://mesonet.agron.iastate.edu/request/coop/fe.phtml. Last accessed in February 2015.

Krysanova V. and M. White. 2015. Advances in water resources assessment with SWAT—an overview. *Hydrological Sciences Journal* 60(5):771-783. doi: 10.1080/02626667.2015.1029482.

Manny, B. A., W. C. Johnson and R. G. Wetzel. 1994. Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality. Proceeding of the Symposium on Aquatic Birds in the Trophic Web of Lakes. J. J. Kerekes, ed.

Metcalf & Eddy. 2013. Wastewater Engineering: Treatment and Resource Recovery. pp 216-219. McGraw-Hill. New York, NY.

Moffitt, D. C. 2009. Documentation of nitrogen and phosphorus loadings from wildlife populations. USDA-NRCS white paper. Web page accessed February 23, 2016. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_013181.pdf

Moriasi, D. N., M. W. Gitau, N. Pai, and P. Daggupati. 2015. Hydrologic and water quality models: Performance measures and evaluation criteria. Trans. of the ASABE 58(6):1763-1785.

National Oceanic and Atmospheric Administration (NOAA). 2015. National Climatic Data Center (NCDC). Download available at http://www.ncdc.noaa.gov/. Last accessed in February 2015.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. 2011. Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute Technical Report No. 406. Texas A&M University. College Station, Texas.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 30 Aug 2016.

Schilling, K., M. Jha, Y. Zhang, P. Gassman, and C. Wolter. 2008. Impact of land use and land cover change on the water balance of a large agricultural watershed: Historical effects and future directions. Water Resources Research, Vol. 44.

The Beef Site. 2012. How Much Forage Does A Beef Cow Consume Each Day? Available at http://www.thebeefsite.com/articles/3154/how-much-forage-does-a-beef-cow-consume-each-day/. Last accessed on May 2, 2016.

Tomer, M.D., S.A. Porter, D.E. James, K.M.B. Boomer, J.A. Kostel, and E. McLellan. 2013. Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning. J. Soil Water Conserv. 68(5):113A-120A.

Tufekcioglu, M., T.M. Isenhart, R.C. Schultz, D.A. Bear, J.L. Kovar, and J.R. Russell. 2012. Stream bank erosion as a source of sediment and phosphorus in grazed pastures of the Rathbun Lake Watershed in southern Iowa, United States. Journal of Soil and Water Conservation. 67(6):545-555.

Unckless, R. L. and J. C. Makarewicz. 2007. The impact of nutrient loading from Canada Geese (Brandta canadensis) on water quality, a mesocosm approach. Hydrobiologia 586:393-401. doi 10.1007/s10750-007-0712-8.

U.S. Department of Agriculture (USDA). 1992. Agricultural Waste Management Field Handbook. 210-AWMFH. Pg. 4-8.

U. S. Department of Agriculture (USDA). 1998. Agricultural Waste Management Field Handbook. National Engineering Handbook.

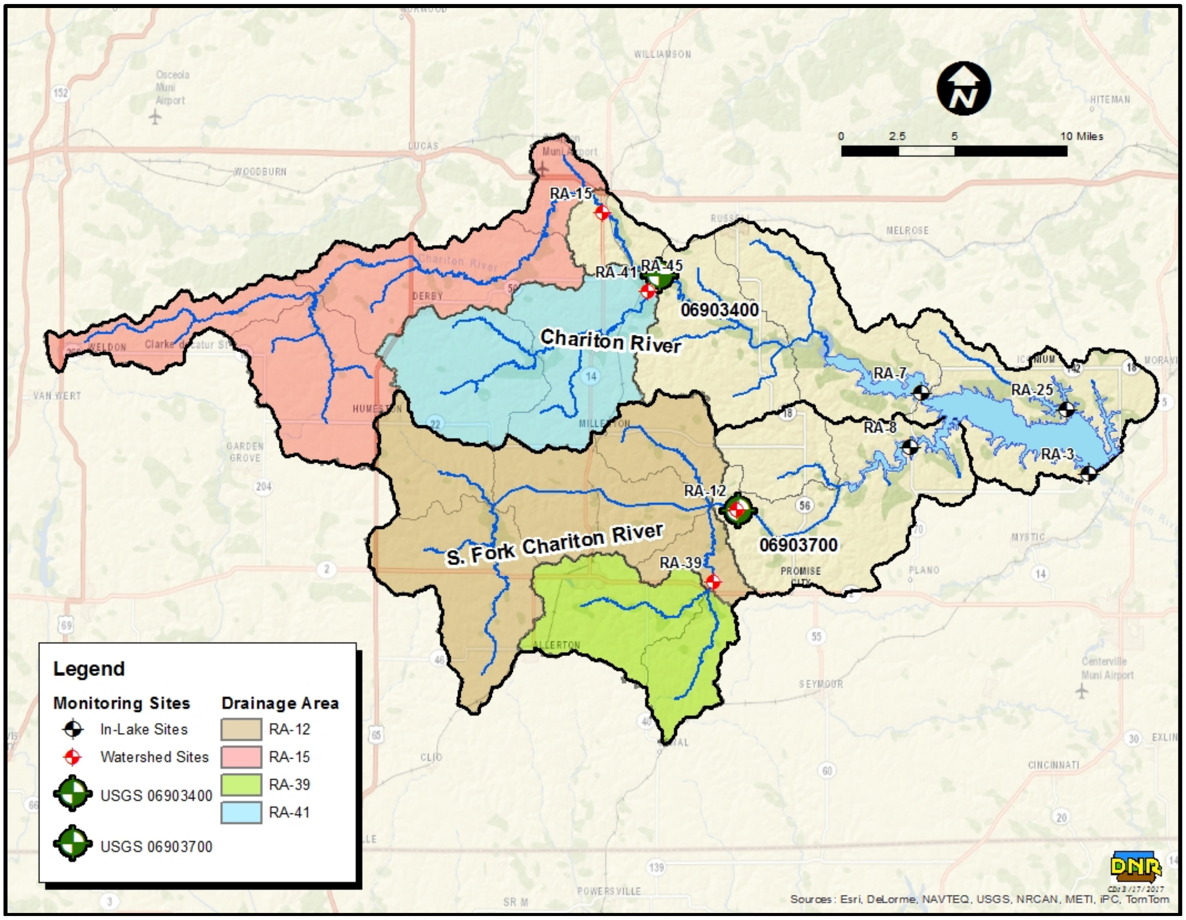
U.S Department of Agriculture-National Agricultural Statistics Service (USDA-NASS). 2013. http://nassgeodata.gmu.edu/CropScape/. Last accessed November 20, 2013.

U.S Department of Agriculture-National Agricultural Statistics Service (USDA-NASS). 2015. http://www.nass.usda.gov/Statistics_by_State/Iowa/Publications/County_Estimates/. Last accessed February 13, 2015.

U.S. Department of Agriculture-Natural Resources Conservation Service (USDA NRCS). 1998. Erosion and sediment delivery. Field Office Technical Guide Notice No. IA-198.U.S. Department of Agriculture and Natural Resources Conservation Service, Des Moines, Iowa.

Appendix E --- Watershed Model Performance

Performance evaluation is critical for identifying model strengths and weaknesses and for understanding the utility (and limitations) of a model for making management decisions. Performance of the Rathbun Lake watershed SWAT model was evaluated using a calibration and validation process that considers model uncertainty, and evaluation of simulated and observed probability distributions (i.e., flow duration curves). In addition to output evaluation, key intermediate / internal model processes (i.e., crop growth, nutrient fluxes, etc.) were also evaluated. The SWAT model was calibrated and validated to streamflow, sediment loads, and total phosphorus (TP) loads at two locations: (1) monitoring site RA-45, located on the Chariton River at USGS gage 06903400, and (2) monitoring location RA-12, located on the S. Fork Chariton River at USGS gage 06903700 (Figure E-1).



Sources: Esri, DeLorme, NAVTEQ, USGS, NRCAN, METI, iPC, TomTom

Figure E-1. Map of Chariton (RA-45) and S. Fork (RA-12) monitoring stations.

E.1. Calibration / Validation Process

The first step in model refinement was to evaluate the impact of varying inputs such as the daily curve number (CN) calculation method, rainfall data sources, and evapotranspiration estimation methods on hydrologic output. Models were ran without calibration to see which primary input sources and simulation equations provided the best agreement between observed and simulated streamflow RA-45 on the Chariton River and RA-12 is on the South Fork Chariton River. This pre-calibration analysis revealed that the default Soil Moisture method (ICN = 0) of calculating daily CN values, the Penman-Monteith method of simulating ET (IPET=1), and rainfall data obtained from the PRISM Climate Group (PRISM, 2016) provided the most accurate streamflow simulation prior to calibration. Therefore, this combination of simulation methodology and precipitation data was utilized for SWAT model calibration and validation.

To facilitate calibration, one-at-a-time sensitivity analysis was performed for several SWAT input parameters that affect each of the desired outputs (i.e., flow, crop yields, sediment, and TP) using the Sequential Uncertainty Fitting (version 2) routine (SUFI2) within the SWAT-CUP software package (Abbaspour, 2015a). Sensitivity analysis quantifies the magnitude of response of output variables to input parameter value changes. Sensitivity was assessed by plotting the impacts of parameter adjustment on time series output. Figure E-2 illustrates an example for the sensitivity of monthly flow at monitoring station RA-45 to the depth to the restrictive soil layer (SWAT parameter DEP_IMP). Similar analysis was performed for each calibration parameter, but results are not discussed in detail in this report, since results were to qualitatively inform the calibration process.

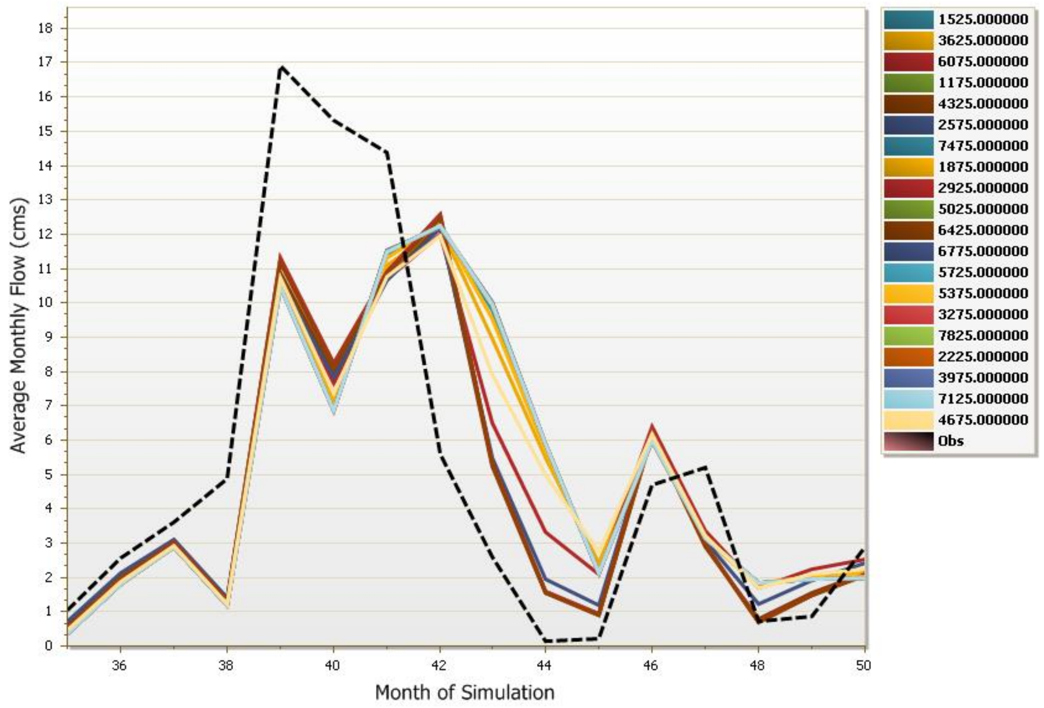


Figure E-2. Example sensitivity analysis of DEP_IMP on monthly flow. Values in the legend are depths (mm).

Performance Measures

Deterministic calibration is the process of adjusting input parameter values, within documented acceptable ranges, in order to minimize differences between simulated and observed / measured variables. Validation is the process of testing a calibrated model's ability to reproduce observed variables for an independent set of conditions without changing input parameter values (Moriasi et al., 2015; Zheng et al., 2012). Validation is typically performed temporally by applying the calibrated model another time period. Spatial validation can also be useful, and involves testing the calibrated model's ability to reproduce measured variables at different geographic locations and / or scales. Performance criteria used for the Rathbun Lake SWAT model calibration and assessment are taken from Moriasi et al. (2015) and reported in Table E-1.

Table E-1. Model performance evaluation criteria.

			Performance Criteria[a]			
Statistic	**Variable**	**Time Scale[b]**	**Very Good**	**Good**	**Satisfactory**	**Not Satisfactory**
NSE[c]	Flow	D-M-A	>0.80	0.70 to 0.80	0.50 to 0.70	≤ 0.50
	Sediment	M-A	>0.80	0.70 to 0.80	0.45 to 0.70	≤ 0.45
	N/P[d]	M-A	> 0.65	0.50 to 0.65	0.35 to 0.50	≤ 0.35
PB[e]	Flow	D-M-A	< ±5	±5 to ±10	±10 to ±15	≥ ±15
	Sediment	M-A	< ±10	±10 to ±15	±15 to ±20	≥ ±20
	N/P	M-A	< ±15	±15 to ±20	±20 to ±30	≥ ±30

[a] Adapted from Moriasi et al. (2015)
[b] D = daily, M = monthly, A = annual
[c] NSE = Nash-Sutcliffe efficiency
[d] N = nitrogen, P = phosphorus
[e] PB = PBIAS = percent bias (%)

Uncertainty Analysis

All models inherently include some level of uncertainty in their constructs and results. Furthermore, there are an infinite number of possible parameter value combinations that could yield similar output statistics (i.e., the problem of non-unique solutions). Deterministic calibration and validation statistics alone do not reflect this uncertainty. Therefore, a stochastic approach that quantifies the degree of model uncertainty was an important part of the calibration process and essential for understanding model performance. The SWAT-CUP software calculates and plots the 95% prediction uncertainty (95PPU) band of a simulation. Two measures of performance included with this analysis are the r-factor, which is the average width of the 95PPU divided by the standard deviation of the measured variable, and the p-factor, which summarizes the percentage of observations that lie within the 95PPU (Abbaspour, 2015; Abbaspour et al., 2015; Arnold et al., 2012).

Model simulations with lower r-factors and higher the p-factors are more reliable than models with high r-factors and low p-factors. Satisfactory values for the r-factor and p-factor are subjective, as there is a tradeoff between the two values and their importance varies by output variable and sites-specific conditions. For example, model performance at high flows is more important than at low flows for pollutant fluxes dominated by wet weather events; however, poor prediction of either extreme would have similar effects on the magnitude of the p-factor. Both r-factors and p-factors are reported with other model performance criteria for simulation of flow, sediment loads, and TP loads.

E.2. Hydrologic Performance

Flow Calibration / Validation

The flow calibration period included calendar years 2002-2013, and the model was validated using 1995-2001 and 2014 flow data. Identical calibration parameters and ranges were selected for both the Chariton and S. Fork HUC-10 watersheds; however, spatial variability was incorporated into the calibration process by allowing unique parameter values for each HUC-10. The calibration process included both manual adjustments and use of Sufi2 algorithm within the SWAT-Calibration and Uncertainty Program (SWAT-CUP) software package (Abbaspour, 2015). Streamflow was first calibrated to the monthly time-step, then to the daily interval (Table E-2).

Table E-2. Hydrologic parameters utilized for SWAT model calibration.

Parameter ID	Description	Calibration Range	Change Units	Calibrated Values	
				RA-45[a]	RA-12[b]
Monthly flow calibration					
DEP_IMP.hru	Depth to restrictive layer	0-6,000	mm	4,650	3,056
CN2.mgt	Curve number for antecedent moisture condition II	± 25	%	+11.1	-2.9
SOL_AWC.sol	Soil available water capacity	± 25	%	-3.5	-18.4
ESCO.hru	Soil evaporation compensation factor	0.4-1.0	--	0.9790	0.9022
GWQMN.gw	Threshold depth of water in shallow aquifer for required return flow to occur	0-5,000	mm	2,025	1,745
GW_REVAP.gw	Groundwater revap coefficient	0.02-0.20	--	0.0799	0.0396
Daily flow calibration					
SURLAG.bsn	Surface runoff lag coefficient	0.05-5	--	0.5005	0.5005
ALPHA_BF.gw	Baseflow recession constant	0-1	d^{-1}	0.5010	0.4990
SLSUBBSN.hru	Average slope length at which sheet flow begins to concentrate	± 90	%	+57.4	+14.6
HRU_SLP.hru	Average slope steepness	± 90	%	-33.3	+5.2
OV_N.hru	Manning's "n" value for overland flow	± 90	%	+70.7	-81.9

[a] Chariton River monitoring location RA-45, USGS gage 06903400, SWAT Reach 11
[b] S. Fork Chariton monitoring location RA-12, USGS gage 06903700, SWAT Reach 59

Overall, hydrologic calibration statistics ranged from satisfactory [S] to very good [VG] (Table E-3), based on the model assessment criteria previously described (Table E-1). Model validation statistics indicated poorer performance outside of the 2002-2013 calibration period. Validation statistics are typically not as good as calibration statistics, which indicates that the model is not as reliable outside of the calibrated conditions. The validation NS values were all satisfactory or better; however the validation PBIAS values were just outside of the satisfactory range of not greater than ±15%. One contributing factor in validation performance of the model is likely that land use inputs to SWAT were based on conditions present in the watershed during the calibration period, and significant land use change was observed in the watershed after 2001.

Table E-3. Hydrologic calibration and validation statistics.

	Calibration (2002-2013)				Validation (1995-2001)	
	NSE[a]	PBIAS[b]	r-factor	p-factor	NSE[a]	PBIAS[b]
RA-45						
Monthly Flow	0.80 [VG]	-4 [VG]	0.83	0.65	0.68 [S]	-17 [NS][c]
Daily Flow	0.67 [S]	-4 [VG]	0.56	0.64	0.56 [S]	
RA-12						
Monthly Flow	0.85 [VG]	+8 [G]	0.72	0.68	0.72 [G]	+16 [NS][c]
Daily Flow	0.75 [G]	-4 [VG]	0.35	0.79	0.65 [S]	

[a] Nash-Sutcliffe efficiency.

[b] Percent bias (negative indicates over-estimation). PBIAS does not vary by time step.

[a,b] VG=very good, G=good, S=satisfactory, NS=not satisfactory (Moriasi et al., 2015)

[c] Just outside of satisfactory range of not greater than 15%, indicating model performance is not as reliable outside of the conditions of the 2002-2013 calibration period. This may be due, in large part, to the fact that land use / cover inputs were based on 2008-2013 data.

