Diamond Lake
Total Maximum Daily Load (TMDL)

August 2011

Prepared For:

Middle Fork Crow River Watershed District
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wq-iw8-28e

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EPA / MPCA Required Elements	Summary	TMDL Page #
Location	Diamond Lake is located in Kandiyohi County , 12 miles northeast of Willmar, Minnesota, within the North Central Hardwoods Ecoregion, Upper Mississippi River Basin	1
303(d) Listing Information	Diamond Lake Assessment Unit Identification Number is 34-0044-00. The MPCA listed Diamond Lake in 1998 because of elevated mercury in fish tissue and concern related to fish consumption. The MPCA identified in 2006 that the lake failed to attain the designated use for aquatic life and recreation, because of excess nutrients and again placed the lake on the 303(d) list. Diamond Lake has remained on the 303(d) list through the current 2010 list. The 2010 303(d) list shows initiation of the TMDL in 2008 and completion by 2012.	3
Applicable Water Quality Standards / Numeric Targets	Diamond Lake is an unlisted water per MR 7050.0430 and is a Class 2B, 3C, 4A, 4B, 5, and 6 water. Classification as 2B means protection as a cool and warm water fisheries. The numeric target is the numeric criteria for a deep lake, Class 2B, located within the North Central Hardwoods Ecoregion. The numeric standards expressed as the June through September average value are: total phosphorus 40 ug/l; chlorophyll-a 14 ug / l; and Secchi disk transparency greater than 1.4 meters.	19
Load Capacity (expressed as daily load)	The loading capacity is the total maximum daily load for Diamond Lake. Based upon “normal” hydrologic conditions. The maximum load capacity is 3.785 kg per day (8.344 lbs/day) expressed as total phosphorus.	55
Wasteload Allocation	The portion of the load capacity attributed to point sources including National Pollutant Discharge Elimination System (NPDES) permitted sources within the contribution drainage is zero. There are no NPDES permitted facilities in the watershed.	55

TMDL Summary Table (CONTINUED)			
EPA / MPCA Required Elements	Summary		TMDL Page #
Load Allocation	The portion of the loading capacity allocated to existing and future nonpoint sources (2008).		55
	Sources	**Load kg/day (lb./day)**	**Load kg/year (lb./day)**
	Atmospheric Deposition	0.321 (0.708)	117 (257.9)
	Subsurface Treatment Systems	0	0
	Watershed Sources	1.926 (4.246)	703 (1,549.9)
	Upstream Lakes	0.426 (0.939)	155.5 (342.8)
	Internal Sources	0.282 (0.622)	103 (227.1)
	TOTAL	**2.955 (6.515)**	**1078.5 (2,377.7)**
Seasonal Variation	Seasonal variation is accounted for by developing targets for the summer critical period where the frequency and severity of nuisance algal growth is greatest . Although the critical period is the summer, the response variables (chlorophyll-a and water clarity) are driven by the variability in annual loads of total phosphorus.		58
Reasonable Assurance	Reasonable assurance is provided by the cooperative efforts of the Middle Fork Crow River Watershed District (MFCRWD), a local unit of government with statutory authority to protect and improve the water quality of water resources including Diamond Lake.		58
Implementation	The TMDL sets forth an implementation framework and general load reduction strategies.		59
Public Participation	A number of stakeholder involvement meetings were completed as a part of the TMDL study		76
Monitoring	The MFCRWD has implemented and operates a water quality monitoring program. Monitoring will continue for a maximum period of 3-years following approval of the TMDL.		79

SECTION 1.0
INTRODUCTION AND APPLICANT DATA

Diamond Lake is a 1,607 acre lake, located in east-central Kandiyohi County in west-central Minnesota. The outlet from Diamond Lake is controlled by a fixed crest dam, constructed in 1952, which is owned by Kandiyohi County. Water leaving Diamond Lake flows into a public drainage system into the Middle Fork of the Crow River, the Crow River, and eventually the Mississippi River. Diamond Lake is about 6 miles northwest of Atwater and 12 miles northeast of Willmar, Minnesota. Diamond Lake is the focus of a Total Maximum Daily Load (TMDL) study lead by the Middle Fork Crow River Watershed District (MFCRWD). The MFCRWD retained Houston Engineering, Inc. (HEI) to assist with technical activities necessary to complete the TMDL study.

This report presents information for the Total Maximum Daily Load (TMDL) for Diamond Lake, and is intended to serve as the report for approval by the Minnesota Pollution Control Agency (MPCA) and the Environmental Protection Agency (EPA). This report includes previously prepared products, including a memorandum assessing the water quality condition of Hubbard, Wheeler, and Schultz Lakes, which are located upstream from Diamond Lake (**Appendix A**), a monitoring report (**Appendix B** on CD), and a memorandum related to the modeling used to complete the TMDL (**Appendix C**).

The MFCRWD is the applicant for this TMDL report. Contact information for the applicant is as follows:

Name of Organization:	Middle Fork Crow River Watershed District
Type of Organization:	Special purpose unit of government – Watershed District
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SECTION 2.0
PROJECT BACKGROUND INFORMATION

The title of this project is the Diamond Lake TMDL Study. **Table 2-1** provides specific information related to this project.

Table 2-1 Project Information for the Diamond Lake TMDL.

Project Title	Diamond Lake TMDL Study
Listed Reach Name	Diamond Lake
Assessment Unit Identification No.	34-0044-00
Year Listed	2006
Impaired Beneficial Use	Aquatic Life and Recreation
Pollutant	Excess Nutrients
303(d) List Scheduled	Start Date: 2008 Target Completion Year: 2012
Grant Amount	$176,215
Project Dates	February 2008 – June 2011

Diamond Lake's lake identification number, as assigned by the Minnesota Department of Natural Resources (MnDNR), (which is the same as the Assessment Unit Identification Number) is 34-0044-00. Minnesota Rule (MR) 7050.0140 *Use Classifications for Waters of the State* identifies the various uses of the state's waters, considered in the best interest of the public (i.e., beneficial uses). These beneficial uses are:

- Drinking water – Class 1
- Aquatic life and recreation – Class 2
- Industrial use and cooling – Class 3
- Agricultural use, irrigation – Class 4A
- Agricultural use, livestock and wildlife watering – Class 4B
- Aesthetics and navigation – Class 5
- Other uses – Class 6
- Limited Resource Value Waters – Class 7

Most water bodies have multiple beneficial uses, rather than a single use. Diamond Lake is an unlisted water, per MR 7050.0430, having multiple (potential) beneficial uses, including aquatic life and recreation (Class 2B), Industrial use and cooling (Class 3C), Agricultural use for irrigation and livestock (Classes 4A and 4B), aesthetics and navigation (Class 5), and other uses (Class 6). Classification as 2B means the lake must be protected as a cool and warm water fishery. Classification as 3C means that the quality of the water shall be such as to permit use for industrial cooling and materials transport without a high degree of treatment being necessary to avoid severe fouling, corrosion, scaling, or other unsatisfactory conditions. Generally, one of these uses requires "better" water quality than the remaining uses. Normally, this use is aquatic life and recreation.

Diamond Lake Assessment Unit Identification Number is 34-0044-00. The MPCA listed Diamond Lake in 1998 because of elevated mercury in fish tissue and concern related to fish consumption. The MPCA identified in 2006 that the lake failed to attain the designated use for aquatic life and recreation, because of excess nutrients and again placed the lake on the 303(d) list. Diamond Lake has remained on the 303(d) list through the current 2010 list. The 2010 303(d) list shows initiation of the TMDL in 2008 and completion by 2012. In November 2007, the MFCRWD submitted a workplan in accordance with the TMDL Workplan Guidance (Minnesota Pollution Control Agency, October 2007) and upon approval by MPCA staff in early 2008, the MFCRWD initiated the field work needed to complete the TMDL. Monitoring began in 2008 and because of dry conditions was extended through 2009.

Diamond Lake was the focus of a previous study, which evaluated water quality. The data collected during that study in part became the basis for placing the lake on the 303(d) list. A Diagnostic and Feasibility Study completed for Diamond Lake by Blue Water Science (1996) was funded by a U.S. EPA Clean Lakes Phase I Grant. The study incorporated stream and lake monitoring for approximately two years and limited paleolimnological sediment cores. The models Agricultural Nonpoint Source Model (AGNPS) and Wisconsin Lake Modeling Suite (WiLMS) were used to assess watershed yields and potential lake response. Phosphorus yields were estimated from the contributing watershed drainage areas. An in-lake nutrient goal was identified in the study and phosphorus reductions were recommended for each source area to reduce the measured mean annual total phosphorus concentration of 72 ug/l. Measured annual mean chlorophyll-a concentrations and secchi disk depths were 29.8 ug/l and 5.6 feet (1.7 meters) respectively (in 1993 and 1994). The report recommended a total phosphorus water quality goal of less than 50 micrograms per liter (ug/l) and a 40 percent load reduction from the estimated 3,697 kg annually to achieve that goal. Specific load reductions were assigned to various subwatersheds.

Diamond Lake was also included as one of the lakes used to establish nutrient criteria for the State of Minnesota (see http://www.pca.state.mn.us/publications/reports/lakes-wqdiatoms.pdf). Sedimentation rates were evaluated and used to estimate the pre-European phosphorus levels within Diamond Lake. The analysis completed by the MPCA infers pre-european phosphorus concentrations between 20 and 30 ug/l.

The Diamond Lake watershed was given a priority ranking for TMDL development due to the impairment impacts on aquatic life, the public value of the impaired water resource, the likelihood of completing the TMDL in an expedient manner, the inclusion of a strong base of existing data and the restorability of the water body, the technical capability and the willingness of local partners to assist with the TMDL and the appropriate sequencing of TMDLs within a watershed or basin. Diamond Lake is a popular location for aquatic recreation including, boating, swimming, fishing and hunting. Water quality degradation has led to efforts to improve the water quality within the Diamond Lake watershed since the late 1990's and to the development of this TMDL.

SECTION 3.0
DESCRIPTION OF THE WATERSHED AND PHOSPHORUS SOURCE ASSESSMENT

3.1 WATERSHED DESCRIPTION

The Diamond Lake watershed area is 19,148 acres (29.9 square miles) and is characterized by a complex drainage pattern (see **Figure 3-1**). Land use in the watershed is 60 percent agricultural **(Figure 3-2)** and there are three public drainage systems. The public drainage systems consist of both tile and open channels that outlet into a chain of shallow lakes (Hubbard, Schultz and Wheeler) upstream from Diamond Lake. Atwater is the only city within the watershed and only a small portion of the city is in the watershed. There are approximately 30 animal feedlots in the watershed, based upon information available from Kandiyohi County. The lake has two public accesses and one county park with a large campground.

Diamond Lake is located within the Upper Mississippi River major basin. **Figure 3-1** shows the watershed upstream of the lake, the subwatershed boundaries, the direction of surface flow, and the location of the public drainage systems. In excess of 2,000 acres of the area upstream of Diamond Lake near Atwater is a “closed basin” meaning it does not contribute surface water runoff to Diamond Lake. The outlet is located in the north-east portion of Diamond Lake. Water leaving the lake flows into a public drainage system, followed by the Middle Fork of the Crow River, the Crow River and eventually the Mississippi River.

The area surrounding Diamond Lake is developed with 365 permanent and seasonal residences, and nearly the entire shoreline in residential land use. At least 70% of the houses were built prior to 1996 and therefore may have inadequate separation of the Subsurface Sewage Treatment System (SSTS) from the seasonal high water table. Some Diamond Lake Area Recreation Association (DLARA) activities have included working on a community-based decision process for sewage treatment, provision of financial assistance for environmental education of local youth, approval of financial incentives for the implementation of best management practices, and assisting in monitoring and data collection. The MPCA placed Diamond Lake on the 303(d) list because excess nutrients impair aquatic life and recreational use in 2006. The various forms of phosphorus (total and dissolved) and nitrogen (inorganic and organic) are the nutrients (i.e., stressors) likely leading to an increase in plant biomass. A certain amount or “level” of phosphorus and nitrogen are “healthy” and integral to the proper interaction among the bacteria, invertebrates, fish, mammals, plants and biota that collectively with the water comprise a lake ecosystem. Phosphorus and nitrogen often limit the growth of phytoplankton and aquatic plants living in lakes and reservoirs. Unfortunately, in excess supply, these nutrients have been associated with a proliferation of phytoplankton and aquatic plants that can interfere with the designated uses of lakes and reservoirs. This excess condition is called “eutrophication”. Although an excessive supply of nutrients in lakes and reservoirs can lead to eutrophic conditions, the nutrients themselves generally do not interfere with the designated uses. Instead, it is the biological response to the excess nutrients that causes most of the problems. Such responses include heavy growths of phytoplankton and aquatic plants that can lead to the depletion of dissolved oxygen concentrations, fluctuations in the pH of the water, changes in composition and structure of aquatic communities, and the release of toxins from certain phytoplankton should

Figure 3-1 Diamond Lake Project Area Sampling Sites

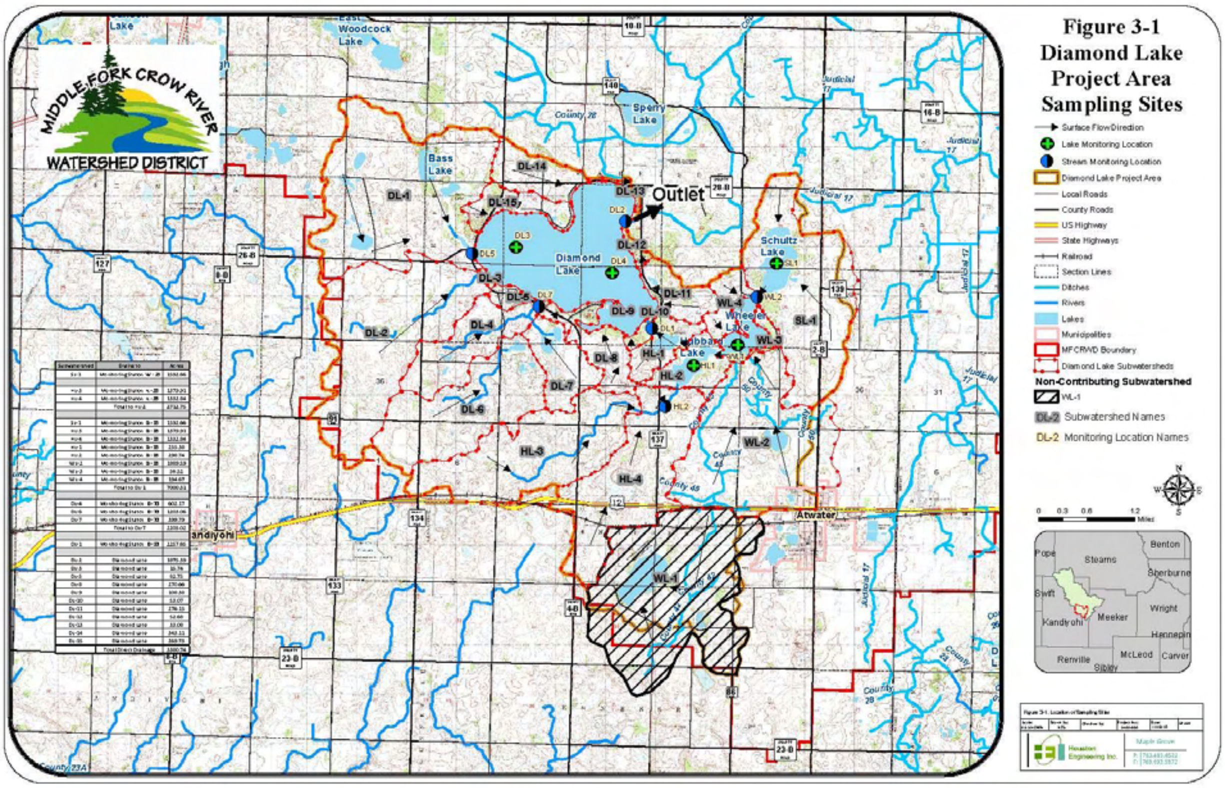
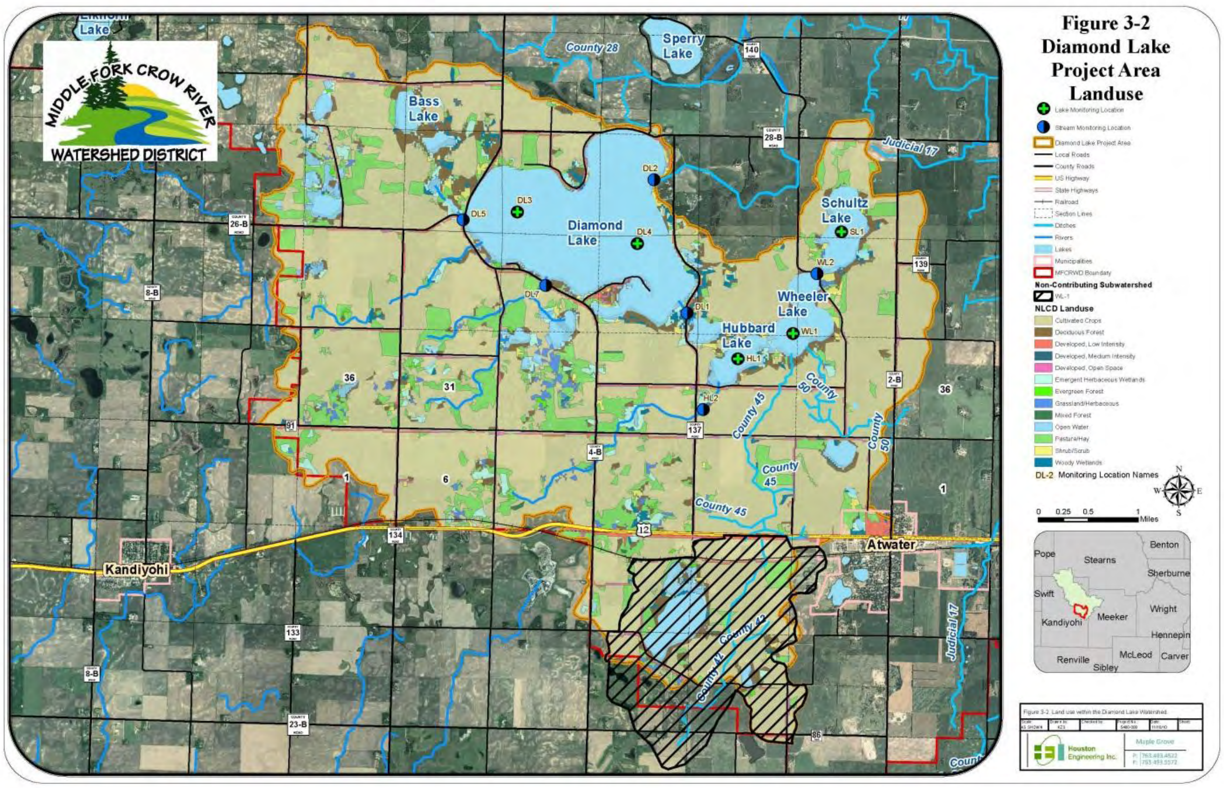


Figure 3-2 Diamond lake Project Area Landuse.



conditions become severe.

3.2 PHOSPHORUS SOURCE INVENTORY

There are a number of possible sources which contribute phosphorus to Diamond Lake. These sources are both external to the lake and internal (i.e., from within the lake itself) and include:

- Animals including livestock;
- Wildlife and fish (e.g., geese and from carp);
- Runoff from undeveloped land surfaces primarily cropland and grassland;
- Runoff from developed land surfaces (e.g., cabins around the lake, road surfaces);
- Runoff through wetland complexes;
- Direct deposition from the atmosphere (precipitation and dustfall);
- Shoreline erosion;
- Failing Subsurface Treatment Systems; and
- Internal Loading (recycling from sediments in the lake).
-

Internal loading may include contribution from wildlife as well as sediment re-suspension through wave action or biological processes.

This remaining portion of this section presents a general summary and discussion of the potential sources of phosphorus to Diamond Lake. In some cases the phosphorus reaching Diamond Lake from external sources is attached to sediment and soil particles. (Note: the phosphorus may also be dissolved and transported downstream, as is the case of water moved downstream from wetland or ponded areas). Therefore, a basic understanding of the potential sources of sediment is important in understanding phosphorus sources. The Watershed Analysis (see **Section 3.3**) presents physical information, which is useful in identifying those areas upstream from Diamond Lake with the greatest likelihood of contributing sediment and soil particles. The total phosphorus mass balance (see **Section 5.1.2**) presented later in this report identifies the magnitude of these sources.

3.2.1 Point Sources

The potential point sources to Diamond Lake within the watershed are from permitted facilities, including wastewater treatment plants, industrial facilities and construction sites. Point sources within this section are generally absent from the watershed. Although an industrial facility is present near Atwater, the drainage area within which this facility is located does not contribute runoff to Diamond Lake. There is little construction related activity within the watershed and phosphorus from this source is generally absent.

3.2.2 Nonpoint Source - Landscape

Nonpoint sources are those which are diffuse and not readily identifiable from a single location. Phosphorus from nonpoint sources is usually related to the type of land cover. Phosphorus from nonpoint sources is transported to Diamond Lake because of the movement of water and sediment. Differing land cover types and uses have differing runoff characteristics, water quality and erosion characteristics. A summary of the land cover types includes:

- **Forest** – Runoff from forests can include decomposing vegetation and organic soils. Forested land is generally absent from the watershed.
- **Agricultural** – Runoff from agricultural lands can include livestock wastes, fertilizers, sediment and soil particles, and organic material from crop residue. Cultivated land typically contributes greater phosphorus load than agricultural land used for other purposes; i.e., hay, pasture and grass hay. Cultivated land dominates the watershed upstream of Diamond Lake. The magnitude of the different agricultural land cover types has been evaluated in the watershed loading model used to establish the TMDL and develop the implementation strategy.
- **Urban/Residential (surface runoff, lake homes)** – Runoff from lake homes can be a considerable source of phosphorus. Runoff from yards can include fertilizer, leaf and grass litter, pet waste, and numerous other sources of phosphorus. The magnitude of this source has been included in this TMDL through the monitoring data collected by the MFCRWD and used to develop the total phosphorus mass balance.
- **Wetlands and Open Water -** Wetlands and open water areas can export phosphorus through the movement of suspended solids and sediment as well as dissolved phosphorus and organic debris that flow through the waterways. Based upon the monitoring data collected by the MFCRWD, the upstream lakes including Hubbard, Schultz and Wheeler lake are known to be considerable sources of phosphorus to Diamond Lake. The magnitude of this source is specifically evaluated as an implementation for Diamond Lake.
- **Confined Animal Feeding Operations (CAFO's)** – CAFO's can contribute phosphorus through runoff at feeding, holding, and manure storage areas as well as direct loading if allowed access to streams or lakes. Additional runoff can occur through upland manure applications. Information about the location, number and type of CAFO's came from Kandiyohi County and are shown in **Figure 3-8**. The estimated load from CAFO's is reflected in the monitoring data used to develop the mass balance.

3.2.3 Nonpoint Source – Subsurface Sewage Treatment Systems

The area surrounding Diamond Lake is developed with 365 permanent and seasonal residences, and nearly the entire shoreline in residential land use. At least 70% of the houses were built prior to 1996 and therefore may have inadequate separation of the SSTS from the seasonal high water table. This TMDL includes specific consideration of the magnitude of SSTS's as a source of phosphorus to Diamond Lake as reflected in the total phosphorus mass balance (see **Section 5.1.2.2**).

3.2.4 Nonpoint Source – Atmospheric

The direct deposition of phosphorus to the lake surface from precipitation and dustfall is considered in establishing the loading capacity for Diamond Lake. Regional data from the Atmospheric Deposition Program were used to identify the magnitude of this source as quantified within the total phosphorus mass balance (see **Section 5.1.2.2**).

3.2.5 Internal Sources

Internal loading can come from a wide variety of sources including the re-suspension of sediments from the lake bottom because of mixing caused by wave action, rough fish, wildlife activity, boating, and biological processes. Diamond Lake does not strongly thermally stratify therefore, mixing by wind is likely to be more important than the release from sediment when strongly stratified. The magnitude of this source as quantified within the total phosphorus mass balance (see **Section 5.1.2.2**) is based on typical release rates.

3.3 WATERSHED ANALYSIS

Several characteristics of the contributing drainage area to Diamond Lake potentially affect water quality. These characteristics, including the land forms and soils within the drainage area, represent potential water quality risk factors. Several risk factors were identified and mapped within the watershed including:

- Land slope;
- Hydric soils;
- Wetland abundance;
- Soil erodibility potential from water;
- Soil erodibility from wind; and
- Feedlot locations.

Steeper slopes tend to increase the rate of water movement across the landscape and result in greater erosion. Most areas within the watershed have fairly mild slopes. However, some areas exceed 15% (**Figure 3-3**) primarily around the upstream lakes and west of Diamond Lake.

Hydric soils tend to be those soils that are poorly or very poorly drained, have a seasonal high water table near or in close proximity to the land surface and tend to be frequently ponded for a relatively long duration during the growing season. The locations of hydric soils can be used as one index of locations where wetlands once existed or currently exist. **Figure 3-4** shows that hydric soils comprise a substantive portion of the drainage area contributing runoff to Diamond Lake. **Figure 3-5** shows the locations of wetlands. Comparison of **Figure 3-4** and **Figure 3-5** suggests many historic wetland areas have been drained. Wetlands are typically considered to have water quality benefits, although the extent varies, depending upon the type of wetland. Wetlands generally tend to reduce the amount of sediment and particulate phosphorus because of settling as the water is stored.

The K- factor is a relative index of the susceptibility of bare, cultivated soil for particle detachment and transport by rainfall. Soil scientists use the "K-factor" (units in tons per acre) as a measure of water erodibility. Soils high in clay have low K-factors generally ranging from 0.05 to 0.15 tons per acre because the soils are resistant to detachment. Coarse textured soils such as sandy soils, also have a low K-factor, generally ranging from 0.05 to 0.2 tons per acre. The reason is these soils typically have low runoff even though particle detachment occurs readily. Silt loams, which are medium textured soils, have a moderate K-factor, which generally ranges from 0.25 to 0.4 tons per acre. These soils are moderately susceptible to particle detachment and generate moderate runoff. Soils having a high silt content are the most water erodible and can be easily detached. These soils tend to crust and produce high rates of runoff and have a K-factor greater than 0.4 tons per acre.

Figure 3-3 Diamond Lake Project Area Slope.

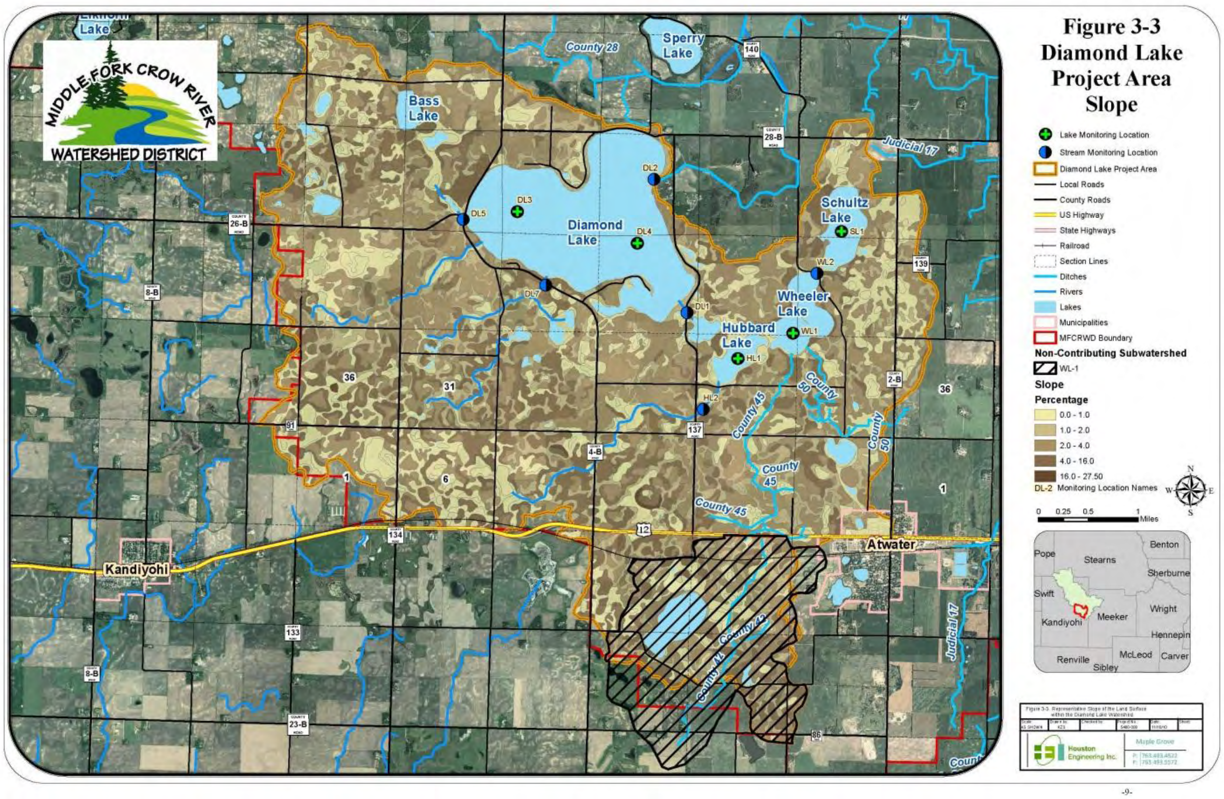


Figure 3-4 Hydric soils within the Diamond Lake watershed.

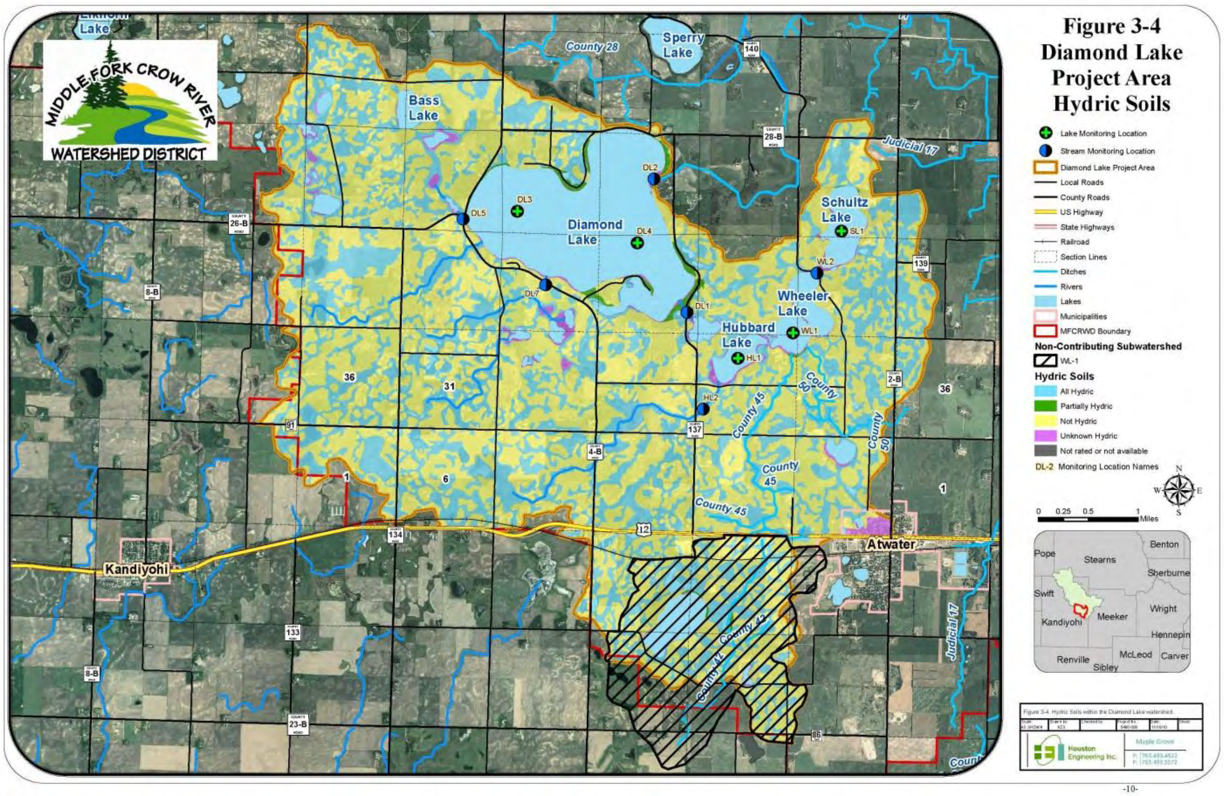
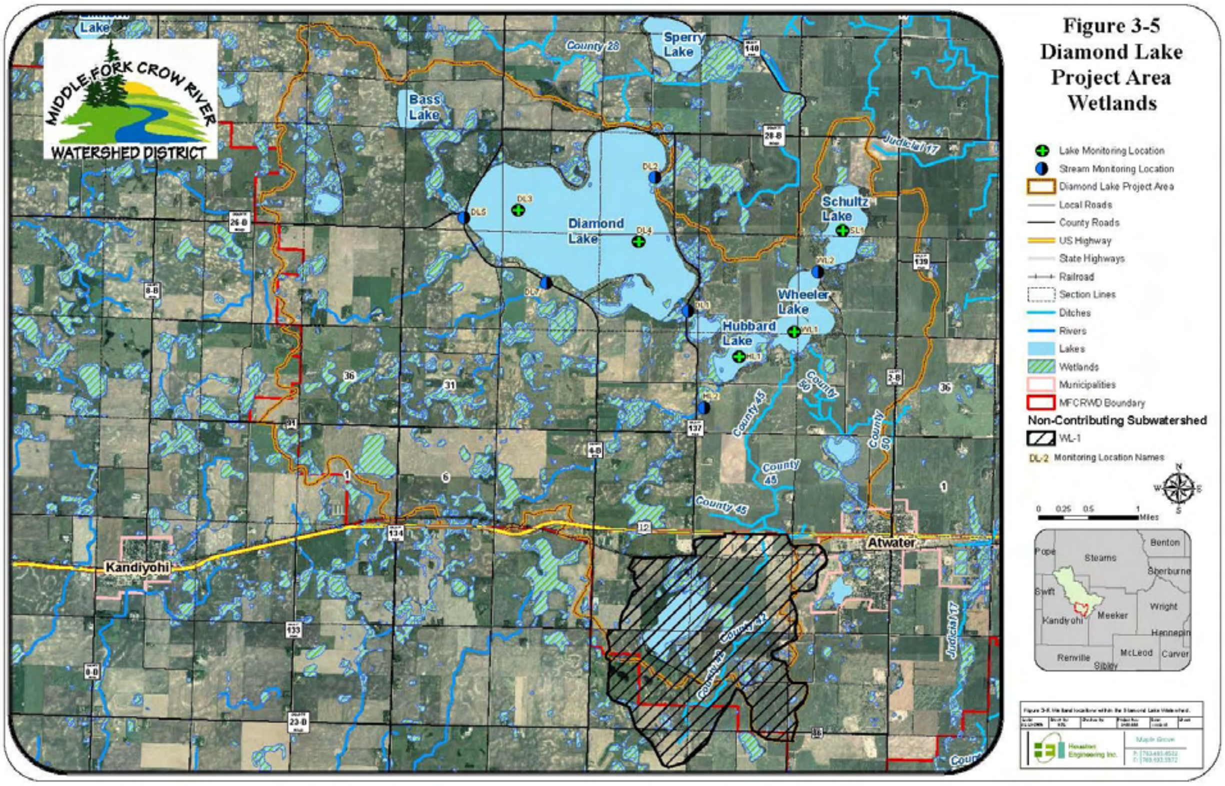


Figure 3-5 Wetland locations within the Diamond Lake watershed.



Potential risk for soil loss due to water erosion in the watershed is moderate, generally ranging from 0.20 – 0.24 tons per acre (**Figure 3-6**). Areas of high water erosion are located south-west of Diamond Lake within the upper portions of subwatersheds DL-2, DL-6 and HL-3.

The potential risk for soil loss due to wind erosion is generally moderate (**Figure 3-7**). Soils types are characterized with regard to wind erodibility. The wind erodibility index is the theoretical, long-term amount of soil lost per year through wind erosion. The index is based upon the assumption that the soil is bare, lacks a surface crust, occurs in an unsheltered position, and is subject to certain weather conditions. The wind erodibility index does not reflect the frequency of tillage or conservation practices. **Figure 3-7** suggests many of the soils in the watershed are susceptible to wind erosion.

Kandhioyi County maintains information about the location of animal feedlots. Animal feedlots are located throughout the drainage area, contributing runoff to Diamond Lake (**Figure 3-8**). Some are located within close proximity to the lake indicating they have the potential to directly influence water quality.

Landfills, chemical storage facilities, hazardous waste sites, and similar facilities can also pose a risk to water quality. A review of the various Environmental Protection Agency (EPA) databases (e.g., CERCLIS, water discharge permits, toxic release inventories (http://www.epa.gov/enviro/) shows that the only potential point source in the watershed is an ethanol facility in Atwater. This facility is located within a non-contribution drainage area. Additional point sources or other potential pollutant sources are absent within the drainage area upstream from Diamond Lake.

The watershed to Diamond Lake is primarily agricultural and expected to remain in this land use for the foreseeable future. Therefore, no measurable increase in population is anticipated. Growth and development around Diamond Lake has occurred during the past 30 years or more, resulting in the currently developed lakeshore. Recreational use is primarily related to fishing and water sports. One resort and a county park are located on the lake.

The Minnesota Department of Natural Resources completed a fisheries survey of Diamond Lake in 2008. The survey indicates that common carp numbers in 2008 were moderate to high compared to the normal range for Diamond Lake.

The historical average weight is 6.7 pounds from trapnets. In 2008, trapnets showed 10.3 pounds per trapnet. Diamond Lake has an abundant black crappie population, which provides for an excellent recreational resource. The number of black crappie in 2008 appeared elevated compared to the average number for previous years. Bluegill numbers were moderate in 2008, as were northern pike numbers. The number of walleye in 2008 were low to moderate. Current fish management activities completed by the Minnesota Department of Natural Resources on Diamond Lake include, monitoring the fish population to assess trends, protecting aquatic vegetation important to the life cycle of fish through their permit program, participating in local watershed activities and stocking various species as warranted.

Figure 3-6 Soil erosion susceptibility because of water erosion.

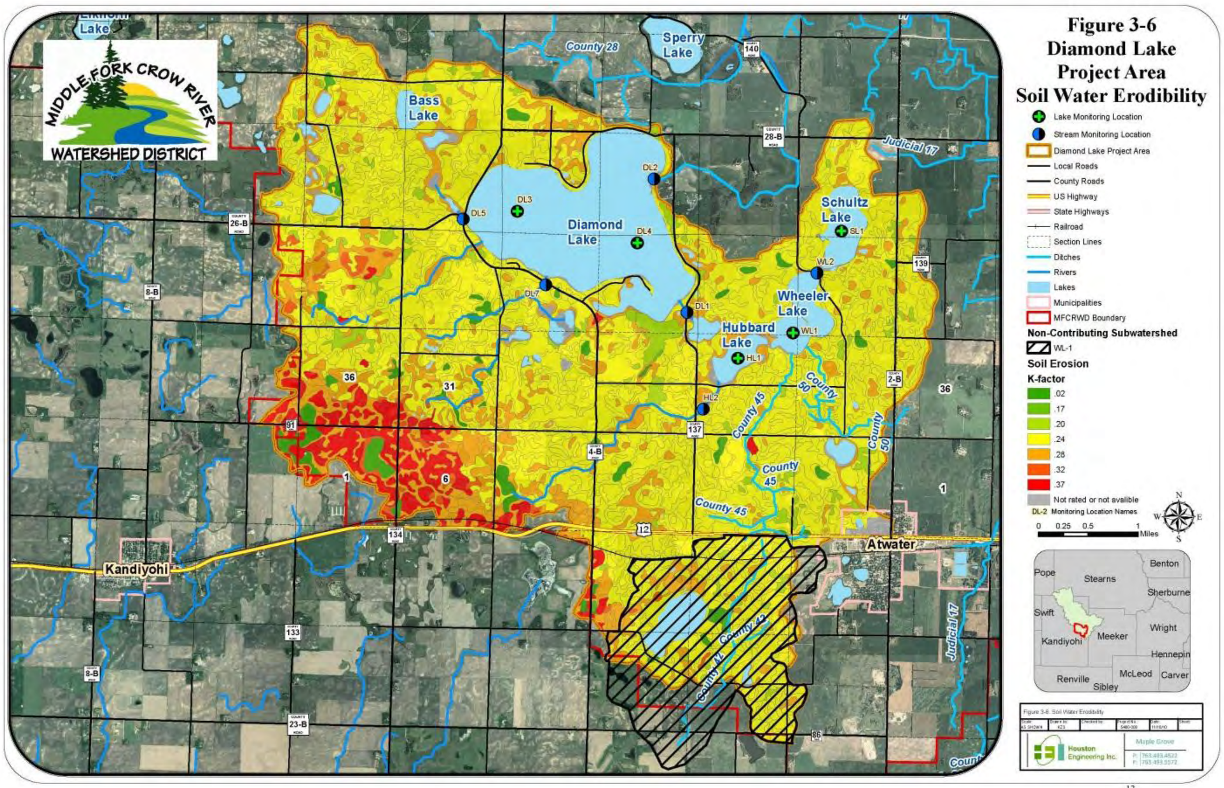


Figure 3-7 Soil erosion susceptibility because of wind erosion.

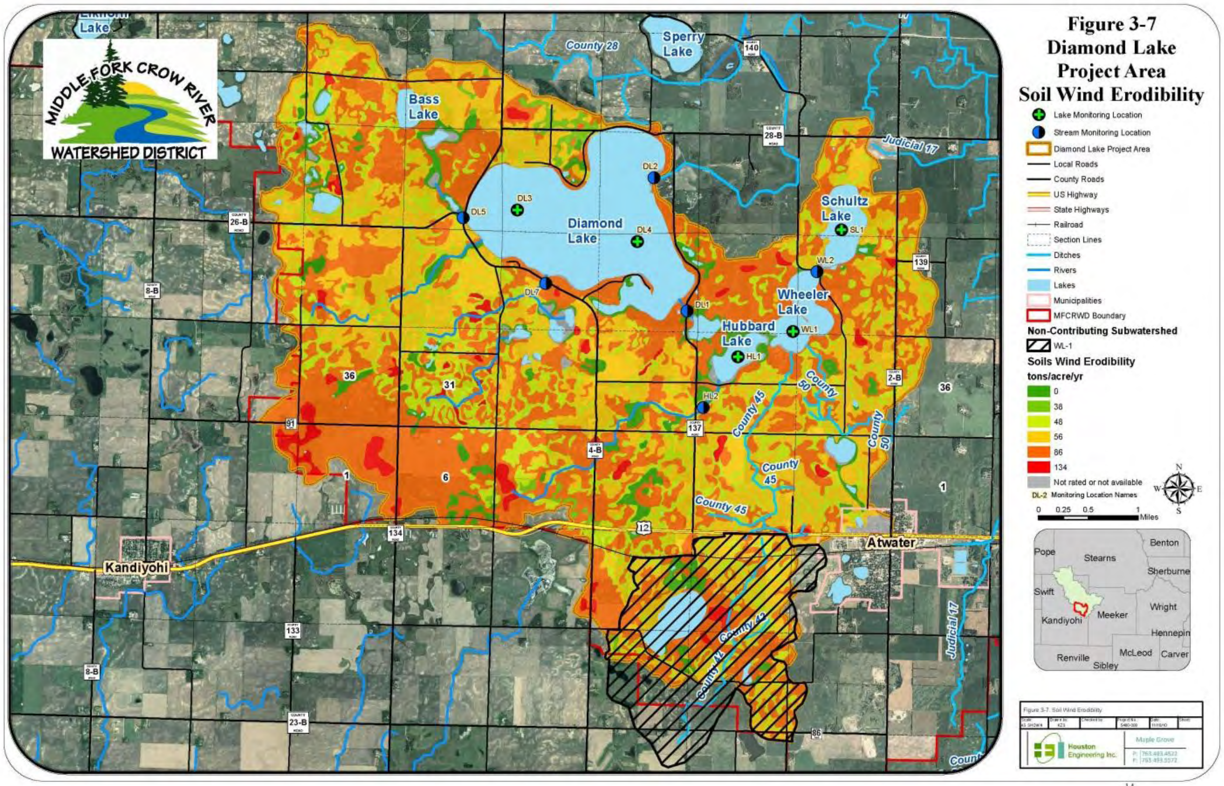
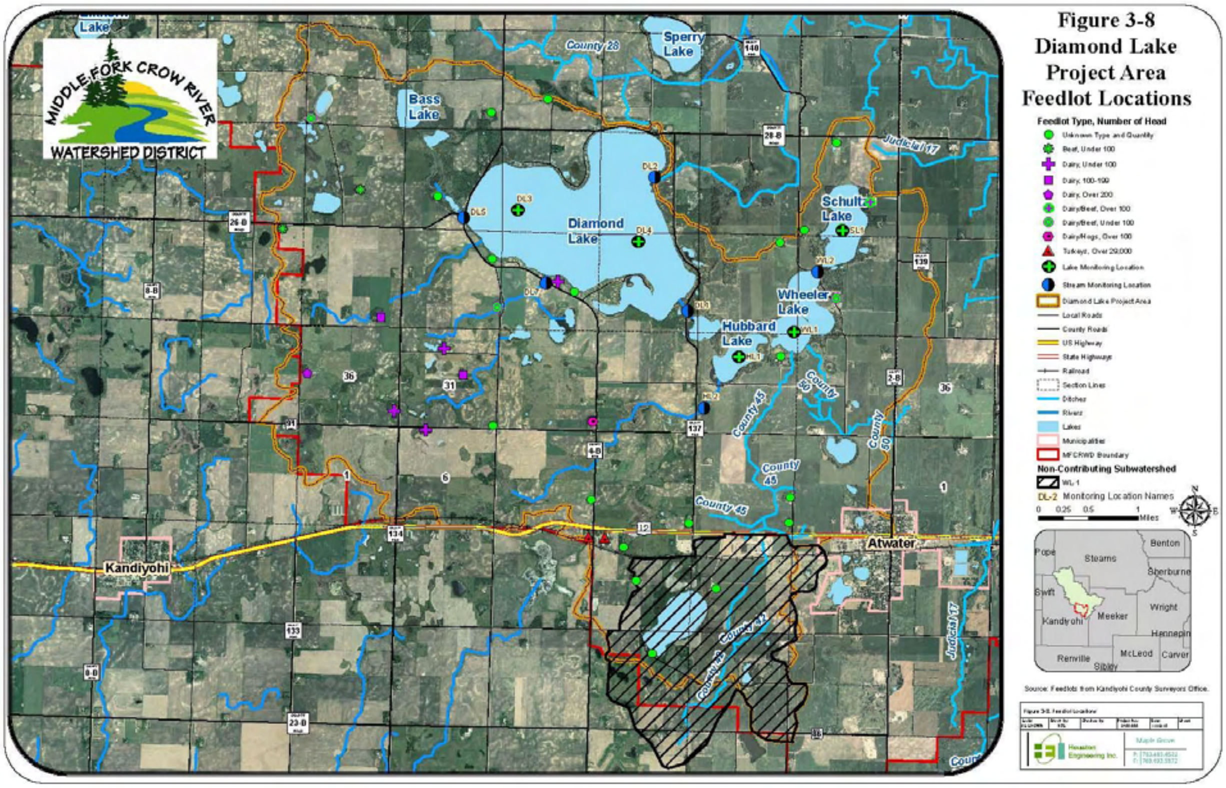


Figure 3-8 Feedlot locations within the Diamond Lake watershed.



SECTION 4.0
PROBLEM STATEMENT

The primary water quality problem in Diamond Lake is that it fails to support the designated use for aquatic life and recreation due to excess nutrients. Excess nutrients (the stressor) lead to an increase in algae and some undesirable rooted aquatic plants (e.g., curly leaf pond weed) and reduced water clarity. The water quality of Diamond Lake does not meet the standards established by the MPCA for a deep lake (Class 2B) within the North Central Hardwood Forest Ecoregion.

There are three types of standards used to establish a regulatory limit that supports a designated use: 1) a numeric standard; 2) a narrative standard; and 3) anti-degradation. A numeric standard represents a "safe" concentration for a particular contaminant intended to protect a designated use. The use will be adversely affected if the pollutant concentration exceeds the numeric standard too frequently. Numeric criteria, which form the basis for standards adopted by the MPCA, are defined in federal rules as a recommended minimum water quality standard. A state can establish a more restrictive standard than the numeric criteria.

The second type of standard is the narrative standard. The narrative standard is usually not as easily defined as a numeric standard. Narrative standards involve keeping waters free of unwanted conditions such as oil sheens, floating solids, or algae blooms. The narrative standard may also be interpreted as the physical condition necessary to achieve the designated use. For example, if the designated use is "cold water fish habitat" the surface water temperature and dissolved oxygen levels must remain within a range that can support cold water fish species.

Anti-degradation pertains to waters that currently have water quality better than the applicable numeric or narrative standards for the designated use. The goal of anti-degradation is to prohibit these high quality waters from sliding "back" to the level of the numeric standard for the designated use.

The designated use that is impaired within Diamond Lake is aquatic life and recreation. Diamond Lake is located in the North Central Hardwood Forest Ecoregion, but near the boundary with the Western Corn Belt Plains Ecoregion. The eutrophication (and conventional pollutant) standards for a 2B lake within the North Central Hardwood Forest Ecoregion are shown in **Table 4-1**. Diamond Lake has an average depth of 16 feet with a maximum depth of 27 feet. The lake's elevation is controlled by a fixed crest dam. The dam has modified the proportion of littoral area within Diamond Lake compared to historic conditions, indirectly affecting water quality. Diamond Lake is classified as a deep lake, since it exceeds 15 feet in depth. The monitoring data collected during this TMDL shows the water quality numeric standards for dissolved oxygen, pH, turbidity and temperature are being attained within Diamond Lake.

The focus of this TMDL study is total phosphorus as the stressor and the amount of plant biomass (as indicated by the amount of chlorophyll-a) and water clarity (expressed as secchi disk) as the response to excess total phosphorus. The eutrophication standard requires that in addition to achieving the total phosphorus concentration, the numeric value for either chlorophyll-a or secchi disk must be attained to comply with the state standard. The standard is based on the average concentrations for the growing season (June through September) and corresponds to the open water period within Diamond Lake when recreational use is greatest. The loading capacity established by this TMDL is capable of achieving the standard; i.e., the total phosphorus concentration and either the secchi disk visibility or chlorophyll-a concentrations. The load capacity for this TMDL is established for an annual time period consistent with the guidance provided by the Minnesota Pollution Control Agency (MPCA 2007). The guidance indicates that if the residence time for a lake exceeds 1 year, that the loading capacity should be established for an annual time period. The rationale is that the lake responds to an annual time period. The residence time for Diamond Lake is estimated at approximately 5 years, based upon the runoff for average hydrologic conditions.

Table 4-1 Applicable numeric standards for Class 2B lakes, shallow lakes and reservoirs.

Parameter	Standard
Total Phosphorus	40 ug / l June through September average
*Chlorophyll-a	14 ug /l June through September average
*Secchi disk transparency	Greater than 1.4 meters June through September average
Dissolved oxygen	Not less than 5 mg/L as a daily minimum
pH	minimum of 6.5 and a maximum of 8.5
Turbidity	25 NTU; need more than 20 observations with no more than 10% exceeding 25 NTU
Temperature	No material increase in temperature

* One of these must be achieved in addition to the June through September total phosphorus concentration.

SECTION 5.0
PROJECT RESULTS

5.1 DIAMOND LAKE WATER BUDGET AND TOTAL PHOSPHORUS MASS BALANCE

This section presents results for the monitoring completed during 2008 and 2009. Details of the monitoring methods and results are provided in **Appendix B** in the document titled *Diamond Lake Monitoring Report, Summary for the Diamond Lake TMDL* (HEI June 11, 2010). Only a summary of the water quality results, specific to the eutrophication of Diamond Lake, the lake hydrologic budget, and the lake total phosphorus budget derived from the monitoring data, are presented. The reader is encouraged to consult **Appendix B** if interested in the details of the monitoring program or a detailed analysis of the results.

The in-lake data collected during the 2008 and 2009 periods are used to diagnose the extent and severity of water quality problems and assess attainment of the numeric standard. The data is also used to calibrate a lake water quality model, which is used to forecast the amount of improvement, which can be expected if "fixes" are implemented by reducing nutrient loads. The stream runoff volume and chemistry data are used to estimate loads, identify potential sources of excess nutrients, and to calibrate and validate the watershed model. The watershed model can then be used to evaluate the effectiveness of certain implementation activities in reducing nutrient loads.

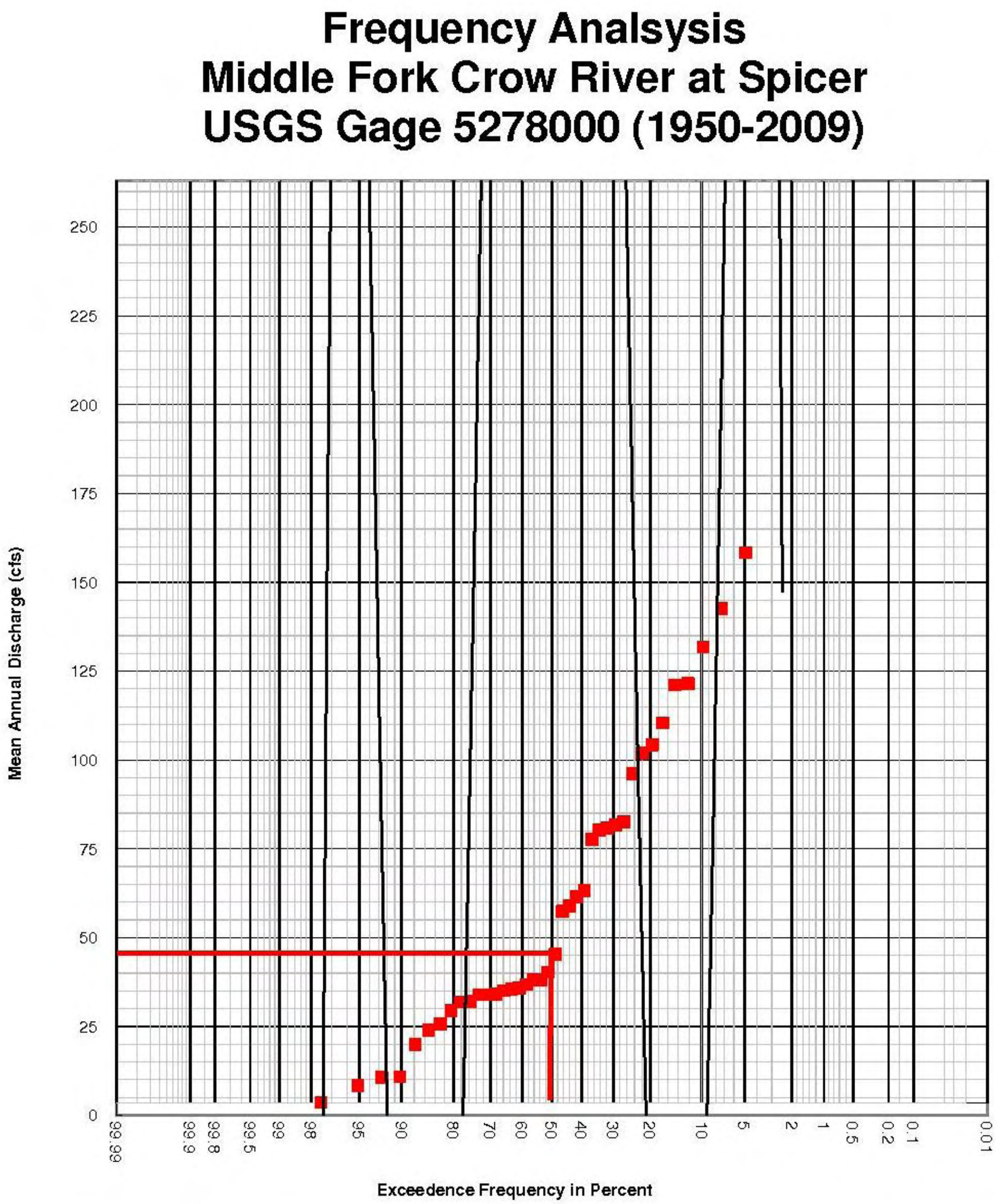
5.1.1 Water Budget for 2008 and 2009

Many factors influence the amount of water reaching Diamond Lake and the various sources of water carry differing amounts of nutrients. Therefore, understanding where the water comes from and how it enters and leaves Diamond Lake is critical to developing an appropriate loading capacity and implementation plan. This portion of the report presents a summary of the sources and amount of water reaching and leaving Diamond Lake.

Placing the type of water year within context is important for understanding the monitoring data. Using information from a nearby long-term gaging site is the best method for establishing the context for the type of water year. The USGS has operated a gage on the Middle Fork Crow River at Spicer since 1950 (gage no. 5278000). Assuming runoff from the Diamond Lake watershed behaves similarly to the runoff from the watershed to the USGS gage on the Middle Fork Crow River at Spicer, the amount of runoff during 2008 was slightly less than normal and near normal during 2009 (**Figure 5-1**). The 50th percentile mean annual discharge at the Spicer gage is an estimated 45 cubic feet per second (cfs) compared to 38.2 cfs in 2008 and 45.3 cfs in 2009. Nearly 33% of the total inflow volume entering the lake comes from surface runoff and an estimated 50% of the total inflow volume from precipitation falling directly on the lake surface.

Although the USGS gage on the Middle Fork Crow River at Spicer suggests slightly below normal runoff conditions for the study period, the actual hydrologic conditions for the study period within the contributing drainage area to Diamond Lake were likely considerably

Figure 5-1 Frequency analysis of annual runoff volume at the Middle Fork Crow River Spicer, Minnesota gage.



2008 mean discharge = 38.2 cfs
2009 mean discharge = 45.3 cfs

drier. Snow depths during the early winter of 2008 and 2009 were considerably below normal (see **Figure 7-3**; Appendix A). Monthly rainfall amounts during the summer months in 2008 were also general at or below normal (see **Figure 7-2**; Appendix A). Spring runoff that occurred early in 2008 became stored in Diamond Lake until the weir controlling the lake level became overtopped. The elevation of Diamond Lake at the time of freeze-up in the fall of 2007 was nearly a foot below the crest elevation of 1172.67 (1988 datum) of the weir. Outflow from Diamond Lake in 2008 occurred only for a short duration; i.e., from May through June because of the lack of inflow to Diamond Lake. During 2009 the snowmelt filled the lake and discharge occurred from end of March through June 3rd with late summer and early fall rains resulting in discharges in August and October. These monitoring data were used to calibrate the watershed runoff (i.e., SWAT) model. Once the SWAT model was calibrated, it was used to estimate the annual average amount of surface runoff and phosphorus load to Diamond Lake using a 30-year precipitation period. These data were then used to estimate these terms in the critical conditions hydrologic budget and total phosphorus budgets.

Water enters Diamond Lake from a number of sources. Precipitation falls directly onto the lake surface, surface runoff enters from areas around the lake, and groundwater interacts with the lake below the land surface. The hydrology of Diamond Lake appears to be dominated by surface water runoff and precipitation falling directly onto the lake surface, although no groundwater measurements were made. The estimated total volume of water entering Diamond Lake in 2008 was 6,379 acre-feet compared to 7,023 acre-feet in 2009 (see **Figure 5-2**). Nearly 33% of the total inflow volume entering the lake comes from surface runoff and an estimated 50% of the total inflow volume from precipitation falling directly on the lake surface.

There are two sources of surface runoff to Diamond Lake; 1) runoff through creeks and streams (tributaries); and 2) direct runoff from those areas immediately surrounding the lake (i.e. ungaged inflow). Gaged runoff is the portion measured within the creeks and streams and in 2008 and 2009 accounted for more than 80% of the runoff entering Diamond Lake. Only a small portion of the surface runoff came from areas draining directly to the lake (ungaged).

The dominant losses of water from the lake are evaporation, outflow over the dam and (potentially) groundwater. The volume evaporated is generally similar to the volume of precipitation falling on the lake surface. The amount of surface outflow depends upon the amount of inflow and elevation of the lake at the beginning of the year.

Runoff was measured from several of the subwatersheds around Diamond Lake during the study. Most of the surface runoff enters Diamond Lake through the primary inlet at DL-1 (**Table 5-1**). In excess of 3-inches and 4-inches of runoff occurred from the area upstream of DL-1 in 2008 and 2009, respectively. Less runoff per unit area occurred upstream of monitoring site HL-2. An estimated 2.4-inches and 3.0 inches were measured in 2008 and 2009, respectively. The tributaries south and west of Diamond Lake (DL-5 and DL-7) showed the least amount of runoff on a unit basis, generally ranging from less than 1-inch to 1.5-inches annually.

Figure 5-2 Water balance for Diamond Lake in 2008, 2009 and long-term average.

