NORTH DAKOTA
DEPARTMENT of HEALTH
Water Quality

State of North Dakota Nutrient Criteria Lentic Systems Plan

Prepared For:
North Dakota Department of Health
Division of Water Quality
918 East Divide Avenue
P.O Box 5520
Bismarck, ND 58502-5520

Prepared By:
Houston Engineering, Inc.
3712 Lockport Street
Bismarck, ND 8503-5535

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SECTION 1.0
INTRODUCTION

1.1 IMPETUS FOR DEVELOPING NUTRIENT CRITERIA

The enrichment of lakes, reservoirs, rivers and wetlands with excess nutrients is consistently one of the top causes of water resource impairment within the United States (EPA, 2000). In 1998, the U.S. Environmental Protection Agency (EPA) published the *National Strategy for the Development of Regional Nutrient Criteria* (the National Strategy) (EPA, 1998). The intent of the National Strategy is to establish numeric water quality criteria for nutrients, implemented as standards, which curtails water quality problems stemming from excessive nutrients in the environment. The need for the State of North Dakota is to develop technically defensible nutrient criteria for surface waters, protective of the resource and consistent with federal guidance.

1.2 OUTCOMES OF THE NORTH DAKOTA NUTRIENT CRITERIA DEVELOPMENT PLAN

Houston Engineering, Inc. (HEI) completed a Nutrient Criteria Development Plan (NCDP) (HEI, 2007) in May 2007 for the North Dakota Department of Health (NDDoH). The NCDP describes the anticipated conceptual approach for developing nutrient water quality criteria by the State of North Dakota. The plan focuses on lotic systems (i.e., small to large wadeable and non-wadeable streams and rivers) and lentic systems (i.e., lakes and reservoirs). The plan is intended to provide clear and meaningful guidance for the development of nutrient criteria within North Dakota. An outcome was a recommended method to uniquely classify the physiographic setting and water resources within the State for development of the criteria. The approach described by the NCDP has enabled the State to explore in detail the feasibility of implementing various development concepts.

The NCDP included a prioritization for developing nutrient criteria for different water resource types, identified data needs, and proposed a schedule and set of milestones for measuring progress. Developing nutrient criteria for lakes and reservoirs was the first priority.

Year 1

- Develop conceptual models for each water resource type;
- Complete review and analysis of existing surface water quality monitoring data for the recommended spatial and temporal scales;
- Modify the current monitoring program design to fill data gaps and needs for criteria development;
- Complete an evaluation of known reference sites and reaches;
- Complete additional Geographic Information System analysis to identify the potential range of reference sites and reaches and other locations across the concentration gradient;
- Evaluate priorities recommended in the plan for criteria development and methods to reduce fiscal impact (e.g., implement by geographic region); and
- Develop a detailed budget for developing the nutrient criteria.

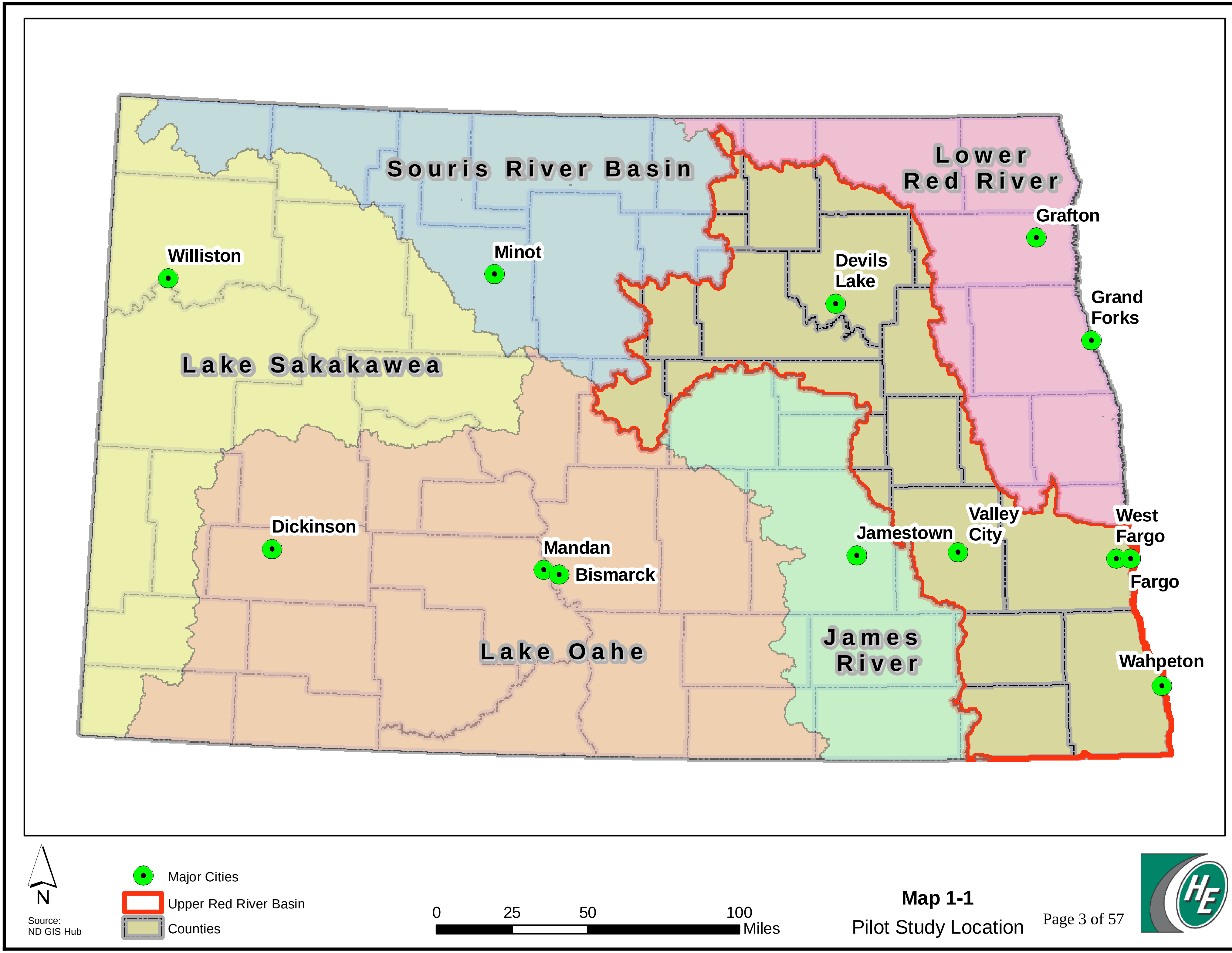
The NCDP schedule included additional years; however, these were beyond the scope of this discussion. The complete implementation schedule can be found in **Section 5** of the NCDP.

1.3 Scope of this Lentic Systems Plan

The scope of this Lentic Systems Plan is two-fold.

- Classify the lentic system resources State-wide; and
- Apply a modeling technique for establishing numeric criteria for lentic systems to a pilot area in the State.

This Lentic Systems Plan identifies the Upper Red River Basin (URRB) as the regional pilot study area (see **Map 1-1**) out of the other major drainage basins in North Dakota. The URRB was selected as the regional pilot study area because the data set available for model calibration was considered the most robust relative to the other drainage basins in the State.



Source: ND GIS Hub

Map 1-1

Pilot Study Location

The goal of the regional pilot study is to test a modeling approach for addressing nutrient criteria development in the absence of reference data or other readily available tools to set criteria. The modeling approach presented could be used to establish interim criteria for different classes of lakes and reservoirs (i.e., small versus large water bodies) for the region and gain feedback from stakeholders. Once the technique for establishing numeric standards has been verified, the intent is to apply the approach to other areas in the State.

1.4 LENTIC SYSTEMS PLAN FRAMEWORK AND CONCEPTS

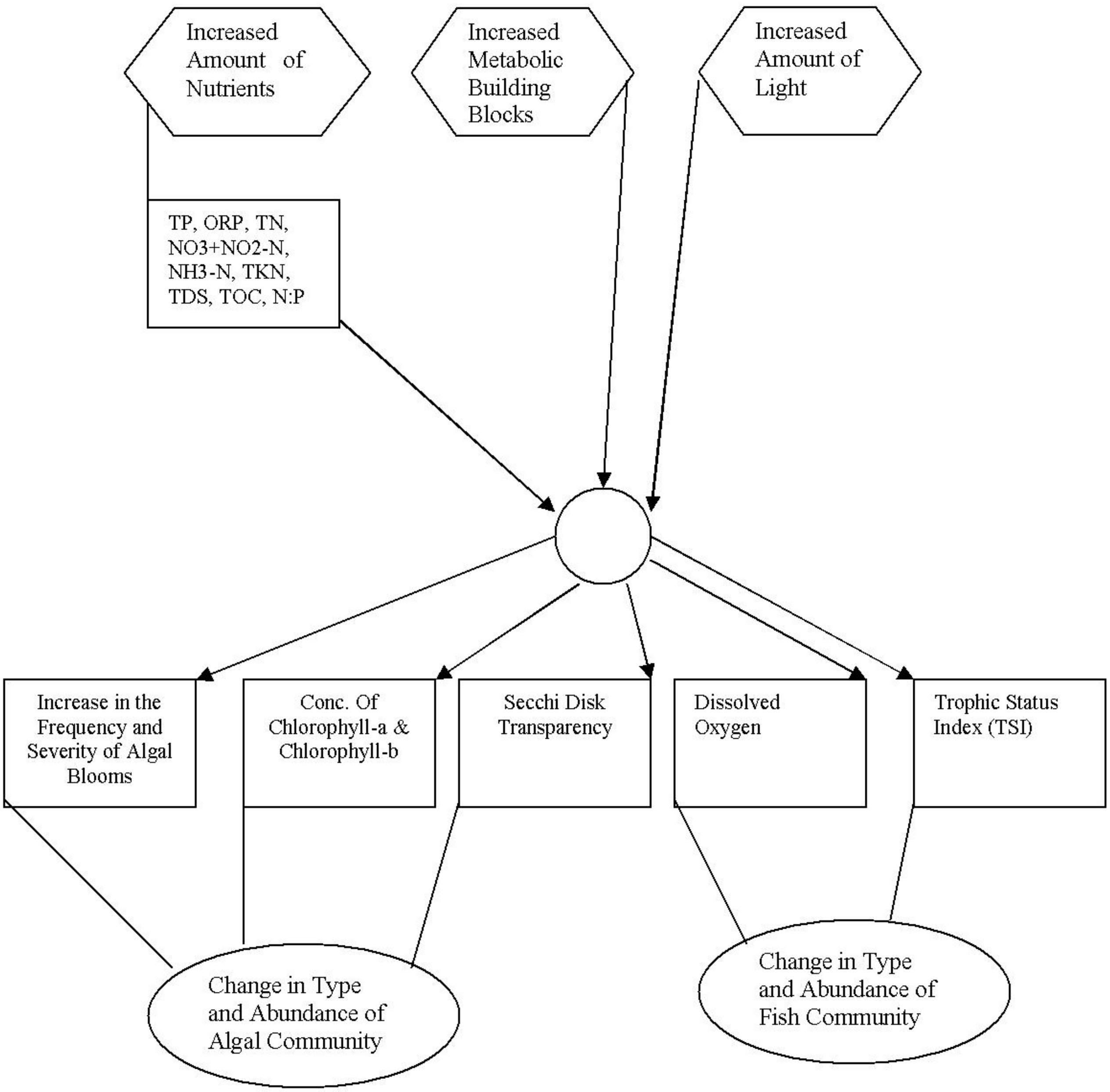
Without some linkage to the stressor-response relationship, the use of statistical methods and the selection of percentile concentrations as an approach for determining nutrient criteria are not recommended for North Dakota, (HEI, 2007). The recommended approach for developing nutrient criteria for lakes and reservoirs is based on establishing regionally defensible cause – effect relationships (i.e., load – eutrophication response).

Figure 1-1 presents a conceptual ecological model showing the response of lentic systems to excess nutrient concentrations. This model suggests potential causative ecological endpoints (i.e., response variables) include the frequency and severity of algal blooms, the concentrations of chlorophyll-a and chlorophyll-b, some measure of water clarity, dissolved oxygen concentrations and TSI. The conceptual model further suggests that the applicable causative variables are those limiting primary production.

A significant issue for North Dakota is the lack of monitoring data relating to lakes and reservoirs that reflect reference conditions. The EPA has undertaken a National Lake Survey utilizing a probabilistic site selection approach but the breadth of sites was limited. However, four groups of lentic systems were proposed in the NCDP (HEI, 2007) for North Dakota's nutrient criteria, so any data reflecting expected condition may only apply to certain groups of lentic systems (e.g., shallow lakes).

Another data gap is the lack of a trophic state index (TSI) model specific to the state. Carlson's TSI model is used by NDDoH to assess eutrophication in lentic systems. A major drawback to using Carlson's TSI is that it was developed for lakes that are primarily phosphorus limited. Because most North Dakota lakes and reservoirs have an abundance of phosphorus, this model may not be appropriate and should be modified for conditions in North Dakota. Another

Figure 1-1. Conceptual Ecological Model for the Response of a Lentic System to increased Nutrient Concentrations (from CADDIS).



tool could be developed to establish causative-variable criteria from endpoints such as Secchi depth transparency. For lakes and reservoirs, the most important data needs identified in the NCDP (HEI, 2007) include:

- Geospatial landscape scale data sufficient to identify and select reference sites and reaches as well as impacted or disturbed sites;
- Geometric and morphometric data for classifying water resources;
- Sufficient data for the causative variables to be representative of the populations at reference sites and reaches; and
- Sufficient data for the response variables to be representative of the populations at reference sites and reaches. These data should be "paired' with the causative variables.

SECTION 2.0
LENTIC SYSTEMS CLASSIFICATION

2.1 CONCEPTUAL APPROACH TO LENTIC SYSTEM CLASSIFICATION

The objective of classification is to identify and group lentic systems (lakes and reservoirs) with similar physical characteristics, ecological function, and limnological processes. The classified lentic systems can then be used to aid in establishing regionalized nutrient criteria that are consistent and protective of groups, or classes, of water bodies. To meet this objective, measures were taken to:

- Identify the entire population of potentially relevant lentic systems (lakes, wetlands, and reservoirs);
- Reduce the entire population of potentially relevant lentic system data to reflect only those State-wide lentic systems considered applicable for nutrient criteria;
- Identify and assess suitable metrics to appropriately group and distinguish the applicable State-wide lentic systems, including:
  - Stratification and mixing dynamics as referenced in the NCDP; and
  - Other metrics based on physical properties that could be used for lentic system classification.
- Apply the selected classification metric whereby all applicable State-wide lentic systems are assigned to a class.

2.2 DATA SOURCES AND COMPILATION

2.2.1 <u>Sources of Data Used to Identify Lakes and Reservoirs</u>

Data were compiled from various sources for North Dakota in an effort to identify the population of various lentic systems in the state (lakes, wetlands, and reservoirs). These sources of data were from: the high resolution National Hydrography Dataset (NHD), the National Wetlands Inventory (NWI), the North Dakota Game and Fish (NDGF), and the National Inventory of Dams (NID). As discussed in the NCDP (HEI, 2007), only lakes and reservoirs were addressed in this classification process.

Challenges arose while working with the various data sets due to:

- Inconsistencies between data sets (e.g., different naming conventions between data sources);
- Inaccuracies within data sets (e.g., locational accuracy of dams); and
- Relatively large number of lentic systems within North Dakota (e.g., 180,978 lakes were identified in North Dakota).

2.2.2 Characterization of Lake Water Bodies

The State of North Dakota does not have a definition of a lake within the Century Code. For the purpose of this plan, the NCDP provides a working definition of a lake using the following criteria to distinguish a lake system from other lentic systems:

1. Surface area of 10 acres (4 hectares) or more;
2. A maximum depth which is not less than 3.3 feet (1 meter);
3. A minimum non-vegetated, contiguous open water area of 1,000 m2 or more; and
4. The standing water forming a lake is not artificially created or increased in depth by obstructing a watercourse through the use of a dam or other man-made obstruction.

Data used to distinguish the population of lakes in North Dakota came from the NHD, NWI, and NDGF databases. First, features identified as lakes within the NHD database layer were used, while wetlands (swamp/marsh) were not. Second, certain wetland types were used from the NWI data layer to represent lakes. It was operationally determined that a lake would be differentiated from a wetland in the NWI by whether it was a lacustrine system (which included palustrine subsystems) or non-lacustrine, as per the Cowardin classification system (Cowardin et al, 1979). Non-lacustrine wetlands were excluded for this effort. Lastly, lakes from the NDGF data set were included if these water bodies had not already been identified and included from the NHD and NWI databases.

Based upon the identification process, 180,978 lakes were identified in North Dakota. Due to the sheer number of lakes that were identified, it was evident that a size limit was needed to constrain data analysis. Areas were quantified from the lake polygons using GIS. The lake data-set was filtered to remove lakes less than 10 acres in size, which was discussed in the NCDP (HEI, 2007). Doing so resulted in 10,335 lakes in North Dakota. Most of the lakes were less than 50 acres in size. **Table 2-1** shows the percentiles of the lake sizes. For these data summaries, extreme outliers (i.e., Devils Lake) were excluded from analysis.

Table 2-1. Lake size percentiles in North Dakota.

Percentile	Size (ac)	
	State-wide	Upper Red pilot
0th	10.0	10.0
25th	13.2	13.2
50th	19.1	20.0
75th	36.8	41.7
95th	141.7	176.9
100th	4,424.4	4,424.3

2.2.3 Characterization of Reservoir Water Bodies

The State of North Dakota does not have a definition of a reservoir within the Century Code. For the purpose of this plan, the NCDP provides a working definition which states that reservoirs are artificial (man-made) lentic systems. At a minimum, reservoirs must meet the first three conditions defined for a lake system. In addition, the following criteria are used to distinguish reservoirs from other lentic systems:

1. Existence of a control structure to actively regulate water levels and discharge; and
2. Generally shorter hydraulic residence time (generally less than 1 year) because of a larger drainage area to surface area ratio compared to a lake.

Data used to distinguish the population of reservoirs in North Dakota came from the NHD and NID databases, as well as the lake identification effort. Reservoirs identified in the NHD data were used but were amended so that they represented features that were impounded systems rather than constructed features (e.g., sewage treatment ponds or aquaculture ponds). Further, reservoirs were distinguished from lakes through the use of the NID data. The NID data was spatially joined to the population of lakes. Lake polygons were determined to be reservoirs if they were within a distance of 3,281 feet (1,000 meters) of a dam point from the NID layer. This distance was an operational determination. To account for the spatial inaccuracy of the NID data set in the instances where the NID layer misrepresents a lentic system polygon (where a lentic system should be a lake instead of a reservoir), manual editing of the reservoir data was performed.

Based upon the identification process 687 reservoirs were found in North Dakota. Areas were quantified from the reservoir polygons using GIS. To be consistent with the process used for lakes, the reservoir data set was filtered to remove reservoirs less than 10 acres in size. Doing so resulted in 284 reservoirs in North Dakota. Most of the reservoirs were less than 200 acres in size. **Table 2-2** shows the percentiles of the reservoir sizes. For these data summaries, extreme outliers (i.e., Lake Sakakawea, Lake Audubon, and Lake Oahe) were excluded from data analysis.

Table 2-2. Reservoir size percentiles in North Dakota.

Percentile	Size (ac)	
	State-wide	Upper Red pilot
0th	10.0	10.9
25th	18.9	27.8
50th	37.8	67.1
75th	110.2	163.4
95th	1,929.1	2,915.8
100th	8,038.8	5,466.6

2.3 EVALUATION OF METRICS FOR CLASSIFYING LAKES AND RESERVOIRS

Existing water body data were evaluated to assess if metrics could be implemented with these data to identify distinct groups, or classes, within the lake and reservoir populations that have similar characteristics. In theory, each class of lakes and reservoirs should have a unique eutrophication response (i.e., nutrient criteria), assuming that the groups can be distinctly identified. Measured water column data for water bodies, as well as physical attributes, from various State agencies were included in this evaluation.

2.3.1 Mixing Metric

Temperature and dissolved oxygen (DO) data had been collected by the NDDoH for many lentic systems in North Dakota. The intent was to use these data to generate vertical profiles that could be used to determine mixing characteristics of the lentic systems and extrapolate the attribute to other lentic systems that display similar physical traits. This process was implemented for the URRB pilot area before performing the analysis on all lentic systems in North Dakota. Temperature and DO data from the NDDoH Sample Identification Database (SID) were compiled and processed for review and profile generation.

It was found that the amount of temperature and DO data available, and the ability to relate the mixing characteristic to other lentic systems which did not have similar data available, was inadequate for State-wide classification development. Water quality data was available for 36 unique SID sites in the URRB pilot area. Approximately one-half of these sites, however, were located on Devils Lake and Lake Ashtabula. Several of the sites also only had one or two dates when data were collected. Ideally, water quality data would be available for spring and summer dates to determine the lentic system's mixing characteristic (monomictic, dimictic, or polymictic).

Additionally, even though there were data available for some lentic systems in the URRB pilot area, the mixing characteristic would need to be related to other lentic systems in the pilot area that did not have similar data available. This relation was to be performed through regression analysis with the physical attributes (depth, volume, and surface area) for lentic systems. Surface area information was readily available; however, information for depth and volume was not. Attempts were made to estimate depth and volume from surface area through regression techniques, but the predictive power of the regressions was low.

Ultimately, it was determined that even though the mixing characteristic may be generated for some lentic systems, there was no way to confidently relate this characteristic back to other lentic systems, due to the poor predictive power of the regressions and due to the fact that there was not enough data to correlate system response.

2.3.2 The Morphoedaphic Index Metric

The Morphoedaphic Index (MEI) (Vighi and Chiaudani, 1985) was investigated for its application and use in classifying lakes. This approach involves the identification of lakes having least-impacted background nutrient phosphorus concentrations by relating the electrical conductivity of the water to lake depth. This would provide an estimate of the concentration of phosphorous to which lakes could be lowered to prevent excess plant growth.

Although conductivity data were available for lentic systems in the NDDoH SID, similar issues were identified as with the evaluation of the mixing metric (Section 2.3.1). Of primary importance is the lack of depth data. Tetra Tech, Inc. faced similar issues when attempting to compute the MEI using information available in the Florida Department of Environmental Protection databases (Tetra Tech, 2002). Tetra Tech attempted to use lake area as a surrogate in the place of average depth because depth data were not available. Their analysis did not produce a significant relationship between MEI and phosphorous concentration, which was attributed to the use of area instead of depth.

Further, the use of the MEI approach appears to be limited to certain lentic system types. The MEI was developed using information from cool-temperate lakes (Vighi and Chiaudani, 1985). The approach has not been calibrated for shallow lakes, naturally eutrophic lakes, warm-temperate lakes, or impoundments (EPA, 2000). Thus, the use of the MEI in North Dakota is not warranted until its application has been tested and calibrated for a wider variety of lakes.