The 95% probability interval of the simulation captures 65% and 68% of the observed monthly flows at RA-45 and RA-12, respectively, as indicated by the p-factors in Table E-3. Of the points observed data that lie outside the probability band, nearly all occur during significantly high or significantly low flow conditions (Figure E-3 and E-4). The r-factors of 0.72 to 0.83 indicate an uncertainty band width well under the maximum recommended value of 1.0 (Abbaspour, 2015).

Deviations between simulated and observed flows in the 2002-2013 calibration period are illustrated at both RA-45 (Figure E-5) and RA-12 (Figure E-6). Generally speaking, the deviations are negative during low flows and positive during high flows, confirming the difficulty of accurately simulating both extremes. However, high flows periods are simulated relatively accurately, and are far more critical to transport of sediment and TP in the Rathbun watershed than low flow conditions. This indicates that hydrologic performance of the model, which is critical for accurate sediment and TP prediction, should provide reasonable estimation of pollutant loads for purposes of the Rathbun Lake TMDL.

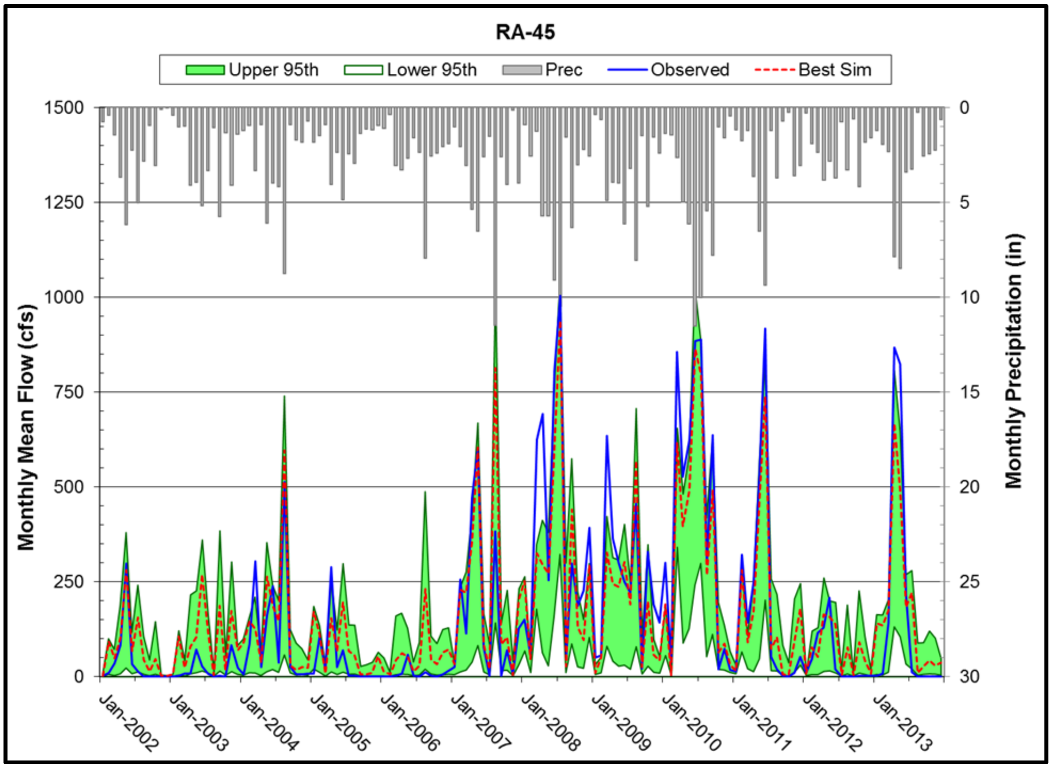


Figure E-3. Monthly flow calibration on the Chariton River (RA-45). Green shaded region represents the 95% probability band (Abbaspour, 2015).

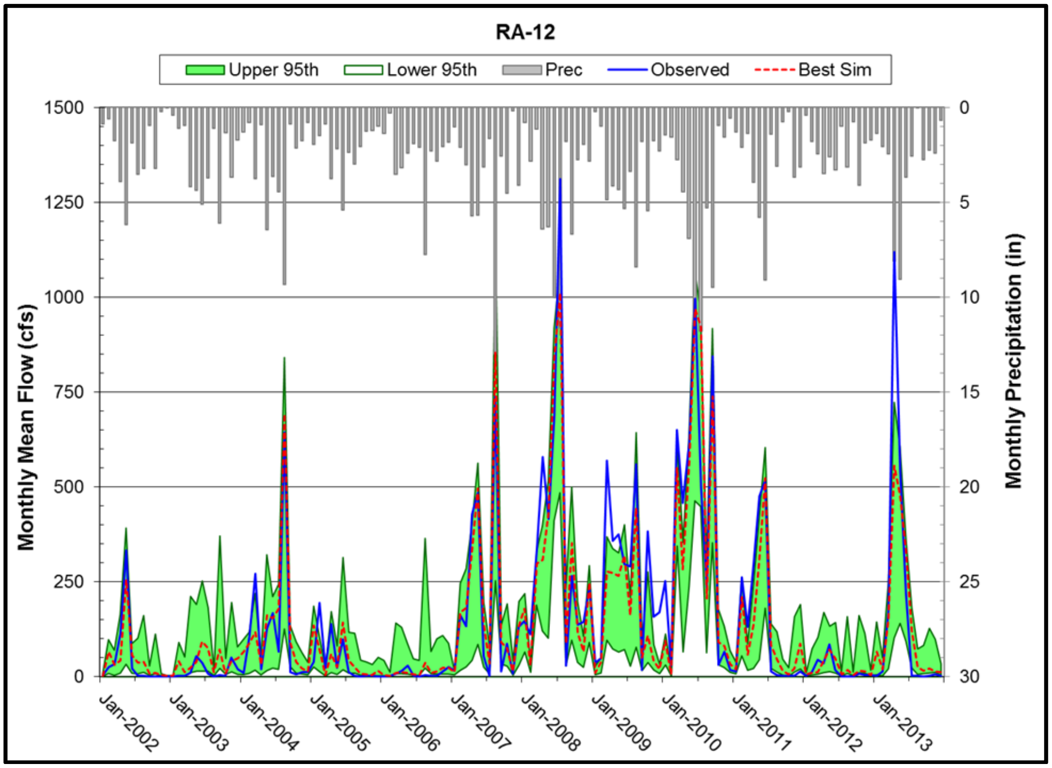


Figure E-4. Monthly flow calibration on the S. Fork Chariton River (RA-12). Green shaded region represents the 95% probability band (Abbaspour, 2015).

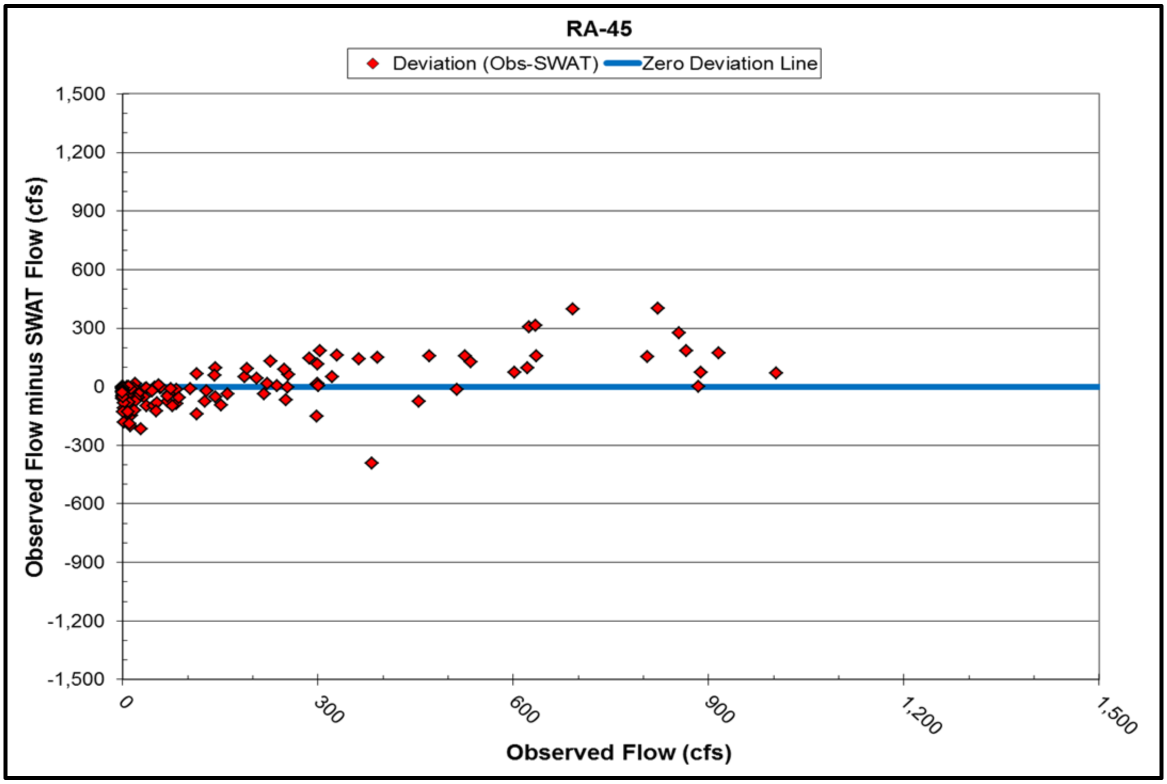


Figure E-5. Deviations between calibrated and observed flows at RA-45.

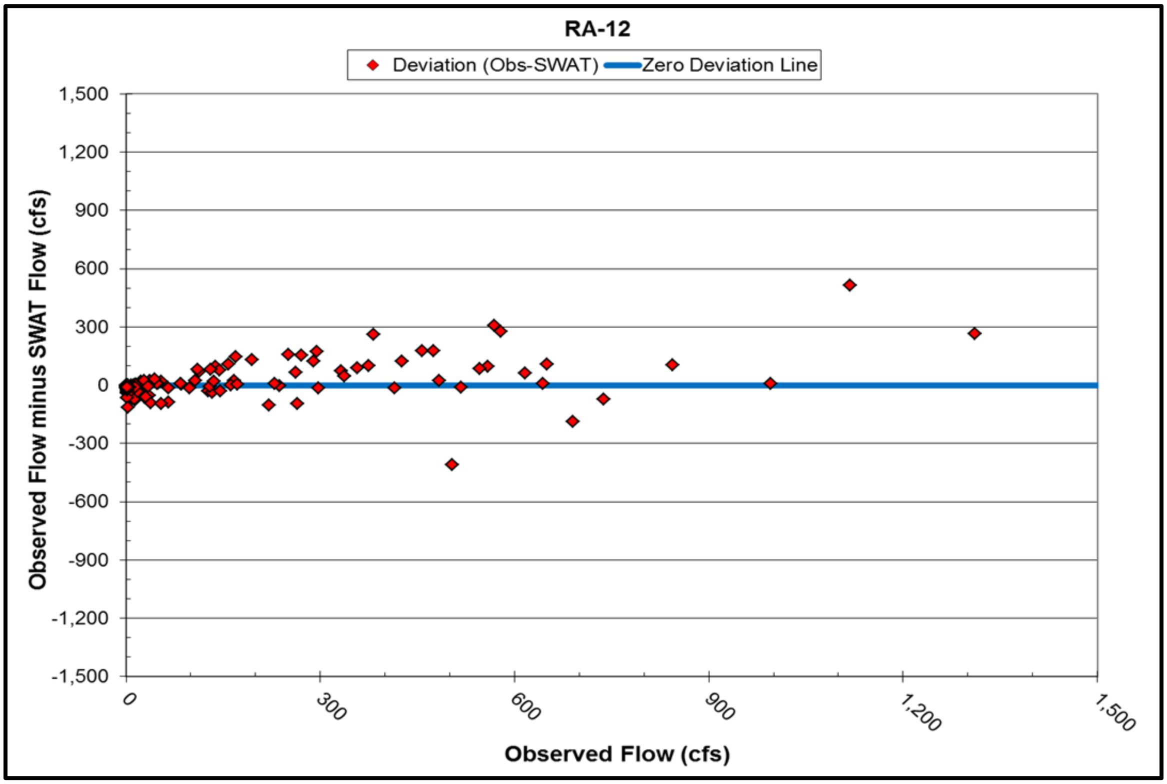


Figure E-6. Deviations between calibrated and observed flows at RA-12.

Flow Duration Analysis

Flow duration curves (FDCs) were developed to help assess model performance across flow conditions, since statistical measures such as NSE and PBIAS are more heavily influenced by performance at high flow conditions. Good performance across flow conditions is reflected by similar shaped and overlapping observed and simulated FDCs. Phosphorus and sediment loading to Rathbun Lake is dominated by wet weather and high flow conditions (i.e., flows to the left of the 50% duration interval), so high flow performance is more critical for accurate estimation of pollutant loads. However, low flow performance of the model is helpful for overall model assessment and for understanding model limitations.

The model tends to over-estimate base flows significantly at RA-45 (Figure E-7) and but only slightly at RA-12 (Figure E-8). Instream monitoring revealed that hydrograph recession after storm events is very pro-longed at RA-45, relative to RA-12. Development of flow estimates from stream level data indicated greater uncertainty even in measured data at RA-45, and the SWAT model did a marginal job of simulating streamflow during average to dry conditions here. The floodplain of the Chariton River contains a number of large wetland complexes just upstream of the RA-45 monitoring site on Hwy. S43. These wetlands are not reflected in the SWAT model and it is possible that these wetlands increase baseflow during much of the year via slow and steady groundwater return flow. Ideally the model would capture this phenomenon, but this deviation from observed baseflow likely has a relatively small impact on sediment and TP predictions.

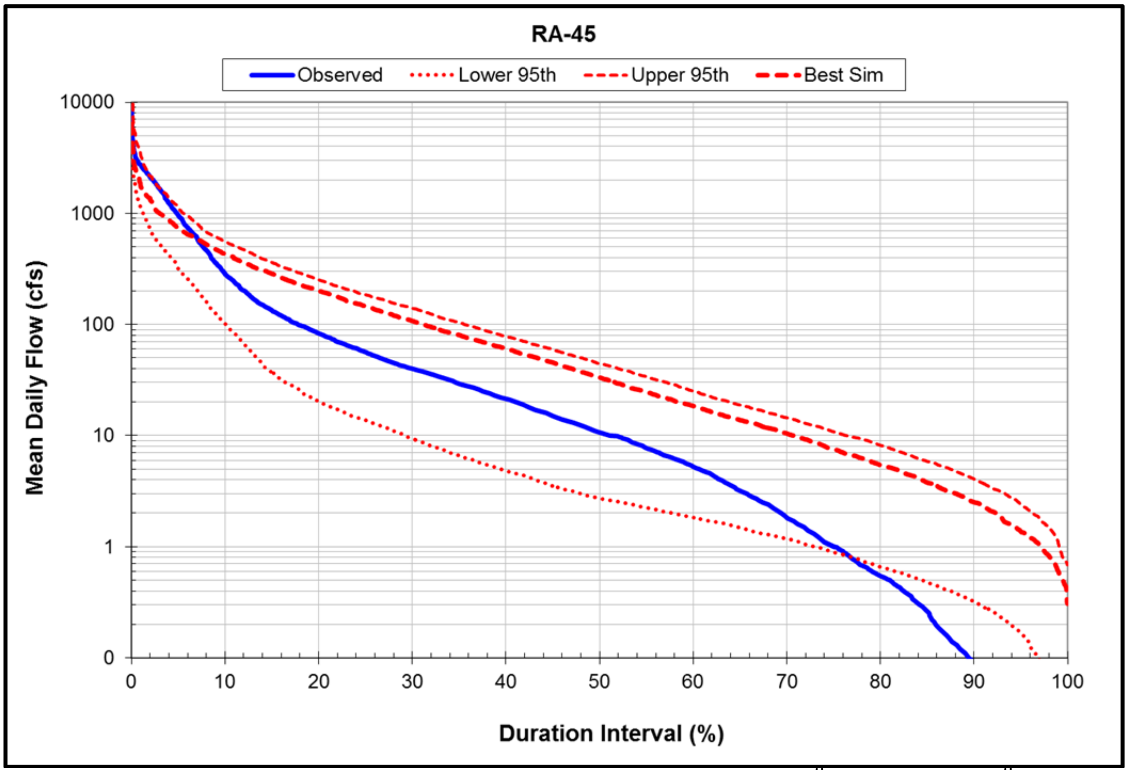


Figure E-7. Daily mean flow duration curve at RA-45. 95th refers to 95th probability band and Best sim refers to the best statistical simulation.

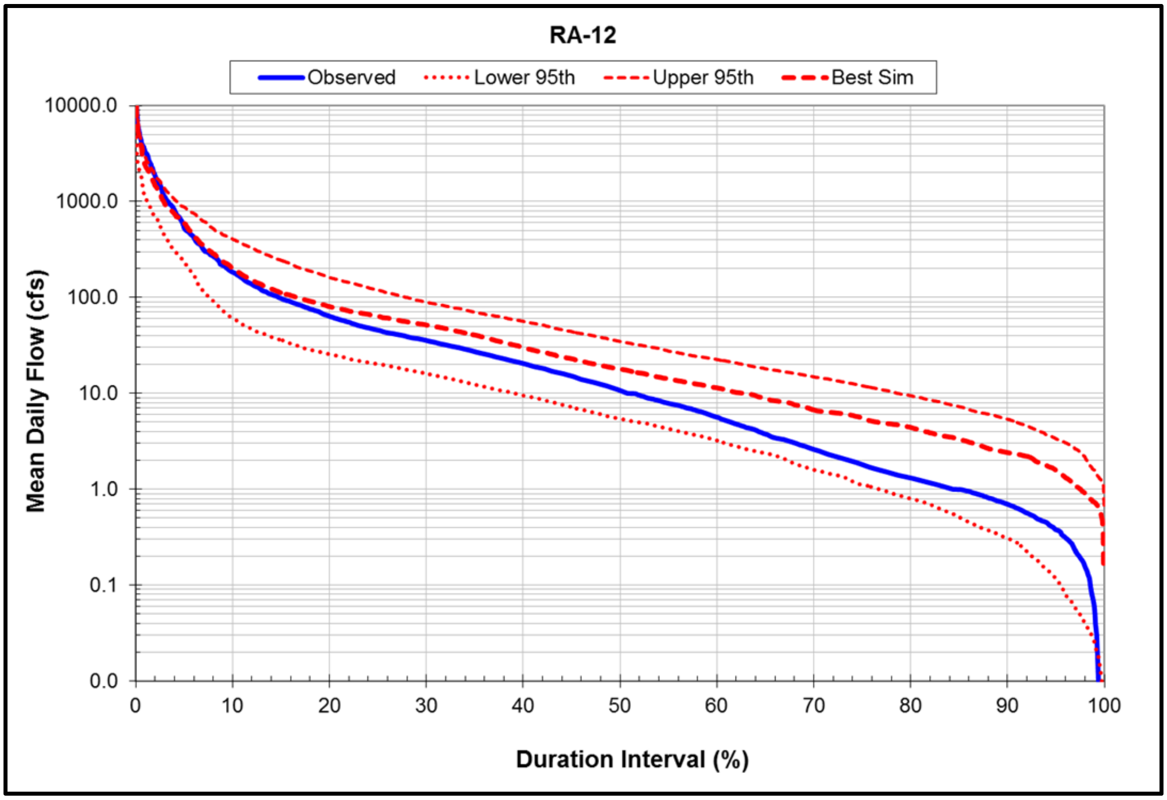


Figure E-8. Daily mean flow duration curve at RA-12. 95th refers to 95th probability band and Best sim refers to the best statistical simulation.