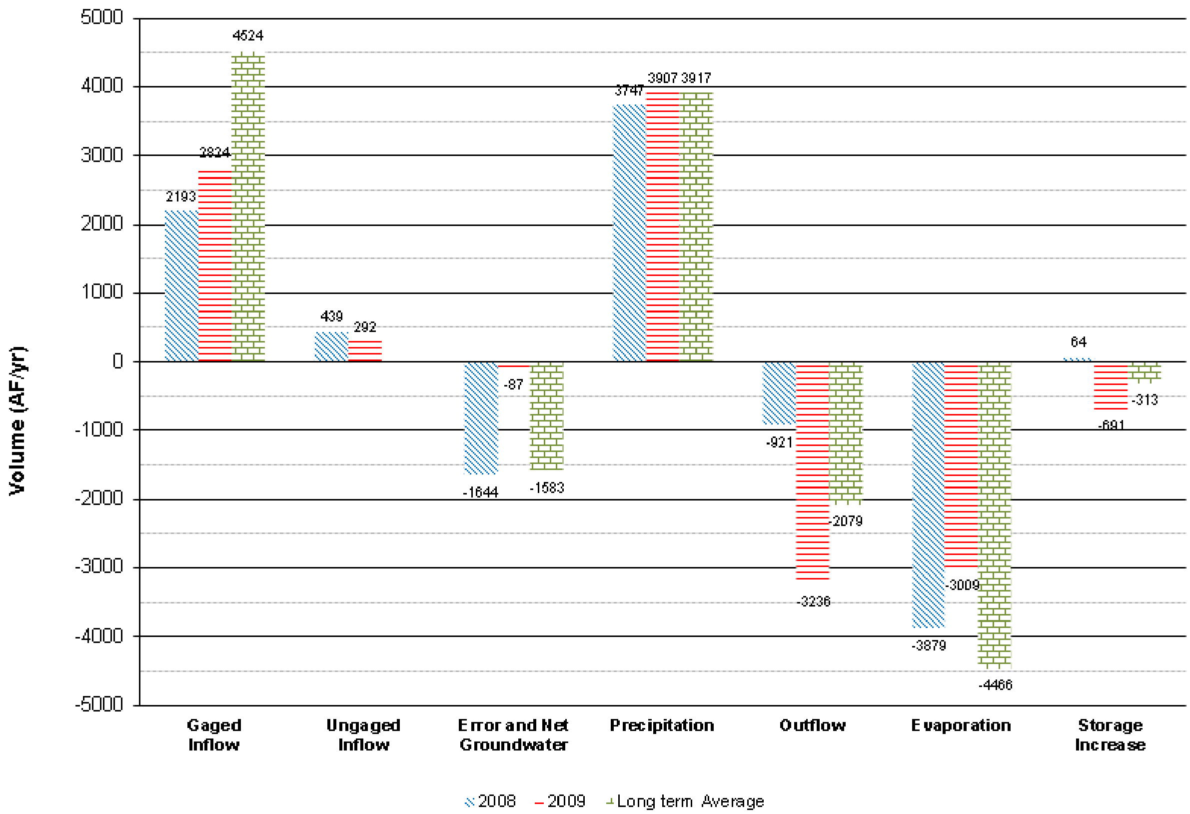


Table 5-1 Gaged runoff at Diamond Lake monitoring stations in 2008 and 2009.

	DL1 (2,258 acres)		DL2 (1,875 acres)		DL5 (83 acres)		DL7 (400 acres)		HL2 (299 acres)		WL3 (57 acres)	
Month	Volume (AF)	Inches of runoff / Acre	Volume (AF)	Inches of runoff / Acre	Volume (AF)	Inches of runoff / Acre	Volume (AF)	Inches of runoff / Acre	Volume (AF)	Inches of runoff / Acre	Volume (AF)	Inches of runoff / Acre
2008												
Jan	--	--	--	--	--	--	--	--	--	--	--	--
Feb	--	--	--	--	--	--	--	--	--	--	--	--
Mar	--	--	0.00	0.00	0.00	0.00	0.00	0.00	23.46	0.10	--	--
Apr	274.6	0.5	0.00	0.00	0.00	0.00	150.72	0.82	220.61	0.98	--	--
May	801.3	1.4	281.65	0.18	0.00	0.00	121.45	0.66	193.34	0.86	--	--
Jun	515.6	0.9	625.86	0.39	36.04	0.19	14.48	0.08	93.22	0.41	--	--
Jul	260.5	0.4	13.75	0.01	1.35	0.01	0.00	0.00	7.98	0.04	--	--
Aug	17.2	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--	--
Sep	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--	--
Oct	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
Nov	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
Dec	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
2008 Total	1869.3	3.2	921.26	0.58	37.39	0.20	286.65	1.56	538.62	2.38	--	--
2009												
Jan	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
Feb	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
Mar	395.6	--	811.21	0.51	92.43	0.49	61.49	0.33	18.88	0.08	--	--
Apr	779.9	1.3	1739.90	1.09	121.23	0.64	127.83	0.70	125.02	0.55	99.36	0.75
May	369.9	0.6	638.48	0.40	0.00	0.00	0.93	0.01	117.48	0.52	192.04	1.45
Jun	60.8	0.1	17.10	0.01	0.00	0.00	0.00	0.00	48.12	0.21	0.00	0.00
Jul	6.2	0.0	0.00	0.00	0.00	0.00	0.00	0.00	3.75	0.02	0.00	0.00
Aug	78.9	0.1	28.11	0.02	0.00	0.00	0.00	0.00	62.32	0.28	7957.64	59.96
Sep	18.6	0.0	1.49	0.00	0.22	0.00	0.00	0.00	152.29	0.67	6791.43	51.17
Oct	310.0	0.5	0.00	0.00	1.05	0.01	0.00	0.00	159.77	0.71	1653.58	12.46
Nov	399.3	0.7	--	--	--	--	--	--	--	--	596.55	4.49
Dec	0.0	--	--	--	--	--	--	--	--	--	--	--
2009 Total	2419.1	4.1	3236.28	2.03	214.93	1.14	190.25	1.04	687.63	3.04	17290.59	130.28

5.1.2 Water Quality Summary and Total Phosphorus Mass Balance

5.1.2.1 Water Quality Summary

Measured total phosphorus and dissolved phosphorus concentrations are presented in **Figure 5-3** and **Figure 5-4**, respectively. These data show Diamond Lake exceeded a mean total phosphorus concentration of 40 ug/l, which is the numeric standard for Diamond Lake. Concentrations infrequently became elevated exceeding 100 ug/l. Mean dissolved phosphorus concentrations were approximately one-third of the total phosphorus concentrations. Chlorophyll-a concentrations were measured at one location in the lake (i.e., DL-3). The mean chlorophyll-a concentration of 17 ug/1 for the 2008 and 2009 data combined, exceeded the numeric standard of 14 ug/1 (**Figure 5-5**). Individual chlorophyll-a measurements exceeded 14 ug/1 an estimated 45% of the time. **Figure 5-6** and **Figure 5-7** show the temporal change in secchi disk visibility and the mean values respectively, measured within Diamond Lake.

Nitrate plus nitrite concentrations were consistently at or below the minimum detectable limit within Diamond Lake (0.05 mg/l). The mean Total Kjeldahl Nitrogen (TKN) concentration was measured at 1.1 mg/l (**Figure 5-8**). The ratio of total nitrogen to total phosphorus based on the mean concentration of TKN and TP at the DL-3 monitoring location is 29.7:1. A time series of the paired measurements is shown in **Figure 5-9**. These data show a phosphorus limited lake based on a total nitrogen to dissolved phosphorus ratio of more than seven. Diamond Lake can be considered eutrophic if classified based on total phosphorus and chlorophyll-a annual mean concentrations. The trophic-state based on secchi disk depth is also eutrophic.

The monitoring data can be used to characterize the response to nutrients in Diamond Lake. Paired measurements between: 1) total phosphorus and chlorophyll-a concentrations; 2) total phosphorus concentrations and secchi disk visibility; and 3) chlorophyll-a concentrations and secchi disk visibility, are shown in **Figure 5-10**, **Figure 5-11** and **Figure 5-12**, respectively. These graphs show a strong linear relationship between total phosphorus and chlorophyll-a and a logarithmic response for secchi disk visibility. The relationship between cholorophyll-a and secchi disk visibility is also logarithmic, which suggests that water clarity within Diamond Lake is driven by the abundance of algae. These graphs show that the amount of algae within Diamond Lake increases and the clarity of water decreases and the amount of total phosphorus increases, a typical response to increasing nutrients.

5.1.2.2 Total Phosphorus Mass Balance

The total phosphorus mass balances for 2008 and 2009 show that Diamond Lake is very effective at phosphorus retention. According to these data, Diamond Lake retained 86% and 97% of the estimated 1,216 kg and 940 kg of total phosphorus entering the lake in 2008 and 2009, respectively (**Figure 5-13**). Surface water runoff is the single largest source of total phosphorus, accounting for between 48% and 71% of the total load. Atmospheric deposition and failing septic systems contribute nearly equal percentages; approximately 15% of the total load. The internal release of total phosphorous accounts for the remaining proportion of the load and ranged from 3% to 32% in 2009 and 2008, respectively.

Figure 5-3 Total phosphorus mean concentrations in Diamond Lake, 2008 – 2009.

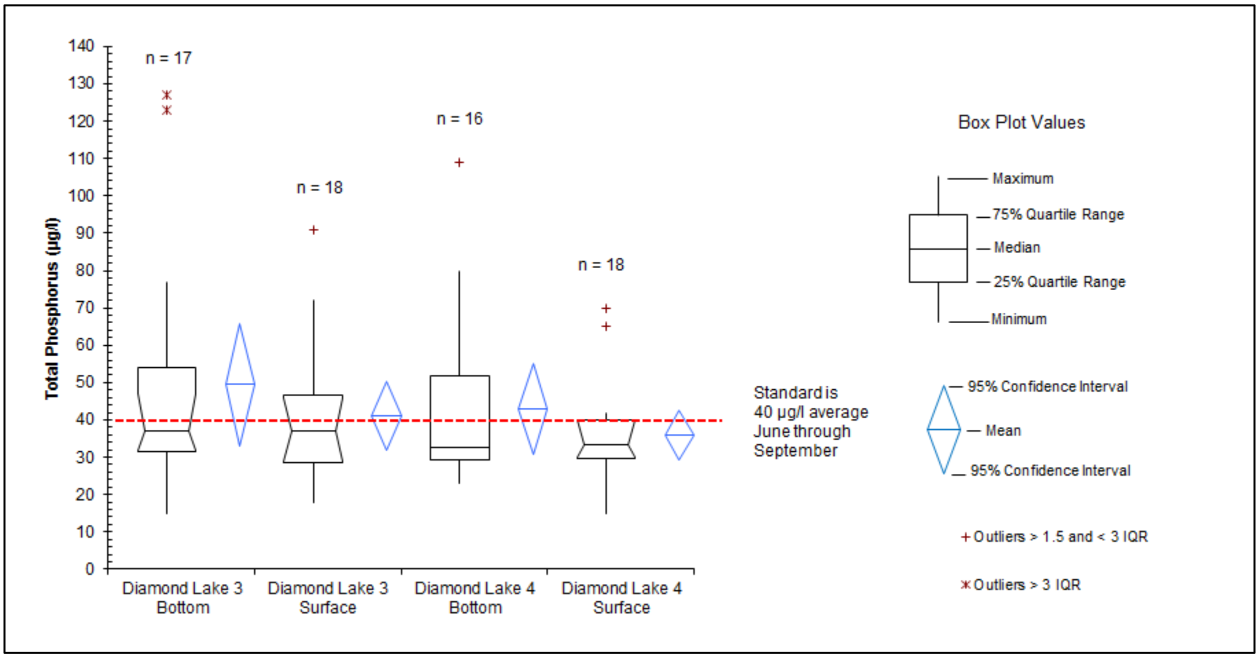


Figure 5-4 Dissolved phosphorus mean concentrations in Diamond Lake, 2008 -2009.

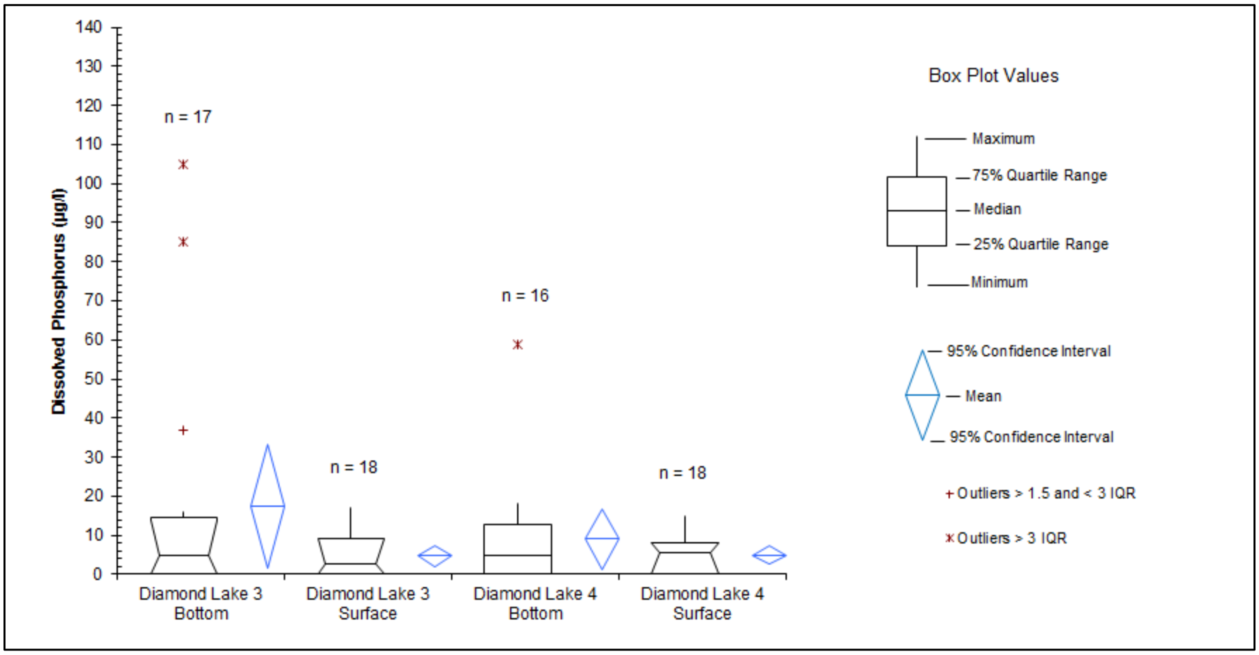


Figure 5-5 Surface Chlorophyll-a mean concentrations in Diamond Lake, 2008 -2009.

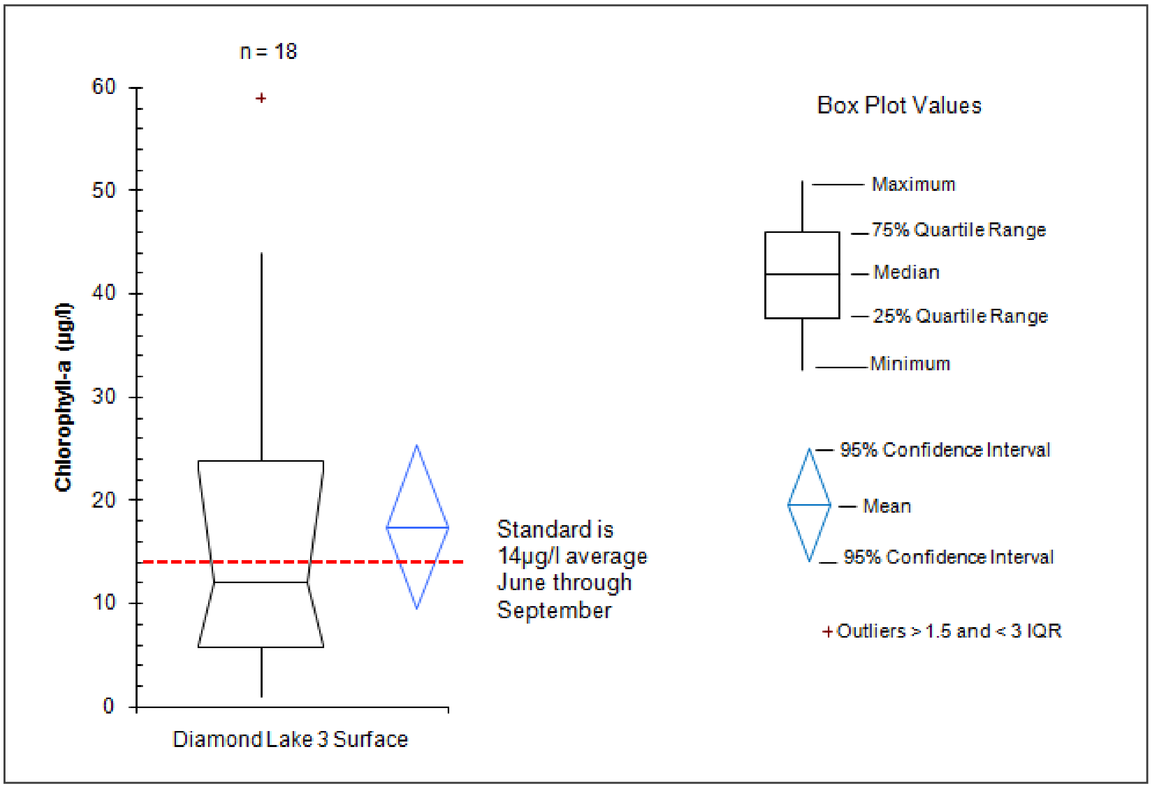


Figure 5-6 Diamond Lake Secchi disk time series, 2008-2009.

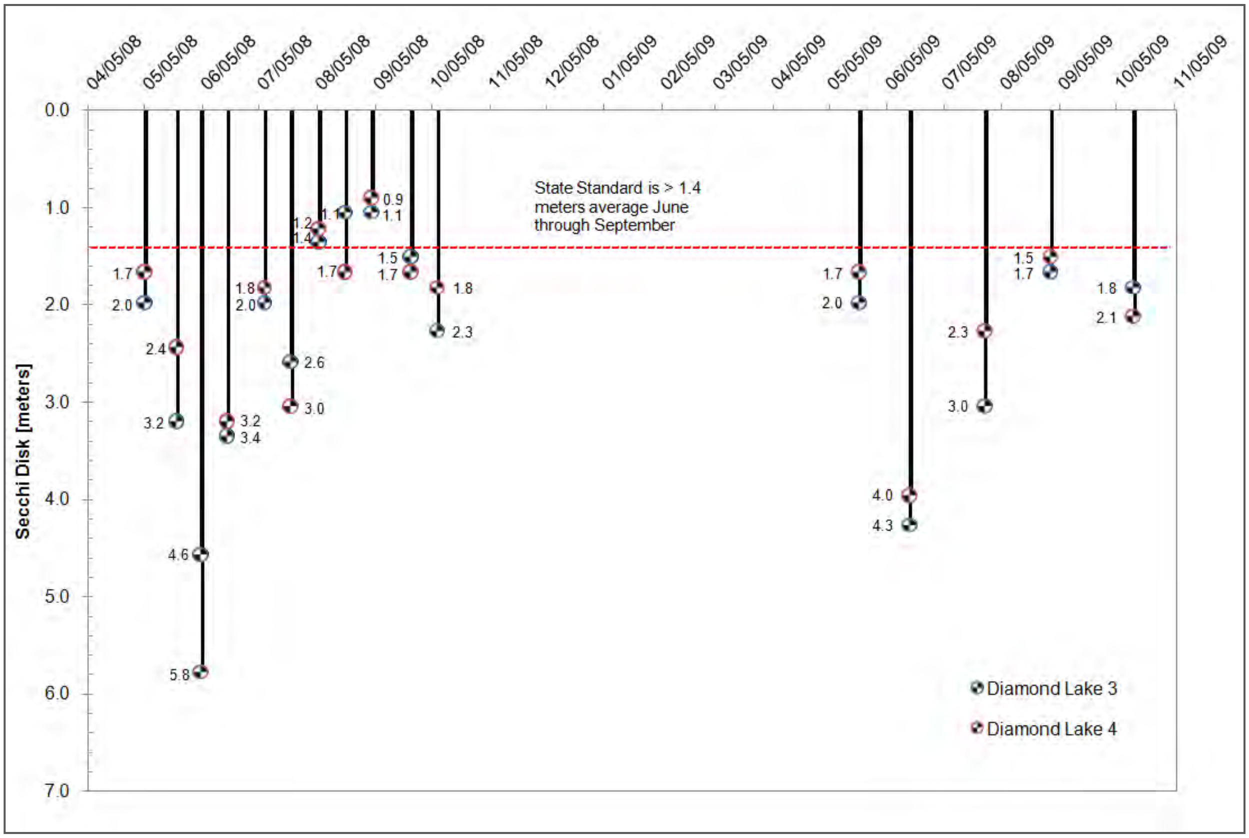


Figure 5-7 Diamond Lake mean Secchi disk measurements, 2008-2009.

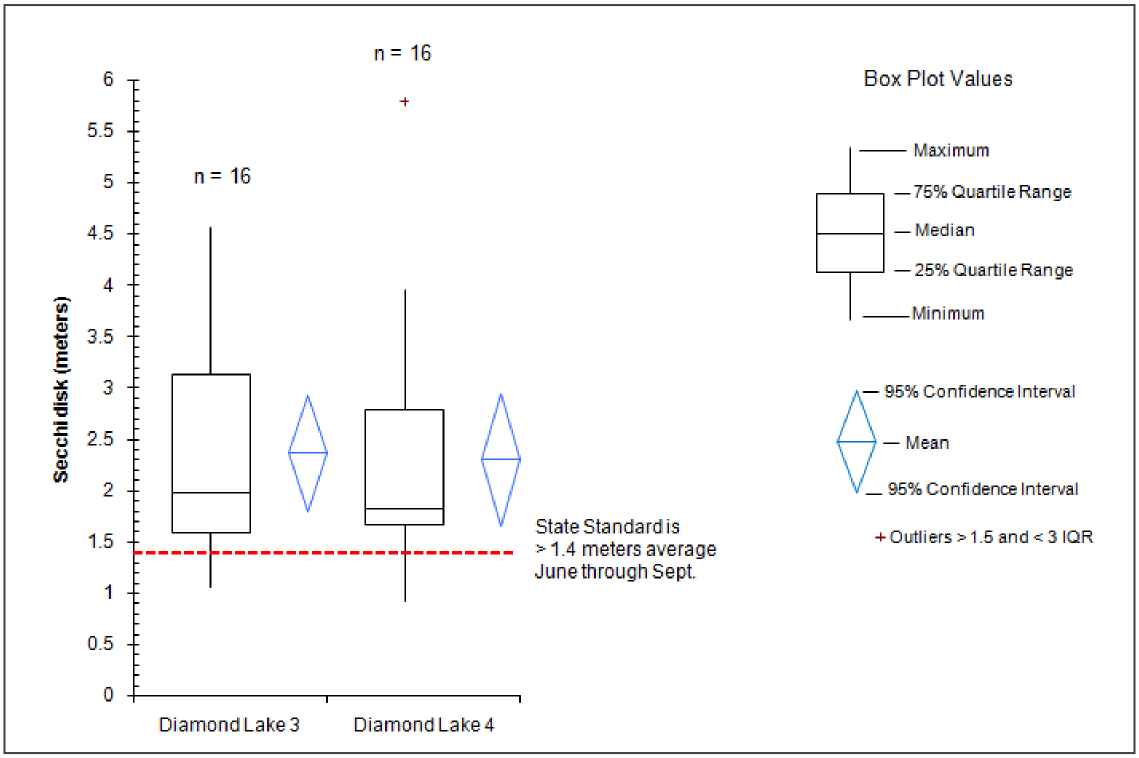


Figure 5-8 Surface mean Total Kjeldahl Nitrogen within Diamond Lake, 2008 – 2009.

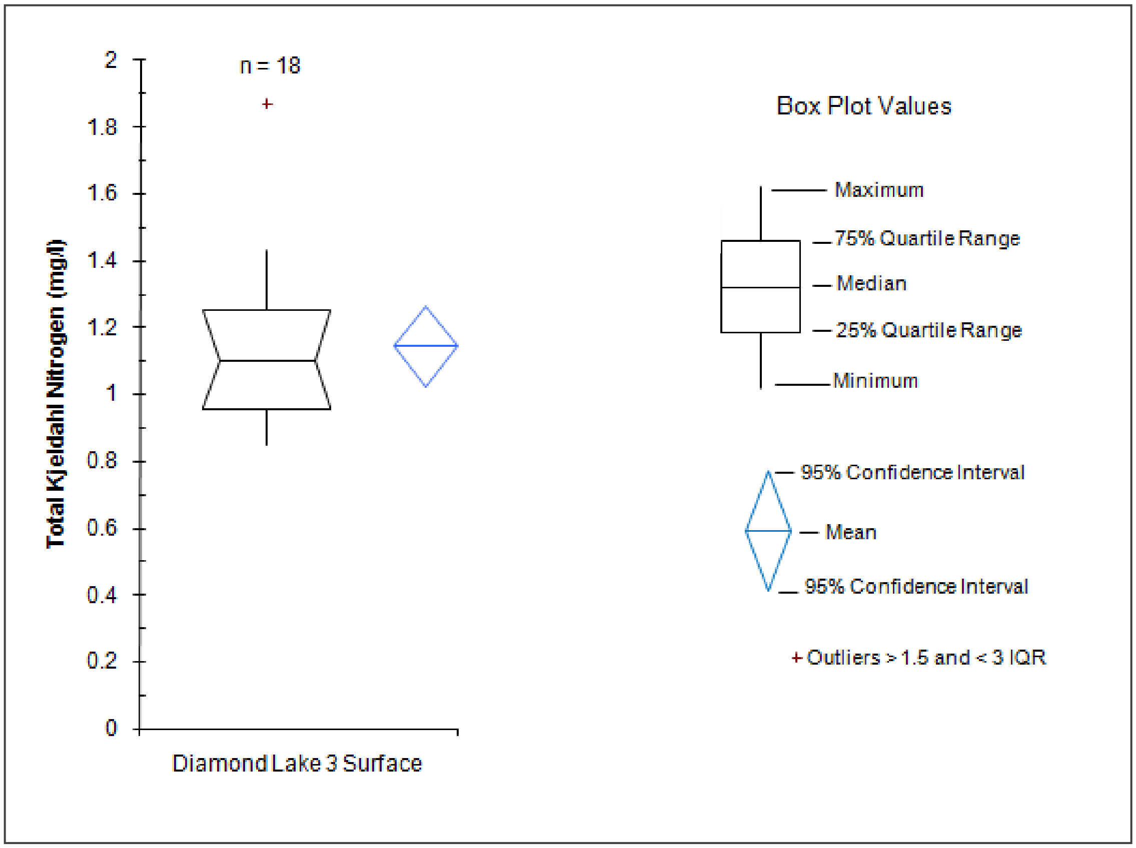


Figure 5-9 Total nitrogen to total phosphorus ratio time series, Diamond Lake, Site 3, 2008 – 2009.

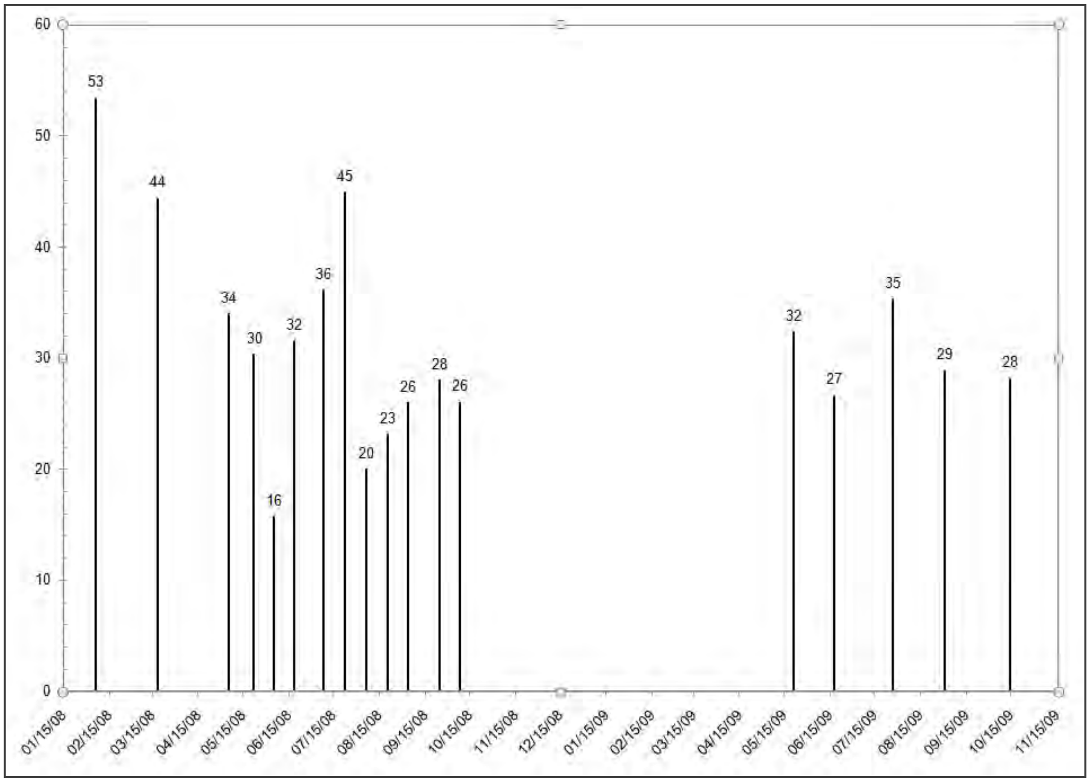


Figure 5-10 Relationship between paired total phosphorus and chlorophyll-a concentrations in Diamond Lake, 2008-2009.

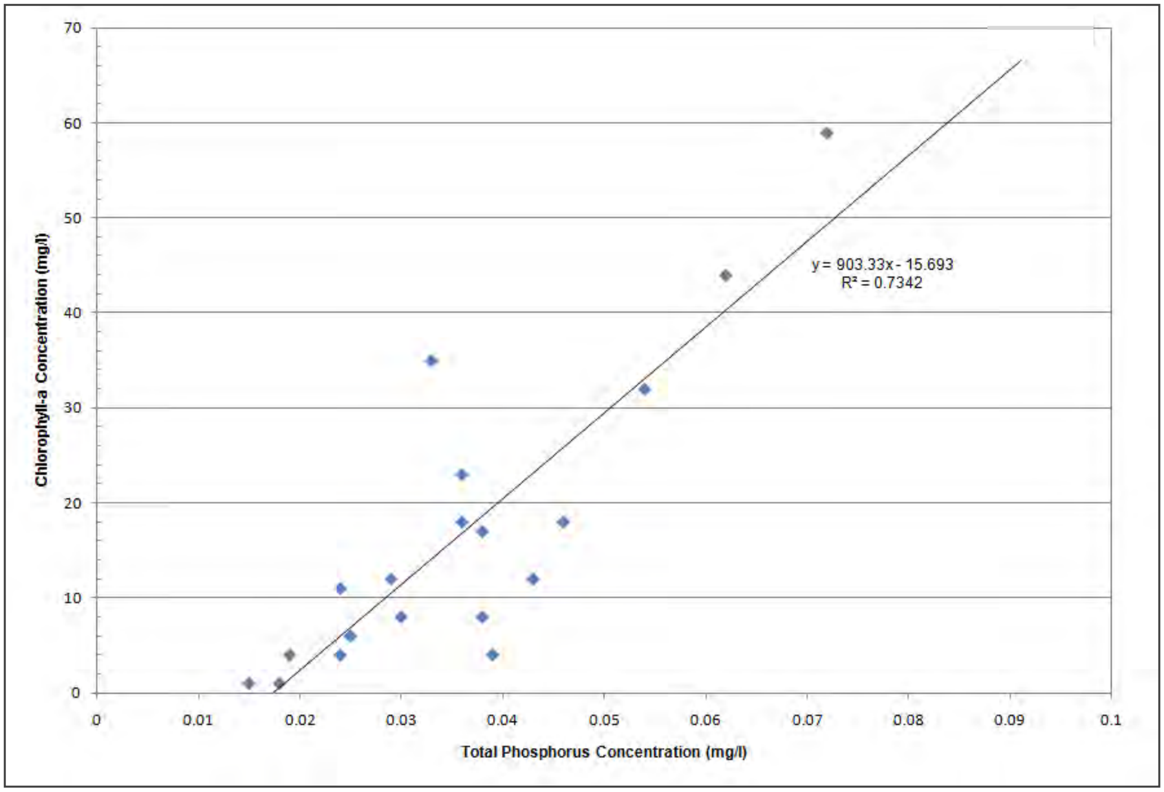


Figure 5-11 Relationship between paired total phosphorus and Secchi disk measurements in Diamond Lake, 2008-2009.

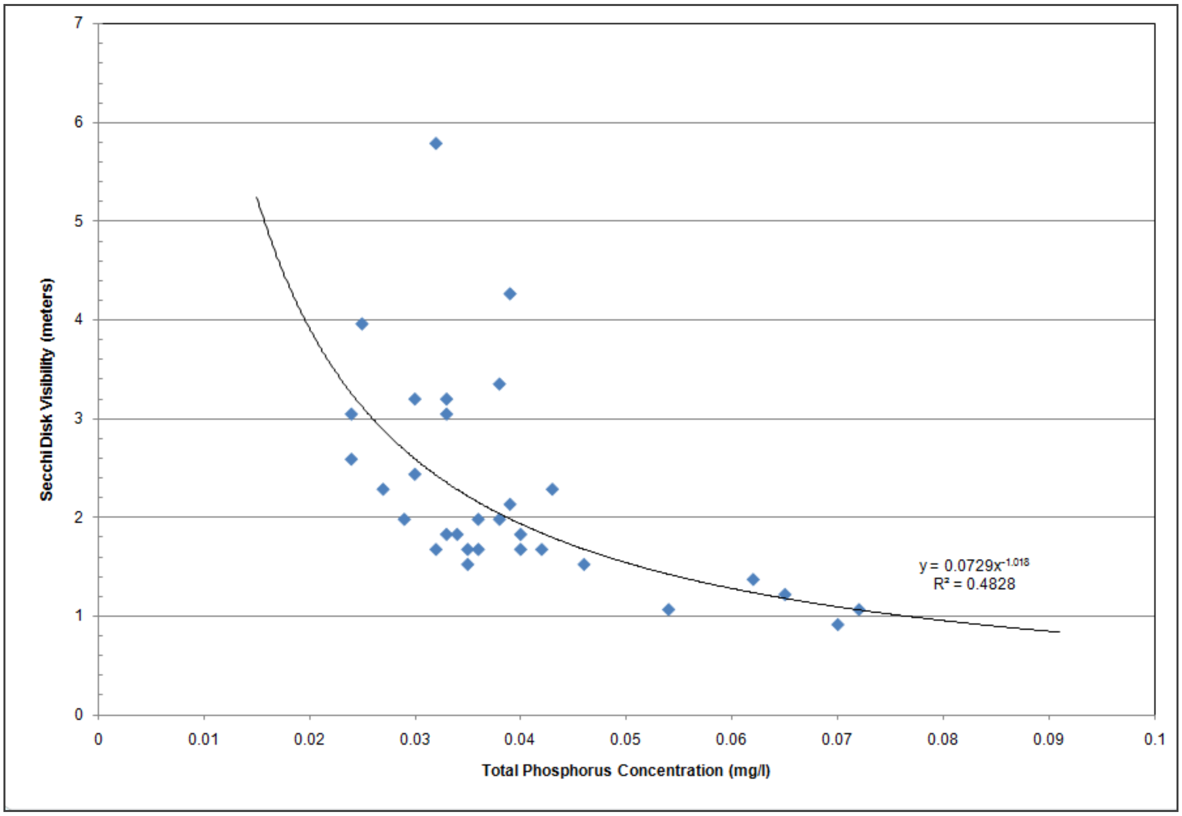


Figure 5-12 Relationship between paired chlorophyll-a concentrations and Secchi disk measurements in Diamond Lake, 2008-2009.

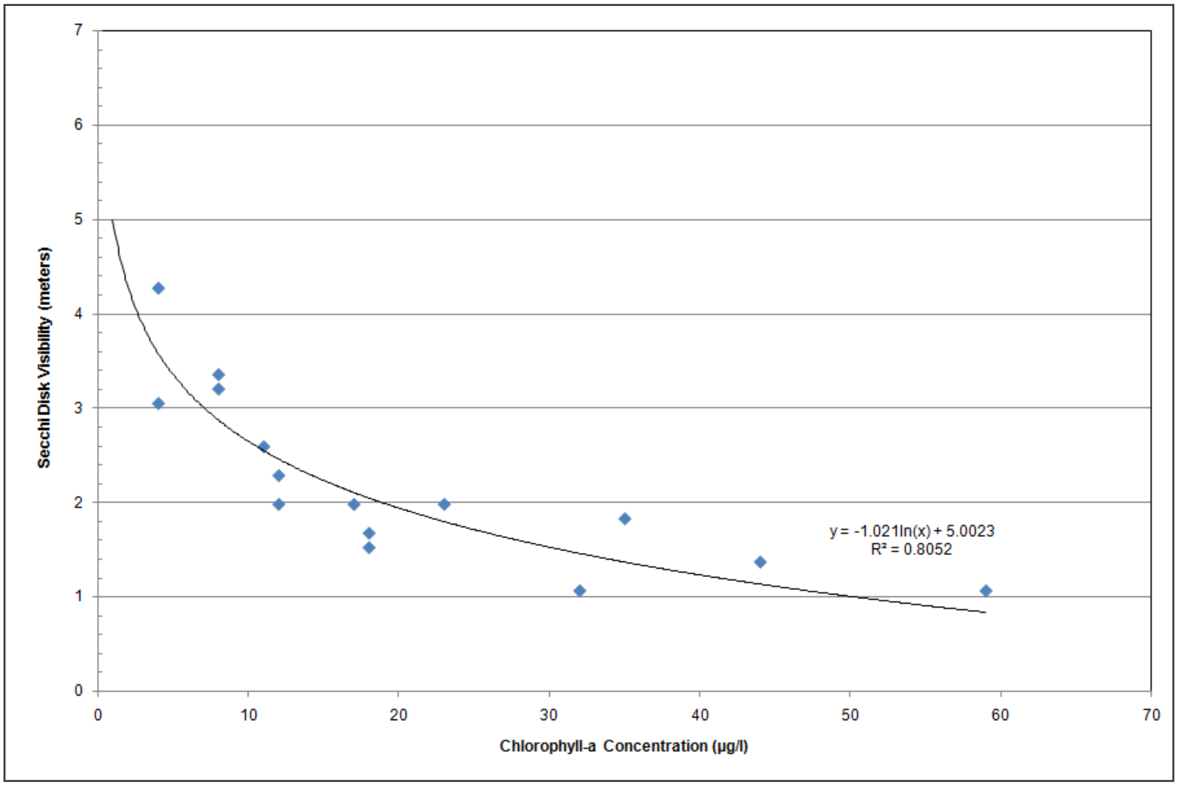
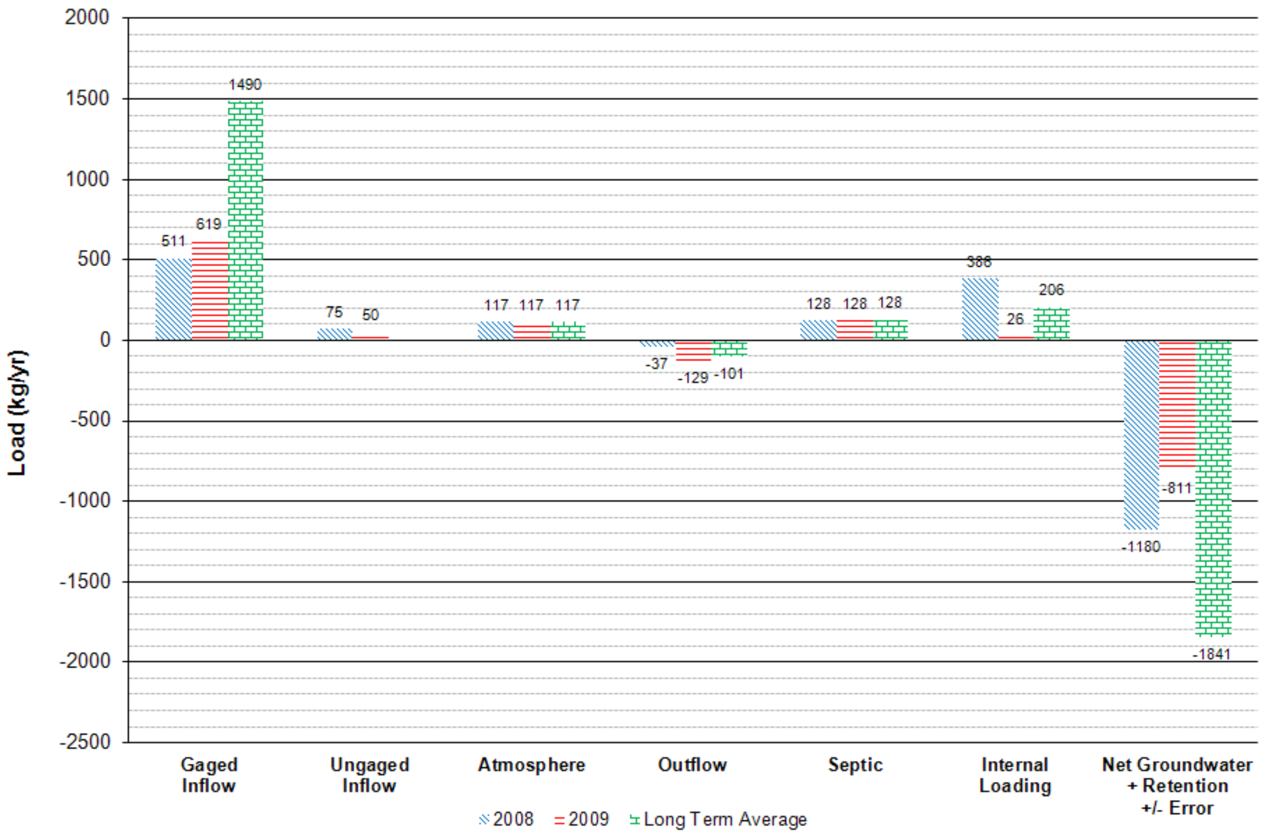


Figure 5-13 Diamond Lake total phosphorus budgets in 2008 and 2009 and long term average.



The load is the mass per unit time while the yield is defined as the load per unit drainage area. **Table 5-2** shows estimated loads and yields at the stream monitoring locations for 2008 and 2009. The streams characterized by monitoring locations Wheeler Lake (WL-2) and Hubbard Lake (HL-2) contribute considerable nutrient loads to the inflow of Diamond Lake (DL-1). However, the total phosphorus load actually increases through the upstream lakes (in 2009), prior to reaching DL-1, indicating they are a source of total phosphorus. The dissolved phosphorus load entering the upstream lakes and Diamond Lake at DL-1 are nearly equal in 2009. This implies the upstream lakes increase the amount of particulate phosphorus.

The annual loads entering Hubbard Lake and Wheeler Lake for nitrate plus nitrite nitrogen exceed the load measured downstream at the inflow to Diamond Lake. This suggests Hubbard Lake is effectively capturing dissolved nitrogen, most likely within plant material (as opposed to sedimentation) as these nutrients are dissolved. **Table 5-2** shows the yields from HL-2 and WL-2 are both elevated compared to the other monitoring locations with the exception of DL-1.

5.2 MODEL DEVELOPMENT AND APPLICATION

5.2.1 Goals and Technical Objectives

Developing written modeling goals and technical objectives should be a component of all projects that include modeling. In order to conduct a successful modeling effort, the modeling goals and technical objectives, must be clearly identified early in the process. The goals and technical objectives, should be memorialized in writing and shared with those parties with an interest in the project, to ensure the results generated, address the water quality issues of concern. The modeling goals and technical objectives establish the anticipated uses, technical methods and outcomes (i.e., products) of the model.

Modeling goals are general statements reflecting the “big picture” expectations or outcomes from the model development and application process. Technical objectives are specific to the water quality problem being addressed and should incorporate the applicable temporal and spatial scales to be addressed by the model (e.g., whether they are caused by some short-term episodic event or long-term conditions). For instance, a modeling goal would be to establish nutrient loads, and the load reductions needed, to achieve water quality numeric standards for a particular lake. The corresponding technical objectives may include assessing the eutrophication response of the lake at each lake inlet and outlet for the average monthly condition.

Water quality modeling goals should consist of a general statement explicitly identifying and describing the problems and issues to be resolved through the application of the model. The specific parameters to be modeled, temporal (time) and spatial scales which need to be generated by the model for these parameters and any additional descriptive information needed from the model (e.g., minimum values), should be described within the technical objectives.

Table 5-2 Estimated loads (lbs) and yields (lbs/acre) at stream monitoring locations, 2008 and 2009 (April - November).

	DL1 (2,258 acres)		DL2 (1,875 acres)		DL5 (83 acres)		DL7 (400 acres)		HL2 (299 acres)		WL2 (57 acres)	
	lbs	lbs/Acre	lbs	lbs/Acre	lbs	lbs/Acre	lbs	lbs/Acre	lbs	lbs/Acre	lbs	lbs/Acre
TP												
2008	954.4	0.14	80.5	0.00	54.2	0.02	117.3	0.05	394.2	0.15	--	--
2009	1222.7	0.17	283.7	0.01	65.0	0.03	77.8	0.04	464.3	0.17	372.6	0.23
Total	2177.0	0.31	364.2	0.02	119.3	0.05	195.1	0.09	858.5	0.32	372.6	0.23
DP												
2008	311.7	0.04	25.6	0.00	80.2	0.04	136.2	0.06	325.4	0.12	--	--
2009	403.4	0.06	90.2	0.00	79.8	0.04	90.4	0.04	393.1	0.14	14.6	0.01
Total	715.2	0.10	115.7	0.01	160.1	0.07	226.6	0.10	718.5	0.26	14.6	0.01
TSS												
2008	48128.4	6.88	11940.8	0.62	15956.9	7.07	8783.8	3.98	17835.4	6.57	--	--
2009	62286.3	8.90	41946.9	2.19	15852.6	7.02	5829.2	2.64	22766.9	8.39	101572.5	63.76
Total	110414.7	15.77	53887.7	2.81	31809.5	14.09	14613.0	6.63	40602.3	14.97	101572.5	63.76
TKN												
2008	9116.2	1.30			3641.1	1.61	1320.8	0.60	2526.0	0.93	--	--
2009	11798.1	1.69			3616.4	1.60	876.5	0.40	3224.2	1.19	5563.7	3.49
Total	20914.4	2.99			7257.5	3.21	2197.3	1.00	5750.3	2.12	5563.7	3.49
NO3												
2008	2749.6	0.39			130.1	0.06	5478.2	2.48	6219.0	2.29	--	--
2009	3632.1	0.52			850.3	0.38	3635.8	1.65	7946.0	2.93	988.3	0.62
Total	6381.7	0.91			980.4	0.43	9114.0	4.13	14165.0	5.22	988.3	0.62

Modeling goals and objectives likely differ depending upon the type of modeling being performed. The two primary types of water quality modeling, can broadly be categorized as watershed (i.e., landscape) and receiving water modeling. The water quality goals and technical objectives for this TMDL are shown in **Table 5-3** for the receiving water model and **Table 5-4** for the watershed model**.**

The Work Plan recommended the use of BATHTUB as the receiving water model and SWAT as the watershed loading model. The BATHTUB model is consistent with the receiving water model goals and technical objectives, although a spreadsheet version called CNET has been used to complete the receiving water modeling. The SWAT model provides an adequate level of detail needed to estimate watershed loads and runoff volumes.

5.2.2 Watershed Modeling

The purpose of this section is to describe the SWAT model that was created to estimate loadings from the Diamond Lake watershed and to simulate BMPs to quantify load reductions. Details of the model construction and calibration are contained in **Appendix C** in a Technical Memorandum prepared to communicate the details of this process. The reader is encouraged to reference that memo to gain an appreciation for the data used to develop the model and the decisions made during model calibration/validation.

Both the CNET and SWAT models were selected because of the ability to achieve the modeling goals and objectives described in **Table 5-3** and **Table 5-4** respectively. The annual average surface water runoff and total phosphorus load from the SWAT model was used as the surface water component in the CNET model of Diamond Lake. Inputs necessary to construct the SWAT model and develop the input parameters include a streams layer, land use / land cover, topography and soils. The data shown in **Figure 3-1** represent the wetlands, shallow lakes, streams and public drainage system network used to develop the routing within the SWAT model. Soils data were represented using the STATSGO soils. The most recent land use data were also used. The land use and soils data were used within SWAT to construct the Hydrologic Response Units (HRUs) which are the computational framework for computing runoff in the SWAT Model). Advantages of using the SWAT model are the ability to evaluate and estimate runoff and loads on a daily basis and to use the model to simulate long-term conditions.

The Diamond Lake watershed SWAT model was created to simulate hydrology and pollutant loadings for 30-years, from 1980 through 2009 (a 5-year “warm-up” period was also included from 1975 through 1979). Observed precipitation data from the Willmar, MN station was used to drive the model’s hydrology. The Diamond Lake SWAT model was calibrated and validated to the total seasonal streamflow volume, and total phosphorus loads observed during the 2008 and 2009 field seasons (and described in **Section 5**). Data from 2009 was used for model calibration; 2008 values were used for validation. In both cases, the calibration/validation focused only on the timeframe that observed data were actually available. For example, flows were collected at site DL-1 from March 16 – October 29 during the 2009 sampling season so modeled and observed flows were compared only during that time period at DL-1.

Table 5-3 Receiving Water Modeling Goals and Technical Objectives for the Diamond Lake TMDL.

Receiving Water Model Goals	Technical Objectives Corresponding to the Water Quality Goal
Assess and understand how the water clarity and amount and frequency of algal blooms respond to the quantity of nutrients entering and leaving the lake and evaluate potential strategies to improve water quality.	• Predict the growing season (or annual) mean concentrations of total phosphorus and chlorophyll-a and a measure of clarity (e.g., secchi disk depth) as a result of current total phosphorus, dissolved phosphorus, inorganic nitrogen and total nitrogen loads OR some measure of eutrophication (e.g., total phosphorus only). • Predict the depth and spatially averaged lake water quality conditions as characterized by the growing season (or annual) mean concentrations of total phosphorus and chlorophyll-a and a measure of water clarity (e.g., Secchi depth). • Explicitly identify and estimate the growing season (or annual) total phosphorus load delivered to and returned by the sediment interacting with the water column. • Characterize the change in the growing season (or annual) mean concentrations of total phosphorus and chlorophyll-a and a measure of clarity (e.g., Secchi depth) as a result of internal and external reductions in dissolved phosphorus, total phosphorus, inorganic nitrogen and total nitrogen OR some measure of eutrophication (e.g., total phosphorus only). • Statistically characterize the response of chlorophyll-a and a measure of clarity (e.g., Secchi depth) to the change in dissolved phosphorus and inorganic nitrogen concentrations OR some measure of eutrophication (e.g., total phosphorus only).

Table 5-4 Watershed Modeling Goals and Technical Objectives for the Diamond Lake TMDL.

Watershed Model Goal	Technical Objectives Corresponding to the Water Quality Goal
Quantify the amount of nutrients and sediment (or solids) leaving the landscape upstream of Diamond Lake and from areas directly contributing runoff to the lake and prioritize locations for implementing Best Management and agricultural conservation practices.	• Estimate the growing season and annual loads and yields of total phosphorus and total suspended solids leaving the landscape and delivered to Diamond Lake, for the long-term hydrologic conditions (e.g., 30-year period).
Assess the performance and removal efficiencies of water quality Best Management and agricultural conservation practices, reasonably expected to be implemented within the contributing drainage area.	• Estimate the growing season and annual average absolute (pounds) and percentage removals of total phosphorus and total suspended solids from BMPs including buffers, wetland restoration and tillage practices and similar practices. • Calibrate existing flow and water quality data at the corresponding nodes located within the model..

The model calibration also focused mainly on the sites in the eastern portion of the watershed; i.e., HL-2, WL-2, and DL-1. A secondary consideration was given to the data collected in the south and western areas at DL-5 and DL-7. Eastern sites were given priority since the majority of surface water and nutrients entering Diamond Lake during 2008 and 2009 came through that portion of the watershed. Calibration and validation results are therefore presented only for the eastern sites in this report. Results at all sites are presented in the modeling memo in **Appendix C**.

Table 5-5 and **Table 5-6** show the results of the streamflow and total phosphorus calibrations at HL-2, WL-2, and DL-1. The model simulated the total seasonal flow volumes at these locations within 7% of the observed values. The errors in simulating 2009 total phosphorus loads are greater, at up to 18%.

Table 5-5 Hydrology Calibration Results.

Site	2009 Field Season Total Observed Volume (m^3)	2009 Field Season Total Modeled Volume (m^3)	Absolute Error (m^3)	% Error
HL-2	848,183	790,980	-57,203	-6.74
DL-1	3,053,022	3,164,963	111,940	3.67

Table 5-6 Total Phosphorus Calibration Results.

Site	2009 Field Season Total Observed Load (lbs)	2009 Field Season Total Modeled Load (lbs)	Absolute Error (lbs)	% Error
HL-2	464	504	40	8.55
WL-2	373	440	67	18.03
DL-1	1,223	1,065	-158	-12.91

Table 5-7 and **Table 5-8** show the results of the model validation at HL-2 and DL-1 (data was not reliably collected at WL-2 in 2008 sufficient for validation). Errors during the validation period are significantly higher than those during calibration. These errors, however, may be influenced by the quality of the 2008 measured data. The 2008 season experienced considerable problems with equipment installation and operation, potentially impacting the accuracy of the monitoring results. Since 2009, data are considered more reliable, the value of the model's performance during the 2009 season is considered more important than the errors encountered during the 2008 season.

Once the SWAT model was calibrated and validated, the total annual flow volume and total phosphorus loadings to Diamond Lake (from tributaries and overland flow) were computed for the years 1980-2009. The 30 years of simulated annual values were then used in developing the average year water budget and mass balance to set the load allocations, as discussed in the following sections.

Table 5-7 Hydrology Validation Results.

Site	2008 Field Season Total Observed Volume (m^3)	2008 Field Season Total Modeled Volume (m^3)	Absolute Error (m^3)	% Error
HL-2	664,476	245,760	-418,716	-63.01
DL-1	2,305,711	976,555	-1,329,156	-57.65

Table 5-8 Total Phosphorus Validation Results.

Site	2008 Field Season Total Observed Load (lbs)	2008 Field Season Total Modeled Load (lbs)	Absolute Error (lbs)	% Error
HL-2	394	363	-32	-8.03
DL-1	954	283	-671	-70.36

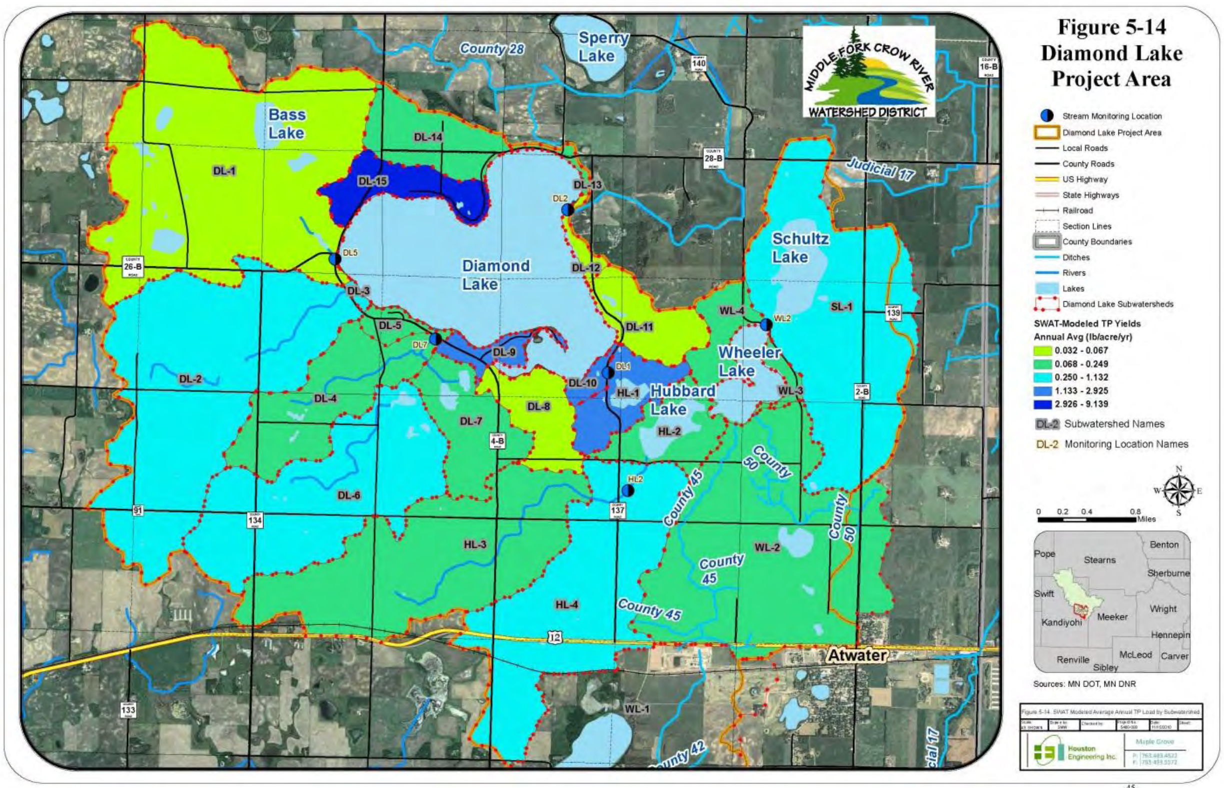
In addition to using the results of the SWAT model to estimate flow volumes and total phosphorus loads into Diamond Lake, the model outputs were also used to identify priority subwatersheds within the contributing area. **Figure 5-14** shows each subwatershed's estimated TP yields in pounds/acre/year. Results show that some areas immediately adjacent to the lake have high yields, while other high yield areas are in the upper watershed. This information can be used in siting BMPs and was taken into consideration when using the SWAT model to simulate the effectiveness of various BMPs, as discussed in Section 6.

5.2.3 Receiving Water Modeling

Based upon the modeling goals and technical objectives, the CNET model was selected for completing the eutrophication modeling. The CNET model is a modified version of the receiving water model BATHTUB (URL: http://wwwalker.net/bathtub/index.htm). CNET is a spreadsheet model currently available as a "beta" version from Dr. William W. Walker. The primary modification to the CNET model completed during this effort was to implement a Monte Carlo approach, which allowed selected modeling parameters and inputs to vary based upon estimated statistical distributions. The Monte Carlo approach generates a statistical distribution of the annual mean total phosphorus and chlorophyll-a concentrations and secchi disk visibility, reflecting the uncertainty in the model parameters and normal variability in inputs (e.g., annual total phosphorus load from surface runoff) as well as the correlation among inputs (e.g., runoff and load).

To complete the Monte Carlo modeling, the CNET model was linked with a program called Crystal Ball. Crystal Ball is proprietary software developed by Oracle (http://www.oracle.com/appserver/business-intelligence/crystalball/crystalball.html) and is applicable to Monte Carlo or "stochastic" simulation and analysis.

Figure 5-14 SWAT Modeled Average Annual TP Load by Subwatershed.



Stochastic modeling is an approach where model parameters and input values (e.g., internal load) used in the equations to compute the annual mean concentration of total phosphorus, chlorophyll-a, and secchi disk visibility, are allowed to vary according to their statistical distribution and therefore their probability of occurrence. This allows the affect of parameter uncertainty and normal variability in the inputs (e.g., amount of surface runoff and nutrient load, which vary annually depending upon the amount of precipitation) to be quantified when computing the annual mean concentration of total phosphorus, chlorophyll-a, and secchi disk visibility.

The Crystal Ball software allowed for multiple probabilistic model computations. Many trial values (10,000 trials in this study case) were generated with each trial representing a different combination of model parameters and input values within the bounds established by the statistical distribution.

The many trials resulted in a computed distribution of annual mean concentrations rather than a single, deterministic output that was based upon only one possible combination of model parameters and inputs. Select inputs, primarily those components of the water budget or total phosphorus mass balance, were allowed to vary during the Monte Carlo simulation (**Table 5-9**). Prior to completing the Monte Carlo modeling analysis, the Diamond Lake CNET model was calibrated using the annual water budget and TP mass balance for 2009 and validated using the annual water budget and total phosphorus mass balance for 2008. The following CNET models were used:

- Total phosphorus: Canfield & Bachman, Reservoirs + Lakes,
- Chlorophyll-*a*: P, Linear, and
- Secchi-disk Transparency: Carlson TSI, Lakes.

Table 5-10 shows the results of model calibration using the 2009 data. The total phosphorus calibration coefficient adjusted the model results to match the observed depth averaged annual mean total phosphorus concentration. **Table 5-11** shows the results of model validation using the 2008 data.

5.2.4 Modeling the Loading Capacity

The loading capacity is the maximum total phosphorus load, which can enter Diamond Lake, while still attaining the total phosphorus numeric standard. The loading capacity is normally based upon the long-term average hydrologic budget and total phosphorus mass balance, but ideally also reflects the range of hydrologic and total phosphorus load conditions. The loading capacity was established using the CNET model and based on the Monte Carlo simulation for an "average year" directly incorporating the variability in hydrologic and total phosphorus load, per MPCA guidance (MPCA 2007) for lakes with a hydraulic residence time exceeding 1 year. The estimated hydraulic residence time for Diamond Lake for an average year approaches 5 years. **Figure 5-2** and **Figure 5-13** show the annual mean values used in completing the loading capacity, and comprise the critical condition used to establish the TMDL equation. **Table 5-9** shows the values allowed to vary in the Monte Carlo simulation and the statistical distribution for each parameter allowed to vary within the model. Some terms used in the water budget and mass balance were developed from estimated values for the 2008 - 2009 monitoring period (e.g., internal loading). Because of the longer residence time, the loading capacity is based on the annual load values, consistent with MPCA guidance (MPCA 2007).