2.3.3 Additional Metrics

A variety of additional metrics was considered for the classification process. These indices primarily rely on physical attributes that are expected to capture the sensitivity of a water body to disturbance due to influence from the contributing drainage area. The metrics considered in this study, along with the units, are as follows:

- (a) (surface area / drainage area) * volume = acre-feet;
- (b) (drainage area * runoff depth) / (surface area * mean depth) = dimensionless ratio of volumes;
- (c) (surface area) / (volume / fetch) = dimensionless ratio of surface area to receive solar radiation and energy required to mix;
- (d) Hydraulic residence time (from outputs of a regional model);
- (e) Total phosphorus (TP) mass residence time (from outputs of a regional model);
- (f) Inflow rate (Q_{in} as cubic feet per year) / surface area = velocity (ft/year);
- (g) Overflow rate / evaporation rate (expressed in ft/year) = a water budget index;

- (h) TP mass residence time in the water body / hydraulic residence time (from model) = dimensionless ratio of hydraulic and mass residence times; and,
- (i) Surface area (from GIS).

Preliminary evaluation of these metrics revealed that metrics (a) and (c) appeared to show "natural" distinctions based on relative frequency distributions. Most other metrics had limited immediate inferential capacity for classifying lakes and reservoirs due to no observable class breaks.

2.3.4 Summary of Evaluated Metrics

Many metrics were evaluated with respect to the suitability for use in lake and reservoir system classification, including mixing characteristic, MEI, and additional metrics based upon water body physical attributes as discussed in Section 2.3.3. It was determined that metric (a), the ratio of water body surface area to watershed drainage area multiplied by water body volume, was the most appropriate for the classification efforts. This metric incorporates a water body's relative vulnerability to landscape inputs. The metric also tacitly incorporates a water body's inherent physical dynamics.

The decision to use this metric was also based in part upon the fact that surface area, a key component of the metric, was easily and reliably obtainable for all lentic systems. Regressions to relate surface area to the other components of the metric were developed from paired measured data within the NDGF database.

2.3.4.1 *Drainage Area Regressions*

Regressions were developed for North Dakota water bodies to predict contributing drainage areas. Water body data was divided between lakes and reservoirs and further subdivided based upon water body surface area. **Table 2-3** provides information relating to the drainage area regressions that were completed. Using these regressions, drainage areas were predicted for water bodies lacking drainage area information within the NDGF database (excluding the water bodies that were considered extreme outliers).

Table 2-3. Drainage area and surface area regressions for water bodies.

	Lakes		Reservoirs	
	10-2,000 ac	*>2,000 ac*	*10-2,000 ac*	*>2,000 ac*
equation	DA = 0.0222xSA + 10	DA = 0.0841xSA + 207.23	DA = 0.3875xSA + 10	DA = 1.5242xSA + 16929
r^2	0.2224	1	0.5129	0.5695
n	75	2	104	7

NOTE: SA = Surface Area (acres)

2.3.4.2 *Volume Regressions*

Regressions were developed for North Dakota water bodies to predict volumes. Water body data was divided based upon the groupings used for predicting drainage area. **Table 2-4** provides information relating to the volume regressions that were completed. Using these regressions, volumes were predicted for water bodies lacking volume information within the NDGF database (excluding the water bodies that were considered extreme outliers).

Table 2-4. Volume and surface area regressions for water bodies.

	Lakes		Reservoirs	
	10-2,000 ac	*>2,000 ac*	*10-2,000 ac*	*>2,000 ac*
equation	V = 10.963xSA + 10	V = 48.268xSA + 284273	V = 9.2905xSA + 10	V = 20.478xSA - 26814
r^2	0.1975	1	0.5255	0.9387
n	108	2	109	5

NOTE: V = Volume (acre-feet)

2.4 APPLICATION OF THE CLASSIFICATION METRIC

As discussed previously, the frequency distributions of metric (a) suggested that the distribution of lakes and reservoirs formed distinct groups. The NDGF data were qualitatively reviewed based on this metric and distinctions were made to isolate three classes within the lake and reservoir populations.

A preliminary watershed model was constructed and executed to test if the lentic system classes displayed distinct responses to landscape inputs. **Section 3** describes the watershed model. The results from the preliminary model were grouped based upon the classes, and they affirmed that the qualitatively-defined classes showed differing eutrophication responses.

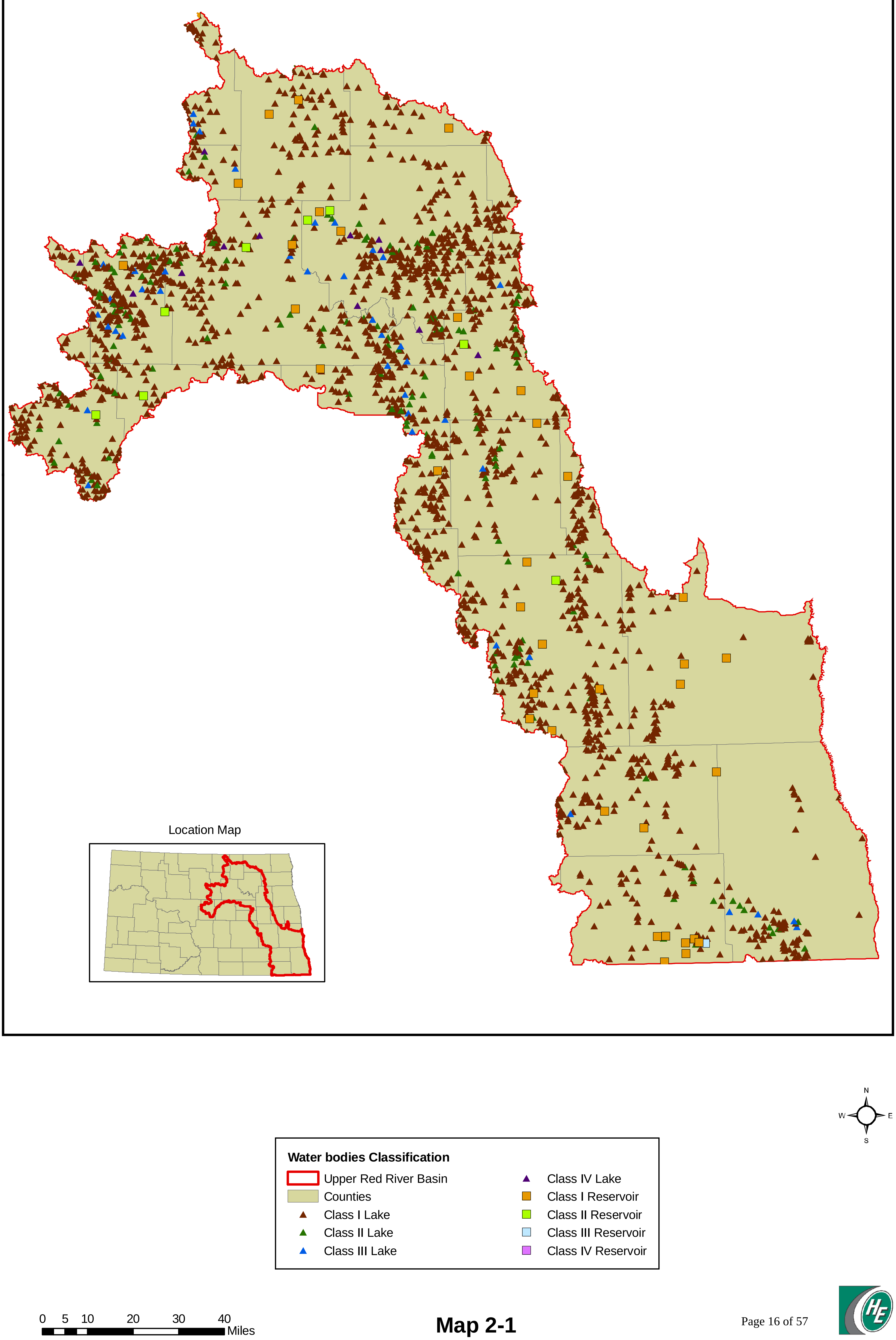
Additionally, one class identified through frequency distributions was further stratified into two classes based on modeling results, resulting in four classes for both lakes and reservoirs*.

Table 2-5 presents a summary of the different classes and the parameters contributing to the metric calculation, based on data available from State sources. The table shows general water body characteristics associated with each class. The table also shows samples sizes by class where variables of surface area, volume and drainage area were known for each water body

Using the regressions developed in **Section 2.3.4**, the metric can be applied to all water bodies that have been identified in the State. Classes for water bodies in the URRB pilot area can be found displayed in **Map 2-1**. Due to the poor predictive power of the regressions to estimate water body drainage area and volume, water body class may be different based upon regression data rather than field measured data. Class differences can be observed in **Tables 2-6** and **2-7**, which compare lake and reservoir class values in the URRB pilot area, respectively, based upon data source used to implement the classification metric. The implication of this situation is that authoritative field measured data must be sufficiently developed to improve the robustness of state-wide regressions. Further, while regressions to generate state-wide classification provides value by establishing a framework for managing lentic systems, the classification of any site-specific lentic system should always be verified with field data prior to beginning a watershed or lentic system improvement project.

*Note: two conference calls (January 2008 and March 2008) were held with EPA Region VIII and NDDoH to discuss the classification system. Subsequent documentation illustrating various histograms and other details were provided to EPA Region VIII and NDDoH in a memorandum dated April 23, 2008.

Water Bodies Classification System
For The Upper Red River Basin



Map 2-1

Table 2-5. Summary of water body classes based upon state-wide NDGF data.

Assigned Class	[(SA:DA) * volume] Statistic Range (ac-ft)	Average Surface Area (acres)	Average Volume (ac-ft)	Average Drainage Area (sq.mi.)	Surface Area Range (acres)	Average Maximum Depth (feet)	Average Mean Depth (feet)	SA:DA range (unitless)	Mean Depth Range (feet)	Volume Range (ac-ft)	Count
LAKES											
I	0 - 15	74.1	575.9	13.8	10.7 - 210.5	14.6	6.9	0 - 0.06	3.3 - 14.5	73 - 2,685	23
II	15 - 100	156.8	1,770.8	12.9	36.5 - 570.4	20.6	10.1	0.01 - 0.28	3.7 - 22	259 - 6,743	31
III	100 - 450	364.3	4,444.3	16.6	38.4 - 820.3	23.7	12.7	0.02 - 0.6	8.2 - 31	584 - 15,167	15
IV	> 450	1,203.5	68,204.0	80.2	276.6 - 2,766.6	19.7	12.8	-	-	-	7
RESERVOIRS											
I	0 - 7	86.2	637.8	70.0	10.5 - 1,596.4	21.3	9.4	0 - 0.04	3.4 - 19.2	20 - 2,864	71
II	7 - 35	279.6	2,760.1	144.8	44.1 - 1,682.9	28.0	11.6	0 - 0.02	4 - 16.4	724 - 8,568	18
III	35 - 150	1,613.0	19,741.5	1,167.9	104.5 - 8,038.8	23.6	10.5	0 - 0.04	4.4 - 15.6	1,762 - 94,555	15
IV	> 150	1,542.7	28,570.0	472.2	306.5 - 3,336.0	56.2	18.1	0 - 0.1	9.9 - 30.4	3,072 - 66,835	4

NOTE: Produced with state-wide data from the NDGF database.

SA = Surface Area (acres)

DA = Drainage Area (square miles)

Table 2-6. Class comparison for lakes in the URRB pilot area.

NUTCRIT_ID	Ecoregion	Surface Area (acres)	Volume (ac-ft)	Drainage Area (acres)	Mean Depth (feet)	CLASS	Source
1870	46	92.11	1,020	7,709	11.1	I	Regression
1870	46	92.11	1,687	448	10.5	III	Measured
1885	48	360.16	3,958	11,517	11.0	I I I	Regression
1885	48	360.16	3,149	19,840	8.4	II	Measured
1923	46	207.03	2,280	9,341	11.0	I I	Regression
1923	46	207.03	6,743	37,120	16.4	II	Measured
1963	46	154.12	1,700	8,590	11.0	I I	Regression
1963	46	154.12	1,588	6,720	8.3	II	Measured
1967	48	38.43	431	6,946	11.2	I	Regression
1967	48	38.43	584	64	14.3	III	Measured
4311	46	94.19	1,043	7,738	11.1	I	Regression
4311	46	94.19	2,338	2,880	22.0	II	Measured
4459	48	21.29	243	6,703	11.4	I	Regression
4459	48	21.29	110	8,576	4.3	I	Measured
8212	46	145.84	1,609	8,472	11.0	I I	Regression
8212	46	145.84	1,119	2,240	9.1	II	Measured
8533	46	2,766.61	417,812	281,537	151.0	IV	Regression
8533	46	2,766.61	417,811	281,600	23.7	IV	Measured
8615	46	152.93	1,687	8,573	11.0	I I	Regression
8615	46	152.93	2,519	9,280	6.9	II	Measured
8660	46	13.53	158	6,592	11.7	I	Regression
8660	46	13.53	680	11,520	7.3	I	Measured
8666	46	179.53	1,978	8,951	11.0	I I	Regression
8666	46	179.53	2,118	2,688	8.8	III	Measured
8722	46	1,500.33	16,458	27,717	11.0	IV	Regression
8722	46	1,500.33	1,890	1,664	5.6	IV	Measured
8723	46	92.28	1,022	7,711	11.1	I	Regression
8723	46	92.28	1,287	4,800	12.5	II	Measured
8889	46	184.30	2,031	9,019	11.0	I I	Regression
8889	46	184.30	684	3,520	3.7	II	Measured
8959	46	149.14	1,645	8,519	11.0	I I	Regression
8959	46	149.14	1,657	8,960	11.1	II	Measured
10628	46	11.70	138	6,566	11.8	I	Regression
10628	46	11.70	87	3,072	7.4	I	Measured

NOTE:

Difference in class.

Table 2-7. Class comparison for reservoirs in the URRB pilot area.

NUTCRIT_ID	Ecoregion	Surface Area (acres)	Volume (ac-ft)	Drainage Area (acres)	Mean Depth (feet)	CLASS	Source
10450	46	38.46	367.34	15938.87	9.55	I	Regression
10450	46	38.46	563	55040	14.8	I	Measured
10452	46	1115.80	10376.31	283117.48	9.30	I I I	Regression
10452	46	1115.8	10617	251200	10	III	Measured
10456	46	97.65	917.21	30616.91	9.39	I	Regression
10456	46	97.65	1014	195520	8	I	Measured
10459	46	29.32	282.44	13672.58	9.63	I	Regression
10459	46	29.32	238	5760	10.3	I	Measured
10460	48	92.07	865.37	29233.17	9.40	I	Regression
10460	48	92.07	1768	40832	18	I	Measured
10484	48	112.99	1059.69	34420.33	9.38	I	Regression
10484	48	112.99	1583	7360	12.6	II	Measured
10490	46	5466.61	85131.16	16167168.82	15.57	I I	Regression
10490	46	5466.61	70573	2648320	13.7	III	Measured
10493	46	20.36	199.18	11449.83	9.78	I	Regression
10493	46	20.36	119	1600	5.5	I	Measured
10497	48	29.58	284.80	13735.42	9.63	I	Regression
10497	48	29.58	146	12160	5.6	I	Measured
10556	46	486.49	4529.74	127049.76	9.31	I I	Regression
10556	46	486.49	1913	204800	11.9	I	Measured
10557	46	270.21	2520.41	73412.61	9.33	I I	Regression
10557	46	270.21	2383	126080	7.9	I	Measured
10562	46	44.21	420.71	17363.43	9.52	I	Regression
10562	46	44.21	483	15360	8.3	I	Measured
10568	46	151.58	1418.27	43992.34	9.36	I	Regression
10568	46	151.58	1610	25600	9.8	II	Measured
10572	46	36.82	352.03	15530.19	9.56	I	Regression
10572	46	36.82	317	8320	10.4	I	Measured
10590	46	15.15	150.72	10156.28	9.95	I	Regression
10590	46	15.15	115	1088	8.4	I	Measured
10597	46	155.23	1452.15	44896.73	9.35	I	Regression
10597	46	155.23	22532	69120	9.8	III	Measured
10616	48	17.33	171.03	10698.65	9.87	I	Regression
10616	48	17.33	161	33920	9.4	I	Measured

NOTE:

(yellow) Difference in class.

2.5 SUMMARY AND RECOMMENDATIONS

Using GIS and a 10-acre size threshold for lentic system classification, 10,335 lakes and 687 reservoirs were identified as representing only those State-wide lentic systems considered applicable for nutrient criteria. Current efforts to further stratify lakes and reservoirs (e.g., based on fetch, mixing characteristic, or other) have been insufficient due to a lack of data. Based on analysis of field data provided by NDGF, it appears that metric (a), the ratio of water body surface area to watershed drainage area multiplied by water body volume, was the most suitable for State-wide classification of applicable lentic systems in North Dakota in this study, and HEI recommends the use of this metric in setting nutrient criteria. Should the NDDoH continue to pursue this metric, refining the drainage area for lentic systems is a task that can be completed with minimal field work, which would strengthen the predictive power of the regressions that underlay the computation of the metric. HEI also recommends that the State collect more information with regard to physical limnology data (i.e., depth) to supplement their databases, as appropriate, for a similar reason. The metric can then be used to class all water bodies in the State.

SECTION 3.0
REGIONAL NUTRIENT CRITERIA MODEL DEVELOPMENT

3.1 MODELING OBJECTIVES

The purpose of the modeling was to explore the feasibility of implementing a regionally calibrated eutrophication model for lakes and reservoirs as a means towards setting nutrient criteria. The scope of the study established the following modeling objectives, prior to selection of the model, realizing that some modification of existing models may be required:

- Parameters – at a minimum, annual volume of runoff and total phosphorus (TP) load, with the ability to include additional nutrients, such as nitrogen;
- Spatial Scale – major water planning regions as the maximum spatial scale, with the ability to modify the spatial scale to evaluate landscape dynamics at the level of a 12-digit Hydrologic Unit Code (HUC). Maintain ability to use modeling to address specific water resources at the local watershed scale;
- Temporal Scale – results expressed as the central tendency value over an annual time period, but which reflects importance of precipitation on a much shorter temporal scale (e.g., by event or daily), within a predominantly agricultural landscape;
- Quantifying Uncertainty – explicitly recognize the inherent uncertainty in modeling input parameters and the variability within nature (e.g., the amount of precipitation) in the computed runoff volumes and loads;
- Address Data Limitations – address the overall paucity of existing data characterizing the physical attributes and nutrient characteristics of lentic systems, and implement a robust generalization over an entire major water planning region;
- Establish Benchmarks – utilize a modeling tool to estimate receiving water quality under minimally impacted, or least impacted, conditions in order to establish water quality benchmarks in the absence of reference sites;
- Landscape Linkages – ability to create a linkage between nutrient criteria for lentic systems and measurable landscape indices, such as water yields, nutrient loading rates, or land use composition;

- Acceptance within the Professional Community – a recognized and commonly used tool within the professional community, with inputs and outputs that are transparent for technical review; and
- Input Data Requirements – model inputs which can be derived from readily available land use / land cover and other landscape-scale data, preferably in a Geographic Information System (GIS) format.

Based upon the modeling objectives, the project used the CNET model for completing the regional assessment. The CNET model is a modified version of the receiving water model BATHTUB (http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=watqual). The CNET model is a spreadsheet model currently available as a "beta" version from Dr. William W. Walker. The two primary modifications to the CNET model implemented to complete the regional assessment included: 1) adding water body classification indices as a computation; and 2) implementing CNET using a Monte Carlo approach based on daily precipitation amounts and regionalized curve numbers (CN). These modifications are discussed below.

3.2 STOCHASTIC ("MONTE CARLO") IMPLEMENTATION

To assist with the modeling objective of quantifying uncertainty, the CNET model was linked with a program called Crystal Ball. Crystal Ball is proprietary software developed by Decisioneering, Inc. (www.decisioneering.com) and is applicable to "stochastic" or "Monte Carlo" simulation and analysis. (Statistical distributions for the Monte Carlo analysis are presented in **Appendix A**). Stochastic modeling is an approach where the input values used in the equations to compute load and runoff volume vary according to their statistical distribution and, therefore, their probability of occurrence. This allows the effect of parameter uncertainty and environmental variability, like annual rainfall depth, to be quantified. Rather than computing a single estimate of the annual load or runoff volume, this approach results in the estimated distribution of annual loads and runoff volumes.

Use of the Crystal Ball tool permitted model input parameters that have attributable uncertainty to be defined by probability distributions. The landscape input parameters in this study defined by a probability distribution were the area-weighted curve numbers for each land use, TP event mean concentrations, and precipitation depths. The receiving water input parameters in this study defined by a probability distribution were the drainage areas, surface areas, and mean depths. These input parameters will be discussed in greater detail in subsequent sections.

The Crystal Ball tool allowed for multiple probabilistic simulations of the model computations. Many trial values (10,000 trials in this study case) were generated, with each trial representing the different permutations of input values. These outcomes produced a model result that defined a distribution (of runoff volume or load) rather than a single, fixed output that was based upon only one possible combination of inputs. The stochastic approach produces results that are statistically robust when generalizing over a broad geographic region. This is of paramount importance for this study because available input data are scare. The stochastic approach reflects the variability in natural processes and allows explicit determination of the confidence in the model results.

3.3 WATERSHED MODEL DEVELOPMENT

3.3.1 Spatial Scale of Study

The URRB was selected as the regional pilot study area for testing the modeling approach, as discussed in **Section 1**. The URRB covers approximately 13,420 square miles and is divided into 309 12-digit Hydrologic Unit Code (HUC) basins. On average, each HUC covers approximately 43 square miles. The URRB contains notable water body features such as Lake Ashtabula and Devil's Lake.

The broad spatial scale of the regional pilot study area and associated HUC basins were the basis for developing model parameters to estimate landscape inputs to receiving waters. However, for any given lentic system stochastically modeled, landscape inputs were proportionately scaled down to reflect a "local" watershed scale. The determination of drainage areas for receiving water modeling is discussed in **Section 3.4**.

3.3.2 Soils and Land Use

Soils data for North Dakota were derived from the Soil Survey Geographic (SSURGO) database. The primary land use data used to complete the regional pilot study for the URRB was the North Dakota Gap Analysis Land Cover database, compiled and processed from 1993-1998. For modeling purposes, five main land use classes, or types, were established in order to consistently represent the dominant land covers. The land use types were: agriculture (cultivated or row cropped), forest (woods), grasslands/shrubs/wetlands (brush or rangeland), water, and urban.

It is important to note that land use type for grasslands/shrub/wetland represents a broad range of landscape features. It was deemed appropriate to assign wetlands into land use type for several reasons. Most importantly, wetlands themselves represent many different resources each with a unique hydrologic regime. The complexity and effort for detailing each type of wetland within this regional model was well beyond the scope of this pilot study, and would not improve model results due to the coarse-scale of the regional approach. Further, the model was not expected to be sensitive to whether or not wetlands were modeled as a separate land use type. This is based on the mechanics built in the model for generating runoff which is discussed later.