Spatial performance of the model was examined by comparing simulated and observed flows at two monitoring stations on smaller creeks within each HUC-10: (i) RA-39, a on Jackson Creek in the S. Fork Chariton, and (ii) RA-41 on Wolf Creek in the Chariton River (Figure E-1). While not a true validation because these subbasins lie within the calibrated watersheds, this evaluation provides insight to model performance and limitations at smaller spatial scales. The NSE for RA-39 from 2002-2014 was 0.79 (good), but the PBIAS was 20.7% (unsatisfactory), indicating that flow appears to be underestimated at smaller spatial scales, although the model does capture the temporal variation well. The NSE for RA-41 was 0.83 (very good) with a PBIAS of -13.7% (satisfactory). Monthly flow (water yield) is illustrated for RA-39 and RA-41 in Figure E-9 and Figure E-10, respectively. The model tends to over-estimate low flow at the smaller scale, in the same manner as it does on the Chariton (RA-45) and South Fork Chariton (RA-12) locations. The XY scatter plots presented for RA-39 (Figure E-11) and RA-41 (Figure E-12) show that while there is variation between predicted and observed monthly flows in these smaller drainage basins of the watershed, the model does a reasonable job of predicting flow at the monthly time step.

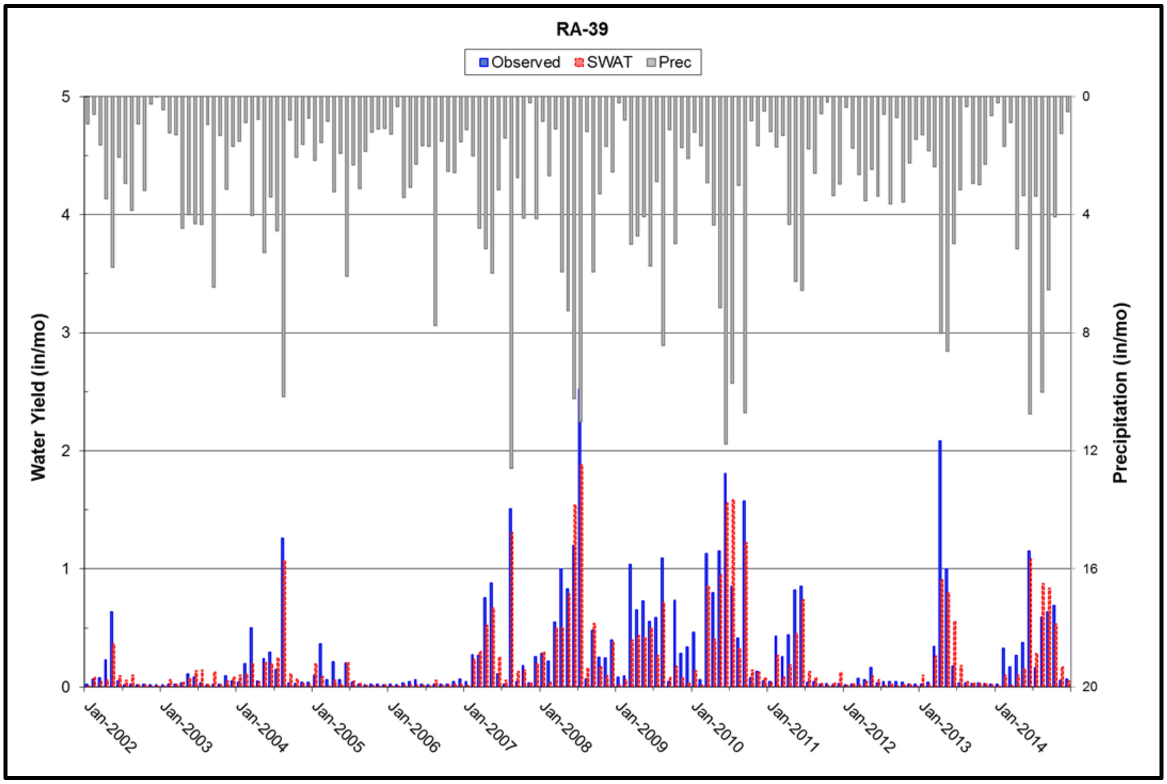


Figure E-9. Monthly flow (water yield) on Jackson Creek (RA-39).

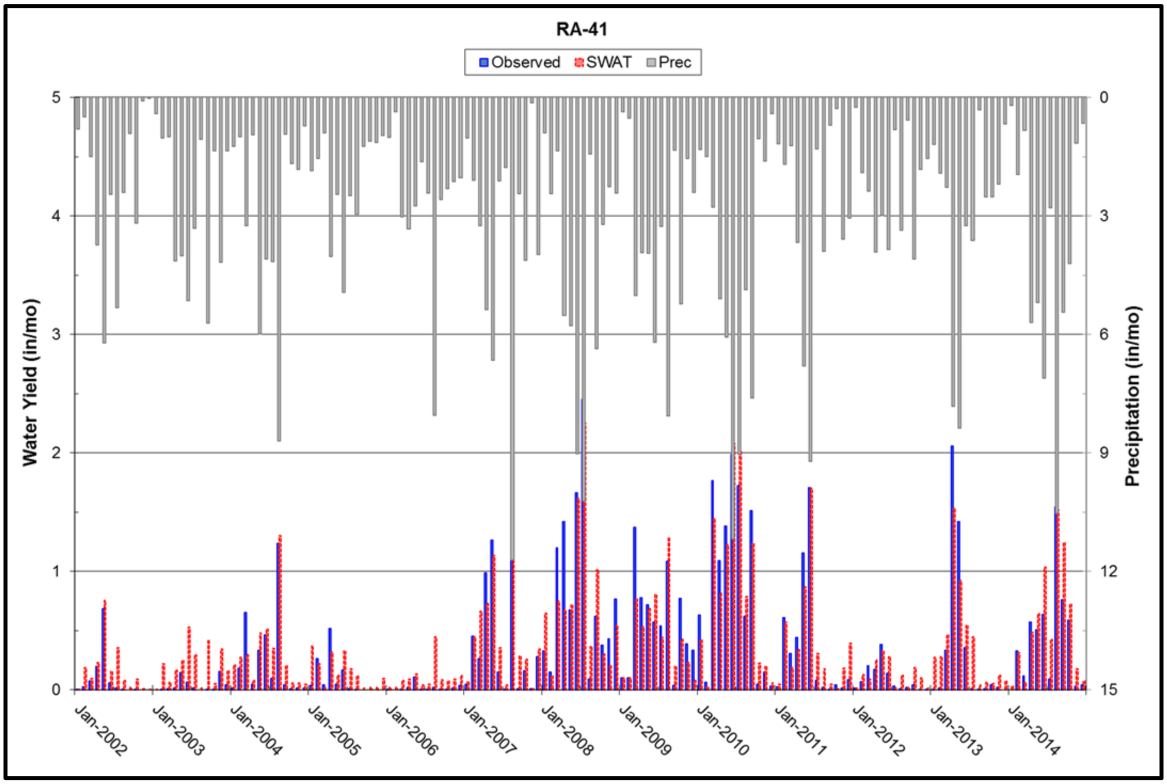


Figure E-10. Monthly flow (water yield) on Wolf Creek (RA-41).

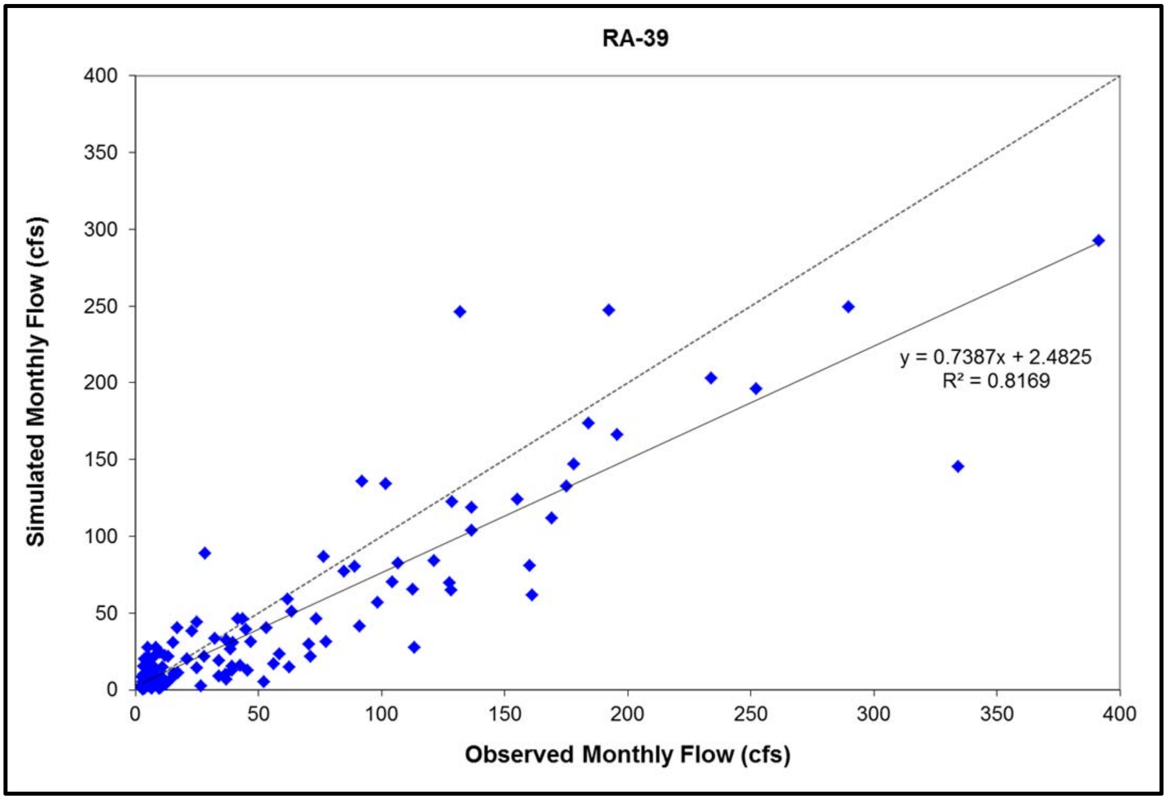


Figure E-11. Simulated vs. observed monthly flow on Jackson Creek (RA-39).

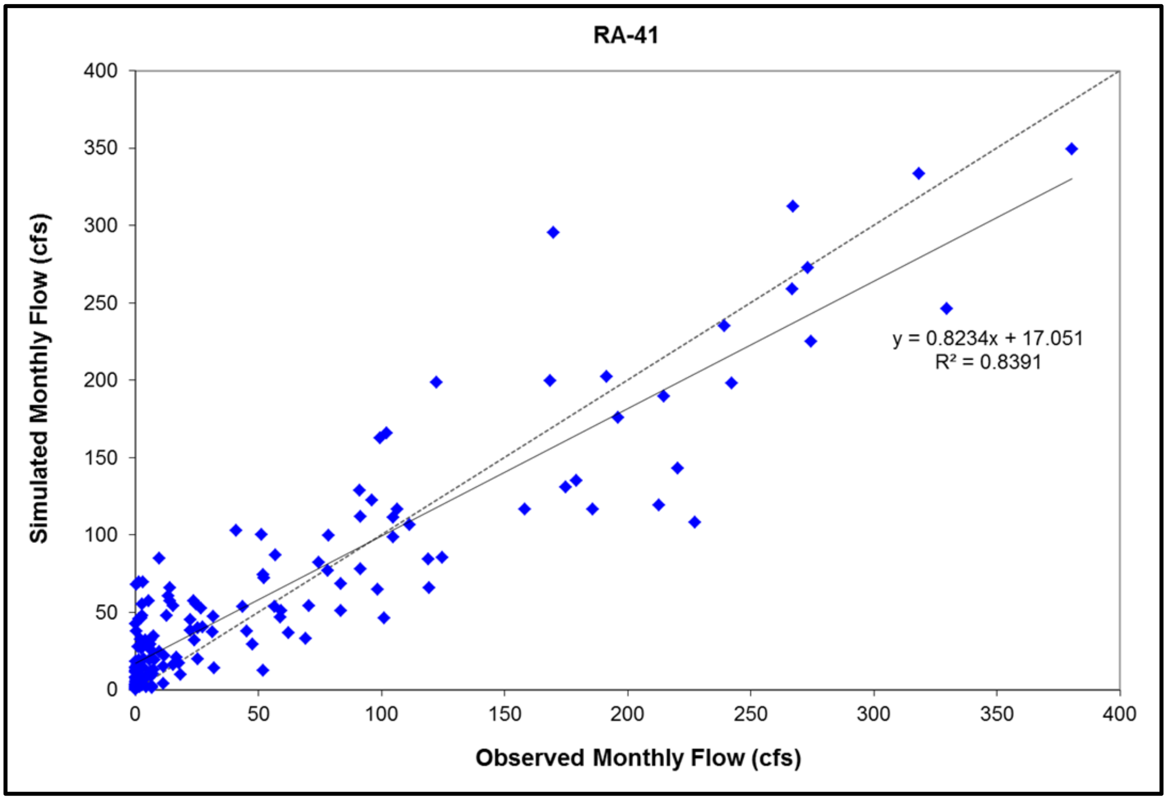


Figure E-12. Simulated vs. observed monthly flow on Wolf Creek (RA-41).

Crop Yield Verification
Simulated crop (corn, soybean, and alfalfa) yields were compared against average crop yields reported by USDA for the six-county area (USDA-NASS, 2016) on a watershed-wide basis from 2002-2013. Crop growth reflects an important intermediate process in the SWAT model because it affects hydrology, land cover and residue (which affect erosion), and nutrient balances / fluxes.

Simulated crop yields, on an average annual basis, compared reasonably well with the county-level data. Average annual corn yield was over-estimated by 7.7% , soybean yields were under-estimated by 14.0%, and alfalfa yields were over-estimated by 11%. Because crop growth and yields contain substantial variability, with many site-specific factors, many of which are unknown, it is not surprising that the model failed to accurately predict year-to-year variability (Figure E-13). The XY scatter plot of simulated vs. observed corn yields (Figure E-14) confirmed that overall, corn yields are simulated well, but the model is limited in its ability to reflect year-to-year variation. The R2 value of 0.45 is fair for such a complete variable; however, R^2 values were lower for both soybeans and alfalfa. Nonetheless, crop growth simulations were considered adequate in for the simulation of hydrology and sediment and TP losses.

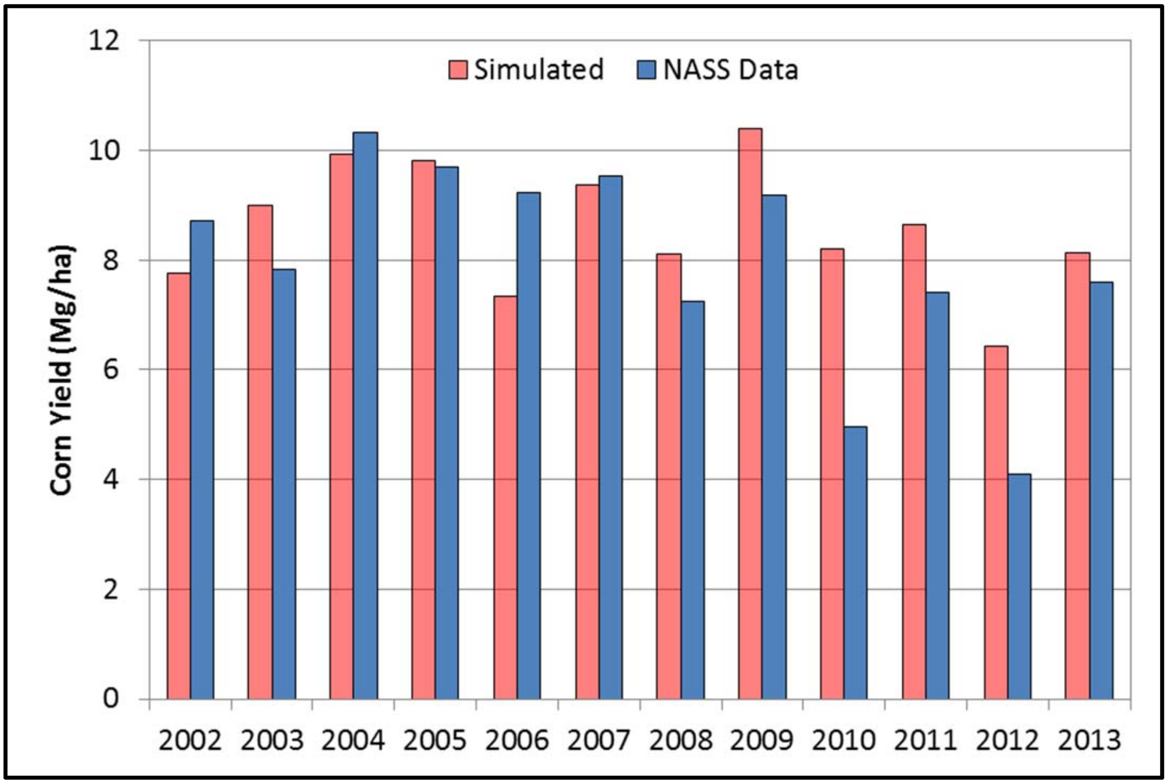


Figure E-13. Simulated and observed (USDA-NASS, 2016) corn yields.