Table 5-9 Model Inputs Used in Monte Carlo Analysis.

Model Input	Statistical Distribution	Basis for Distribution	Distribution Truncated at Extreme Values?	Correlation	
				Considered?	Input Correlated With
Precipitation	Weibull	1980 – 2009 Willmar National Weather Service Station	Yes (low)	Yes	Evaporation (0.19) Surface runoff (0.74) Surface load (0.56)
Evaporation	Weibull	1991 – 2005; 2008 – 2009 computed	Yes (high)	Yes	Precipitation (0.19)
Atmospheric Load	Weibull	Distribution Assumed Same as Precipitation	No	No	Not applicable
Surface Water Runoff Volume	Lognormal	1975 – 2009 calibrated SWAT model	Yes (low)	Yes	Precipitation (0.74) Surface Load (0.89)
Surface Runoff Load	Triangular	1975 – 2009 calibrated SWAT model	No	Yes	Precipitation (0.56) Surface Runoff Volume (0.89)
Internal Load	Triangular	Developed from mean values for 30-lakes	No	No	Not applicable

Notes:

Distributions generally were best fit for 30-year period of annual values.
Correlation coefficients derived from actual data.
Atmospheric TP load distribution assumed to be same as precipitation with equal coefficient of variation.
Value in parentheses is correlation coefficient.
See **Appendix D** for the statistical distribution parameters.
Statistical distributions were the "best fit" distribution.

Table 5-10 CNET model calibration results for 2009 annual mean concentrations.

Parameter	Calibration Coefficient	Measured	Modeled	Absolute Difference	Percent Difference
Total Phosphorus	1.13	30 ug/l	30.1 ug/l	0.1 ug/l	< 1%
Chlorophyll-a	1.08	15.6 ug/l	15.6 ug/l	0.0 ug/l	< 1%
Secchi disk	1.05	2.44 meters	2.44 meters	0 meters	< 1%

Table 5-11 CNET model validation results for 2008 annual mean concentrations.

Parameter	Measured	Modeled	Absolute Difference	Percent Difference
Total Phosphorus	44 ug/l	35.8 ug/l	-8.2 ug/l	-18.6%
Chlorophyll-a	15.9 ug/l	18.4 ug/l	2.5 ug/l	15.7%
Secchi disk	2.33 meters	2.13 meters	-0.2 meters	-8.6%

5.3 Lake Eutrophication Response, Loading Capacity, and TMDL

5.3.1 Lake Response to Total Phosphorus Loads

Figures 5-15, 5-17, and **5-19** show the effects of reducing total phosphorus loads on the total phosphorus, chlorophyll-*a,* and secchi disk visibility means within Diamond Lake, based on the CNET model, for the average year. Loads reductions within the CNET model were applied using the following priority:

- Upstream lake restoration;
- Watershed load reduction; and
- Internal load reduction.

The intent is not to imply the actual implementation priority, but provide a sense of the maximum amount of total phosphorus load from each source, that will lead to attainment of the numeric standards. The magnitude of the load to attain the numeric standard is the important consideration.

Model results are presented both in terms of the annual mean concentrations as shown by the column graphs and the results of the Monte Carlo analysis. The Monte Carlo analysis results are presented as a series of lines, where each line represents a statistical distribution of the total phosphorus annual mean values (**Figure 5-16)**. Similar graphs are presented for chlorophyll-a, (**Figure 5-17** and **Figure 5-18**) and secchi disk visibility (**Figure 5-19** and **Figure 5-20**).

5.3.2 Loading Capacity, TMDL Equation, and Allocation of Loads

The loading capacity (i.e., the TMDL) is the maximum allowable TP load to Diamond Lake which can occur while still achieving the total phosphorus water quality numeric standard of the MPCA (40 ug/l),and a chlorophyll-a concentration less than 14 ug/l or a secchi clarity greater than 1.4 meters. Attaining a loading capacity will achieve the State's water quality standard. The loading capacity is comprised of the load allocation (LA), the wasteload allocation (WLA), and the Margin of Safety (MOS). The LA component of the loading capacity includes existing and future nonpoint sources; i.e., atmospheric deposition, internal load and nonpoint sources. Nonpoint sources are those sources, which do not require an NPDES (National Pollutant Discharge Elimination System) permit. The WLA component of the loading capacity

Figure 5-15 Annual Mean Total Phosphorus Concentrations corresponding to Various Total Phosphorus Load Scenarios

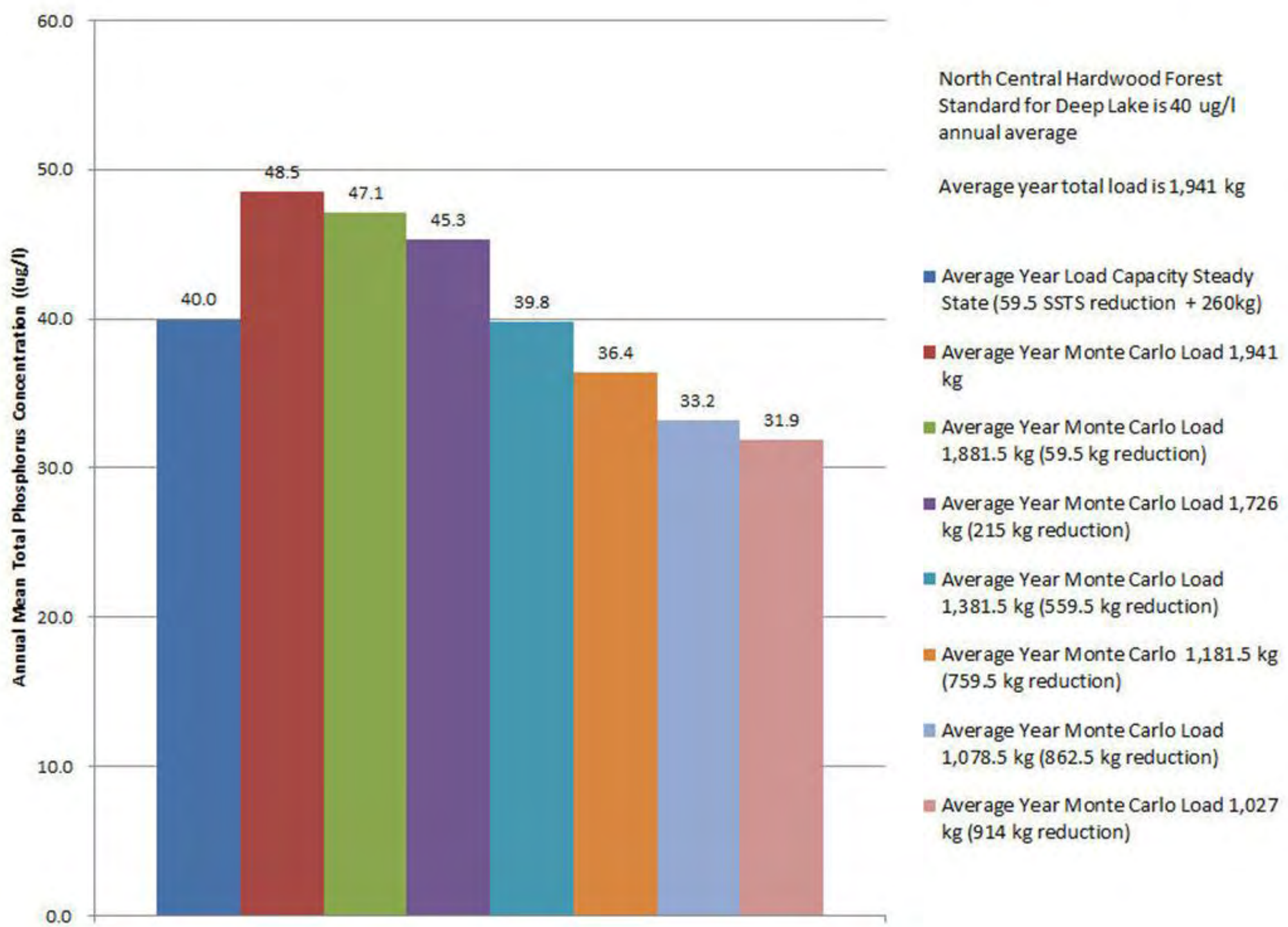


Figure 5-16 Frequency Distribution of Annual Mean Total Phosphorus Concentrations corresponding to Various Total Phosphorus Load Scenarios.

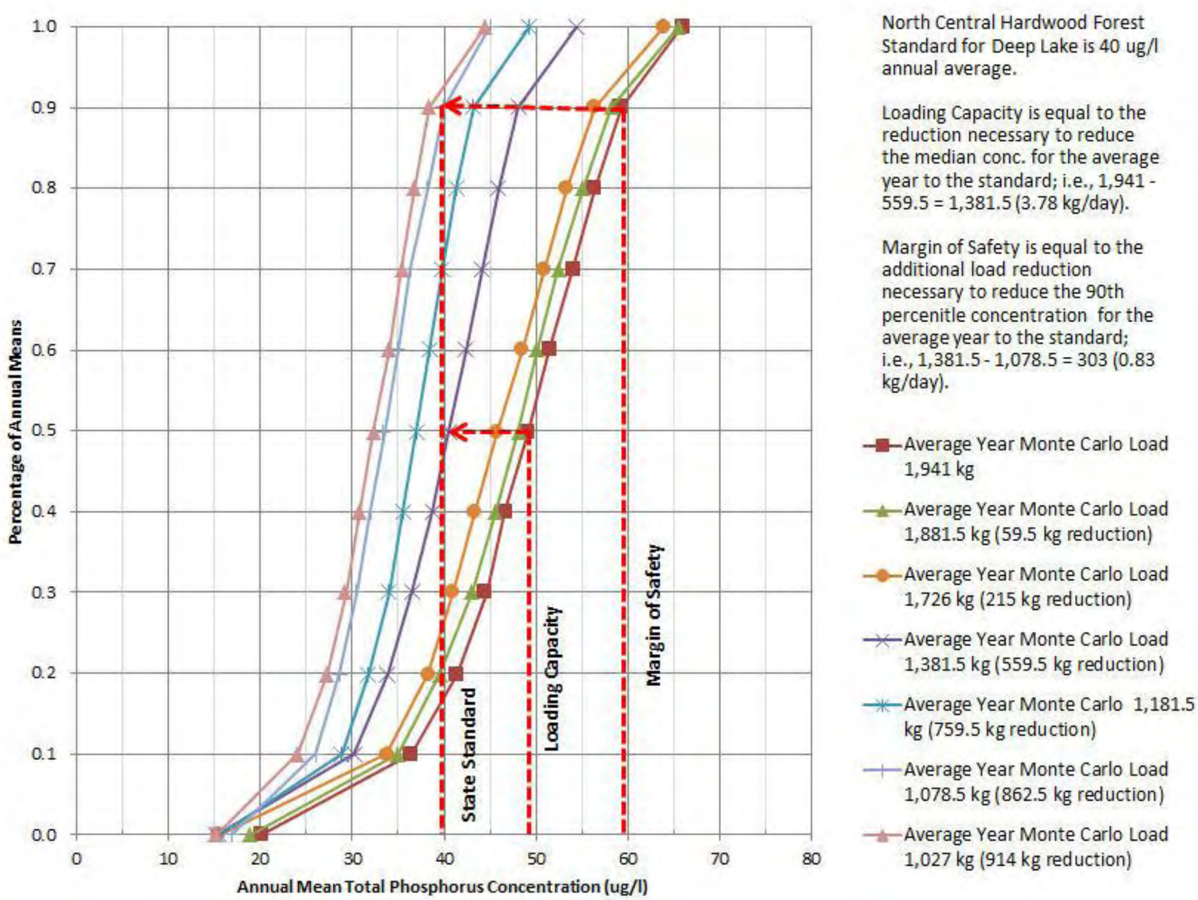


Figure 5-17 Annual Mean Chlorophyll-a Concentrations corresponding to Various Total Phosphorus Load Scenarios.

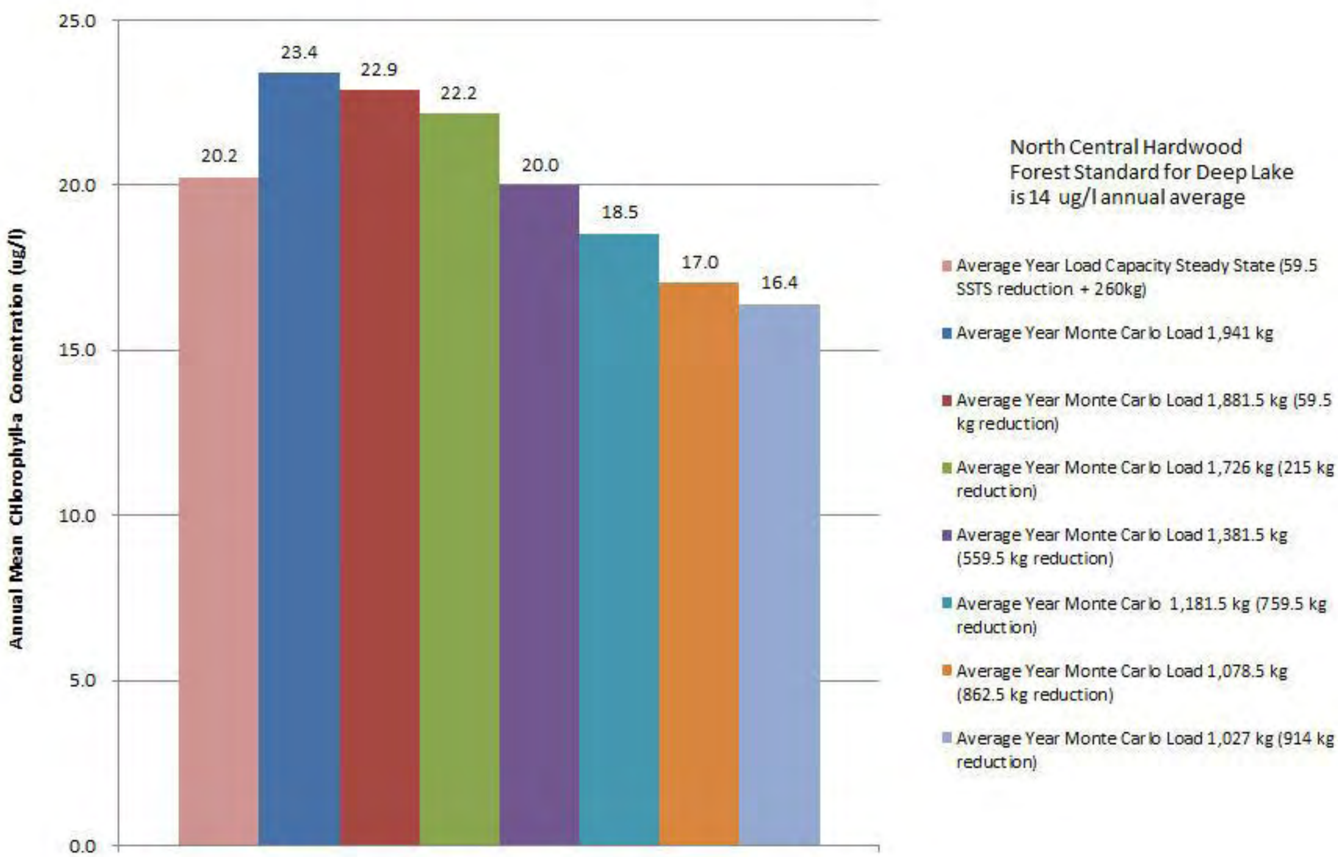


Figure 5-18 Frequency Distribution of Annual Mean Chlorophyll-a Concentrations corresponding to Various Total Phosphorus Load Scenarios.

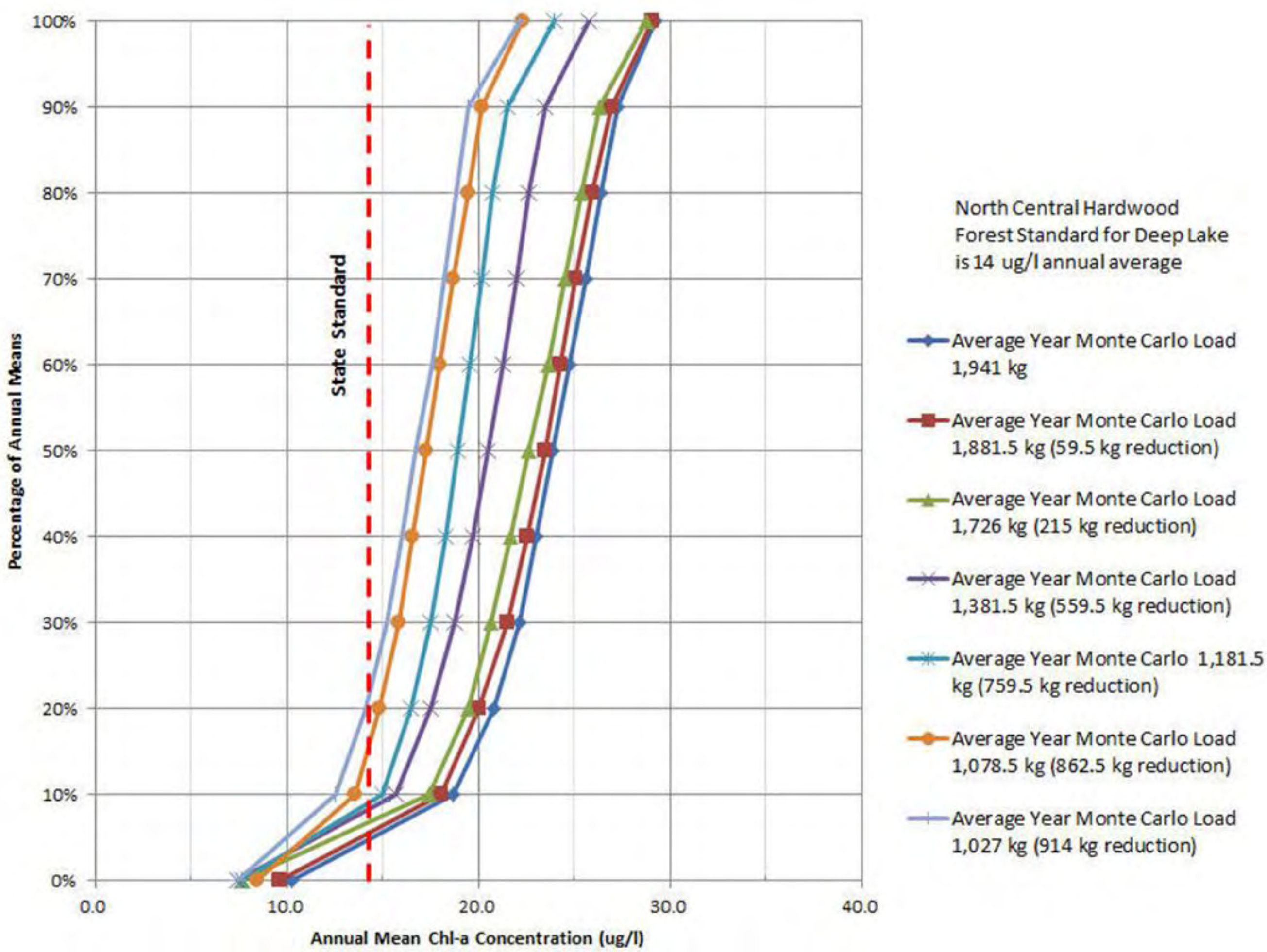


Figure 5-19 Annual Mean Secchi disk Visibility corresponding to Various Total Phosphorus Load Scenarios.

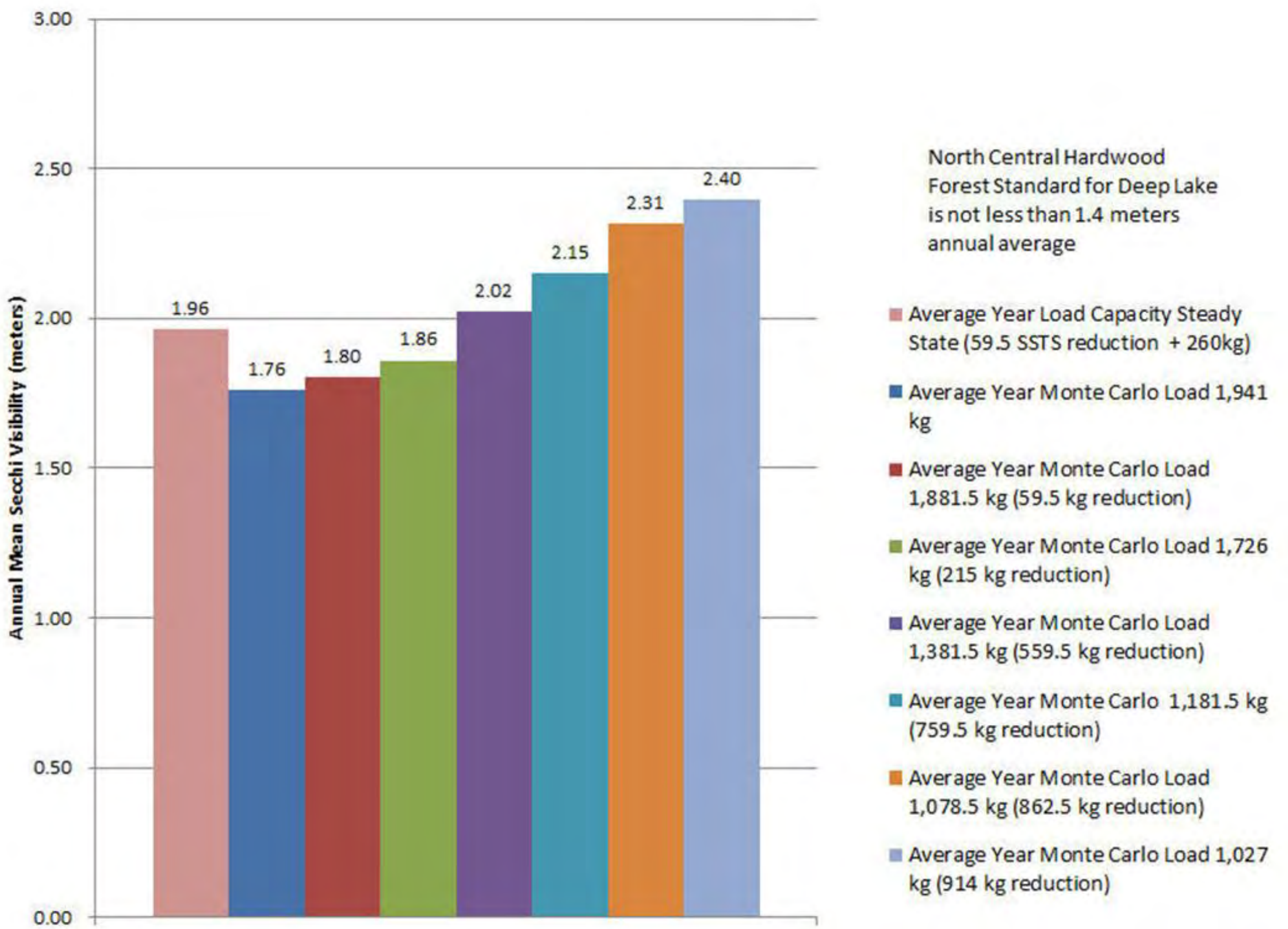
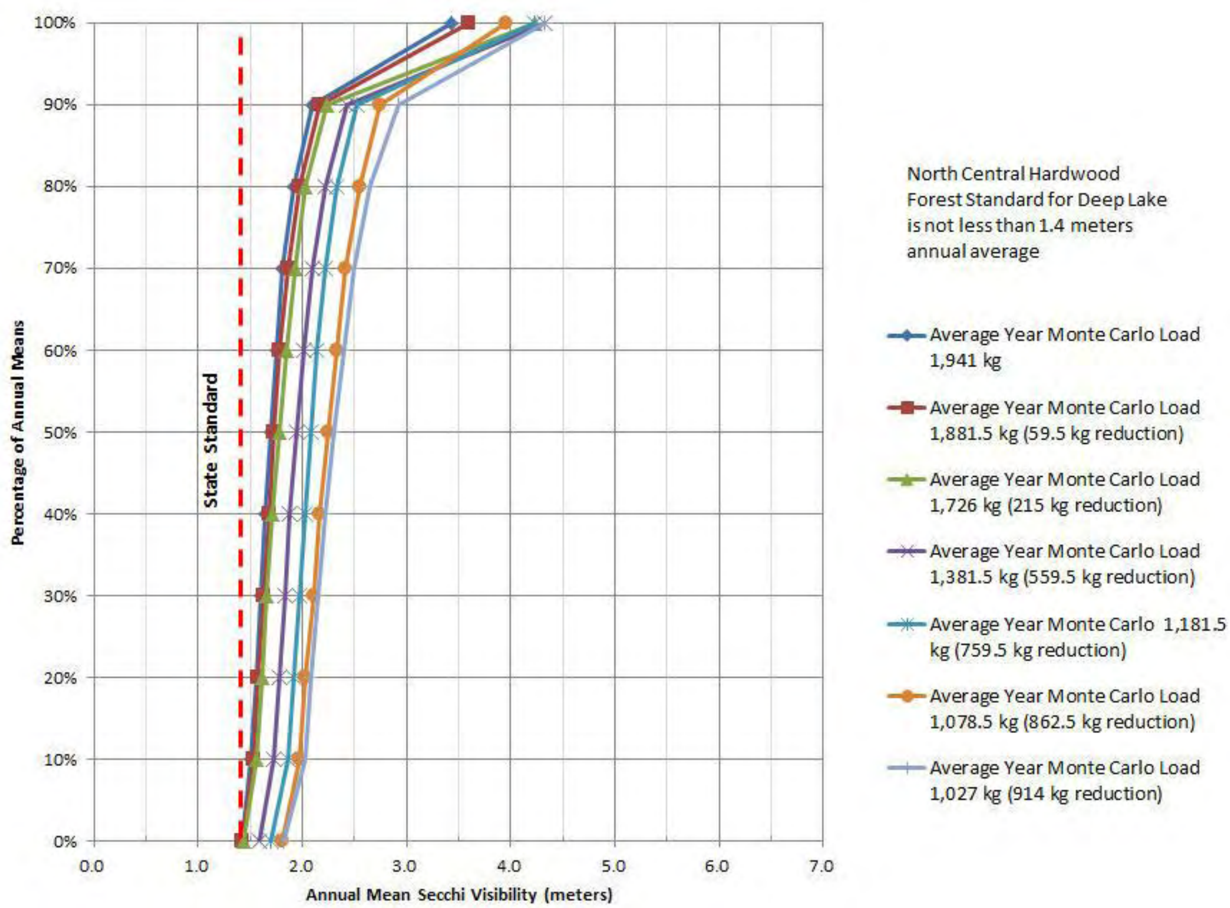


Figure 5-20 Frequency Distribution of Annual Mean Secchi disk Visibility corresponding to Various Total Phosphorus Load Scenarios.



encompasses those existing and future sources that are issued a NPDES permit, including a municipal separate storm sewer permit (i.e., for stormwater). The MOS may be implicit (i.e., conservative assumptions) or explicit (an expressed amount of load), but is intended to reflect the uncertainty in establishing the load capacity.

The loading capacity for this TMDL was established as the mass loading rate for the average year total phosphorus load (1,941 kg). The approach explicitly incorporates the expected variability in annual runoff and total phosphorus loads to Diamond Lake. The loading capacity is equal to the maximum total phosphorus load, which results in the reduction of the existing conditions median total phosphorus concentration being reduced to a concentration of 40 ug/l of total phosphorus (see **Figure 5-15**). The critical duration average annual water budget (see **Figure 5-2**) and total phosphorus mass balance (see **Figure 5-13**) are the starting point for establishing the loading capacity. The loading capacity is therefore 1,941 kg/year minus 559.5 kg/year equals 1,381.5 kg/year (or 3.78 kg/day) (see **Figure 5-15**). The annual load assigned to the Margin of Safety is the incremental additional load required to reduce the 90th percentile existing conditions total phosphorus concentration to a concentration of 40 ug/l total phosphorus. The MOS is therefore 1,381.5 kg/year minus 1,078.5 kg/year equals 303 kg/year (0.83 kg/day). Establishing the loading capacity in this manner ensures that the 1.4 meter Secchi disk value will be attained.

This approach is as protective of the resource as establishing the loading capacity based on the mean concentration (**Figure 5-16**). The 90th percentile non-exceedance annual mean concentration, is estimated using the results of the Monte Carlo analysis and reflects attaining the water quality standards 9 out of 10 years on average. Because it is nearly impossible to achieve 100% compliance with the standard 90% compliance was used to establish the Margin of Safety. The MOS was determined as the load reduction necessary to reduce the annual summer mean TP concentration from the Monte Carlo distribution to the MPCA numeric standard of 40 ug/l.

Figure 5-16 shows a line at 40 ug/l representing the average summer TP concentration eutrophication standard provided in MR 7050.0222, for the protection of lake quality in Class 2B surface waters in the North Central Hardwood Forest ecoregion. This line was used to determine the level of total phosphorus load (i.e., loading capacity) needed to achieve the desired quality (i.e., the numeric standard) within Diamond Lake. **Table 5-12** shows the loading capacity table in the form of the TMDL equation.

It is estimated that the current 5.3 kg/day phosphorus load to Diamond Lake would have to be reduced to 3.78 kg/day. A portion of the load allocation is comprised of both atmospheric and internal loading from the bottom sediments. The atmospheric loading cannot be controlled, so the reduction would need to come from other sources. **Table 5-13** shows the maximum load by source type corresponding to the loading capacity. The assumptions used to allocate the loads to the source type are described in Section 6.0, Implementation Plan Summary.

Figure 5-21 shows the probability distribution of the mean annual summer total phosphorus concentration for Diamond Lake.

Table 5-12 Diamond Lake Loading Capacity and TMDL Equation to Meet the MPCA Standard of 40 ug/l Total Phosphorus for average conditions. Values are in kilograms per day (Loading capacity rounded to nearest tenth).

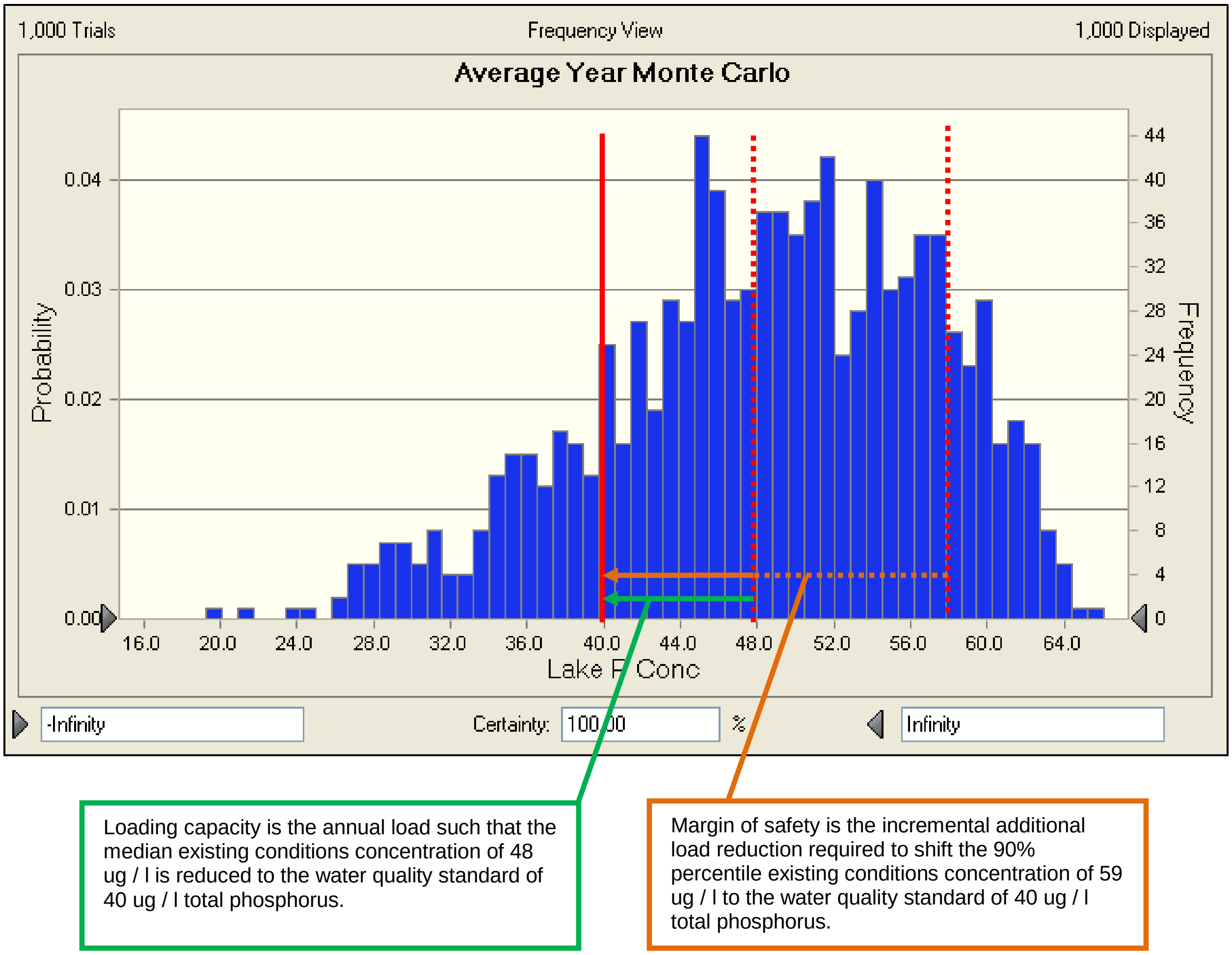
Condition	Loading Capacity kg/day (lbs./day)	=	Load Allocation kg/day (lbs./day)	+	Wasteload Allocation kg/day (lbs./day)	+	Margin of Safety kg/day (lbs./day)
Loading Capacity (LC)	3.785 (8.345)	=	2.955 (6.515)	+	0	+	0.83 (1.830)

Current load is 5.318 kg / day (11.724 lbs./day).

Table 5-13 Diamond Lake Annual Loading Capacity by Source to meet the MPCA Standard of 40 ug/l Total Phosphorus for average conditions. Values are in kilograms.

	Current Estimated Annual Load (kg/year)		**Allocated Load (kg)**		**Total Reduction Required (kg)**	
Source	**kg**	**kg/day**	**kg**	**kg/day**	**kg**	**kg/day**
Subsurface Treatment Systems	128	0.351	0	0.000	128	0.351
Upstream Lakes	311	0.852	155.5	0.426	155.5	0.426
Watershed	1179	3.230	703	1.926	476	1.304
Atmospheric Deposition	117	0.321	117	0.321	0	0.000
Internal Load	206	0.564	103	0.282	103	0.282
Total (kg)	1941	5.318	1078.5	2.955	862.5	2.363
Total (kg/day)	5.318		2.955		2.363	

Figure 5-21 Illustration Showing the Method Used to Establish the Loading Capacity and Margin of Safety Using the Monte Carlo Modeling Results.



The solid red vertical line shows the current annual mean of the total phosphorus concentration that occurs about 50% of the time and is close to the 40 ug/l standard. The furthest right dotted red vertical line shows the total concentration that would occur on average once every 10 years (the 90th percentile; about 60 ug/l). To achieve the 40 ug/l standard, the distribution needs to be shifted (orange arrow) so that the 40 ug/l goal is achieved 90% of the time. The margin of safety, the adjustment factor needed to ensure compliance with the standard, is shown with the green arrow in proportion to the load reduction.

5.3.3 Margin of Safety

A TMDL must include a margin of safety (MOS) to account for the uncertainty concerning the relationship between load and waste load allocations and water quality. The MOS may be implicit or explicit. An implicit MOS is incorporated into the TMDL through assumptions in the analysis. An explicit MOS is incorporated into the TMDL as loadings set aside for the MOS. If the MOS is implicit, the conservative assumptions in the analysis that account for the MOS must be described. If the MOS is explicit, the loading set aside for the MOS must be identified.

The basic purpose of the MOS component of the TMDL equation is to estimate uncertainty to allow the project a reasonably high likelihood of success (e.g. probability of success). As such, MOS encompasses two primary factors affecting these outcomes: variability and uncertainty. “Variability” refers to the fluctuations in measured values for a given parameter over a lake (spatially) as well as by time - such as within year (seasonal) and year-to-year changes (induced by climatic conditions and biological response). “Uncertainty” refers to prediction error resulting from limits in the data and predictive models.

This TMDL incorporates an explicit Margin of Safety. Specific assumptions related to annual variability as well as the uncertainty in the amount of precipitation, evaporation, surface water runoff, atmospheric load, internal load and surface runoff load, are incorporated into the Monte Carlo modeling analysis. **Table 5-9** and **Appendix D** describe these assumptions. Using the difference in loads between the 90^{th} and 50^{th} percentile values (to achieve 40 ug/l) to establish the MOS, ensures a reasonably high likelihood of success, defined as achieving the numeric standard.

5.3.4 Reserve Capacity

Reserve Capacity is that portion of the TMDL that accommodates future loads. The reserve capacity can be ascribed singly to the WLA, the LA, or both; e.g. new and expanding WWTF’s, MS4s that will be covered by a permit in the future or that are permitted now and may expand, and/or land use changes. If an allocation for reserve capacity is not included, either no new future loads are anticipated or allowed, or increased loads must be accommodated by pollutant trading. A typical 20-year planning timeline for consideration of reserve capacity is recommended.

No reserve capacity is included in the TMDL equation. The reason is that point source discharges are absent within the contributing drainage area. Land use within the next 20-year period is expected to remain largely unchanged from the currently predominant agricultural use. The lack of establishing a reserve capacity for the TMDL means that all of the load is allocated. Any future additional load will have to be offset by an equivalent reduction from an existing source.

5.3.5 Seasonal Variation

The TMDL needs to provide an explanation of why the TMDL, when implemented, will be protective during all seasons. For example, a lake nutrient TMDL expressed as an annual load and developed to be protective of the most sensitive time of year will ensure attainment with water quality standards during all seasons. The need for establishing the TMDL seasonally depends in part upon the hydraulic residence time, which, for Diamond Lake is estimated at nearly 5 years. For lake and reservoir systems with a short hydraulic residence time (generally less than 1 year) the eutrophication response can also be short; i.e., less than one year and at the growing season temporal scale. The residence time for Diamond Lake is reasonably long and the eutrophication response occurs over longer time period. The standard is based on the average conditions for the growing season but in the case of Diamond Lake, the growing season response is driven by the long-term average condition (because of the longer residence time). The seasonal variability of the lake response is explicitly incorporated into the Monte Carlo modeling method.

5.3.6 Reasonable Assurances

When a TMDL is developed for waters impaired by point sources only, the issuance of a National Pollutant Discharge Elimination System (NPDES) permit(s) provides the reasonable assurance that the wasteload allocations contained in the TMDL will be achieved. When a TMDL is developed for waters impaired by both point and nonpoint sources and the WLA is based on an assumption that nonpoint source load reductions will occur, EPA's 1991 TMDL Guidance states, that the TMDL should provide reasonable assurances that nonpoint source control measures will achieve expected load reductions in order for the TMDL to be approvable. Although EPA does not require reasonable assurances when the loading capacity is attributed only to nonpoint sources (LA), the MPCA requires a description of reasonable assurances. Reasonable assurances in these types of TMDLs allow the MPCA to evaluate the potential options available to enable reductions from nonpoint sources.

The implementation of this TMDL is reasonably assured for several reasons. Upon approval of the TMDL by the EPA, the MFCRWD, a local unit of government guided by a state Board of Water and Soil Resources (BWSR) approved Watershed Management Plan (WMP), will incorporate the various implementation activities described by this TMDL into the WMP. The MFCRWD also has the ability to generate revenue and receive grants to finance the implementation items. The MFCRWD is committed to taking a lead role during the implementation of this TMDL.

SECTION 6.0
IMPLEMENTATION PLAN SUMMARY

6.1 General Description of Possible Implementation Activities

The TMDL implementation plan focuses on reducing both external watershed and internal in-lake sources of total phosphorus. An estimated 561.3 kilogram annual total phosphorus load reduction (1.5 kg/day) is needed to attain the loading capacity of 1,387 kg/year (3.8 kg/day) to achieve the 40 ug/L annual average total phosphorus water quality standard (see **Section 5.3.2**). Portions of the loading capacity have been allocated to external watershed and internal in-lake sources (both are part of the non-point source load allocation). The external watershed sources include Subsurface Sewage Treatment Systems (SSTS). The amount of load allocated to each nonpoint source is based in part on the technical feasibility of the probable implementation measures necessary (discussion follows) to achieve the reduction as follows. Implementation priorities are qualitatively ranked as high, moderate and low, reflecting the probable implementation order (i.e., implement high priority activities preferentially).

Implementation activities can occur concurrently or in a sequential manner depending on the availability of funding and the willingness of potential participants. A minimum of 10 years is expected to implement the activities required to achieve the maximum allocated loads and the loading capacity. This section generally describes the range of implementation measures considered to achieve the allocated load by type of source and specifically identifies the proposed implementation activities.

6.1.1 Watershed (External) Sources

Three primary watershed sources of total phosphorus to Diamond Lake have been identified that can be controlled to attain the loading capacity and achieve the water quality numeric standards for total phosphorus, cholorophyll-a, and secchi disk visibility. The following section generally discusses the implementation activities for watershed sources followed by specific implementation recommendations.

6.1.1.1 Subsurface Sewage Treatment Systems (SSTS)

SSTS's can directly or indirectly affect the quality of Diamond Lake via subsurface flows, if the systems are aged and failing (meaning it is leaking), have inadequate separation between the treatment systems and the underlying groundwater and are located within soils such that the leachate can move horizontally toward and reach Diamond Lake. The seasonal and year-round residences surrounding Diamond Lake are currently served by Subsurface Sewage Treatment Systems (SSTS) (a.k.a. septic systems). The area surrounding Diamond Lake is developed with 365 permanent and seasonal residences and nearly the entire shoreline is in residential land use. At least 70% of the permanent and seasonal residences were built prior to 1996 and therefore, may have inadequate separation of the SSTS with the seasonal high water table. The lack of separation is one indication of inadequate design and treatment.

Information about SSTSs came from a 2008 study completed by Wenck Associates (Wenck, 2008). The information used from this study included the number of structures located on the lake and the percentage believed to comply with Minnesota standards for design. Those failing to achieve the design standards are considered as potentially failing and contributing total phosphorus to Diamond Lake. Based upon a review of the SSURGO soils, one-half of the residences on Diamond Lake served by an SSTS and not meeting the current design standards, were considered failing and contributing nutrients to Diamond Lake, when constructing the total phosphorus mass balance. (Note: approximately one-half of the soils around Diamond Lake are of a nature that the movement of SSTS leachate has a low probability of reaching Diamond Lake, consisting predominately of clays.) An estimated 128 kg of total phosphorus annually reaches Diamond Lake because of failing septic systems. This equates to 11% and 14% of the total phosphorus entering Diamond Lake in 2008 and 2009, respectively.

Three alternatives for addressing SSTSs were evaluated in the report by Wenck (2008):

1. Managed SSTS program;
2. Cluster systems for each service area; and
3. Connect to the Green Lake Sanitary Sewer District (GLSSD) for the entire Study Area and a subset of Study Area.

Table 6-1 provides the probable cost for various alternatives to address SSTSs serving residences around Diamond Lake.

Table 6-1 Opinion of probable construction cost for addressing Diamond Lake SSTSs.

	Option 1 Managed SSTS Program	Option 2 Cluster Treatment Systems	Option 3 Connect to GLSSD[1]
Total Assessed System Costs	$ 3,536,000	$ 5,592,000	$ 6,941,000
Average Cost/Unit	$ 10,000	$ 16,000	$ 18,700

[1]Does not include trunk costs carried by the County

Residents elected to proceed with Option 3. Present estimates are that 170 of the 365 residences will be connected to the GLSSD. The estimated load reduction associated with connecting these residences to the regional system (again assuming a 70% failure rate and that one-half of those that fail have soil conditions which allow an actual contribution to the lake) is 59.5 kilograms.

6.1.1.2 Upstream Lake Management

Schultz, Wheeler, and Hubbard lakes, are upstream shallow lakes / wetlands that following current conventional scientific thinking should reduce the amount of total phosphorus load to Diamond Lake when in the clear state, thereby serving as a phosphorus sink. **Table 5-2** shows the loads and yields of TP contributed by monitored tributaries to Diamond Lake. The data contained within **Table 5-2** suggest an increase in the total phosphorus load moving downstream through Wheeler Lake and Hubbard Lake into Diamond Lake. Only the 2009 monitoring data are adequate to estimate the change in load through the upstream lakes. The long term data suggest an increase in the annual total phosphorus load through the upstream lakes of 500 kg.

An estimated 48% (433 kg) and 71% (555 kg) of the total phosphorus entering Diamond Lake from ***all*** sources in 2008 and 2009 came through the primary inflow to Diamond Lake (i.e., the DL-1 monitoring location). An estimated 74% (433 kg) and 83% (555 kg) of the total phosphorus entering Diamond Lake from surface runoff in 2008 and 2009, respectively, came through the DL-1 monitoring location from the upstream lakes. The SWAT model estimated 500 kg annually through DL-1.

Monitoring data show that the upstream shallow lakes (wetlands) have elevated turbidity (**Appendix A)**. Observations during monitoring confirm that the elevated turbidity is most likely the result of a large carp population. Carp have the ability to stir up sediments and disturb vegetation, mobilizing phosphorus that otherwise could be retained in the bottom sediments of the shallow lakes. Essentially no information about the density of the carp population is available. It is known that carp winter killed (i.e. suffered a die off) within Wheeler Lake during the winter of 2009. It is also known that controlling rough fish like carp has the ability to alter the state of a shallow lake from turbid to clear.

These upstream lakes are in a turbid state and conversion to the clear state has considerable potential for improving not only the water quality of the upstream lakes, but the water quality of Diamond Lake. Available water quality data from Lake Christina in central Minnesota shows that total phosphorus and chlorophyll-a concentrations can be reduced dramatically, by maintaining a shallow lake in the clear state compared to the turbid state. Average annual total phosphorus concentrations within Lake Christina are near 100 ug/l when in the turbid state, compared to near 40 ug/l when in clear state (a reduction of 2.5 times). Average annual total chlorophyll-a concentrations are near 50 ug/l when in the turbid state, compared to near 10 ug/l when in the clear state (a reduction of 5 times). For planning purposes the conversion of Hubbard and Wheeler lakes to the clear state from the current state is assumed to reduce average annual total phosphorus and cholorphyll-a concentrations by 2 and 4 times respectively.

6.1.1.3 Surface Inflow

Agricultural Conservation Practices

Surface inflow or surface water runoff from the surrounding watershed from agricultural lands is a source of total phosphorus. The estimated loads from gaged and ungaged surface inflow to Diamond Lake are 586 kg per year (48%) and 669 kg per year (71%), for 2008 and 2009 respectively.

A broad range of Agricultural Conservation Practices (ACPs) can potentially be used to reduce the amount of phosphorus entering Diamond Lake. The costs for the ACPs vary and some have limited applicability. ACPs can often be used in combination to gain the greatest benefit. A recent report by the Natural Resource Conservation Service (NRCS) (USDA-NRCS, 2010), http://www.nrcs.usda.gov/technical/nri/ceap/umrb/index.html suggests that combinations of ACPs often provide the most effective means of reducing soil loss and nutrients to downstream areas. One of the most challenging aspects of installing ACPs is getting support and commitment of local landowners and other stakeholders. Education and financial support often are needed to initiate and maintain a long-term commitment to ACP implementation and function. Local organizations including the MFCRWD and the Kandiyohi County Soil & Water Conservation District are important in providing the education and support needed to establish ACPs wherever possible and effective.

Table 6-2 identifies a range of potential ACPs suggested by the Minnesota office of the NRCS for agricultural lands. The table also provides estimates of the 2009 probable installation costs by the type of ACP. The costs for the same practice can vary considerably depending upon the cost of land and site, specific design and implementation considerations. Operation, maintenance, and forgone income previously provided by harvested crops, are not included in the probable installation cost.

Considering the current physical characteristics of the landscape contributing runoff to Diamond Lake (see **Section 3.0**, Description of the Watershed), certain ACPs seem more logical for implementation based on wind and water erosion rates, the slope of the land surface, and the locations of potential storage areas. These ACPs are:

- Filter strips adjacent to waterways;
- Wetland restorations;
- Temporary storage of water adjacent to drainage systems and waterways; and
- Residue and tillage management.

The maps contained within **Section 3.0**, provide information about soil erosivity from wind and water, the location of drained wetlands, and the locations of watercourses and public drainage systems, can be used to prioritize the locations of these ACPs for implementation. Information derived from the watershed source assessment can also be used to prioritize potential implementation areas (see **Section 3.0**).

Table 6-3 summarizes the estimated range of removal efficiencies for sediment and total phosphorus for these ACPs. This range has been used to identify the probable reduction associated with the various implementation strategies in Section 6.2 Implementation Plan.

Urban Best Management Practices

Because of the largely rural nature of the Diamond Lake watershed, there is little opportunity for the use of Best Management Practices, typically used within urbanized areas. These BMPs can include rain gardens, infiltration trenches, porous pavers, biofiltration swales, wet and dry detention ponds, and similar BMPs. There is an opportunity however, for residents on the lake to improve water quality. The BMPs applicable to lake residents include the use of no-phosphorus fertilizers and establishing native planting / buffer strips adjacent to the

Table 6-2 NRCS Suggested Agricultural Conservation Practices and Associated Costs - 2009.

Practice/Activity Name	Practice/Activity Type	Unit Type	Total Cost
Conservation Crop Rotation	Annual Crops to 2 Years with Cover	Acre	$11.61
Conservation Crop Rotation	Annual Crops to 2 Years with Cover - Organic	Acre	$15.48
Conservation Crop Rotation	Low Residue Crops to High Residue Crop Rotation	Acre	$15.48
Filter Strip	Single Species Introduced or Native Grass	Acre	$127.09
Filter Strip	Introduced Grasses and Legumes	Acre	$99.35
Filter Strip	Mixed Native Grasses with or without Forbs	Acre	$168.46
Filter Strip	Single Species Introduced or Native Grass with Shaping	Acre	$216.92
Filter Strip	Introduced Grasses and Legumes with Shaping	Acre	$179.49
Filter Strip	Mixed Native Grasses with or without Forbs with Shaping	Acre	$248.60
Pasture and Hayland Planting	Lime	ton	$29.21
Pasture and Hayland Planting	Introduced Grasses for Pasture into Cropland	acre	$123.73
Pasture and Hayland Planting	Introduced Grasses for Hayland into Cropland	acre	$118.69
Pasture and Hayland Planting	Seed Native Grasses into Existing Cropland	acre	$153.23
Pasture and Hayland Planting	Introduced Grasses for Pasture into Sod or CRP	acre	$150.07
Pasture and Hayland Planting	Introduced Grasses for Hayland into Sod or CRP	acre	$140.53
Pasture and Hayland Planting	Seed Native Grasses into Sod or CRP	acre	$179.57
Pasture and Hayland Planting	Broadcast Legumes into Existing Pasture	acre	$36.50

Table 6-2 (continued) NRCS Suggested Agricultural Conservation Practices and Associated Costs - 2009.

Practice/Activity Name	Practice/Activity Type	Unit Type	Total Cost
Residue and Tillage Management - No Till, Strip Till	Residue and Tillage Management - No-till, Strip Till	acre	$30.50
Residue and Tillage Management - Ridge Till	Residue and Tillage Management - Ridge-Till	acre	$30.70
Sediment Basin	Feedlot Slotted Wall	Feet	$55.35
Sediment Basin	Concrete Bottom	sq ft	$4.19
Sediment Basin	*Silt Fence*	*Feet*	*$2.30*
Water and Sediment Control Basin	*3 ft of fill height or less*	*each*	*$1,000.00*
Water and Sediment Control Basin	Fill height of greater than 6 and a drainage area of less than 10 acres	each	$4,500.00
Water and Sediment Control Basin	Fill height of 3.1 to 6 feet	each	$3,000.00
Water and Sediment Control Basin	Greater than 6 feet fill height and a drainage area 10 to 20 acres	each	$6,000.00
Water and Sediment Control Basin	6.1 feet to 10 feet fill height and a drainage area 20 to 40 acres	each	$9,000.00
Water and Sediment Control Basin	Greater than 10 feet fill height and a drainage area 20 to 40 acres	each	$12,000.00
Wetland Restoration	Ditch Plugs	Each	$500.00
Wetland Restoration	Embankments	Cu Yd	$6.00
Wetland Restoration	Scrapes	acre	$6,000.00
Wetland Restoration	Tile Breaks	each	$500.00
Wetland Restoration	Water Control Structure	each	$2,500.00

NOTE: Total Cost includes Material, Equipment/Installation, Labor and Mobilization. It does not include operation and maintenance or foregone income. These rates were developed for FY2009.

Table 6-3 Estimate range of annual removal rates for various Agricultural Conservation Practices.

Practice / Activity Name	Estimate Range of Annual Removal Rates	
	Total Phosphorus	Sediment
Filter Strips [1]	0.09-0.67 lbs/acre treated/year	0.0001-0.19 tons/acre treated/year
Pasture and Hayland Planting (conversion to permanent cover) [1]	0.13-0.65 lbs/acre treated/year	-0.0005-0.19 tons/acre treated/year
Temporary Storage (i.e., wetland restoration or side inlet controls) [1]	0.07-4.11 lbs/AF additional storage/year	-0.03-0.56 tons/AF additional storage/year

[1.] BMP effectiveness estimated from simulation in the Diamond Lake SWAT model. Load reductions represent net reductions – i.e., those achieved at the outlet of a subbasin and not at the field level.

lakeshore to filter runoff. The effectiveness of buffer strips in reducing total phosphorus is similar to filter strips used for agricultural purposes. Residents that decide not to connect to the regional wastewater treatment system that have a failing SSTS, should be expected to upgrade their system to be in compliance with design standards.

6.1.2 Internal (In-Lake) Sources

Internal sources of TP may also be addressed to reduce total phosphorus loading. In many deep lakes, phosphorus accumulated in bottom sediments through time can be released back into the water column under anoxic conditions. The amount released from the sediments depends in part upon whether there is a lack of oxygen (actually reduced conditions) at the sediment – water interface. Higher release rates occur during anoxic conditions.

Because Diamond Lake typically does not thermally stratify and develop an anoxic hypolimnion for a long period of time, this source of phosphorus can be small relative to the amount from surface runoff. The estimated range for the internal load of total phosphorus released from sediment is 386 (31% of the budget) kg per and 20 kg per year (2.8% of the budget) for 2008 and 2009 respectively (an average 206 kg per year which was used in the modeling) based upon the monitoring data.

There are several potential methods to reduce internal loading. These methods include aeration of the hypolimnetic water and the use of aluminum sulfate to "sequester" phosphorus within the sediment. The use of aeration is considered marginal because Diamond Lake only weakly thermally stratifies. The use of aluminum sulfate is a viable implementation activity although the longevity of the treatment is a concern because the lake has a large littoral zone. Experience with the use of aluminum sulfate in lakes shows reduced longevity (on the order of 3 to 7 years) for lakes which fail to or only weakly thermally stratify compared to deep lakes that strongly thermally stratify (on the order of 10 or more years). Longevity is also reduced in lakes, where the external load has not been effectively reduced.

An aluminum sulfate treatment can be effective in reducing the internal loading. The reduction in lake concentration is typically 80%. Aluminum sulfate treatment costs range from $280 to $700 per acre (average $450 per acre).

Another source of phosphorus to the lake is the annual growth and summer die-off of curly leaf pondweed, which can result in the release of phosphorus, which may lead to algal blooms. In two lakes in east-central Minnesota, the concentration of TP increased by 21 ug/L and 52 ug/L following the senescence of curly leaf pondweed (http://www.elmcreekwatershed.org/2004ARapp3.pdf accessed July 9, 2010). This exotic infestation is confined to a relatively small part of Diamond Lake and may be relatively easy for professional applicators to control.

6.1.3 Public Information and Education

Some load reduction may be achieved by changing the behavior of residents within the drainage area contributing runoff to Diamond Lake. Examples of behaviors that can be changed through providing information to and education of the public, include the use of no-phosphorus fertilizers, the proper disposal of yard waste, the implementation of buffer strips adjacent to the lake, and disconnecting impervious surfaces.

6.2 RECOMMENDED IMPLEMENTATION PLAN

This section describes the recommended Implementation Plan. Each implementation strategy is described in tabular format and includes an estimated implementation cost.

6.2.1 Watershed (External) Sources

The goal for these sources is a reduction of 550 kilograms of phosphorus annually, which includes a 155.5 kg reduction internally within the upstream lakes. The MFCRWD will work with other organizations and agencies to educate landowners, homeowners, and farmers about the benefits of reducing nutrient loads. The MFCRWD will identify and promote cost share and reimbursement programs that will encourage participation and minimize financial burdens. Agricultural conservation practices likely eligible for these programs will include filter strips, conservation tillage, and the planting of cover crops. Wetland restorations will also be considered. Around lake homes, rain gardens, shoreline filter strips and fertilizer management, can reduce negative impacts on Diamond Lake.

Implementation Activity WS-1: Connect Diamond Lake SSTSs to the Green Lake Regional Wastewater Treatment System

Description	Based upon currently available estimates up to 286 of the 365 residences surrounding Diamond Lake will be connected to the regional wastewater treatment system.
Implementation Priority	High
Estimated Total Phosphorus Load Reduction	The estimated load reduction associated with connecting residences to the regional system is 59.5 kilograms from 127.5 kilograms annually.
Assumptions Implicit in the Estimated Load Reduction	Assumes a 70% failure rate and one-half of those that fail have soil conditions which allow an actual contribution to the lake. No other failing SSTSs will be upgraded to reduce loads. Load reduction based upon earlier estimate of 170 residencies becoming connected.
Responsible Parties	MFCRWD, DLARA, Green Lake Sanitary Sewer District
Timeline	Completed 2014
Planning Level Estimated Cost	$6,941,000

Implementation Activity WS-2: Upstream Lake Management To Achieve Clear Water States within Hubbard and Wheeler Lakes

Description	Develop and implement a management plan for Hubbard and Wheeler Lakes, with the purposes of maintaining the lakes in the clear phase. Expectations are that the plan would focus on the management of "rough fish" and primarily carp populations. The plan is expected to consist of installing fish barriers between Diamond Lake and Hubbard Lake and between Wheeler Lake and Schultz lake, to isolate the carp population to Hubbard and Wheeler Lakes. A gravity flow water level management system from Wheeler Lake to the outlet bypassing Diamond Lake appears to be technically feasible. Therefore, lowering the water surface elevation of these lakes to induce a winterkill as a means of controlling the carp population appears feasible. The use of rotenone is another probable approach for reducing the density of carp within Hubbard and Wheeler Lakes, to a level considered sufficient to initially change the lake from the turbid to clear states. Expectations are that periodic rough fish removal may be necessary (~ once every ten years) to maintain these lakes in the clear phase. This may be accomplished either by commercial fishing, future rotenone applications, or by inducing winterkill by some other means. The winter conditions in 2009 did lead to an observed die-off of carp within Wheeler Lake.
Implementation Priority	Moderate
Estimated Total Phosphorus Load Reduction	The annual average total phosphorus concentration for 2008 and 2009 is 117 ug/l. For the purposes of estimating the load reduction, based on experience with similar shallow lakes, the annual average total phosphorus concentration could be reduced by a factor of 2 to 58.8 ug/l. Assuming an annual average inflow to Diamond Lake from Hubbard Lake of 2.64 cubic hectometers per year (2144 af per year) and a reduction in the annual average total phosphorus concentration of 58.8 ug/l, the estimated load reduction is 155.5 kg/year (total watershed sources by 1,490 kg/yr).
Assumptions Implicit in the Estimated Load	The volume of water delivered from Hubbard to Diamond Lake will be equal to the average annual amount and the annual mean total

Reduction	phosphorus concentration as described by the 2008 and 2009 monitoring data for Hubbard Lake reduced by a factor of two.
Responsible Parties	MnDNR, MFCRWD
Timeline	Complete Carp Management 2014 Fish Barrier Installation 2016 First Carp Control Treatment 2017
Planning Level Estimated Cost	Carp Management Plan: $15,000 Administration and Engineering $35,000 Fish Barriers ($160,000): Physical barrier between Wheeler and Schultz $15,000 Physical barrier between Hubbard and Diamond $150,000 Initial Rotenone Treatment (powder application) ($46,500 rounded) Chemical Unit Cost $20 to $30 per acre-foot treated (use $30) Application Cost $10 to $25 per surface acre treated (use $25) Hubbard Lake 32.1 acres @ 5 ft ave. depth = $5,617.50 Wheeler Lake (@ 5-ft ave. depth) South-west lobe 83 acres = $14,525 North-east lobe 173 = $25,950 Carp Reduction Maintenance @ 10 years assuming same as initial rotenone treatment $46,500 Gravity System for Water Level Management $500,000 *Note: rotenone chemical cost for liquid nearly doubles. Based on cost ranges provided by MnDNR Shallow Lakes program.*

Implementation Activity WS-3: Implement Agricultural Conservation Practice Program

<table>
<tr><td>Description</td><td>Implementation of agricultural conservation practices within priority subwatersheds as identified by the watershed loading (SWAT) model. The following assumes that a load reduction of 344.5 kg is achieved entirely through a single practice.