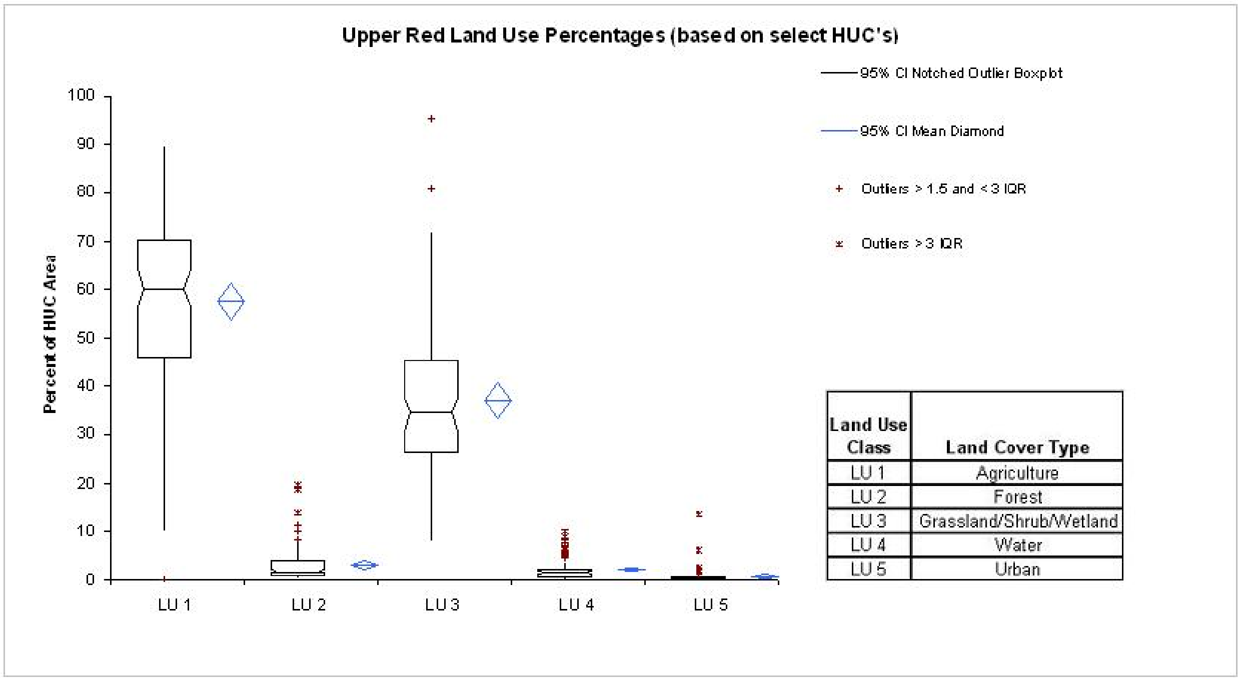
These land use types are an integral component to the model as they aid in assigning nutrient concentrations and the input values used to estimate runoff. These land uses were selected because they represented the most diverse categories for the purpose of computing runoff volumes and loads. They are also relatively well-defined and quantifiable. A summary of land use across the URRB is shown in **Table 3-1**. A sub-set of 89 HUC basins in the URRB out of the 309 HUC basins was analyzed in detail to evaluate the data in **Table 3-1**. A summary of sub-set land use sampling and analysis within is shown in **Figure 3-1,** which supports the data in **Table 3-1**.

Table 3-1. Land use in the Upper Red River Basin.

Land Use Class	Land Cover Type	Total (Acres)	Land Use %
LU1	Agriculture	5,263,913.6	61.28
LU2	Forest	156,577.1	1.82
LU3	Grassland/Shrub/Wetland	2,814,688.7	32.77
LU4	Water	299,720.6	3.49
LU5	Urban	55,029.6	0.64
Sum		8,589,929.7	100.00

In order that a "benchmark" (or, reference) condition could be estimated, runoff volumes and loads for historic conditions were predicted by adjusting the proportions of land use. Model scenarios were established that reflected various levels of dominance by agriculture land use. The scenarios reflected 90%, 82%, 75%, 50%, 25% and 10% agriculture land use in the drainage area. As the proportion of agriculture (cultivated) was reduced, the amount of grasslands/shrubs/wetlands area was proportionately increased. In each modeling scenario, the water land use type was subtracted from the total subwatershed area, which allowed for calculations that reflected runoff from only the non-water portions of the contributing drainage areas.

Figure 3-1. Land use percentages in the Upper Red River Basin for select HUC's.

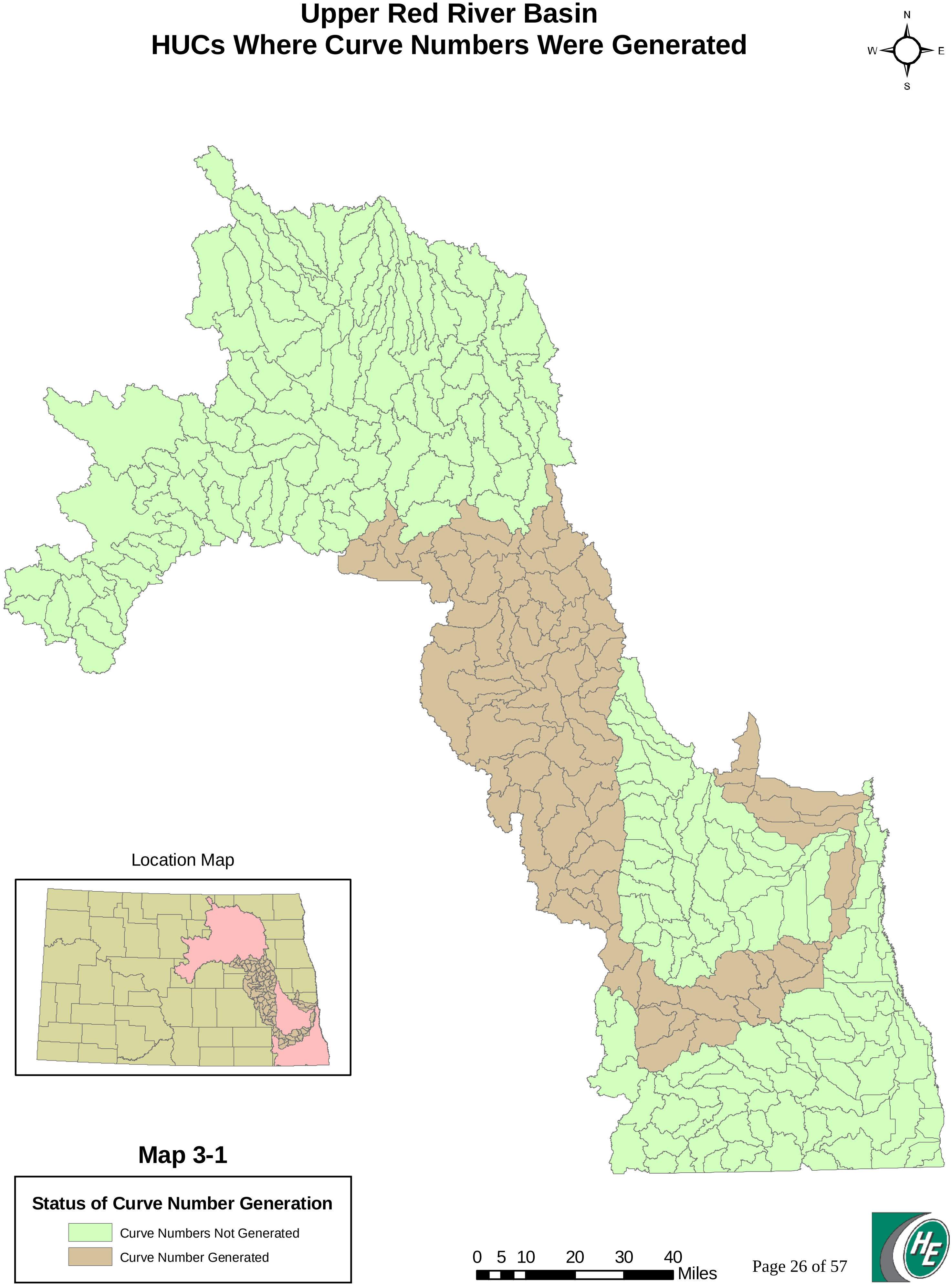


3.3.3 Runoff Volume and Curve Numbers

Within the spreadsheet model, runoff volumes were calculated on a daily basis and summed for an entire year to estimate the annual runoff volume for a specific "local" watershed area. This is different than the approach used in the CNET model, where aggregate runoff volumes are directly specified on an annual basis. The CNET model was modified to estimate daily runoff volumes using the TR-55 method (NRCS, 1986).

Area-weighted curve numbers were produced for the different land uses in each HUC based upon soils. A sample of 89 HUC (approximately 30% of those within the URRB) areas was used to estimate the regionalized inputs for area-weighted curve numbers, and these HUCs are shown in **Map 3-1**. Analysis of the sample values indicated that further time-intensive geoprocessing of land use and soils would not significantly affect or improve the robustness of

Upper Red River Basin
HUCs Where Curve Numbers Were Generated



the regionalized inputs that were generated with the 89 HUCs. **Figure 3-2** shows the curve number value distributions that were assigned to the different land use types.

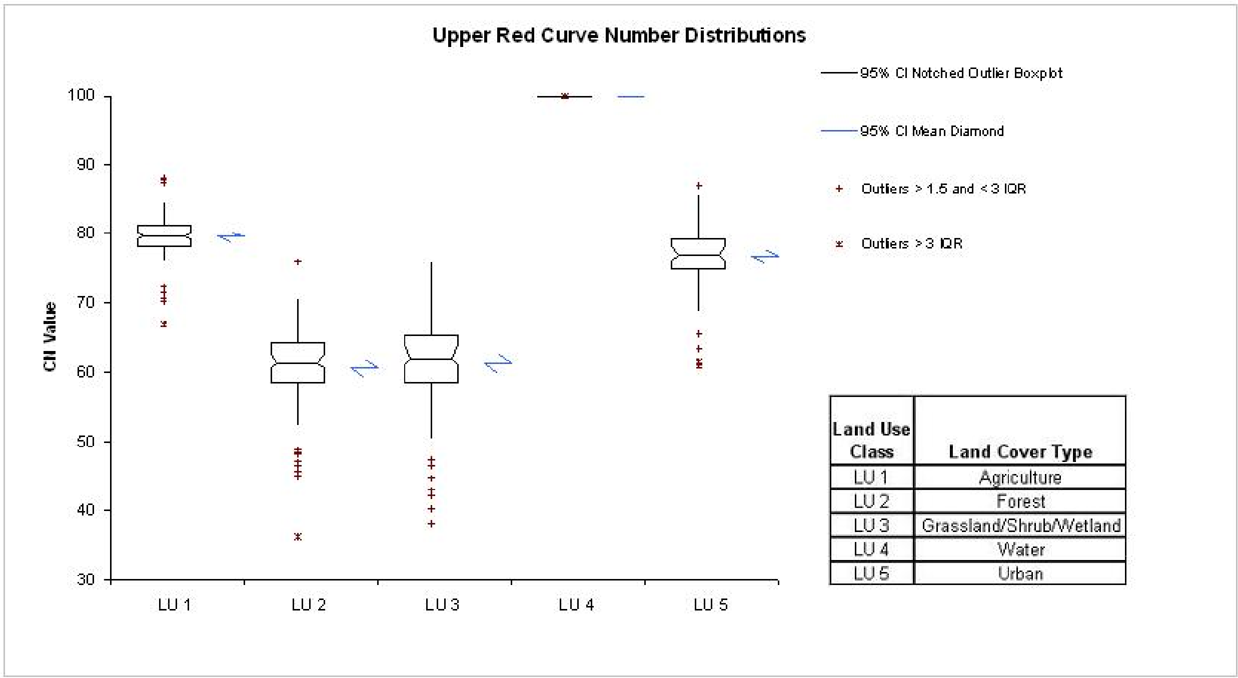
The area-weighted curve numbers for each land use type were then adjusted to reflect seasonality (primarily winter/frozen conditions). The seasonal adjustments are described as follows:

- Agriculture
  - Growing season CN as a distribution, with adjustments to reflect crop growth by increasing the area-weighted curve number early in the growing season and reducing the curve number during the summer months
  - Winter CN = 98
- Forest
  - Growing season CN as a distribution
  - Winter CN = 98
- Grass/Shrubs/Wetlands
  - Growing season CN as a distribution
  - Winter CN = 98
- Water (Not used in runoff calculations)
  - CN = 100
- Urban
  - Growing season CN as a distribution
  - Winter CN = 98

3.3.4 Daily Precipitation

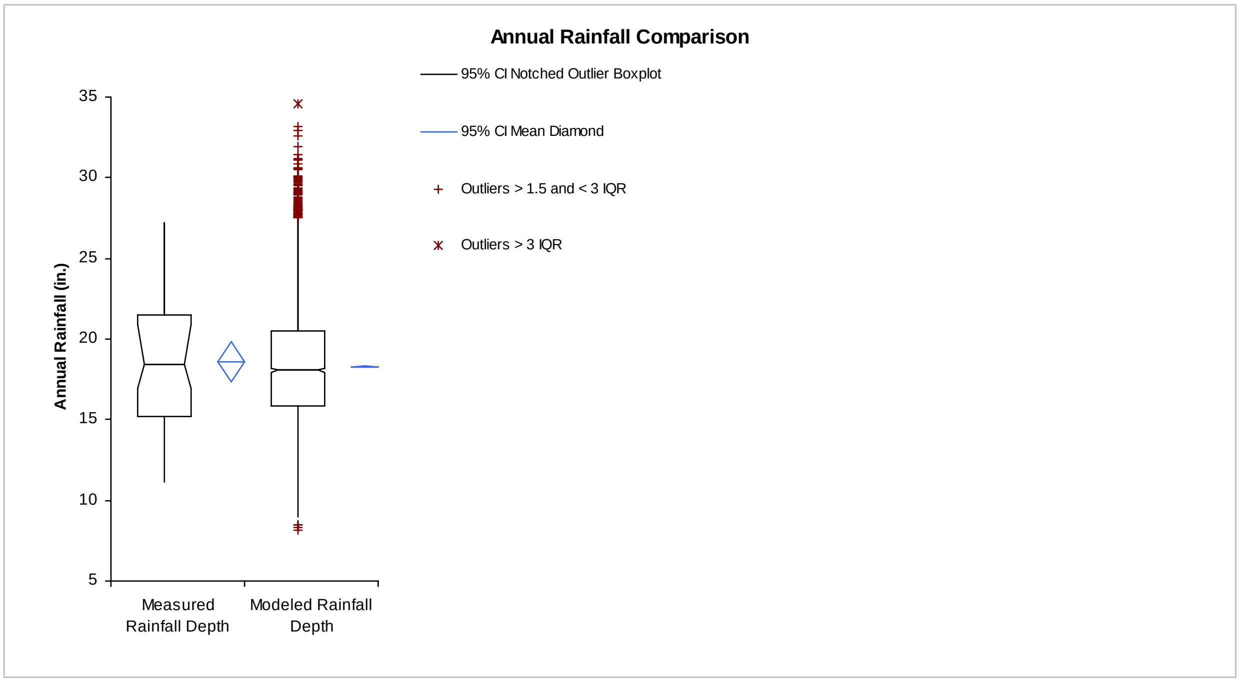
Precipitation input in the model was based upon a 48 year historical daily rainfall record for the McHenry, North Dakota rain gage. Daily precipitation values were defined by probability distributions based upon this historical record and values were generated so that daily runoff volumes and nutrient loads could be calculated.

Figure 3-2. Curve number distributions for land use types in the URRB.



The precipitation information used to generate the annual runoff volume and loads truly represents a range of precipitation conditions. The historical precipitation record was divided into seasons (winter, spring, summer, and fall). A lognormal distribution (i.e., the best statistical fit) was fit to the data for each season. The precipitation record was also evaluated to determine the number of precipitation-free days occurring historically. The percent chance of precipitation occurring on any given day in the season was calculated. Consequently, the generated values for each day represent the potential for precipitation based upon the percent chance of precipitation and a statistical representation of the seasonal rainfall distributions based upon several years of historical data (if precipitation did occur). This approach made the model precipitation data more robust because it allowed for many different types of rainfall patterns to occur in the model instead of basing the rainfall input on a single, average precipitation depth. **Figure 3-3** shows a comparison of historic measured annual rainfall depths versus what was obtained for rainfall depth from the modeling process on an annual basis. This figure shows that the precipitation input to the model compares favorably to historic measured annual rainfall depths based upon visual comparison of the central tendencies of the box-plots.

Figure 3-3. Comparison of measured and modeled rainfall depths.



3.3.5 Event Mean Concentrations

Most likely Event Mean Concentrations (EMCs) were used in the CNET model to estimate TP loadings on a daily basis through multiplication with the daily runoff volume. These TP EMCs were estimated from a wide variety of data sources (see **Appendix B**). Average values were estimated from these sources for the different land use types and used to complete the loading assessment. For Monte Carlo simulation the TP concentrations were represented by a triangular distribution using minimum, most likely, and maximum values. The calculated average concentration values represented the most likely EMC value for each land use type. These most likely values were bracketed by the minimum and maximum concentration values listed in the literature (see **Table 3-2**).

Table 3-2. Total phosphorus event mean concentration value ranges by land use.

Total Phosphorus

Parameter	Dist.	Lower Bound (mg/L)	Upper Bound (mg/L)	Most Likely (mg/L)
Agriculture (LU1)	triangular	0.32	1.14	0.79
Forest (LU2)	triangular	0.01	0.30	0.14
Grassland/Shrub/Wetland (LU3)	triangular	0.04	0.56	0.24
Water (LU4)	NA	NA	NA	NA
Urban (LU5)	triangular	0.10	0.93	0.35

3.4 RECEIVING WATER MODEL DEVELOPMENT

As noted in **Section 3.1**, the project used the "beta" CNET model, which is a modified version of the receiving water model BATHTUB. In addition to watershed in-flow parameters for the CNET model, information must be supplied about the lentic system characteristics, including: tributary drainage area; water surface area; mean depth (computed by dividing volume by surface area); mean depth of mixed layer; and, mean depth of hypolimnion. Additionally, various algorithms must be specified in the model for estimating response to excess nutrients.

3.4.1 Probablistic Lentic System Characteristics

State-wide NDGF data (refer to **Table 2-5**) were used to generate model inputs for the three parameters of interest: tributary area, surface area, and volume. These parameters are essential to characterize lentic systems for classification or modeling purposes. As described in **Sections 2.3.4 and 2.4**, surface area regressions were used to estimate tributary area and volume for state-wide lake and reservoirs. This allowed for using the identified metric to assign a class to each water body state-wide. However, for receiving water modeling within the URRB regional pilot study area, the state-wide NDGF data were re-analyzed using probability distributions to facilitate stochastic modeling.

Developing probability distributions from state-wide NDGF data (for tributary area, surface area, and volume), and applying those distributions to represent lentic systems in the regional pilot study area, was the preferred approach for several reasons. Using probability distributions to generate model inputs allows for an explicit expression of the error inherent within any regression estimate. This approach allowed unique combinations of tributary area, surface area, and volume to represent the range of possible lentic systems within the regional pilot area. The capacity for variable combinations based on probability distributions allowed the development of a high number of model trials (10,000) with different outcomes.

To develop the probability distributions, data were aggregated for each of the three parameters of interest. This was necessary due to the limited samples sizes of NDGF state-wide data for each class. The aggregations were performed separately for lakes and reservoirs (total counts of 76 and 108, respectively, as shown in **Table 2-5**). The aggregated data were input into Crystal Ball to fit a probability for each parameter within lakes and reservoirs.

During model execution, each of the 10,000 trials simulated within the CNET model represents a variable combination of tributary area, surface area, and mean depth (calculated from volume). The trials were independently developed for lakes and reservoirs, but were linked to a single file with 10,000 trials of watershed input parameters for precipitation, curve numbers, and total phosphorus concentrations by land use. When the model was executed, outcomes from the 10,000 trials for lakes were sorted based on the classification metric computed from the three parameters of interest. Reservoir trials were sorted in the same fashion.

3.4.2 Key Model Assumptions and Adjustments

Using hypothetical inputs, the response to excess nutrients predicted by the CNET model was reconciled with predicted responses generated by the BATHTUB model. In-lake TP concentrations for all eutrophication model choices were predicted consistently between models. However, predictions for water clarity and chlorophyll-a concentrations were not consistent between the CNET and BATHTUB models. No adjustments were made to account for this inconsistency. Model results for water clarity and chlorophyll-a are assumed to be reasonable but cannot be confidently used for interpretation of nutrient response dynamics.

Key assumptions and adjustments explicitly incorporated into the model include:

- Modifying algorithms to allow calculation of very minor amounts of outflow from receiving waters when water balance deficits occurred (i.e., evaporation exceeded inflows). This was most noticeable for large surface area lakes with small watersheds and low amounts of cultivated land. Without the modification, model calculations were not executable.

- Modifying algorithms to estimate inflow TP concentrations by dividing total TP loads by estimated inflow volume. The "beta" version of the model estimates inflow TP concentration through dividing TP loads by estimated outflow volume. Often, inflow volume did not equal outflow volume in the stochastic modeling due to evaporation.

- Assuming the model input values both for mean depth of the mixed layer and mean depth of the hypolimnion were equivalent to the value for mean depth of the water body. These three mean depth input values are required to run the model, however, no data were available to provide refinement to this assumption.

The following algorithms were used as the preliminary basis for beginning the model execution process:

- Total phosphorus: Canfield & Bachman, Reservoirs+Lakes
- Chlorophyll-a: P, Linear
- Water clarity: Carlson TSI, Lakes

3.5 QUALITY ASSURANCE REVIEW OF MODELING RESULTS

The purpose of completing a quality assurance review process is to establish the "known quality" of the results. Quality assurance program plans have traditionally been prepared for water quality monitoring programs. The plans are prepared prior to the data collection effort and describe the desired accuracy, precision, and completeness of the results. Formal quality assurance programs and reviews for the collection of water quality data are, in some respect, easier to implement than for model results. The reason is that formal criteria, like accuracy, precision, completeness, and detection limits, are well established for traditional water quality monitoring programs.

The quality assurance review of model results fundamentally differs from traditional water quality monitoring programs. The quality assurance review of models is more focused on ensuring:

- Equations representing the important physical, chemical, and biological processes are included in the model;
- The input data used by the model equations to derive parameters (e.g., curve number) are within an "acceptable" range. Acceptable may be based either on a comparison to observed data or through calibration;
- Values used to describe the rates of various biological, chemical, or physical processes (e.g., first-order decay rates) are within an "acceptable" range;
- Understanding the sensitivity of the model results to the various model assumptions and inputs;
- Whether the model results reflect the proper temporal and spatial scales of the biological, chemical, and physical processes;
- Independent technical review by an experienced modeler; and
- Model results are "reasonable." Reasonable can be determined using a variety of methods, including: model calibration and validation, comparison of the model results to the results using other methods or models, comparison to the results presented in the scientific literature and other technical reports, and best professional judgment of the modeler.

SECTION 4.0
REGIONAL NUTRIENT CRITERIA MODEL EXECUTION

4.1 REGIONAL CALIBRATION

4.1.1 Approach

A "weight of evidence" approach was taken for calibrating the regional nutrient criteria model. A true calibration approach, where model parameters are adjusted until model predictions reflect measured conditions, was not realistic or possible. This is generally due to the broad spatial scale of the model and the paucity of available response data for water bodies within the different lake and reservoir classifications. The intent of the approach was to develop confidence in the accuracy, not precision, of model outputs.