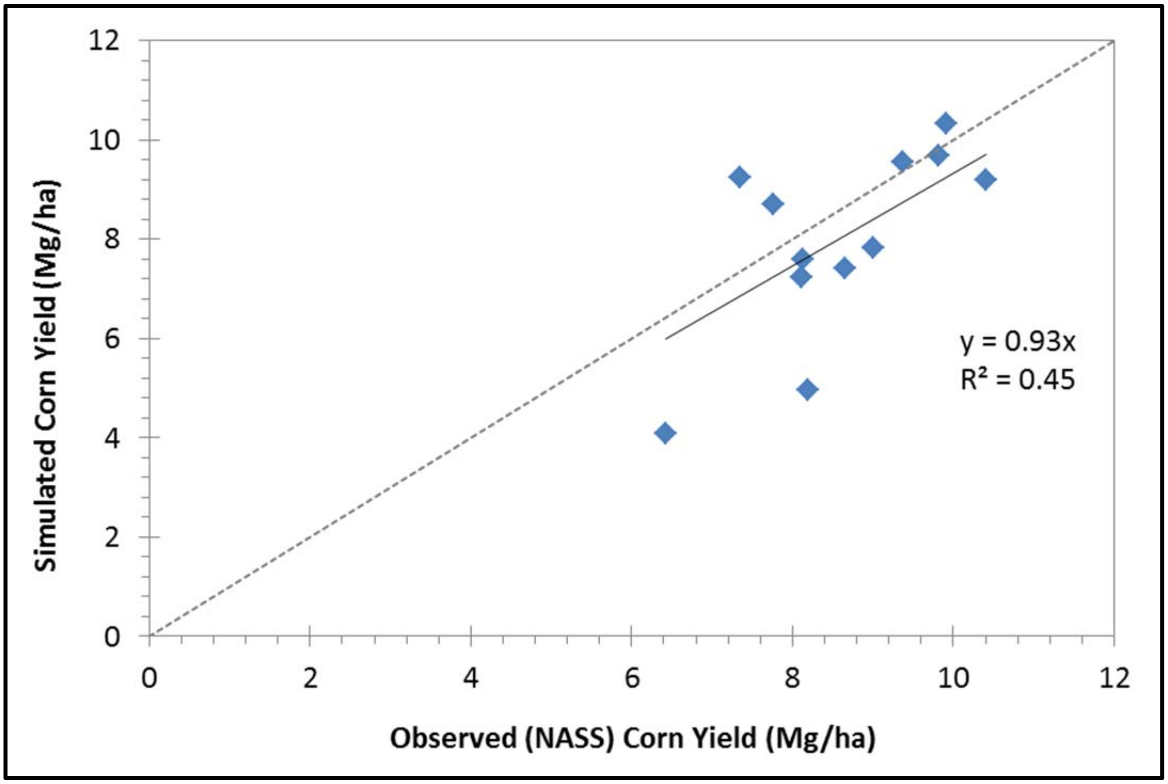


Figure E-14. Simulated and observed (USDA-NASS, 2016) corn yields.

Sediment Calibration / Validation
The sediment load calibration period included calendar years 2002-2013, and the model was validated using sediment flux estimates developed using observed flow and total suspended solids (TSS) data from 1997-2001 and 2014. Because TSS is a proxy, rather than a direct measure of sediment, depth-integrated sediment sampling was conducted in 2013-2014. Results of the depth-integrated sampling indicated that measured TSS concentrations reliably predict suspended sediment concentrations at the monitoring locations in this watershed; therefore, observed sediment loads are based on TSS and flow data. In other geographic locations, TSS may not be an appropriate measure of sediment.

Sediment input parameters selected for calibration are input at the basin (i.e., watershed-wide level, with the exception of channel erodibility and cover factors, which were varied by HUC-10. The calibration process began with sensitivity analysis of all sediment factors, including those not utilized for the final calibration iteration. The Sufi2 algorithm within the SWAT-Calibration and Uncertainty Program (SWAT-CUP) software package was utilized to automate the final sediment calibration process (Abbaspour, 2015). Sediment was calibrated to the monthly interval with results also reported for the annual time-step (Table E-4). The model was not evaluated for daily sediment loads due to limitations in both the calculation of load estimates and limitations of the SWAT model for simulation of daily sediment transport.

Table E-4. Calibration parameters utilized for simulation of sediment.

Parameter ID	Description	Calibration Range	Units[a]	Calibrated Values	
				RA-45[b]	RA-12[c]
PRF.bsn	Peak rate adjustment factor for sediment routing in main channel	0.75-1.25	--	0.976	0.976
ADJ_PKR.bsn	Peak rate adjustment factor for sediment routing in subbasins	0.75-1.25	--	0.751	0.751
SPCON.bsn	Linear coefficient for sediment transport equation	0.001-0.0025	--	0.0019	0.0019
SPEXP.bsn	Exponential parameter for sediment transport equation	1.00-1.75	--	1.644	1.644
CH_COV1.rte	Channel erodibility factor	0.5-1.0	--	0.991	0.943
CH_COV2.rte	Channel cover factor	0.5-1.0	--	0.996	0.649

[a] All sediment calibration parameters have dimensionless units
[b] Chariton River monitoring location RA-45, USGS gage 06903400, SWAT Reach 11
[c] S. Fork Chariton monitoring location RA-12, USGS gage 06903700, SWAT Reach 59

Sediment calibration statistics ranged from good [G] to very good [VG] (Table E-5), based on the model assessment criteria previously described (Table E-1). The 95% probability interval of the simulation captures 67% and 79% of the observed annual sediment loads at RA-45 (Figure E-15) and RA-12 (Figure E-16), respectively, as indicated by the p-factors in Table E-5 and the green-shaded band in the time series plots. Simulated and observed monthly sediment loads, including the 95% uncertainty bands, are plotted for both RA-45 (Figure E-17) and RA-12 (Figure E-18), and indicate that model performance at the monthly interval is not as reliable as annual predictions.

Table E-5. Sediment calibration and validation statistics.

	Calibration (2002-2013)				Validation[a]	
	NSE[a]	PBIAS[b]	r-factor	p-factor	NSE[b]	PBIAS[c]
RA-45						
Annual Load	0.90 [VG]	-11 [G]	1.37	0.67	-0.10 [NS]	-45.7 [NS]
Monthly Load	0.79 [G]	-11 [G]	0.85	0.47	0.56 [S]	-45.7 [NS]
RA-12						
Annual Load	0.72 [G]	+12 [G]	0.83	0.79	0.37 [NS]	+26.4 [NS]
Monthly Load	0.71 [G]	+12 [G]	0.42	0.38	0.65 [S]	+26.4 [NS]

[a] Validation period included 1997-2001 and 2014.
[b] Nash-Sutcliffe efficiency.
[c] Percent bias (negative indicates over-estimation). PBIAS does not vary by time step.
[b,c] VG=very good, G=good, S=satisfactory, NS=not satisfactory (Moriasi et al., 2015)

Stream / Channel Erosion

The model predicted 447,873 tons/yr of gross erosion from stream reaches upstream of the extents of Rathbun Lake. This compares well with the field assessment estimate of 450,431 tons/yr (Appendix D). Although the simulated total is similar in magnitude to the field survey estimate, the model does not appear to represent the spatial distribution of channel erosion and deposition accurately, and therefore should not be used to prioritize stream segments for potential mitigation or protection.

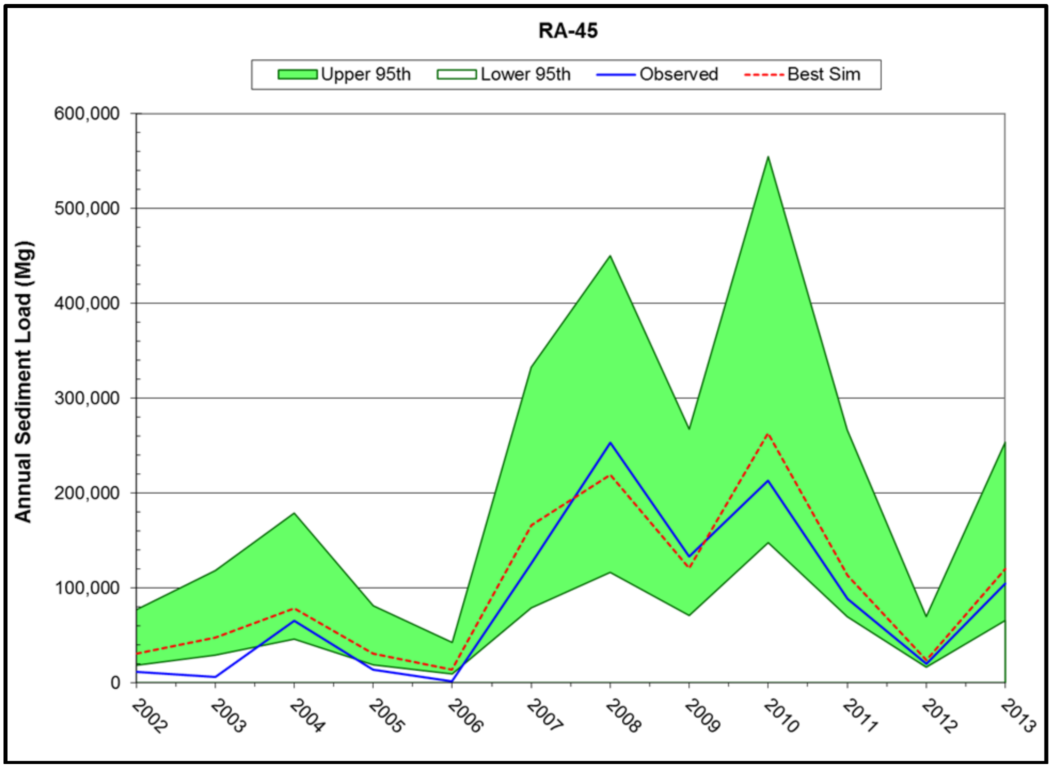


Figure E-15. Annual sediment calibration on the Chariton River (RA-45). Green shaded region represents the 95% probability band (Abbaspour, 2015).

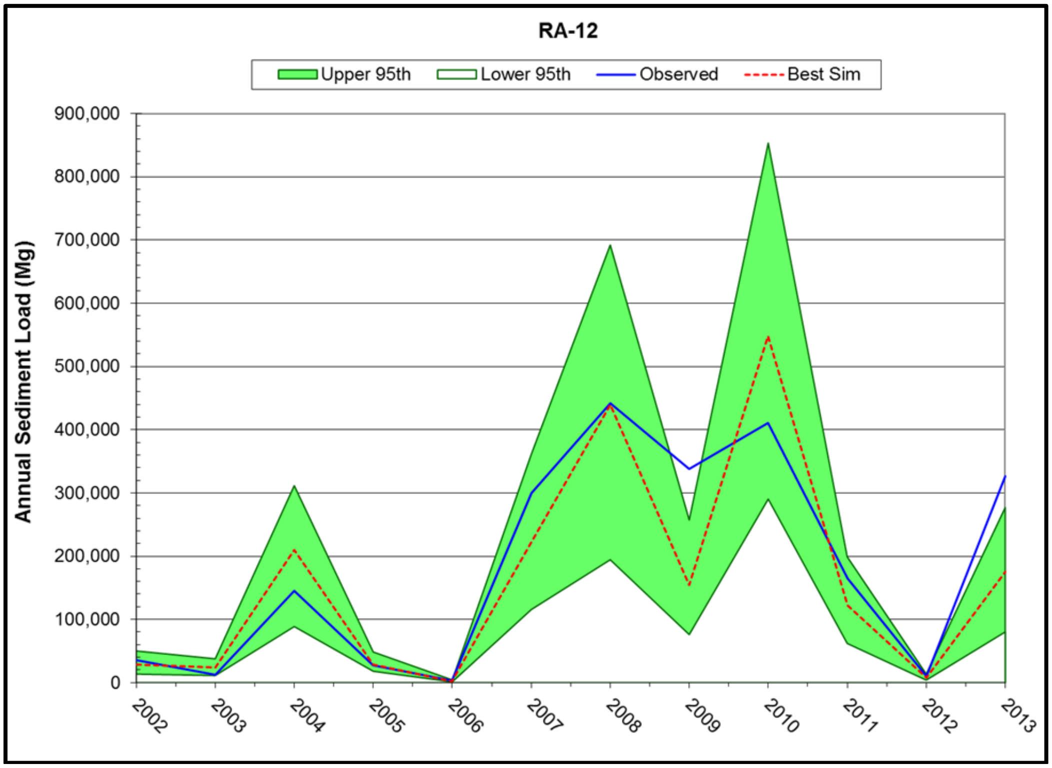


Figure E-16. Annual sediment calibration on the Chariton River (RA-12). Green shaded region represents the 95% probability band (Abbaspour, 2015).

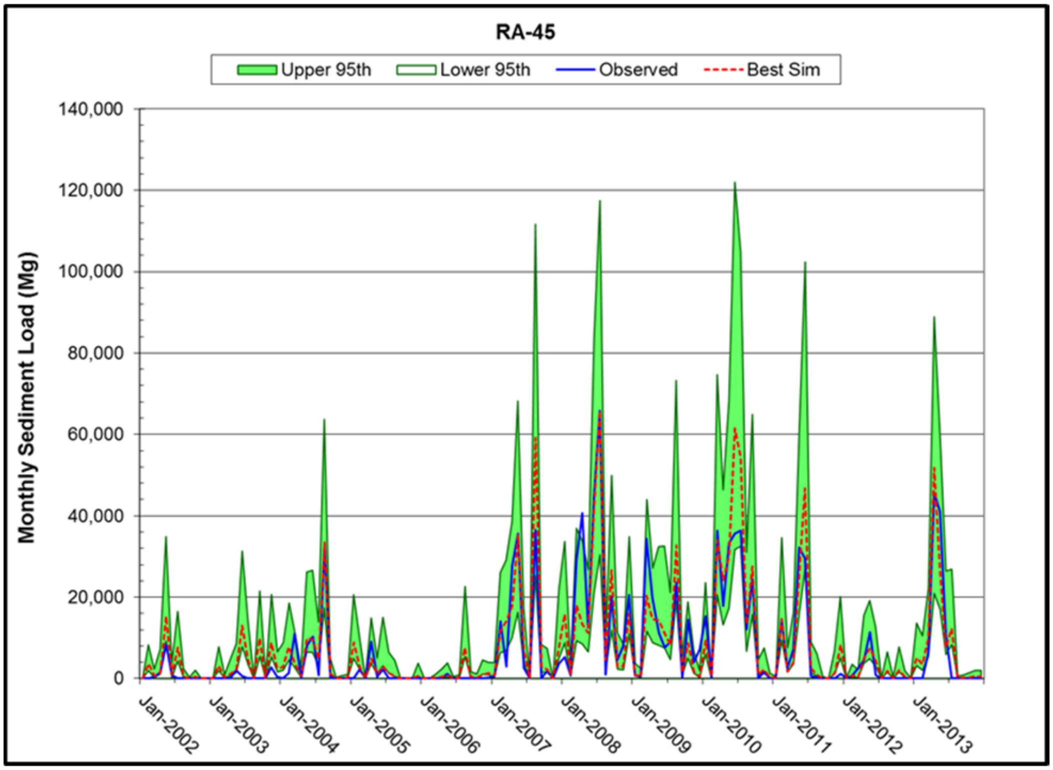


Figure E-17. Monthly sediment calibration on the Chariton River (RA-45). Green shaded region represents the 95% probability band (Abbaspour, 2015).

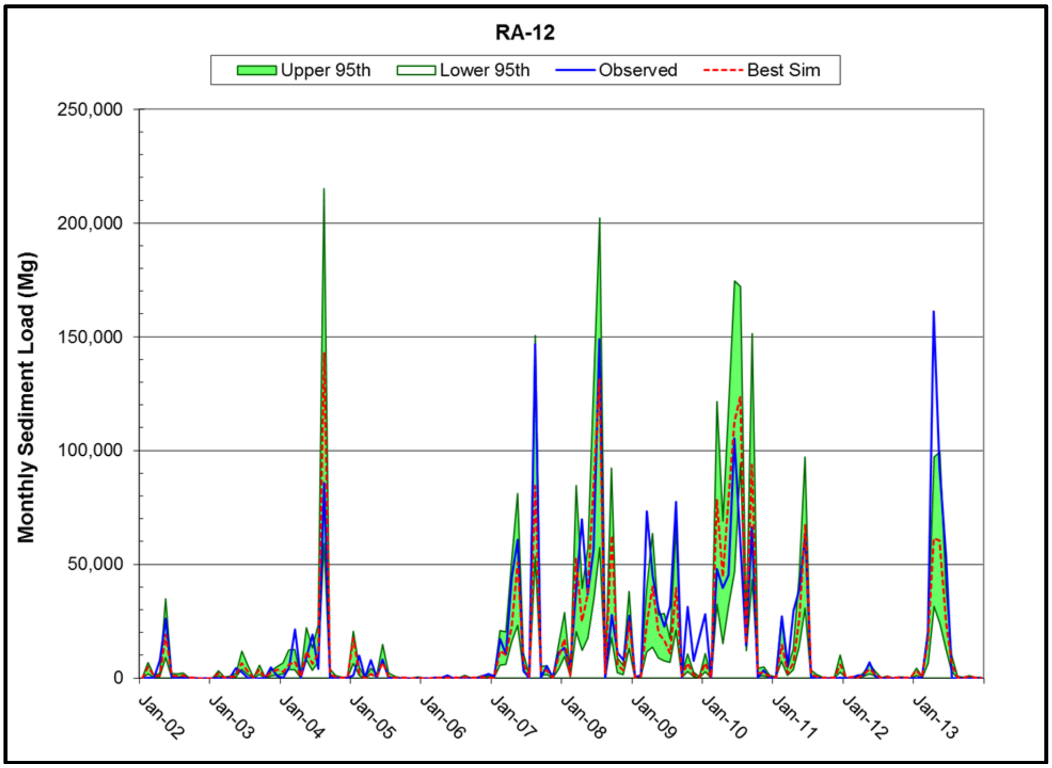


Figure E-18. Monthly sediment calibration on the Chariton River (RA-12). Green shaded region represents the 95% probability band (Abbaspour, 2015).

Despite good performance in the calibration period, NSE and PBIAS values indicate unsatisfactory model performance for the validation period. Validation performance was further evaluated by exploring the correlation between simulated and observed sediment loads in the validation period (Figure E-19). The slope and R^2 values suggest that performance may not be as poor as the NSE and PBIAS statistics suggest, nonetheless, there is notable deviation between simulated and observed annual sediment loads outside of the calibration period.