<table>
<tr><th>Practice</th><th>No.</th><th>Cost Units</th><th>Cost per Unit</th><th>Estimated Cost</th></tr>
<tr><td>Filter / Buffer Strips</td><td>36.6 acres or 15.1 miles @ 20-feet width</td><td>Acre</td><td>$3,170 including land</td><td>$116,000</td></tr>
<tr><td>Pasture and Hayland Planting (conversion to permanent cover)</td><td>1,946 acres converted from agricultural product to permanent cover</td><td>Acres</td><td>$3,160</td><td>$6,149,360</td></tr>
<tr><td>Temporary Storage (i.e., wetland restoration or side inlet controls)</td><td>165 acre-feet of new storage</td><td>Acre-feet</td><td>$1000</td><td>$165,000</td></tr>
</table>
Assumes permanent easement needed for BMPs with land value of $3,000 per acre. Only first costs are included (no maintenance or recurring cost). No estimate is provide for loss of revenue for land set-aside. Total estimate agricultural land acreage in contributing drainage area is 11,385 acres. Generally assumes native grass plantings.</td></tr>
<tr><td>Implementation Priority</td><td>High</td></tr>
<tr><td>Estimated Total Phosphorus Load Reduction</td><td>An estimated 476 kg/year is needed. This assumes that the upstream lakes will be successfully managed to convert them to the clear state with a corresponding 155.5 kg load reduction. The current watershed load including the upstream lakes load is 1,490 kg/yr.</td></tr>
<tr><td>Assumptions Implicit in the Estimated Load Reduction</td><td>SWAT modeled unit load reductions represent actual field performance. Values used were 0.11 lbs/acre/year (0.0.05 kg/acre/year), 2.09 lb/acre/year (0.95 kg/acre/year) and 0.39 lbs/acre/year (0.177 kg/acre/year) for filter strips, temporary storage, and conversion of agricultural land to permanent cover.</td></tr>
<tr><td>Responsible Parties</td><td>Responsible Parties MFCRWD, Kandiyohi county SWCD</td></tr>
<tr><td>Timeline</td><td>2011 and ongoing.</td></tr>
<tr><td>Planning Level Estimated Cost</td><td>No maintenance cost assumed.</td></tr>
</table>

Implementation Activity WS-4: Lakeshore and Urban Best Management Practices

Description	Implement Best Management Practices (BMPs) to reduce pollutant loads directly from lakeshore development and other areas within increased amounts of impervious surface. These BMPs may include rain gardens, infiltration trenches, biofiltration swales and similar related BMPs.
Implementation Priority	High
Estimated Total Phosphorus Load Reduction	An estimated 476 kg/year is needed for all external source reduction strategies. A portion of this load reduction can be achieved through this implementation activity in addition to the agricultural conservation practices.
Assumptions Implicit in the Estimated Load Reduction	None
Responsible Parties	Responsible Parties MFCRWD
Timeline	2011 and ongoing.
Planning Level Estimated Cost	Depends upon the type of BMP

6.2.2 Internal (In-Lake) Sources

The goal for reduction of internal loading is 103 kilograms of phosphorus over the growing season. To achieve that goal, the internal sources of phosphorus require management of the invasive, nuisance curly leaf pondweed. The reduction of curly leaf pondweed is expected to reduce internal phosphorus loading caused by this macrophyte as can the use of aluminum sulfate.

Implementation Activity IS-1: Macrophyte Management to Control Curly Leaf Pondweed

Description	Treat the affected parts of Diamond Lake with herbicide or mechanical means to limit the growth of curly leaf pondweed and reduce the internal phosphorus loading from curly leaf pondweed.
Implementation Priority	High
Estimated Total Phosphorus Load Reduction	No estimate made.
Assumptions Implicit in the Estimated Load Reduction	Not applicable.
Responsible Parties	MFCRWD, MPCA
Timeline	2011-2012 (seasonal treatment)
Planning Level Estimated Cost	$ 25,000 per treatment

Implementation Activity IS-2: Inactivation of Sediment Released Phosphorus

Description	Aluminum Sulfate Treatment
Implementation Priority	Low
Estimated Total Phosphorus Load Reduction	Because the lake is shallow and only weakly stratifies, the estimated reduction in the annual mean in-lake concentration is 50% (103 kilograms).
Assumptions Implicit in the Estimated Load Reduction	Surface area treatment applied only to the open water portion of the lake. Assumes area less than 6-feet in depth (20% of the lake) is littoral area and not treated.
Responsible Parties	MFCRWD
Timeline	2020
Planning Level Estimated Cost	Engineering Plan for Application and Initial Feasibility Analysis $30,000 Alum Treatment of 1,285 acres at $450 per acre = $578,250.

6.2.3 Public Information and Education

Implementation Activity PIE-1: Educate Lakeshore Property Owners to Reduce Phosphorus Runoff

Description	An annual newsletter or similar advertisement, with a copy on the MFCRWD web site could be provided to local landowners pointing out ways they can protect their lake. This also should point out the other activities that will further protect the lake: agricultural BMPs, SSTS enhancements, etc.
Implementation Priority	High
Estimated Total Phosphorus Load Reduction	No estimate made.
Assumptions Implicit in the Estimated Load Reduction	Not applicable.
Responsible Parties	MFCRWD
Timeline	2011 and seasonally thereafter.
Planning Level Estimated Cost	Approximate Cost: Design in house, print 500 for $300, address and mail 400 for $300; total $600 per year. Items to promote include: rain gardens, porous pavement, nutrient management for fertilizers and household detergents, lawn overwatering, and pet wastes.

6.3 Implementation Plan Cost Range

The total estimated planning level cost range for implementing the recommendations in this TMDL including tasks that address both external and internal source phosphorus reductions is provided in **Table 6-4**.

Table 6-4 Planning Level Estimated Cost Range for TMDL Implementation.

Implementation Activity	Estimated TP Load Reduction (kg)	Probable Initial Cost Range (excludes operation and maintenance)	
		Low	High
WS-1: Connect Diamond Lake SSTSs to the Green Lake Regional Wastewater Treatment System	59.5	$6,941,000	
WS-2: Upstream Lake Management To Achieve Clear Water States within Hubbard and Wheeler Lakes	155.5	$500,000	
WS-3: Implement Agricultural Conservation Practice Program	344.5*	~ $116,000	
WS-4: Lakeshore and Urban Best Management Practices	None estimated	Use current District Programs	
IS-1: Macrophyte Management to Control Curly Leaf Pondweed	None estimated	$25,000 per treatment	
IS-2: Inactivation of Sediment Released Phosphorus	Reduction of in lake total P concentration for 5-7 years by 50%	$578,250	
PIE-1: Educate Lakeshore Property Owners to Reduce Phosphorus Runoff.	None estimated	$600 per year	

*Additional reduction of 389 need to achieve Margin of Safety

6.4 Long Term Planning

After the first 10 years, a comprehensive analysis of the program will be conducted, to determine if the activities planned and implemented are achieving the required reductions in phosphorus concentrations within Diamond Lake. If the water quality standards are not achieved within this 10-year time frame, the MFCRWD will meet with MPCA staff and local citizen organizations and other stakeholders to determine future direction and if additional participation by these groups is needed, as well as more aggressive measures for achieving the water quality standards. Consideration of the need for an alum treatment would occur at this time.

6.5 Public Participation

6.5.1 Introduction

The MFCRWD has an excellent track record with inclusive participation of its citizens, as evidenced through the establishment of the District itself in 2005 (led by an active citizen base), the development and completion of the MFCRWD Watershed Management Plan in 2007, and its very active citizen volunteer monitoring program. The MFCRWD has utilized stakeholder meetings, surveys, open houses, and a citizens' advisory committee, to share information with the public and to gather input to help guide implementation activities (**Appendix E**). The extensive public participation has helped guide the development of the implementation plan herein, and will help direct future projects to improve the water quality of Diamond Lake.

6.5.2 Technical Advisory Committee

The Diamond Lake TMDL Technical Advisory Committee (TAC), was established as an ad hoc committee, to guide the process of the Diamond Lake TMDL. The TAC consisted of the following advisors:

- 1 Board Conservationist from the Minnesota Board of Water and Soil Resources
- 1 Program Coordinator from the County Soil and Water Conservation District
- 1 Area Hydrologist from the Minnesota Department of Natural Resources
- 1 County Director of Environmental Services
- 1 County Ditch Inspector

The TAC met as a group one time with MCFRWD and MPCA staff on October 9, 2008, following the first season of monitoring. The purpose of the meeting was to discuss the overall role of the Committee, provide an overview of the project, a status report on the major project tasks and next steps. TAC discussion centered on the need to conduct sampling for a second water year, the importance of sampling, and ultimately addressing water quality issues in the Schultz/Wheeler/Hubbard Chain of Lakes, and ideas that could eventually be used in the implementation plan.

6.5.3 Public Meetings/Information

A webpage dedicated to the Diamond Lake TMDL was created on the Minnesota Pollution Control Agency's website, to provide the public with a background on the TMDL study, a map indicating project location within the state, a link to a fact sheet, an announcement of upcoming public meetings, relevant links, and contact information for the MPCA Project Manager and MFCRWD Administrator.

A fact sheet was prepared for the TMDL, and provided background information on the study, progress to date, and opportunities on ways that residents can learn more on the TMDL process and reduce nutrient loading into the lake. One fact sheet was prepared and posted on the MPCA website in November 2008, and an updated fact sheet was prepared and posted on the website in July 2010.

Stakeholders were given the opportunity to participate in the TMDL process on several levels throughout the study, including public meetings, small group discussions, a survey, MFCRWD open houses, and Citizens Advisory Committee (CAC) meetings, and at monthly MFCRWD Board meetings. Public meetings were announced, via notices on the MPCA website, news releases in newspapers, newsletter articles, and individual invitations to all residents of the Diamond Lake watershed, in addition to county commissioners, local legislators, townships, implementation partners, and others. The first public meeting, held on December 10, 2008, was attended by 68 individuals, and was designed to share information, solicit input from the public, encourage their participation in the process, and offer an opportunity for questions and answers. A second public meeting took place on June 19, 2010, at the invitation of the Diamond Lake Area Recreation Association. Similar to the first public meeting, it entailed a presentation that provided a background of the TMDL process, and an update on the current status of the study. Preliminary water quality conclusions and data were shared with the audience, which numbered approximately 30 people. Questions were asked and answered, and the next planned public meeting was announced. Following the second public meeting, a third public meeting was publicized in a similar way as the first, and was held on July 29, 2010 with 39 attendees. The third public meeting followed a similar format as the first, with some additional opportunity to include public input. Following a presentation and question/answer session, attendants were given the opportunity to split up and join small group discussions on monitoring results, phosphorus dynamics, and implementation ideas. This strategy was employed in consideration of the fact that many people are reticent to ask questions and voice opinions in large groups. Attendees were also asked to complete a survey that was designed to allow those uncomfortable to offer ideas in the small group setting with the opportunity to have their voices heard. A summary of some of the comments received:

- Solar Bee technology to increase oxygen levels through all water columns to prevent phosphorus from releasing into the lake
- Holding ponds in Ag ditches to slow up the runoff
- Have all lake property owners contribute to problem solving fund
- Need a carp kill
- Buffer strips

- Deepen existing wetlands near the lake
- Chain of lakes management
- Better manage lake water levels by making the dam
- Utilize drained wetland inventory to restore strategic wetlands (most bang for the buck).
- Incentives to promote establishment of permanent vegetation along streams/ditches (intensive rotational grazing, biomass generation from grasses, brush, etc.).

6.5.4 PUBLIC PARTICIPATION CONCLUSION

Extending the opportunity for the public to participate in the TMDL process was emphasized from the outset, as indicated by the high attendance levels in public meetings and resultant feedback. A variety of methods for sharing information with the public were employed, including large group meetings, small group meetings, anonymous surveys, website announcements, fact sheets, newsletter articles, and others. Much of the feedback that was provided by the public has been included in the implementation plan, and will continue to be solicited and utilized as the implementation plan is carried out.

SECTION 7.0
MONITORING PLAN

Two types of "monitoring" are envisioned to evaluate TMDL effectiveness; i.e., water quality monitoring and an accounting process documenting the estimated load reduction for each of the implementation activities and progress toward the load reductions.

7.1 WATER QUALITY MONITORING

7.1.1 Diamond Lake

The water quality in Diamond Lake has been monitored for several years, and should continue to be monitored for the foreseeable future, until the accounting process demonstrates the implementation activities have achieved the load capacity. Volunteers may be used to assist with monitoring. The MFCRWD plans to continue to measure the water quality in the lake monthly during May through September. The following water quality measurements should be made during each visit:

Field measurements:
- Secchi disk transparency (SD)
- Water temperature (WT)
- Dissolved oxygen (DO)
- pH
- Specific Conductance (SC)

Near-surface water sample analyzed for:
- Total phosphorus
- Dissolved phosphorus
- Chlorophyll *a*

At least once during June through August, and after a stable-weather period, a more complete annual check-up of the lake will include a complete vertical profile of water temperature, dissolved oxygen, pH, and specific conductance taken at one-meter intervals. This additional more intensive surface sample be analyzed for total and volatile suspended solids, turbidity, and alkalinity, in addition to the parameters identified above. A sample will be collected from near the bottom of the lake, and analyzed for the same extended suite of constituents.

7.1.2 Stream Sites

It will be important to monitor the long-term effectiveness of the projects being constructed, to control runoff and loads to Diamond Lake. The flow monitoring equipment operated at site DL1 provided reliable results and should continue operation to monitor for trends in water quality from this important part of the watershed.

Now that a specific phosphorus reduction goal has been set for Diamond Lake inflows, achievement of those goals can be monitored.

Samples will be collected monthly during March through September and during selected runoff events, and analyzed for total phosphorus, dissolved phosphorus, total and volatile suspended solids, and turbidity. Field measurement will be completed for streamflow, water temperature, dissolved oxygen, pH, turbidity, and specific conductance. The streamflow measurements will be used to check and possibly adjust the streamflow records. The streamflow, together with the phosphorus and suspended solids concentrations, will be used to develop load estimates using the Flux model, and evaluate annually whether changes in phosphorus and suspended solids loads have occurred

7.2 MONITORING OF IMPLEMENTATION ACTIVITIES

Implementation activities will not be specifically monitored by measuring flows and collecting water quality samples. Rather, a spreadsheet accounting process, or the e-link reporting system will be used to track the estimated total phosphorus load reduction for each implementation activity, and cumulatively for comparison to the loading capacity. Periodic visual inspections will occur to ensure proper design and performance of the implementation activity, and make decisions about whether the design effectiveness is being achieved and the need for maintenance.

SECTION 8.0
REFERENCES

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APPENDICES

Appendix A – Upstream Lakes Memo

Appendix B – Monitoring Report

Appendix C – Watershed Modeling Memorandum

Appendix D – CNET Model

FINAL

MEMO

(External Memorandum)

HoustonEngineering Inc.

To: Chad Anderson

Date: July 7, 2010

Cc: File 5480-000

From: Mark Deutschman

Subject: Hubbard Chain of Lakes, Kandiyohi County, Minnesota; Summary of Water-Quality Data

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Introduction

Three lakes upstream of Diamond Lake were sampled routinely during the Total Maximum Daily Load (TMDL) study of Diamond Lake. The lakes, east of Diamond Lake and shown in **Figure 1**, are (in downstream order) Schultz, Wheeler, and Hubbard. They were sampled to determine how they affect the quality of Diamond Lake and whether they required further evaluation to assess their condition relative to water-quality standards based on trophic-status, which is discussed later. Schultz Lake and Wheeler Lake flow into Hubbard Lake, which is divided into two water bodies in a complex wetland system. Local observers have described that there is no clearly-defined channel connecting the two parts of Hubbard Lake suggesting a diffuse flow through the aquatic vegetation which could result in attenuation of peak flows and retention of some constituents. However, water from the lake eventually forms a channel that flows into site DL1. Site DL1 is the primary source of surface water inflow to Diamond Lake.

There is little official morphometric information available for these lakes, although they all are relatively shallow (less than 10-feet maximum depth). Field measurements showed that Schultz Lake had a maximum depth of 7 feet, Wheeler lake 6 feet, and Hubbard Lake about 4 feet. These are approximations based on soundings made during this study. The lake area can be determined from maps and aerial photographs, but that is dependent on the water elevation at the time the maps were made and the extent of emergent vegetation within and around the lakes, which can vary considerably.

The focus of the TMDL study is Diamond Lake. However, during the planning phase and design of the monitoring plan, the decision was made by project participants to include the sampling and monitoring of the upstream lakes. These lakes were included because they are tributary to Diamond Lake, a considerable portion of the contributing drainage area to Diamond Lake also flows through these lakes, and the lakes were anticipated to have considerable influence on the fate and transport of nutrients to Diamond Lake. To capture the results of the monitoring effort on these upstream lakes, project participants agreed early in the study to develop a memorandum describing their water quality by assessing whether the lakes meet beneficial uses. This memorandum presents the assessment of the water quality of the upstream lakes relative to their classification and beneficial uses. This memorandum is expected to be included as an addendum to the (future) Diamond Lake TMDL study report.

Lake Assessment Process

Procedures established by the Minnesota Pollution Control Agency (MPCA) to assess lake condition were used to evaluate the water quality within these lakes (see *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* - http://www.pca.state.mn.us/publications/wq-iw1-04.pdf). The process followed within this memorandum is consistent with the guidance and may assist the MPCA assessing impairment. The decision relative to the actual listing of the lakes as impaired rests with the MPCA. **Table 1** shows the factors used in the assessment process.

Figure 1. Locations of upstream lakes relative to Diamond Lake.

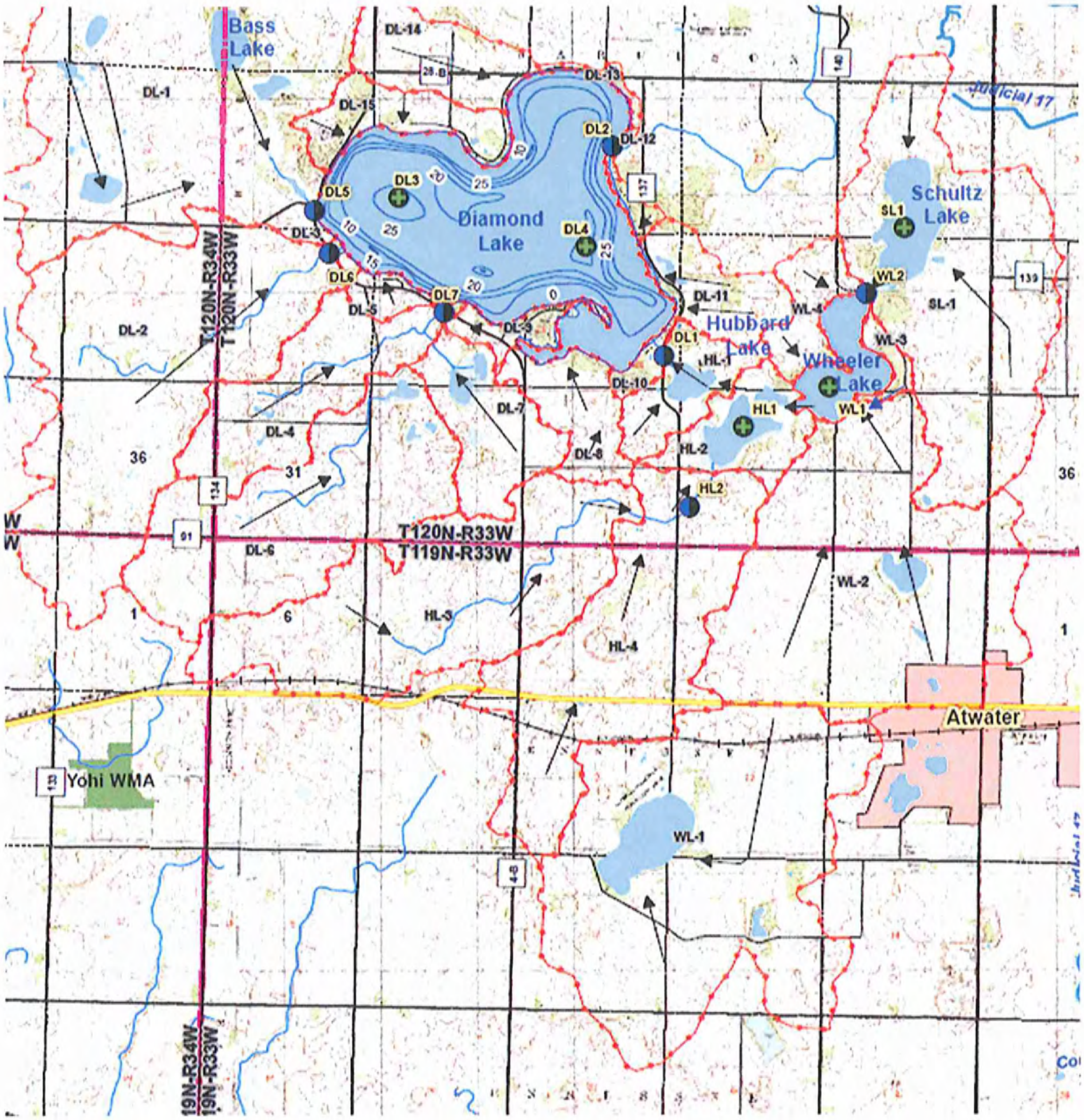


Table 1 - Factors considered in assessing the water quality of lakes upstream from Diamond Lake.

Factor	Lake		
Lake Name	Schultz Lake	Wheeler Lake	Hubbard Lake
County	Kandiyohi	Kandiyohi	Kandiyohi
Location (Township, Section Range	T120N, R 33W, Sections 23, 26	T120N, R33W, Sections 26, 27, 34, 35	T120N, R33W, Sections 34,27
Minnesota DNR Public Waters Identification No.	49P	51P	54W
Maximum Depth	7-feet	6-feet	4-feet
Greater than 80% characterized by emergent or submergent plants (i.e., littoral)	Yes	Yes	Yes
Thermally Stratify	No	No	No
Assessed as Lake or Wetland	Lake	Lake	Lake
Assessed as Deep or Shallow Lake	Shallow	Shallow	Shallow
Classification (not listed in MR 7050.0470 Classifications for Surface Waters in Major Drainage Basins)	2B, (aquatic life), 3 (industrial uses), 4A and 4B (agricultural uses) 5 (aesthetics and navigation) and 7 (other)	2B, (aquatic life), 3 (industrial uses), 4A and 4B (agricultural uses) 5 (aesthetics and navigation) and 7 (other)	2B, (aquatic life), 3 (industrial uses), 4A and 4B (agricultural uses) 5 (aesthetics and navigation) and 7 (other)
Component of Standard Evaluated	Numeric criteria	Numeric criteria	Numeric criteria
Beneficial Use Assessed	2B - Aquatic Rec. Use	2B - Aquatic Rec. Use	2B - Aquatic Rec. Use
Level III Ecoregion	County is bisected by Western Corn Belt and North Central Hardwood Forest ecoregions. Lake is located in North Central Hardwood Forest ecoregion.	County is bisected by Western Corn Belt and North Central Hardwood Forest ecoregions. Lake is located in North Central Hardwood Forest ecoregion.	County is bisected by Western Corn Belt and North Central Hardwood Forest ecoregions. Lake is located in North Central Hardwood Forest ecoregion.
Shallow Lake Numeric Criteria Applied (Aquatic Life Beneficial Use)	North Central Hardwood Forest	North Central Hardwood Forest	North Central Hardwood Forest
Data Years Used	2008 and 2009	2008 and 2009	2008 and 2009
No. of Samples Used	10	10	10
Lake Eutrophication Minimum Data Requirement Category	Excellent	Excellent	Excellent
Applicable Numeric Standard	Dissolved Oxygen, pH, Temperature, Turbidity, Total Phosphorus, Chlorophyll-a, Secchi depth	Dissolved Oxygen, pH, Temperature, Turbidity, Total Phosphorus, Chlorophyll-a, Secchi depth	Dissolved Oxygen, pH, Temperature, Turbidity, Total Phosphorus, Chlorophyll-a, Secchi depth

For the purposes of this assessment we have assumed classification as shallow lakes within the North Central Hardwood Forest Ecoregion (see definition of lake versus shallow lake within MR 7050). The eutrophication standards for a 2B lake are shown within **Table 2.** The lakes have a depth of less than 15 feet deep, have permanent or semi-permanent water regimes and are typically dominated by emergent and submergent vegetation. The upstream lakes are also directly connected to Diamond Lake and therefore, could be a component of the management plan for improving the water quality of Diamond Lake. There is also some history of fish management of the upstream lakes by the Minnesota Department of Natural Resources.

Table 2 -- Eutrophication numeric standards (expressed as average values) for Class 2B lakes, shallow lakes, and reservoirs.

Lakes and Reservoirs in Western Corn Belt Plains and Northern Glaciated Plains Ecoregions	
Phosphorus, total	65 µg/L (0.060 mg/l)
Chlorophyll-a	22 µg/L (0.022 mg/l)
Secchi disk transparency greater than 0.9 meters	
Shallow Lakes in Western Corn Belt Plains and Northern Glaciated Plains Ecoregions	
Phosphorus, total	90 µg/L (0.090 mg/l)
Chlorophyll-a	30 µg/L (0.030 mg/l)
Secchi disk transparency greater than 0.7 meters	
Lakes and Reservoirs in North Central Hardwood Forest Ecoregion	
Phosphorus, total	40 µg/L (0.040 mg/l)
Chlorophyll-a	14 µg/L (0.014 mg/l)
Secchi disk transparency greater than 1.4 meters	
Shallow Lakes in North Central Hardwood Forest Ecoregion	
Phosphorus, total	60 µg/L (0.060 mg/l)
Chlorophyll-a	20 µg/L (0.020 mg/l)
Secchi disk transparency greater than 1.0 meters	

Additional standards which apply to Class 2B lakes are shown in **Table 3.**

Table 3 - Conventional numeric standards for Class 2B lakes, shallow lakes, and reservoirs.

Parameter	Standard
Dissolved oxygen	Not less than 5 mg/L as a daily minimum
pH	minimum of 6.5 and a maximum of 8.5
Turbidity	25 NTU; need more than 20 observations with no more than 10% exceeding 25 NTU
Temperature	Material increase in temperature

Upstream Lakes Water Quality and Assessment Results

General Water Quality

The lakes were sampled on 10 occasions during 2008 and 2009, during which all of the lakes were sampled in a short time period from late morning to early afternoon. **Table 4** summarizes the data collected from those water bodies that may be important to the quality of Diamond Lake. Although each of the sites were sampled 10 times during the 2-year study, a few field values had only 9 measurements and are marked with an asterisk (*).

Table 4 - Mean values (2008 – 2009) for selected measurements for lakes upstream of Diamond Lake.

Site Name	Number of samples	Specific Conductance (uS/cm)	pH (units)	Dissolved Oxygen (mg/L)	Secchi Disk transparency (meters)	Total Phosphorus (mg/L)	Dissolved Phosphorus (mg/L)	Nitrite + Nitrate Nitrogen (mg/L)	Chlorophyll *a* (ug/L)
Schultz Lake	10	398	8.5	9.1	0.41	0.167	0.010	0.13	126*
Wheeler Lake	10	411	8.6	8.7	0.73	0.354	0.153	0.08	126
Hubbard Lake	10	413*	8.9*	9.8	0.68*	0.117*	0.029*	0.20*	44*

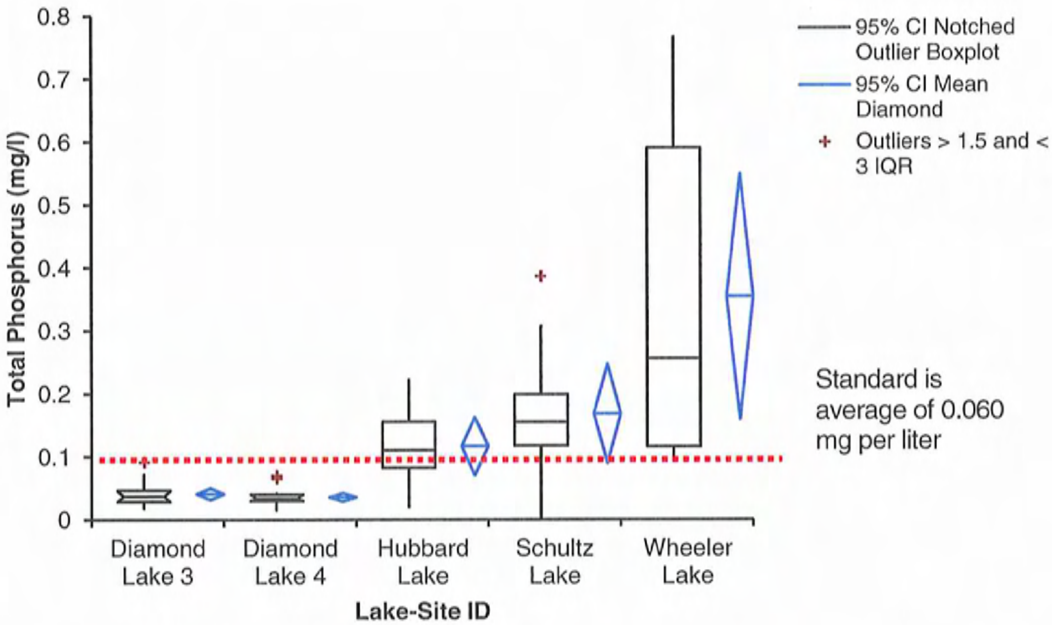
Generally, it would be expected that the lakes would have similar quality because they all are connected and are in the same general land-use setting. Presumably other influences would be equivalent. Drain-tile inputs may be a factor, because much of the watershed is drained by tile-drainage systems. The relative influence of artificial drainage on the hydrology of the watershed has not been documented. Groundwater inflow may be a consideration that has not been evaluated.

The specific conductance increases from Schultz Lake to Wheeler Lake, but the specific conductance in Hubbard Lake is considerably lower. Specific conductance is closely related to dissolved-solids (salts dissolved in the water) concentrations. Dissolved oxygen (DO) and pH values in each of the lakes are comparable and within expected variability. Transparency increased substantially from upstream to downstream through the lakes. Hubbard Lake was treated during the winter of 2007 by the Minnesota Department of Natural Resources (MNDNR) using reverse aeration in an effort to control rough fish, and that may have helped improve the transparency and water chemistry of the lake.

Eutrophication Assessment

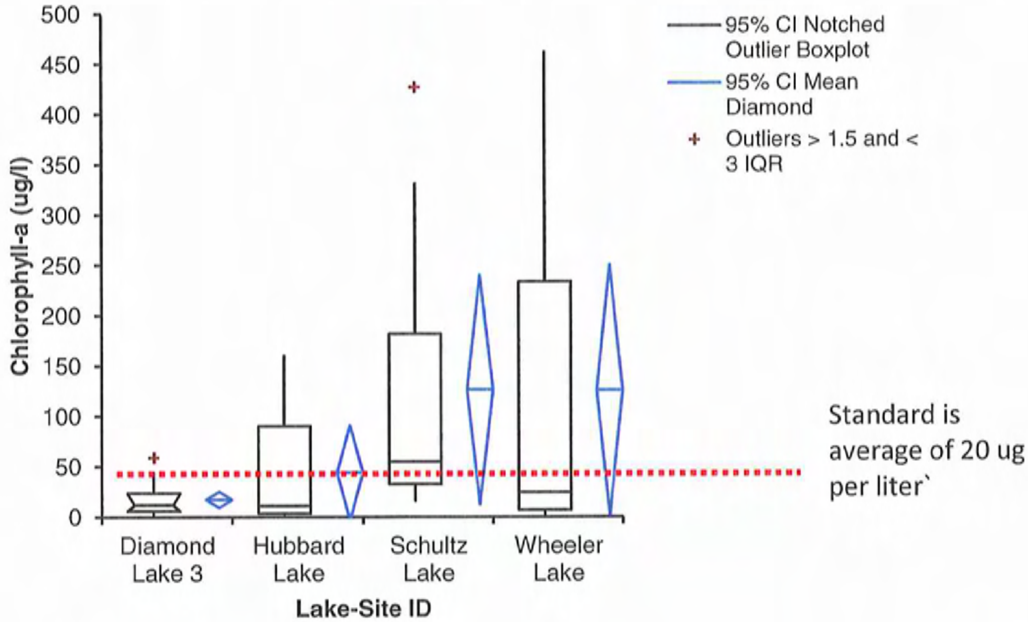
At least 8 paired measurements are required to determine the impairment of a lake (June through September), according to the Guidance Manual for Assessing the Quality of MN Surface Waters for Determination of Impairment (http://www.pca.state.mn.us/publications/wq-iw1-04.pdf, accessed February 17, 2010). The 10 samples collected from each of these lakes exceed those requirements. The mean total phosphorus concentrations in all lakes exceeded standards (note – one sample was taken in October 2009). The mean concentration of 0.116 mg/L (which is 116 micrograms per liter, ug/L) in Hubbard Lake was higher than the 60 ug/L standards for shallow lakes in the North Central Hardwood ecogregion. The mean total phosphorus concentration in Schultz Lake (0.168 mg per liter) was comparable to what was measured in Hubbard Lake, but the concentration in Wheeler Lake was considerably higher (**Figure 2**). (Note: data for Diamond Lake have been included in the Figures for comparison purposes). The chlorophyll *a* concentrations for the upstream lakes exceeds the numeric standard of 20 ug per liter (**Figure 3**).Transparency as expressed by secchi depth at Hubbard, Shultz and Wheeler Lake was also less than the numeric standard of 1 meter (**Figure 4**).

Figure 2. Total phosphorus concentrations relative to the Class 2B numeric standards.



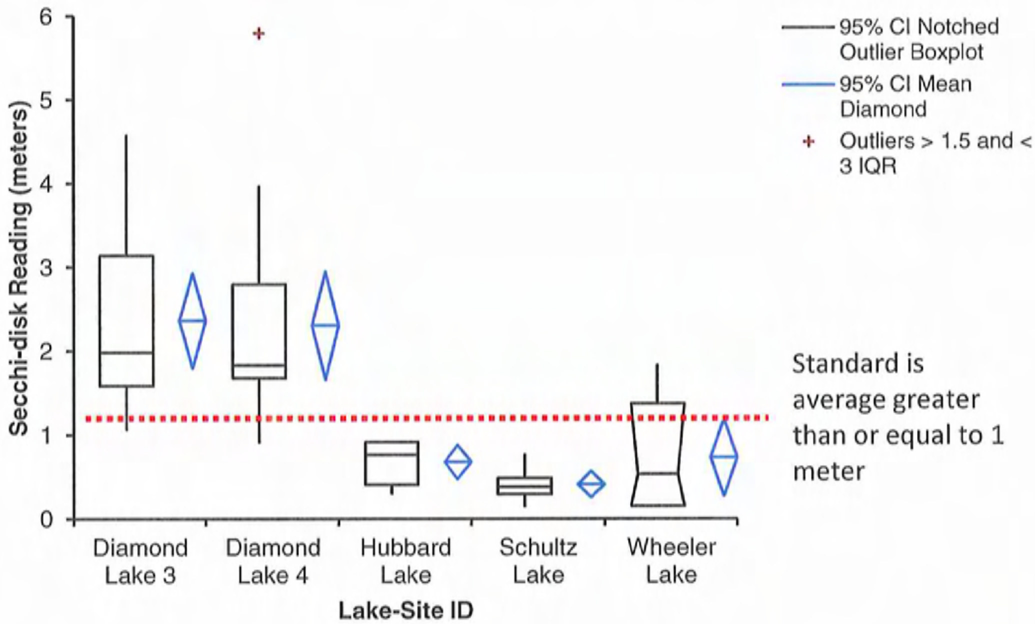
Total Phosphorus (mg/l) by Lake-Site ID	n	Mean	95% CI		SE	SD
Diamond Lake 3	18	0.0410	0.0318	to 0.0502	0.00438	0.01857
Diamond Lake 4	18	0.0359	0.0292	to 0.0426	0.00318	0.01350
Hubbard Lake	9	0.1167	0.0706	to 0.1627	0.01996	0.05988
Schultz Lake	10	0.1683	0.0893	to 0.2473	0.03494	0.11050
Wheeler Lake	10	0.3543	0.1593	to 0.5493	0.08621	0.27261

Figure 3. Chlorophyll-a concentrations relative to the Class 2B numeric standards.



Chlorophyll-a (ug/l) by Lake-Site ID	n	Mean	95% CI		SE	SD
Diamond Lake 3	18	17.4	9.5	to 25.3	3.75	15.90
Hubbard Lake	9	44.0	-2.9	to 90.9	20.35	61.06
Schultz Lake	9	126.4	12.8	to 240.1	49.30	147.90
Wheeler Lake	10	125.8	1.3	to 250.3	55.02	173.99

Figure 4. Secchi disk depth relative to the Class 2B numeric standards.



Secchi-disk (meters) by Lake-Site ID)	n	Mean	95% CI		SE	SD
Diamond Lake 3	16	2.36220	1.79568	to 2.92872	0.265791	1.063165
Diamond Lake 4	16	2.30505	1.65886	to 2.95124	0.303168	1.212674
Hubbard Lake	9	0.67733	0.47350	to 0.88117	0.088395	0.265184
Schultz Lake	10	0.41148	0.25687	to 0.56609	0.068344	0.216124
Wheeler Lake	10	0.73152	0.27531	to 1.18773	0.201670	0.637737

Conventional Parameters

According to the MPCA guidance document, the number of samples collected during the last two years is insufficient to meet the threshold data requirements. A minimum of 20 data points within the last 10 years is required. A water body is not "listed" if 10% or less of the measured values exceed the standard. This section summarizes the data collected for 2008 and 2009 within the upstream lakes. The data presented are for the surface, mixed layer.

Dissolved Oxygen

Instantaneous measurements from a meter were collected for dissolved oxygen (**Figure 5**). With the exception of Hubbard Lake, which had one value less than 5 mg/l, dissolved oxygen levels exceeded the 5 mg/l daily average standard.

pH

Instantaneous pH values within the upstream lakes were within a range considered normal for freshwater systems, and consistent with the numeric standard (**Figure 6**).

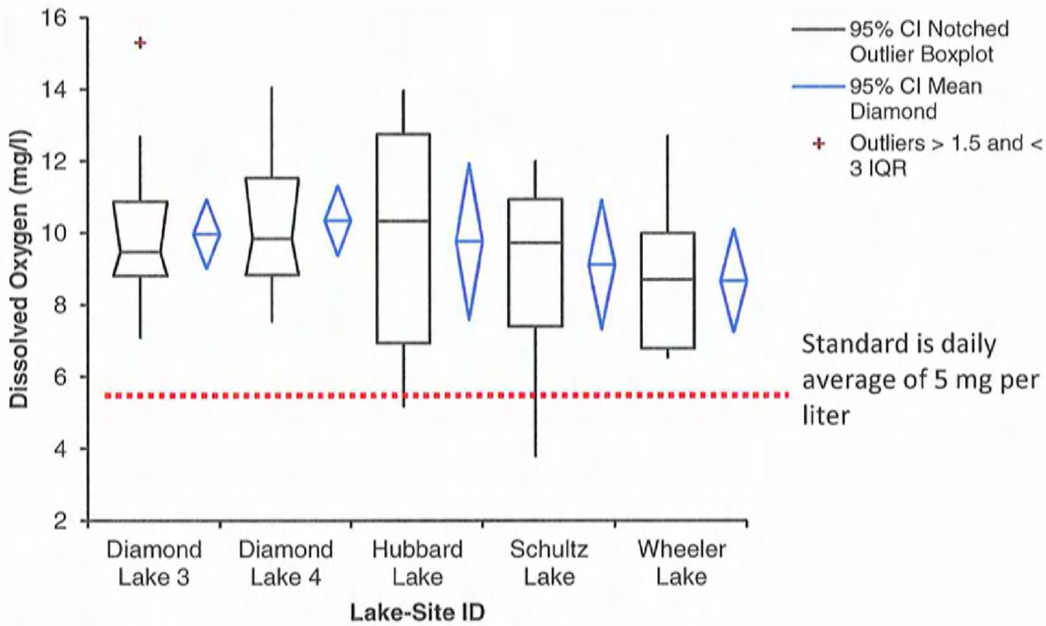
Turbidity

Average turbidity concentrations within Schultz and Wheeler Lakes exceeded the numeric standard of 25 NTU (**Figure 7**). The primary reason is a select number of values exceeding 1100 NTU's.

<u>Summary</u>

The lakes upstream of Diamond Lake are located within the North Central Hardwood Forests ecoregion, but in close proximity to the Western Corn Belt ecoregion. For the purposes of this assessment, the numeric standards for the North Central Hardwood Forests ecoregion have been applied. The assessment also is based on the assumption that Schultz, Wheeler and Hubbard Lake are shallow lakes rather than wetlands. The assessment shows that these lakes fail to meet the numeric standards for eutrophication. Insufficient data are available to complete the assessment procedure for conventional parameters. However, the measured values are generally consistent with the numeric standards.

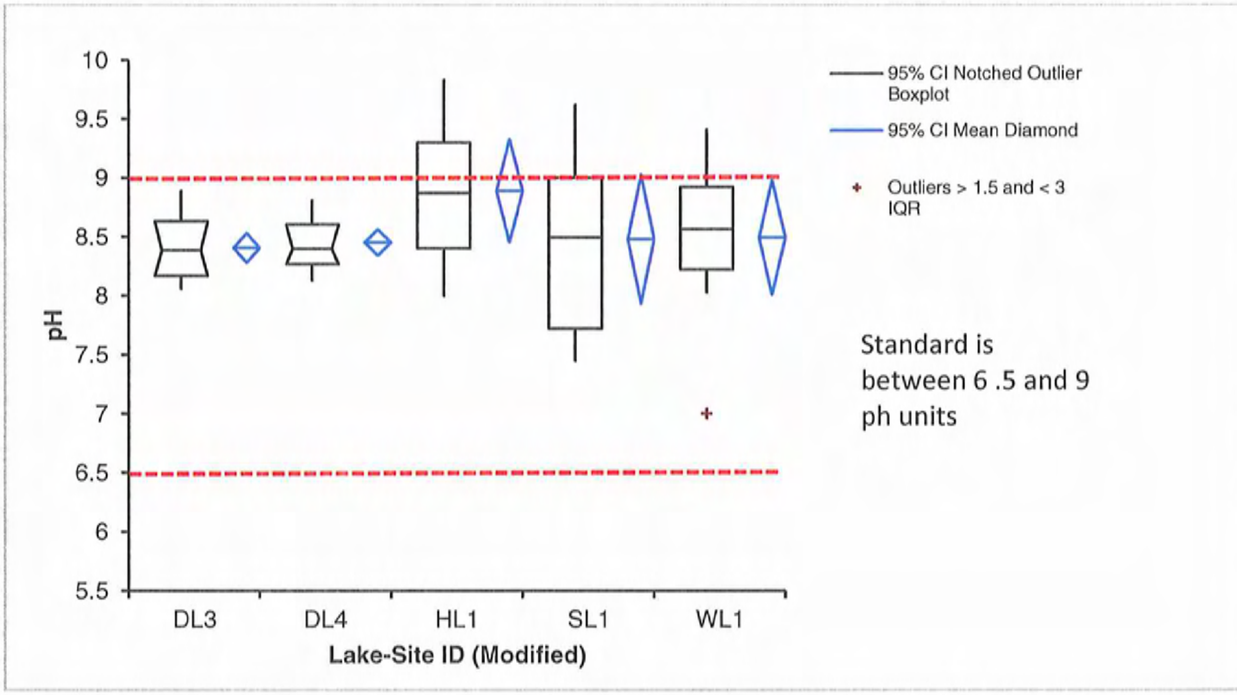
Figure 5. Dissolved oxygen concentrations within lakes.



Dissolved Oxygen (mg/l) by Lake-Site ID	n	Mean	95% CI		SE	SD
Diamond Lake 3	18	9.976	9.017	to 10.934	0.4542	1.9270
Diamond Lake 4	18	10.346	9.373	to 11.319	0.4611	1.9564
Hubbard Lake	10	9.765	7.588	to 11.942	0.9625	3.0436
Schultz Lake	10	9.120	7.324	to 10.916	0.7937	2.5101
Wheeler Lake	10	8.667	7.238	to 10.096	0.6315	1.9970

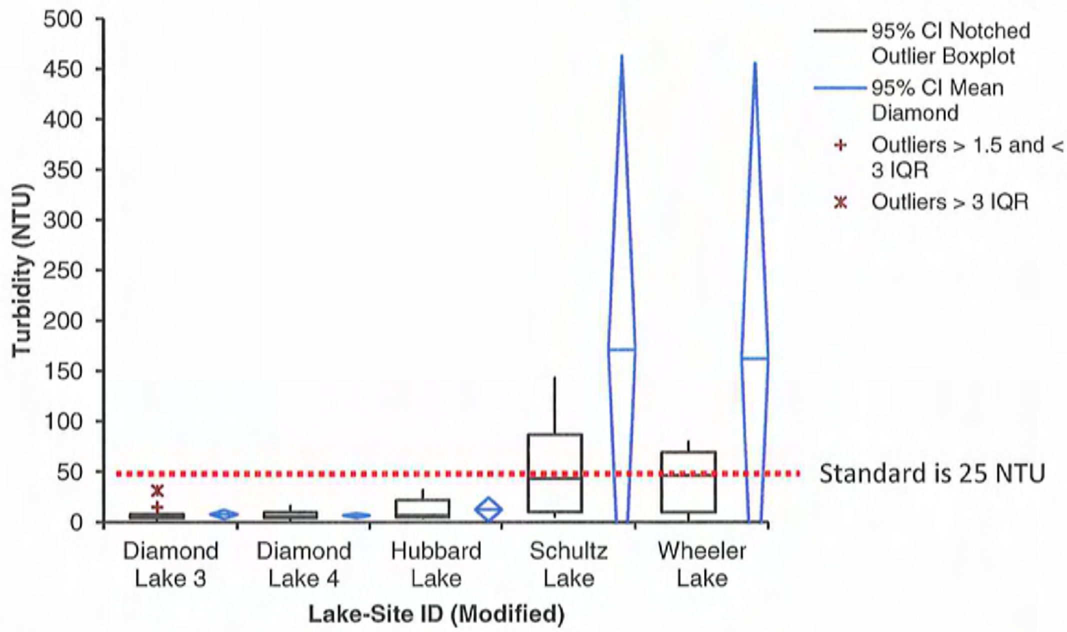
Dissolved Oxygen (mg/l) by Lake-Site ID	n	Min	1st Quartile	Median	95% CI		3rd Quartile	Max	IQR
Diamond Lake 3	18	7.10	8.803	9.475	8.820	to 10.840	10.869	15.30	2.067
Diamond Lake 4	18	7.54	8.833	9.835	8.850	to 11.460	11.529	14.05	2.696
Hubbard Lake	10	5.18	6.934	10.325	6.100	to 12.870	12.751	13.96	5.817
Schultz Lake	10	3.80	7.403	9.720	6.770	to 11.430	10.935	11.99	3.533
Wheeler Lake	10	6.54	6.783	8.700	6.590	to 10.550	9.991	12.70	3.208

Figure 6. Measured pH within lakes.



pH by Lake-Site ID	n	Mean	95% CI		SE	SD
Diamond Lake 3	18	8.408	8.284	to 8.532	0.0587	0.2489
Diamond Lake 4	18	8.454	8.346	to 8.562	0.0510	0.2164
Hubbard Lake	9	8.891	8.456	to 9.326	0.1886	0.5658
Schultz Lake	10	8.482	7.932	to 9.032	0.2433	0.7692
Wheeler Lake	10	8.495	8.011	to 8.979	0.2138	0.6762

Figure 7. Turbidity concentrations within Lakes.



Turbidity (NTU) by Lake-Site ID	n	Mean	95% CI		SE	SD
Diamond Lake 3	15	7.87	3.57	to 12.16	2.003	7.756
Diamond Lake 4	15	6.76	4.23	to 9.29	1.179	4.565
Hubbard Lake	6	12.62	0.92	to 24.32	4.552	11.149
Schultz Lake	9	170.84	-121.60	to 463.28	126.817	380.450
Wheeler Lake	9	161.96	-131.80	to 455.72	127.389	382.168

Diamond Lake Monitoring Report

Summary for the Diamond Lake Total Maximum Daily Load (TMDL)

June 11, 2010

MIDDLE FORK CROW RIVER WATERSHED DISTRICT

HoustonEngineering Inc.

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1.0 INTRODUCTION

Diamond Lake is a 1,607 acre lake located in east-central Kandiyohi County in west-central Minnesota. The outlet from Diamond Lake is controlled by a fixed crest dam constructed in 1952, which is owned by Kandiyohi County. Diamond Lake is about 6 miles northwest of Atwater and about 12 miles northeast of Willmar, Minnesota. Diamond Lake is the focus of a Total Maximum Daily Load (TMDL) study lead by the Middle Fork Crow Watershed District (MFCRWD). The MFCRWD retained Houston Engineering, Inc. (HEI) to assist with technical activities necessary to complete the TMDL study.

Project participants agreed early in the study process to develop a report, which describes the monitoring results for the Diamond Lake TMDL study, prior to completion of the formal TMDL report. By summarizing the monitoring results for Diamond Lake prior to completion of the TMDL, this report describes the water quality condition of Diamond Lake. The water budgets and total phosphorus mass balances developed using the monitoring data and information needed for calibrating a receiving water model are also presented within this report. This interim report also provides an opportunity for early review of the monitoring results by the Minnesota Pollution Control Agency (MPCA).

This report presents the assessment of the water quality for Diamond Lake, including the water budgets and total phosphorus mass balances, and is intended to compliment a previous memorandum prepared to assess the water quality condition of Hubbard, Wheeler and Schultz Lakes. These lakes are tributary to, upstream from, and affect the water quality of Diamond Lake. This report is expected to be included as an addendum to the (future) Diamond Lake TMDL report.

2.0 PROJECT INFORMATION

The title of this project is the Diamond Lake TMDL Study. Diamond Lake's lake identification number, as assigned by the Minnesota Department of Natural Resources (MnDNR), (which is the same as the Assessment Unit Identification Number) is 34-0044-00. Minnesota Rule (MR) 7050.0140 *Use Classifications for Waters of the State* identifies the various uses of the state's waters, considered in the best interest of the public (i.e., beneficial uses). These beneficial uses are:

- Drinking water – Class 1
- Aquatic life and recreation – Class 2
- Industrial use and cooling – Class 3
- Agricultural use, irrigation – Class 4A
- Agricultural use, livestock and wildlife watering – Class 4B
- Aesthetics and navigation – Class 5
- Other uses – Class 6
- Limited Resource Value Waters – Class 7

Most water bodies have multiple beneficial uses, rather than a single use. Diamond Lake is an unlisted water per MR 7050.0430 having multiple (potential) beneficial uses including aquatic life and recreation (Class 2B), Industrial use and cooling (Class 3C), Agricultural use for irrigation and livestock (Classes 4A and 4B), aesthetics and navigation (Class 5) and other uses (Class 6). Classification as 2B means that the lake must be protected as a cool and warm water fishery. Classification as 3C means that the quality of the water shall be such as to permit use for industrial cooling and materials transport without a high degree of treatment being necessary to avoid severe fouling, corrosion, scaling, or other unsatisfactory conditions. Generally, one of these uses requires "better" water quality than the remaining uses. Normally, this use is aquatic life and recreation.

In 1998, the MPCA determined that Diamond Lake failed to attain the designated use for aquatic life and recreation due to excess nutrients and placed the lake on the 303(d) list. Diamond Lake has remained on the 303(d) list through the most recent 2010 version. The 2010 303(d) list shows initiation of the TMDL in 2008 and completion by 2012. In November 2007, the MFCRWD submitted a workplan in accordance with the *TMDL Workplan Guidance* (Minnesota Pollution Control Agency, October 2007) and, upon approval by MPCA staff in early 2008, the MFCRWD initiated the field work needed to complete the TMDL. Monitoring began in 2008 and, because of dry conditions, was extended through 2009.

Diamond Lake was the focus of a previous study which evaluated water quality. The data collected during that study in part became the basis for placing the lake on the 303(d) list. A Diagnostic and Feasibility Study completed for Diamond Lake by Blue Water Science (1996) was funded by a U.S. EPA Clean Lakes Phase I grant. The study incorporated stream and lake monitoring for approximately two years and limited paleolimnological sediment cores. The models Agricultural Nonpoint Source Model (AGNPS) and Wisconsin Lake Modeling Suite (WiLMS) were used to assess watershed yields and potential lake response. Phosphorus yields were estimated from the contributing watershed drainage areas. An in-lake nutrient goal was identified in the study and phosphorus reductions were recommended for each source area, to reduce the measured mean annual total phosphorus concentration of 72 ug/l. Measured annual mean chlorophyll-a concentrations and secchi disk depths were 29.8 ug/l and 5.6 feet respectively (in 1993 and 1994). The report recommended a total phosphorus water quality goal of less than 50 micrograms per liter (ug/l) and a 40 percent load reduction from the estimated 3,697 kg annually to achieve that goal. Specific load reductions were assigned to various subwatersheds.

Diamond Lake was also included as one of the lakes used to establish nutrient criteria for the State of Minnesota (see http://www.pca.state.mn.us/publications/reports/lakes-wqdiatoms.pdf). Sedimentation rates were evaluated and used to estimate the pre-European phosphorus levels within Diamond Lake. The analysis completed by the MPCA infers pre-European phosphorus concentrations between 20 and 30 ug/l.

3.0 A DISCUSSION OF SOME LIMNOLOGICAL CONCEPTS

Limnology is the study of lakes and is central to the idea of lake management. A basic understanding of limnological concepts is needed to understand why certain lake management measures are effective in improving water quality and why other measures fail. This portion of the report presents some important limnological concepts and ideas for the lay person. Those disinterested readers may directly proceed to Section 4.0, Description of the Watershed.

3.1 THE LIMITING NUTRIENT CONCEPT

The idea of nutrient limitation is basic to terrestrial (dry-land) and aquatic biology. All plants that use light as an energy source need nutrients and a source of carbon (eg., carbon dioxide) to grow. When a nutrient is present in quantities small enough to limit or reduce plant growth it is considered the limiting nutrient. By reducing the amount of nutrients entering Diamond Lake, the quantity of plant biomass (material) can, in theory, be reduced. The analogy is the use of fertilizers by farmers on crops to increase yield or on an urban lawn to increase the growth of grass.

Phosphorus and nitrogen are the two nutrients potentially limiting plant growth in lakes; although light, a carbon source, or a lack of micronutrients can also limit plant growth. Therefore, it is important to know the concentrations or amount of nutrients per volume of water, for various forms of phosphorus and nitrogen. The ratio of nitrogen to phosphorus is also important. Generally, lakes with inorganic nitrogen to inorganic phosphorus ratios exceeding approximately 7-10 are considered phosphorus limited (Walker, 1986). Lakes with a ratio less than 7 are considered nitrogen limited. One way to interpret this information is that if a lake is phosphorus limited, the addition of 1 μg/l of inorganic phosphorus can potentially result in 500 μg/l of plant biomass, or 500 times the weight in living algae. The addition 1 μg/l of inorganic nitrogen can potentially result in 71 μg/l of plant biomass, or 71 times the weight in living algae if the lake is nitrogen limited (Wetzel, 1983).

In reality, it is difficult to control the amount of nitrogen entering a lake. Nitrogen gas is a major component in the atmosphere and many blue-green algae can directly use or "fix" atmospheric nitrogen. For this reason, most lake management strategies concentrate on controlling the amount of phosphorus entering a lake. At certain times of the year nitrogen may limit plant growth, while during other times of the year phosphorus or the availability of light may limit growth.

3.2 Trophic Status

The trophic status of a lake is an index or measure of the potential for plant growth, the amount of oxygen, and a general yardstick of nutrient availability (which leads to plant growth) within a lake. In short, it is an index of water quality. A variety of methods have been developed to measure trophic status. **Figure 3-1** presents two commonly used trophic state indices: the Carlson's Trophic State Index and an index derived from the National Eutrophication Survey. These indices (and other techniques) can be used to classify lakes as (in order of "decreasing" water quality as):

- Oligotropic
- Mesotrophic
- Eutrophic
- Hypereutrophic

These classifications are really a measure of a lake's ability to produce plant material. A common restoration goal is stated as the desire to "move" from one tropic status to another (e.g., eutrophic to mesotrophic).

3.3 Spatial Variation in Lake Water Quality

Water quality varies not only within a season and between years, but spatially within a specific lake. For example, water quality in one portion of a lake (e.g., a bay) can differ from the quality in another portion of that lake (e.g., the main lake). This difference in water quality (and the growth of algae) is usually due to currents within the lake, the shape of the lake basin, and the location of nutrient inputs. A user in one portion of the lake may "see" different water quality than a user in another portion of the lake. Recognizing the spatial variation in water quality is especially important if the total phosphorus concentration or concentration of algae is used as a measure of trophic status in applying models to evaluate lake management alternatives and in establishing in-lake water quality goals. Any model used to evaluate management alternatives should account for the spatial difference in water quality. Most models predict or forecast spatially averaged conditions within a lake either over a growing season or a period of one year.

Figure 3.1 Two Common Trophic State Indices

Carlson's Trophic State Index

Trophic State Index	Using Secchi Disk Depth (m)	Using Surface Total Phosphorus Concentration (mg/l)	Using Chlorophyll-a Concentration (mg/l)
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.34
30	8	6	0.94
35			
40	5	12	2.61
50	2	24	7.23
52			
60	1	48	20
67			
70	0.5	96	55.5
80	0.25	192	154
90	0.125	384	426
100	0.0625	768	1180

Oligotrophic
Mesotrophic
Eutrophic
Hypereutrophic

TSI (secchi) = 60-14.41*ln (secchi depth)
TSI (total p) = 14.42*ln (total phosphorus concentration) + 4.15
TSI (chl-a) = 9.81 * ln (chl-a concentration) + 30.6

National Eutrophication Survey Trophic State Index

Trophic State	Chlorophyll-a Concentration (ug/l)	Total Phosphorus Concentration (mg/l)	Secchi Disk Depth (m)
Oligotrophic	< 7	< 10	> 3.7
Meostrophic	7 - 12	10 - 12	2.0 - 3.7
Eutrophic	> 12	> 20	< 2.0

3.4 IN-LAKE WATER QUALITY GOALS

An in-lake water quality goal is a concentration level established by the lake users or a water quality standard, which is used to evaluate the amount of nutrient reduction needed to attain the designated uses. Most often an in-lake water quality goal is expressed in terms of the annual mean (or growing season mean) total phosphorus or chlorophyll-a concentration within a lake for a "typical" year; i.e., typical with respect to the amount of water and nutrients entering the lake. The goal should be attainable and reasonable based on how the lake is used. Better water quality is needed if swimming is desired than if irrigation is the sole use of the water, for example. The water quality goal for a lake might be to increase the number of days the lake is swimmable and fishable.

3.5 LAKE MORPHOMETRY

Lake morphometry describes the physical characteristics of a lake basin; i.e., the maximum depth of the lake, the average depth, and the volume. Physical characteristics are important because lake morphometry influences water quality and are used as input to the water quality model. Lakes with smaller volumes that flush rapidly or have a large amount of water entering compared to the lake volume, generally have lower algae concentrations.