The weight of evidence approach principally included evaluating the reasonableness of landscape inputs used to predict excess nutrients to receiving waters. The landscape inputs evaluated included annual water yields and TP unit loads. The predicted in-lake TP concentrations were also evaluated, but other response variables were not closely evaluated due to a lack of regional specific algorithms, as previously discussed.

4.1.2 Data Analysis for Calibration

Mean annual water yield data were provided by the United States Geological Survey (USGS) for streamflow-gauging stations within North Dakota based on historic periods of record. The mean annual water yield data were divided by the effective drainage area to normalize the data to units of inches. These data are summarized in **Table 4-1**.

In-lake response variables (TP concentration, Secchi depth, and chlorophyll-a concentration) were obtained and summarized from North Dakota SID stations within the URRB regional pilot study area. For each SID station, daily in-lake data were summarized to represent annual average values. The annual average values for in-lake TP concentration, Secchi depth, and chlorophyll-a concentration in the URRB can be found in **Table 4-2**, along with the minimum, maximum, and count of SID stations for each year of data. Annual average values across SID stations in the URRB were then further reduced (pooled) to represent a regionalized average annual value, excluding Devils Lake and Lake Ashtabula because of the bias introduced by the larger sample sizes associated with these water bodies. This resulted in thirteen regional annual average data points. The data were not further stratified based on whether the SID station was considered a lake or reservoir system because of the small sample size. Data were also analyzed by

Table 4-1. Annual water yields for USGS gage stations in North Dakota.

Station Number	Station Name	Begin Year	End Year	Mean Water Yield (in/yr)
05051600	WILD RICE RIVER NR RUTLAND, ND	10/1/1959	9/30/2006	0.38
05051700	WILD RICE RIVER NR CAYUGA, ND	6/1/1956	9/30/2006	0.46
05056400	BIG COULEE NR CHURCHS FERRY, ND	10/1/1950	9/30/1997	0.51
05056200	EDMORE COULEE NR EDMORE, ND	4/1/1956	9/30/2006	0.68
05056100	MAUVAIS COULEE NR CANDO, ND	6/1/1956	9/30/2006	0.71
05059300	SHEYENNE R AB SHEYENNE R DIVERSION NR HORACE, ND	10/1/1992	9/30/2006	0.76
05056239	STARKWEATHER COULEE NR WEBSTER, ND	10/1/1979	9/30/2006	0.78
05060000	MAPLE RIVER NR MAPLETON, ND	10/1/1958	9/30/2006	0.94
05059700	MAPLE RIVER NR ENDERLIN, ND	6/1/1956	9/30/2006	0.98
05057200	BALDHILL CREEK NR DAZEY, ND	4/1/1956	9/30/2006	1.01
05059500	SHEYENNE RIVER AT WEST FARGO, ND	5/1/1903	9/30/2006	1.04
05060100	MAPLE RIVER BL MAPLETON, ND	4/1/1944	9/30/2006	1.10
05059000	SHEYENNE RIVER NEAR KINDRED, ND	8/1/1949	9/30/2006	1.18
05058700	SHEYENNE RIVER AT LISBON, ND	9/10/1956	9/30/2006	1.21
05098700	HIDDEN ISLAND COULEE NR HANSBORO, ND	10/1/1961	9/30/1995	1.25
05058000	SHEYENNE RIVER BELOW BALDHILL DAM, ND	10/1/1949	9/30/2006	1.26
05056000	SHEYENNE RIVER NR WARWICK, ND	10/1/1949	9/30/2006	1.29
05057000	SHEYENNE RIVER NR COOPERSTOWN, ND	10/1/1944	9/30/2006	1.48
05060500	RUSH RIVER AT AMENIA, ND	8/1/1946	9/30/2006	1.50
06468170	JAMES RIVER NR GRACE CITY, ND	6/1/1968	9/30/2006	1.82
05051500	RED RIVER OF THE NORTH AT WAHPETON, ND	5/1/1942	9/30/2006	2.22
06468250	JAMES RIVER ABOVE ARROWWOOD LAKE NR KENSAL, ND	10/1/1985	9/30/2006	2.58
05051522	RED RIVER OF THE NORTH AT HICKSON, ND	10/1/1975	9/30/2006	2.66

4.1.3 Calibration Results

Once data were analyzed and developed to serve as a framework for regional model calibration, the stochastic model was executed using the preliminary algorithms previously discussed. Observed and predicted annual water yields and in-lake TP concentrations were compared through the use of box-plots, which can be found as **Figures 4-1 and 4-2**. It should be noted that water yield inputs in the model are the same without regard to water body type (lake

Table 4-2. Annual average in-lake response values available for calibration within the URRB regional pilot area based on North Dakota SID data.

Year	Avg of TP (mg/L)	Min of TP (mg/L)	Max of TP (mg/L)	Count of SID IDs	Avg of SECCHI (m)	Min of SECCHI (m)	Max of SECCHI (m)	Count of SID IDs	Avg of CHL-A (ug/L)	Min of CHL-A (ug/L)	Max of CHL-A (ug/L)	Count of SID IDs
1986					0.0	0.0	0.0	4				
1987					0.5	0.5	0.5	6				
1988												
1989												
1990					2.3	2.3	2.3	5				
1991					1.3	0.5	2.3	71				
1992					1.3	0.4	2.5	119				
1993	0.118	0.040	0.270	24	0.0	0.0	0.0	11				
1994	0.101	0.055	0.156	9	1.6	1.4	1.8	19	21.00	13.00	29.00	2
1995									17.00	17.00	17.00	1
1996	0.023	0.009	0.057	6	1.2	0.8	1.5	15	8.50	4.00	13.00	2
1997	0.009	0.009	0.009	3	0.0	0.0	0.0	6				
1998												
1999	0.292	0.189	0.374	5	1.2	0.8	1.8	18	12.83	1.50	28.00	3
2000	0.309	0.186	0.540	8	1.0	0.0	2.4	13	38.17	1.50	78.00	3
2001	0.282	0.033	0.450	7	1.2	0.0	2.9	11	1.50	1.50	1.50	1
2002	0.119	0.002	0.769	26	1.0	0.5	1.5	11	16.89	1.50	42.00	9
2003	0.134	0.002	0.572	37	0.9	0.4	1.2	38	10.64	1.50	32.00	8
2004	0.165	0.011	1.240	54	1.6	0.5	3.6	18	12.08	0.75	45.90	14
2005	0.179	0.002	0.561	80	1.2	0.3	2.5	159	14.99	0.75	66.80	31
2006	0.179	0.020	0.367	16	2.5	0.7	5.3	83	30.37	0.75	211.00	9
2007	0.194	0.125	0.243	4	1.5	0.5	2.4	9	1.25	1.00	1.50	2

Note: Averages of data represent samples taken at various depths within any given system, and can also represent samples collected at more than one spatial location for any given system.

Figure 4-1. Annual water yield comparison for the URRB regional pilot area.

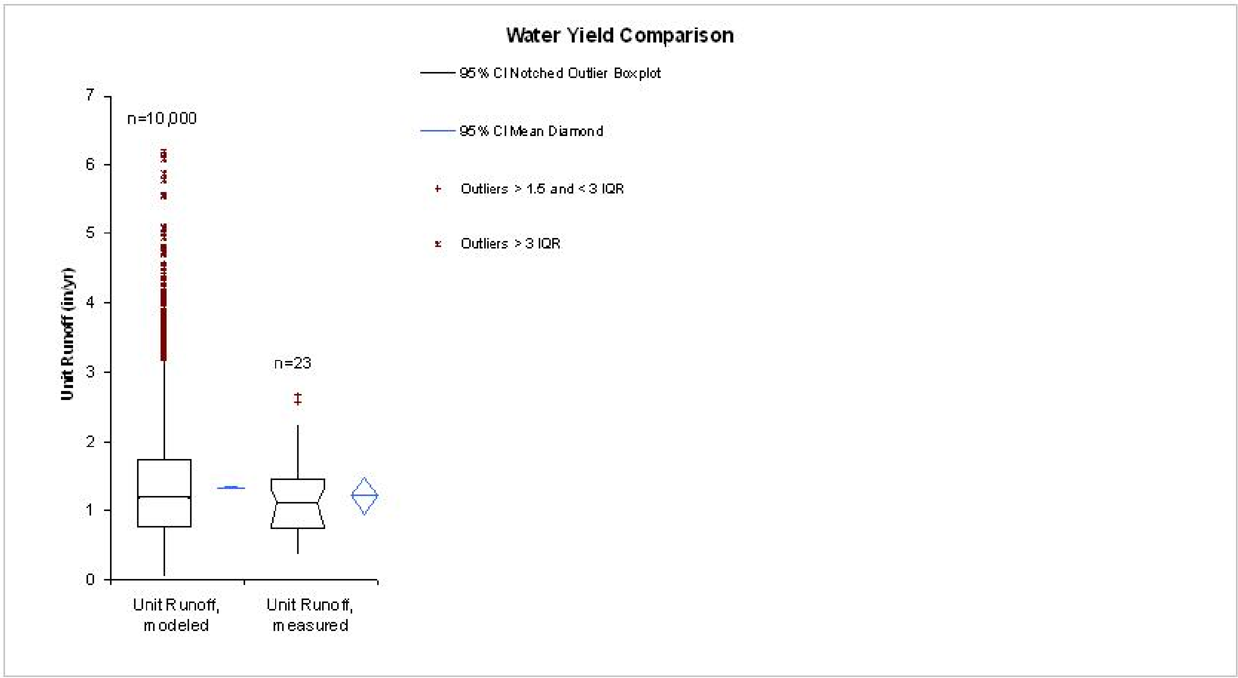
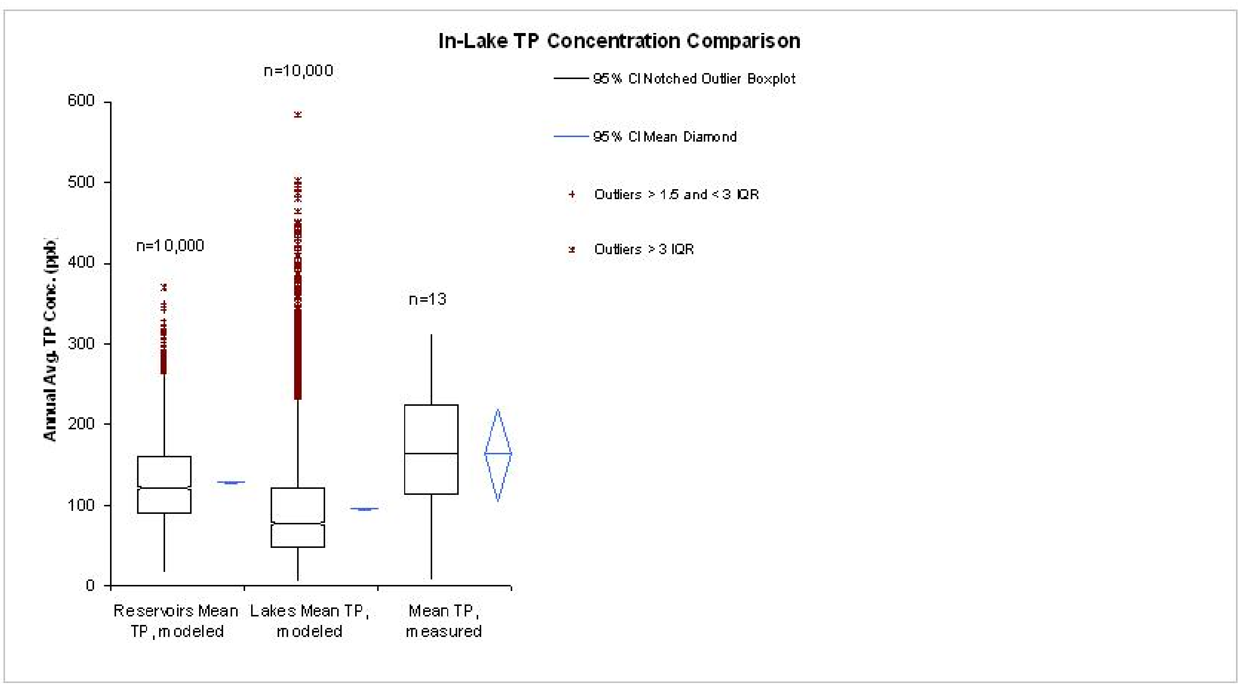


Figure 4-2. Annual in-lake TP concentration comparison for the URRB regional pilot area.



or reservoir), while in-lake TP concentrations differ based upon water body type. Further, the model results in these figures represent a land cover condition of 82% cultivated agriculture. This land cover scenario represents what is considered “modern” land use conditions, which was an important consideration for temporal consistency when comparing modeled with measured results.

While the data support the general reasonableness of the curve number-based approach for hydrology, it is acknowledged that the flow monitoring data includes base flow as well as storm flow discharge. Also, although event mean concentrations were estimated per land use based on literature values instead of actual field measured data in the study area, predicted in-lake TP concentrations still appeared within a reasonable range of measured regional average water column values. As noted in Section 3.4.2, predicted in-lake TP concentrations were determined using the Canfield & Bachman Reserviors+Lakes algorithm in CNET. Other TP response models were assessed within CNET but none displayed better representation of regional regional measured values. (Note that CNET algorithms for Secchi depth and chlorophyll-a predictions need refinement beyond this current “beta” version of the model.)

Several factors limited a more rigorous analysis of assessing the regional model calibration for this pilot study. First is the small sample size of pooled measured data. Second, pooled data represent a mix of data at various vertical and spatial locations. Thus, outliers in pooled data may be a vestige of a discrete sample(s) reflecting high nutrient concentrations at deep locations in a reservoir during anoxic periods. Third, it was difficult to precisely align the classification metrics for systems between modeled and measured results of Figure 4.2. A site-specific side-bar analysis was performed on three systems with water column field data and having NDGF data to allow computation of a classification metric. The results are displayed in **Appendix C**. The results indicate that model predictions for regional classes appear to align with site-specific values, or may over predict measured values.

Overall, the calibration effort for the pilot study illustrates the need for more data to better define the confidence of the regional model. Again, the data within Figure 4.2 are not entirely equivalent in what they conceptually represent; however, the regional model appears to be a reasonable tool to represent aggregate impacts.

4.2 Regional Model Results for the URRB Regional Pilot Study Area

4.2.1 <u>Watershed Yields and Land Use</u>

Upon calibration, the regional model was applied to the URRB regional pilot study area. Scenario analysis was performed in the CNET model by varying land use percentages. An operational determination was made that over time, the predominant land use change in North Dakota was the conversion of grassland areas to cultivated agricultural fields. This was based on information from the United States Department of Agriculture, National Agricultural Statistics Service. Data for the cultivated crop trend in North Dakota for the early 1900's to present was analyzed, which can be found as **Figure 4-3**.

Instead of fixing land use percentages for certain time periods (e.g., pre-European settlement, pre-modern agriculture, and modern agriculture), several different percentages of agricultural land use were modeled, ranging from 10 to 90 percent cultivated agriculture. It should be noted, as discussed previously, that the 82 percent cultivated agriculture scenario is used to represent what is considered "modern" conditions. This percentage is based on land use from one representative HUC in the URRB regional pilot study area. The grassland land use percentage was inversely adjusted in proportion to cultivated agriculture adjustments for each scenario, while the other land use percentages were held constant, to keep the overall total amount of area constant between scenarios. Model results are presented as watershed yield percentiles, both annual runoff and TP nutrient load, and can be found in **Table 4-3** for each land use scenario. Normalized yields were considered the best measure for analysis of land use impact results because the tributary areas were varied stochastically in the model (as discussed in Section 3).

The results are presented as a range of predicted values that were obtained in the stochastic scenario analysis. The results show that as the percentage of cultivated agriculture is increased, the predicted amount of runoff and TP loading increases. As a visual aid, a graph of the median watershed yields (both annual runoff and TP nutrient load) was prepared per scenario and can be found as **Figure 4-4**.

Figure 4-3. North Dakota cultivated crop trend.

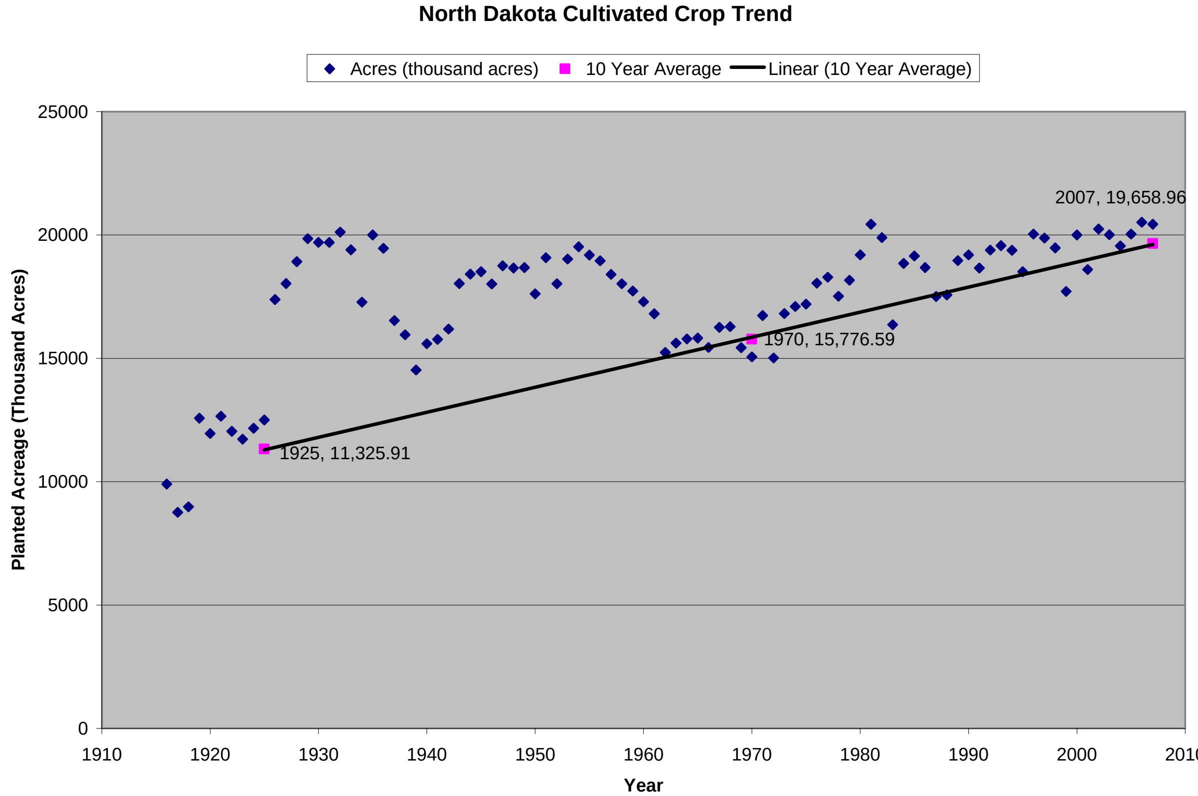
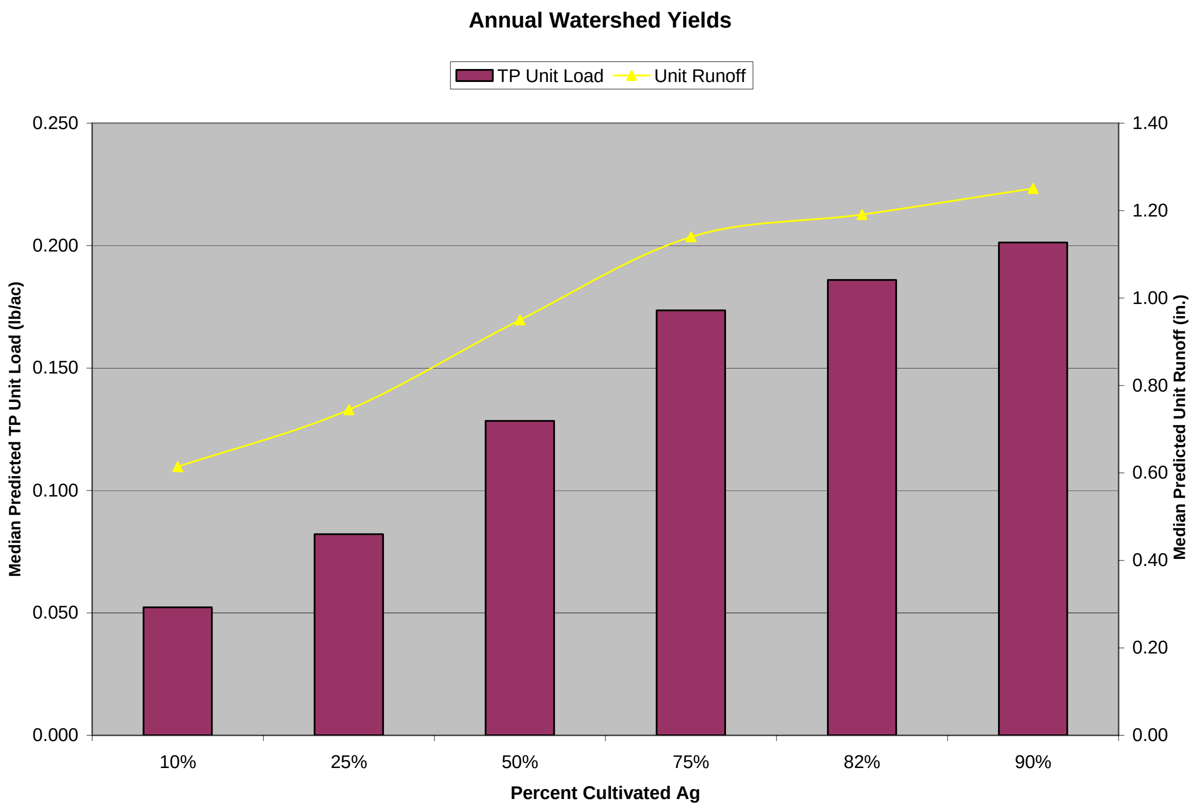


Table 4-3. Annual watershed yield percentiles URRB pilot study area. [Cult = cultivated; Ag = agricultural]

Predicted Unit Runoff (inches)						
Percentiles	**10% Cult. Ag**	**25% Cult. Ag**	**50% Cult. Ag**	**75% Cult. Ag**	**82% Cult. Ag**	**90% Cult. Ag**
0th	0.03	0.05	0.05	0.05	0.05	0.05
25th	0.39	0.49	0.63	0.75	0.78	0.82
50th	0.61	0.74	0.95	1.14	1.19	1.25
75th	0.92	1.09	1.37	1.66	1.74	1.84
100th	4.12	4.20	4.84	5.91	6.19	6.70
Predicted TP Unit Load (lb/ac)						
Percentiles	**10% Cult. Ag**	**25% Cult. Ag**	**50% Cult. Ag**	**75% Cult. Ag**	**82% Cult. Ag**	**90% Cult. Ag**
0th	0.002	0.004	0.005	0.006	0.006	0.007
25th	0.033	0.052	0.081	0.108	0.115	0.124
50th	0.052	0.082	0.128	0.174	0.186	0.201
75th	0.079	0.122	0.193	0.265	0.284	0.308
100th	0.364	0.449	0.824	1.199	1.300	1.424

Figure 4-4. Median annual watershed yields.