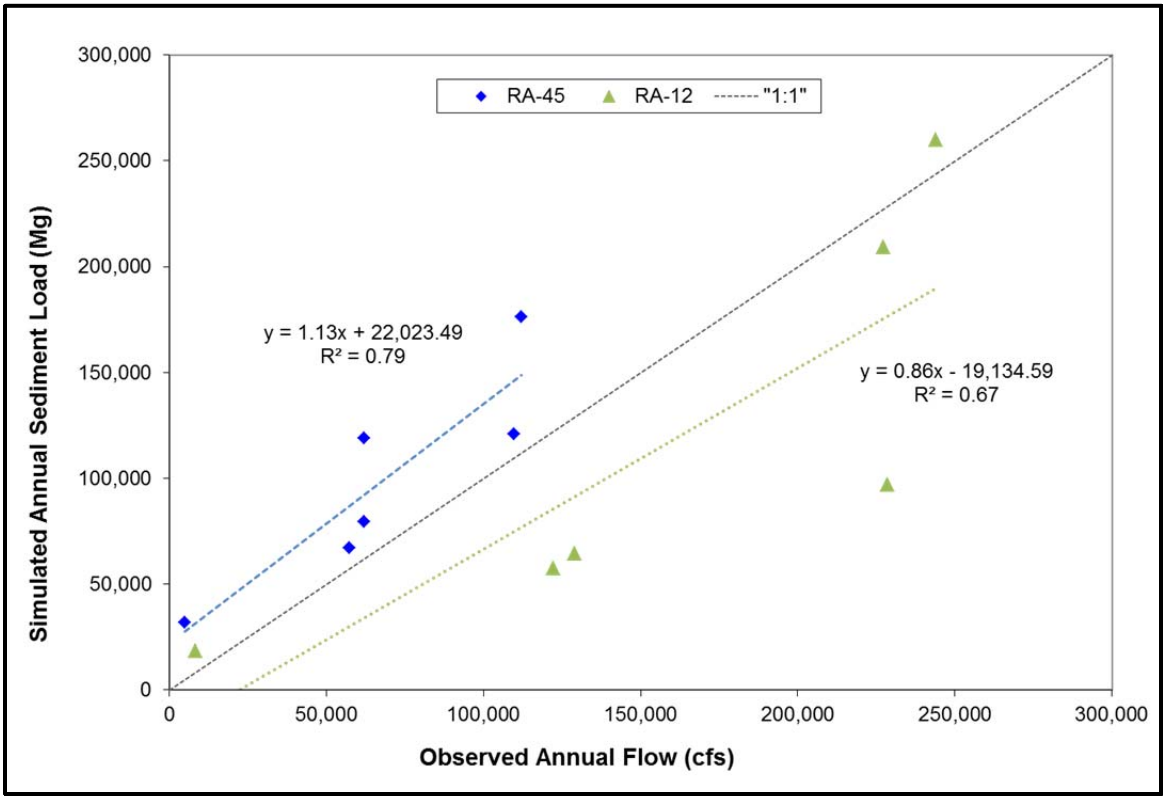


Figure E-19. Validation period correlation analysis of simulated and observed sediment loads.

Poor validation performance of the model is likely due, in part, to land use changes observed in the watershed between the calibration and validation periods. These temporal changes result in poor reflection of land use conditions in the validation model, which hinders model performance. In addition to land use changes, water quality data collected over the years has increased in spatial and temporal resolution, therefore, some of the model error may be due to worse estimates of observed sediment loads within the validation period. This performance limits the utility of the model for predicting trends in sediment transport in periods with significantly different land use patterns (unless the land use changes are reflected in model inputs).

Phosphorus Calibration / Validation
The TP calibration period was the same as for flow and sediment (i.e., 2002-2013). Simulated annual TP loads were calibrated TP flux estimates developed from flow and TP monitoring data. Phosphorus simulation is highly dependent on the performance of

sediment simulation. Therefore, calibration of TP followed sediment calibration, and was refined using the phosphorus-related parameters in Table E-6. The model was not evaluated for daily sediment loads due to limitations in both the calculation of load estimates and limitations of the SWAT model for phosphorus transport.

Table E-6. Calibration parameters utilized for simulation of TP.

Parameter ID	Description	Calibration Range	Units	Calibrated Values RA-45[a]	RA-12[b]
PPERCO.bsn	Phosphorus percolation coefficient	10-17.5	$m^3\ Mg^{-1}$	10.6	10.6
PHOSKD.bsn	Phosphorus soil partitioning coefficient	100-200	$m^3\ Mg^{-1}$	108.8	108.8
PSP.bsn	Phosphorus availability index	0.01-0.70	--[c]	0.66	0.66
ERORGP.hru	Phosphorus enrichment ratio	0.1-0.5	--[c]	0.282	0.439

[a] Chariton River monitoring location RA-45, USGS gage 06903400, SWAT Reach 11
[b] S. Fork Chariton monitoring location RA-12, USGS gage 06903700, SWAT Reach 59
[c] Dashes (--) indicate dimensionless units

Overall, performance statistics were either good [G] or very good [VG], with only one instance of a satisfactory [S] rating, which was for RA-12 during the validation period (Table E-7). Although calibrated NSE and PBIAS values for annual TP loads are very good at both locations, there are years in which the model under-estimates TP loads significantly. Examples include 2008 for both RA-45 (Figure E-20) and RA-12 (Figure E-21), and additionally 2013 for RA-12. Despite better statistical results for TP than for sediment, the model has significant limitations with respect to phosphorus transport.

In its current state, the SWAT model simulates instream transport of phosphorus and sediment separately. While the model does simulate channel erosion and its impact on sediment transport, it does not simulate the phosphorus that, in reality, is attached to channel-derived sediment. This creates a "disconnect" in the SWAT model. Better statistical results for TP, therefore, are somewhat artificial. The model is representing instream TP loads well, but not for all of the right reasons (i.e, it is not simulating all of the physical processes involved). As a result, TP simulation results must be viewed with caution and used judiciously. It is likely that the disconnect between instream sediment and TP partially explains under-estimated TP loads in 2008 and 2013.

Table E-7. TP calibration and validation statistics.

	Calibration (2002-2013)				Validation[a]	
	NSE[b]	PBIAS[c]	r-factor	p-factor	NSE[b]	PBIAS[c]
RA-45						
Annual Load	0.84 [VG]	-7 [VG]	0.84	0.67	0.68 [VG]	-15 [VG]
Monthly Load	0.71 [VG]	-7 [VG]	0.43	0.42	0.57 [G]	-15 [VG]
RA-12						
Annual Load	0.71 [VG]	+7 [VG]	0.66	0.75	0.41 [S]	+4 [VG]
Monthly Load	0.60 [G]	+7 [VG]	0.29	0.40	0.55 [G]	+4 [VG]

[a] Validation period included 1997-2001 and 2014.
[b] Nash-Sutcliffe efficiency.
[c] Percent bias (negative indicates over-estimation). PBIAS does not vary by time step.

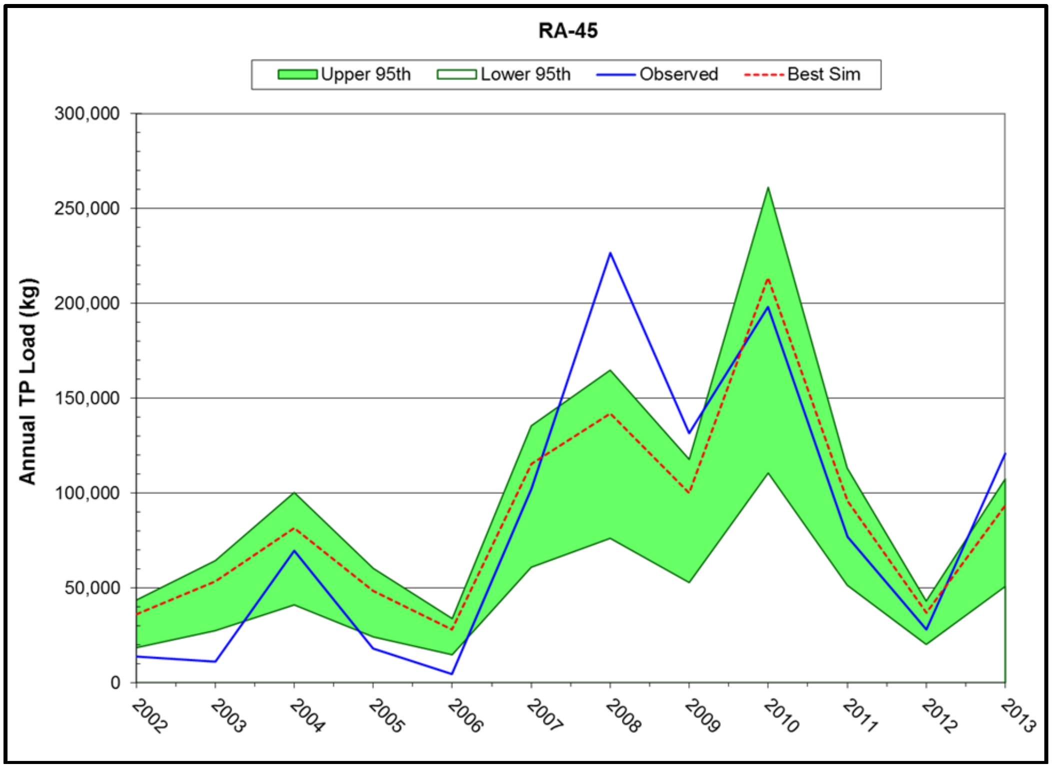


Figure E-20. Annual TP calibration on the Chariton River (RA-45). Green shaded region represents the 95% probability band (Abbaspour, 2015).

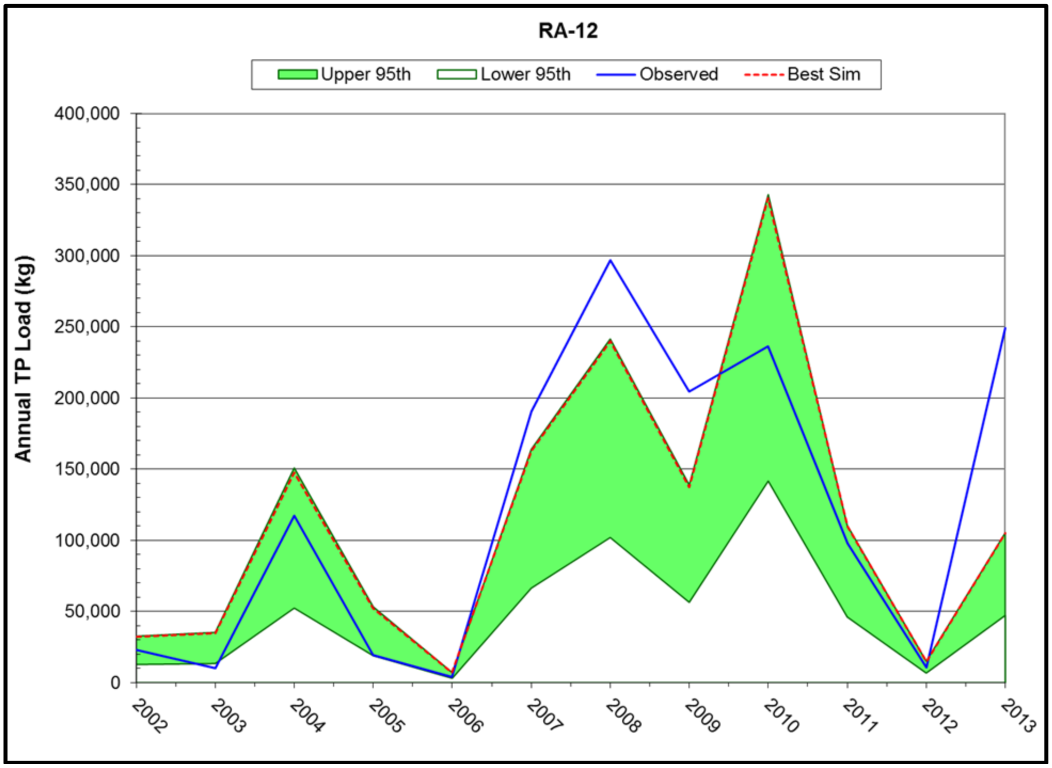


Figure E-21. Annual TP calibration on the Chariton River (RA-12). Green shaded region represents the 95% probability band (Abbaspour, 2015).

E.3. Model Limitations and Capabilities

All watershed / water quality models are over-simplifications of various and complex biological-chemical-physical processes that occur in nature, often with significant spatial and temporal variability and high degrees of uncertainty. As such, models are always imperfect representations of reality. The goal of modeling is to provide reasonable estimations of these complex processes to explain historical and / or future trends and assist decision-making.

Limitations
The SWAT model developed for the Rathbun Lake watershed has several limitations, including:

i. The model cannot reliably simulate spatial variation in channel erosion, and there is a disconnect between channel erosion and instream phosphorus transport (both erosion and deposition).

ii. The model was developed using land use inputs that reflect the mid-to-lake 2000s, a period during which significant land use conversion was observed.

iii. Model performance indicates declining accuracy at small spatial and temporal (i.e., daily) scales.

iv. Calibration was limited to hydrology, sediment, and nutrient loads.

Ramifications of these limitations include:

i. The model cannot be used to prioritize stream segments for mitigation of channel erosion, nor should it be used to simulate potential channel improvement practices and their impact on sediment and phosphorus transport.

ii. Use of the model outside of the calibration period will require, at a minimum, updating land use-based inputs that are representative of the desired scenario and / or simulation period.

iii. The model cannot reliably simulate the impacts of individual best management practices (BMPs) and there is a high degree of uncertainty in the prediction of short-term (e.g., single-event) peak flows and sediment and phosphorus losses.

iv. Without refinement, the model is not suitable for the predicting of nitrogen, pesticides, or other water quality parameters for which performance was not evaluated.

Capabilities
Despite these limitations, the DNR has determined the Rathbun Lake SWAT model to be useful for:

i. Deriving estimates of sediment and phosphorus losses from individual land use categories and planning-level subbasins (provided that the inherent uncertainty involved is acknowledged / understood.

ii. Assessing general spatial and temporal trends in hydrology and sediment and phosphorus transport

iii. Quantifying / illustrating the importance of prioritizing and targeting implementation of water quality improvement practices and strategies.

E.4. Interpretation of Model Output for Watershed Planning

Due to the instream transport limitations previously described, manipulation of simulated TP loads was required to reconcile instream TP loads with TP loads from upland areas. Even though acceptable calibration and validation was obtained for sediment and TP loads at the calibration locations, RA-45 on the Chariton River and RA-12 on the S. Fork Chariton, the disconnect between instream transport (particularly deposition) of sediment and TP resulted in artificially low TP yields simulated from upland areas. This was rectified by applying an adjustment factor, which is simply the ratio of simulated instream sediment-P concentrations at the monitoring locations to simulated upland sediment-P (Table E-8).

Table E-8. Upland sediment-phosphorus adjustment factors.

HUC-10 Basin (Monitoring ID)	SWAT Subbasins	SWAT Upland Sed-P (lbs/ton)	SWAT Instream Sed-P (lbs/ton)	Adjustment Factor
Chariton River (RA-45	1-39, 42, 45	1.26	1.79	1.42
S. Fork Chariton (RA-12)	40, 41, 43, 44, 46-68	0.75	1.40	1.87

The adjustment to annual TP loads is documented for each SWAT subbasin in Table E-9, along with a full inventory of simulated annual sediment and TP loads. The same adjustment was made to each hydrologic response unit (HRU), or unique combination of land use, soil type, and slope classification. The SWAT-simulated sediment values and adjusted TP values can be used for watershed planning purposes, including prioritization and estimation of potential load reductions through implementation of conservation practices. See Section 4 for more information on watershed planning and implementation.

Table E-9. Sediment and TP yields and exports by subbasin.

SWAT Subbasin	Sub Area (ac)	SWAT Sediment Yield (tons/ac)	SWAT Sediment Export (tons)	SWAT TP Yield[a] (lb/ac)	Adjusted TP Yield[b] (lbs/ac)	Adjusted TP Export[b] (tons)	Adjusted Sed-P[b] (lbs/ton)
1	2,759	0.52	1444.9	1.35	1.92	2.6	3.67
2	6,121	1.45	8871.9	1.85	2.63	8.1	1.82
3	5,252	1.30	6820.4	1.66	2.36	6.2	1.81
4	4,206	1.19	5003.6	1.68	2.39	5.0	2.01
5	7,248	1.03	7481.6	1.36	1.94	7.0	1.88
6	6,248	0.91	5658.2	1.26	1.80	5.6	1.99
7	5,894	0.90	5294.8	1.31	1.87	5.5	2.08
8	6,179	1.13	7001.6	1.51	2.14	6.6	1.89
9	4,831	1.08	5197.9	1.50	2.14	5.2	1.99
10	3,928	0.63	2482.8	1.10	1.57	3.1	2.48
11	3,807	0.57	2163.8	0.88	1.26	2.4	2.21
12	4,910	1.10	5422.9	1.41	2.00	4.9	1.81
13	4,793	1.47	7047.7	1.80	2.56	6.1	1.74
14	4,605	1.36	6249.1	1.61	2.29	5.3	1.69
15	4,424	0.90	3972.4	1.36	1.94	4.3	2.16
16	5,911	1.18	7000.8	1.51	2.15	6.4	1.82
17	3,252	1.27	4115.8	1.28	1.83	3.0	1.44
18	4,010	1.75	7019.4	1.75	2.49	5.0	1.42
19	6,551	0.62	4038.7	0.93	1.32	4.3	2.14
20	5,887	1.46	8597.6	1.79	2.54	7.5	1.74
21	2,236	1.89	4227.7	2.04	2.90	3.2	1.54
22	4,090	1.03	4210.8	1.50	2.14	4.4	2.08
23	7,583	1.13	8540.9	1.48	2.10	8.0	1.87
24	3,774	1.98	7458.7	1.91	2.71	5.1	1.37
25	4,293	1.83	7850.7	1.50	2.14	4.6	1.17
26	3,430	0.61	2079.3	1.36	1.93	3.3	3.19
27	4,799	1.30	6248.3	1.68	2.39	5.7	1.84
28	7,481	1.13	8440.2	1.22	1.73	6.5	1.53
29	4,484	0.83	3708.5	1.36	1.94	4.3	2.34
30	4,563	1.41	6446.9	1.74	2.48	5.7	1.75
31	3,658	1.78	6520.9	1.85	2.63	4.8	1.47
32	6,105	1.66	10128.6	1.74	2.47	7.5	1.49
33	7,233	0.43	3097.2	0.85	1.21	4.4	2.83
34	2,249	1.38	3097.7	1.45	2.06	2.3	1.50
35	2,097	0.49	1037.4	0.71	1.01	1.1	2.03
36	6,036	1.32	7996.4	1.85	2.63	8.0	1.99
37	4,340	2.88	12495.6	2.37	3.37	7.3	1.17
38	4,019	1.36	5483.8	1.58	2.24	4.5	1.64
39	6,462	0.45	2905.7	0.59	0.84	2.7	1.88
40	1,021	0.95	970.3	0.98	1.84	0.7	1.94
41	5,601	4.22	23625.8	2.96	5.53	11.8	1.31
42	2,467	0.38	925.6	0.95	1.36	1.7	3.61
43	4,391	2.75	12070.8	1.77	3.32	5.5	1.21
44	5,695	1.98	11293.0	2.01	3.76	8.1	1.90
45	10,124	0.37	3735.1	0.61	0.87	4.4	2.37
46	3,770	1.13	4277.1	1.09	2.04	2.9	1.80
47	6,763	5.09	34411.4	3.25	6.07	15.6	1.19
48	2,927	1.29	3778.7	1.47	2.75	3.1	2.13
49	4,109	5.58	22927.1	3.27	6.12	9.6	1.10
50	13,203	3.62	47819.8	2.55	4.77	24.0	1.32
51	4,842	4.00	19360.9	2.55	4.76	8.8	1.19
52	4,184	2.17	9069.0	1.79	3.34	5.3	1.54
53	5,950	2.78	16557.9	2.36	4.41	10.0	1.58
54	6,377	2.58	16459.6	1.97	3.68	8.9	1.43

SWAT Subbasin	Sub Area (ac)	SWAT Sediment Yield (tons/ac)	SWAT Sediment Export (tons)	SWAT TP Yield[a] (lb/ac)	Adjusted TP Yield[b] (lbs/ac)	Adjusted TP Export[b] (tons)	Adjusted Sed-P[b] (lbs/ton)
55	7,048	2.36	16612.9	1.70	3.17	8.5	1.35
56	6,597	3.17	20928.7	2.23	4.18	10.5	1.32
57	6,622	2.28	15128.4	1.77	3.31	8.3	1.45
58	2,114	2.91	6154.4	1.83	3.42	2.8	1.18
59	8,103	3.02	24431.0	2.09	3.90	12.0	1.29
60	5,809	3.25	18858.6	2.28	4.26	9.4	1.31
61	6,457	2.77	17914.2	2.39	4.46	11.0	1.61
62	8,049	3.96	31892.9	3.01	5.63	17.2	1.42
63	6,697	1.87	12546.5	1.79	3.34	8.5	1.78
64	7,221	2.13	15413.3	2.01	3.75	10.3	1.76
65	4,718	2.21	10440.0	1.63	3.04	5.5	1.38
66	4,870	2.41	11749.5	1.87	3.50	6.5	1.45
67	3,522	3.35	11785.7	2.81	5.26	7.0	1.57
68	5,037	2.80	14113.8	2.27	4.24	8.1	1.51
Totals	354,035		678,112			443.7	

[a] Unadjusted upland TP yields. Should not be used for watershed planning purposes.
[b] Adjusted upland TP yields to be used for watershed planning purposes.