Figures 3-2 and 3-3 show the relationship between percent volume and percent area (respectively) versus depth. These graphs show that a considerable portion of Diamond Lake is shallow. Due to this shallow depth, light on most areas of the lake

Figure 3.2 Lake depth versus percentage of surface area

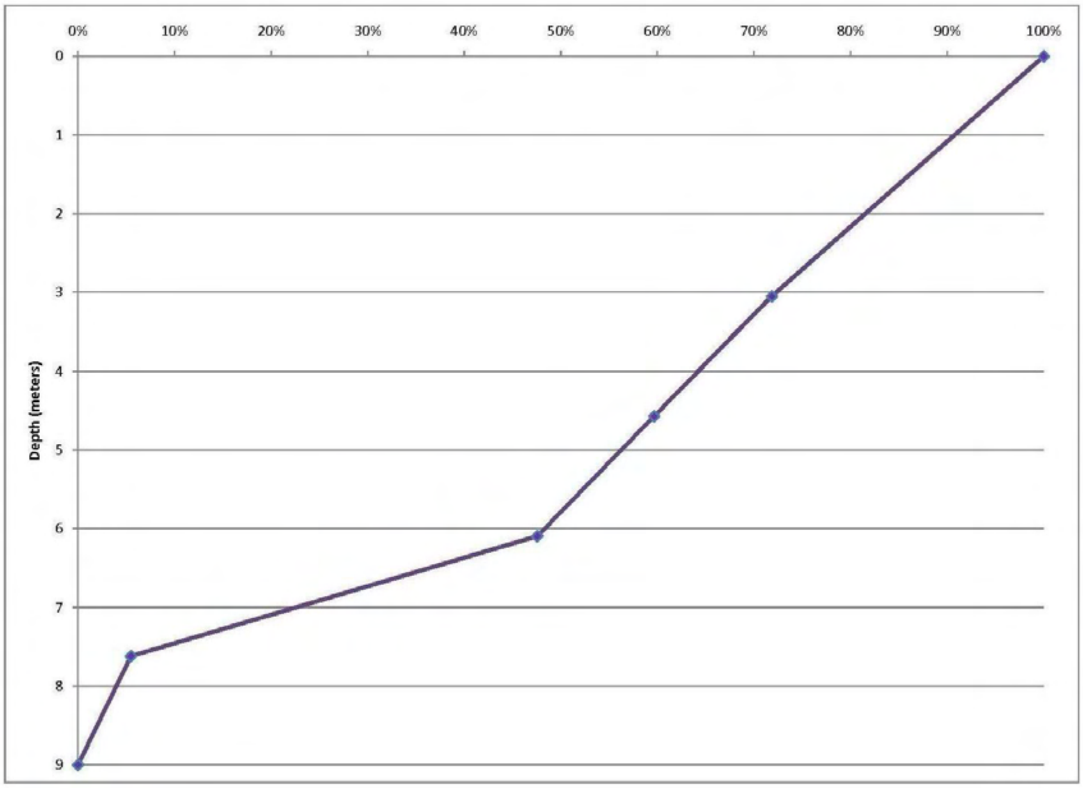
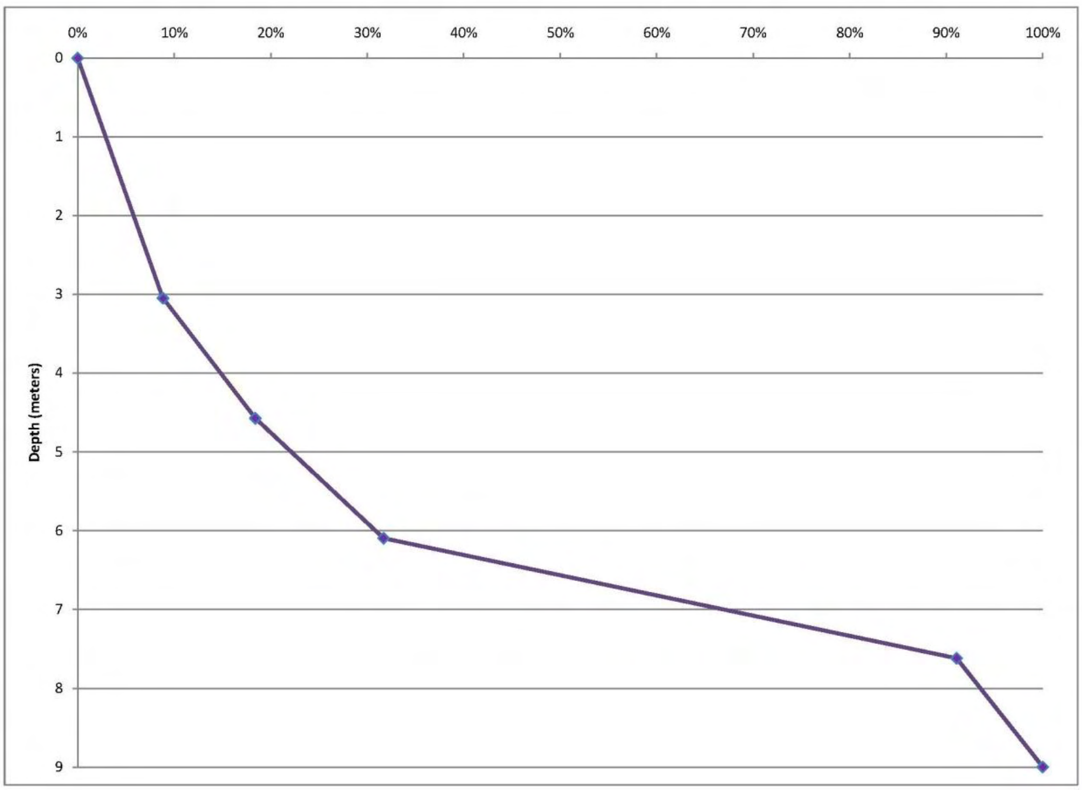


Figure 3.3 Lake depth versus percentage of lake volume



likely penetrates to the bottom and reaches growing plants, provided light penetrations is not prohibited by the clarity of the water.

3.6 TEMPORAL VARIATION IN LAKE WATER QUALITY

Water quality varies with not only the location within a lake, but also within a season and between years. Even though a goal is set for a lake on an annual basis, it does not guarantee water quality will always be suitable or ideal on a specific day. Use of mean annual or growing season concentrations to describe in-lake water quality and for goal setting can be deceiving. There may be periods during the year when water quality is poorer than desired. Similarly, there may be periods during the year when water quality is better than the goal established.

3.7 THE HYDROLOGIC BUDGET

A hydrologic budget is an accounting of the amount of water entering and leaving a lake. Naturally, the amount of water entering and leaving Diamond Lake varies from year-to-year depending on the amount of rainfall and runoff. The hydrologic budget is important because the various sources of water can contain different amounts of nutrients. The hydrologic budget is also important because it is used during the water quality modeling analysis to set water quality goals. A hydrologic budget accounts for "gains" in water like precipitation runoff and groundwater inflow. A budget also accounts for "losses" like evaporation, surface outflow, and groundwater outflow. Each of these affect the volume of water in the lake (storage).

Residence time is an important concept when considering how a lake responds to excess nutrients. The residence time can be defined based upon how long on average it takes the volume of the lake to be replaced (hydraulic residence time) or how long a substance like phosphorus is retained (mass residence time). Lakes with a short residence time respond more rapidly to a change in nutrient load than lakes with a longer residence time. Lakes that have a longer mass residence time retain nutrients longer and take more time to improve once loads are reduced.

3.8 THE NUTRIENT BUDGET

Like a hydrologic budget, which is an accounting of water, a nutrient budget is an accounting of the amount or mass of nutrients entering and leaving Diamond Lake. Often the term "load" is used. A load is the amount or mass of a substance passing a specific location during some period of time. Loads are expressed in units of mass per time (e.g., kg/year, lb/year) and estimated by considering the concentration of a substance in the water and the amount of water over a timeframe. In other words, a load is computed as the concentration times the flow. A high load may result from a high flow and low concentration. Or, a high load may result from a high concentration and a low flow. Both concentration and flow are needed when calculating loads.

The concept of nutrient loading to a lake is key to understanding how a lake works. Generally, the lower the loading of nutrients like phosphorus and nitrogen the less plant growth lake will have. The strategy of most lake management plans is to reduce nutrient loading. Strategies generally concentrate on reducing the phosphorus load because phosphorus is usually the limiting nutrient in lakes and is typically more easy to control than nitrogen. The large atmospheric source of nitrogen and the ability of some algae to use elemental nitrogen makes control difficult. Lake management strategies are dictated by the source and magnitude of the nutrient load.

3.9 WATER QUALITY MODELING

A water quality model is simply a mathematical representation of the processes occurring within a lake; i.e., a set of mathematical equations "packaged" together. Models may be simplistic or complex. Simple models generally treat a lake as a "black box" and balance the nutrient load entering and leaving a lake. Algae "grow" in the black box model, based on observations from other lakes or empiricism. Complex models use equations to represent specific processes within a lake like the growth or settling of algae. Often, these equations are based on measurements made within the laboratory, biological, physical, or chemical theory.

The power of water quality modeling is that it allows the prediction of water quality within a lake (in this case, Diamond Lake) under assumed conditions; i.e., assumed nutrient loadings if various management measures are implemented. For example, a model can be used to evaluate the amount of phosphorus reduction needed within a certain subarea to attain a specific in-lake phosphorus concentration.

3.10 WATER TRANSPARENCY

Water transparency plays an important role in shaping public perception of a lake's water quality. Eutrophic and highly productive lakes are not very clear because aquatic plants such as algae and suspended material reduce light penetration and transparency. Water transparency values are usually determined by Secchi disk readings; the greater the depth, the greater the transparency. Suspended solid and organic matter result in color and decreased transparency. Secchi disk transparency generally correlates to about 1 to 15 % light transmission.

3.11 LAKE STRATIFICATION

Water temperature and "stratification" is one of the factors that govern physical, chemical, and biological processes in a lake. During the summer, the sun warms the lake surface and creates a difference in water density between the surface and bottom of the lake. In deeper lakes, the water density differences between the surface and bottom may be great enough to prevent the wind from thoroughly mixing the lake. The result is a seasonally stratified lake consisting of three layers: a warmer surface layer (epilimnion), a transitional layer characterized by a rapid change in water temperature (metalimnion), and a deeper, colder zone (hypolimnion). A lake may also stratify during the winter. In this case, however, the epilimnion (or surface water) is generally colder than the hypolimnion. Stratified lakes are then thoroughly mixed by wind as the water temperature and density become uniform with depth during the spring and fall.

Generally, lakes that do not stratify are shallower and tend to have greater amounts of phosphorus and algae. Lakes that stratify tend to have a greater proportion of the phosphorus load released from sediments, because of the lack of oxygen in the deepest locations during the summer months.

4.0 DESCRIPTION OF THE WATERSHED

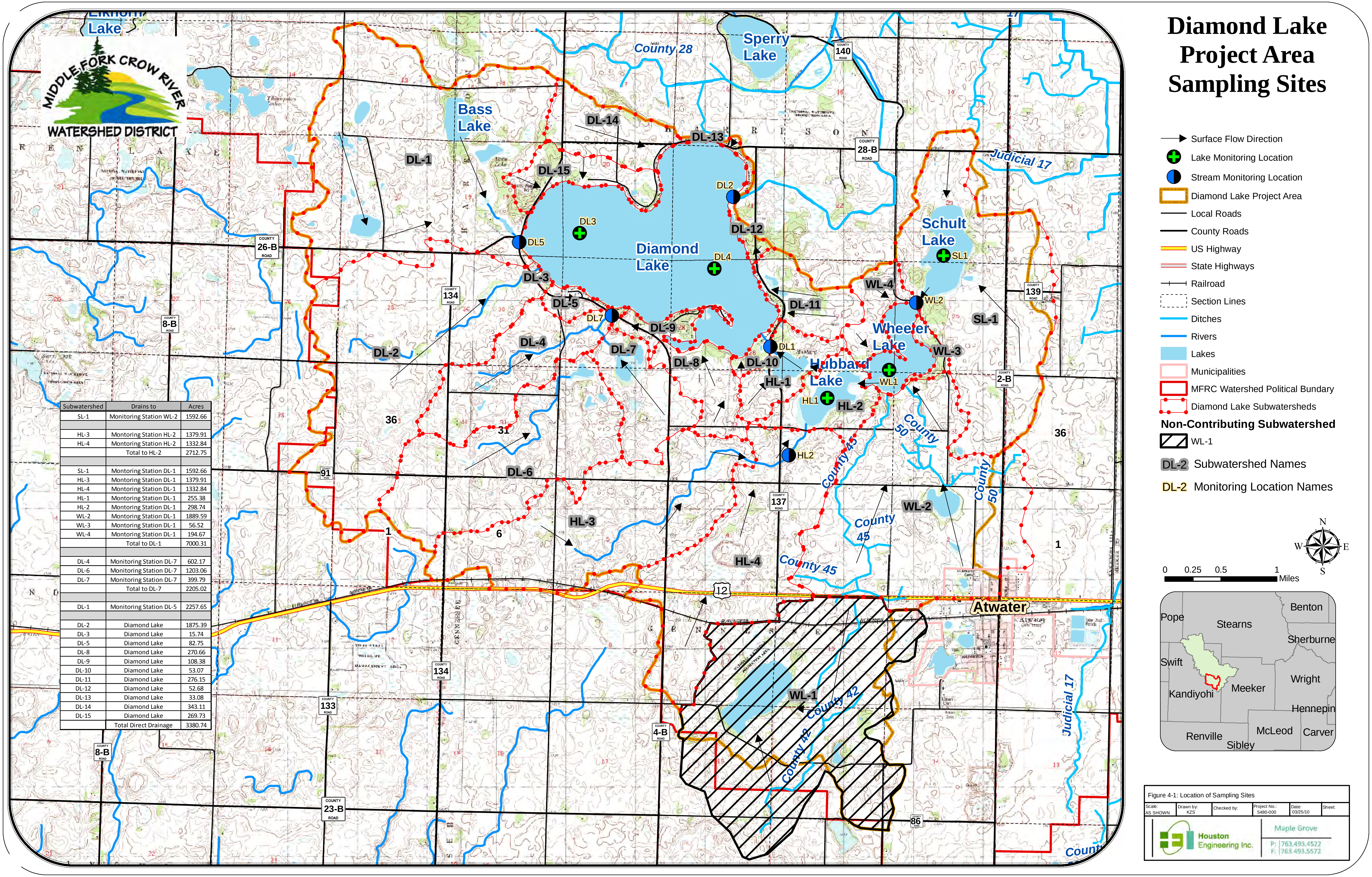
The Diamond Lake watershed area is 19,148 acres (29.9 square miles) and is characterized by a complex drainage pattern (see **Figure 4-1**). Land use in the watershed is 60 percent agricultural **(Figure 4-2)** and there are three public drainage systems. The public drainage systems consist of both tile and open channels that outlet into a chain of shallow lakes (Hubbard, Schultz and Wheeler) upstream from Diamond Lake. Atwater is the only city within the watershed and only a small portion is in the watershed. There are approximately 30 animal feedlots in the watershed, based upon information available from Kandiyohi County. The lake has two public accesses and one county park with a large campground.

Diamond Lake is located within the Upper Mississippi River major basin. **Figure 4-1** shows the watershed upstream of the lake, the direction of surface flow, and the location of the public drainage systems. In excess of 2,000 acres of the area upstream of Diamond Lake near Atwater is a "closed basin" meaning it does not contribute surface water runoff to Diamond Lake.

The area surrounding Diamond Lake is developed with 365 permanent and seasonal residences and nearly the entire shoreline in residential land use. At least 70% of the houses were built prior to 1996 and, therefore, may have inadequate separation of the Subsurface Sewage Treatment System (SSTS) with the seasonal high water table. The Diamond Lake Area Recreation Association (DLARA) is very active. Current activities include working on a community-based decision process for sewage treatment and assisting in monitoring and data collection.

The MPCA placed Diamond Lake on the 303(d) list because excess nutrients impair aquatic life and recreational use. The various forms of phosphorus (total and dissolved) and nitrogen (inorganic and organic) are the nutrients (i.e., stressors) likely leading to an increase in plant biomass and poor water quality. Phosphorus is the nutrient of greatest interest as it is the nutrient limiting primary productivity within most freshwater aquatic systems. Excess nutrients result in an increase in plant biomass and a decrease in water clarity. The amount of chlorophyll-a is used as the metric for plant biomass and secchi disk visibility as the metric for water clarity.

Diamond Lake Project Area Sampling Sites



Subwatershed	Drains to	Acres
SL-1	Monitoring Station WL-2	1592.66
HL-3	Montoring Station HL-2	1379.91
HL-4	Montoring Station HL-2	1332.84
	Total to HL-2	2712.75
SL-1	Montoring Station DL-1	1592.66
HL-3	Montoring Station DL-1	1379.91
HL-4	Montoring Station DL-1	1332.84
HL-1	Montoring Station DL-1	255.38
HL-2	Montoring Station DL-1	298.74
WL-2	Montoring Station DL-1	1889.59
WL-3	Montoring Station DL-1	56.52
WL-4	Montoring Station DL-1	194.67
	Total to DL-1	7000.31
DL-4	Monitoring Station DL-7	602.17
DL-6	Monitoring Station DL-7	1203.06
DL-7	Monitoring Station DL-7	399.79
	Total to DL-7	2205.02
DL-1	Monitoring Station DL-5	2257.65
DL-2	Diamond Lake	1875.39
DL-3	Diamond Lake	15.74
DL-5	Diamond Lake	82.75
DL-8	Diamond Lake	270.66
DL-9	Diamond Lake	108.38
DL-10	Diamond Lake	53.07
DL-11	Diamond Lake	276.15
DL-12	Diamond Lake	52.68
DL-13	Diamond Lake	33.08
DL-14	Diamond Lake	343.11
DL-15	Diamond Lake	269.73
	Total Direct Drainage	3380.74

Figure 4-1: Location of Sampling Sites

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AS SHOWN	KZS		5480-000	03/25/10	

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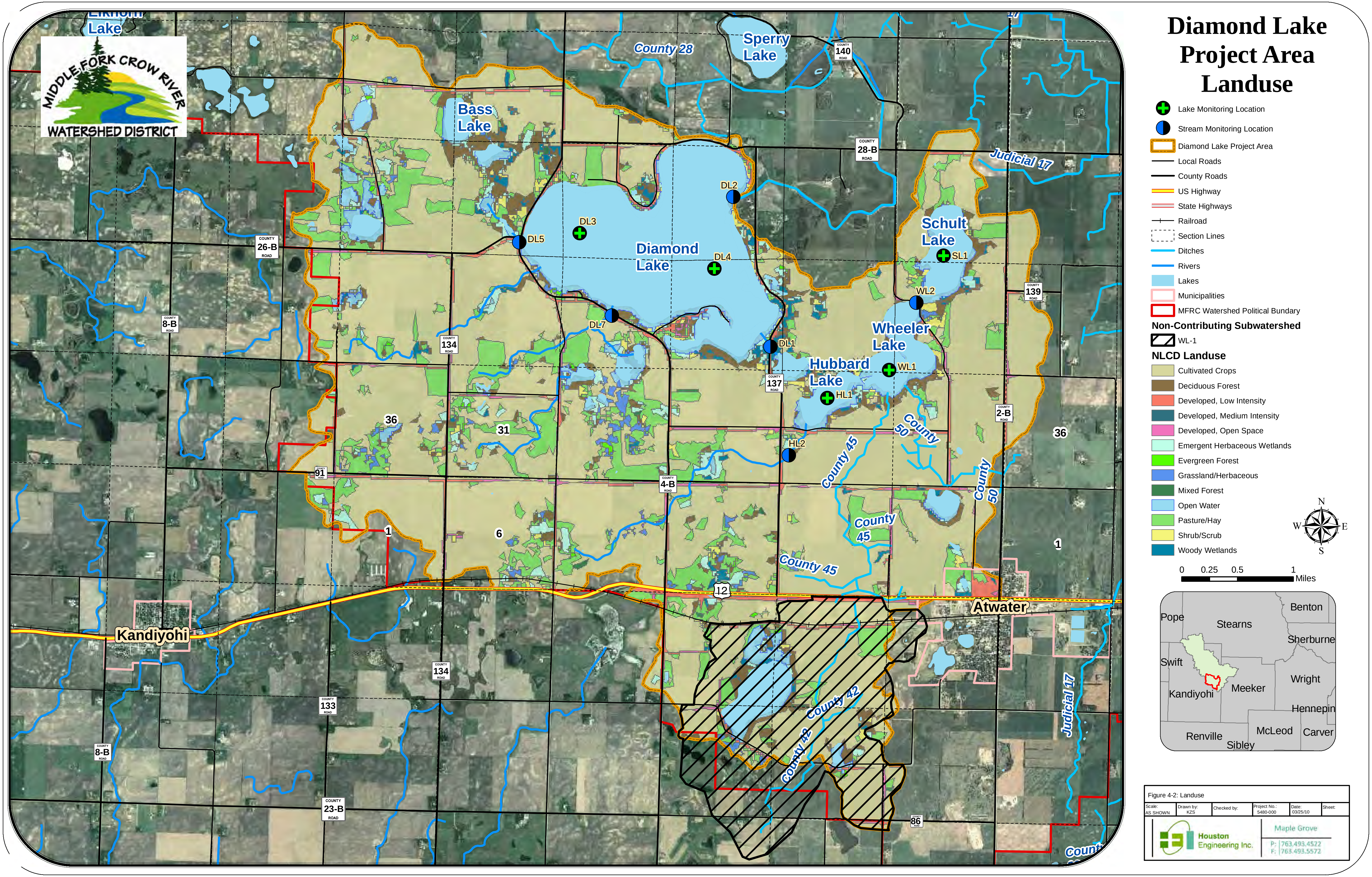

Diamond Lake Project Area Landuse
Lake Monitoring Location
Stream Monitoring Location
Diamond Lake Project Area
Local Roads
County Roads
US Highway
State Highways
Railroad
Section Lines
Ditches
Rivers
Lakes
Municipalities
MFRC Watershed Political Bundary
Non-Contributing Subwatershed
WL-1
NLCD Landuse
Cultivated Crops
Deciduous Forest
Developed, Low Intensity
Developed, Medium Intensity
Developed, Open Space
Emergent Herbaceous Wetlands
Evergreen Forest
Grassland/Herbaceous
Mixed Forest
Open Water
Pasture/Hay
Shrub/Scrub
Woody Wetlands
0 0.25 0.5 1 Miles
N S E W
Pope
Stearns
Benton
Sherburne
Swift
Kandiyohi
Meeker
Wright
Hennepin
Renville
Sibley
McLeod
Carver
MIDDLE FORK CROW RIVER WATERSHED DISTRICT
Elkhorn Lake
Sperry Lake
Bass Lake
Diamond Lake
Schult Lake
Wheeler Lake
Hubbard Lake
County 28
Judicial 17
County 50
County 45
County 42
Kandiyohi
Atwater
DL1
DL2
DL3
DL4
DL5
DL7
SL1
WL1
WL2
HL1
HL2
Figure 4-2: Landuse
Scale: AS SHOWN
Drawn by: KZS
Checked by:
Project No.: 5480-000
Date: 03/25/10
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Within watersheds characterized by a land use dominated by agricultural products, a considerable portion of the total phosphorus is generally associated with sediment and solids. The source of sediment and solids includes erosion from the landscape, from stream banks and the stream bed and from bluffs. Various data can be used to identify the potential sources of sediment, solids, and therefore phosphorus. Several characteristics of the contributing drainage area to Diamond Lake potentially affect water quality. These characteristics, including the land forms and soils within the drainage area, represent potential water quality risk factors. Several risk factors were identified and mapped within the watershed, including:

- Land slope;
- Hydric soils;
- Wetlands abundance;
- Soil erodibility potential from water;
- Soil erodibility from wind; and
- Feedlot locations.

Steeper slopes tend to increase the rate of water movement across the landscape and result in greater erosion. Most areas have fairly mild slopes. However, some areas exceed 15% (**Figure 4-3**), primarily around the upstream lakes and west of Diamond Lake.

Hydric soils tend to be those soils that are poorly or very poorly drained, have a seasonal high water table near or in close proximity to the land surface, and tend to be frequently ponded for a relatively long duration during the growing season. The locations of hydric soils can be used as one index of locations where wetlands once existed or currently exist. **Figure 4-4** shows that hydric soils comprise a substantive portion of the drainage area contributing runoff to Diamond Lake. **Figure 4-5** shows the locations of wetlands. Comparison of **Figure 4-4** and **Figure 4-5** suggests many historic wetland areas have been drained. Wetlands are typically considered to have water quality benefits, although the extent varies depending upon the type of wetland. Wetlands generally tend to reduce the amount of sediment and particulate phosphorus because of settling as the water is stored.

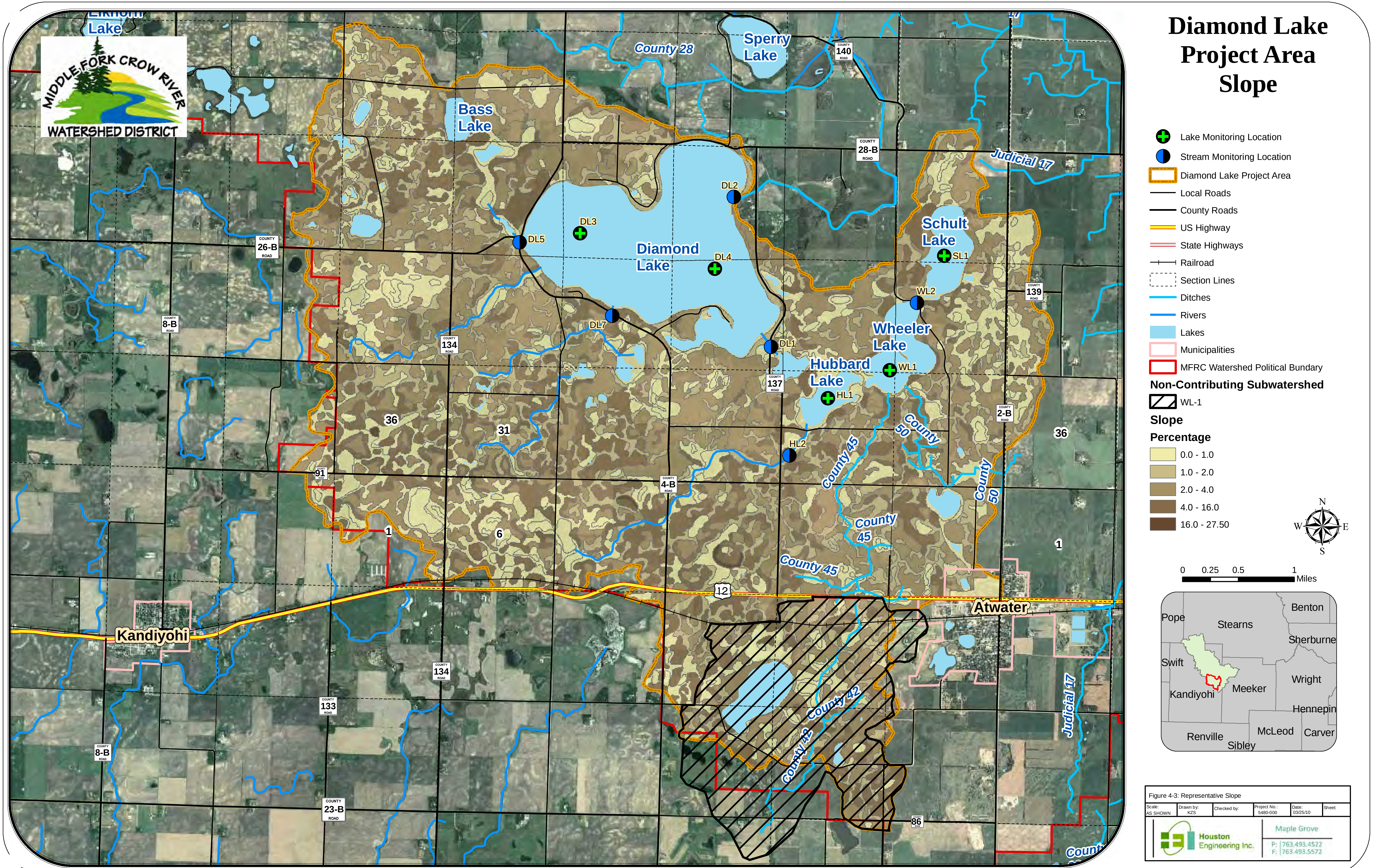
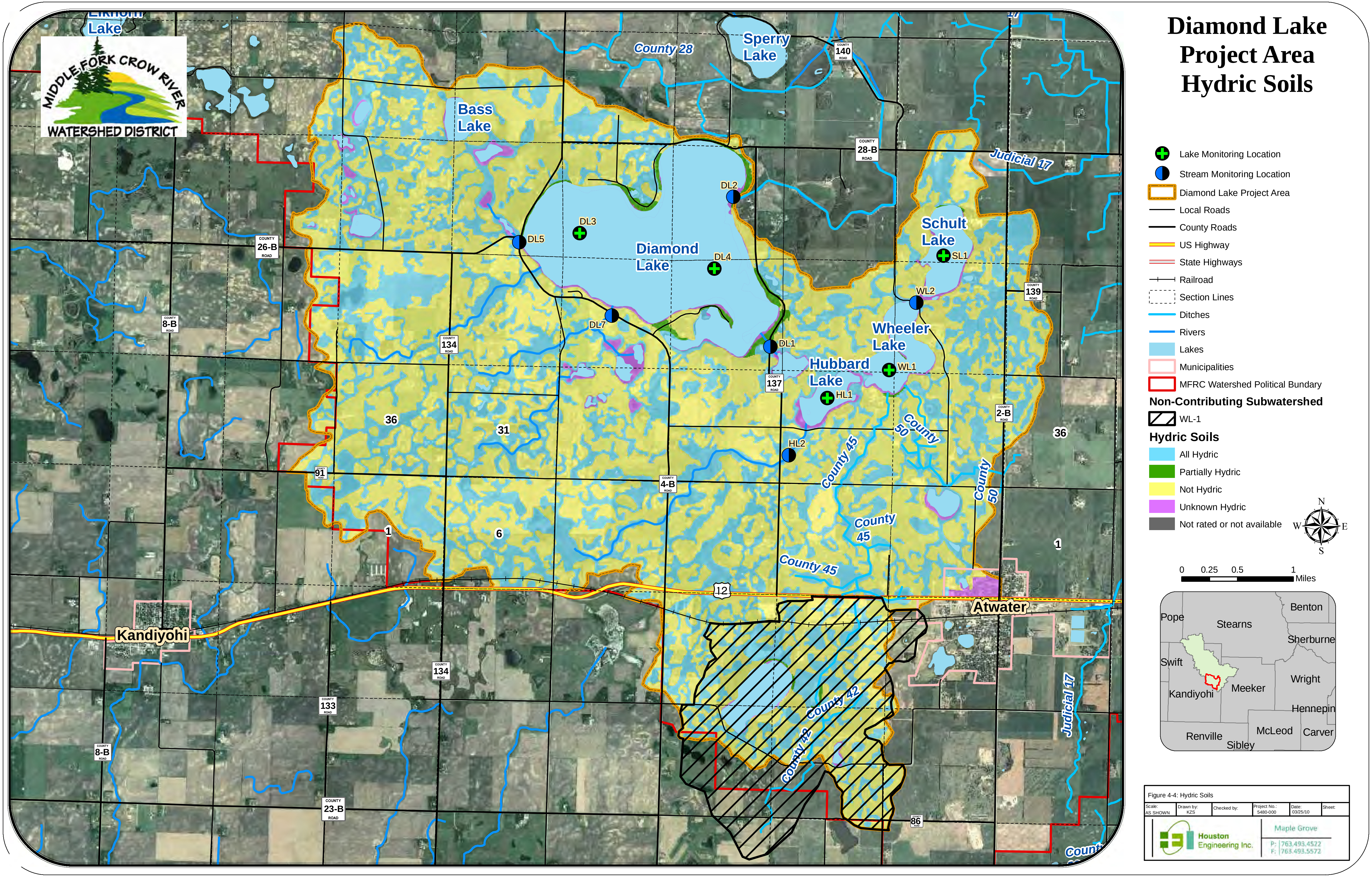


Figure 4-3: Representative Slope



Diamond Lake Project Area Hydric Soils
Lake Monitoring Location
Stream Monitoring Location
Diamond Lake Project Area
Local Roads
County Roads
US Highway
State Highways
Railroad
Section Lines
Ditches
Rivers
Lakes
Municipalities
MFRC Watershed Political Bundary
Non-Contributing Subwatershed
WL-1
Hydric Soils
All Hydric
Partially Hydric
Not Hydric
Unknown Hydric
Not rated or not available
N
S
E
W
0 0.25 0.5 1 Miles
Pope
Stearns
Benton
Sherburne
Swift
Kandiyohi
Meeker
Wright
Hennepin
Renville
McLeod
Carver
Sibley
MIDDLE FORK CROW RIVER WATERSHED DISTRICT
Diamond Lake
Bass Lake
Sperry Lake
Schult Lake
Wheeler Lake
Hubbard Lake
Elkhorn Lake
DL1
DL2
DL3
DL4
DL5
DL7
SL1
WL1
WL2
HL1
HL2
County 28
Judicial 17
County 45
County 50
County 42
Kandiyohi
Atwater
12
26-B
8-B
134
91
4-B
137
28-B
140
139
2-B
133
23-B
86
36
31
6
1
Figure 4-4: Hydric Soils
Scale: AS SHOWN
Drawn by: KZS
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Project No.: 5480-000
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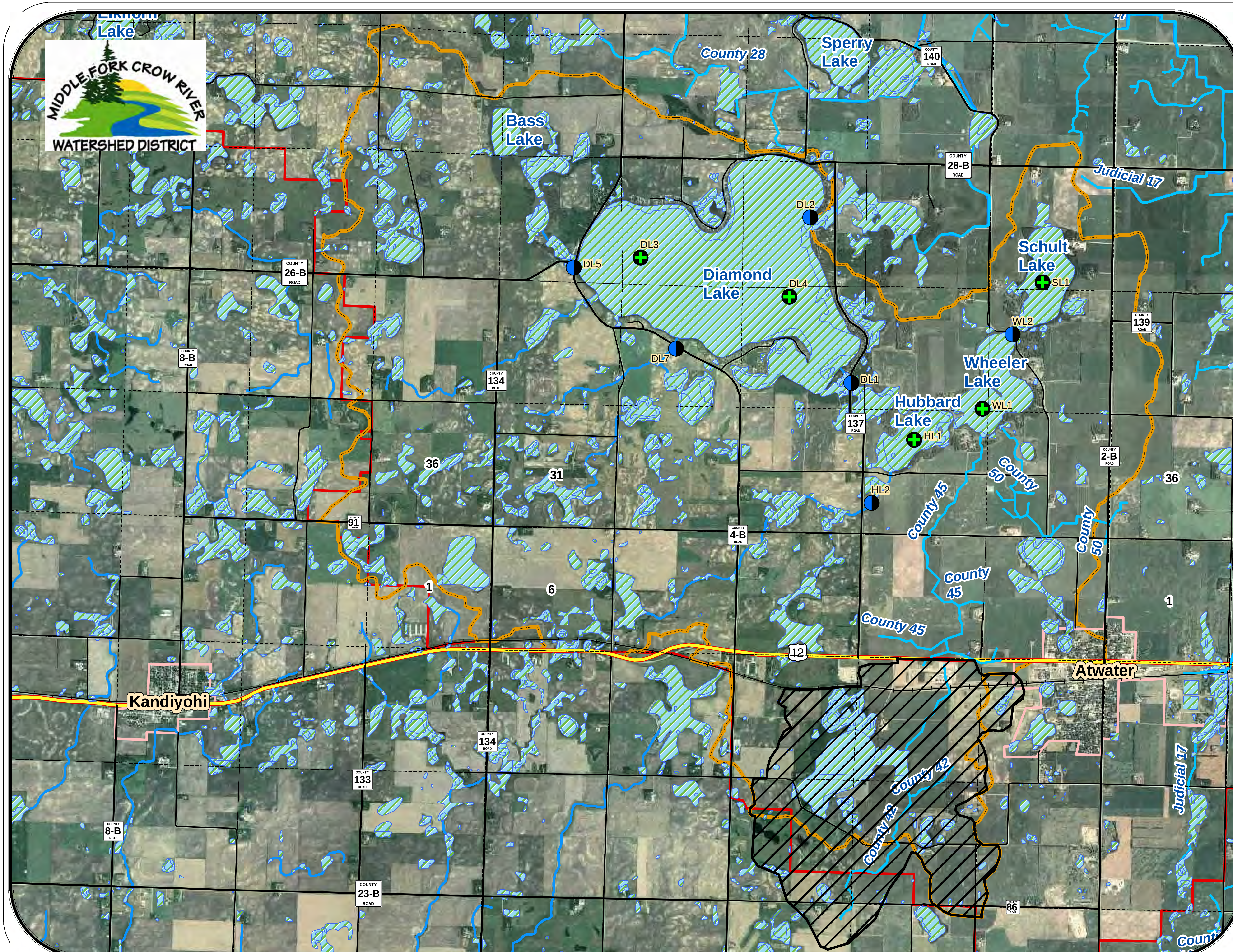
Diamond Lake Project Area Wetlands



Lake Monitoring Location
Stream Monitoring Location
Diamond Lake Project Area
Local Roads
County Roads
US Highway
State Highways
Railroad
Section Lines
Ditches
Rivers
Lakes
Wetlands
Municipalities
MFRC Watershed Political Bundary

Non-Contributing Subwatershed

WL-1

N W E S

0 0.25 0.5 1 Miles

Pope, Stearns, Benton, Sherburne, Swift, Kandiyohi, Meeker, Wright, Hennepin, Renville, Sibley, McLeod, Carver

Figure 4-5: Wetlands					
Scale: AS SHOWN	Drawn by: KZS	Checked by:	Project No.: 5480-000	Date: 03/25/10	Sheet:

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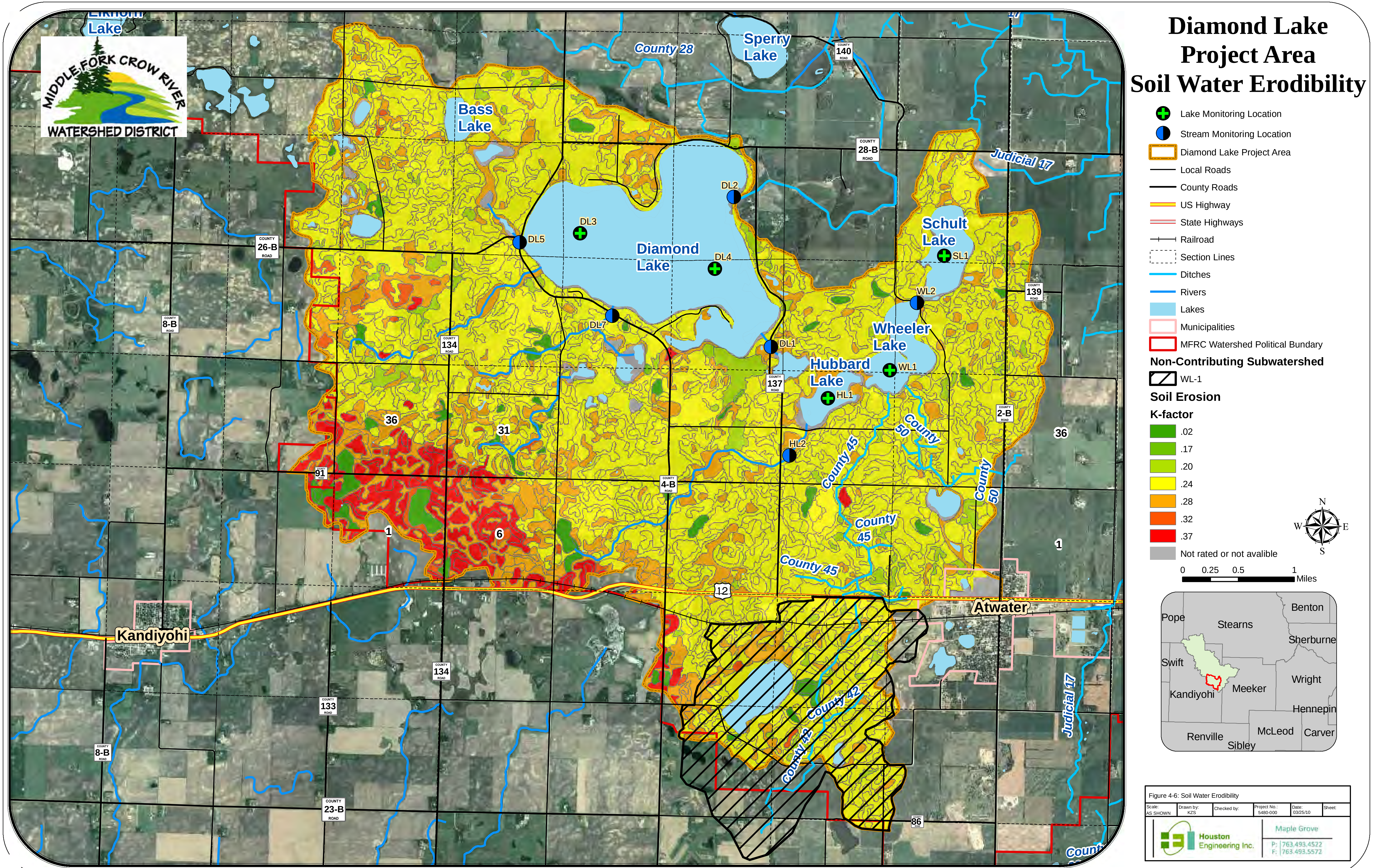
F: 763.493.5572

The K- factor is a relative index of the susceptibility of bare, cultivated soil for particle detachment and transport by rainfall. Soil scientSSTS use the "K-factor" (in tons per acre) as a measure of water erodibility. Soils high in clay have low K-factors, generally ranging from 0.05 to 0.15 tons per acre, because the soils are resistant to detachment. Coarse textured soils, such as sandy soils, also have a low K-factor, generally ranging from 0.05 to 0.2 tons per acre. The reason is these soils typically have low runoff even though particle detachment occurs readily. Silt loams, which are medium textured soils, have a moderate K-factor, which generally ranges from 0.25 to 0.4 tons per acre. These soils are moderately susceptible to particle detachment and generate moderate runoff. Soils having a high silt content are the most water erodible and can be easily detached. These soils tend to crust and produce high rates of runoff and have a K-factor greater than 0.4 tons per acre. Potential risk for soil loss due to water erosion in the watershed is moderate, generally ranging from 0.20 – 0.24 tons per acre (**Figure 4-6**). Areas of high water erosion are located south-west of Diamond Lake within the upper portions of subwatersheds DL-2, DL-6 and HL-3.

The potential risk for soil loss due to wind erosion is generally moderate (**Figure 4-7**). Soils types are characterized with regard to wind erodibility. The wind erodibility index is the theoretical, long-term amount of soil lost per year through wind erosion. The index is based upon the assumption that the soil is bare, lacks a surface crust, occurs in an unsheltered position, and is subject to certain weather conditions. The wind erodibility index does not reflect the frequency of tillage or conservation practices. **Figure 4-7** suggest many of the soils in the watershed are susceptible to wind erosion.

Kandhioyi County maintains information about the location of animal feedlots. Animal feedlots are located through the drainage area which contributes runoff to Diamond Lake (**Figure 4-8**). Some are located within close proximity to the lake indicating they have the potential to directly influence water quality.

Landfills, chemical storage facilities, hazardous waste sites, and similar facilities can also pose a risk to water quality. A review of the various Environmental Protection Agency (EPA) databases (e.g., CERCLIS, water discharge permits, toxic release inventories (http://www.epa.gov/enviro/) shows that the only potential point source in the watershed is an ethanol facility in Atwater. This facility is located within a non-contribution drainage area. Additional point sources or other potential pollutant sources are absent within the drainage area upstream from Diamond Lake.


Diamond Lake
Project Area
Soil Water Erodibility
Lake Monitoring Location
Stream Monitoring Location
Diamond Lake Project Area
Local Roads
County Roads
US Highway
State Highways
Railroad
Section Lines
Ditches
Rivers
Lakes
Municipalities
MFRC Watershed Political Bundary
Non-Contributing Subwatershed
WL-1
Soil Erosion
K-factor
.02
.17
.20
.24
.28
.32
.37
Not rated or not avalible
0 0.25 0.5 1
Miles
N
E
S
W
MIDDLE FORK CROW RIVER
WATERSHED DISTRICT
Diamond Lake
Bass Lake
Sperry Lake
Schult Lake
Wheeler Lake
Hubbard Lake
Elkhorn Lake
DL1
DL2
DL3
DL4
DL5
DL7
SL1
WL1
WL2
HL1
HL2
County 28
Judicial 17
County 45
County 50
County 42
Kandiyohi
Atwater
Pope
Stearns
Benton
Sherburne
Swift
Kandiyohi
Meeker
Wright
Hennepin
Renville
Sibley
McLeod
Carver
Figure 4-6: Soil Water Erodibility
Scale: AS SHOWN
Drawn by: KZS
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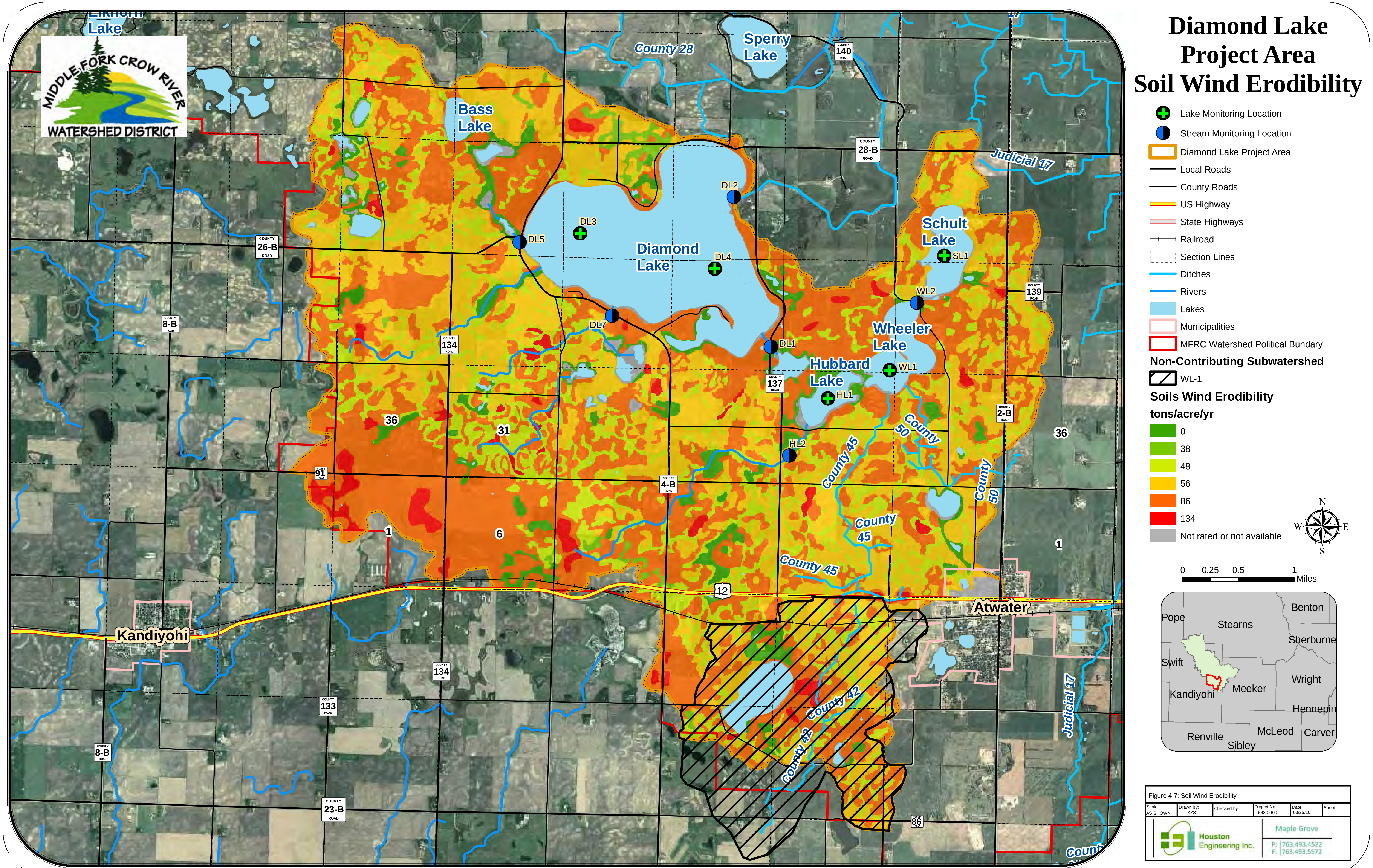

Diamond Lake Project Area Soil Wind Erodibility
Lake Monitoring Location
Stream Monitoring Location
Diamond Lake Project Area
Local Roads
County Roads
US Highway
State Highways
Railroad
Section Lines
Ditches
Rivers
Lakes
Municipalities
MFRC Watershed Political Bundary
Non-Contributing Subwatershed
WL-1
Soils Wind Erodibility
tons/acre/yr
0
38
48
56
86
134
Not rated or not available
0 0.25 0.5 1 Miles
N
S
E
W
MIDDLE FORK CROW RIVER WATERSHED DISTRICT
Diamond Lake
Bass Lake
Sperry Lake
Schult Lake
Wheeler Lake
Hubbard Lake
Elkhorn Lake
DL1
DL2
DL3
DL4
DL5
DL7
SL1
WL1
WL2
HL1
HL2
County 28
Judicial 17
County 45
County 50
County 42
Kandiyohi
Atwater
Pope
Stearns
Benton
Sherburne
Swift
Wright
Kandiyohi
Meeker
Hennepin
Renville
McLeod
Carver
Sibley
Figure 4-7: Soil Wind Erodibility
Scale: AS SHOWN
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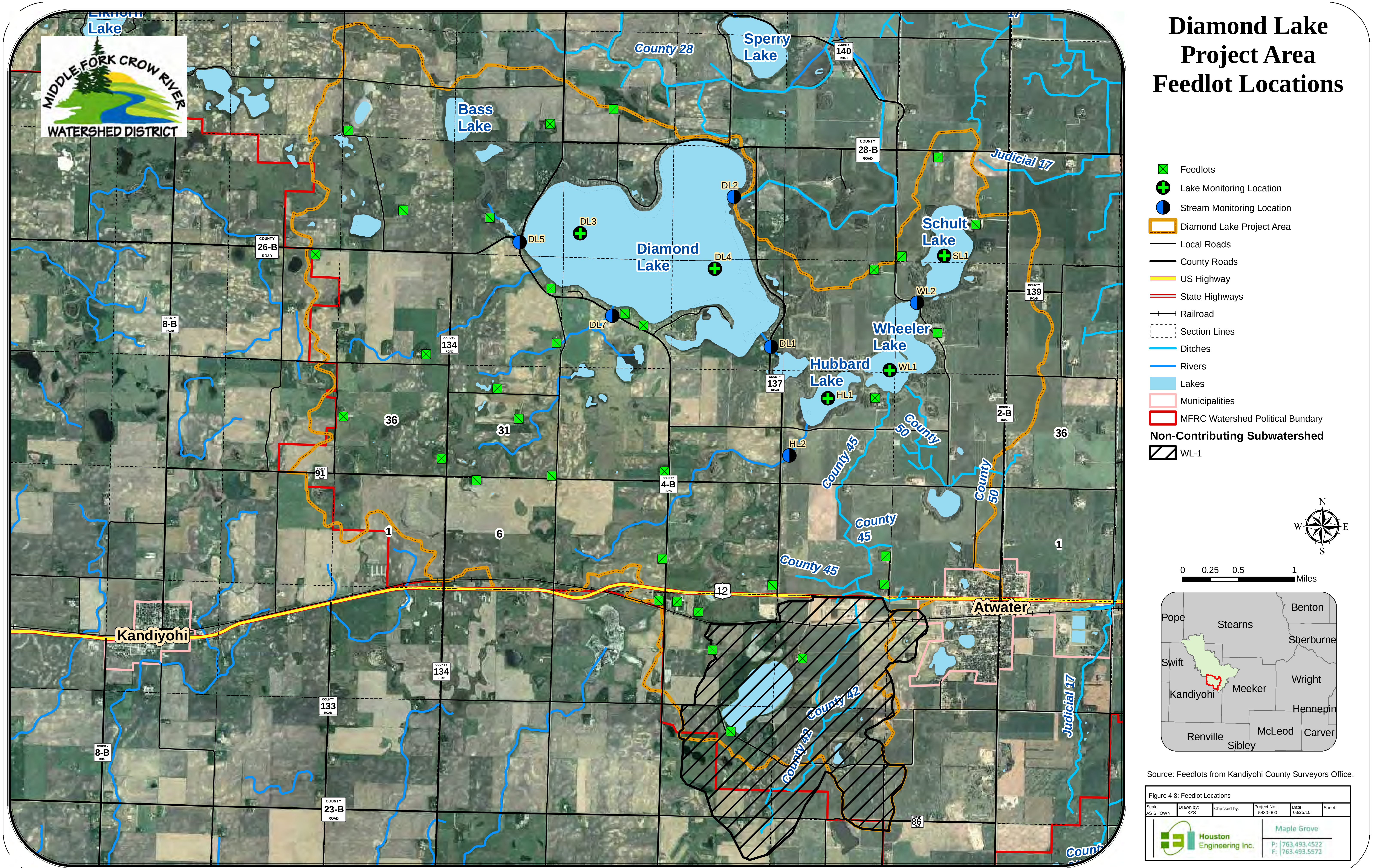

Diamond Lake Project Area Feedlot Locations
Feedlots
Lake Monitoring Location
Stream Monitoring Location
Diamond Lake Project Area
Local Roads
County Roads
US Highway
State Highways
Railroad
Section Lines
Ditches
Rivers
Lakes
Municipalities
MFRC Watershed Political Bundary
Non-Contributing Subwatershed
WL-1
0 0.25 0.5 1 Miles
N
E
S
W
Pope
Stearns
Benton
Sherburne
Swift
Kandiyohi
Meeker
Wright
Hennepin
Renville
Sibley
McLeod
Carver
Source: Feedlots from Kandiyohi County Surveyors Office.
Figure 4-8: Feedlot Locations
Scale: AS SHOWN
Drawn by: KZS
Checked by:
Project No.: 5480-000
Date: 03/25/10
Sheet:
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F: 763.493.5572
MIDDLE FORK CROW RIVER WATERSHED DISTRICT
Diamond Lake
Sperry Lake
Bass Lake
Schult Lake
Wheeler Lake
Hubbard Lake
Elkhorn Lake
County 28
Judicial 17
County 45
County 50
County 42
DL1
DL2
DL3
DL4
DL5
DL7
SL1
WL1
WL2
HL1
HL2
Kandiyohi
Atwater
12
36
31
6
1

5.0 PROBLEM STATEMENT

The primary water quality problem in Diamond Lake is that it fails to support the designated use for aquatic life and recreation due to excess nutrients. Excess nutrients (the stressor) lead to an increase in algae and some undesirable rooted aquatic plants (e.g., curly leaf pond weed) and reduced water clarity. The water quality of Diamond Lake does not meet the standards established by the MPCA for a deep lake (Class 2B) within the North Central Hardwood Forest Ecoregion.

There are three types of standards used to establish a regulatory limit that supports a designated use: 1) a numeric standard; 2) a narrative standard; and 3) anti-degradation. A numeric standard represents a "safe" concentration for a particular contaminant intended to protect a designated use. The use will be adversely affected if the pollutant concentration exceeds the numeric standard too frequently. Numeric criteria, which form the basis for standards adopted by the MPCA, are defined in federal rules as a recommended minimum water quality standard. A state can establish a more restrictive standard than the numeric criteria.

The second type of standard is the narrative standard. The narrative standard is usually not as easily defined as a numeric standard. Narrative standards involve keeping waters free of unwanted conditions such as oil sheens, floating solids, or algae blooms. The narrative standard may also be interpreted as the physical condition necessary to achieve the designated use. For example, if the designated use is "cold water fish habitat" the surface water temperature and dissolved oxygen levels must remain within a range that can support cold water fish species

The anti-degradation standard pertains to waters that currently have water quality better than the applicable numeric or narrative standards for the designated use. The goal of the anti-degradation standard is to prohibit the degradation of such resources, essentially disallowing a high quality resource from sliding "back" to the level of the numeric standard for the designated use.

The designated use that's impaired within Diamond Lake is aquatic life and recreation. Diamond Lake is located in the North Central Hardwood Forest Ecoregion, but near the boundary with the Western Corn Belt Plains Ecoregion. The eutrophication (and conventional pollutant) standards for a 2B lake within the North Central Hardwood Forest Ecoregion are shown in **Table 5-1.** Diamond Lake has an average depth of 16 feet with a maximum depth of 27 feet. The lake's elevation is controlled by a fixed crest dam. The dam has modified the proportion of littoral area within Diamond Lake compared to historic conditions, indirectly affecting water quality. Diamond Lake is classified as a deep lake, since it exceeds 15 feet in depth.

Table 5-1

Applicable numeric standards for Class 2B lakes, shallow lakes, and reservoirs

Parameter	Standard
Total Phosphorus	40 ug / l June through September average
Chlorophyll-a	14 ug /l June through September average
Secchi disk transparency	Greater than 1.4 meters June through September average
Dissolved oxygen	Not less than 5 mg/L as a daily minimum
pH	minimum of 6.5 and a maximum of 8.5
Turbidity	25 NTU; need more than 20 observations with no more than 10% exceeding 25 NTU
Temperature	No material increase in temperature

6.0 MONITORING PROGRAM METHODS

The intent of the monitoring activities within the Diamond Lake watershed was to obtain representative hydrologic and water quality data for use in characterizing stream and lake water quality, nutrient loads, hydrology and nutrient budgets, and load reduction recommendations. Monitoring activities occurred for a period of approximately two years beginning in April 2008 and ending November 2009. Monitoring was extended for an additional year following the 2008 sampling season because of the low amount of runoff and a desire to obtain results for more "normal" hydrologic conditions. Streamflow monitoring generally began immediately following ice-out in the spring and terminated just prior to freeze-up in November. Lake sampling occurred throughout the entire year, but the number of sampling events were limited during the winter months.

6.1 WATER QUALITY MONITORING

Water quality data from a variety of sources is needed to characterize stream and lake water quality and to develop a mass balance for Diamond Lake. In-lake data are needed to understand the chemistry and biology of the lake system and for calibration of water quality models. Surface runoff data are necessary to characterize the nature of pollutant loading into the lake.

6.1.1 In-Lake Monitoring

Water quality samples were collected at two locations within Diamond Lake (**Figure 4-1**). Two locations were necessary because the shape of lake was anticipated to increase the likelihood of spatially variable water quality. Samples were collected over the deepest locations in the lake.

The number of samples collected at each location differed; this was primarily because only the mixed layer samples collected at DL-3 were analyzed for the various forms of nitrogen, phosphorus, and Chlorophyll-a. Water samples were typically collected at two depths: a surface mixed layer 2-meter composite and a sample near the lake bottom. A beta water bottle was used to collect the sample from near the bottom at about 1-meter above the sediment. Sampling at multiple depths ensured vertical variations in water quality during stratification could be characterized.

Concurrent physical measurements occurred at the time of sample collection. The primary purpose of these physical measurements was to increase understanding of the mixing characteristics of Diamond Lake. Physical measurements included temperature profiles, dissolved oxygen profiles, and the pH and surface specific conductance within the mixed (surface) layer. Water clarity was determined using a secchi disk. Measurements occurred in accordance with accepted Standard Operating Procedures as defined within the Quality Assurance Program Plan (MFCRWD 2008). **Table 6-1** identifies the frequency of in-lake sample collection and the parameters for which each sample was analyzed.

6.1.2 Surface Water Runoff Monitoring

All surface runoff samples collected for water quality analysis were grab samples. No automated equipment was used. Surface water runoff grab samples were collected using a bottle sampler, generally from mid-depth of the stream or open channel. Samples were collected in accordance with accepted Standard Operating Procedures as defined within the Quality Assurance Program Plan (MFCRWD 2008). **Table 6-2** identifies the frequency of stream sample collection and the parameters for which each sample was analyzed.

6.2 HYDROLOGY

Field measurements were also taken to gather information on the hydrology of the watershed. Hydrologic measurements give insight to the water balance around the lake (i.e., the amount of water entering the lake from surface versus groundwater) and are combined with water quality data to compute pollutant loads.

6.2.1 Evaporation

Evaporation accounts for an important component of the overall water budget of Diamond Lake, making an estimate of this process essential.

Table 6-1

In-lake Sample Collection Frequency and Parameters of Interest for the Diamond Lake TMDL Study

Lake	2008 No. of Samples	2008 Sample Dates	2009 No. of Samples	2009 Sample Dates
Diamond Lake 3 & Diamond Lake 4				
Surface	13	February 5 March 18 May 5 May 33 June 4 June 18 July 8 July 22 August 6 August 20 September 3 September 24 October 8	5	May 21 June 17 July 27 August 31 October 14
Bottom	12	March 18 May 5 May 33 June 4 June 18 July 8 July 22 August 6 August 20 September 3 September 24 October 8	5	May 21 June 17 July 27 August 31 October 14
Hubbard Lake, Schultz Lake, Wheeler Lake	4	June 15 June 30 August 11 October 8	6	May 21 June 18 July 28 August 11 September 9 October 26

Sampled for stage, temperature, dissolved oxygen, total phosphorus, dissolved phosphorus, Total Kjeldahl Nitrogen, Nitrate plus Nitrite, Total Suspended Solids, turbidity, pH, specific conductance, chlorophyll-a

Table 6-2

Surface Water (Inflow/Outflow) Sample Collection Frequency and Parameters of Interest for Routine Stream Monitoring Sites for Diamond Lake TMDL Study

<table>
<tr><th rowspan="2">Location</th><th colspan="2">2008</th><th colspan="2">2009</th></tr>
<tr><th>No. of Samples</th><th>Sample Dates</th><th>No. of Samples</th><th>Sample Dates</th></tr>
<tr><td>Diamond Lake 1</td><td>7</td><td>April 7
April 17
April 25
May 13
May 29
June 6
June 12</td><td>6</td><td>March 23
April 8
April 15
April 30
May 13
October 29</td></tr>
<tr><td>Diamond Lake 5</td><td>7</td><td>April 7
April 17
April 25
May 13
May 29
June 6
June 12</td><td>8</td><td>March 23
April 8
April 15
April 30
May 15
October 2
October 13
October 29</td></tr>
<tr><td>Diamond Lake 7</td><td>7</td><td>April 7
April 17
April 25
May 13
May 29
June 6
June 12</td><td>7</td><td>March 23
April 8
April 15
August 17
October 2
October 13
October 29</td></tr>
<tr><td>Hubbard Lake 2</td><td>7</td><td>April 7
April 17
April 25
May 13
May 29
June 6
June 12</td><td>8</td><td>March 24
April 8
April 15
April 30
May 13
October 2
October 13
October 29</td></tr>
<tr><td>Wheeler Lake 2</td><td>5</td><td>April 25
May 13
May 29
June 6
June 12</td><td>6</td><td>March 26
April 8
April 15
April 30
May 13
October 29</td></tr>
</table>

Sampled for stage,streamflow, temperature, dissolved oxygen, total phosphorus, dissolved phosphorus, Total Kjeldahl Nitrogen, Nitrate plus Nitrite, Total Suspended Solids, turbidity, pH, specific conductance, transparency tube.

A variety of estimation techniques exist that are physically-based, empirically-based or both physically- and empirically-based, and account for some or all of the influencing meteorological parameters. A method derived from both physical and empirical relationships, accounting for many of the influencing meteorological parameters, was used for this study. The method is well accepted for the estimation of open water evaporation and is known specifically as the combined aerodynamic and energy balance method and more commonly as the Myer method for shallow lake evaporation. This method was compared to several similar physically-based equations and the average value for all methods used.