4.2.2 In-Lake TP and Classes

As discussed in **Section 3.4.1**, model trials were independently developed for lakes and reservoirs, but were linked to a single file of watershed input parameters for precipitation, curve numbers, and total phosphorus concentration by land use. Therefore, unit runoff and unit nutrient loadings were the same for both the lakes and reservoirs. Also as noted previously, 10,000 trials were modeled each for lakes and reservoirs, and for each trial, the classification metric was computed using the three parameters of interest for receiving waters. Model results of the 10,000 trials were then sorted into the four classes established for lake and reservoir systems.

Box-plot summaries of the classed model results were produced for the in-lake TP concentrations, using the 82% cultivated agriculture land use scenario. **Figure 4-5** is a summary of the lake TP response data, and **Figure 4-6** is a summary of the reservoir TP response data. These results support that the lake and reservoir classes are theoretically valid for use in development of criteria because there is a difference in the median value between classes and the confidence intervals about the median values do not overlap. Further, TP concentration values decrease as the class value increases. This means that each water body class displays a distinct response.

Figure 4-5. Lake TP response box-plot by class.

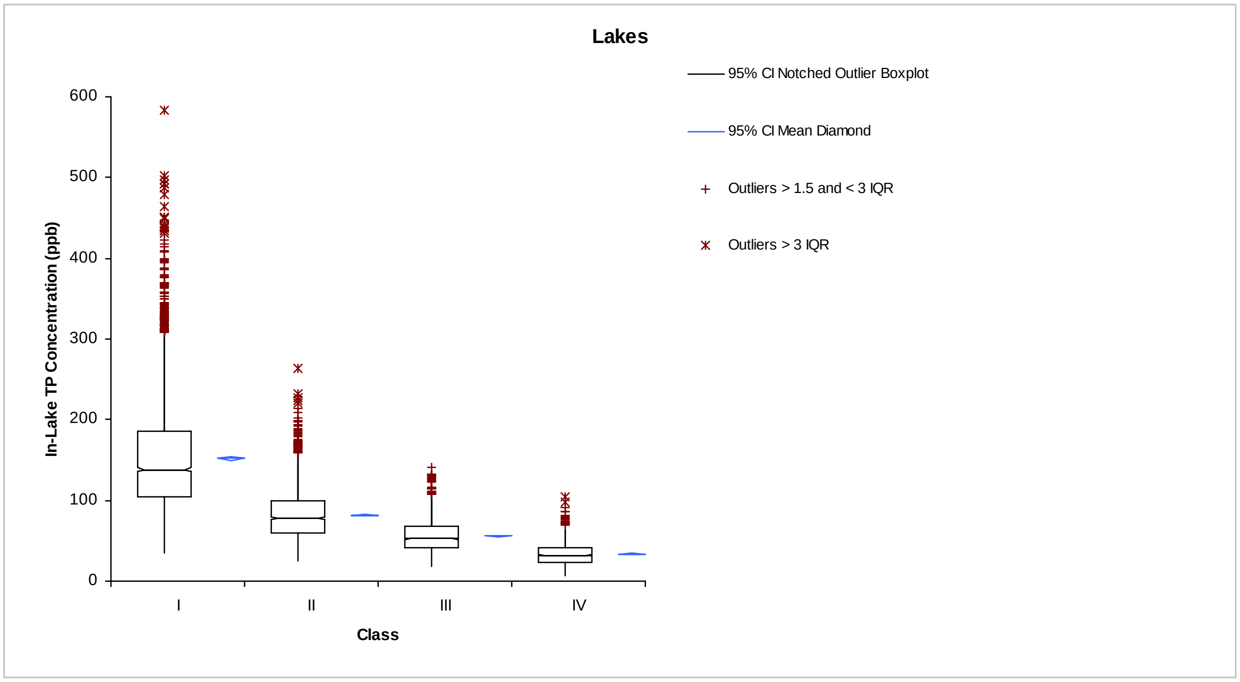
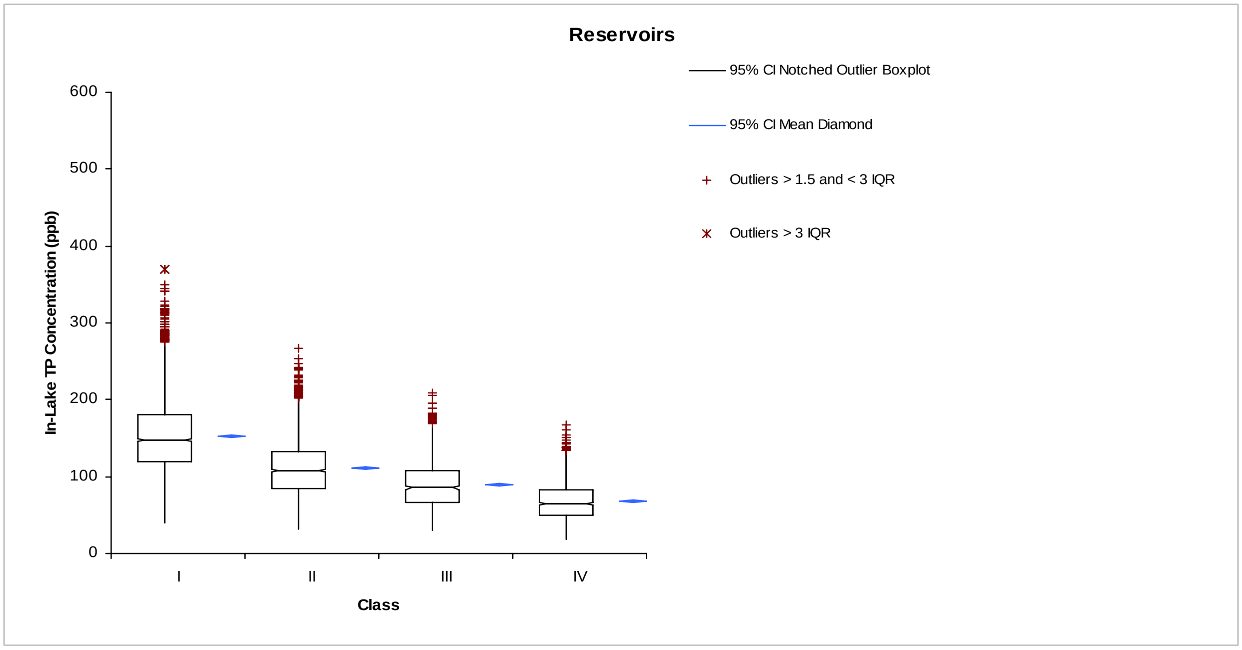


Figure 4-6. Reservoir TP response box-plot by class.



The classed model results for the lake and reservoir in-lake TP concentrations were analyzed further for all land use scenarios by isolating the median values for each class. Graphical summaries can be found as **Figures 4-7 and 4-8** for lakes and reservoirs, respectively. These summaries display the effect the amount of cultivated agriculture and water body class, in unison, has with regards to predicted in-lake TP concentrations. It was found that the land use composition in the surrounding drainage area has a greater impact upon water quality of the smaller size water bodies (Class I) in comparison to the larger size water bodies (Class IV). The relative difference between classes, compared across different water body types, was found to differ under varying cultivated agriculture land use scenarios, however. The relative difference differed amongst the classes for lake systems, while the relative difference was fairly uniform amongst the classes for reservoirs. The relative difference for in-lake TP concentrations between the 10% and 90% cultivated agriculture scenarios for lake and reservoir classes I-IV can be found in **Table 4-4**.

Figure 4-7. Median TP concentrations of lake classes relative to percent cultivated agricultural land use.

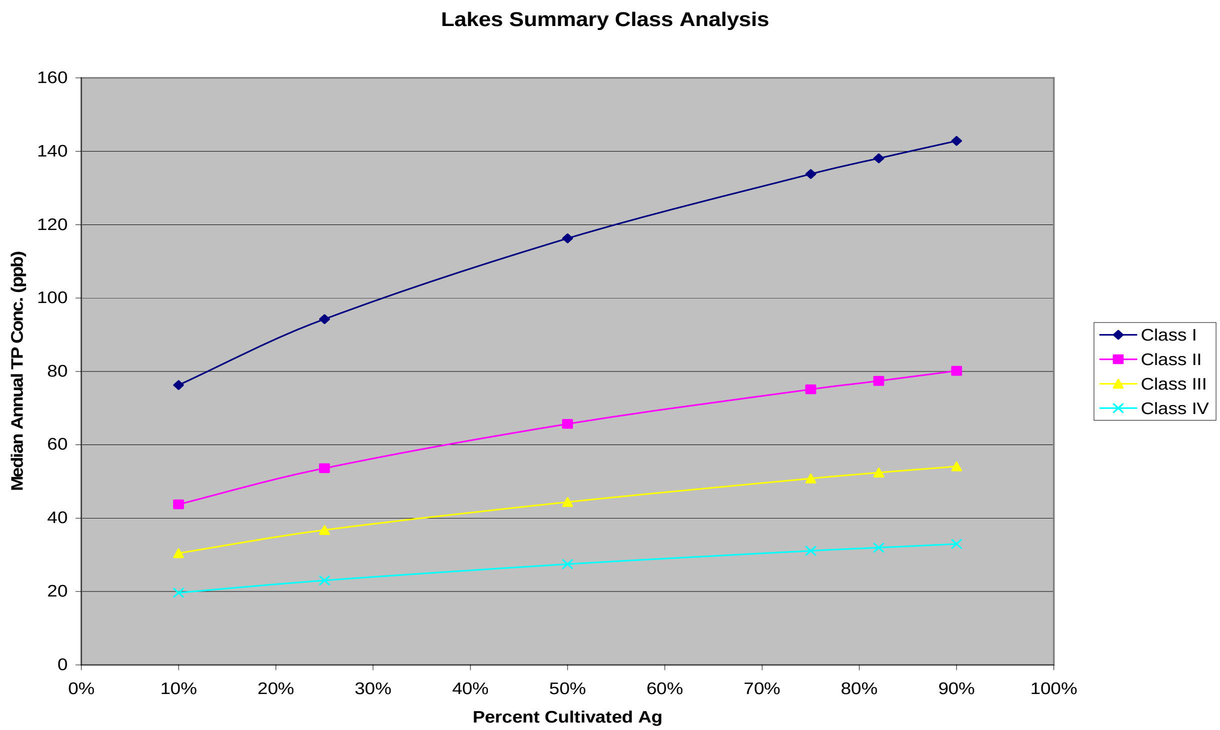


Figure 4-8. Median TP concentrations of reservoir classes relative to percent cultivated agricultural land use.

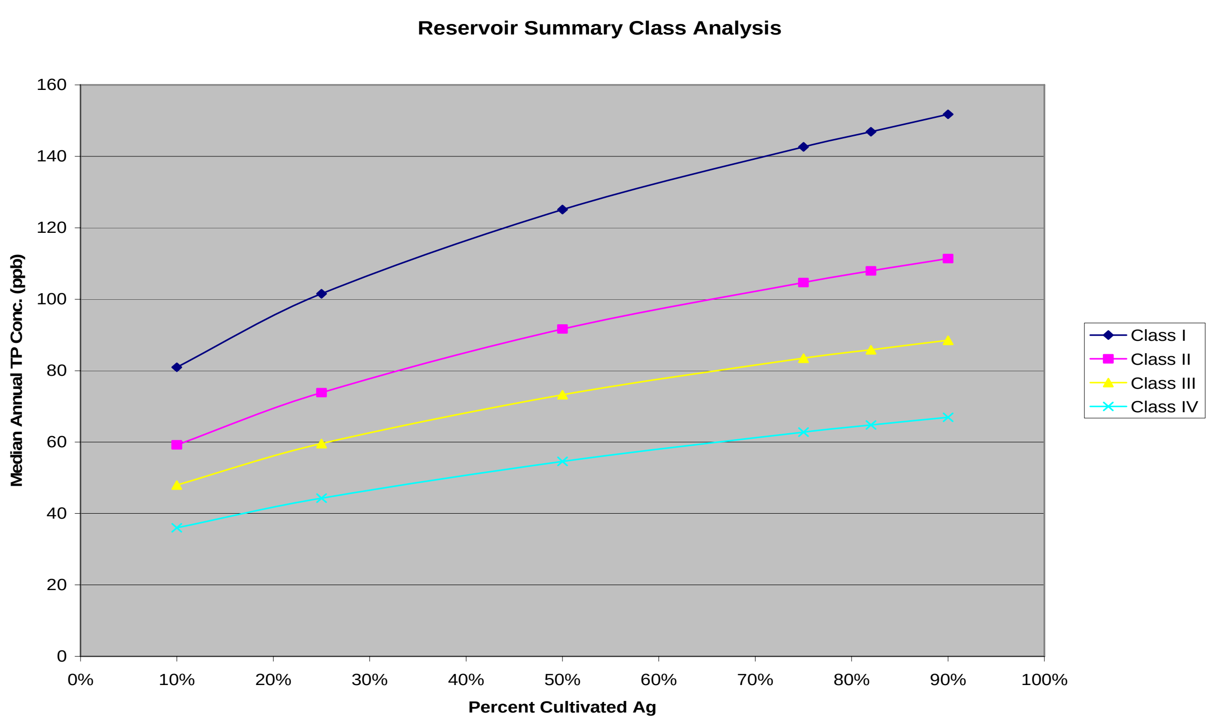


Table 4-4. Relative difference of median in-lake TP concentrations between 10 and 90% cultivated agriculture scenarios.

	Class	10% Cultivated Ag	90% Cultivated Ag	Percent Difference
Lakes	I	76.3	142.8	60.8
	II	43.8	80.2	58.8
	III	30.4	54.1	56.1
	IV	19.7	33.0	50.5
Reservoirs	I	81.0	151.8	60.9
	II	59.2	111.4	61.2
	III	48.0	88.5	59.4
	IV	36.0	67.0	60.1

These results seem reasonable as smaller water body systems are generally more influenced by fluctuations in the surrounding landscape due to their smaller volumes and more frequent flushing and hydraulic exchange within the system. Further, reservoirs should respond similarly regardless of size due to similar hydraulic characteristics, while lakes of varying sizes should respond differently to watershed inputs due to differing hydraulic characteristics. It is recommended that these system responses should be validated in the field for water bodies in the URRB regional pilot study area, however.

4.2.3 Secchi Depth and Chlorophyll-a

The other model response variables (Secchi disk depth and chlorophyll-a concentration) were only examined for general reasonableness of model results. This involved comparing the predicted response for the variables by class. Box-plot summaries of the classed model results were produced for Secchi depth and chlorophyll-a concentrations, similar to the in-lake TP concentrations. **Figures 4-9 and 4-10** summarize the predicted lake and reservoir Secchi depth data, respectively; **Figures 4-11 and 4-12** summarize the predicted lake and reservoir chlorophyll-a data, respectively. These results also support that the lake and reservoir classes make sense because there is a difference in the median value between classes and the confidence intervals about the median values do not overlap. Further, the Secchi disk depths increase, while chlorophyll-a concentration values decrease, with an increase in class value.

Figure 4-9. Lake Secchi depth response box-plots by class.

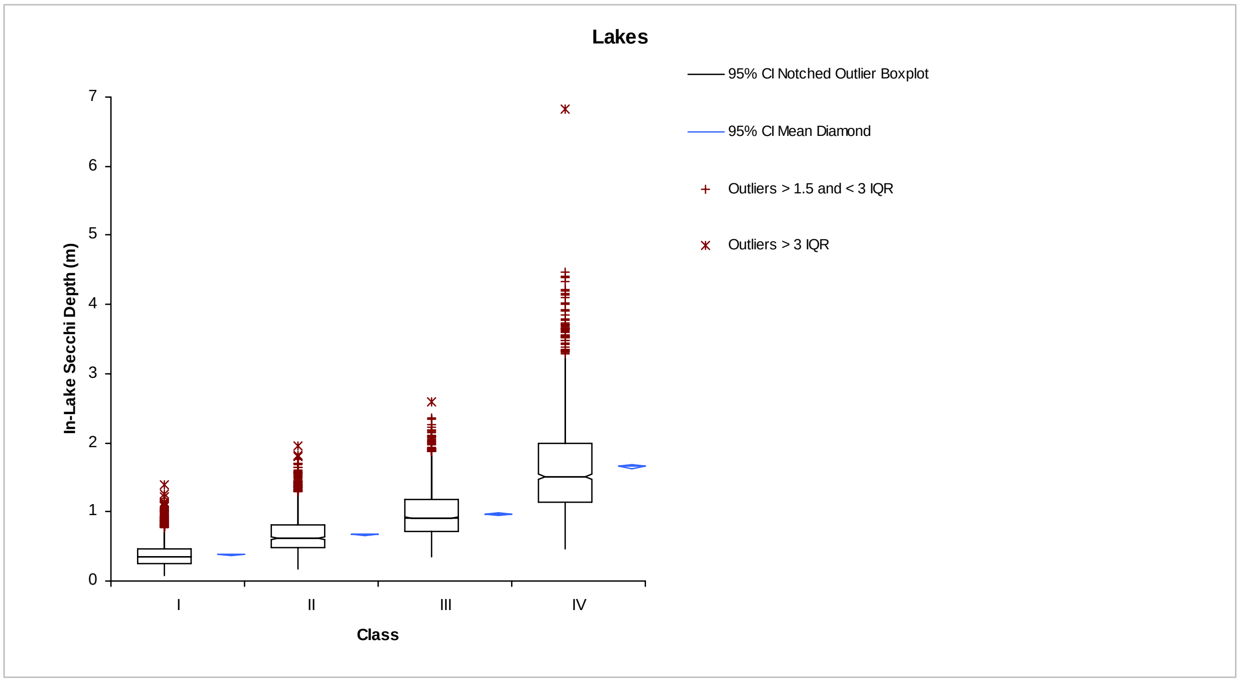


Figure 4-10. Reservoir Secchi depth response box-plots by class.

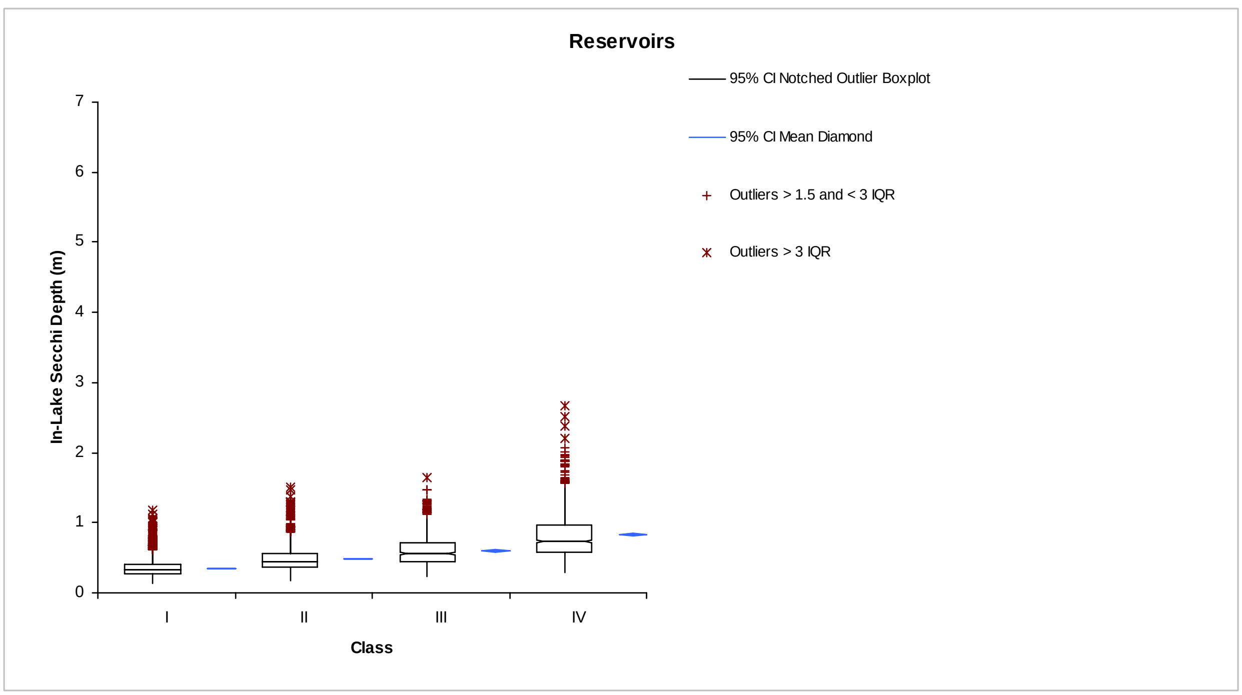


Figure 4-11. Lake chlorophyll-a response box-plot by class.