E.5. References

Abbaspour, K.C. 2015. SWAT-CUP: SWAT Calibration and Uncertainty Programs - A User Manual. Eawag, Swiss Federal Institute of Aquatic Science and Technology. http://swat.tamu.edu/media/114860/usermanual_swatcup.pdf

Abbaspour, K. C., E. Rouholahnejad, S. Vaghefi, R. Srinivasan, H. Yang, and B. Klove. 2015b. A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWTA model. Journ. of Hydrol. 524: 733-752.

Arnold, J. G., D. N. Moriasi, P. W. Gassman, K. C. Abbaspour, M. J. White, R. Srinivasan, C. Santhi, R. D. Harmel, A. van Griensven, M. W. Van Liew, N. Kannan, and M. K. Jha. 2012. SWAT: Model use, calibration, and validation. Trans. of the ASABE. 55(4): 1491-1508.

Moriasi, D. N., M. W. Gitau, N. Pai, and P. Daggupati. 2015. Hydrologic and water quality models: Performance measures and evaluation criteria. Trans. ASABE. 58(6): 1763-1785.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 30 Aug 2016.

U.S Department of Agriculture-National Agricultural Statistics Service (USDA-NASS). 2016. https://quickstats.nass.usda.gov/. Last accessed May 3, 2016.

Zheng, C., M. C. Hill, G. Cao, & R. Ma. 2012. MT3DMS: Model use, calibration, and validation. Trans. ASABE. 55(4): 1549-1559. http://dx.doi.org/10.13031/2013.42263.

Appendix F --- Water Quality Model

In-lake water quality simulations were performed using BATHTUB 6.14, an empirical lake and reservoir eutrophication model. The BATHTUB model does not simulate dynamic conditions associated with storm events or individual growing seasons, but predicts average growing season conditions over multiple years. This section of the Water Quality Improvement Plan (WQIP) documents development and parameterization of the BATHTUB model for Rathbun Lake. Measurement and simulation of key watershed input variables to the BATHTUB model are discussed in Appendices C and D.

F.1. BATHTUB Model Description

BATHTUB is a steady-state water quality model developed by the U.S. Army Corps of Engineers (USACE) that performs empirical eutrophication simulations in lakes and reservoirs (Walker, 1999). It predicts average conditions for eutrophication-related parameters such as total phosphorus (TP), total nitrogen (TN), chlorophyll a (Chl-a), and transparency (Secchi depth). The model can distinguish between organic and inorganic forms of phosphorus and nitrogen if observed data are available, and simulates hypolimnetic oxygen depletion rates for lakes that are highly stratified. Water quality predictions are based on empirical models that have been calibrated and tested for lake and reservoirs nation-wide, and are particularly applicable to USACE flood control reservoirs such as Rathbun Lake (Walker, 1985). Simulated pathways for nutrient levels and water quality response in BATHTUB are illustrated in Figure F-1.

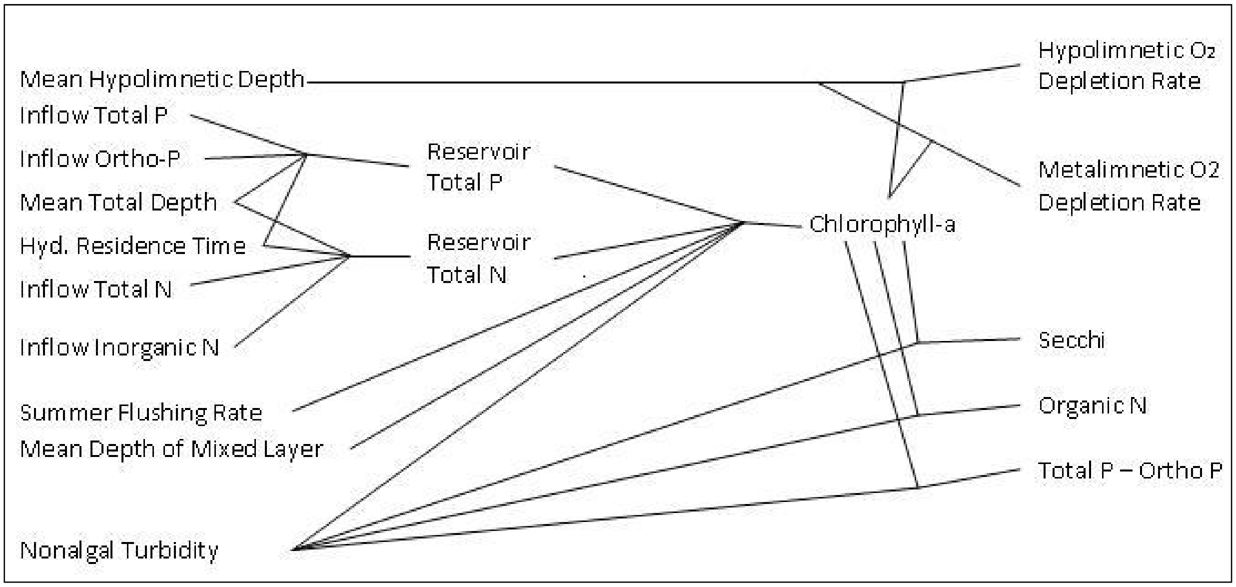


Figure F-1. Eutrophication control pathways in BATHTUB (Walker, 1999).

F.2. BATHTUB Model Development

BATHTUB includes several data input menus / modules to describe lake characteristics, simulation equations, and external (i.e., watershed) inputs. Data menus utilized to develop the BATHTUB model for Rathbun Lake include: model selections, global variables, segment data, and tributary data. The model selections menu allows the user to specify which modeling equations (i.e., empirical relationships) are used in the simulation of in-lake nitrogen, phosphorus, Chl-a, transparency, and other parameters. The global variables menu describes parameters consistent throughout the lake such as precipitation, evaporation, and atmospheric deposition. The segment data menu is used to describe lake morphometry, observed water quality, calibration factors, and internal loads in each segment of the lake / reservoir. The tributary data menu specifies nutrient loads to each segment using mean flow and concentration in the averaging period. The following sub-sections describe the development of the BATHTUB models and report input parameters for each menu. Three separate models were developed for Rathbun Lake: (1) a 2002-2007 conditions model used for calibration, (2) a 2008-2013 conditions model used for validating model inputs, and (3) a 2002-2013 model used to develop water quality targets and TMDLs for impaired segments of the lake.

Model Selections
BATHTUB includes several models / empirical relationships for simulating in-lake nutrients and eutrophication response. For TP, TN, Chl-a, and transparency, Models 1 and 2 are the most widely applicable to USACE reservoirs based upon model development and testing (Walker, 1999). However, alternative models are provided in BATHTUB to allow use of other well-established eutrophication models for water quality simulation in light of data constraints and site-specific conditions that do not fit Models 1 and 2.

Table F-1 reports the models selected for each parameter used to simulate eutrophication response in Rathbun Lake. Preference was given to Models 1 and 2 during evaluation of model performance and calibration, but final selection of model type was based on applicability to lake characteristics, availability of data, and agreement between predicted and observed data. Model selection inputs are the same for the calibration (2002-2007), validation (2008-2013), and long-term (2002-2013) models of Rathbun Lake. Model performance is discussed in more detail in Appendix F.3.

Table F-1. Model selections for Rathbun Lake.

Parameter	Model No.	Model Description
Total Phosphorus (TP)	*01	2nd order available P
Total Nitrogen (TN)	01	2nd order available N
Chlorophyll *a* (Chl-a)	02	P, Light, T
Transparency	03	vs. TP
Longitudinal Dispersion	04	Fischer
Phosphorus Calibration	*01	decay rates
Nitrogen Calibration	*01	decay rates
Availability Factors	02	All models except 2

* Asterisks indicate BATHTUB defaults

Global Variables
Global input variables for the Rathbun Lake BATHTUB model are monitored / estimated data consistently applied to all segments of the lake for a specified condition or time

period. The first global input is the averaging period. Either seasonal or annual averaging periods may be appropriate, depending on site-specific conditions. An annual averaging period was utilized to quantify historical / existing loads and in-lake water quality, and to develop TMDL targets for Rathbun Lake.

Average annual precipitation and evaporation inputs for both calibration (2002-2007) and validation (2008-2013) periods were taken from SWAT model output for Subbasin 45, which is adjacent to the main body of the lake just upstream of the dam (Segment A). Lake evaporation was assumed equal to evapotranspiration (ET) in Subbasin 45, which was calculated in SWAT using the Penman-Monteith (see Appendix E.1). Net change in reservoir storage was calculated as the average calendar year water level change within each modeling period according to USGS lake stage data (USGS Site 06903880). These data were summarized and converted to BATHTUB units (meters) and entered in the global data menu. Atmospheric deposition rates were obtained from regional and state studies (Anderson and Downing, 2006; Christiansen et al., 2012). Nutrient deposition rates are assumed to be entirely inorganic and consistent across calibration and validation periods (Table F-2).

Table F-2. Global variables input data.

Parameter	Observed Data	BATHTUB Input
Calibration Period (2002-2007):		
Averaging Period	Annual	1.0 year
Precipitation	35.5 in	0.90 m
Evaporation	34.0 in	0.86 m
Increase in Storage[a]	1.1 in	0.03 m
Atmospheric TP[b]	0.3 kg ha^{-1} yr^{-1}	30 mg m^{-2} yr^{-1}
Atmospheric TN [b]	11 kg ha^{-1} yr^{-1}	1100 mg m^{-2} yr^{-1}
Validation Period (2008-2013):		
Averaging Period	Annual	1.0 year
Precipitation	46.5 in	1.18 m
Evaporation	33.5 in	0.85 m
Increase in Storage[a]	0.3 in	0.01 m
Atmospheric TP[b]	0.3 kg ha^{-1} yr^{-1}	30 mg m^{-2} yr^{-1}
Atmospheric TN[b]	11 kg ha^{-1} yr^{-1}	1100 mg m^{-2} yr^{-1}

[1] Change in lake volume from beginning to end of simulation period.

[2] From Anderson and Downing (2006) and Christiansen et al. (2012).

Segment Data

Lake morphometry, observed water quality, calibration factors, and internal loads are all included in the segment data menu of the BATHTUB model, with distinct parameter values for each segment. In lakes with simple morphometry and one primary tributary, simulation of the entire lake as one segment is often acceptable. For Rathbun Lake, evaluation of individual segments of the lake (and inflowing tributaries / subbasins) is desirable and the lake is split into multiple segments. This provides more spatial resolution (Figure F-2) and allows water quality assessment of distinct segments included on the state's 303(d) list of impaired waters (Table F-3).

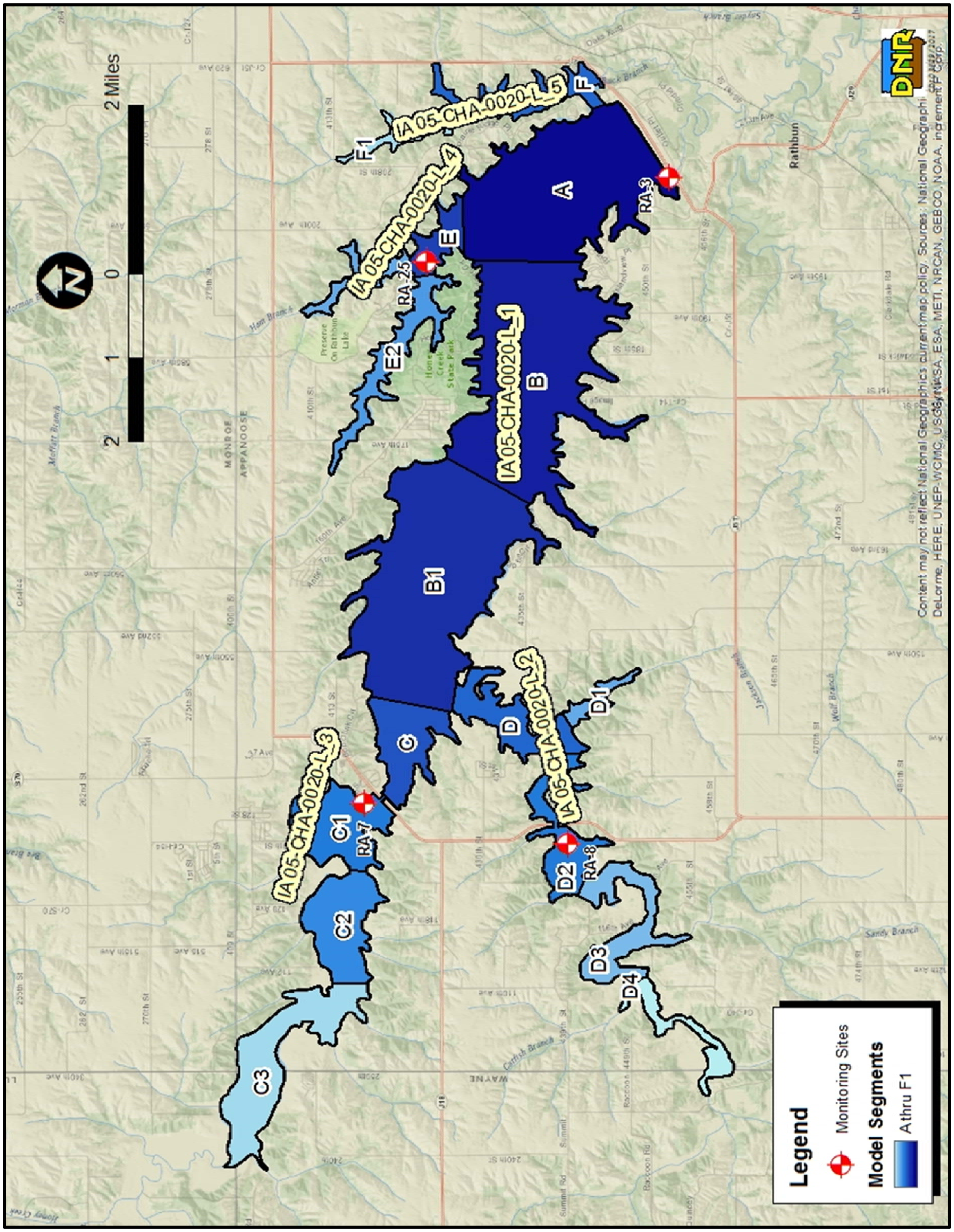


Figure F-2. BATHTUB model and 303(d) segments. One and two-digit alphanumeric labels are for model segments. Text strings beginning with “IA” indicate 303(d) list segments. Red and white symbols indicate monitoring locations.

Table F-3. Corresponding model and 303(d) list segments.

303(d) Segment	Description	BATHTUB Segment
IA 05-CHA-0020-L_1	Main lake near dam	A
IA 05-CHA-0020-L_2	S. Fork Chariton arm	D2
IA 05-CHA-0020-L_3	Chariton River arm	C1
IA 05-CHA-0020-L_4	Honey Creek arm	E

Segment morphometry was calculated for each segment in the model. Bathymetric survey data and ESRI ArcGIS software were used to estimate segment surface area, mean depth, and segment length. Temperature and dissolved oxygen (DO) profiles (Appendix C.5) were used to estimate the mixed layer depth and hypolimnetic thickness at the ambient monitoring locations in Segments A, C1, D2, and E. Most segments were determined to be unstratified based on profile data, segment depth, and propensity for wind-induced mixing. Observed water quality parameters (Table F-4) observed for the calibration period (2002-2007) and validation period (2008-2013) used for model performance evaluation were available only in Segments A, C1, D2, and E, which correspond to the 303(d) list segments included in Table F-3.

Table F-4. Observed water quality inputs for BATHTUB model segments.

	Calibration (2002-2007)				Validation (2008-2013)			
Parameter / Segment	A	C1	D2	E	A	C1	D2	E
Non-algal turbidity[a] (m^{-1})	0.76	1.59	2.49	0.66	1.27	1.36	1.61	1.38
TP (ppb)	58.4	118.9	191.1	63.7	72.3	117.5	125.0	66.1
TN (ppb)	1,060	1,260	2,010	960	1,620	1,820	1,870	1,500
Chl-a (ppb)	13.2	29.3	48.7	23.6	10.9	25.5	35.8	24.8
Secchi depth (m)	0.92	0.43	0.27	0.80	0.65	0.50	0.40	0.50
Organic-N (ppb)	594	649	1,091	567	667	831	1,068	687
TP – Ortho-P (ppb)	45.2	87.9	145.2	48.4	52.4	78.8	94.4	52.6

[a] Non-algal turbidity is calculated in BATHTUB as a function of Secchi depth and Chl-a.