Each evaporation calculation method requires the following meteorological data: 1) air temperature; 2) wind speed; and 3) water vapor pressures (expressed as dew point). Data measured by a first-order weather monitoring station at the Willmar, Minnesota airport was used to compute evaporation for the 2008 and 2009 seasons. Data obtained from the weather station were on a daily time step; evaporation was computed for this daily time scale and summarized annually.

6.2.2 Lake Stage (Change in Storage)

A continuous-recording pressure transducer was used to collect information on lake elevations, which were then used (along with a co-located staff gage) to compute the change in storage within Diamond Lake. Continuous stage readings were taken every 10 minutes, and averaged to determine daily average stage; these values were supplemented by stage measurements made by volunteer monitors. For computing the water balance, the change in lake elevation was computed on a yearly basis, determined by using the last elevations measured in successive years (i.e., freeze-up to freeze-up).

6.2.3 Surface Water Runoff

Surface runoff to Diamond Lake was measured at multiple locations including the primary inflow (DL-1) on the south side of the lake (see **Figure 4-1**). A large portion of Diamond Lake's watershed contributes runoff to the primary inflow at DL-1. Additional locations were gaged on the east side of Diamond Lake. Because not all of the contributing drainage area could be monitored, an assumption of unit runoff per area was needed for those areas that contribute runoff directly to Diamond Lake. For this work, we assumed that these areas contributed runoff in the same manner as the DL-7 location since the land use characteristics within the DL-7 subwatershed were most similar to the ungaged drainage areas.

Surface runoff was generally measured by placing an electronic stage recorder or acoustic Doppler probe in the open channel or within a hydraulic control (e.g., the bridge at DL-1). The geometric characteristics of the channel (e.g., channel slope, channel width, channel depth, etc.) were determined by a field survey. These data were used to convert local elevations to 1988 NAVD[1]. Staff from the MFCRWD measured streamflow and staff gage height, which was used to develop rating curves (see **Appendix A)**. Rating curves were then used to estimate the streamflow from the measured stage. Average daily channel stages were computed and the rating curve was used to determine daily streamflow.

Most streamflow sites were configured with a submersible pressure transducer that recorded stream stage. Based on measurements of streamflow and its relation to stream stage, a streamflow rating was established. That rating was applied to records of stream stage to determine streamflow (sometimes called 'discharge') on a nearly continuous basis. The detailed record, however, was generally averaged to provide a mean-daily streamflow.

Two of the sites (DL1 and WL2) were configured with transducers that included both stage and Doppler technology to estimate velocity. These units did not work as expected during 2008, but the stage record and back-up systems provided reliable data that was used to compute the streamflow. During 2009, a more advanced system was installed at these sites, which provided a more reliable result.

Staff from the MFCRWD was responsible for collecting and processing the streamflow data for all of the sites. Consultation was provided by the MPCA and HEI, as requested. The streamflow record from sites DL2, DL5, and DL7 were processed by MPCA staff using the Hydstra software. The data from sites DL1, HL2 and WL2 were processed by developing rating curves, which were applied to records of stream stage to estimate streamflow. These data were

[1] This is a means of describing the elevation at a specific location on the earth.

reviewed by HEI staff and adjusted as needed. One example of adjustment is related to accounting for snowmelt. Some streamflow records did not include snowmelt runoff, since the instruments were installed in mid-April. Snowmelt can provide a significant portion of the annual constituent load. In such cases, HEI estimated snowmelt by using a drainage area transfer relationship (ratio of drainage areas multiplied by daily discharge at the Spicer gage) with measured streamflow at the USGS Spicer gage.

6.2.4 Ground Water

No ground water monitoring occurred as component of the Diamond Lake TMDL study.

6.3 TRIBUTARY LOAD ESTIMATES

Observed flow and water quality data was used in the computer program FLUX, developed by the U.S. Army Corps of Engineers, to estimate pollutant loads from the watershed tributaries. FLUX is an interactive menu driven program, consisting of six unique methods for load estimation (Walker, 1986). The program uses daily streamflow volume and chemistry data to compute pollutant loads through a variety of statistical methods. The program is supported by the U.S. Army Corps of Engineers, Vicksburg, Mississippi.

The goal of the load estimation procedure is to minimize the error (expressed as the coefficient of variation and variance) associated with the load estimate. This is accomplished by first estimating the load using each technique, noting the variance and coefficient of variation in each run. Often the error can be reduced by stratifying the data either by flow or season. We typically evaluated whether the error was reduced by using two flow strata: one greater and one less than the mean flow. After stratification, most of the estimate methods converged toward a similar load estimate, provided there was some relationship between streamflow and the chemical concentration within the data series. Next, the period of record load estimate with the lowest error was selected as the “correct” estimate. This tended either to be the product of the average flow and average concentration or the flow weighted mean concentration method. The latter method is described mathematically as follows:

$W = \text{Mean}(w_i)\,[\text{Mean}(Q_j) / \text{Mean}(q_i)]$

Where:

W = estimated mean flux (load) over N days (kg/yr)

w = measured flux during a sample i (kg/yr)

Q = mean flow on day j (cubic hectometers per year)

q = measured flow during sample i (cubic hectometers per year)

An additional description of the typical process used to estimate loads can be found in **Appendix B.** The data used to compute the loads were the time series of estimated daily streamflow and the paired chemical concentrations (as determined from grab samples / measured streamflow at the time of sample collection from a given location). Analysis of the data showed that grab samples tended to be collected during moderate flow conditions. Because grab samples were not collected for monitoring location DL-2 (the outlet from Diamond Lake), in-lake concentrations on the days that the MFCRWD gaged streamflow were used to compute the loads for this location.

6.4 SUBSURFACE SEWAGE TREATMENT SYSTEM SURVEY

Information about SSTS came from a 2008 study completed by Wenck Associates. The information used from this study included the number of structures located on the lake and the percentage believed to comply with Minnesota standards for design. Based upon a review of the SSURGO soils, one-half of those SSTSs not meeting the standards were considered failing and contributing nutrients to Diamond Lake (see **Appendix C**).

6.5 FIELD QUALITY ASSURANCE MEASUREMENT OBJECTIVES

Field quality assurance objectives define the expected accuracy, precision, and completeness for field measurements. The quality assurance objectives for field measurements are described in **Table 6-3**.

Additional field quality assurance/quality control activities included sampling equipment checks, sample custody procedures, equipment calibration, and the use of field blanks. Field blanks and duplicates comprised approximately 10% of the total samples.

Table 6-3
Field Quality Assurance Objectives

Parameter (Method)	Precision (Std. Deviation)	Accuracy	Completeness[1]
Transparency (secchi disk)	±5%	0.5 feet	100%
Dissolved Oxygen (meter)	±0.05 mg/l	±0.3 mg/l	100%
Temperature (thermister)	±0.1°C	+0.2°C	100%
pH (meter)	±0.1 units	0.01 units	100%
Specific Conductance (meter)	±5%	±1% of scale	100%
Precipitation depth (electronic gage)	±5%	0.001-inch	100%
Water levels Lake stage Stream stage	±5% ±5%	0.1-foot 0.1-foot	99% 95%

1 Completeness means percentage of desired measurements that are usable

Table 6-4

Results of Duplicate Analyses (averages for 10 samples) for Lake and Stream Samples

	Dissolved Phosphorus (mg/l)	Total Phosphorus (mg/l)	Total Suspended Solids (mg/l)
Sample Blank	0.0335	0.0834	4.85
Sample Duplicate	0.0713	0.0711	5.1

Review of the chemical concentrations for 3 stream samples and 9 lake samples with field sample blanks showed all parameters at the minimum detection limit with the exception of one blank from Wheeler Lake in June 2009. Ten duplicate field samples were collected during the study; primarily for total phosphorus, dissolved phosphorus, and total suspended solids (**Table 6-4)**.

6.6 LABORATORY QUALITY ASSURANCE

Laboratory quality assurance responsibilities rested with the analytical laboratory, RMB Labs. Three items important enough for presentation within this document are sample preservation requirements, holding times, and laboratory quality assurance goals**. Table 6-5** shows sample preservation and storage requirements maintained, while **Table 6-6** shows laboratory precision and accuracy goals.

Table 6-5
Sample Holding Times and Preservation Requirements[1]

Parameter	Sample Preservation	Sample Storage	Holding Time
pH	None	None	None
Total phosphorus	To pH<2 w/H_2SO_4	In dark at 4°C	Max. 28 days
Dissolved phosphorus	To pH<2 w/H_2SO_4	In dark at 4°C	Max. 48 days
Total Kjeldahl nitrogen	To pH<2 w/H_2SO_4	In dark at 4°C	Max. 28 days
Nitrate + nitrite nitrogen	To pH<2 w/H_2SO_4	In dark at 4°C	Max. 7 days
Total suspended solids	None	At 4°C	Max. 7 days
Color	None	In dark at 4°C	Max. 24 hrs.
Chlorophyll-a[2]	Field filtrated at time of sample collection	Store filters in aluminum foil	Max. 24 days frozen
Specific conductance	None	At 4°C	Max. 7 days
Temperature	Measure in the field with a thermistor.		
Dissolved oxygen	Measure in situ with dissolved oxygen probe and meter. Meter calibrated with azide modification of the Winkler Method, USEPA (1079).		

[1] Samples are generally analyzed within 24 hours of collection.
[2] Samples are filtered immediately following collection.

Table 6-6 Laboratory Quality Assurance Goals for Range of Concentrations Anticipated in Surface Waters

Parameter	Method	Precision	Accuracy as Percent Recovery	Data Completeness	Minimum Detection Limit	Method Reference
Total Phosphorus	Ascorbic Acid Digestion	< 10%	≥ 90%	≥ 95%	0.005 mg/L	EPA 365.3
Ortho-Phosphorus	Filtration; automated	< 10%	≥ 90%	≥ 95%	0.005 mg/L	EPA 365.3
Total Kjeldahl Nitrogen	Cupric Sulfate Digestion	< 10%	≥ 90%	≥ 95%	0.30 mg/L	EPA 351.2 Rev 2.0
Nitrate + Nitrite Nitrogen	LACHAT	< 10%	≥ 90%	≥ 95%	0.03 mg/L	EPA 353.2 Rev 2.0
Ammonia Nitrogen	Automated Phenol	< 10%	≥ 90%	≥ 95%	0.04 mg/L	EPA 350.1 Rev 2.0
Total Suspended Solids	Drying and Gravimetric	< 10%	NA	≥ 95%	1 mg/L	SM 2540 D-97
Total Suspended Volatile Solids	Drying and Gravimetric	< 10%	NA	≥ 95%	1 mg/L	EPA 160.4
Biochemical Oxygen Demand	5 day incubation	< 10%	≥ 80%	≥ 95%	1 mg/L	SM 5210 B-01
Turbidity	Nephelometric Method	< 10%	≥ 90%	≥ 95%	0.02 NTU	EPA 180.1 Rev 2.0
Chlorophyll a	Spectrophotometric	< 10%	≥ 90%	≥ 95%	1 mg/L	SM 10200 H
Fecal Coliform Bacteria	Membrane filtration	NA	NA	≥ 95%	1 CFU/100ml	SM 9222D (m-FC) 97
E. coli Bacteria	Enzyme Substrate	NA	NA	≥ 95%	1 MPN/100ml	Colilert-18 Quanti-Tray

7.0 MONITORING RESULTS

This section presents results for the monitoring completed during 2008 and 2009. The in-lake data collected during this period are used to diagnose the extent and severity of water quality problems and assess attainment of the numeric standard. The data are also used to calibrate a lake water quality model, which is used to forecast the amount of improvement which can be expected if "fixes" are implemented by reducing nutrient loads. The stream runoff volume and chemistries are used to estimate loads, identify potential sources of excess nutrients and to calibrate and validate the watershed model. The watershed model can then be used to evaluate the effectiveness of certain management practices in reducing nutrient loads.

7.1 PRECIPITATION AND AIR TEMPERATURES - 2008 AND 2009

An understanding of climatic conditions during 2008 and 2009 is important when evaluating and understanding the water quality data. Specifically, it is important to understand whether climatic conditions were relatively normal[2], wetter than normal, or drier than normal. More runoff usually means greater nutrient loads and poorer water quality. Higher air temperatures can result in warmer water and greater rates and amounts of algae growth.

The nearest long-term weather station is located in Willmar, Minnesota. Monthly mean air temperatures at Willmar, Minnesota were near normal in both 2008 and 2009 (**Figure 7-1**). Monthly mean air temperatures tended to be near normal or cooler than normal during 2009, although September 2009 appeared warmer than normal. Annual precipitation in 2008 was near normal, while exceeding normal by several inches in 2009 (**Figure 7-2**). Monthly precipitation in 2009 was noticeably greater than normal in August and October. Total annual snow depths in both 2008 and 2009 were approximately one-third of normal (**Figure 7-3**).

[2] Normal is defined as the condition for years 1971-2000.

7.2 HYDROLOGY

Climatic factors influence the amount of runoff reaching Diamond Lake. The various sources of water carry differing amounts of nutrients. Therefore, understanding where the water comes from and how it enters and leaves Diamond Lake is critical to developing an appropriate implementation plan. This portion of the report describes the sources and amount of water reaching and leaving Diamond Lake.

Figure 7.1 Monthly Mean Air Temperatures at Willmar, Minnesota, 2008-2009

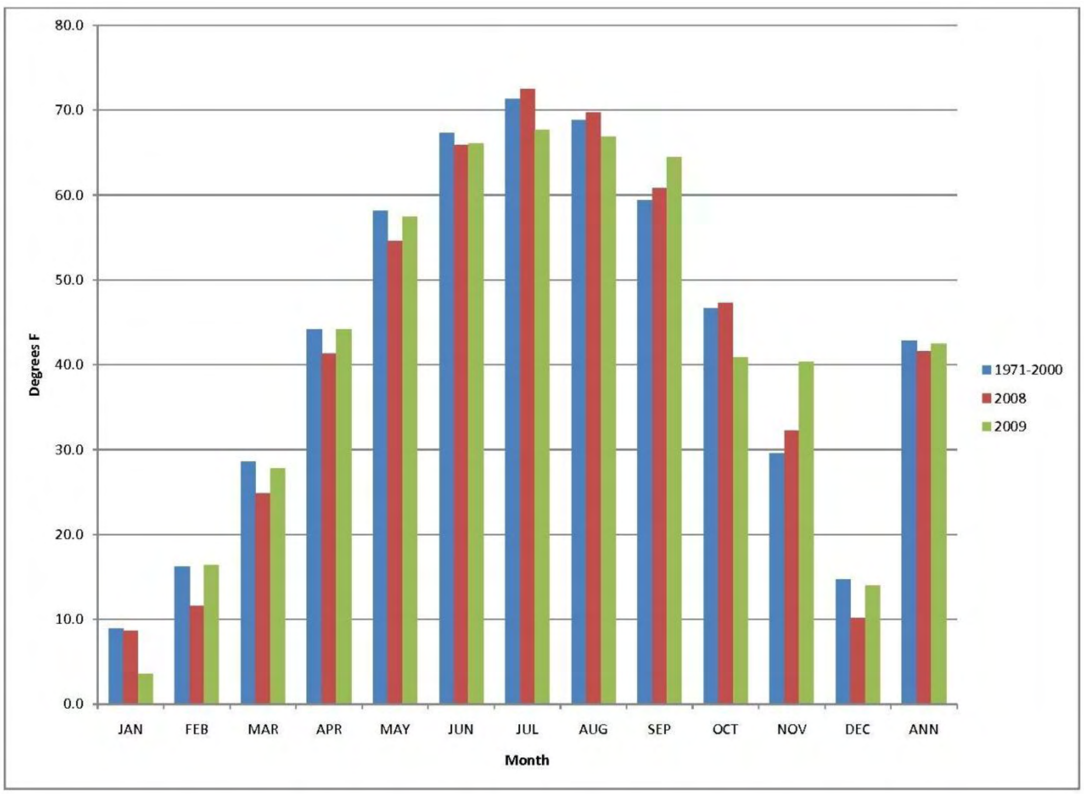


Figure 7.2 Monthly Precipitation Amounts at Willmar, Minnesota, 2008-2009

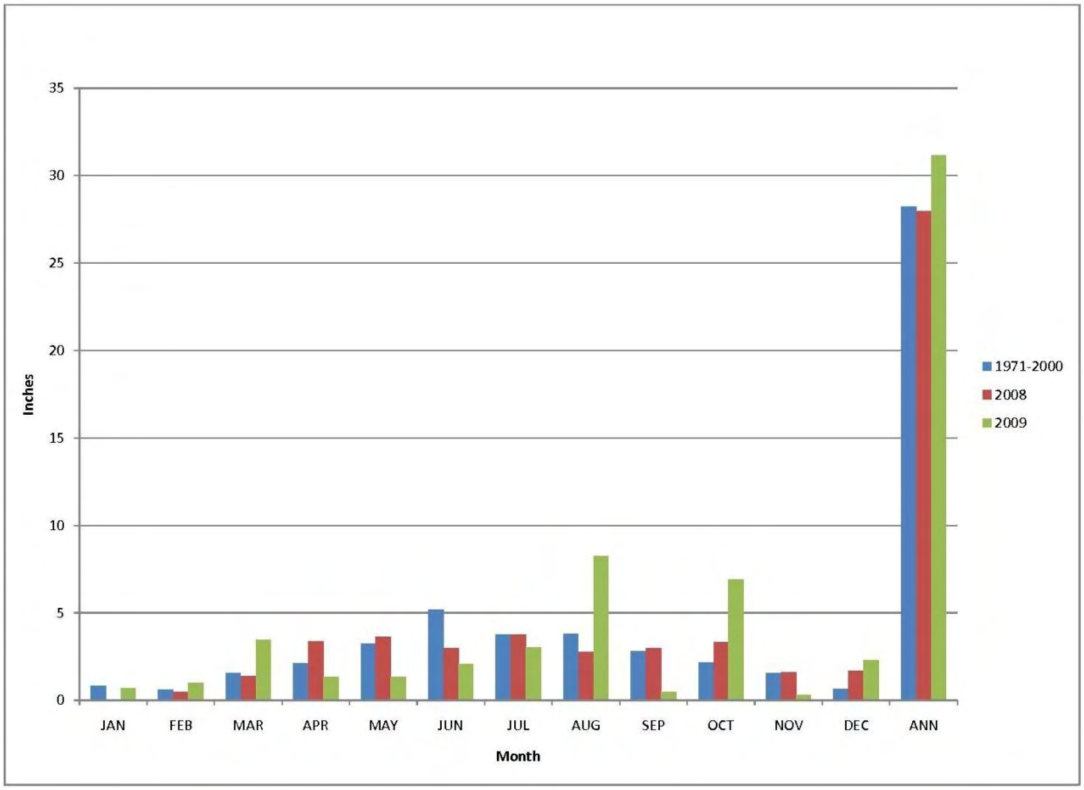
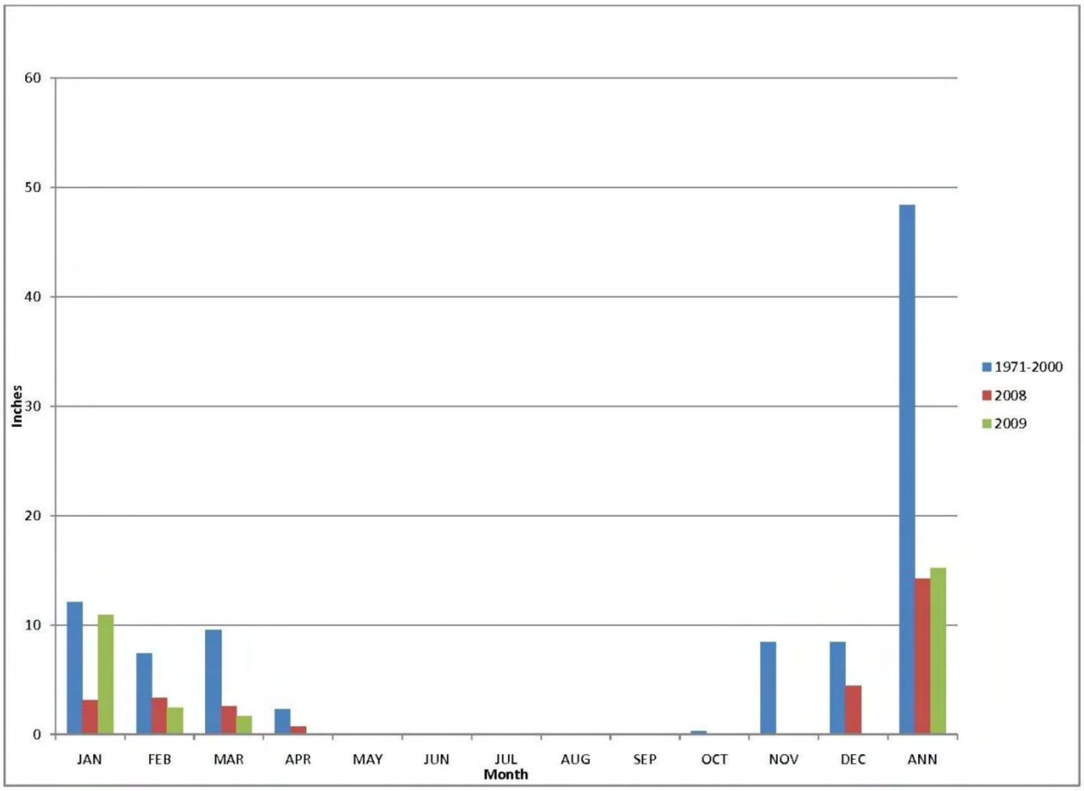


Figure 7.3 Monthly Total Snow Depths at Willmar, Minnesota, 2008-2009



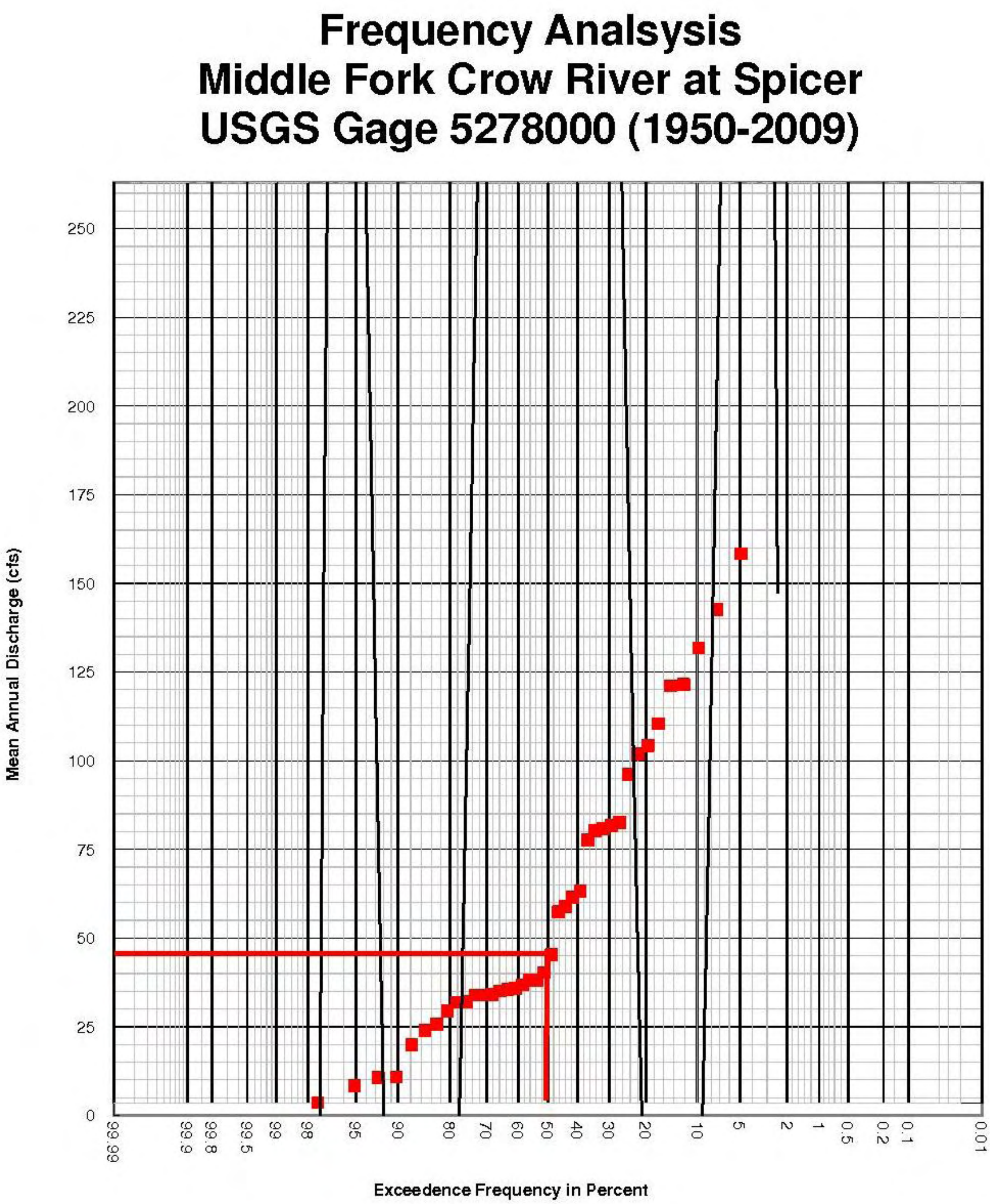
Placing the type of water year within context is important for understanding the monitoring data. Using information from a nearby long-term gaging site is the best method for establishing the context for the type of water year. The USGS has operated a gage on the Middle Fork Crow River at Spicer since 1950 ((gage no. 5278000). Assuming runoff from the Diamond Lake watershed behaves similarly to the runoff from the watershed to the USGS gage on the Middle Fork Crow River at Spicer, the amount of runoff during 2008 was slightly less than normal and near normal during 2009 (**Figure 7-4**). The 50th percentile mean daily discharge at the Spicer gage is an estimated 45 cubic feet per second (cfs), compared to 38.2 cfs in 2008 and 45.3 cfs in 2009 at the Diamond Lake gage.

Figure 7-5 shows that the elevation of Diamond Lake responds primarily to the amount of snowmelt runoff in the spring and surface runoff from rainfall during the summer months. The lake declined in stage (elevation) by nearly 1.0 feet from the beginning to the end of the 2008 season. Lake stage reached a maximum during late June.

Water enters Diamond Lake from a number of sources. Precipitation falls directly onto the lake surface, surface runoff enters from areas around the lake, and ground water interacts with the lake below the land surface. The hydrology of Diamond Lake appears to be dominated by surface water runoff and precipitation falling directly onto the lake surface, although no ground water measurements were made. The estimated total volume of water entering Diamond Lake in 2008 was 6,379 acre-feet; in 2009 it was 6,937 acre-feet (see **Figure 7-6**). Nearly one-third of the volume entering the lake comes from surface runoff and an estimated one-half from precipitation.

There are two distinct sources of surface runoff to Diamond Lake; 1) direct runoff from those areas immediately surrounding the lake; and 2) runoff through creeks and streams (tributaries). Gaged runoff is the portion measured within the creeks and streams and, in 2008 and 2009, accounted for more than 80% of the runoff entering Diamond Lake. Only a small portion came from areas draining directly to the lake.

Figure 7.4 Frequency analysis of annual runoff volume at the Middle Fork Crow River Spicer, Minnesota gage



2008 mean discharge = 38.2 cfs
2009 mean discharge = 45.3 cfs

Figure 7.5 Diamond Lake hydrologic response in 2008

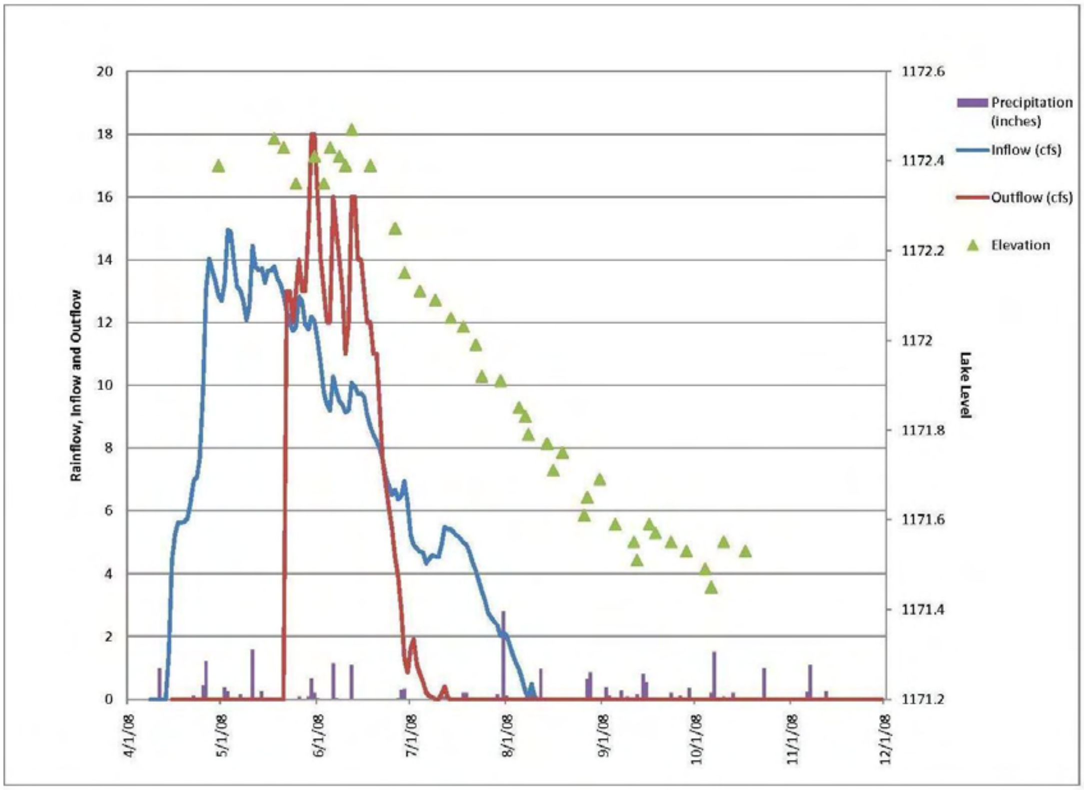
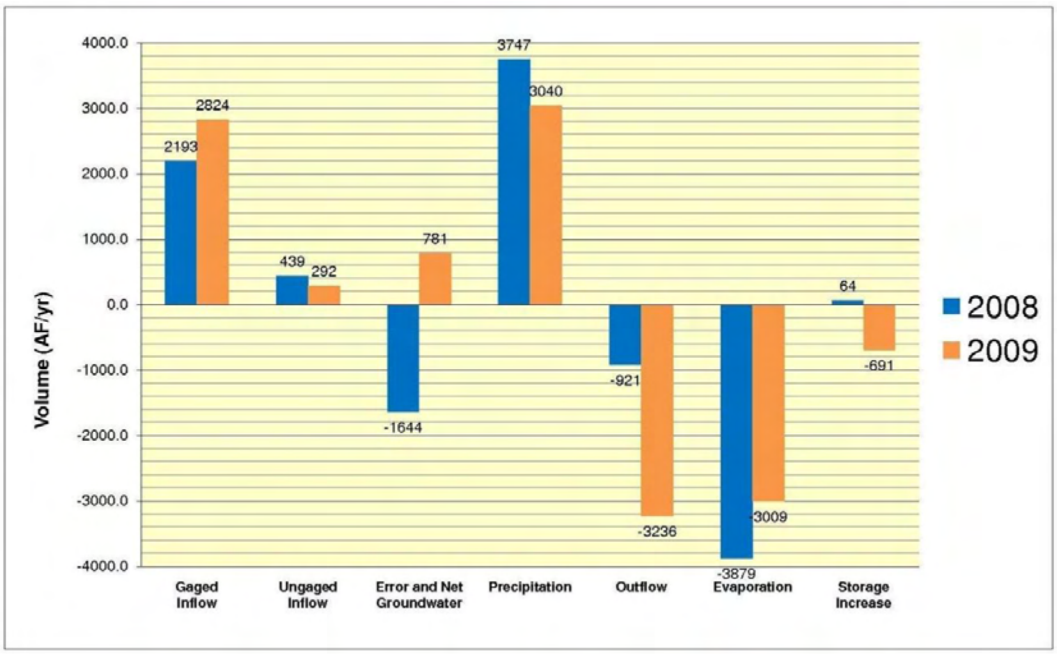


Figure 7.6 Water balance for Diamond Lake in 2008 and 2009



The dominant losses of water from the lake, during this time period, were evaporation, outflow over the dam, and (potentially) groundwater. The volume evaporated is generally similar to the volume of precipitation falling on the lake surface. The amount of surface outflow depends upon the amount of inflow and elevation of the lake at the beginning of the year.

Runoff was measured from several of the subwatersheds around Diamond Lake during the study (**Table 7-1**). Most of the surface runoff enters Diamond Lake through the primary inlet at DL-1. In excess of 3-inches and 4-inches of runoff occurred from the area upstream of DL-1 in 2008 and 2009, respectively. Less runoff per unit area occurred upstream of monitoring site HL-2; an estimated 2.4-inches and 3.0 inches were measured in 2008 and 2009, respectively. The tributaries south and east of Diamond Lake (DL-5 and DL-7) showed the least amount of runoff on a unit basis, generally ranging from less than 1-inch to 1.5-inches annually.

7.3 WATER QUALITY

7.3.1 Diamond Lake

7.3.1.1 Physical Limnology

The mixing characteristics of a lake determine, in large part, the chemical and biological characteristics. A lake's mixing characteristics are a function of a lake's temperature structure and the amount of wind striking the lake surface. **Figure 7-7** and **Figure 7-8** shows the temperature profile of Diamond Lake at the two monitoring locations in 2008 and 2009. Profiles show that the lake was weakly stratified during late July, but otherwise was typically well-mixed from the surface to the bottom. This mixing was likely the result of the relatively shallow average depth, large fetch, and sufficient exposure to wind to mix the lake.

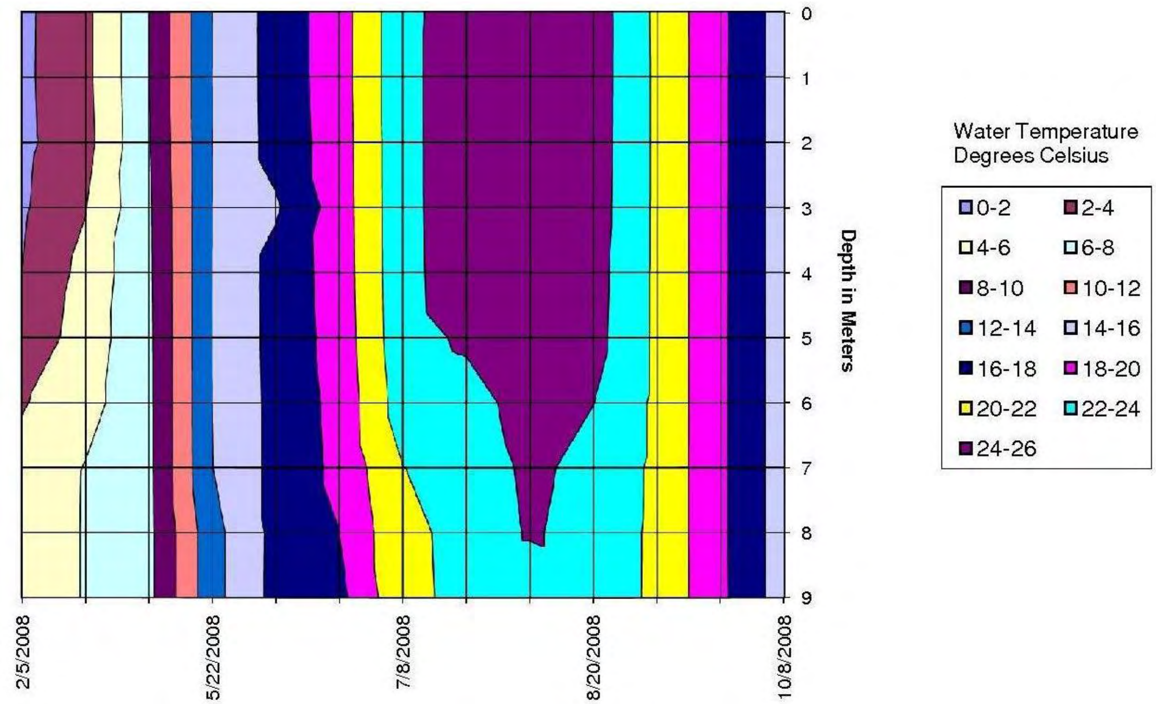
Dissolved oxygen is also important within a lake ecosystem. Aquatic life needs dissolved oxygen for survival. Dissolved oxygen also influences the rate of phosphorus release from sediment; i.e., release is reduced if O_2 is present. During periods that the

Table 7-1 Gaged runoff at Diamond Lake monitoring stations in 2008 and 2009

	DL1		DL2		DL5		DL7		HL2		WL3	
Month	Volume (AF)	Inches of runoff / Acres	Volume (AF)	Inches of runoff / Acres	Volume (AF)	Inches of runoff / Acres	Volume (AF)	Inches of runoff / Acres	Volume (AF)	Inches of runoff / Acres	Volume (AF)	Inches of runoff / Acres
2008												
Jan	--	--	--	--	--	--	--	--	--	--	--	--
Feb	--	--	--	--	--	--	--	--	--	--	--	--
Mar	--	--	0.00	0.00	0.00	0.00	0.00	0.00	23.46	0.10	--	--
Apr	274.6	0.5	0.00	0.00	0.00	0.00	150.72	0.82	220.61	0.98	--	--
May	801.3	1.4	281.65	0.18	0.00	0.00	121.45	0.66	193.34	0.86	--	--
Jun	515.6	0.9	625.86	0.39	36.04	0.19	14.48	0.08	93.22	0.41	--	--
Jul	260.5	0.4	13.75	0.01	1.35	0.01	0.00	0.00	7.98	0.04	--	--
Aug	17.2	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--	--
Sep	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--	--
Oct	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
Nov	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
Dec	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
2008 Total	1869.3	3.2	921.26	0.58	37.39	0.20	286.65	1.56	538.62	2.38	--	--
2009												
Jan	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
Feb	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	--	--	--	--
Mar	395.6	--	811.21	0.51	92.43	0.49	61.49	0.33	18.88	0.08	--	--
Apr	779.9	1.3	1739.90	1.09	121.23	0.64	127.83	0.70	125.02	0.55	99.36	0.75
May	369.9	0.6	638.48	0.40	0.00	0.00	0.93	0.01	117.48	0.52	192.04	1.45
Jun	60.8	0.1	17.10	0.01	0.00	0.00	0.00	0.00	48.12	0.21	0.00	0.00
Jul	6.2	0.0	0.00	0.00	0.00	0.00	0.00	0.00	3.75	0.02	0.00	0.00
Aug	78.9	0.1	28.11	0.02	0.00	0.00	0.00	0.00	62.32	0.28	7957.64	59.96
Sep	18.6	0.0	1.49	0.00	0.22	0.00	0.00	0.00	152.29	0.67	6791.43	51.17
Oct	310.0	0.5	0.00	0.00	1.05	0.01	0.00	0.00	159.77	0.71	1653.58	12.46
Nov	399.3	0.7	--	--	--	--	--	--	--	--	596.55	4.49
Dec	0.0	--	--	--	--	--	--	--	--	--	--	--
2009 Total	2419.1	4.1	3236.28	2.03	214.93	1.14	190.25	1.04	687.63	3.04	17290.59	130.28

Figure 7.7 Diamond Lake temperature profiles for in 2008

Diamond Lake 3



Diamond Lake 4

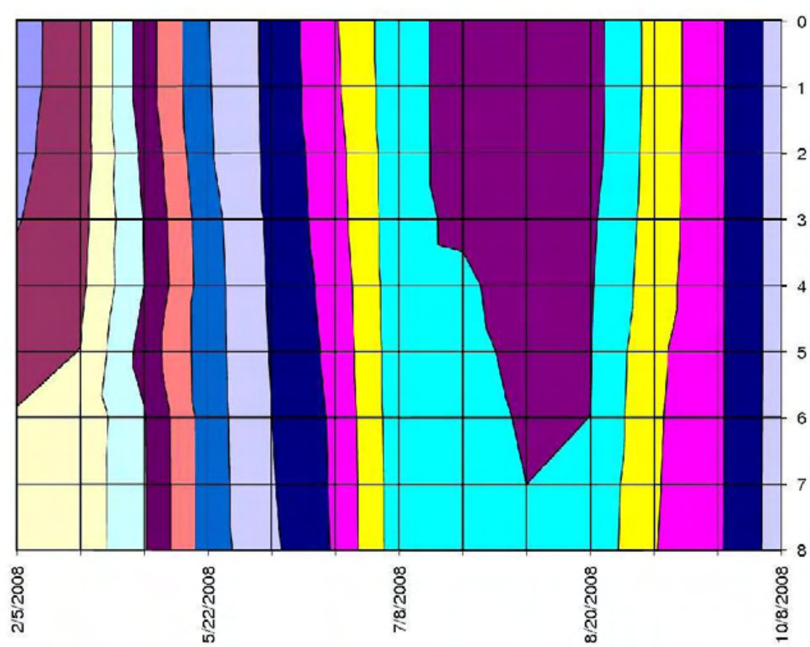
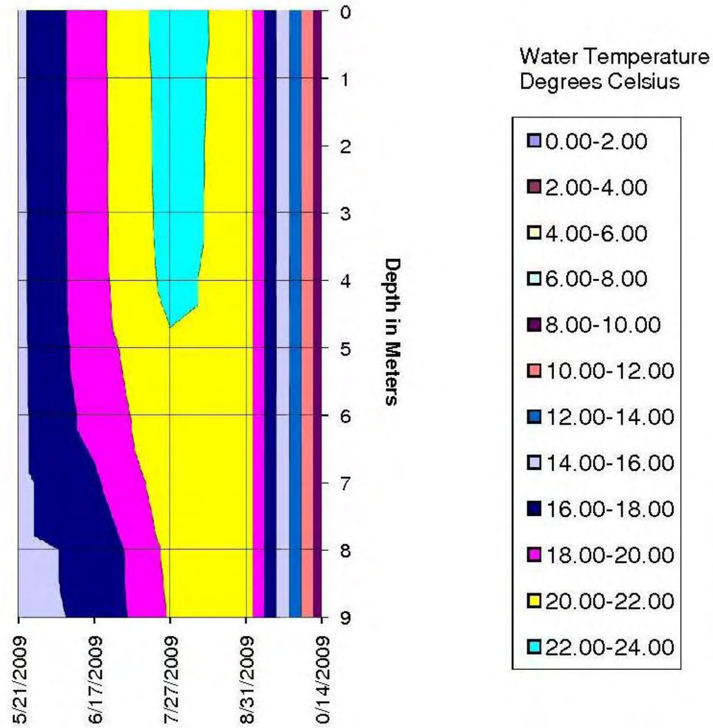
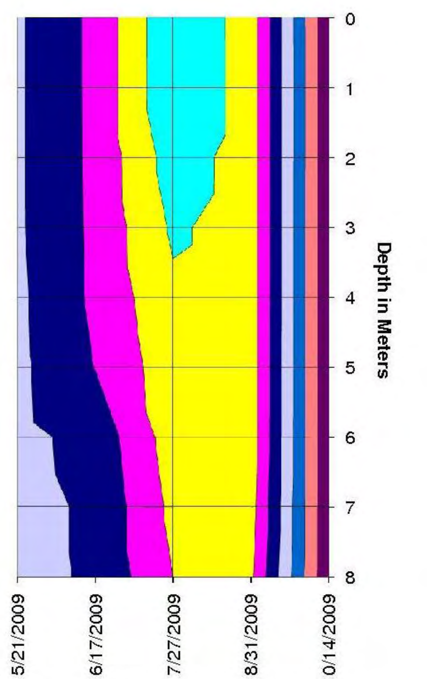


Figure 7.8 Diamond Lake temperature profiles for in 2009

Diamond Lake 3



Diamond Lake 4



lake is stratified, low dissolved oxygen occurs in deeper depths (**Figure 7-9 and Figure 7-10)**. The typical concentrations of dissolved oxygen needed for game fish survival range from 4-5 mg/l, depending upon water temperature. Diamond Lake dissolved oxygen concentrations fall below this at a depth of greater than 7 to 8-meters during mid-July. Surface dissolved oxygen levels remain above the 5 mg/l numeric standard (**Figure 7-11**). The surface pH in Diamond Lake remained within a range considered normal for freshwater systems (**Figure 7-14**), as was specific conductance (**Figure 7-15**). Turbidity concentrations were considerably lower than the numeric standard of 25 NTUs (**Figure 7-16**).

7.3.1.2 Nutrients and Chloropyll-a

Observed total phosphorus and dissolved phosphorus concentrations are presented in **Figure 7-17** and **Figure 7-18,** respectively. These data show Diamond Lake exceeded a mean total phosphorus concentration of 40 ug/l, which is the numeric standard for Diamond Lake. Concentrations infrequently became elevated, exceeding 100 ug/l. Mean dissolved phosphorus concentrations were approximately one-third of the total phosphorus concentrations. Chlorophyll-a concentrations were measured only at DL-3. The mean chlorophyll-a concentration (during 2008 and 2009) of 17 ug/l exceeded the numeric standard of 14 ug/l (**Figure 7-19**). Individual chlorophyll-a measurements exceeded 14 ug/l an estimated 45% of the time.

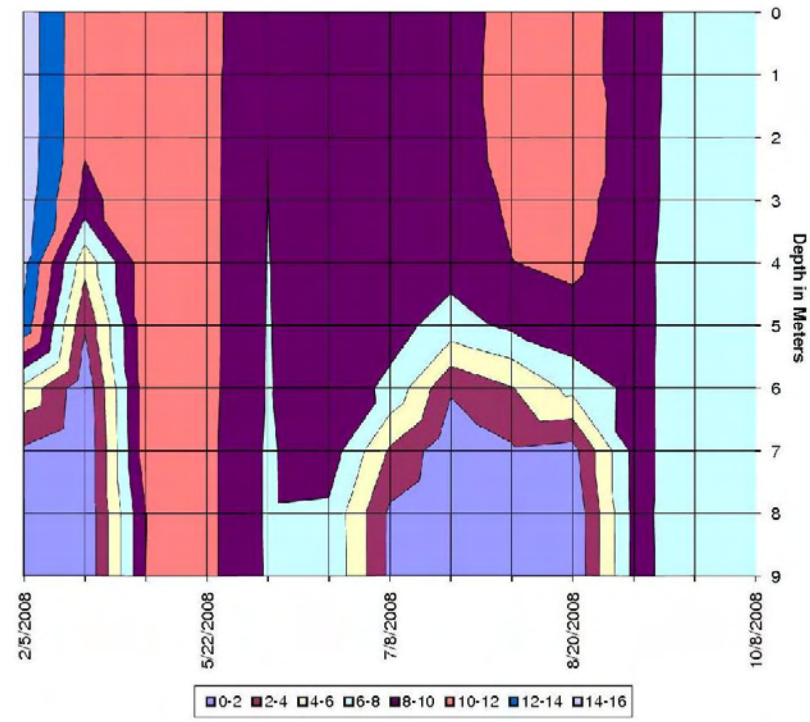
Lake sediment plays an important role in the phosphorus cycle within lakes. Each location monitored showed elevated concentrations of total phosphorus and orthophosphate within the hypolimnion at some period during the summer. These periods of sediment release corresponded with stratification and low dissolved oxygen. Phosphorus concentrations in sediment are likely sufficient to provide the total phosphorus observed within the hypolimnion. Dissolved phosphorus is more readily used by algae than particulate, and typically stimulated algal blooms more quickly than particulate phosphorus.

Nitrate plus nitrite concentrations were consistently at or below the minimum detectable limit within Diamond Lake (0.05 mg/l). The mean Total Kjeldahl Nitrogen (TKN) concentration was measured at 1.1 mg/l (**Figure 7-20**). The ratio of total nitrogen to total phosphorus, based on the mean concentration of TKN and TP, at the DL-3 monitoring location is 29.7:1. A time series of the paired measurements is shown in **Figure 7-21**. These data show a phosphorus limited lake, based on a total nitrogen to dissolved phosphorus ratio of more than seven. Diamond Lake can be considered eutrophic if classified based on total phosphorus and chlorophyll-a concentrations (see Figure 3-1). The trophic-state based on secchi disk depth is also eutrophic.

The monitoring data can be used to characterize the response to nutrients in Diamond Lake. Paired measurements for the samples collected between total phosphorus and chlorophyll-a concentrations, total phosphorus concentrations and secchi disk visibility, and chlorophyll-a concentrations and secchi disk visibility, are shown in **Figure 7-22**, **Figure 7-23** and **Figure 7-24**, respectively. These plots show a strong linear relationship between total phosphorus and chlorophyll-a and a logarithmic response for secchi disk visibility. The relationship between cholorophyll-a and secchi disk visibility is also logarithmic, which suggests that water clarity within Diamond Lake is strongly driven by the abundance of algae.

Figure 7.9 Dissolved oxygen concentration (mg/l) profiles in Diamond Lake for 2008

Diamond Lake 3



Diamond Lake 4

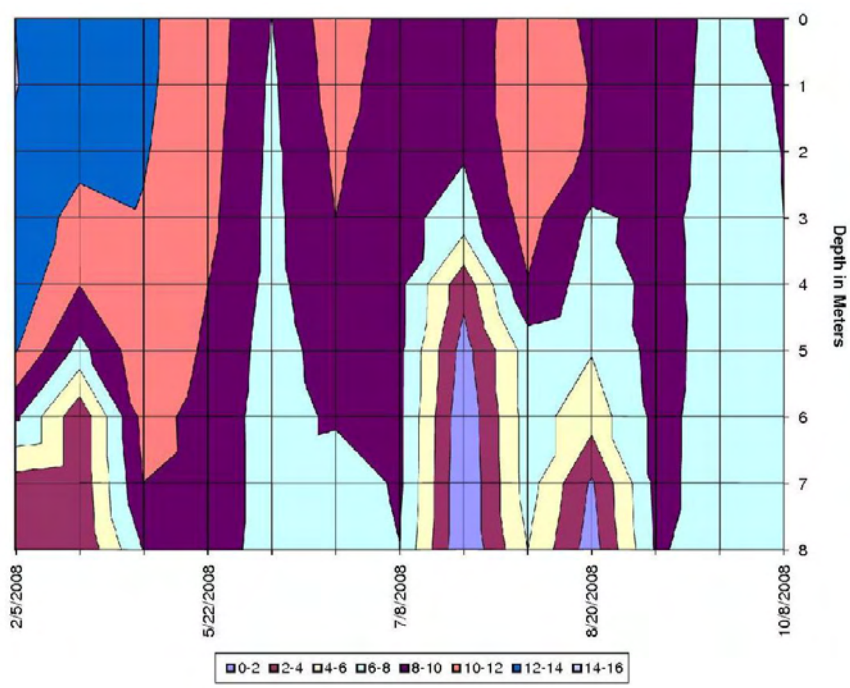
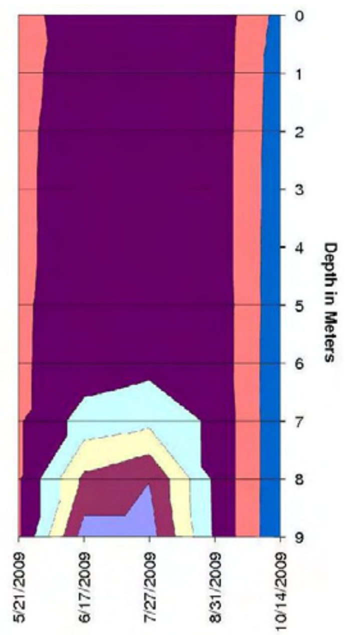