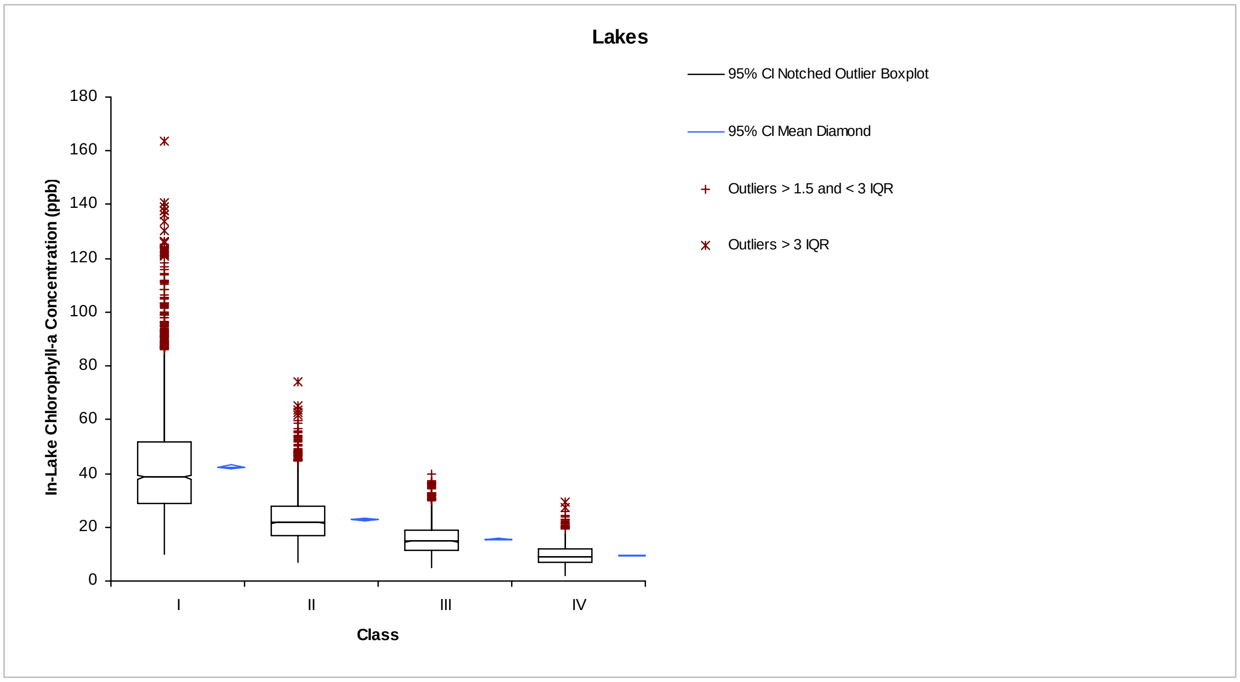
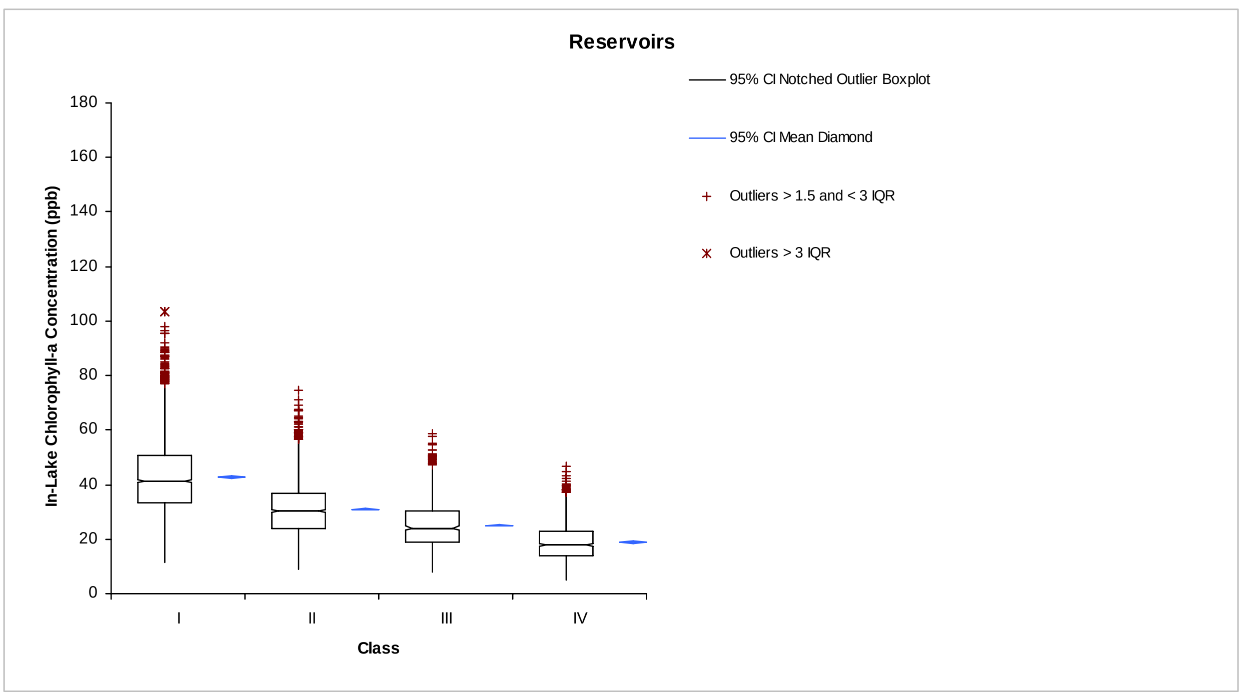


Figure 4-12. Reservoir chlorophyll-a response box-plot by class.



SECTION 5.0
RECOMMENDATIONS AND CONCLUSIONS

5.1 REVIEW OF SELECTED CLASSIFICATION SYSTEM

Classification of lentic systems is crucial for development of regional nutrient criteria that are consistent and protective of groups of water bodies. In this process, several metrics were evaluated for use in classifying lentic systems in North Dakota. The selected metric was developed internally to HEI and is: (surface area / drainage area) * volume = acre-feet.

The metric used in this nutrient criteria development process was found to be the most suitable, for several reasons.

- The modeling output displayed a difference in the median results for the model response variables (in-lake TP concentrations, Secchi depths, and chlorophyll-a concentrations) between the four groups that were established for lakes and reservoirs and the confidence intervals about the median values did not overlap. Box-plot analysis of modeling results did display some overlap of the interquartile ranges between the groups. This is expected, however, because of the overlap in the range of the physical characteristics for the groups that underpinned the computation of the metric.
- There was an observed inverse relationship between in-lake TP concentrations water body class (classes I, II, III and IV). In-lake TP concentration decreased with an increase in class value from I to IV.

It is expected that this classification system will work for the other planning regions in North Dakota. The metric is based upon descriptive water body physical characteristics and the model tool is unbiased with regard to area where descriptive data is collected.

5.2 REVIEW OF MODELING RESULTS

The completion of a quality assurance review process is important for determining the reasonableness and quality of the results. The quality assurance review method employed in this study involved, among other steps, comparing the model results to field data that have been collected in the study area.

This study's modeling results were determined to be "reasonable" for the following reasons:

- The modeling results for the water bodies appear to reflect, and compare with, regional data that has been measured by the USGS and the State in the URRB regional pilot study area for water yield and in-lake TP concentrations.
- There was an observed direct relationship between the amount of cultivated agriculture and watershed yield where, as the amount of cultivated agricultural land use increased, the predicted unit runoff and TP unit load increased.

5.3 Acknowledgement of Limitations and Issues

Although the model was determined to be reasonable, it was discovered that there were limitations and issues with regard to the modeling approach that was selected.

- Strong confidence exists for estimations of lentic system TP concentrations using the CNET model. However, a limitation is that the CNET model is a "beta" version and equations that underlie the calculation of chlorophyll-a concentrations and Secchi depths need refinement. This limitation was discovered upon a side-by-side comparison with the BATHTUB model (the precursor to CNET).
- The evaluation of landlocked lakes was not included within this study. Water balance issues were encountered when executing the model. Instabilities occurred in the model when watershed inflows were less than evaporation (which is typical for landlocked lakes).
- The robustness of the model and confidence in the classification system can be greatly enhanced using an improved dataset. Many water bodies did not have physical attribute or morphometric data (i.e., volume and drainage area). This led to low predictive power of the regression equations used for estimating these attributes for other water bodies. There also was a lack of water quality data available for water bodies, which constrained the model calibration and verification processes. The model results were calibrated through evaluation of data for water bodies in aggregate rather than by lake and reservoir class.

- Water yields were found to be reasonably consistent with USGS data. However, an assumption to acknowledge in the CNET model is that watershed runoff includes all delivered water (such as base flow), and the model approach did not account for regional abstractions (such as wetlands). Further, it is important to acknowledge that although the model was executed on a daily time step, watershed runoff results should only be examined in aggregate (annually).
- Ideally, total phosphorus yields would be tied back to Clean Water Act Section 319 watershed assessment and implementation projects or TMDL development projects in North Dakota. This should be considered during model refinement but these data were not available at the time of this study. From review of the model results, it was found that the TP yields were generally lower than what would be expected based on professional judgment.

The results of this regional pilot study support the proposed classification system. However, it is important to acknowledge the results suggest (based on median annual TP concentrations) that lakes in Class I are substantially eutrophic even under land use conditions of minimal agricultural cultivation, while lakes in Class IV maintain a mesotrophic condition even when the landscape is in full agricultural production. Further, the results from agricultural land use condition adjustment suggest that reservoirs do not obtain a condition better than a eutrophic state. Data collected to implement class-specific model calibrations will address this limitation.

5.4 IMPLICATIONS FOR NUTRIENT CRITERIA DEVELOPMENT

Models are useful tools to help answer questions or use in predicting past or future conditions. For developing nutrient criteria for North Dakota's lentic systems, the absence of sufficient data about reference water bodies across the State supports the need for a regional model used to develop criteria.

A notable gap in the data is information characterizing water quality conditions for a bench mark (or reference, or minimally impacted) situation. The regional model developed for the URRB regional pilot study allows decision makers to examine the relationship between land use and lake eutrophication response. The "percent cultivated agriculture" land use condition best reflects anthropogenic influences through time. A reduction in this land use coverage represents a shift towards bench mark, or minimally impacted, conditions. However, the regional model is generally not sensitive to distinctions among different types of “bench mark condition” land uses, so land use class 3 reflects an aggregate of grassland/shrub/wetlands.

The URRB regional pilot study utilizes a TP model to assess eutrophication impacts. A ratio of water column total nitrogen concentration to total phosphorus concentration is less than seven (i.e., < 7:1) indicates a lake or reservoir is nitrogen limited. In situations of eutrophication, however, true nitrogen limitation does not exist, but rather, there is an overabundance of phosphorus in the water column. Under these conditions, certain nitrogen fixing species such as some blue-green algae are favored. For this reason, a TP model was developed in lieu of a total nitrogen model.

The URRB regional pilot study demonstrated that there is a difference in median TP concentrations between different classes of lakes and reservoirs. Further, the results of the regional pilot study provide estimated median annual TP concentrations under varying percent cultivated agriculture land use conditions for water body classes. However, while it was determined that the regional model is a feasible tool for setting nutrient criteria, the limitations and issues identified in **Section 5.3** should be addressed before utilizing and applying any data generated by modeling.

Other considerations and steps must also be recognized for development of nutrient criteria based on a regional model. The following steps illustrate a general template of how decision makers can build upon the regional modeling to develop numeric criteria, and the implications associated with those steps.

1. Determine what level of “percent cultivated agricultural” land use condition represents a bench mark condition for the region. Possible alternatives include land use conditions typified by pre-settlement or pre-modern (circa 1950s) periods. The implication is that because no monitoring data are available for bench mark conditions, model predictions must be used to indicate an expected average nutrient concentration for that condition. Another implication is that certain classes of lentic systems may still reflect eutrophic conditions under bench mark conditions, and designated uses such as recreation may or may not be fully supported.

2. Based on a bench mark land use target, use the regional model to determine a predicted central tendency value for lentic system nutrient concentration, with confidence intervals

about the central tendency value. The implication is that a single numeric value for each lentic system class can be codified into statute. However, standards can be developed to address modeling uncertainty and the variability in field sampling inherent due to environmental factors and other issues. Depending on desired levels of protection, a narrative standard can provide flexibility to allow lake or reservoir quality to fluctuate within a range about the standard. Once the range is exceeded given some frequency (such as twice every five years), then the regional nutrient criteria is considered violated.

3. Correlate the targeted central tendency for nutrient criteria concentration to modeled values for water clarity and chlorophyll-a concentration. These values can be used within a regional model to estimate algal bloom frequencies. Establish a secondary criterion that relates the targeted nutrient criteria to an acceptable algal bloom frequency for bench mark condition. The implication of this step is that other metrics can, and should, be used as a surrogate for assessing whether a lentic system is maintaining designated beneficial uses based on regional criteria.

4. Recognize that although a lentic system may exceed the regional criteria, this does not automatically imply that the designated beneficial uses are not being met. The implication of exceedance is that a site-specific diagnostic study is warranted to confirm the status of beneficial use.

5. Based on a bench mark land use target, identify the central tendency and range of nutrient (TP) and water yields from a regional landscape that correspond with the nutrient criteria concentrations set as criteria for lentic classes. The implication of this step is that it provides a common frame of reference to begin identifying necessary nutrient load reductions in any TMDL study in a region. Further, if desired, the nutrient and water yields can be accurately allocated to the different land uses developed within the regional model.

5.5 KEY NEXT STEPS

There are two key next steps, or "follow up" points, to address with the completion of this regional pilot study. These steps relate to making policy decisions for the nutrient criteria effort and implementing data collection for refining the nutrient criteria modeling process.

5.5.1 Policy Decisions

The following are the key policy decisions that need to be addressed to move the nutrient criteria development process forward for the State of North Dakota:

- Establishment of a "reference" condition, or target, for lakes and reservoirs across classes (i.e., % cultivated agriculture);
- Setting a "nuisance" chlorophyll-a concentration level; and,
- Reviewing the pilot methodology for lake response and determining if it is worthy of application to the other planning regions in North Dakota.

5.5.2 Implementation

An implementation schedule was recommended in the NCDP to completely develop and implement nutrient criteria for the State of North Dakota. A summary of first year activities for lentic systems was presented in **Section 1**. Through this Lentic System Plan, much progress has been accomplished in implementing the NCDP. Progress to-date includes:

- Completion of a review and analysis of existing surface water quality monitoring data;
- Development of a state-wide classification for all lentic systems needing nutrient criteria;
- Completion of a Geographic Information Systems analysis for current landscape conditions;
- Development of a conceptual model to aid in establishing nutrient criteria for lentic classes; and
- Estimation of potential nutrient criteria values under differing ranges of anthropogenic influence.

Based on project progress thus far, and the results of this Lentic System Plan, several items are recommended to continue implementation of nutrient criteria. The recommended items are intended for short-range implementation and will allow the NDDoH to establish a plan of action for 2008-2010 for lentic system nutrient criteria. Recommendations include:

- Supplement current nutrient criteria development efforts by assessing other lines of evidence to support potential criteria derived from modeling. This weight-of-evidence approach can acknowledge or incorporate literature values, percentiles of datasets, or other evidence. Some of this effort was included within the NCDP. Further efforts to calibrate a regional model, and establishment of a "bench mark" for modeling, can be supplemented with consideration of other lines of evidence.

- Develop a program to collect and compile digital drainage area information for lakes and reservoirs. Drainage areas can be developed using USGS topography maps. Begin by compiling drainage areas for lentic systems in the URRB regional pilot study area. Use Table 2-5 as a guide. Strive to collect sufficient data such that a minimum count of 30 is attained for each class within 2009. This information is required to identify the class of a lentic system. The data can also be used to refine regressions used in modeling.

- Develop a program to collect and compile water volume information for lakes and reservoirs. Water volume information can be developed by implementing field surveys. Begin by compiling bathymetry for lentic systems in the URRB regional pilot study area. Use Table 2-5 as a guide. Strive to collect sufficient data such that a minimum count of 30 is attained for each class by the end of 2009. This information is required to identify the class of a lentic system. The data are also used within the model to estimate in-lake nutrient concentrations and other eutrophication-response variables. Water volume information is also required if the NDDoH chooses to evaluate metric (c) in the classification of lentic systems.

- Develop a lentic sampling program to implement in 2009 and 2010 for the URRB regional pilot study area. At a minimum the following parameters should be included:
    - Total phosphorus;
    - Transparency (Secchi); and
    - Chlorophyll-a.

Collect data for all four classes of lake systems in one year. Collect data for all four classes of reservoir systems in the other year. The program should implement a “paired” sampling approach whereby data for targeted parameters are always collected at the same date and time. The paired data will be used to perform model calibrations specific to each class; eight calibrated lentic models will be achieved. Commit sufficient resources in order to collect samples for 30 lentic systems in each class, a total of 120 sample sites each year. Data should be collected bi-weekly from May 1 – September 30.

- Implement a user-perception survey in 2009 and 2010 for the URRB regional pilot study area. If possible, pair the survey for the lakes and reservoirs being sampled as described above. The data will be used to relate chlorophyll-a concentrations to frequency of algal blooms and perceptions of nuisance conditions. Carry the user-perception survey efforts into other planning regions in the future.
- Consider developing a program to collect data on temperature and dissolved oxygen profiles for the URRB regional pilot study area. This information can be used to assign mixing characteristics to each of the lentic classes. This would serve to supplement data on water chemistry so profiles may not be required for all 30 sampling sites in each class. Frequency of data collection through out the year (e.g. weekly) would be more beneficial than a high quantity of sample sites.
- Construct a summary of TP and watershed runoff yields for all TMDL or diagnostic studies performed in the state. The summary should include the size of the monitoring area, the land use, and the period of monitoring. This data will be used to confirm the range of inputs used in the regional model, and to help refine the calibration of eutrophication responses to landscape inputs.

In conclusion, we recommend the next Lentic System Plan focus on developing nutrient criteria for the Lower Red River Basin. The implementation of this next Plan will be dependent on sufficient funding and availability of resources. It is possible that the geographic scope of recommendations set forth in the above bullets can be extended to include the Lower Red River

Basin. This approach would likely have a beneficial impact by streamlining development of nutrient criteria and reducing costs for administration and implementation.

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APPENDIX A

Statistical Distributions for the Monte Carlo Analysis

Rainfall Input

historic annual average = 18.59

season	chance of rain
winter	0.22
spring	0.25
summer	0.33
fall	0.22

winter stats	
Mean	0.08
Median	0.05
Mode	0.02
Standard Deviation	0.1
Variance	0.01
Skewness	6.47
Kurtosis	127.15
Coeff. of Variability	1.34
Minimum	0.01
Maximum	1.16
spring stats	
Mean	0.18
Median	0.08
Mode	0.02
Standard Deviation	0.36
Variance	0.13
Skewness	13.59
Kurtosis	874.37
Coeff. of Variability	1.97
Minimum	0.01
Maximum	3.4
summer stats	
Mean	0.32
Median	0.13
Mode	0.02
Standard Deviation	0.75
Variance	0.57
Skewness	19.87
Kurtosis	2,437.52
Coeff. of Variability	2.34
Minimum	0.01
Maximum	3.41
fall stats	
Mean	0.21
Median	0.09
Mode	0.02
Standard Deviation	0.46
Variance	0.21
Skewness	16.85
Kurtosis	1,559.08
Coeff. of Variability	2.18
Minimum	0.01
Maximum	3.08

Phosphorus EMC

	Parameter	Dist.	Min (mg/L)	Max (mg/L)	Most Likely (mg/L)
LU1	Ag, Row Crop	triangular	0.32	1.14	0.79
LU2	Forest, Woods	triangular	0.01	0.30	0.14
LU3	G/S/W, brush	triangular	0.04	0.56	0.24
LU5	Urban, Imprv. Area	triangular	0.10	0.93	0.35