Profile sampling (Appendix C.5) indicated that the lake is continuously well-mixed, therefore anoxic release of phosphorus from bottom sediments is likely a very rare occurrence. Additionally, it is the sediment-attached portion of TP, not the dissolved fraction, that is associated with non-algal turbidity impairments. Further, BATHTUB model guidance states that internal loading rates are normally set to 0, since the nutrient retention equations in the model already account for nutrient recycling that would normally occur in reservoirs (Walker, 1999; Walker, 1985). Relationships between wind speed and water quality in the Chariton River (RA-7) and S. Fork Chariton (RA-8) arms of the lake do suggest that, at times, wind-driving mixing and resuspension could affect non-algal turbidity levels (Section 3.2 of this WQIP). However, this observation may also be attributed to decreased settling rates during windy periods and not release or resuspension of bottom material. For these reasons internal phosphorus TP loads associated with sediment release / resuspension are not explicitly quantified in this WQIP.

Although not derived from the bottom sediments, in-lake deposition by waterfowl occurs in the water column of the lake. Nutrient loads from waterfowl, documented in Appendix D.10, were incorporated into the BATHTUB model using the internal load tab of the segments menu. Total loading rates of 165 kg yr^{-1} for TP and 529 kg yr^{-1} for TN equate to areal loading rates of 0.009 mg-P m^{-2} day^{-1} and 0.030 mg-N m^{-2} day^{-1}. These areal-based loading rates were added to each segment of the model. Because BATHTUB assumes all internal loads are bioavailable, the impact of waterfowl on eutrophication is likely over-estimated because some portion of the nutrient load is in non-bioavailable, organic forms and because goose-generated P does not directly contribute to the non-algal turbidity impairments.

Tributary Data

BATHTUB predicts in-lake water quality based on the global and segment parameters previously described and flow and nutrient loads from the contributing drainage area (i.e., watershed). Watershed flow and nutrient exports are entered into the tributary menu of the BATHTUB model. For the Rathbun Lake TMDL, tributary inputs were obtained from the flow and load estimates calculated using existing historical watershed monitoring data and the Flux calculations described in Appendix C.3. Contributions from ungaged areas of the watershed were projected to the lake using estimates derived from the monitoring data and characteristics of the ungaged drainage areas. Flow and load estimates were converted to units required for BATHTUB input and entered in the tributary data menu. Note that input requires conversion of watershed loads into concentrations. Table F-5 lists the monitored drainage areas (i.e., subwatersheds) that drain to each BATHTUB tributary and also documents the connectivity of BATHTUB tributaries and segments. Tributary input values are reported for the calibration (2002-2007) and validation (2008-2013) periods in Table F-6.

Table F-5. Relationship between monitored areas and BATHTUB.

Monitored DA[a]	Projected to: [b]	BATHTUB Tributary	BATHTUB Segment Name	BATHTUB Segment ID	BATHTUB Flows to Segment	BATHTUB Flows to ID
RA-39	Lake	--	A	1	Out of Res	0
RA-39	Lake	2	B1	3	B	2
RA-39	Lake	1	B	2	A	1
RA-15 & RA-41	RA-7	4	C3	7	C2	7
RA-15 & RA-41	RA-7	3	C2	6	C1	6
RA-15 & RA-41	RA-7	--	C1	5	C	5
RA-15 & RA-41	RA-7	--	C	4	B1	4
RA-12	RA-8	8	D4	12	D3	12
RA-12	RA-8	7	D3	11	D2	11
RA-12	RA-8	6	D2	10	D	10
RA-12	RA-8	5	D1	9	D	9
RA-12	RA-8	--	D	8	B1	8
RA-39	Lake	10	E2	15	E	15
RA-39	Lake	9	E1	14	E	14
RA-39	Lake	--	E	13	A	13
RA-39	Lake	12	F1	17	F	17
RA-39	Lake	11	F	16	A	16

[a] DA = drainage area (i.e., watershed) upstream of monitoring sites.

[b] Loads from unmonitored drainage areas (i.e., areas adjacent to the lake and draining to sites RA-7 and RA-8) were estimated based on projections from monitored areas.

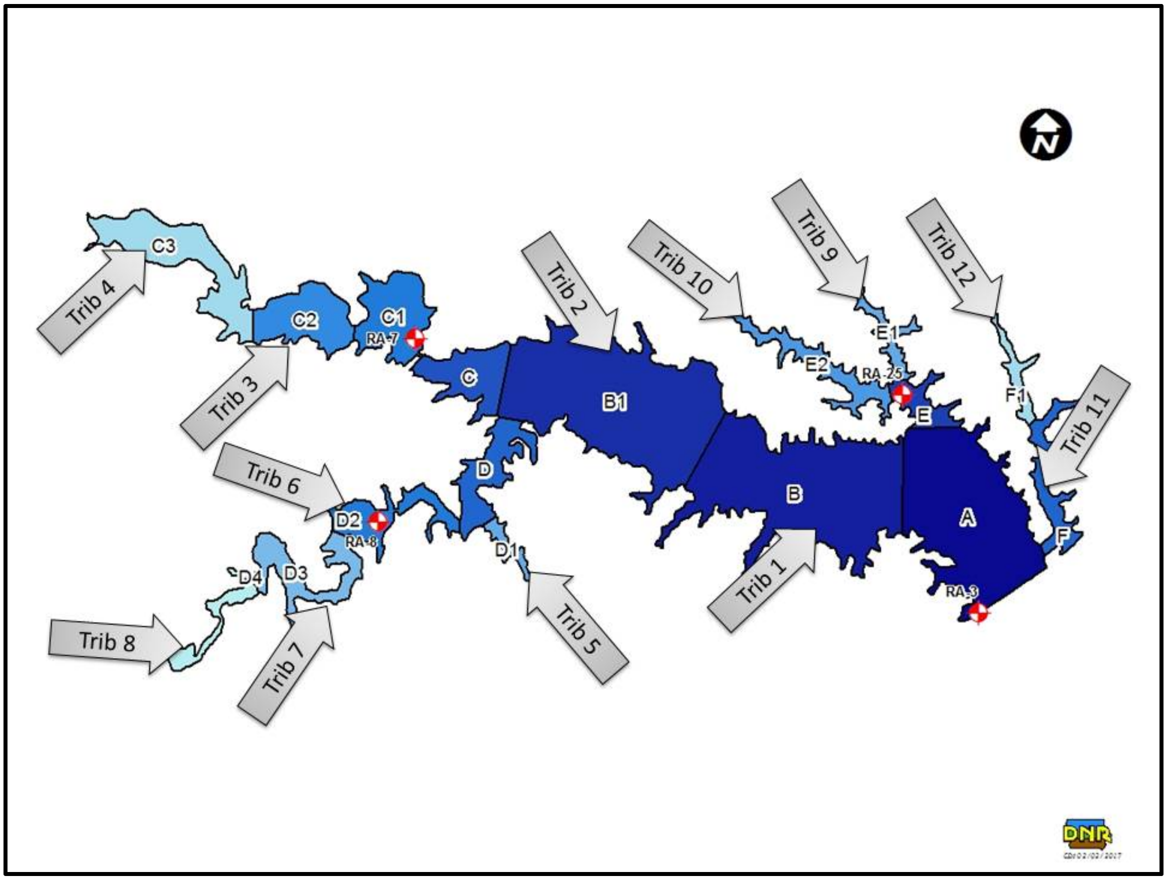


Figure F-3. BATHTUB tributary and segment linkage map.

Table F-6. BATHTUB tributary input values.

		Calibration (2002-2007)					Validation (2008-2013)				
Trib	DA[a] (km^2)	Flow (hm^3)	TP[b] (ppb)	OP[b] (ppb)	TN[b] (ppb)	IN[b] (ppb)	Flow (hm^3)	TP[b] (ppb)	OP[b] (ppb)	TN[b] (ppb)	IN[b] (ppb)
1	40.97	7.3	624.1	179.6	3723.9	2183.9	21	555.5	118.9	3996.1	1880.2
2	30.28	5.4	624.1	179.6	3723.9	2183.9	15.5	555.5	118.9	3996.1	1880.2
3	29.27	4.3	964.4	146.5	4739.7	2706.0	13.8	897.2	101.2	5009.5	2097.1
4	660.47	88.4	746.1	165.8	4722.3	2973.7	298.9	732.1	127.6	4747.4	2504.4
5	11.85	1.7	964.4	146.5	4739.7	2706.0	5.6	897.2	101.2	5009.5	2097.1
6	15.26	2.2	964.4	146.5	4739.7	2706.0	7.2	897.2	101.2	5009.5	2097.1
7	23.05	3.4	964.4	146.5	4739.7	2706.0	10.9	897.2	101.2	5009.5	2097.1
8	559.61	81.8	964.4	146.5	4739.7	2706.0	264.7	897.2	101.2	5009.5	2097.1
9	9.1	1.6	624.1	179.6	3723.9	2183.9	4.7	555.5	118.9	3996.1	1880.2
10	26.63	4.8	624.1	179.6	3723.9	2183.9	13.7	555.5	118.9	3996.1	1880.2
11	9.98	1.8	624.1	179.6	3723.9	2183.9	5.1	555.5	118.9	3996.1	1880.2
12	16.26	2.9	624.1	179.6	3723.9	2183.9	8.3	555.5	118.9	3996.1	1880.2

[a] DA = drainage area to each BATHTUB tributary
[b] TP = total phosphorus, OP = ortho-phosphorus, TN = total nitrogen, IN = inorganic nitrogen

F.3. BATHTUB Calibration and Performance

Performance of the BATHTUB model was assessed by comparing predicted water quality with observed data collected in Rathbun Lake. Simulation of TP concentration and Secchi depth were critical for TMDL development and were the focus of calibration efforts. Chl-a predictions were also calibrated even though there are no current algal impairments in the lake. If non-algal turbidity is reduced to the point of preventing light-limiting conditions, algal growth could impair the lake, especially in the shallower, upper arms of the impoundment. Though not pertinent to the TMDL, nitrogen was also calibrated so that decision-makers could make use of the nitrogen algorithms in BATHTUB to evaluate nitrogen removal in the lake (for downstream water quality benefits) or if future conditions ever warrant nitrogen reduction for control of algal blooms.

Calibration/Validation
The BATHTUB model was calibrated to 2002-2007 conditions, which includes observed rainfall near the lake, nutrient loads to the lake estimated from monitoring data, and observed water quality in Segments A, C1, D2, and E of the lake during the calibration period. Adjustments were made to the calibration coefficients for each segment group (Table F-7) to reconcile observed and predicted water quality parameters. Spatial calibration required a wide range of coefficient adjustments across BATHTUB Segment Groups, but all values are within the recommended range according to the BATHTUB user guidance (Walker, 1999). After calibrating BATHTUB, hydrologic and nutrient-related inputs were adjusted to reflect 2008-2013 conditions, which was much wetter than 2002-2007. Model selections and calibration coefficients were unchanged from calibrated values, providing validation of the model's performance in conditions that differ from the calibration period.

Predicted annual average TP, TN, Chl-a, and Secchi depth values for each of the monitored segments of Rathbun Lake are reported in Table F-8. Percent bias between observed and predicted TP and Secchi depth values are also provided, as those two parameters are critical for development of the TMDLs for Rathbun Lake. Calibrated water quality parameters values are in near-perfect agreement with observed values, having percent bias values no greater than 0.2%.

Predicted TP and Secchi depth in the validation model is good (low bias) in the main body of the lake near the dam (RA-3), but do deviate more significantly from observed values in the arms of the reservoir. Secchi depth values are under-predicted by 20.9 and 34.3% for Segments C1 and D2, respectively, revealing that the model simulates worse water clarity than the monitoring data. Conversely, Secchi depth (i.e., water transparency) was over-predicted by 43.5% for Segment E (Honey Creek). Although these biases seem large, they equate to Secchi depth differences of no greater than 0.2 meters and translate to no greater than 8.3% difference in the predicted Secchi depth TSI (Table F-8). The increased bias associated with the validation model is not surprising since the model was calibrated to much drier conditions, which influenced the water balance, loading rates, and likely the dispersion / mixing between lake segments.

Table F-7. Segment-specific calibration coefficients.

Segment Group	Segment Name	Segment ID	Calibration Parameters & Coefficients TP	TN	Chl-a	Secchi
1	A	1	1.28	0.57	0.64	1.12
	B	2	1.28	0.57	0.64	1.12
	B1	3	1.28	0.57	0.64	1.12
2	C	4	0.42	2.64	0.54	0.9
	C1	5	0.42	2.64	0.54	0.9
	C2	6	0.42	2.64	0.54	0.9
	C3	7	0.42	2.64	0.54	0.9
3	D	8	0.6	1.2	0.48	0.82
	D1	9	0.6	1.2	0.48	0.82
	D2	10	0.6	1.2	0.48	0.82
	D3	11	0.6	1.2	0.48	0.82
	D4	12	0.6	1.2	0.48	0.82
4	E	13	1	1.56	0.73	1.05
	E1	14	1	1.56	0.73	1.05
	E2	15	1	1.56	0.73	1.05
5	F	16	1	1.56	0.73	1.05
	F1	17	1	1.56	0.73	1.05

Table F-8. Simulated water quality for calibration and validation periods.

	Calibration (2002-2007)				Validation (2008-2013)			
Parameter / Segment	A	C1	D2	E	A	C1	D2	E
TP (ppb)	58.4	119.0	191.4	63.6	75.5	130.3	197.5	72.9
TN (ppb)	1060	1260	2010	962	1467	1678	2356	1256
Chl-a (ppb)	13.2	29.4	49.3	23.6	14.5	33.1	54.9	21.9
Secchi depth (m)	0.9	0.4	0.3	0.8	0.7	0.4	0.3	0.7
Secchi TSI	61.4	72.4	78.9	63.3	64.2	73.4	79.3	64.8
Performance Measures	% Bias[a]				% Bias[a]			
TP	0.0	-0.1	-0.2	+0.1	-4.4	-10.9	-58.0	-10.3
Secchi depth	+1.5	+1.4	+0.3	+0.5	-14.7	+20.9	+34.3	-43.5
Secchi TSI	-0.4	-0.3	-0.1	-0.1	+3.0	-4.7	-8.3	+7.4

[a] Difference (%) between observed and simulated values for TMDL parameters. Negative values indicate over-prediction.

Development of Water Quality Targets and TMDLs

In-lake water quality targets and the subsequent TMDLs were developed using the 2008-2013 validation conditions model previously described. The Load Response option in BATHTUB was run for 2008-2013 conditions to quantify the allowable phosphorus loads that meet the delisting Secchi TSI criteria of no greater than 63. The load response (Section 3.3) and subsequent TMDLs (Section 3.6) are based on the total loads to Rathbun Lake rather than isolated loads to each segment via corresponding tributaries. The practical ramification of this is that simulated reductions are uniform across tributaries to the lake. This is necessary oversimplification because water quality of individual lake segments is inter-related through dispersion processes, and because it is not possible to predict the spatial distribution of future TP reductions.

In-Lake Model for Long-Term Planning

A third model scenario that is representative of the entire 2002-2013 period better reflects long-term conditions because it includes both wet and dry periods and a 12-year time frame is more appropriate for detecting changes in water quality resulting from implementation of conservation practices. To provide information useful to implementation planning, hydrologic and loading inputs to the BATHTUB model were modified to reflect the 2002-2013 average conditions, but calibration coefficients were left unchanged from the calibration and validation models. Observed and predicted water quality is reported in Table F-9. Predicted Secchi depths are slightly lower than observed values, but differences are not apparent when rounding to the nearest tenth of a meter. Additionally, under-prediction of Secchi depth (and corresponding over-prediction of Secchi TSI values) introduces an implicit margin of safety when utilized for planning, since observed water quality is better than the modeled result. Therefore, Secchi depths accompanying the necessary TP reductions will likely be better than predicted by the model.

Table F-9. Observed and predicted water quality useful for long-term planning.

	Observed (2002-2013)				Predicted (2002-2013)			
Parameter / Segment	**A**	**C1**	**D2**	**E**	**A**	**C1**	**D2**	**E**
TP (ppb)	64.2	118.2	159.0	64.9	67.0	123.2	191.8	67.3
TN (ppb)	1,290	1,530	1,939	1,218	1,283	1,492	2,203	1,115
Chl-a (ppb)	12.3	27.5	42.5	24.1	14.9	30.1	48.0	25.3
Secchi depth (m)	0.8	0.4	0.3	0.8	0.8	0.4	0.3	0.8
Secchi TSI	62.5	71.5	77.3	63.8	62.9	72.8	78.9	63.9
Performance Measures					**% Bias[a]**			
TP					-4.3	-4.3	-20.6	-3.8
Secchi depth					+2.8	+8.3	+10.4	+1.0
Secchi TSI					-0.7	-1.7	-2.1	-0.2

[a] Difference (%) between observed and simulated values for TMDL parameters. Negative values indicate over-prediction.

F.4. References

Anderson, K., and J. Downing. 2006. Dry and wet atmospheric deposition of nitrogen, phosphorus, and silicon in an agricultural region. Water, Air, and Soil Pollution, 176:351-374.

Walker, W. 1985. Empirical methods for predicting eutrophication in impoundments; Report 4, Phase III: Applications manual, "Technical Report E-81-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Walker, W. 1996 (Updated 1999). Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. US Army Corps of Engineers Waterways Experiment Station. Instruction Report W-96-2.

Appendix G --- Expressing Average Loads as Daily Maximums

In November of 2006, The U.S. Environmental Protection Agency (EPA) issued a memorandum (EPA, 2006) entitled *Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits.* In the context of the memorandum, EPA

> *"…recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increments. In addition, TMDL submissions may include alternative, non-daily pollutant load expressions in order to facilitate implementation of the applicable water quality standards…"*

G.1. Calculation of Maximum Daily Loads

Per the EPA requirements, the loading capacity of Rathbun Lake for TP is expressed as both a maximum annual average and a daily maximum load. The annual average load is equivalent to the long-term average utilized for development of water quality-based effluent limits, and is more applicable to the assessment of in-lake water quality and water quality improvement actions. The daily maximum load expression satisfies the legal uncertainty addressed in the EPA memorandum.

The maximum daily load was estimated from the allowable growing season average using a statistical approach. The methodology for this approach is taken directly from the follow-up guidance document titled *Options for Expressing Daily Loads in TMDLs* (EPA, 2007), which was issued shortly after the November 2006 memorandum cited previously. This methodology can also be found in EPA's 1991 *Technical Support Document for Water Quality Based Toxics Control*.