Figure 7.10 Dissolved oxygen concentration profiles in Diamond Lake for 2009

Diamond Lake 3



Diamond Lake 4

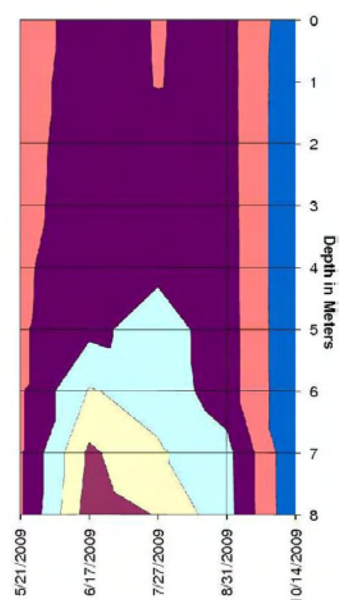


Figure 7.11 Surface dissolved oxygen in Diamond Lake, 2008-2009

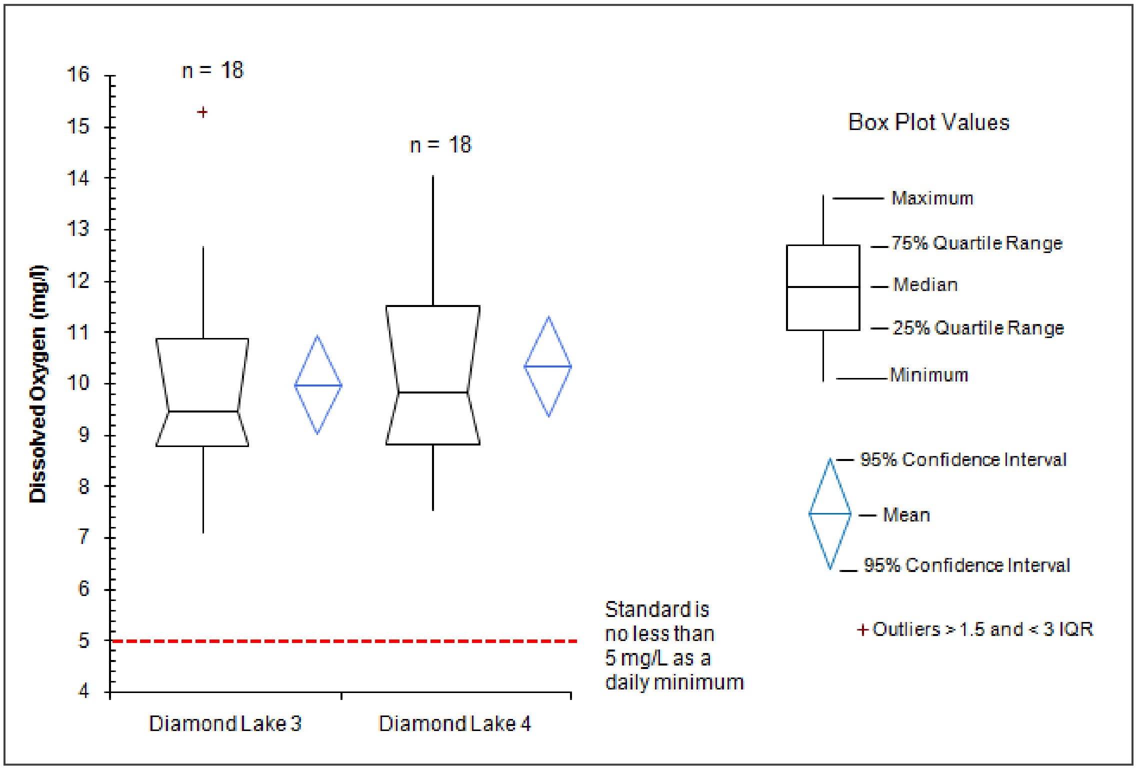


Figure 7.12 Diamond Lake secchi disk time series, 2008-2009

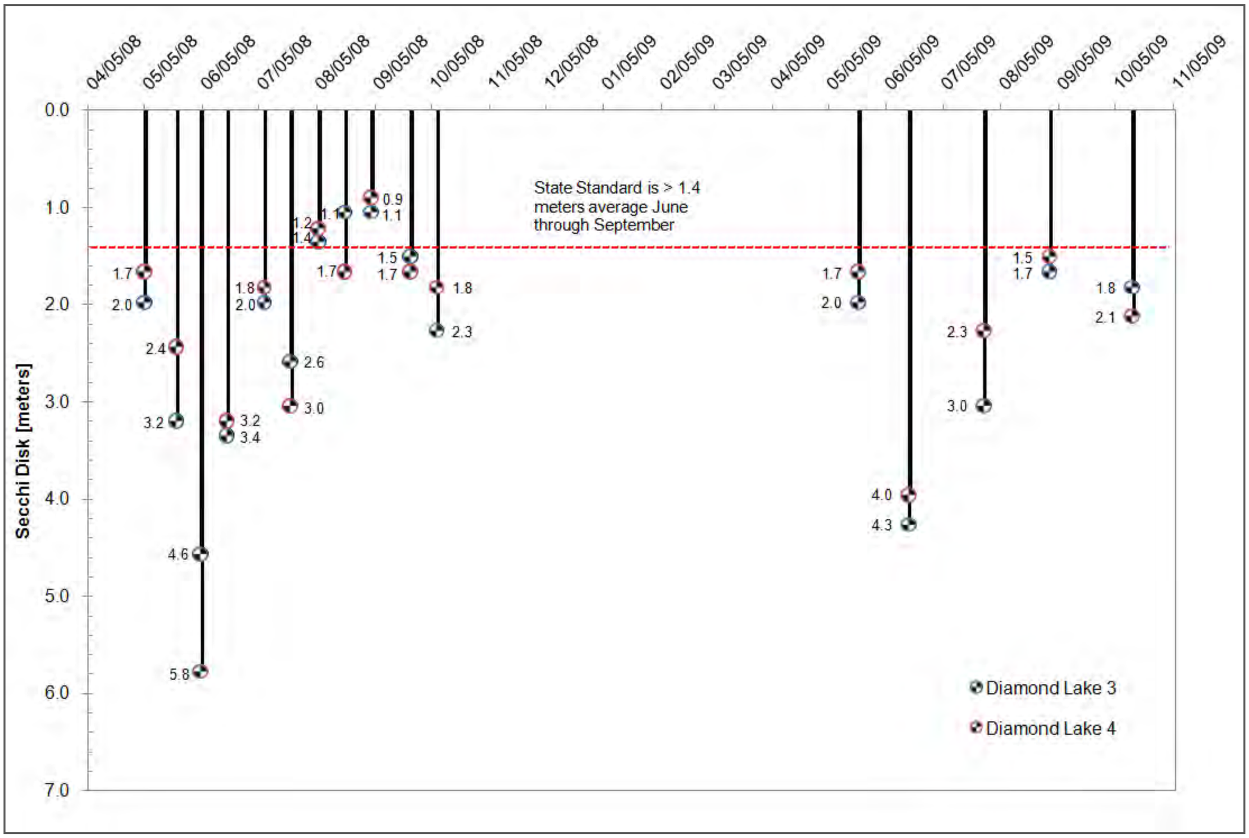


Figure 7.13 Diamond Lake mean secchi disk measurements, 2008-2009

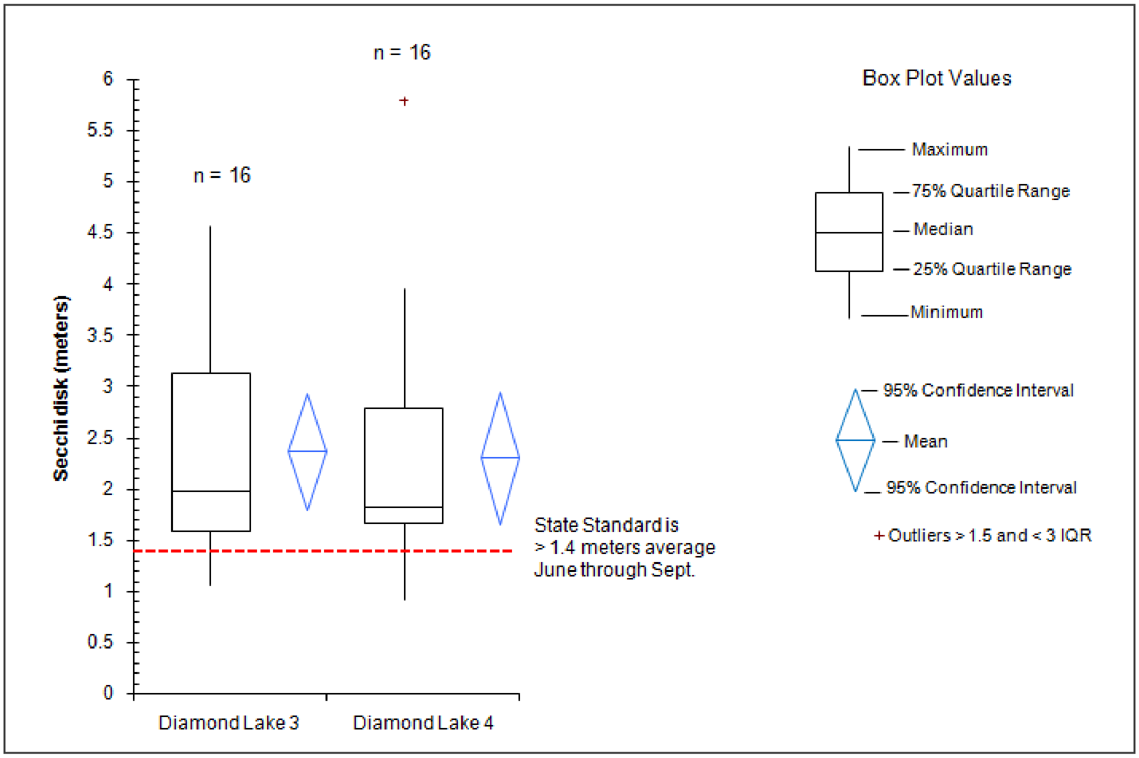


Figure 7.14 Surface pH within Diamond Lake, 2008 -2009

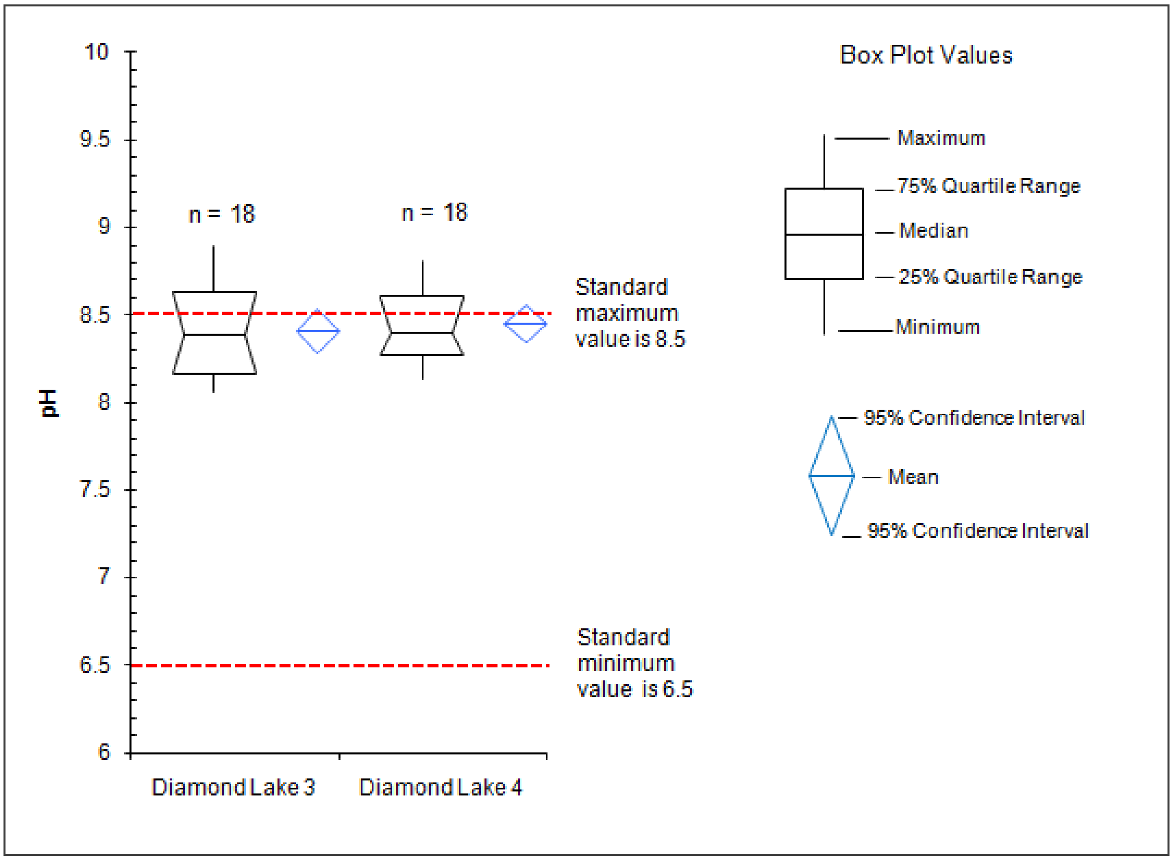


Figure 7.15 Surface mean specific conductance within Diamond Lake, 2008 - 2009

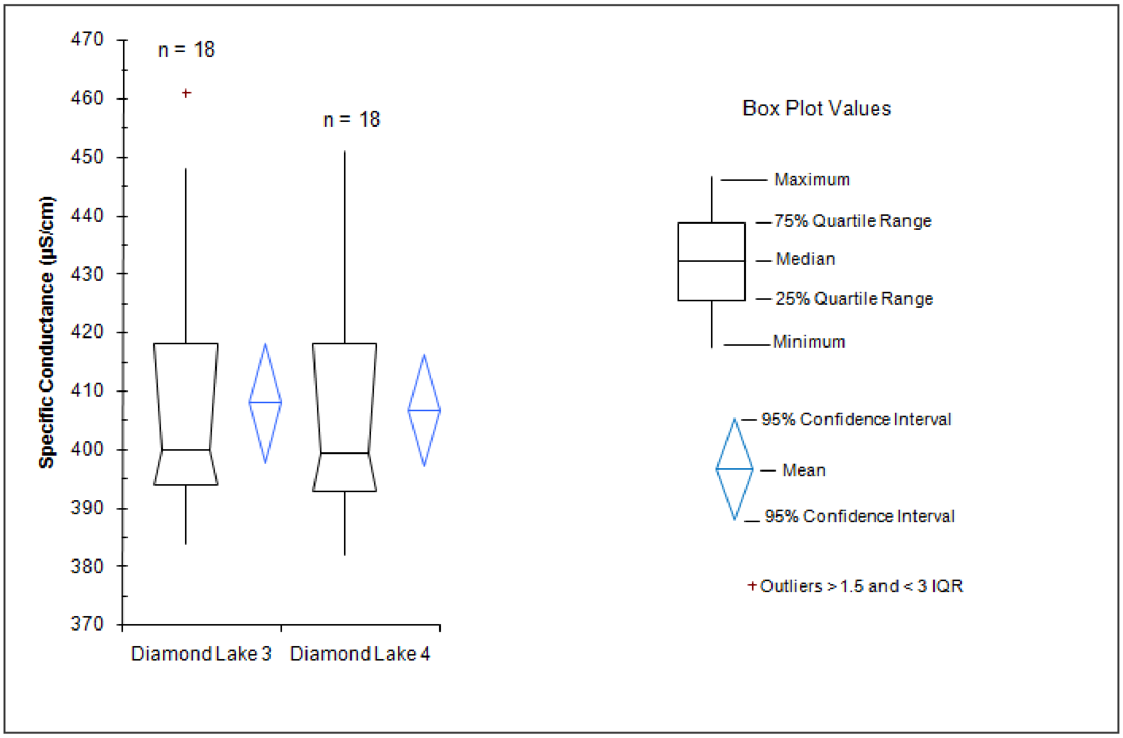


Figure 7.16 Surface mean turbidity within Diamond Lake, 2008 – 2009

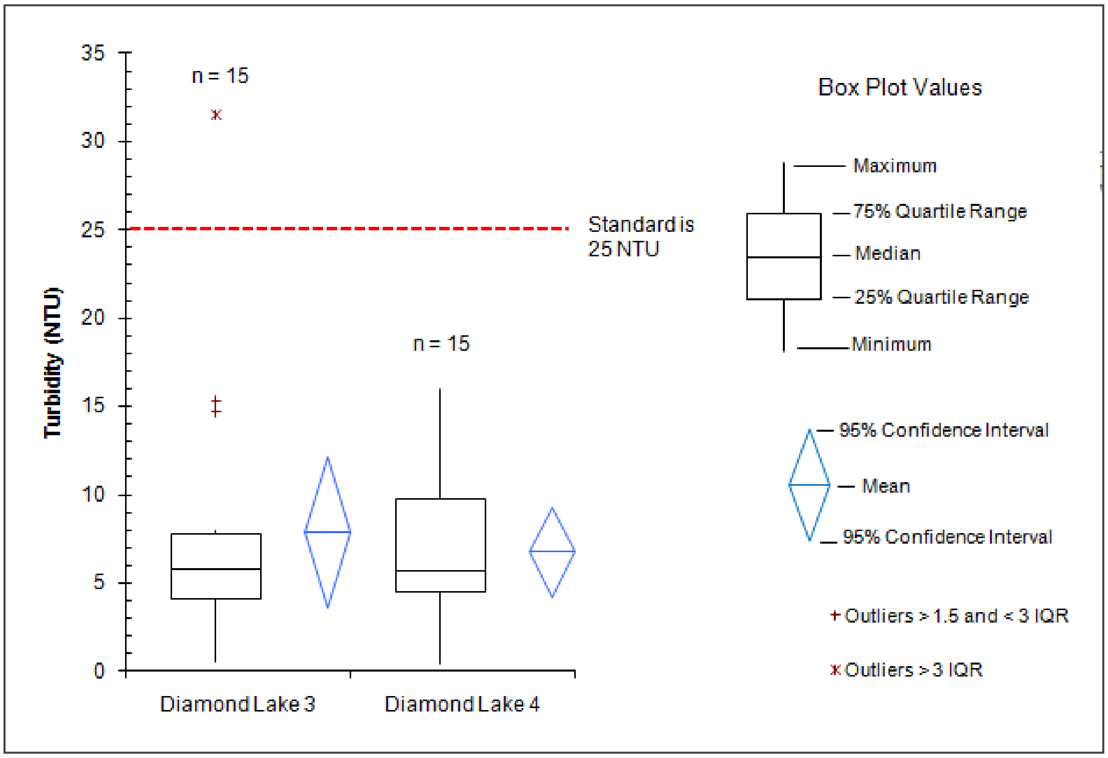


Figure 7.17 Total phosphorus mean concentrations in Diamond Lake, 2008 - 2009

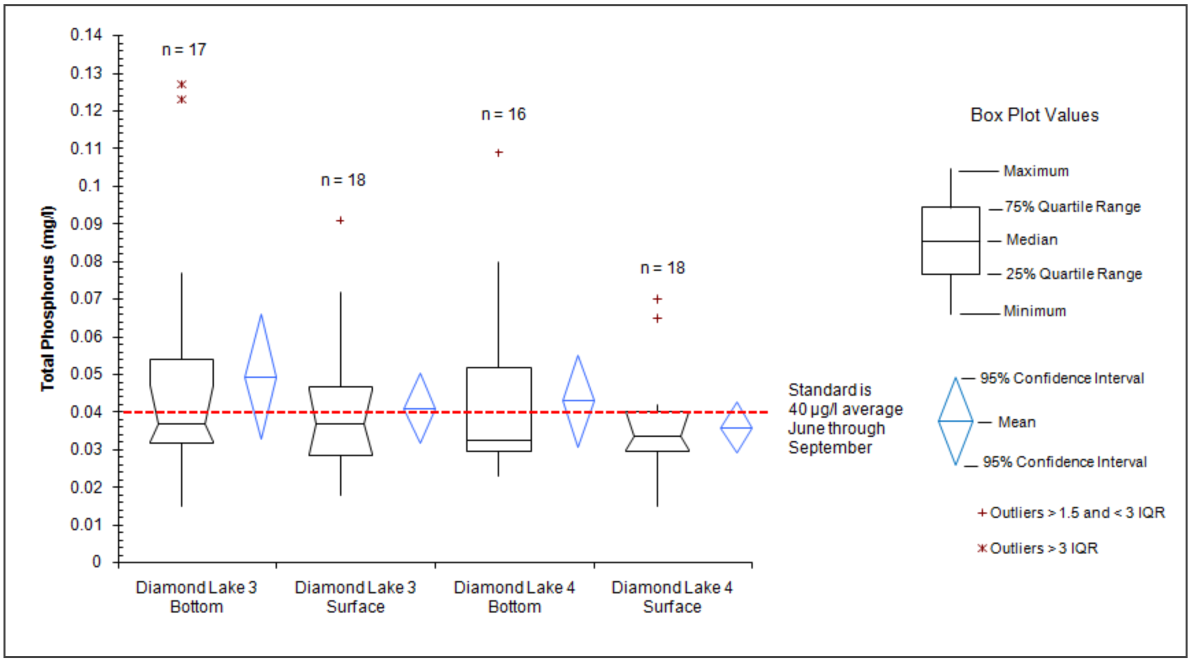


Figure 7.18 Dissolved phosphorus mean concentrations in Diamond Lake, 2008 -2009

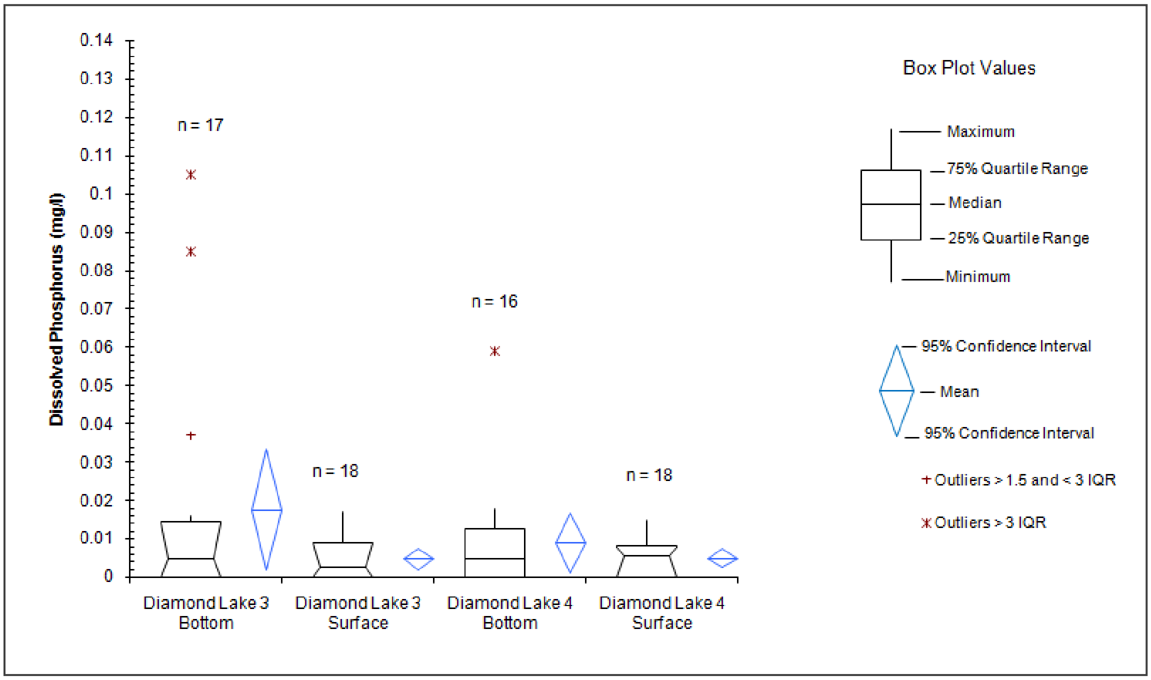


Figure 7.19 Surface Chlorophyll-a mean concentrations in Diamond Lake, 2008 -2009

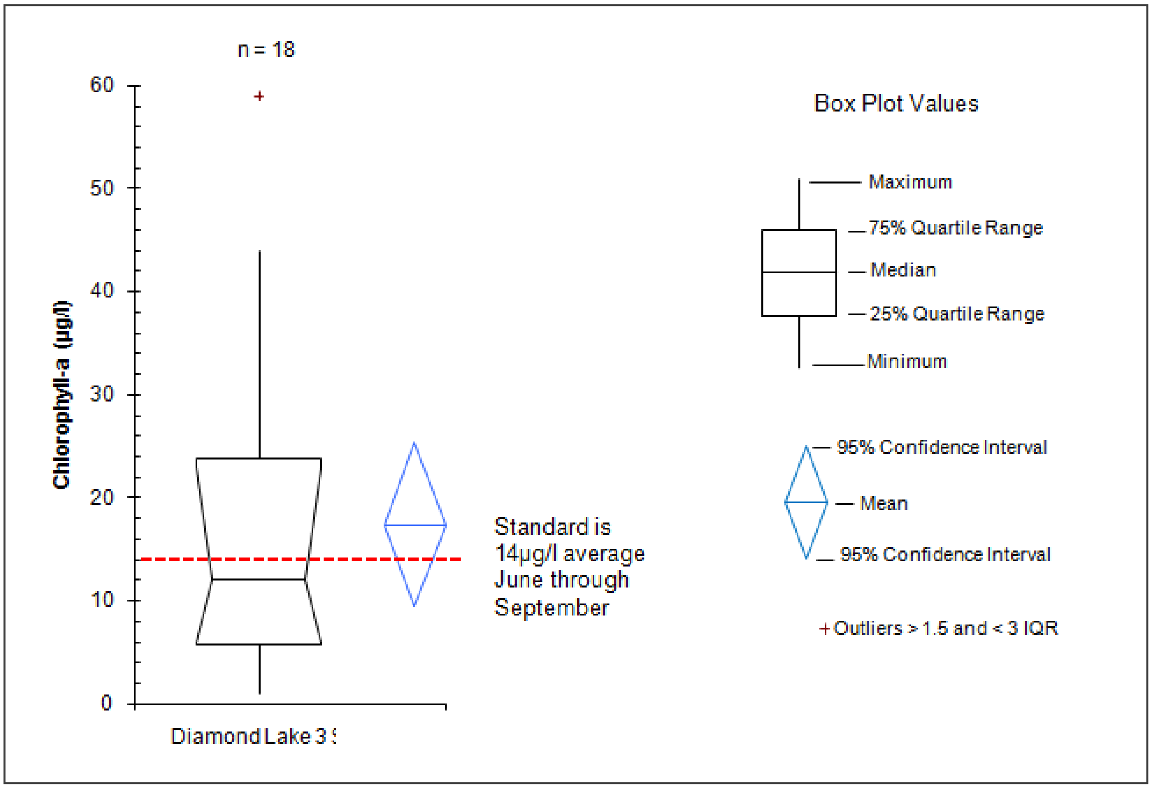


Figure 7.20 Surface mean total Kjeldahl Nitrogen within Diamond Lake, 2008 - 2009

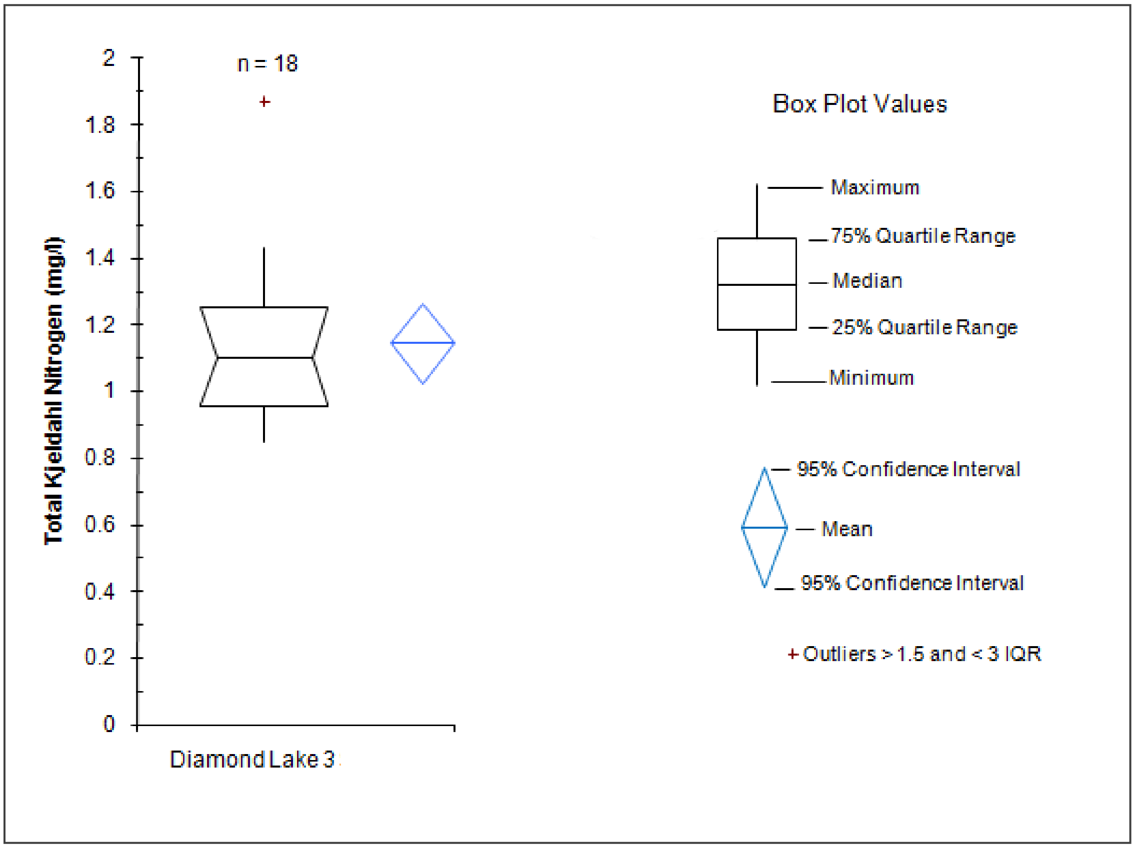


Figure 7.21 Total nitrogen to total phosphorus ratio time series, Diamond Lake, Site 3, 2008 - 2009

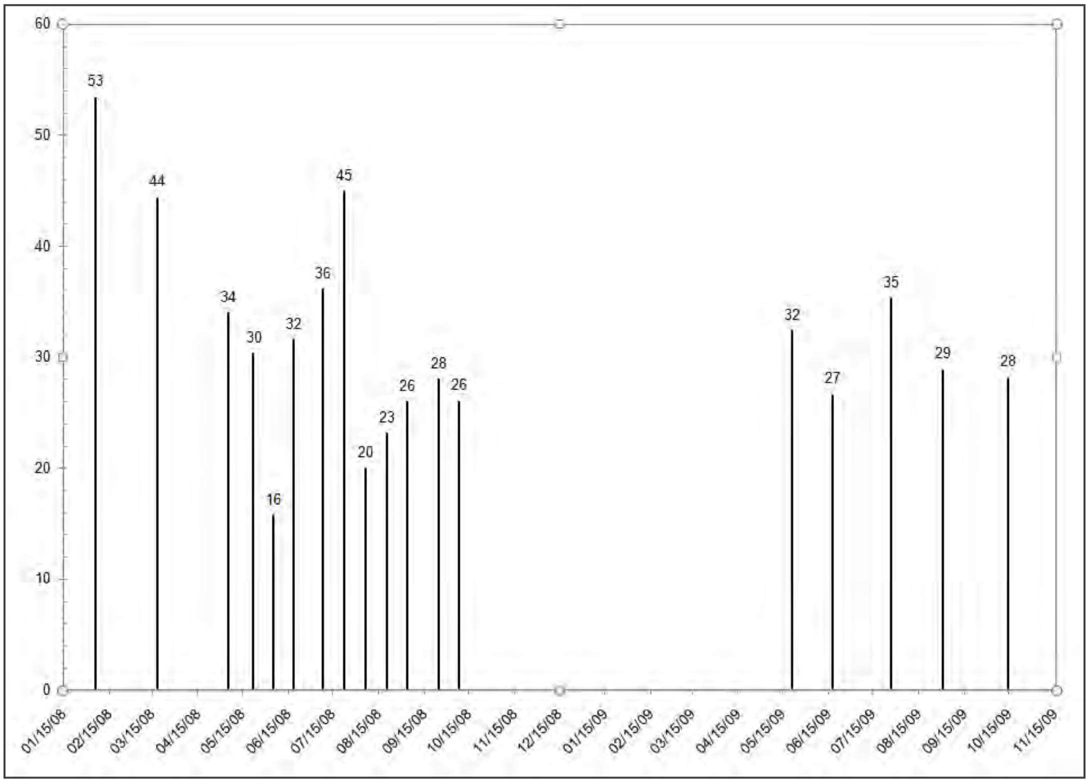


Figure 7.22 Relationship between paired total phosphorus and chlorophyll-a concentrations in Diamond Lake, 2008-2009

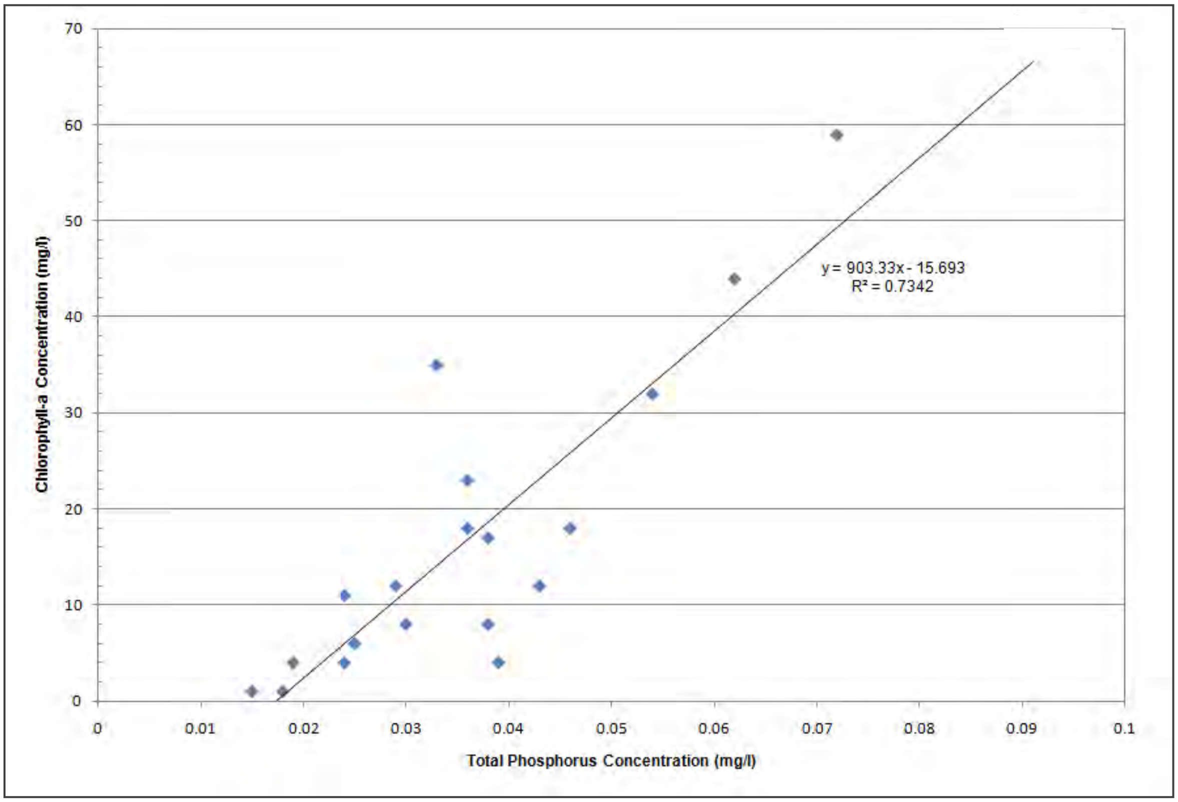


Figure 7.23 Relationship between paired total phosphorus and secchi disk measurements in Diamond Lake, 2008-2009

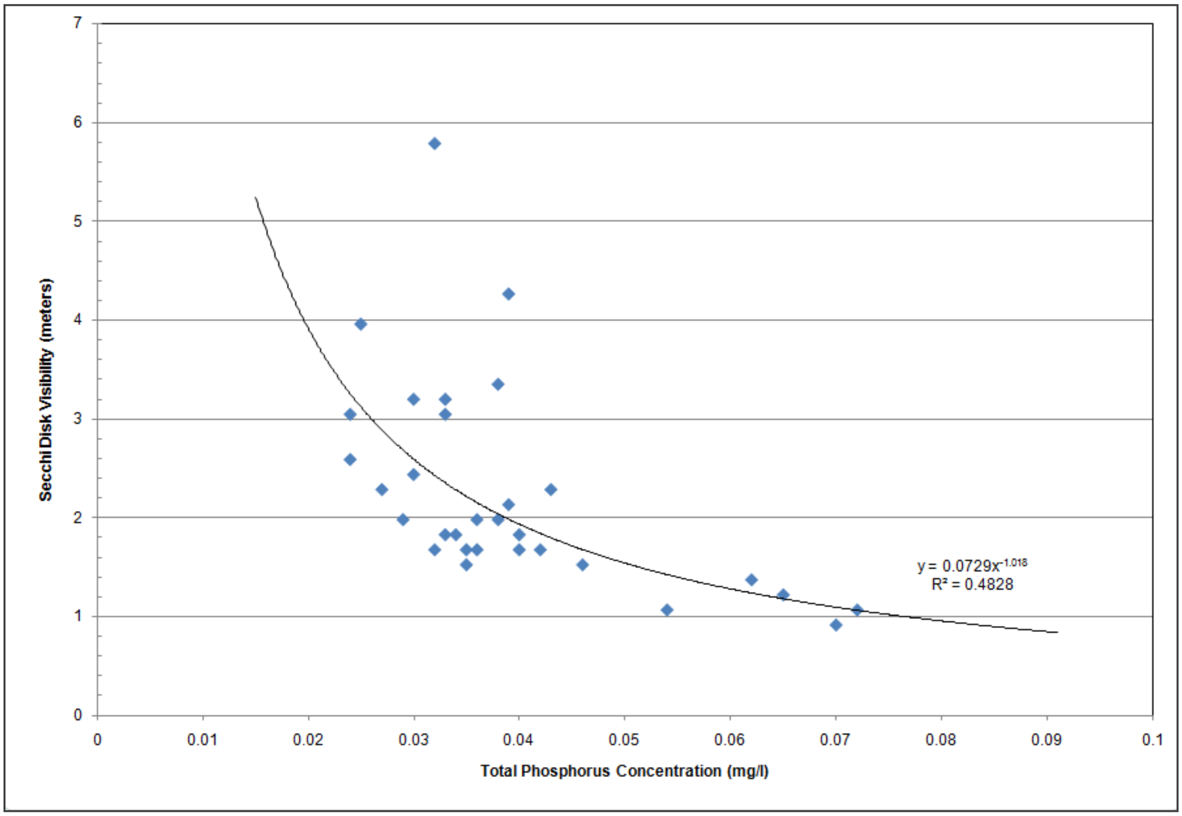


Figure 7.24 Relationship between paired chlorophyll-a concentrations and secchi disk measurements in Diamond Lake, 2008-2009

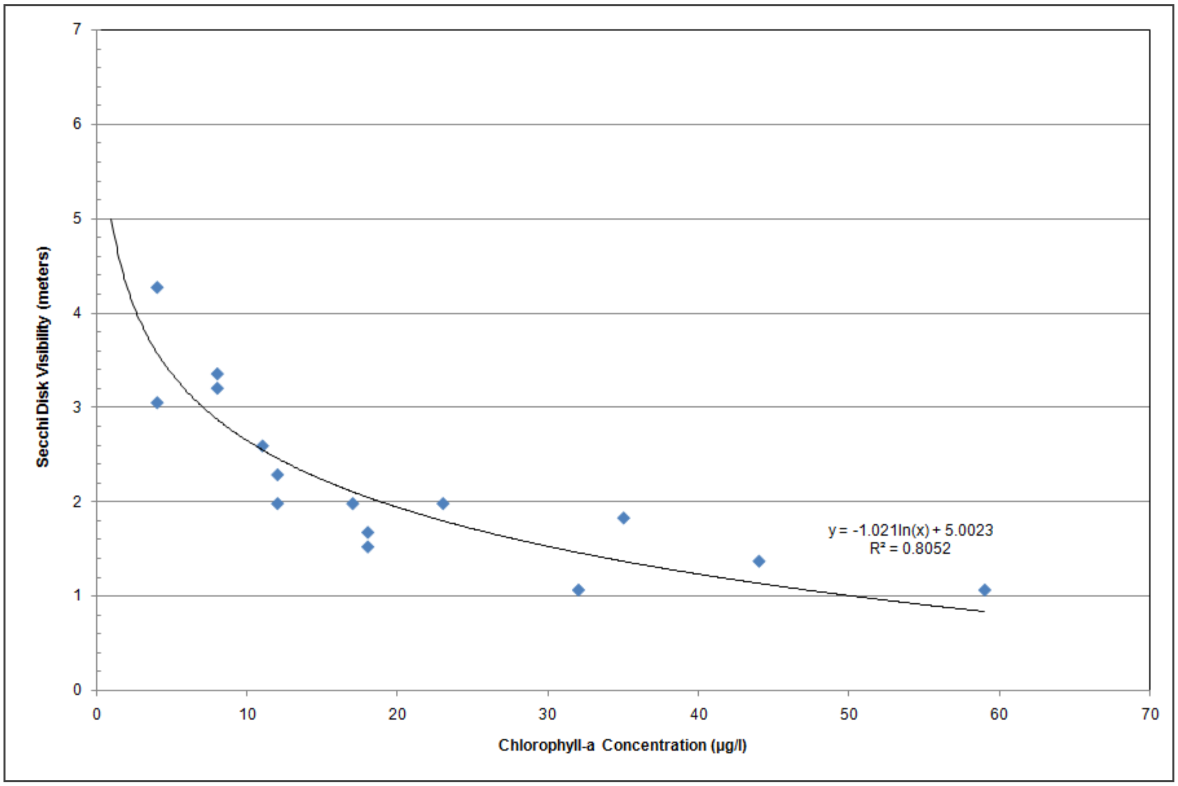
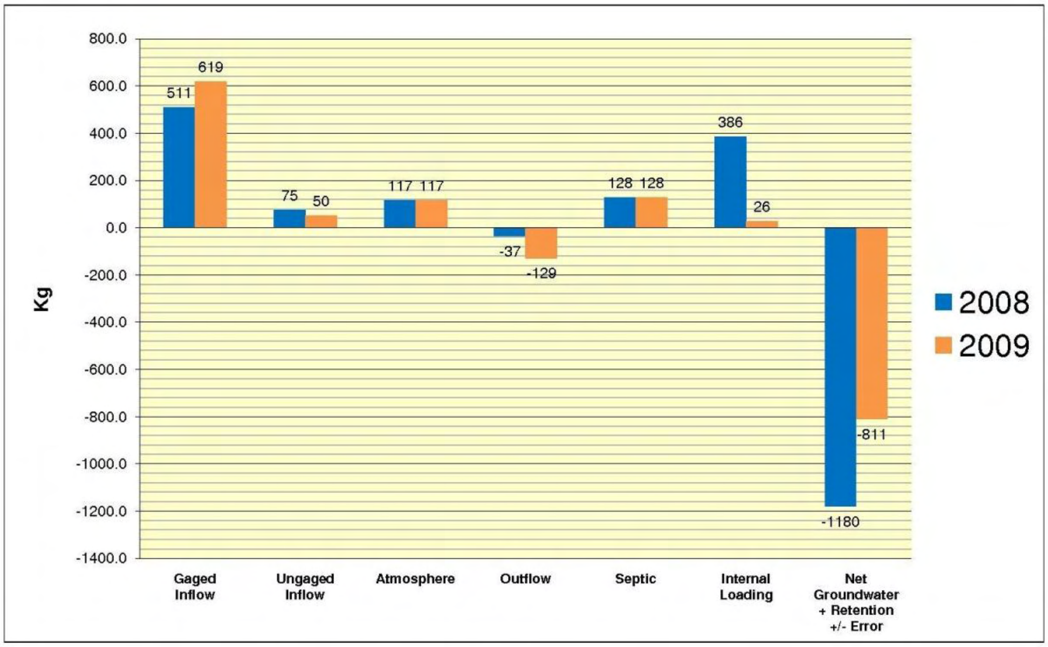


Figure 7.25 Diamond Lake total phosphorus budgets, 2008 and 2009



7.3.1.3 Total Phosphorus Budget

When considering water quality in natural systems, two forms of phosphorus are important. Dissolved phosphorus is readily available to microscopic algae and rooted aquatic plants. Total phosphorus provides an indication of the total amount of phosphorus entering the Lake. Typically the phosphorus in ground water is dissolved.

Field data from the 2008 and 2009 sampling show that Diamond Lake is very effective at retaining phosphorus. According to these data, Diamond Lake retained 86% and 97% of the estimated 1,216 kg and 940 kg of total phosphorus entering the lake in 2008 and 2009, respectively (**Figure 7-25**). Surface water runoff is the single largest source of total phosphorus, accounting for between 48% and 71% of the total load. Atmospheric deposition and failing septic systems contribute nearly equal percentages, approximately 15% of the total load. The internal release of total phosphorous accounts for the remaining proportion and ranged from 3% to 32% in 2009 and 2008, respectively.

7.3.2 Streams

This portion of the report presents information about runoff quality, estimated loads, and yields from the various subwatersheds contributing runoff to Diamond Lake. Annual loads were estimated using the streamflow information previously presented along with measured concentrations from grab samples obtained by the MFCRWD. Annual yields were estimated by dividing the annual load by the upstream contributing drainage area (see **Figure 4-1**).

The specific conductance, turbidity, total suspended solids, and pH within the streams contributing runoff to Diamond Lake provide a sense of the physical-chemical characteristics of water quality in the watershed. Water with higher specific conductance typically contains greater dissolved substances, including ions and salts. Lower specific conductance generally means “better” water quality. **Figures 7-26** through **7-29** show the physical-chemical characteristics of the stream water quality. Monitoring locations DL-7 and HL-2 show greater mean specific conductance than the other locations. Mean turbidity and total suspended solids concentrations at HL-2 are similar to or lower than those measured at the other locations, with the exception of DL-7. The mean turbidity at DL-7 and WL-2 are greater than the 25 NTU water quality standard. The greater mean turbidity at these sites corresponds with greater mean total suspended solids concentrations. Mean dissolved oxygen concentrations are sufficient to support aquatic life (i.e., greater than 5 mg/l), although periodically concentrations become low (2-3 mg /l) (**Figure 7-30**).

Nutrients are the stressor reaching Diamond Lake causing the aquatic life impairment. The response to the excess nutrients in Diamond Lake is the stimulation of algal growth and reduction in water clarity (see **Figure 7-21** and **Figure 7-22**). Several items based upon a review of the mean concentrations for the stream monitoring locations seem noteworthy. Monitoring locations DL-7 and HL-2 showed the greatest mean concentrations of total phosphorus and dissolved phosphorus (**Figure 7-31** and **Figure 7-32**). A large proportion of the total phosphorus at both DL-7 and HL-2 is dissolved. Agricultural areas are generally characterized by greater proportions of particulate rather than dissolved phosphorus. DL-7 and HL-2 also have high proportions of dissolved nitrogen. The nitrate plus nitrite mean concentrations at DL-7 and HL-2 are elevated compared to the remaining monitoring locations and the amount of Kjeldahl nitrogen (organic nitrogen plus ammonia) (see **Figure 7-33** and **Figure 7-34**).

Pollutant yield is defined as the pollutant load per unit drainage area. **Table 7-2** shows estimated loads and yields at the stream monitoring locations for 2008 and 2009. Monitoring locations WL-2 and HL-2 contribute considerable nutrient loads to the inflow of Diamond Lake (DL-1). The annual loads entering Hubbard Lake for dissolved phosphorus and nitrate plus nitrite nitrogen exceed the loads measured downstream at the inflow to Diamond Lake. This suggests Hubbard Lake is effectively capturing these nutrients, mostly likely within plant material (as opposed to sedimentation, as these nutrients are dissolved). **Table 7-2** shows the yields from DL-7 and HL-2 are both elevated compared to the other monitoring locations.

Figure 7.26 Specific conductance at stream monitoring locations, 2008-2009

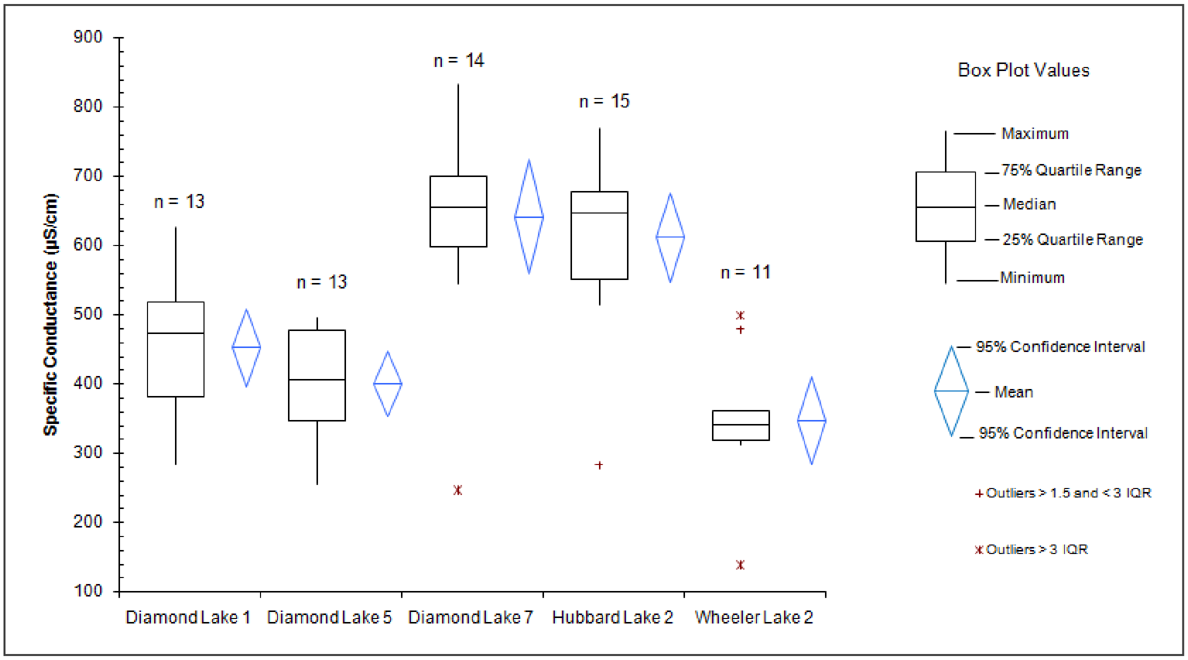


Figure 7.27 Turbidity at stream monitoring locations, 2008-2009

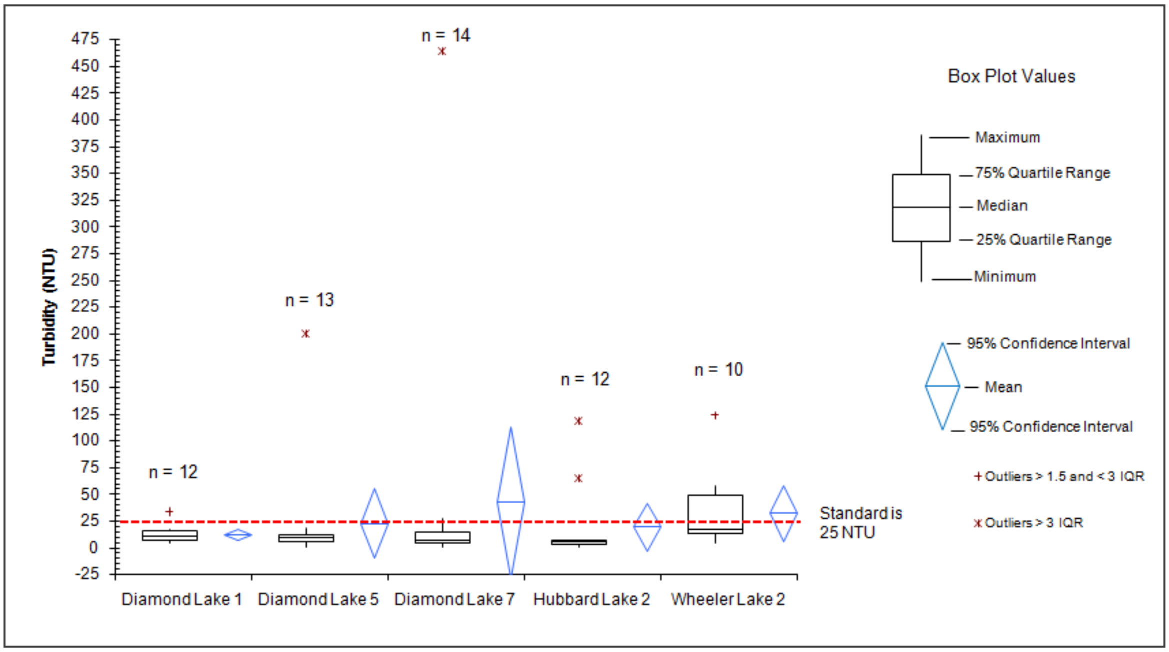


Figure 7.28 Total suspended solids at stream monitoring locations, 2008-2009

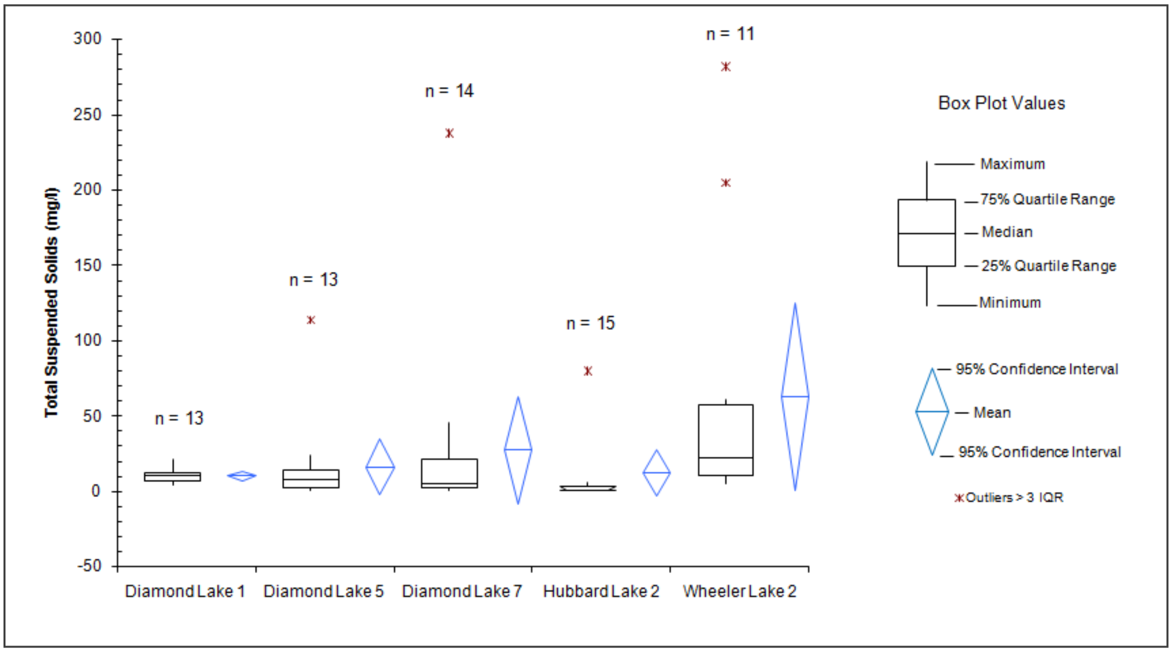


Figure 7.29 pH at stream monitoring locations, 2008-2009

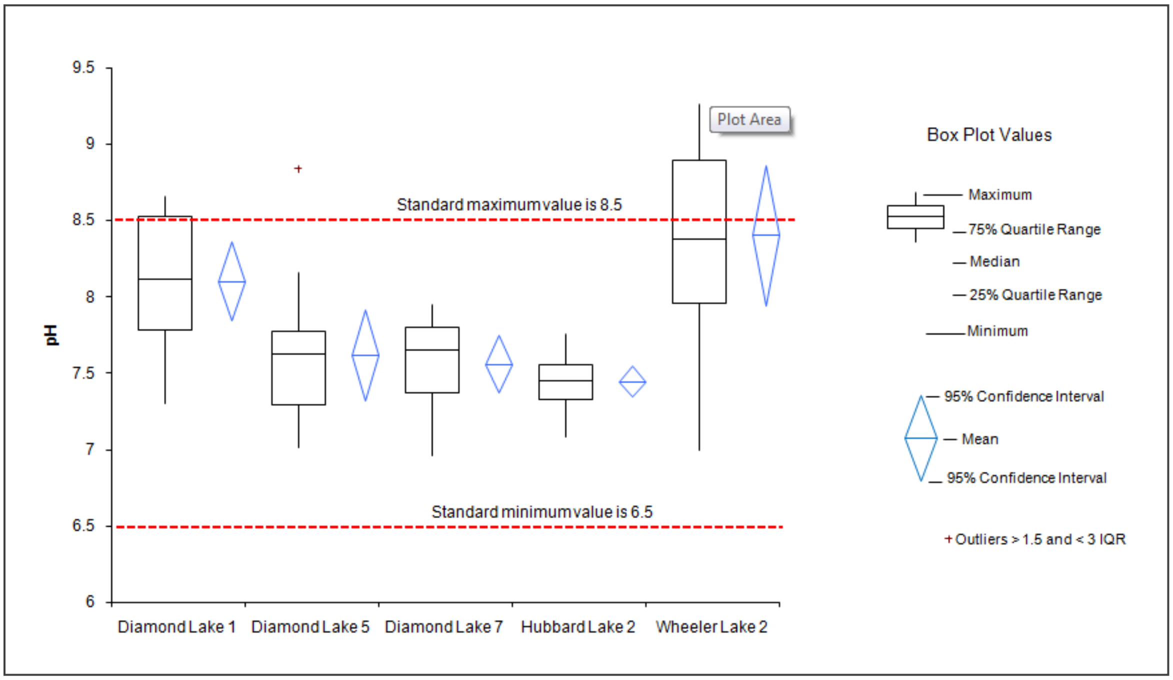


Figure 7.30 Dissolved oxygen at stream monitoring locations, 2008-2009

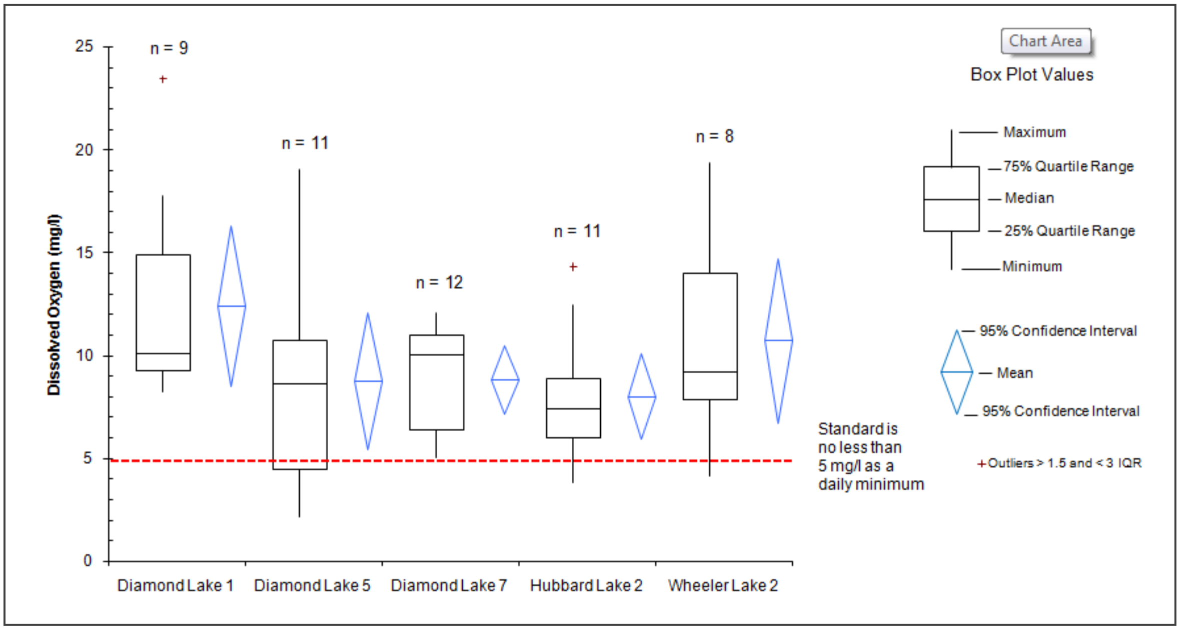


Figure 7.31 Total phosphorus at stream monitoring locations, 2008-2009

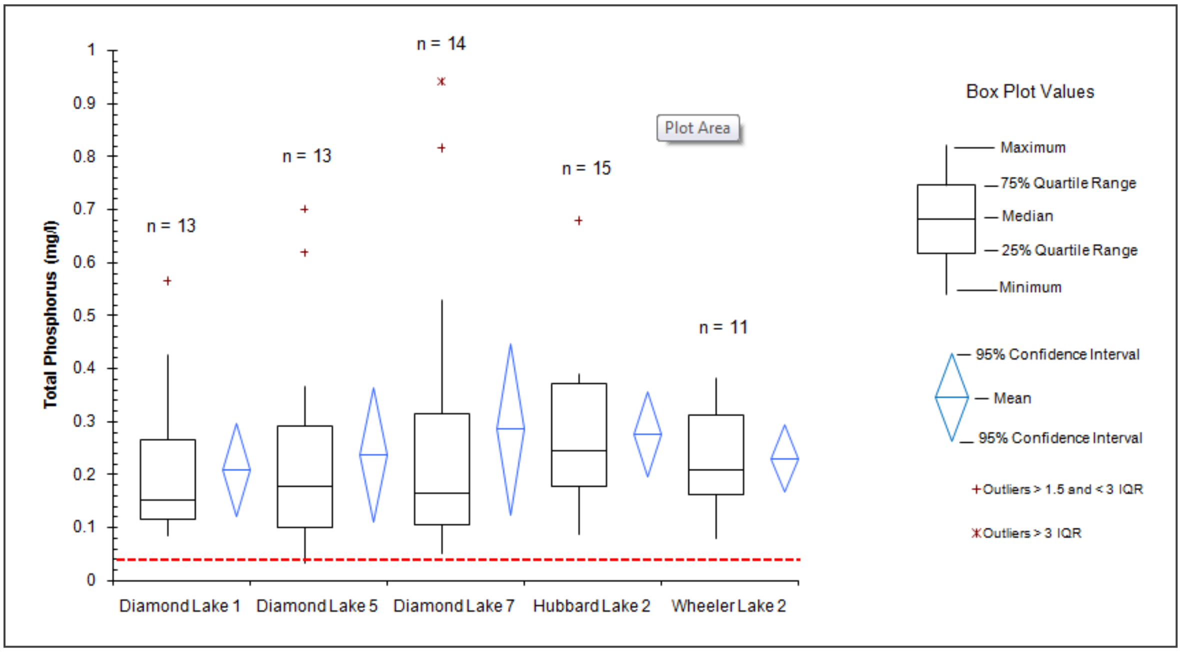


Figure 7.32 Dissolved phosphorus at stream monitoring locations, 2008-2009

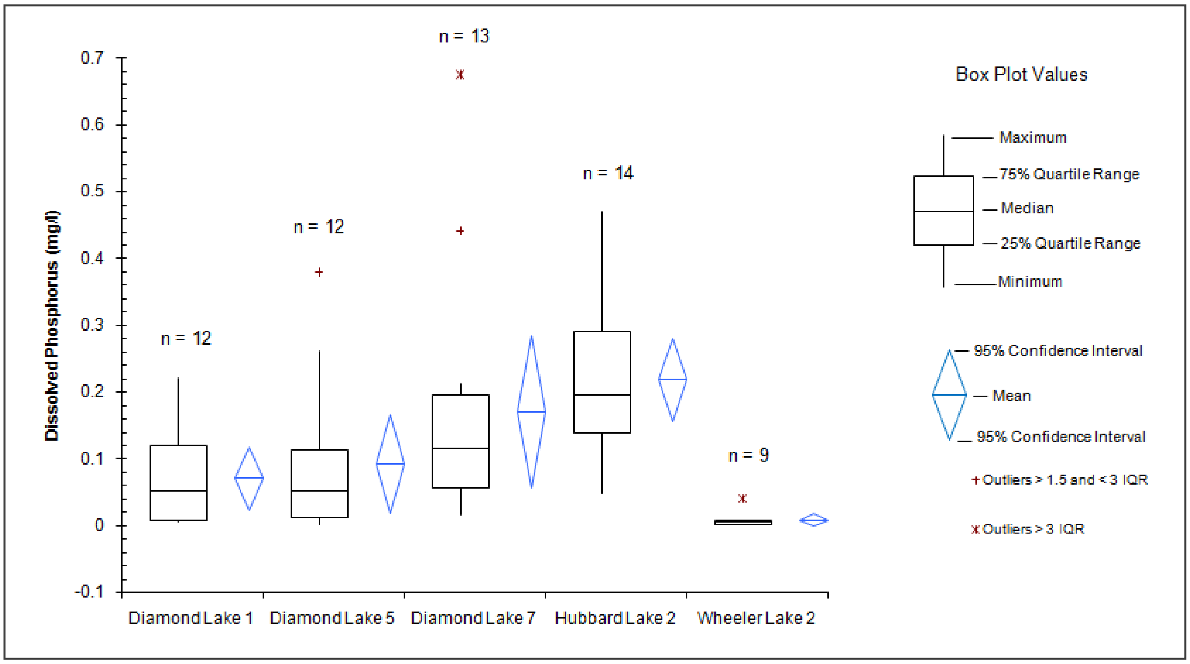


Figure 7.33 Nitrate plus nitrite nitrogen at stream monitoring locations, 2008-2009

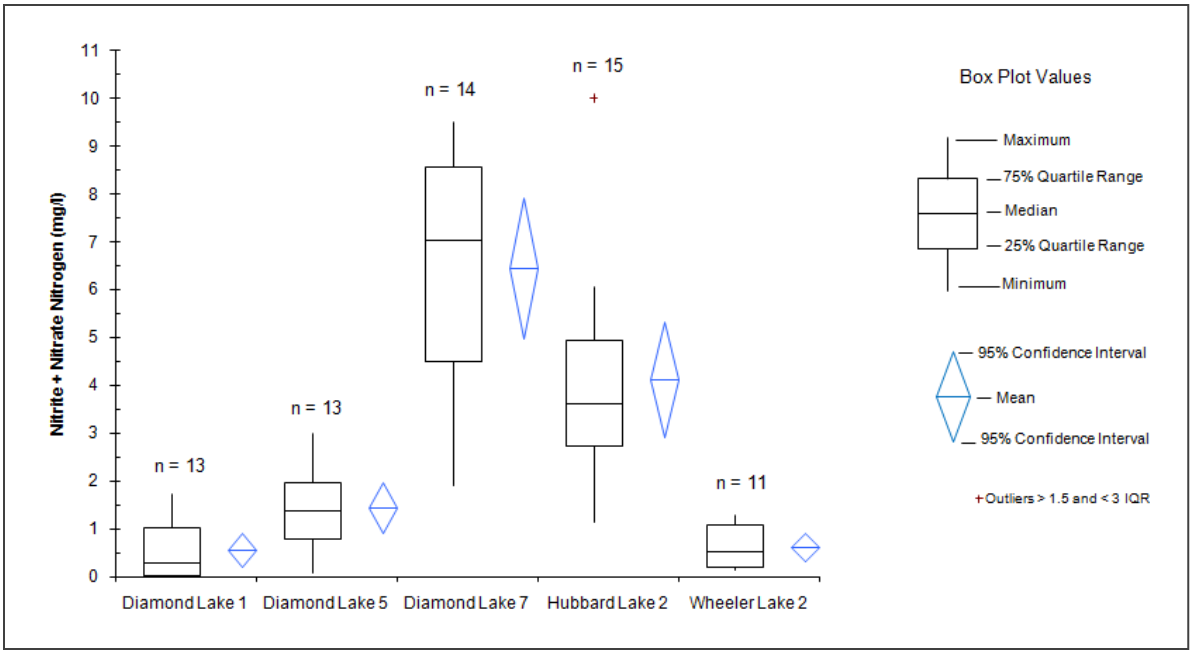


Figure 7.34 Total Kjeldahl nitrogen at stream monitoring locations, 2008-2009

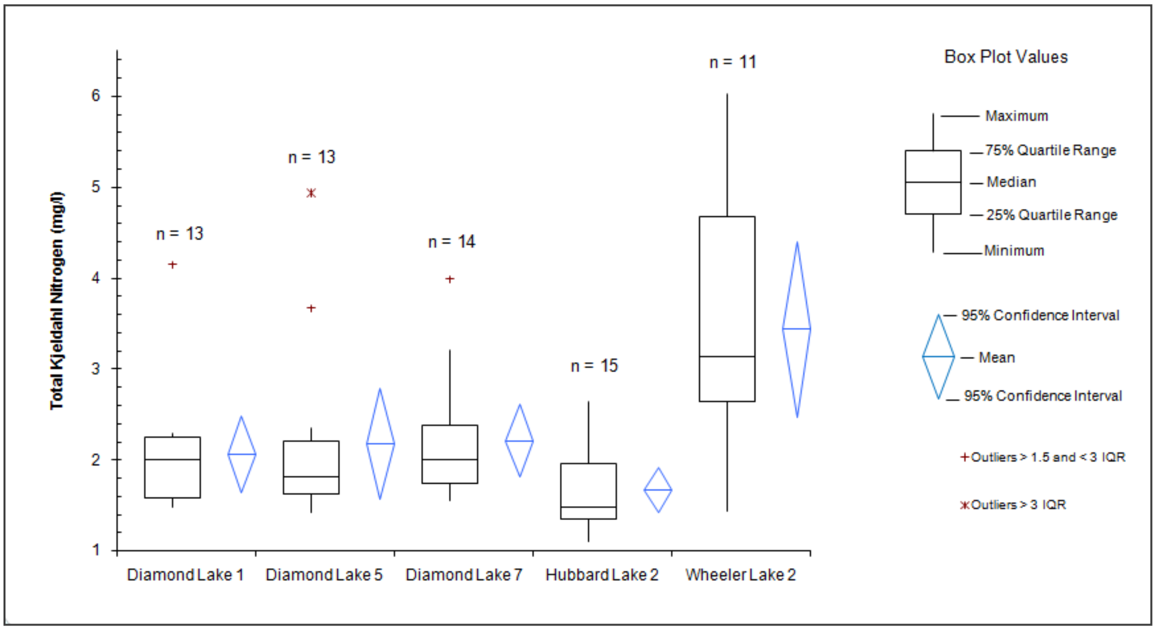


Table 7-2 Annual loads (lbs) and yields (lb/acre) at stream monitoring locations, 2008 and 2009

	DL1		DL2		DL5		DL7		HL2		WL2	
	lbs	lb/Acres	lbs	lb/Acres	lbs	lb/Acres	lbs	lb/Acres	lbs	lb/Acres	lbs	lb/Acres
TP												
2008	954.4	0.14	80.5	0.00	54.2	0.02	117.3	0.05	394.2	0.15	--	--
2009	1222.7	0.17	283.7	0.01	65.0	0.03	77.8	0.04	464.3	0.17	372.6	0.23
Total	2177.0	0.31	364.2	0.02	119.3	0.05	195.1	0.09	858.5	0.32	372.6	0.23
DP												
2008	311.7	0.04	25.6	0.00	80.2	0.04	136.2	0.06	325.4	0.12	--	--
2009	403.4	0.06	90.2	0.00	79.8	0.04	90.4	0.04	393.1	0.14	14.6	0.01
Total	715.2	0.10	115.7	0.01	160.1	0.07	226.6	0.10	718.5	0.26	14.6	0.01
TSS												
2008	48128.4	6.88	11940.8	0.62	15956.9	7.07	8783.8	3.98	17835.4	6.57	--	--
2009	62286.3	8.90	41946.9	2.19	15852.6	7.02	5829.2	2.64	22766.9	8.39	101572.5	63.76
Total	110414.7	15.77	53887.7	2.81	31809.5	14.09	14613.0	6.63	40602.3	14.97	101572.5	63.76
TKN												
2008	9116.2	1.30			3641.1	1.61	1320.8	0.60	2526.0	0.93	--	--
2009	11798.1	1.69			3616.4	1.60	876.5	0.40	3224.2	1.19	5563.7	3.49
Total	20914.4	2.99			7257.5	3.21	2197.3	1.00	5750.3	2.12	5563.7	3.49
NO3												
2008	2749.6	0.39			130.1	0.06	5478.2	2.48	6219.0	2.29	--	--
2009	3632.1	0.52			850.3	0.38	3635.8	1.65	7946.0	2.93	988.3	0.62
Total	6381.7	0.91			980.4	0.43	9114.0	4.13	14165.0	5.22	988.3	0.62

8.0 CONCLUSIONS

Runoff conditions within the Diamond Lake watershed during 2008 and 2009 (assuming these conditions were similar to the watershed contributing runoff to the USGS Middle Fork Crow River gage at Spicer) were only slightly below normal (2008) or normal (2009). The field data collected during these time periods and discussed in this report should, therefore, be representative of "normal" conditions for establishing the load allocation associated with the TMDL. Quality assurance information collected during the study indicates technically defensible data collection, as sample duplicates showed reasonable precision and sample blanks showed a lack of contamination.