RESERVOIRS

NUTCRIT_ID	Drainage (ac)	Drainage(km2)	ACRES	SA(km2)	AVERDEPTH	Mean Depth(m)	ACREFEET	Calc Mean Depth(ft)	Calc Mean Depth(m)	SA:DA*vol.
10399	3968.00	16.06	10.53	0.04	15.60	4.75	802.00	76.18715843	23.22071272	2.13
10577	1600.00	6.48	10.62	0.04	8.00	2.44	112.00	10.55008368	3.215508588	0.74
10427	1344.00	5.44	11.01	0.04	6.80	2.07	80.00	7.264383403	2.214076014	0.66
10629	2240.00	9.07	11.10	0.04	8.20	2.50	91.00	8.198198198	2.498688875	0.45
10588	7168.00	29.01	11.18	0.05	7.50	2.29	72.00	6.441639781	1.963315995	0.11
10410	9600.00	38.85	11.20	0.05	6.50	1.98	73.00	6.517857143	1.986545914	0.09
10630	12800.00	51.80	12.00	0.05	16.70	5.09	20.00	1.666666667	0.507975211	0.02
10437	1600.00	6.48	12.45	0.05	17.30	5.27	286.00	22.97444877	7.002270273	2.23
10445	2880.00	11.66	12.98	0.05	13.10	3.99	164.00	12.63179622	3.849983608	0.74
10623	4864.00	19.68	13.10	0.05	10.30	3.14	139.00	10.61068702	3.233979586	0.37
8660	11520.00	46.62	13.53	0.05	7.30	2.22	680.00	50.27547978	15.32321846	0.80
10498	9280.00	37.56	14.21	0.06	10.70	3.26	173.00	12.17149835	3.709691663	0.26
10590	1088.00	4.40	15.15	0.06	8.40	2.56	115.00	7.592616448	2.314116564	1.60
10411	960.00	3.89	15.63	0.06	10.30	3.14	180.00	11.51606041	3.509923929	2.93
10616	33920.00	137.27	17.33	0.07	9.40	2.86	161.00	9.288497737	2.830995958	0.08
10627	1408.00	5.70	17.70	0.07	7.50	2.29	133.00	7.514124294	2.290193323	1.67
10441	2560.00	10.36	17.97	0.07	8.80	2.68	143.00	7.957562177	2.425346595	1.00
579	20160.00	81.59	18.00	0.07	4.20	1.28	75.00	4.166666667	1.269938027	0.07
10443	1920.00	7.77	18.81	0.08	14.00	4.27	267.00	14.19670156	4.326943479	2.62
10603	11520.00	46.62	19.19	0.08	7.60	2.32	176.00	9.169120347	2.794611505	0.29
10615	4352.00	17.61	20.10	0.08	13.30	4.05	790.00	39.30991935	11.98107874	3.65
10493	1600.00	6.48	20.36	0.08	5.50	1.68	119.00	5.844154416	1.781211343	1.51
10425	2752.00	11.14	23.51	0.10	17.30	5.27	411.00	17.47900719	5.327341416	3.51
10505	11520.00	46.62	23.57	0.10	5.50	1.68	132.00	5.601232407	1.707172328	0.27
10436	640.00	2.59	24.14	0.10	7.10	2.16	165.00	6.835576255	2.083381973	6.22
10622	3008.00	12.17	24.20	0.10	7.30	2.22	179.00	7.396694215	2.254402382	1.44
10397	1600.00	6.48	25.28	0.10	9.60	2.93	297.00	11.74905573	3.580937437	4.69
10434	3840.00	15.54	25.79	0.10	11.80	3.60	333.00	12.9107711	3.935011003	2.24
10339	1920.00	7.77	26.08	0.11	7.20	2.19	216.00	8.281111587	2.523959642	2.93
10352	7680.00	31.08	26.42	0.11	5.00	1.52	126.00	4.768464334	1.453357005	0.43
10347	23040.00	93.24	28.26	0.11	8.70	2.65	222.00	7.85555304	2.394255727	0.27
10403	5440.00	22.02	28.27	0.11	7.30	2.22	205.00	7.252411977	2.210427302	1.07
10502	4672.00	18.91	28.35	0.11	12.10	3.69	326.00	11.49948312	3.504871416	1.98
10459	5760.00	23.31	29.32	0.12	10.30	3.14	238.00	8.115967481	2.473626175	1.21
10497	12160.00	49.21	29.58	0.12	5.60	1.71	146.00	4.936049851	1.504434578	0.36
10398	4160.00	16.84	31.92	0.13	12.70	3.87	385.00	12.06136849	3.676125722	2.95
10341	1152.00	4.66	32.24	0.13	5.30	1.62	174.00	5.397611307	1.645111645	4.87
10361	1600.00	6.48	33.17	0.13	7.10	2.16	254.00	7.65720518	2.333802249	5.27
10621	2048.00	8.29	35.20	0.14	8.90	2.71	218.00	6.193181818	1.887589704	3.75
10475	68480.00	277.13	35.58	0.14	6.20	1.89	629.00	17.67966715	5.388499589	0.33
10413	9920.00	40.15	36.59	0.15	4.90	1.49	203.00	5.548198804	1.691008474	0.75
10572	8320.00	33.67	36.82	0.15	10.40	3.17	317.00	8.610556729	2.624369622	1.40
10450	55040.00	222.74	38.46	0.16	14.80	4.51	563.00	14.63736791	4.461252031	0.39
10360	3840.00	15.54	44.11	0.18	13.20	4.02	724.00	16.41223539	5.002205238	8.32
10562	15360.00	62.16	44.21	0.18	8.30	2.53	483.00	10.92577345	3.330013244	1.39
4313	9856.00	39.89	49.20	0.20	5.70	1.74	236.00	4.796817416	1.461998603	1.18
6431	5120.00	20.72	52.41	0.21	12.00	3.66	777.00	14.82551114	4.518595287	7.95
10528	4672.00	18.91	52.98	0.21	13.50	4.11	785.00	14.81648304	4.515843659	8.90
10438	3200.00	12.95	53.32	0.22	8.00	2.44	293.00	5.495336711	1.674896895	4.88
10606	14080.00	56.98	54.57	0.22	9.60	2.93	578.00	10.59269278	3.228495209	2.24
10340	41280.00	167.06	57.80	0.23	5.50	1.68	350.00	6.055148505	1.845519203	0.49
10428	44160.00	178.71	60.71	0.25	10.20	3.11	638.00	10.50842505	3.202811657	0.88
10351	9792.00	39.63	60.86	0.25	18.10	5.52	943.00	15.4946653	4.722543523	5.86
10589	40960.00	165.76	66.63	0.27	11.10	3.38	746.00	11.19664748	3.412571619	1.21
10412	53120.00	214.97	73.22	0.30	5.60	1.71	628.00	8.576437486	2.613970584	0.87
10395	27520.00	111.37	83.03	0.34	13.80	4.21	1155.00	13.91073254	4.239784376	3.48
10583	70400.00	284.90	83.64	0.34	10.80	3.29	1620.00	19.3681296	5.90311783	1.92
10599	9920.00	40.15	83.81	0.34	13.00	3.96	1036.00	12.3608253	3.767395701	8.75
10444	36480.00	147.63	91.45	0.37	4.90	1.49	430.00	4.701865794	1.433058761	1.08
10460	40832.00	165.24	92.07	0.37	18.00	5.49	1768.00	19.20294299	5.852771409	3.99
10456	195520.00	791.26	97.65	0.40	8.00	2.44	1014.00	10.38414917	3.164934219	0.51
10552	12288.00	49.73	104.47	0.42	10.50	3.20	1171.00	11.20855538	3.416200969	9.96
10624	74240.00	300.45	108.10	0.44	11.40	3.47	1239.00	11.46160962	3.493328138	1.80
10484	7360.00	29.79	112.99	0.46	12.60	3.84	1583.00	14.01068437	4.270248207	24.30
10576	99200.00	401.46	121.97	0.49	19.20	5.85	2496.00	20.46430782	6.237216648	3.07
10368	25600.00	103.60	128.99	0.52	4.50	1.37	581.00	4.50437377	1.372866129	2.93
10504	13760.00	55.69	130.69	0.53	11.50	3.51	1483.00	11.34746183	3.45853759	14.09
10625	47360.00	191.66	135.30	0.55	10.20	3.11	1388.00	10.25868441	3.126694424	3.97
10509	7360.00	29.79	136.82	0.55	10.50	3.20	1511.00	11.04394014	3.366028692	28.09
10534	54400.00	220.15	141.81	0.57	7.90	2.41	1129.00	7.961436481	2.426527425	2.94
10530	17472.00	70.71	144.25	0.58	16.40	5.00	2413.00	16.72766138	5.098342389	19.92
10568	25600.00	103.60	151.58	0.61	9.80	2.99	1610.00	10.62131156	3.237217787	9.53
10353	143360.00	580.17	158.39	0.64	5.10	1.55	1130.00	7.134322552	2.174435401	1.25
10377	37120.00	150.22	172.12	0.70	5.50	1.68	942.00	5.472768559	1.668018458	4.37
10527	23680.00	95.83	177.04	0.72	9.20	2.80	1751.00	9.89034829	3.014431055	13.09
10584	26240.00	106.19	185.49	0.75	11.00	3.35	2056.00	11.08420041	3.378299425	14.53
10246	144640.00	585.35	191.81	0.78	16.50	5.03	2864.00	14.9313922	4.550866262	3.80
10439	59520.00	240.87	210.29	0.85	7.30	2.22	1212.00	5.763565812	1.756649135	4.28
10610	92160.00	372.97	214.92	0.87	7.20	2.19	1300.00	6.048841603	1.843596953	3.03
10573	125440.00	507.65	269.34	1.09	8.10	2.47	2507.00	9.307894348	2.836907756	5.38
10557	126080.00	510.24	270.21	1.09	7.90	2.41	2383.00	8.818996559	2.687898982	5.11
10366	83840.00	339.30	274.43	1.11	10.60	3.23	2671.00	9.732807575	2.966414988	8.74
10581	123520.00	499.88	327.94	1.33	12.60	3.84	4102.00	12.50824931	3.812328348	10.89
10626	54976.00	222.48	342.10	1.38	14.10	4.30	4782.00	13.9783689	4.260398933	29.76
10447	153600.00	621.61	394.87	1.60	14.60	4.45	5965.00	15.10620661	4.604147092	15.33
10556	204800.00	828.81	486.49	1.97	11.90	3.63	1913.00	3.932241606	1.198488755	4.54
176	262400.00	1061.92	633.15	2.56	9.00	2.74	8568.00	13.53240435	4.124475573	20.67
10471	960000.00	3885.07	1596.35	6.46	3.40	1.04	2721.00	1.704508176	0.51950874	4.52
10468	832000.00	3367.06	1682.90	6.81	4.00	1.22	6693.00	3.977053791	1.212146843	13.54
10406	4096.00	16.58	104.49	0.42	10.90	3.32	1819.00	17.40891721	5.305979033	46.40
10511	3008.00	12.17	106.98	0.43	13.70	4.18	1762.00	16.47000079	5.019811273	62.67
10597	69120.00	279.72	155.23	0.63	9.80	2.99	22532.00	145.1535187	44.24063355	50.60
10426	10240.00	41.44	177.91	0.72	12.30	3.75	2432.00	13.66982337	4.166358846	42.25
10350	85120.00	344.48	526.18	2.13	15.60	4.75	8792.00	16.70910221	5.092685832	54.35
10553	54400.00	220.15	599.87	2.43	8.50	2.59	5733.00	9.557028103	2.912840019	63.22
10432	45440.00	183.89	850.34	3.44	7.20	2.19	7065.00	8.30846853	2.532297632	132.21
10380	87040.00	352.25	881.86	3.57	4.40	1.34	3857.00	4.373702614	1.333039504	39.08
10431	36800.00	148.93	956.68	3.87	5.60	1.71	5319.00	5.559843754	1.694557682	138.28
10452	251200.00	1016.59	1115.80	4.52	10.00	3.05	10617.00	9.51517762	2.900084615	47.16
6020	288000.00	1165.52	1211.85	4.90	8.90	2.71	12510.00	10.32305296	3.146313001	52.64
10378	304000.00	1230.27	1929.08	7.81	11.30	3.44	20409.00	10.57963319	3.224514839	129.51
10470	796800.00	3224.61	2073.40	8.39	15.10	4.60	28147.00	13.57530988	4.137552539	73.24
10490	2648320.00	10717.60	5466.61	22.12	13.70	4.18	70573.00	12.90983775	3.934726531	145.68
10539	6528000.00	26418.45	8038.80	32.53	10.00	3.05	94555.00	11.76232904	3.584982944	116.44
10594	3072.00	12.43	306.54	1.24	9.90	3.02	3072.00	10.02155935	3.054422234	306.54
10463	9600.00	38.85	1003.85	4.06	30.40	9.27	26927.00	26.82384371	8.175508597	2815.68
10593	37760.00	152.81	1524.39	6.17	11.30	3.44	17446.00	11.44461382	3.48814807	704.30
10386	1158400.00	4687.98	3336.02	13.50	20.70	6.31	66835.00	20.03436659	6.106176954	192.47

LAKES

NUTCRIT_ID	Drainage (ac)	Drainage(km2)	ACRES	SA(km2)	AVERDEPTH	Mean Depth(m)	ACREFEET	Calc Mean Depth(ft)	Calc Mean Depth(m)	SA:DA*vol.
693	16000.00	64.75	10.69	0.04	7.70	2.35	73.00	6.829853539	2.081637775	0.05
10628	3072.00	12.43	11.70	0.05	7.40	2.26	87.00	7.435897436	2.266350941	0.33
6392	6208.00	25.12	14.48	0.06	12.40	3.78	2685.00	185.4264854	56.51523481	6.26
116	1920.00	7.77	19.63	0.08	10.30	3.14	196.00	9.982755	3.042595245	2.00
4459	8576.00	34.71	21.29	0.09	4.30	1.31	110.00	5.165927507	1.574497869	0.27
1046	640.00	2.59	30.85	0.12	5.80	1.77	184.00	5.96434564	1.81784384	8.87
2955	4480.00	18.13	36.43	0.15	6.90	2.10	267.00	7.328600548	2.233648445	2.17
7434	128.00	0.52	36.45	0.15	8.10	2.47	259.00	7.105051394	2.165513988	73.76
10178	384.00	1.55	36.79	0.15	15.90	4.85	594.00	16.14650984	4.921216045	56.91
4557	3968.00	16.06	37.05	0.15	9.90	3.02	369.00	9.959958604	3.035647243	3.45
6193	512.00	2.07	41.06	0.17	9.60	2.93	411.00	10.00881165	3.050536925	32.96
409	4160.00	16.84	41.23	0.17	14.50	4.42	647.00	15.69094966	4.782368077	6.41
6493	4160.00	16.84	43.80	0.18	3.30	1.01	143.00	3.264840183	0.995074728	1.51
6494	4160.00	16.84	43.80	0.18	3.30	1.01	143.00	3.264840183	0.995074728	1.51
10130	832.00	3.37	44.21	0.18	13.60	4.15	647.00	14.63398132	4.460219847	34.38
9220	12160.00	49.21	47.30	0.19	8.20	2.50	408.00	8.626339764	2.629180056	1.59
1257	960.00	3.89	53.43	0.22	4.50	1.37	241.00	4.510722909	1.374801252	13.41
1486	2240.00	9.07	53.99	0.22	7.50	2.29	569.00	10.53987747	3.212397889	13.71
9321	512.00	2.07	54.68	0.22	11.00	3.35	572.00	10.4609315	3.188336331	61.09
9354	1408.00	5.70	67.90	0.27	11.40	3.47	760.00	11.19307494	3.411482761	36.65
9369	1600.00	6.48	68.73	0.28	14.30	4.36	1084.00	15.77199994	4.807070998	46.56
4922	2880.00	11.66	79.39	0.32	9.10	2.77	783.00	9.862795417	3.006033349	21.58
9960	960.00	3.89	80.68	0.33	11.20	3.41	895.00	11.09315492	3.381028624	75.22
281	22400.00	90.65	84.00	0.34	5.10	1.55	1210.00	14.4045663	4.390297561	4.54
863	6400.00	25.90	84.29	0.34	8.10	2.47	2160.00	25.62536272	7.810229417	28.45
5712	5632.00	22.79	88.43	0.36	7.80	2.38	656.00	7.418111321	2.260929997	10.30
8723	4800.00	19.43	92.28	0.37	12.50	3.81	1287.00	13.94670487	4.250748209	24.74
2435	4160.00	16.84	93.14	0.38	8.20	2.50	865.00	9.287075248	2.830562404	19.37
4311	2880.00	11.66	94.19	0.38	22.00	6.71	2338.00	24.82317216	7.565733668	76.46
492	11840.00	47.92	102.29	0.41	8.20	2.50	659.00	6.442378603	1.963541177	5.69
9701	4160.00	16.84	114.75	0.46	11.00	3.35	1264.00	11.01494817	3.357192372	34.87
5021	9344.00	37.81	123.87	0.50	6.50	1.98	1164.00	9.396845373	2.864018705	15.43
2078	26240.00	106.19	124.97	0.51	5.40	1.65	766.00	6.12926208	1.868107918	3.65
7030	10880.00	44.03	129.03	0.52	8.10	2.47	1077.00	8.34712774	2.544080384	12.77
8212	2240.00	9.07	145.84	0.59	9.10	2.77	1119.00	7.672716134	2.338529758	72.86
8959	8960.00	36.26	149.14	0.60	11.10	3.38	1657.00	11.11007589	3.386185885	27.58
8615	9280.00	37.56	152.93	0.62	6.90	2.10	2519.00	16.47164947	5.020313766	41.51
1963	6720.00	27.20	154.12	0.62	8.30	2.53	1588.00	10.30383982	3.140457122	36.42
410	10560.00	42.74	161.86	0.66	3.30	1.01	554.00	3.422743148	1.043201203	8.49
9441	4480.00	18.13	165.55	0.67	4.20	1.28	93.00	0.561754325	0.171214363	3.44
1387	21760.00	88.06	171.23	0.69	6.10	1.86	1050.00	6.132134236	1.868983309	8.26
5482	5760.00	23.31	182.53	0.74	8.90	2.71	1941.00	10.63409797	3.241114894	61.51
8889	3520.00	14.25	184.30	0.75	3.70	1.13	684.00	3.711239816	1.131130697	35.81
935	3520.00	14.25	197.50	0.80	6.60	2.01	1362.00	6.896080846	2.101822873	76.42
5852	12800.00	51.80	201.38	0.81	10.00	3.05	2245.00	11.1483297	3.397845079	35.32
2114	7040.00	28.49	201.95	0.82	6.90	2.10	1441.00	7.135353208	2.17474953	41.34
1923	37120.00	150.22	207.03	0.84	16.40	5.00	6743.00	32.57051392	9.927008205	37.61
4704	16960.00	68.64	210.50	0.85	5.10	1.55	1059.00	5.030935332	1.533354261	13.14
5456	8768.00	35.48	222.10	0.90	7.90	2.41	2282.00	10.2746213	3.131551752	57.80
4716	16640.00	67.34	228.00	0.92	10.60	3.23	2378.00	10.42987113	3.178869591	32.58
6508	19840.00	80.29	281.95	1.14	9.20	2.80	2804.00	9.945101848	3.031119125	39.85
770	14720.00	59.57	309.34	1.25	7.60	2.32	3175.00	10.26377589	3.128246233	66.72
1885	19840.00	80.29	360.16	1.46	8.40	2.56	3149.00	8.743379819	2.664852124	57.16
2500	38400.00	155.40	570.37	2.31	7.30	2.22	4726.00	8.285894667	2.525417454	70.20
1967	64.00	0.26	38.43	0.16	14.30	4.36	584.00	15.19584438	4.631467352	350.69
1870	448.00	1.81	92.11	0.37	10.50	3.20	1687.00	18.31539572	5.5822602	346.85
9970	832.00	3.37	95.92	0.39	14.30	4.36	1449.00	15.10678646	4.604323823	167.05
9365	1024.00	4.14	129.81	0.53	10.00	3.05	984.00	7.580157219	2.310319177	124.74
8666	2688.00	10.88	179.53	0.73	8.80	2.68	2118.00	11.79740111	3.595672389	141.46
3022	2560.00	10.36	222.25	0.90	18.00	5.49	5123.00	23.05049686	7.025448602	444.76
9712	2880.00	11.66	258.08	1.04	8.20	2.50	2343.00	9.07855137	2.767007428	209.96
2481	4800.00	19.43	296.98	1.20	16.30	4.97	6209.00	20.90726897	6.372224617	384.15
3706	25280.00	102.31	386.58	1.56	31.00	9.45	15167.00	39.23343898	11.95776866	231.93
3312	8960.00	36.26	512.59	2.07	9.00	2.74	4745.00	9.256833569	2.82134519	271.46
947	25600.00	103.60	532.69	2.16	9.00	2.74	5026.00	9.43509447	2.875676461	104.58
2434	10880.00	44.03	602.77	2.44	12.90	3.93	2196.00	3.643155767	1.110379691	121.66
4754	29760.00	120.44	604.16	2.45	9.20	2.80	5781.00	9.568642764	2.916379995	117.36
7909	10880.00	44.03	692.01	2.80	9.60	2.93	5634.00	8.141556172	2.481425228	358.34
2852	32640.00	132.09	820.29	3.32	9.30	2.83	7618.00	9.286926918	2.830517196	191.45
2775	6400.00	25.90	276.63	1.12	15.80	4.82	13089.00	47.31511416	14.42094305	565.76
10046	2304.00	9.32	523.88	2.12	11.30	3.44	4776.00	9.116557388	2.778591097	1085.96
10051	2816.00	11.40	826.89	3.35	9.30	2.83	7388.00	8.934684678	2.723159	2169.41
628	28480.00	115.26	882.88	3.57	16.70	5.09	20665.00	23.40626622	7.13388181	640.62
8722	1664.00	6.73	1500.33	6.07	5.60	1.71	1890.00	1.259718826	0.383943562	1704.11
6417	35840.00	145.04	1647.56	6.67	7.20	2.19	11809.00	7.167570013	2.184568733	542.86
8533	281600.00	1139.62	2766.61	11.20	23.70	7.22	417811.00	151.0190195	46.02835097	4104.83

Area Weighted Curve Numbers

12-Digit HUC	LU1 CN	12-Digit HUC	LU2 CN	12-Digit HUC	LU3 CN	12-Digit HUC	LU4 CN	12-Digit HUC	LU5 CN
090202030101	76.9	090202030101	57.5	090202030506	63.1	090202030101	100	090202030103	76.6
090202030102	78.0	090202030102	61.8	090202030601	68.8	090202030102	100	090202030104	73.8
090202030103	79.4	090202030103	61.3	090202030602	69.4	090202030103	100	090202030106	65.6
090202030104	81.7	090202030104	62.7	090202030603	69.0	090202030104	100	090202030201	69.0
090202030105	77.7	090202030105	58.4	090202030701	70.8	090202030105	100	090202030202	75.5
090202030106	76.4	090202030106	53.3	090202030702	67.6	090202030106	100	090202030203	75.7
090202030201	76.5	090202030201	56.5	090202030703	69.3	090202030201	100	090202030204	75.0
090202030202	78.1	090202030202	57.3	090202030804	63.8	090202030202	100	090202030205	71.3
090202030203	78.3	090202030203	59.1	090202030806	66.1	090202030203	100	090202030206	71.9
090202030204	78.3	090202030204	59.4	090202030807	60.3	090202030204	100	090202030207	76.5
090202030205	77.1	090202030205	46.9	090202030808	63.3	090202030205	100	090202030301	75.5
090202030206	78.0	090202030206	48.4	090202030901	61.3	090202030206	100	090202030302	77.4
090202030207	78.1	090202030207	56.5	090202030902	59.6	090202030207	100	090202030303	74.8
090202030301	79.1	090202030301	58.8	090202030903	60.2	090202030301	100	090202030304	77.9
090202030302	81.0	090202030302	63.1	090202030904	62.4	090202030302	100	090202030305	77.3
090202030303	79.3	090202030303	62.2	090202030905	61.3	090202030303	100	090202030401	76.2
090202030304	79.6	090202030304	62.9	090202030101	55.5	090202030304	100	090202030402	75.4
090202030305	80.0	090202030305	62.4	090202030102	57.9	090202030305	100	090202030403	75.5
090202030401	79.2	090202030401	62.2	090202030103	64.3	090202030401	100	090202030404	75.8
090202030402	78.7	090202030402	59.4	090202030104	67.0	090202030402	100	090202030405	76.9
090202030403	79.2	090202030403	59.4	090202030105	56.0	090202030403	100	090202030501	79.1
090202030404	79.9	090202030404	63.5	090202030106	50.5	090202030404	100	090202030502	79.6
090202030405	79.9	090202030405	61.3	090202030201	53.7	090202030405	100	090202030503	75.5
090202030501	80.5	090202030501	62.7	090202030202	59.4	090202030501	100	090202030504	75.0
090202030502	80.3	090202030502	63.5	090202030203	61.2	090202030502	100	090202030505	79.4
090202030503	79.4	090202030503	59.1	090202030204	60.1	090202030503	100	090202030506	79.5
090202030504	79.0	090202030504	61.6	090202030205	55.5	090202030504	100	090202030507	79.3
090202030505	80.8	090202030505	64.2	090202030206	55.1	090202030505	100	090202030601	79.0
090202030506	81.6	090202030506	61.2	090202030207	59.9	090202030506	100	090202030602	76.3
090202030507	81.7	090202030507	62.9	090202030301	60.4	090202030507	100	090202030603	80.8
090202030601	81.3	090202030601	64.7	090202030302	66.7	090202030601	100	090202030701	79.5
090202030602	83.8	090202030602	67.8	090202030303	60.9	090202030602	100	090202030702	77.3
090202030603	82.9	090202030603	67.6	090202030304	65.1	090202030603	100	090202030703	75.1
090202030701	82.5	090202030701	66.7	090202030305	61.3	090202030701	100	090202030801	75.7
090202030702	81.6	090202030702	65.1	090202030401	61.1	090202030702	100	090202030802	77.0
090202030703	82.5	090202030703	65.9	090202030403	63.2	090202030703	100	090202030803	75.0
090202030801	80.1	090202030801	59.6	090202030404	64.5	090202030801	100	090202030804	78.6
090202030802	79.1	090202030802	59.5	090202030501	67.9	090202030802	100	090202030805	75.6
090202030803	78.5	090202030803	61.0	090202030502	65.0	090202030803	100	090202030806	79.0
090202030804	81.8	090202030804	64.1	090202030402	61.6	090202030804	100	090202030807	76.1
090202030805	79.0	090202030805	60.2	090202030405	61.6	090202030805	100	090202030808	80.3
090202030806	81.8	090202030806	65.3	090202030503	62.8	090202030806	100	090202030901	81.1
090202030807	80.1	090202030807	61.2	090202030504	61.2	090202030807	100	090202030902	87.0
090202030808	81.9	090202030808	64.8	090202030505	67.4	090202030808	100	090202030903	78.1
090202030901	80.0	090202030901	61.4	090202030507	64.9	090202030901	100	090202030904	74.5
090202030902	79.8	090202030902	61.1	090202030801	62.7	090202030902	100	090202030905	83.3
090202030903	81.1	090202030903	61.0	090202030802	59.7	090202030903	100	090202040102	80.1
090202030904	80.3	090202030904	65.9	090202030803	59.3	090202030904	100	090202040103	79.3
090202030905	79.9	090202030905	62.1	090202030805	62.9	090202030905	100	090202040104	79.8
090202040101	80.9	090202040101	64.1	090202040401	56.5	090202040101	100	090202040105	78.2
090202040102	81.7	090202040102	64.0	090202040402	58.5	090202040102	100	090202040106	76.4
090202040103	81.5	090202040103	65.7	090202040403	56.5	090202040103	100	090202040107	78.8
090202040104	82.1	090202040104	65.7	090202040404	64.4	090202040104	100	090202040201	82.5
090202040105	80.4	090202040105	60.7	090202040405	61.7	090202040105	100	090202040202	73.0
090202040106	79.3	090202040106	61.1	090202040406	57.0	090202040106	100	090202040203	79.6
090202040107	79.3	090202040107	63.5	090202040501	55.9	090202040107	100	090202040204	77.2
090202040201	80.1	090202040201	65.1	090202040502	53.9	090202040201	100	090202040205	81.4
090202040202	79.7	090202040202	66.2	090202040503	40.3	090202040202	100	090202040301	76.8
090202040203	79.2	090202040203	65.2	090202040504	44.6	090202040203	100	090202040303	79.4
090202040204	79.5	090202040204	66.4	090202040505	46.5	090202040204	100	090202040401	74.0
090202040205	80.0	090202040205	63.1	090202040506	38.1	090202040205	100	090202040402	78.4
090202040301	81.1	090202040301	64.2	090202040601	42.1	090202040301	100	090202040403	72.3
090202040302	80.2	090202040302	63.8	090202040602	42.9	090202040302	100	090202040404	77.7
090202040303	80.1	090202040303	69.4	090202040603	47.4	090202040303	100	090202040405	78.3
090202040401	78.3	090202040401	60.2	090202040101	66.5	090202040401	100	090202040406	73.0
090202040402	79.3	090202040402	58.4	090202040102	65.5	090202040402	100	090202040501	76.5
090202040403	79.3	090202040403	58.5	090202040103	71.4	090202040403	100	090202040502	75.1
090202040404	82.1	090202040404	65.6	090202040104	68.2	090202040404	100	090202040503	61.0
090202040405	81.1	090202040405	62.5	090202040105	61.9	090202040405	100	090202040504	69.1
090202040406	79.0	090202040406	58.3	090202040106	64.0	090202040406	100	090202040505	61.5
090202040501	77.5	090202040501	54.6	090202040107	64.5	090202040501	100	090202040601	63.4
090202040502	78.4	090202040502	54.2	090202040201	63.3	090202040502	100	090202040602	78.5
090202040503	67.0	090202040503	36.3	090202040202	65.5	090202040503	100	090202040604	83.5
090202040504	76.5	090202040504	53.6	090202040203	64.8	090202040504	100	090202040605	85.1
090202040505	70.3	090202040505	48.2	090202040204	67.7	090202040505	100	090202040606	78.4
090202040506	70.8	090202040506	48.8	090202040301	64.1	090202040506	100	090202040702	74.9
090202040601	72.3	090202040601	45.6	090202040302	64.7	090202040601	100	090202040703	75.0
090202040602	71.6	090202040602	44.8	090202040605	75.3	090202040602	100	090202040704	82.0
090202040603	76.3	090202040603	46.5	090202040606	67.7	090202040603	100	090202040705	82.2
090202040604	84.1	090202040604	56.4	090202040701	58.1	090202040604	100	090202040706	85.5
090202040605	88.2	090202040605	76.0	090202040702	58.3	090202040605	100	090202040707	81.6
090202040606	87.5	090202040606	60.6	090202040703	60.6	090202040606	100		
090202040701	78.1	090202040701	57.9	090202040704	61.8	090202040701	100		
090202040702	77.4	090202040702	52.4	090202040705	71.6	090202040702	100		
090202040703	78.6	090202040703	60.6	090202040706	75.8	090202040703	100		
090202040704	81.4	090202040705	60.7	090202040707	68.2	090202040704	100		
090202040705	84.5	090202040705	67.3	090202040205	64.5	090202040705	100		
090202040706	88.1	090202040706	70.5	090202040303	65.4	090202040706	100		
090202040707	83.7	090202040707	66.2	090202040604	55.9	090202040707	100		