The *Options for Expressing Daily Loads in TMDLs* document presents a similar case study in which a statistical approach is considered the best option for identifying a maximum daily load (MDL) that corresponds to the allowable average load. The method calculates the daily maximum based on a long-term average and considers variation. This method is represented by the equation:

$$MDL = LTA \times e^{[z\sigma - 0.5\sigma^2]}$$

Where: MDL = maximum daily limit
LTA = long term average
z = z statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2 + 1)$
CV = coefficient of variation

The long-term average (LTA) is the allowable average annual load divided by the 365-day averaging period. A recurrence interval of 99% was chosen for all calculations, which corresponds to a z-statistic of 2.326. The coefficient of variation (CV) is the ratio of the standard deviation to the mean of daily loads. For calculation of the TMDL daily maximum expression, a CV of 4.5 was derived from the 2008-2013 daily loads estimated using monitoring data and the Flux32 software (Walker, 1999). Daily maximum WLA values were calculated individually (see Table 3-7) and aggregated. Daily maximum values for the MOS are 10% of the TMDL values. Daily maximum LAs are equal to the daily maximum TMDL values minus the MOS and WLA values. The calculation of maximum daily values for the main-body, near-dam segment of the lake (IA 05-CHA-0020-L_1) at monitoring location RA-3 is summarized in Table G-1. The calculation was performed on all four impaired lake segments as reported in Section 3.6 (Table 3-10).

Table G-1. LTA to MDL calculations for IA 05-CHA-0020-L_1 (RA-3).

Parameter	TMDL	Σ WLA	Σ LA	MOS
LTA (lbs/day)	2,511.2	Aggregate of individual WLAs (see Table 3-7)	LA=TMDL-WLA-MOS	10% of TMDL
Z Statistic	2.326			
CV	4.5			
σ^2	3.056			
Multiplier	12.66			
MDL (lbs/day)	**31,786**	**93**	**28,514**	**3,179**

G.2. References

U.S. Environmental Protection Agency (EPA). 1991. Technical Support Document for Water Quality-based Toxics Control. EPA/505/2-90-001. EPA Office of Water, Washington, DC.

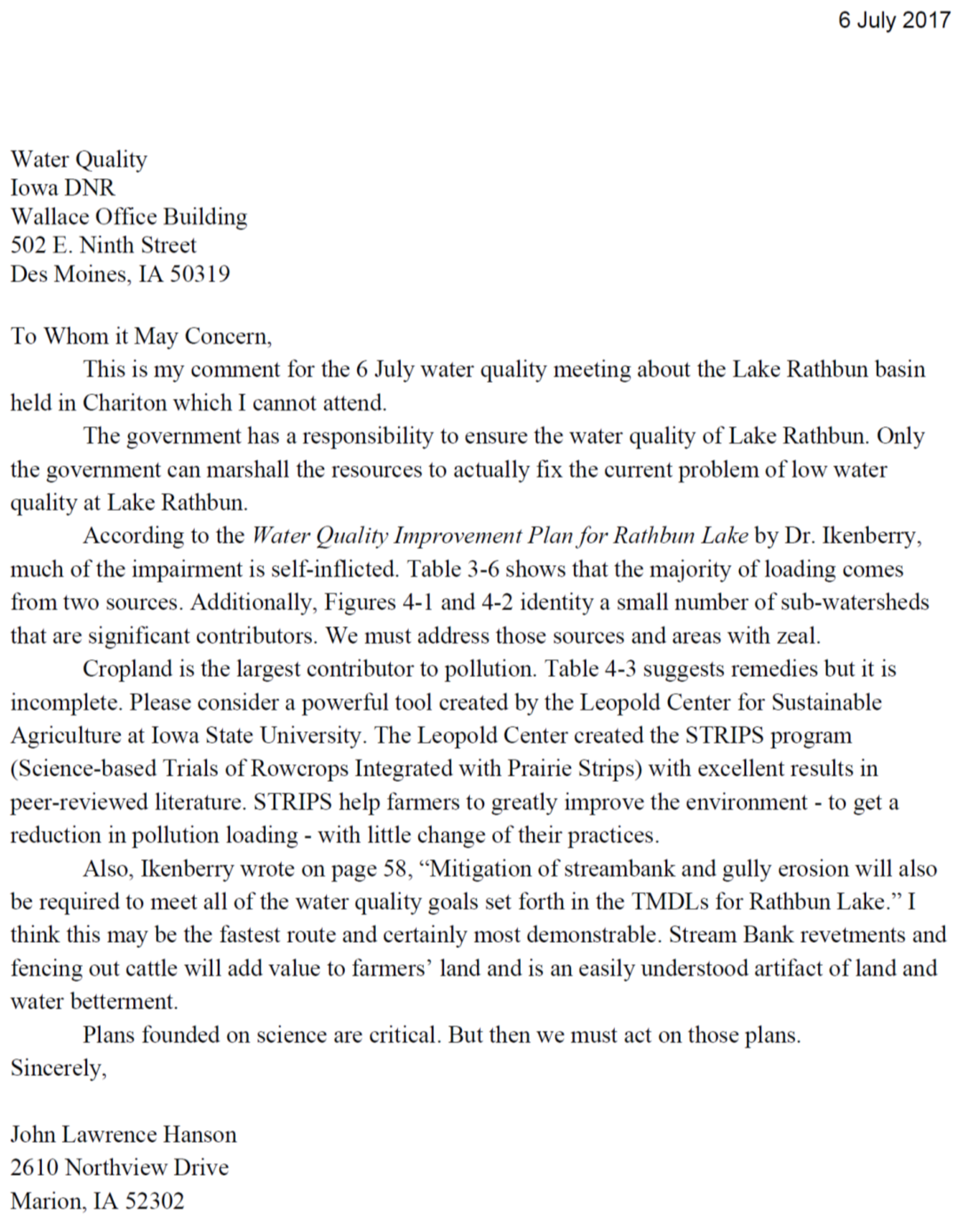
U.S. Environmental Protection Agency (EPA). 2006. Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits. Memorandum from Benjamin Grumbles, Assistant Administrator, EPA Office of Water, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2007. Options for Expressing Daily Loads in TMDLs (Draft). EPA Office of Wetlands, Oceans & Watersheds, Washington, DC.

Walker, W. 1999. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. US Army Corps of Engineers Waterways Experiment Station. Instruction Report W-96-2.

Appendix H --- Public Comments

One public comment was made during the public comment period. That comment and the Iowa DNR response is included on the next two pages.



6 July 2017

Water Quality
Iowa DNR
Wallace Office Building
502 E. Ninth Street
Des Moines, IA 50319

To Whom it May Concern,

This is my comment for the 6 July water quality meeting about the Lake Rathbun basin held in Chariton which I cannot attend.

The government has a responsibility to ensure the water quality of Lake Rathbun. Only the government can marshall the resources to actually fix the current problem of low water quality at Lake Rathbun.

According to the *Water Quality Improvement Plan for Rathbun Lake* by Dr. Ikenberry, much of the impairment is self-inflicted. Table 3-6 shows that the majority of loading comes from two sources. Additionally, Figures 4-1 and 4-2 identity a small number of sub-watersheds that are significant contributors. We must address those sources and areas with zeal.

Cropland is the largest contributor to pollution. Table 4-3 suggests remedies but it is incomplete. Please consider a powerful tool created by the Leopold Center for Sustainable Agriculture at Iowa State University. The Leopold Center created the STRIPS program (Science-based Trials of Rowcrops Integrated with Prairie Strips) with excellent results in peer-reviewed literature. STRIPS help farmers to greatly improve the environment - to get a reduction in pollution loading - with little change of their practices.

Also, Ikenberry wrote on page 58, "Mitigation of streambank and gully erosion will also be required to meet all of the water quality goals set forth in the TMDLs for Rathbun Lake." I think this may be the fastest route and certainly most demonstrable. Stream Bank revetments and fencing out cattle will add value to farmers' land and is an easily understood artifact of land and water betterment.

Plans founded on science are critical. But then we must act on those plans.

Sincerely,

John Lawrence Hanson
2610 Northview Drive
Marion, IA 52302

DEPARTMENT OF NATURAL RESOURCES
GOVERNOR KIM REYNOLDS
LT. GOVERNOR ADAM GREGG
DIRECTOR CHUCK GIPP

July 26, 2017

J. Lawrence Hanson
2610 Northview Drive
Marion, IA 52302

Subject: Rathbun Lake public comment response

Dear Mr. Hanson,

Thank you for your comments on the Rathbun Lake draft Water Quality Improvement Plan received during the public comment period.

The Iowa DNR's TMDL Program is well aware of the STRIPs research that Dr. Helmers and his associates at Iowa State University have conducted. Research from the STRIPs program has reported water quality benefits and is consistent with many of the recommendations found in the Implementation Section of the Water Quality Improvement Plan. It is not the intent of the Water Quality Improvement Plan to prescribe any specific best management practices but rather to provide a toolbox full of practices that would potentially work to improve water quality. The ultimate choice for any land use changes in the watershed would be made by the landowners If landowners are interested in implementing practices like those researched in the STRIPs research there are outlets to receive technical assistance.

As to your comment regarding streambank and gully erosion, we would encourage you to engage with the local watershed planning group with specific implementation ideas. Rathbun has a well-established watershed group focused on improving the watershed.

Thank you again for your comments and let me know if you have further questions.

Sincerely,

Jeff Berckes, TMDL Program Coordinator
Watershed Improvement Section

WALLACE BUILDING, 502 E 9TH ST, DES MOINES IA 50319
Phone: 515-725-8200 www.IowaDNR.gov Fax: 515-725-820

Appendix I --- DNR Project Files and Locations

This appendix is primarily for future reference by DNR staff that may wish to access the original spreadsheets, models, maps, figures, and other files utilized in the development of the TMDL. Files/folders highlighted in yellow included in submittal to EPA.

Folder	File(s)	Description
DATA		
\\...\Data\Analysis\TribData_Analysis\ObservedFlows_DataReduction	Final_Observed_Flows_2015-07-28.xls	The source for annual, monthly, and daily flow data for RA-45 (USGS 06903400), RA-12 (USGS 06903700), RA-15, RA-39, and RA-41.
\\...\Data\Analysis\TribData_Analysis\WaterQualityMonitoring	Tributary_WQ.xls	The source for all instream (tributary) water quality data (both grab and event sampling data).
\\...\Data\Analysis\Trib_Lake_Correlations	multiple files	Development of matrix plots investigating relationships between tributary data and lake data.
\\...\Data\NPDES	multiple files	Raw and reduced data for WWTPs and unsewered communities
\\...\Data\Analysis\LakeData_Analysis	InLake_Analysis.xls	The source for all reduction/analysis of in-lake data by USACE and DNR. Includes calculation of WQ data/stats for BATHTUB model segments and periods/conditions.
MODELING		
\\...\Modeling\	Source_Inventory_2008-2013.xls	Sediment estimates, sediment delivery correction, and load allocation info for Table 3-6, Figure 3-19, and Table 3-8.
	TMDL_Equation_Calcs_2008-13.xls	Summary calcs for annual avg and daily max TMDL components for Chapter 3.
\\...\Modeling\PointSources\	OnsiteWW_Loads.xls	Calculations for P loads from onsite WW systems.
	WWTPs_UnsewCom.xls	Calculations for P loads from WWTPs.
\\...\Modeling\Streambank	BankErosion.xls	Streambank estimates from Jason Palmer with SWAT output and sediment-P estimates added.
	BankSediment-P.xls	Summary of Rathbun streambank studies for selection of bank sediment-P value.
\\...\Modeling\Wildlife\	Deer_Loads.xls	Calculation of loads from deer and wildlife
	Goose_Loads.xls	Calculation of nutrient loads from geese
\\...\Modeling\SWAT\	SWAT_Monitoring.xls	Matches up monitoring station IDs, SWAT Reach/Sub IDs, contributing subs and sub areas, etc. Used for linking SWAT to BATHTUB
	HRU_list.xls	List of HRUs post-filtering (i.e., actual simulated HRUs).
	SWAT_LU	Includes LU and HRU reports for various land use inputs evaluated during model setup. Most importantly is the 2006 HRU report, which summarizes final LU for modeling.
\\...\Modeling\SWAT\OpsMgt\	CropGrowth.xls	Includes calculations/basis for crop parameters in PMIX (added to plant.dat) for pasture
	Grazing.xls	Includes data and calcs for cattle population/density and grazing inputs to SWAT. Also includes calcs for direct deposition by cattle into streams.
	OpsMgtSch.xls	Includes all scheduled management operations (crop rotations, plant/harvest, fertilizer application, etc.
	OpsMgt_Ref folder	Supporting/reference data for management operations (fertilizer, crop growth, grazing, etc.)

\\...\Modeling\SWAT\Output\	SubLoading_Scenarios.xls	Subbasin output for calculating subwatershed sediment and P yields and sediment P concentrations.
	HRU_Loading_Scenarios.xls	HRU output for calculating HRU-specific sediment and P yields and sediment P concentrations.
\\...\Modeling\SWAT\Output\Calibration\	P_Final.Sufi2.SwatCup_Output.hru_2008-2013.xls	Model output (annual) to develop and-use based source assessment results for Tables 3-6 and 3-8.
	P_Final.Sufi2.SwatCup_Output.sub	Model output (annual) used to develop SWAT subbasin-based sediment and TP yields/losses. Used primarily for the Implementation Plan in Section 4.
	P_Final.Sufi2.SwatCup_Output.rch	Model output (annual) for reaches.
	P_Final.Sufi2.SwatCup_Output.sed	Model output (annual) for sediment in reaches.
\\...\Modeling\SWAT\Output\Calibration\CropGrowth	Final_CORN.xls	Files to check/verify appropriateness of corn yields
	Final_SOYB.xls	Files to check/verify appropriateness of soybean yields.
	Final_ALFA.xls	Files to check/verify appropriateness of alfalfa yields
\\...\Modeling\\SWAT\Output\Calibration\Hydro	Various hydrology calibration files.	Too many files to send. If EPA checks calibration, they will likely develop their own output spreadsheets. Could provide to EPA upon request.
\\...\Modeling\\SWAT\Output\Calibration\Phosphorus	Various phosphorus calibration files.	Too many files to send. If EPA checks calibration, they will likely develop their own output spreadsheets. Could provide to EPA upon request.
\\...\Modeling\\SWAT\Output\Calibration\Sediment	Various sediment calibration files.	Too many files to send. If EPA checks calibration, they will likely develop their own output spreadsheets. Could provide to EPA upon request.
\\...\Modeling\SWAT\Climate_Input\	various text files and folder with updated PRISM data	SWAT model temp and precip input files
\\...\Modeling\SWAT\RTE_Inputs	Subs_Cross-Sections.xls	Includes point data and adjusted trapezoidal cross-sections for SWAT input from ArcGIS cross-section construction using 3m DEM.
\\...\Modeling\SWAT\Final_TxtInOut	The final, calibrated SWAT model input files.	Includes all final, calibrated, text input/output files. This is where the model can be run from.
\\...\Modeling\SWAT-CUP	CUP_RA12_06903700_TPOut_2016-09-23.xls	Excel files for SWAT-CUP input data sets (for flow, TSS, and TP).
	CUP_RA45_06903400_TPOut_2016-09-23.xls	
	CUP_RA45_06903400_TSSOut_2017-03-10.xls	
	CUP_RA12_06903700_TSSOut_2017-03-10.xls	
	CUP_USGS_06903700_FlowOut_2015-07-30.xls	
	CUP_USGS_06903400_FlowOut_2015-07-30	
\\...\Modeling\SWAT-CUP\Hydro_Final.Sufi2.SwatCup\Iterations\Daily_FullRange	Daily flow calibration (SWAT-CUP iteration files)	
\\...\Modeling\SWAT-CUP\Hydro_Final.Sufi2.SwatCup\Iterations\Monthly_FullRange	Monthly flow calibration (SWAT-CUP iteration files)	
\\...\Modeling\SWAT-CUP\P_Final.Sufi2.SwatCup\Iterations\Monthly\Monthly_FullRange	Monthly TP calibration (SWAT-CUP iteration files)	Sufi2.In files to set up monthly TP calibration run. Sufi2.Out files contain results (not actual SWAT model input/output, but the files controlling and summarizing calibration.
\\...\Modeling\SWAT-CUP\P_Final.Sufi2.SwatCup\Iterations\Annual\FullRange	Annual TP calibration (SWAT-CUP iteration files)	Sufi2.In files to set up annual TP calibration run. Sufi2.Out files contain results (not actual SWAT model input/output, but the files controlling and summarizing calibration.

\\...\Modeling\SWAT-CUP\Sediment_Final.Sufi2.SwatCup\Iterations\Monthly_FullRange	Monthly sediment calibration (SWAT-CUP iteration files)	Sufi2.In files to set up monthly sediment calibration run. Sufi2.Out files contain results (not actual SWAT model input/output, but the files controlling and summarizing calibration.
\\...\Modeling\SWAT-CUP\Sediment_Final.Sufi2.SwatCup\Iterations\Annual_FullRange	Annual sediment calibration (SWAT-CUP iteration files)	Sufi2.In files to set up annual sediment calibration run. Sufi2.Out files contain results (not actual SWAT model input/output, but the files controlling and summarizing calibration.
\\...\Modeling\BATHTUB	Global_WatBal_2016-12-13.xls	**ET estimates (from SWAT) reduced for BATHTUB input **Reservoir levels (from USGS) reduced to stage changes for BATHTUB input
	HydResTime_checks.xls	**Comparison of residence time calculated using lake volume USGS flows downstream of dam with residence times calculated using inflows measured/calculated using monitoring data. Helpful for comparing with BATHTUB predictions.
\\...\Modeling\BATHTUB\BT_Flux	LoadResponse_2002-2007.xls LoadResponse_2008-2013.xls LoadResponse_2002-2013.xls	Inputs and outputs for BATHTUB models for 2002-2007 calibration, 2008-2013 validation, and 2002-2013 application. Developed using monitoring data and Flux32 projections (not watershed model).
	Cal_02-07_SegGrp.btb	Final calibration period model
	Val_08-13_SegGrp.btb	Final validation period model
	Val_02-13_SegGrp.btb	Final model used for TMDL development
\\...\Modeling\BATHTUB\BT_Flux\ConservativeSubstance_calib	Files in which conservative substance (TDS, chloride, spec cond) was attempted	Goal was to develop diffusion coefficients using conservative substance. Did not work due to inconsistent monitoring parameters and results.
\\...\Modeling\Load_Calcs	Projected Loads.xls	Loads projected to the lake, by tributary and lake segment, using 1997-2014 monitoring data and the USACE Flux32 tool.
\\...\Modeling\Load_Calcs\Flux	Flux_Summary.xls	Flux outputs summarized for RA-12, RA-15, RA-39, and RA-41 (pre-cursor to Projected_Loads.xls
	Flux_Methods.doc	Describes Flux32 assumptions and methodology
\\iowa.gov.state.ia.us\data\DNR_WQB_WIS_TMDL\Draft_TMDLs\Rathbun-L_00\Modeling\MassBalance	Multiple files	Attempted mass balance modeling of water and P. In the end, decided not to utilize the results. With some work, this could be useful or interesting.