APPENDIX B

Nutrient Event Mean Concentrations (EMC's)

LU Type	TP Conc. (mg/L)	Source	Location
Mixed Decid. Forest	0.011	Singer and Rust, 1975	Lake Minnetonka Watershed, MN
Corn	1.14	Minshall et al., 1970	WI
Corn	1.128	Minshall et al., 1970	WI
Corn	6.871	Burwell et al., 1975	Morris, MN
Corn	6.912	Burwell et al., 1975	Morris, MN
Pasture	0.563	Harms et al., 1974	Eastern SD
New suburb. Sites	0.26	Schueler, 1987	Simple Method NURP sites, Wash. DC
Residential	0.28	US EPA, 2001	PLOAD
Commercial and Services	0.1	US EPA, 2001	PLOAD
Industrial	0.1	US EPA, 2001	PLOAD
Trans., Comm., Util.	0.33	US EPA, 2001	PLOAD
Indust and Comm. Compl	0.1	US EPA, 2001	PLOAD
mxd urban	0.1	US EPA, 2001	PLOAD
other urban	0.1	US EPA, 2001	PLOAD
cropland and pasture	1	US EPA, 2001	PLOAD
orch., grove	1	US EPA, 2001	PLOAD
other ag land	1	US EPA, 2001	PLOAD
shrub and brush	0.14	US EPA, 2001	PLOAD
deciduous forest	0.14	US EPA, 2001	PLOAD
streams	0.03	US EPA, 2001	PLOAD
lakes	0.03	US EPA, 2001	PLOAD
trans. Areas	0.14	US EPA, 2001	PLOAD
Ag - Cult.	4	CH2MHill, 2002	Wake County, NC
Forest	0.3	CH2MHill, 2002	Wake County, NC
Herbaceous Upland	0.2	CH2MHill, 2002	Wake County, NC
LDR	0.2	CH2MHill, 2002	Wake County, NC
MDR	0.2	CH2MHill, 2002	Wake County, NC
HDR	0.3	CH2MHill, 2002	Wake County, NC
Commercial and Services	0.4	CH2MHill, 2002	Wake County, NC
Industrial	0.4	CH2MHill, 2002	Wake County, NC
Water	0.1	CH2MHill, 2002	Wake County, NC
Cropland	0.32		MN Stormwater Manual
Forest/Shrub/Grass	0.04		MN Stormwater Manual
Open Water	0.01		MN Stormwater Manual
Freeway	0.25		MN Stormwater Manual
Commercial	0.22		MN Stormwater Manual
Farmstead	0.46		MN Stormwater Manual
Industrial	0.26		MN Stormwater Manual
Residential	0.3		MN Stormwater Manual
Open Space	0.31		MN Stormwater Manual
Forest/Rural Open	0.11	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
Urban Open	0.11	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
Ag/Pasture	0.37	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
LDR	0.52	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
MDR	0.52	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
HDR	0.24	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
Commercial	0.33	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
Industrial	0.32	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
Water	0.08	Cave et al., 1994	Rouge River National Wet Weather Demo Project study
Residential	0.26	Schueler, 1987	

LU Type	TP Conc. (mg/L)	Source	Location
Residential	0.33	Gibb et al., 1991	
Residential	0.26	Smullen and Cave, 1998	
Commercial	0.26	Smullen and Cave, 1998	
Industrial	0.26	Smullen and Cave, 1998	
Residential	0.38	US EPA, 1983	
Commercial	0.201	US EPA, 1983	
Residential	0.65	Caraco and Schueler, 1999	
Commerical	0.65	Caraco and Schueler, 1999	
Industrial	0.65	Caraco and Schueler, 1999	
Residential	0.62	Whalen and Cullum, 1988	
Commercial	0.29	Whalen and Cullum, 1988	
Industrial	0.42	Whalen and Cullum, 1988	
Mixed Use Urban	0.51	Wenck/MCWD, 1998	
Mixed Use Urban	0.38	Wenck/MCWD, 1998	
Mixed Use Urban	0.69	Wenck/MCWD, 1998	
Mixed Use Urban	0.417	City of Minneapolis, 1992	
Mixed Use Urban	0.242	Schuler, 1998	
Mixed Use Urban	0.56	Oberts, 1983	
Mixed Use Urban	0.258	Barten, 1994	
Mixed Use Urban	0.63	USGS, 1982	
Mixed Use Urban	0.62	USGS, 1982	
Mixed Use Urban	0.541	MPRB, 2002	
Mixed Use Urban	0.652	MPRB, 2002	
Mixed Use Urban	0.255	MPRB, 2002	
Mixed Use Urban	0.377	MPRB, 2002	
Mixed Use Urban	0.525	MPRB, 2002	
Mixed Use Urban	0.235	City of Eagan, 1995	
Mixed Use Urban	0.371	City of Eagan, 1995	
Mixed Use Urban	0.934	MPRB, unpublished	
Mixed Use Urban	0.635	MPRB, unpublished	
Mixed Use Urban	0.466	MPRB, unpublished	
Mixed Use Urban	0.366	MPRB, unpublished	
Mixed Use Urban	0.344	MPRB, 2003a	
Mixed Use Urban	0.278	MPRB, 2003a	
Mixed Use Urban	0.391	MPRB, 2003a	
Mixed Use Urban	0.305	MPRB, 2003a	
Mixed Use Urban	0.24	Barr, 1993	
Mixed Use Urban	0.41	Barr, 1993	
Mixed Use Urban	0.34	Barr, 1993	
Mixed Use Urban	0.224	Barr, 1992	
Mixed Use Urban	0.213	Barr, 1992	
Mixed Use Urban	0.211	Barr, 1992	
Mixed Use Urban	0.179	Barr, 1992	
Mixed Use Urban	0.255	Barr, 1992	
Mixed Use Urban	0.224	Barr, 1992	
Mixed Use Urban	0.23	Barr, 1992	
Mixed Use Urban	0.232	Barr, 1992	
Mixed Use Urban	0.211	Barr, 1992	
Mixed Use Urban	0.173	Barr, 1992	
Urban (pervious)	0.479	Barten, 1995	

LU Type	TP Conc. (mg/L)	Source	Location
Urban (pervious)	0.892	Barten, 1995	
Urban (pervious)	0.476	Barten, 1995	
Urban (pervious)	0.341	TRPD, unpublished	
Urban (pervious)	0.195	TRPD, unpublished	
Urban (pervious)	0.377	TRPD, unpublished	
Urban (pervious)	0.254	TRPD, unpublished	
Urban (pervious)	0.244	TRPD, unpublished	
Urban (pervious)	0.219	TRPD, unpublished	
Urban (pervious)	0.213	TRPD, unpublished	
Urban (pervious)	0.249	TRPD, unpublished	
Urban (pervious)	0.329	TRPD, unpublished	
Urban (pervious)	0.29	TRPD, unpublished	
Mixed Use Urban	0.232	Barr, 2003	
Mixed Use Urban	0.308	Barr, 2003	
Mixed Use Urban	0.202	Barr, 2003	
Mixed Use Urban	0.398	RWMWD, unpublished	
Mixed Use Urban	0.332	RWMWD, unpublished	
Mixed Use Urban	0.446	RWMWD, unpublished	
Mixed Use Urban	0.322	RWMWD, unpublished	
Mixed Use Urban	0.588	MPRB, unpublished	
Mixed Use Urban	0.539	MPRB, unpublished	
Mixed Use Urban	0.296	MPRB, unpublished	
Mixed Use Urban	0.426	MPRB, unpublished	
Mixed Use Urban	0.253	Ramsey County Public Works, unpublished	
Mixed Use Urban	0.93	Hennepin County	
Mixed Use Urban	0.47	Hennepin County	
Mixed Use Urban	0.316	RWMWD, unpublished	
Residential	0.383	NURP	
Residential	0.316	MPRB	
Commercial	0.201	NURP	
Commercial	0.386	MPRB	
Mixed	0.263	NURP	
Mixed	0.31	MPRB	
Commercial	0.3	Univ. of WI Extension	
HDR	0.46	Univ. of WI Extension	
MDR	0.25	Univ. of WI Extension	
AG	1.03	Univ. of WI Extension	
AG	0.57	Univ. of WI Extension	
Residential	0.3	Pitt et al., 2003	
Commercial	0.22	Pitt et al., 2003	
Industrial	0.26	Pitt et al., 2003	

APPENDIX C

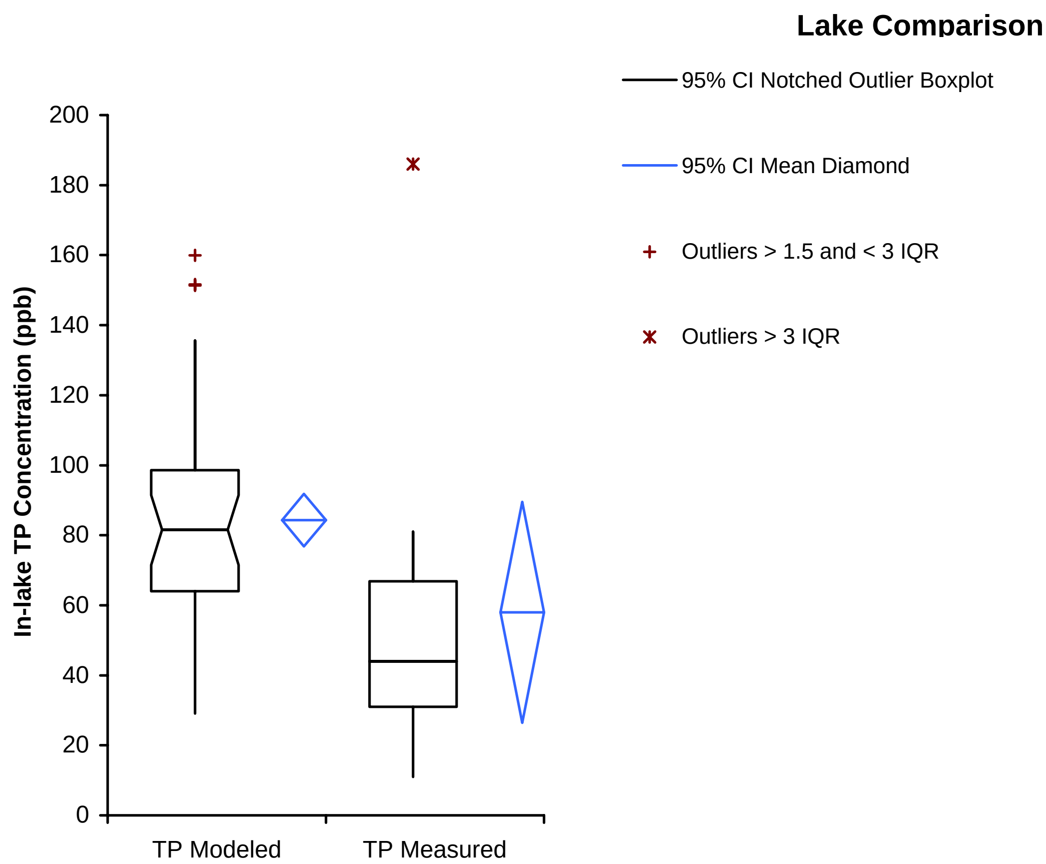
Side-bar Analysis for Regional Model Calibration

Appendix C

Test | **Describe - Comparative**
TP Modeled, TP Measured
Red Willow Lake (NUTCRIT_ID: 8959)
Class Number: II, Metric Value (based on field measurements): 27.58

Date | 21 November 2008

Analyse-it v2.07



Appendix C

Analyse-it v2.07

Test: **Describe - Comparative**
TP Modeled, TP Measured
Red Willow Lake (NUTCRIT_ID: 8959)
Class Number: II, Metric Value (based on field measurements): 27.58

Date: 21 November 2008

	n	Mean	95% CI	SE	SD
TP Modeled	59	84.33	76.83 to 91.82	3.745	28.766
TP Measured	11	58.0	26.46 to 89.54	14.15	46.94

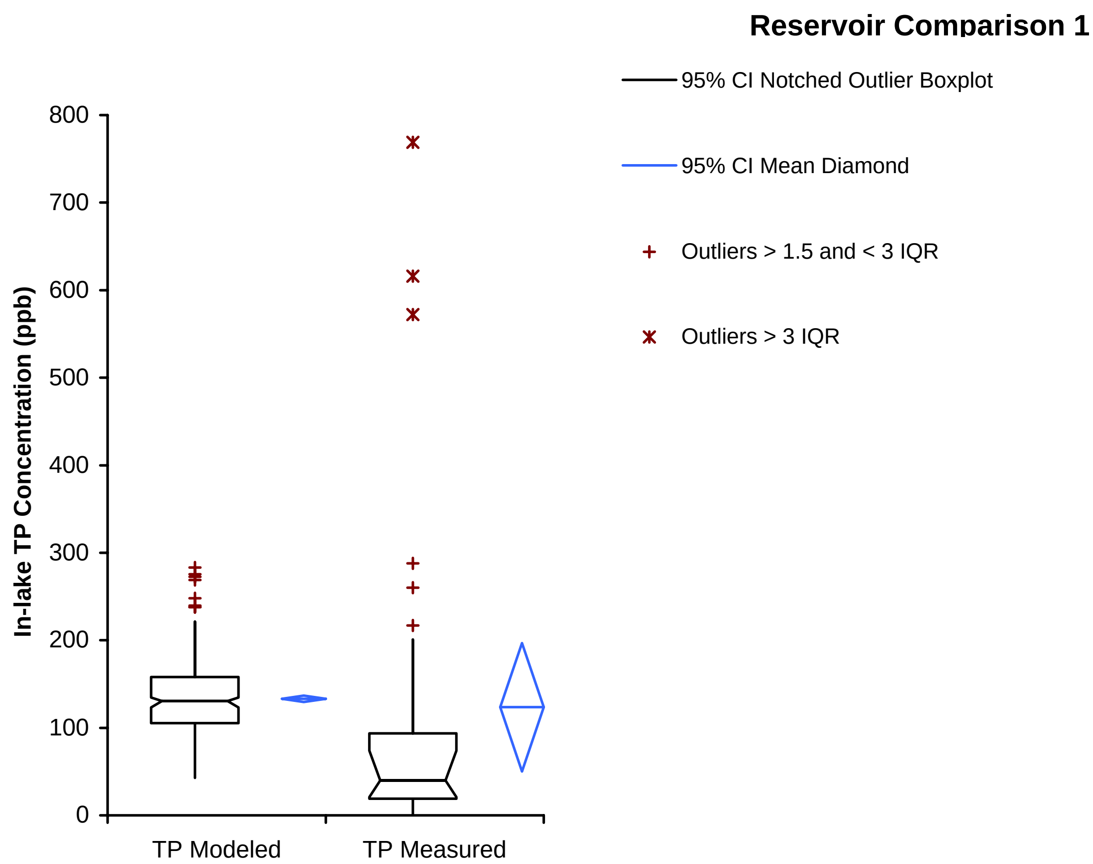
	n	Min	1st Quartile	Median	95% CI	3rd Quartile	Max	IQR
TP Modeled	59	29.1	63.99	81.58	71.52 to 91.49	98.61	159.9	34.62
TP Measured	11	11	31.0	44.0	29.00 to 81.00	66.8	186	35.8

Appendix C

Test | **Describe - Comparative**
TP Modeled, TP Measured
Dead Cold Creek (NUTCRIT_ID: 10460)
Class Number: I, Metric Value (based on field measurements): 3.99

Analyse-it v2.07

Date | 21 November 2008



Appendix C

v2.07

Test **Describe - Comparative**
TP Modeled, TP Measured
Dead Cold Creek (NUTCRIT_ID: 10460)
Class Number: I, Metric Value (based on field measurements): 3.99

Date 21 November 2008

	n	Mean	95% CI	SE	SD
TP Modeled	448	133.32	129.67 to 136.97	1.858	39.333
TP Measured	30	123.5	50.18 to 196.82	35.85	196.35

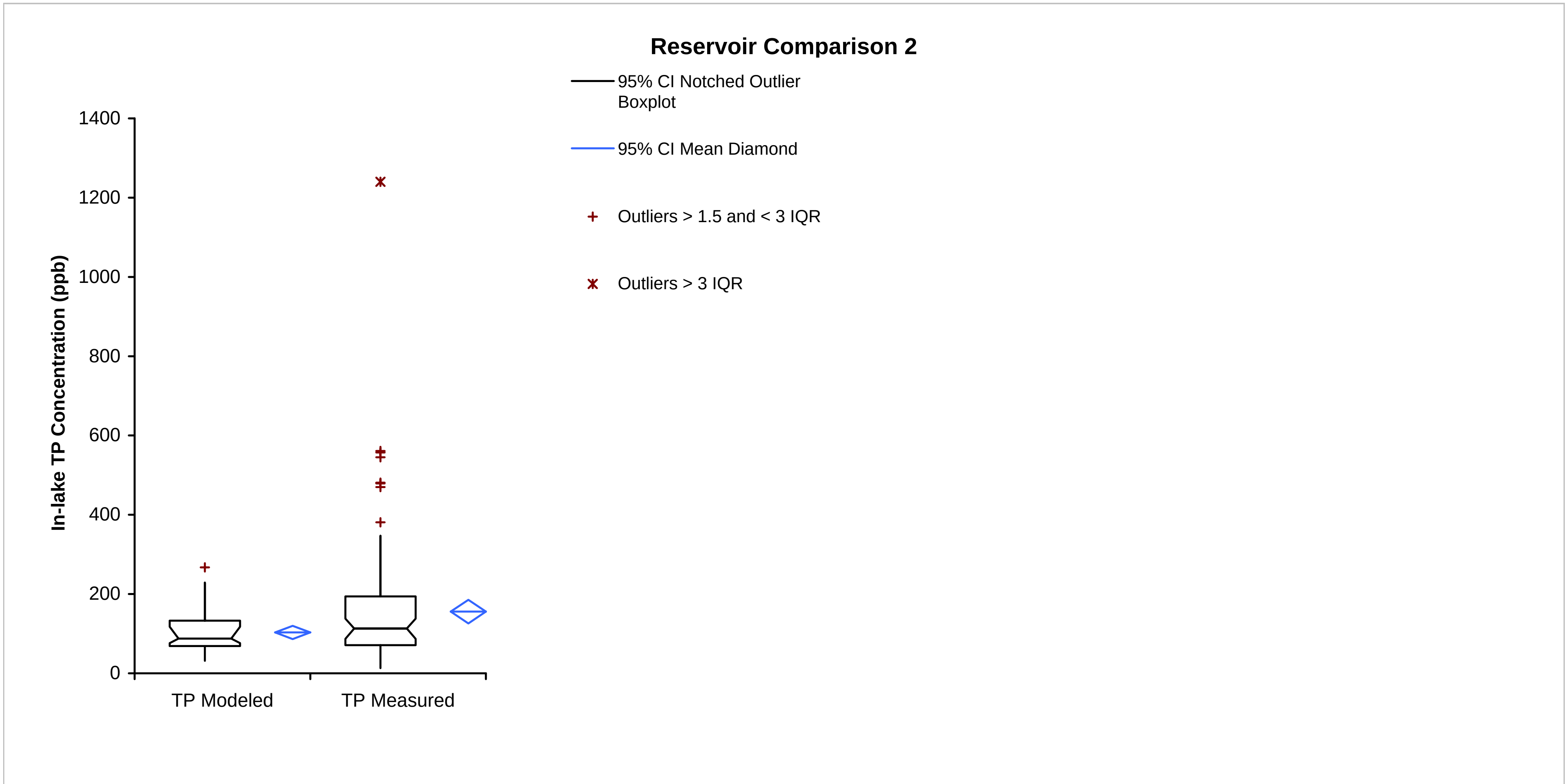
	n	Min	1st Quartile	Median	95% CI	3rd Quartile	Max	IQR
TP Modeled	448	42.8	105.52	130.47	123.37 to 134.73	158.04	283.0	52.53
TP Measured	30	2	18.9	40.0	21.00 to 74.00	93.7	769	74.8

Appendix C

Test | **Describe - Comparative**
TP Modeled, TP Measured
Brewer Lake (NUTCRIT_ID: 10484)
Class Number: II, Metric Value (based on field measurements): 24.30

Analyse-it v2.07

Date 21 November 2008



Appendix C

Analyse-it v2.07

Test: **Describe - Comparative**
TP Modeled, TP Measured
Brewer Lake (NUTCRIT_ID: 10484)
Class Number: II, Metric Value (based on field measurements): 24.30

Date: 21 November 2008

	n	Mean	95% CI	SE	SD
TP Modeled	39	103.18	86.47 to 119.90	8.257	51.562
TP Measured	108	155.7	125.90 to 185.55	15.05	156.36

	n	Min	1st Quartile	Median	95% CI	3rd Quartile	Max	IQR
TP Modeled	39	31.7	68.74	87.66	76.01 to 117.46	132.96	267.2	64.22
TP Measured	108	13	71.0	113.0	87.00 to 138.00	194.0	1240	123.0