Future watershed and receiving water modeling should use 2009 for model calibration and 2008 for model validation purposes. Diamond Lake only weakly thermally stratifies during the summer months, but still has periods of low dissolved oxygen within the hypolimnion. Total phosphorus concentrations within the hypolomion of Diamond Lake become elevated during the periods of low dissolved oxygen. The mean concentrations of total phosphorus, chlorophyll-a and mean secchi disk depth failed to attain the numeric standards (using all 2008 and 2009 data) for a deep Class 2B located within the North Central Hardwoods Ecoregion.

Water enters Diamond Lake from a number of sources. Precipitation falls on the lake surface, surface runoff enters directly from areas around the lake, and ground water interacts with the lake below the land surface. The hydrology of Diamond Lake appears to be dominated by surface water runoff and precipitation falling directly onto the lake surface, although no ground water measurements were made. The estimated total volume of water entering Diamond Lake in 2008 was 6,379 acre-feet; in 2009 it was 6,937 acre-feet. Nearly one-third of the volume entering the lake comes from surface runoff and an estimated one-half from precipitation onto the lake surface.

According to monitoring results, Diamond Lake is very effective at retaining phosphorus. In 2008 and 2009, it retained 86% and 97% of the estimated 1,216 kg and

940 kg of total phosphorus entering the lake, respectively. Surface water runoff is the single largest source of total phosphorus, accounting for between 48% and 71% of the total load. Atmospheric deposition and failing septic systems contribute nearly equal percentages, approximately 15% of the total load. The internal release of total phosphorous accounts for the remaining proportion and ranged from 3% to 32% in 2009 and 2008, respectively.

Monitoring data show a strong linear relationship between total phosphorus and chlorophyll-a and a logarithmic response for secchi disk visibility. The relationship between cholorophyll-a and secchi disk visibility is also logarithmic and strong. This suggests the water clarity within Diamond Lake is strongly driven by the abundance of algae. This also implies that reducing total phosphorus loads will have a direct reduction in the amount of chlorophyll-a and an improvement in water clarity.

9.0 REFERENCES

Middle Fork Crow River Watershed District (MFCRWD). 2008. Diamond Lake Excess Nutrients TMDL Project Quality Assurance Project Plan. Prepared by: R. Fisher, MPCA Water Quality QA/QC Coordinator, Environmental Analysis and Outcomes Division, Minnesota Pollution Control Agency, 520 Lafayette Road North, St. Paul, MN 55155-4194. 39 pp.

Minnesota Pollution Control Agency. 2007. Lake Nutrient TMDL Protocols and Submittal Requirements. Prepared by: Steve HSteve Heiskary, Jeff Hrubes, Frank Kohlasch, Tim Larson, Dave Maschwitz, Jeff Risberg, Mark Tomasek, Bruce Wilson, Mike Trojan, Mike Findorff. 127 pp.

Walker, W.W. Jr. 1986. Empirical Methods for Predicting Eutrophication in Impoundments; Report 4, Phase III: Applications Manual. Technical Report E-81-9; prepared by William W. Walker, Jr., Environmental Engineer, Concord, Massachusetts, for U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi.

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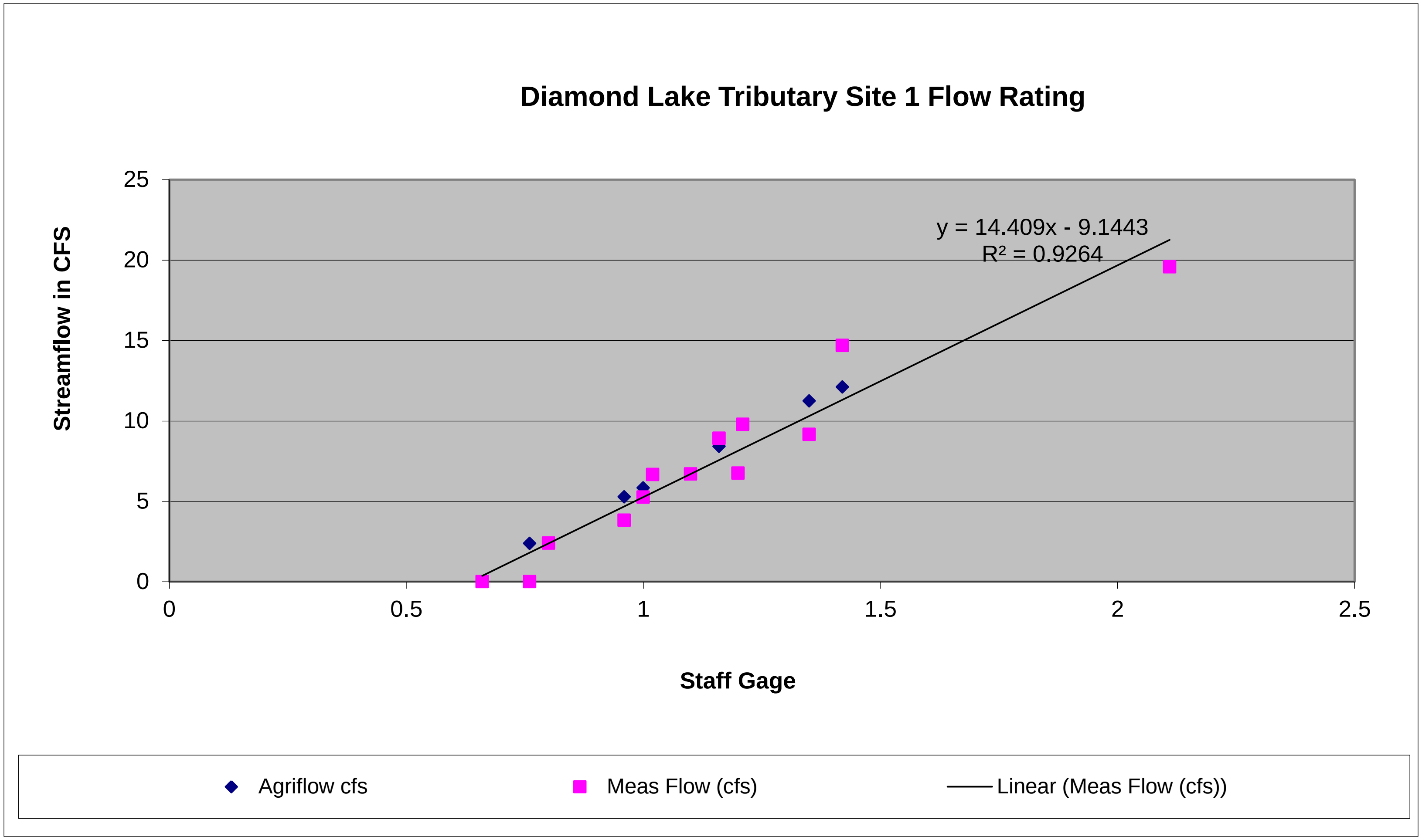
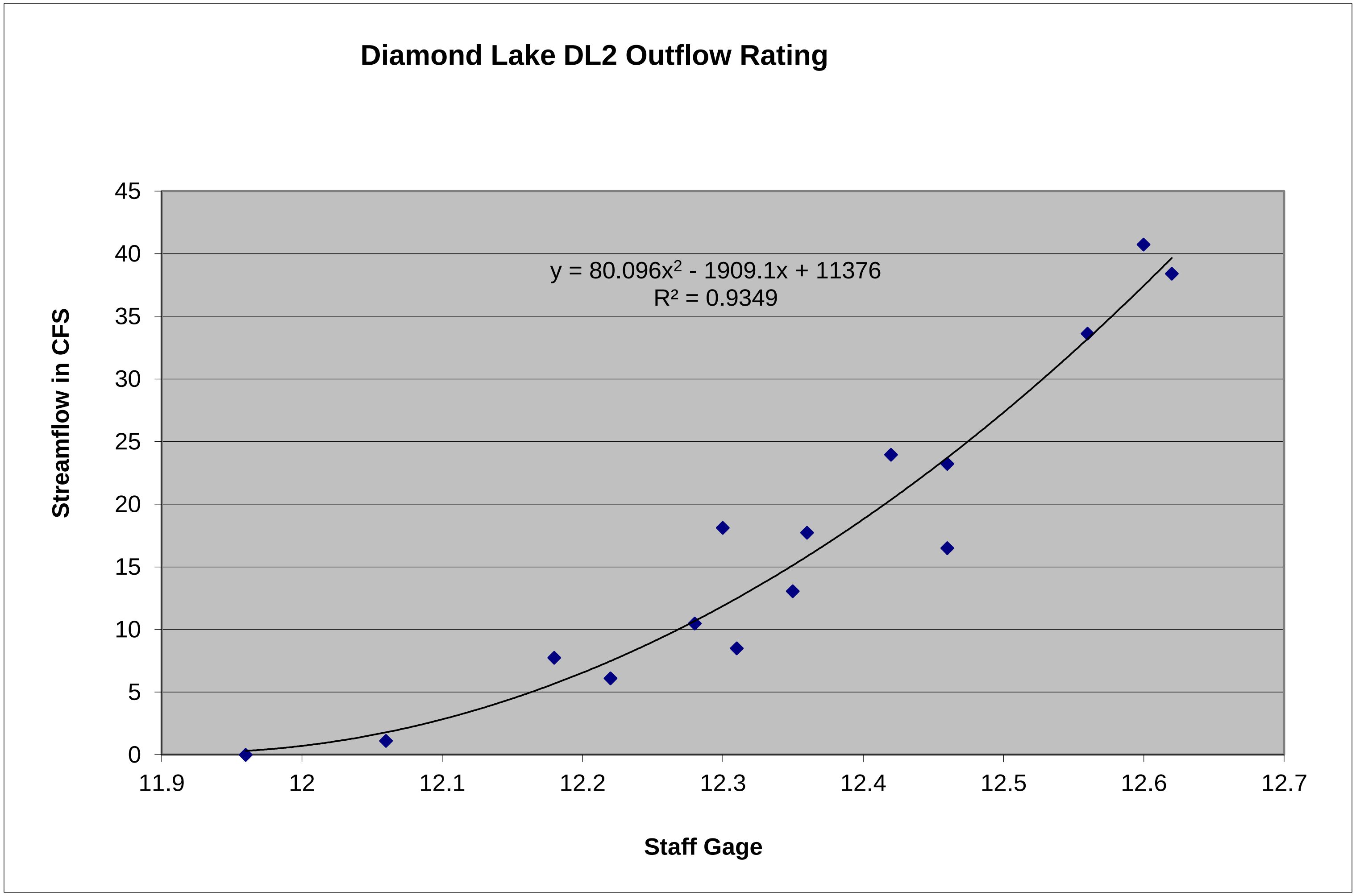
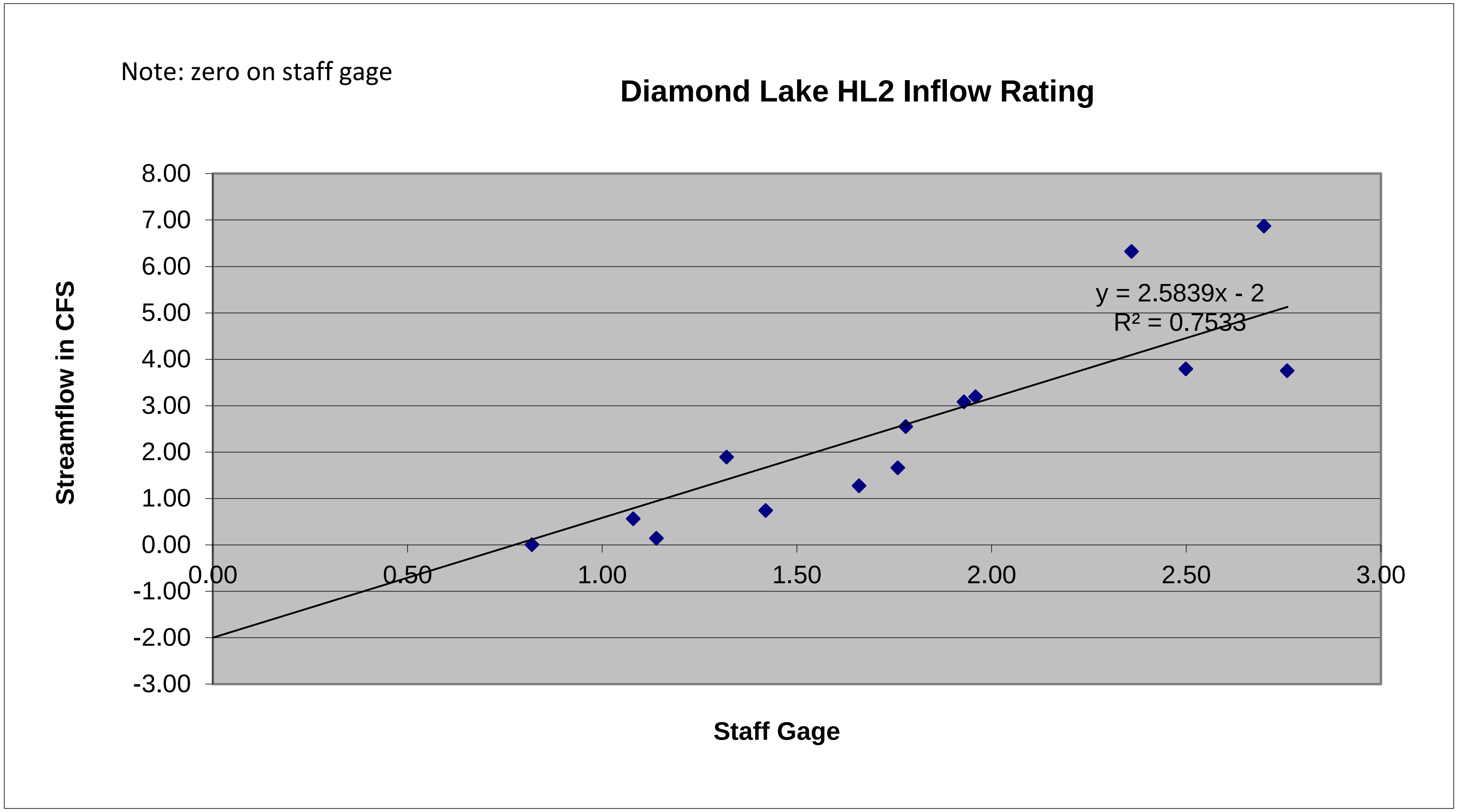
APPENDIX A
Rating Curves




Diamond Lake DL2 Outflow Rating
$y = 80.096x^2 - 1909.1x + 11376$
$R^2 = 0.9349$
Streamflow in CFS
45
40
35
30
25
20
15
10
5
0
11.9
12
12.1
12.2
12.3
12.4
12.5
12.6
12.7
Staff Gage


Note: zero on staff gage
Diamond Lake HL2 Inflow Rating
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
y = 2.5839x - 2
R² = 0.7533
Streamflow in CFS
Staff Gage

APPENDIX B

Load Estimation Using the U.S. Army Corps of Engineer's FLUX Program

Loads for a variety of time periods can be estimated using the U.S. Army Corps of Engineers (COE) FLUX program (http://el.erdc.usace.army.mil/elmodels/emiinfo.html). The program allows estimation of mass discharges (loadings) from sample concentration data and continuous (e.g., daily) stream flow records. ***The FLUX program can only be used when there are paired concentration and stream flow measurements (either instantaneous or daily averages).*** The collection of water quality samples without paired stream flow information is of limited value, other than to generally characterize water quality condition.

Five estimation methods or statistical models are available and the potential errors in the estimates can be quantified. One of the challenges of using the FLUX program (and estimating loads in general) is selecting the appropriate estimation method and deciding which estimate of load is "best." Generally, the estimation method[3] which gives the lowest estimated error (in this case expressed as the variance of the estimate) should be considered best and selected as the tributary load. The following procedure is one approach for proceeding through the load estimation process with the intent of determining the "best" load estimate.

- Read the files containing the daily flow record and sample concentration and paired instantaneous or daily stream flow;
- Generate diagnostic plots of: 1) flow versus concentration; and 2) flow versus date. By evaluating these plots, you will get some sense if concentration is correlated to stream flow or time. These plots can give you some sense of the values to use in the stratification process used to improve your load estimate (see below);

[3] Report 4, Phase III: Application Manual of Technical Report E-81-9, Empirical Methods for Predicting Eutrophication in Impoundments provides an example load estimate session which also may be followed. The method presented here is an annotated method.

- Generate a histogram of the sampled concentrations. Assess the distribution of the sampled events;
- Based on the distribution of the data consider whether a log transformation is required;
- Generate a plot of flow cumulative frequency for the measured stream flows and the sampled stream flows. Do the lines overlap through the flow range (this gives you an indication of whether you sampled events through the entire flow range);
- Use each method within the FLUX program to estimate the load for the period of interest (generally growing season or annual to use as input into a receiving water model);
- Note (write down) the estimate load and variance associated with each estimate under the appropriate method in table (see attached);
- Stratify the data by flow, generally using the mean stream flow for the period of record as an initial value. (Note: you may try several different flow values or multiple flows, but must pay attention to the sample size of measured concentrations within each flow range. A reasonable number of samples should be within each flow range.)
- Use each method within the FLUX program (again) with the data stratified by flow range, to estimate the load and variance for the period of interest. Again, note (write down) the variance associated with each estimate in the table.
- Stratify the data by season or date, generally using the spring, summer, fall and winter for the as initial periods. (Note: you may try several different seasons or dates. What you are trying to do is break the period of record into reasonably similar flow ranges);
- Use each method within the FLUX program (again) with the data stratified by season or date, to estimate the load and variance for the period of interest. Again, note (write down) the variance associated with each estimate in the table.
- Stratify the data by flow AND season or date;
- Use each method within the FLUX program (again) with the data stratified by season or date and flow, to estimate the load and variance for the period of interest. Again, note (write down) the variance associated with each estimate in the table;
- Evaluate the estimate loads and variances within the table. Generally, the estimated loads for one method will tend to converge to a reasonably similar estimated loads and variance estimates. Select the load corresponding to the lowest estimated variance.

APPENDIX C

Estimated Loads from Individual Sewage Treatment Systems

Diamond Lake
Individual Sewage Treatment System Load Analysis

10-Mar-10

INPUTS		
Total Phosphorus Input (kg/person/year)		0.75
Total Nitrogen Input (kg/person/year)		1.5
Length of Seasonal use (no. of months)		4
Number of Structures		
Seasonal	70%	256
Year-round	30%	109
Number of persons per structure		
Seasonal		2.5
Year-round		2.5
Treatment System Estimate Failure Rate		
Seasonal		70%
Year-round		70%
Proportion of Failing Systems Contributing to Lake Load (soils adjustment factor)		50%

ESTIMATED ANNUAL LOAD IN KILOGRAMS PER YEAR	
Total Phosphorus	
Seasonal	56.0
Year-round	71.5
Total	127.5
Total Nitrogen	
Seasonal	112.0
Year-round	143.1
Total	255.1

Treatment system estimated failure defined as less than 3-feet separation from seasonal high groundwater table.

Estimated input per person from D. Gustafson, MN Ext.

Estimated failure rate and no. of persons per structure based on Wenck, September 2008 study.

Length of seasonal use assumed as May through September.

Diamond Lake Watershed Modeling Memo

November 11, 2010

Introduction

The purpose of this memo is to detail the modeling effort put forth to simulate the surface water hydrology and associated pollutant loading observed in the Diamond Lake watershed. This modeling was performed as a component of the Diamond Lake Total Maximum Daily Load (TMDL) study and the memo is meant as a complement to the Diamond Lake TMDL Report.

Watershed loading models are used to combine information on a study area's hydrology and landscape processes to predict the amount of pollutants that will leave the landscape and be transported downstream. By calibrating the model to observed data, the model is "trained" to properly reflect the characteristics of the study area, including how the area may respond to changes in operations within the landscape processes (i.e., modifying land use or installing pollution prevention strategies).

In the case of the Diamond Lake watershed, the goal of developing a watershed loading model is three fold: 1) to quantify the amount of nutrients leaving the landscape upstream of Diamond Lake and from areas directly contributing runoff to the lake; 2) to prioritize locations for implementing structural best management practices (BMPs) and agricultural conservation measures based on that quantification; 3) to assess the performance and removal efficiencies of water quality structural BMPs and agricultural conservation practices, reasonably expected to be implemented within the Diamond Lake contributing drainage area.

The following memo describes the watershed loading model that was created for the Diamond Lake watershed and the process of its development, calibration, and validation. The memo summarizes the data sources (many of which are discussed further in the main body of the TMDL report) that were used to create the model and the errors in the modeling output (based on the calibration and validation results). The final section of the memo addresses the use of the model to simulate various BMP scenarios for use in supporting an Implementation Plan. BMP effectiveness estimates are given, based on the model scenarios run.

Modeling Approach

The Diamond Lake watershed was modeled using the 2005 version of the Soil and Water Assessment Tool (SWAT), a watershed-scale loading model commonly used in the development of TMDLs. The SWAT model was "developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time" (Neitsch, et. al, 2005a). As such, it is a complex, process-oriented model that runs on a sub-daily or greater time step. SWAT has the capacity to interface directly with QUAL2E, a one-dimensional stream water quality model. The inclusion of QUAL2E allows for the simulation of major nutrient cycles, algal production, and processes surrounding dissolved oxygen concentrations in the area's streams. The combination of these two models was used to simulate pollutant loading from the Diamond Lake watershed and into Diamond Lake.

Model Input Data and Sources

The SWAT model requires various inputs to build its applications upon, including information about the study area's soils and terrain. ArcSWAT is an ArcGIS interface to the SWAT model that allows the user to input the required information through various GIS layers, such as digital soil maps and a digital elevation model (DEM). The type of data included in the modeling and the sources that these data came from are as follows:

- Land use data are from the 2001 version of the National Land Cover Database (NLCD) provided by the USGS National Land Cover Institute. More information is available at: http://landcover.usgs.gov/index.php
- Soils data were obtained from the State Soil Geographic (STATSGO) Database. This database is maintained by the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center (NCGC), available at: http://soils.usda.gov/survey/geography/statsgo/
- Land-surface topography was determined using the 30-meter Digital Elevation Model (DEM) provided by the USGS (http://edc2.usgs.gov/geodata/index.php).
- Precipitation data were retrieved from the National Climate Data Center (NCDC). Data were originally recovered for the New London and Willmar Stations. Data at the Willmar station were more complete than those at the New London Station (i.e., had a longer period of record and missed less data points during each year), so the Willmar data was used to develop the SWAT model inputs.
- Other weather-related data, such as temperature and wind direction and speed, were defaulted to values contained within the SWAT software. Measured values for these parameters generally would not provide better information than estimated or default values at this temporal and spatial scale; they also have less of an impact on the simulated hydrology than variations in precipitation.
- Hydrography in the Diamond Lake watershed, including lakes and stream information were obtained from the MN DNR and the Middle Fork of the Crow River Watershed District (MFCRWD).
- The sub-watershed boundaries used for this project were developed by the MFCRWD and input directly into the SWAT model.
- Flow and water quality data used in the model calibration and validation were collected during 2008 and 2009 field monitoring efforts by MFCRWD and MPCA personnel.

Model Setup

The Diamond Lake SWAT model was set up following the model's user's manual (Neitsch et. al, 2005a; 2005b; Winchell et. al, 2008). Key procedures in this process involve:

- Delineating and/or defining the watershed and sub-basins;
- Defining the hydrologic response units (HRUs) based upon land use, soils, and slope;
- Defining the weather data;
- Editing the default input files;
- Setting up (specifying the simulation period, etc.) and running SWAT – debugging the model;
- Calibrating the model;
- Validating the model; and
- Analyzing and graphing the SWAT model output.

Once the base model was set up, the Theoretical Documentation (Neitsch, et. al, 2005a) and Input/Output Documentation (Neitsch et. al, 2005b) were used as references for refining the model and interpreting the SWAT model output.

The Diamond Lake watershed was divided into 16 sub-watersheds, which SWAT further divided into 130 hydrologic response units (HRUs) based on unique combinations and thresholds for land use, soils, and slope. HRUs are the computational framework within the SWAT model; i.e., the spatial units to which calculations for runoff, sediment, and total phosphorus (TP) yield are applied.

All SWAT model simulations were run using a daily timestep. The model was set up to simulate the watershed's hydrology and water quality from 1975 to 2009. The period from 1970 through 1975 was used as a model warm-up period, allowing the model compartments (soil moisture, nutrient content, pond/reservoir conditions) to "wash" the potential influence of initial model conditions from the modeling results.

Model Calibration/Validation

To ensure that the model accurately reflects conditions within the study area, the SWAT model was then calibrated/validated to 2008-2009 field data. Model calibration is the process of "fine tuning" a model's parameters to adjust the modeled output until the results are as close to observed data as possible. The model input parameters that were adjusted during the calibration of the Diamond Lake SWAT model are shown at the end of this memo in the Supplemental Information. The range of values explored is shown, as is the actual value used in the final, calibrated model. Model validation is the process of comparing the calibrated model against an additional set of observations, preferably collected under conditions that differ from those used to calibrate the model (e.g., different amount of streamflow, magnitude of precipitation). In both model calibration and validation, the modeler then quantifies how the model performs.

In this case, less than two years of data were available for the SWAT model calibration and validation. Of these data, those collected in 2009 were considered more reliable than those from 2008 (due to a number of issues, including potential errors with the operation of the field equipment and installing the field equipment late into the season). The 2009 data were, therefore, used for the model calibration and those collected during 2008 were used for model validation. It is important to note that potential errors in the observed data might have increased the difference between observed and simulated values, particularly during the validation period. It is recommended, therefore, that results of the model validation interpreted with some caution.

Though SWAT simulates (and the Diamond Lake model was developed using) a daily timestep, calibrating to day outputs is not normally desired (Neitsch, et. al, 2005a). SWAT's design and the complexity of its simulations can result in significant errors when attempting to simulate this level of accuracy. One reason for these potential errors is the difficulty of replicating the actual timing of runoff events. This is particularly true when field data are collected in streams that experience backwater effects due to downstream impedances, as is the case in the Diamond Lake watershed. When modeled and observed values are considered over longer periods of time, much of the variability in the data is removed and modeling errors are typically reduced.

The issues associated with excess nutrients in the Diamond Lake system are less dependent on daily operations than they are on the general and/or overall watershed condition and nutrient load over a longer period of time (e.g., a growing season). The goal of modeling the Diamond Lake watershed was to understand the nutrient loading to the Lake over these longer periods. Since the issue that the Diamond Lake SWAT model is created to address is a seasonal (not a daily) phenomena and since the uncertainty involved with calibrating to a daily time step is unnecessarily large for this work, the SWAT model was calibrated and validated to the total flow and TP load observed during the 2009 and 2008 field seasons, respectively (shown in **Table 1**). Details on the field data collection and manipulation can be found in the *Diamond Lake Monitoring Report, Summary for the Diamond Lake TMDL*.

Table 1: Time Period of Observed Flows and Computed TP Loads for each Site during 2008 and 2009

Site	2008 (validation)	2009 (calibration)
HL-2	March 15 – September 12	March 16 – October 29
WL-2	N/A	March 15 – November 15
DL-1	March 15 – September 12	March 15 – December 31
DL-5	June 6 – September 11	March 28 – October 26
DL-7	April 17 – October 21	March 28 – September 13

The locations for model calibration focused mainly on the sites in the eastern portion of the watershed: Sites HL-2 and DL-1. A secondary consideration was given to the data collected in the south and western areas, at Sites DL-5 and DL-7. Eastern sites were given priority since the vast majority of surface water and nutrients entering Diamond Lake during 2008 and 2009 came through the eastern portion of the watershed (see **Table 2** and **Table 3**). Therefore, priority was given to reducing the errors at these sites in advance of errors at the southern and western locations.

CALIBRATION

Hydrology

The first step in model calibration is to match up modeled and observed flows. Model parameters were adjusted to optimize the streamflow so modeled values successfully approximated what was observed. Calibration results at each of the flow monitoring sites are shown in **Table 2** and **Figure 1** through **Figure 4**. Results show that the SWAT model slightly over-predicts the flow at Site DL-1, while under-predicting at the remaining stations. In all cases, errors are less than ten percent.

Table 2: Observed vs. Modeled Hydrology at Calibration Points

Site	Observed Volume (m^3)	Modeled Volume (m^3)	Absolute Error (m^3)	% Error
HL-2	848,183	790,980	-57,203	-6.74
DL-1	3,053,022	3,164,963	111,940	3.67
DL-5	345,041	338,328	-6,713	-1.95
DL-7	234,676	228,211	-6,465	-2.75

Figure 1: Streamflow Calibration Results at Site HL-2

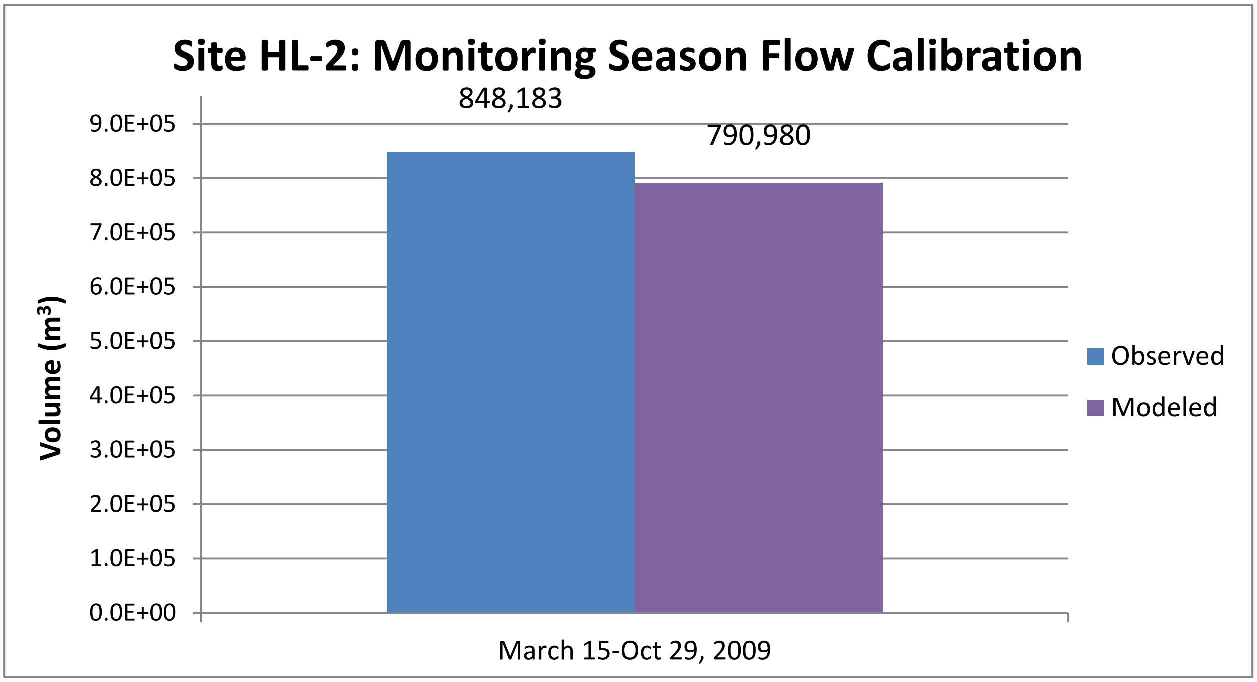


Figure 2: Streamflow Calibration Results at Site DL-1

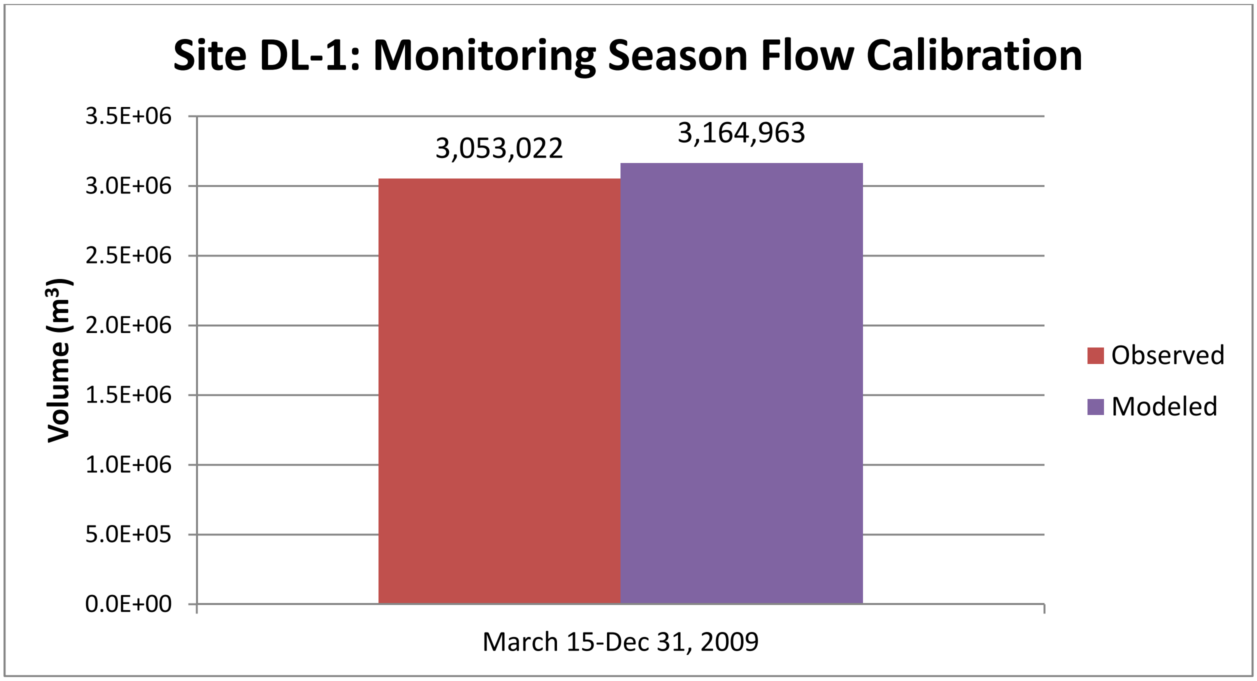


Figure 3: Streamflow Calibration Results at Site DL-5

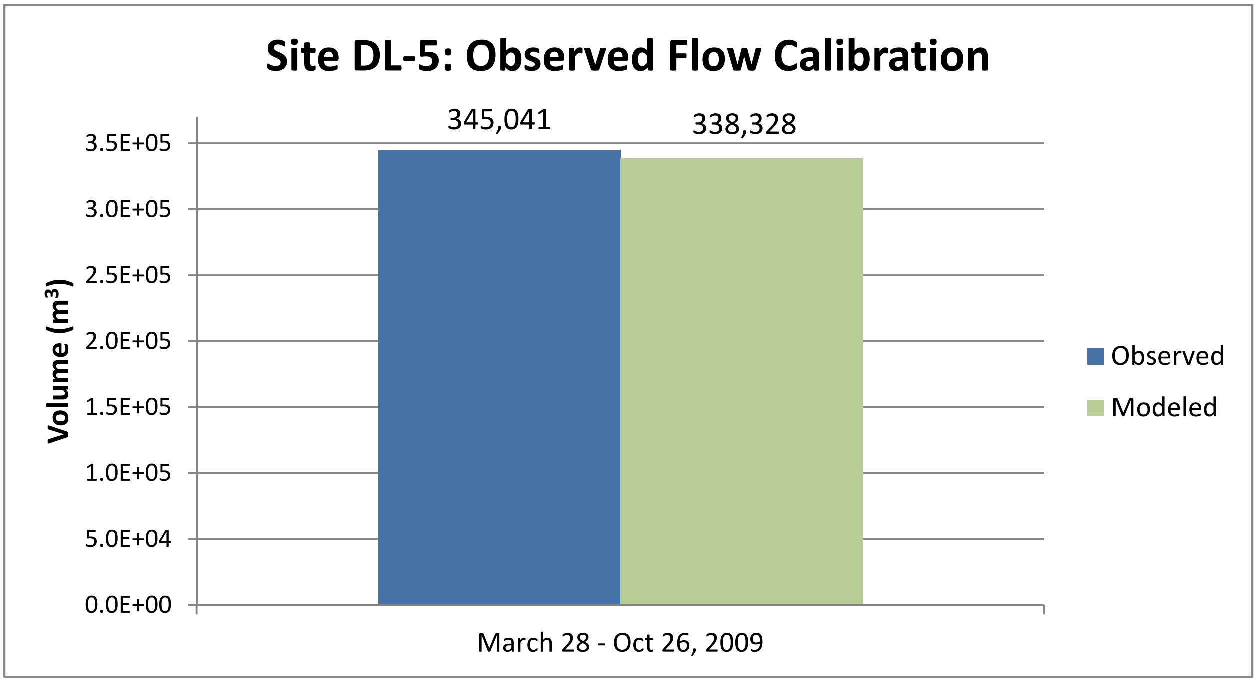
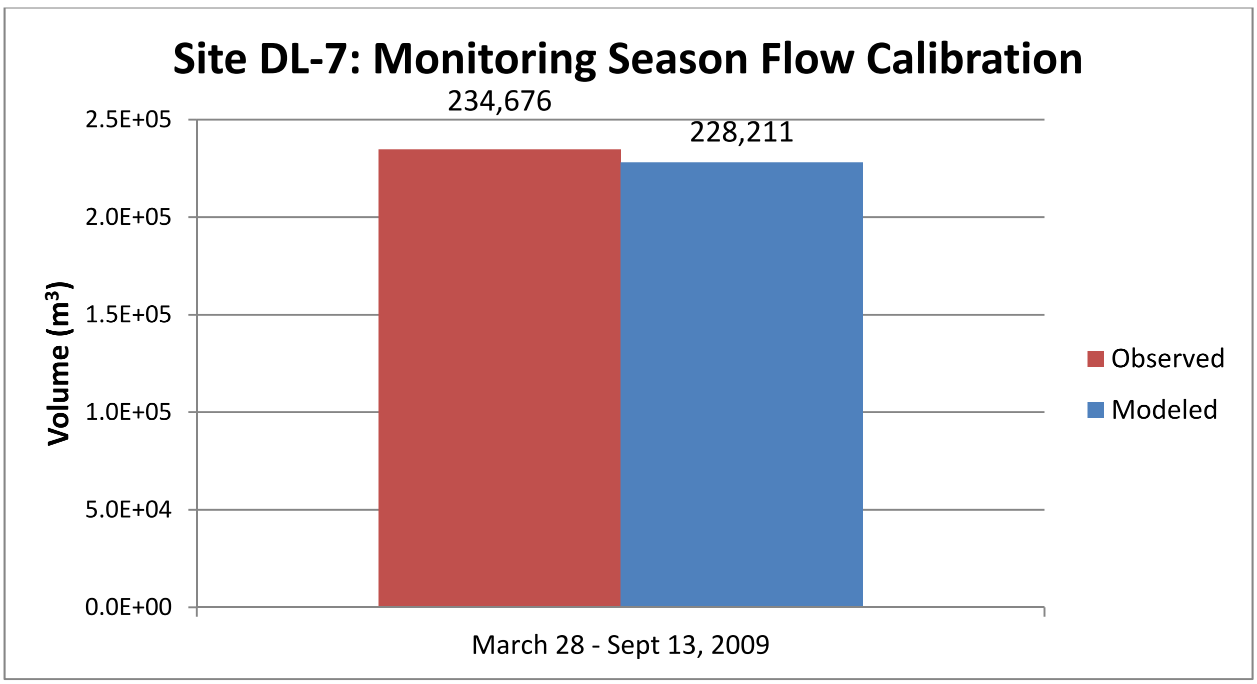


Figure 4: Streamflow Calibration Results at Site DL-7



When considering results at those sites that contribute flow directly to Diamond Lake (Sites DL-5, DL-7, and DL-1), the simulated total flow is 3,731,052 cfs. The observed total flow at these sites is 3,632,739 cfs, resulting in the model over-predicting the flow by 2.72%.

Total Phosphorus Loading

The second step to calibrating the model is to consider the observed vs. simulated TP load at each of the monitoring sites. Results of the TP calibration are shown in **Table 3** and **Figure 5** through **Figure 8**. Results show that the model is over-predicting the phosphorus loading at every site except DL-1. The over-prediction at site DL-5 is substantial in percent, but not in absolute value (when compared to the TP load at the other sites). When considering the model calibration for the TP loading from the three sites that feed directly into Diamond Lake (Sites DL-5, DL-7, and DL-1), the simulated load is 1,347 lbs and the observed load is 1,366 lbs; resulting in an under-prediction of -1.39%.

Table 3: Observed vs. Modeled TP Loading at Calibration Points

Site	Observed Load (lbs)	Modeled Load (lbs)	Absolute Error (lbs)	% Error
HL-2	464	504	40	8.55
DL-1	1,223	1,065	-158	-12.91
DL-5	65	152	87	134.21
DL-7	78	130	52	67.19

Figure 5: TP Loading Calibration Results at Site HL-2

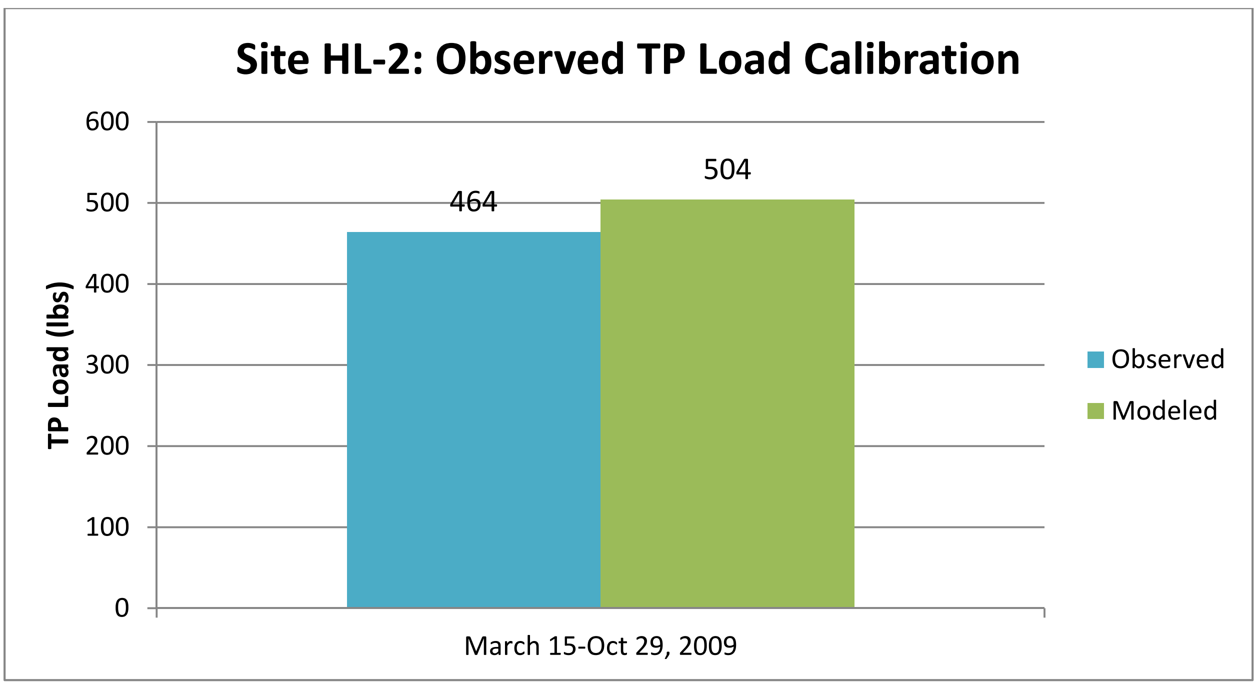


Figure 6: TP Loading Calibration Results at Site DL-1

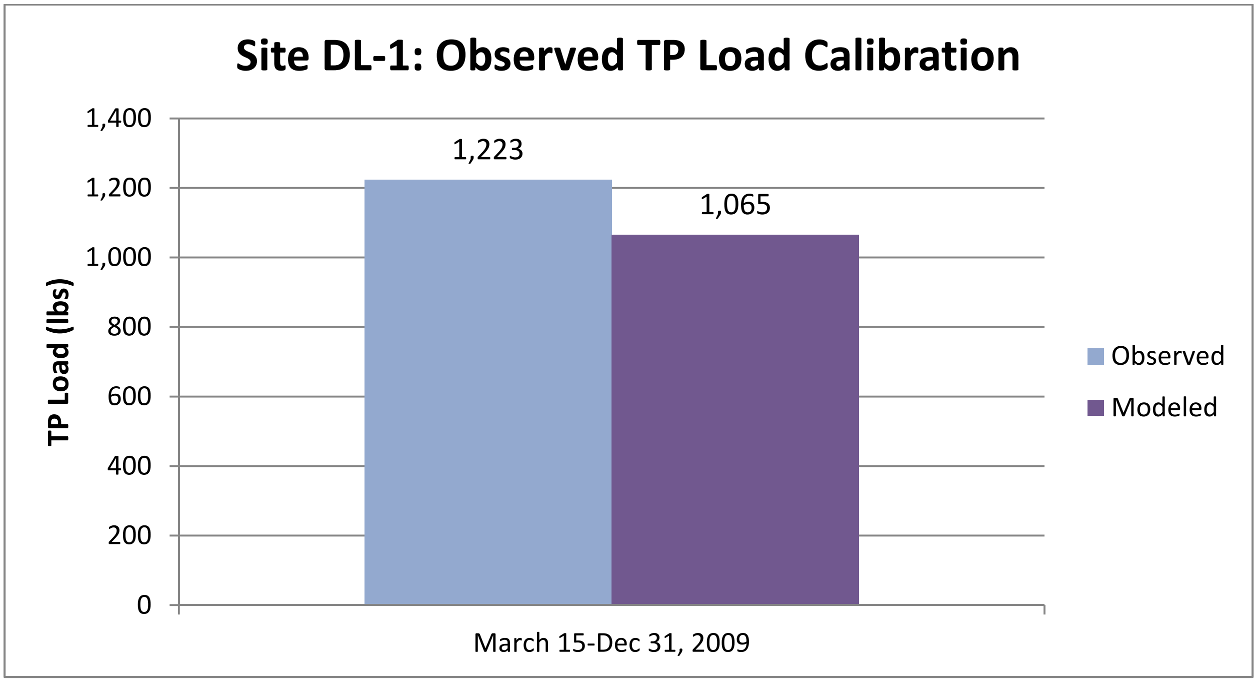


Figure 7: TP Loading Calibration Results at Site DL-5

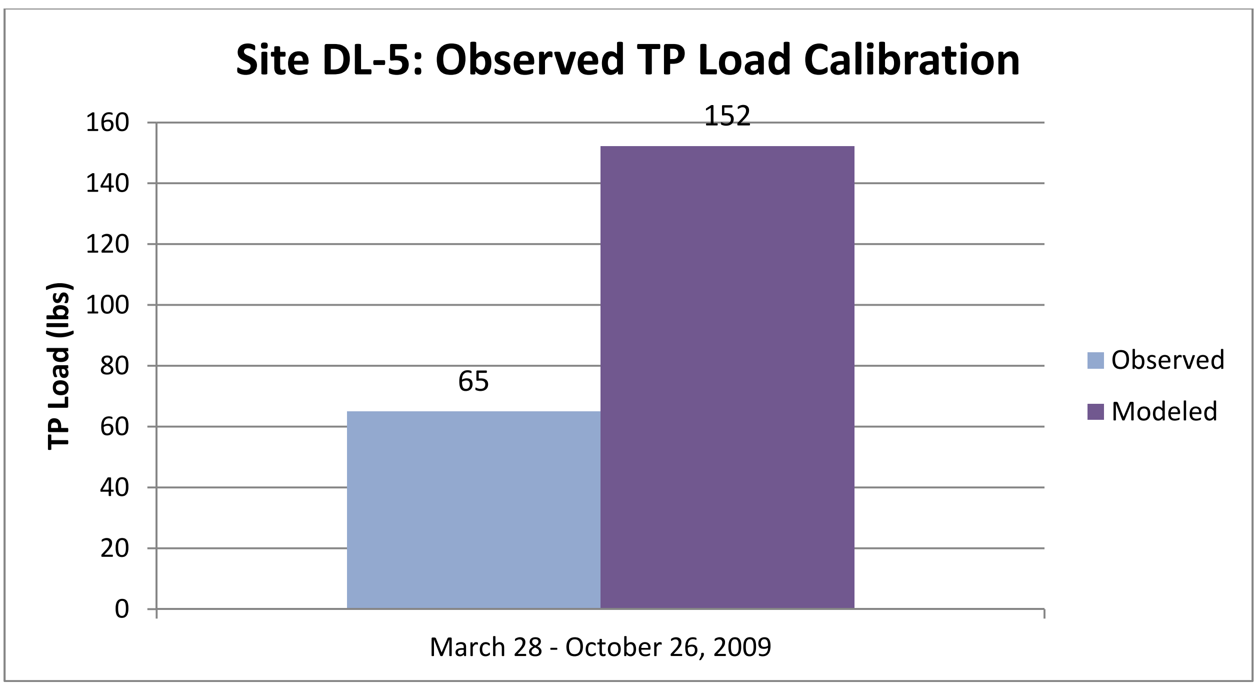
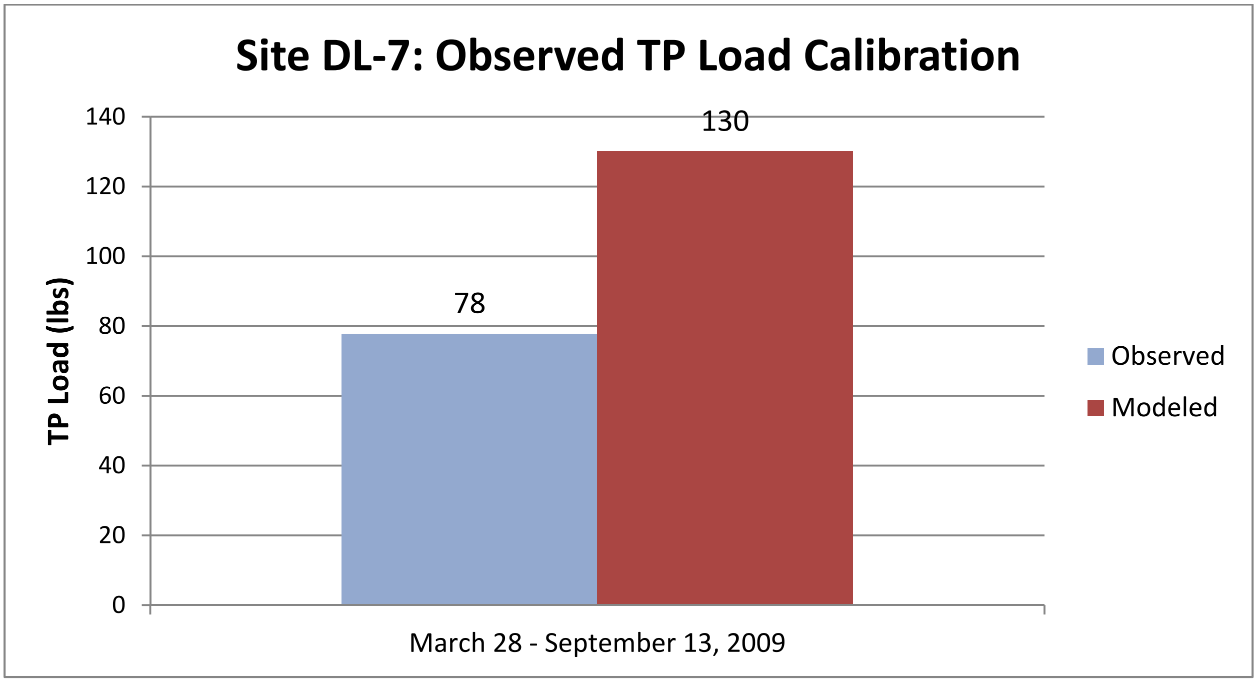


Figure 8: TP Loading Calibration Results at Site DL-7



VALIDATION

Hydrology

Similar to calibration, model validation is a process of comparing simulated and observed values of streamflow and TP loading. **Table 4** and **Figure 9** through **Figure 12** show these values for the four streamflow monitoring sites in the Diamond Lake watershed. Validation results have higher errors than seen during model calibration, with the model tending to under-predict flows at all sites except DL-5. Again, considering the flow at the three sites that feed directly into Diamond Lake (Sites DL-1, DL-5, and DL-7) the model predicts 1,152,440 m^3 of water entering the lake while observed values show 2,705,409 m^3. This results in an error of -57.40%. As mentioned earlier, problems with equipment installation and operation during the 2008 field data raised questions about the accuracy the monitoring results. Since 2009 data are considered more reliable, the value of the model's performance during the 2009 season is considered more important than the errors encountered during the 2008 season (which could be, at least in part, due to errors in the observed values).

Table 4: Observed vs. Modeled Hydrology at Validation Points

Site	Observed Volume (m^3)	Modeled Volume (m^3)	Absolute Error (m^3)	% Error
HL-2	664,476	245,760	-418,716	-63.01
DL-1	2,305,711	976,555	-1,329,156	-57.65
DL-5	46,118	53,012	6,894	14.95
DL-7	353,580	122,873	-230,706	-65.25

Figure 9: Streamflow Validation Results at Site HL-2

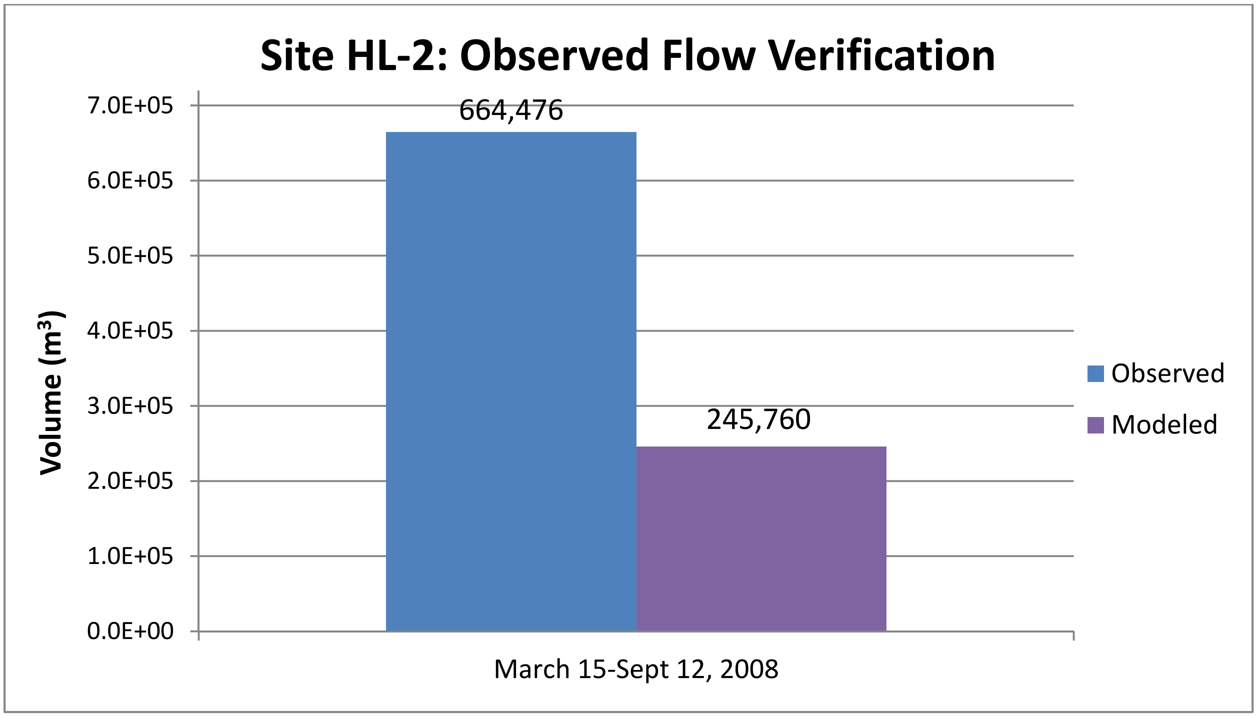


Figure 10: Streamflow Validation Results at Site DL-1

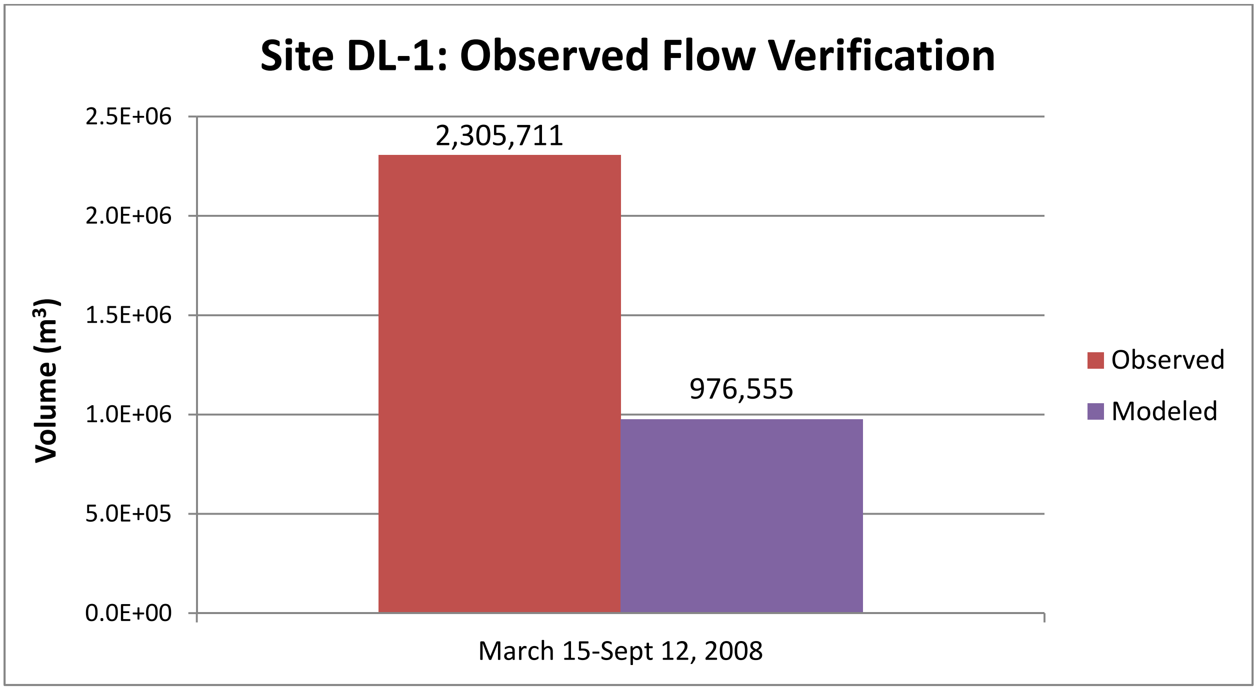


Figure 11: Streamflow Validation Results at Site DL-5

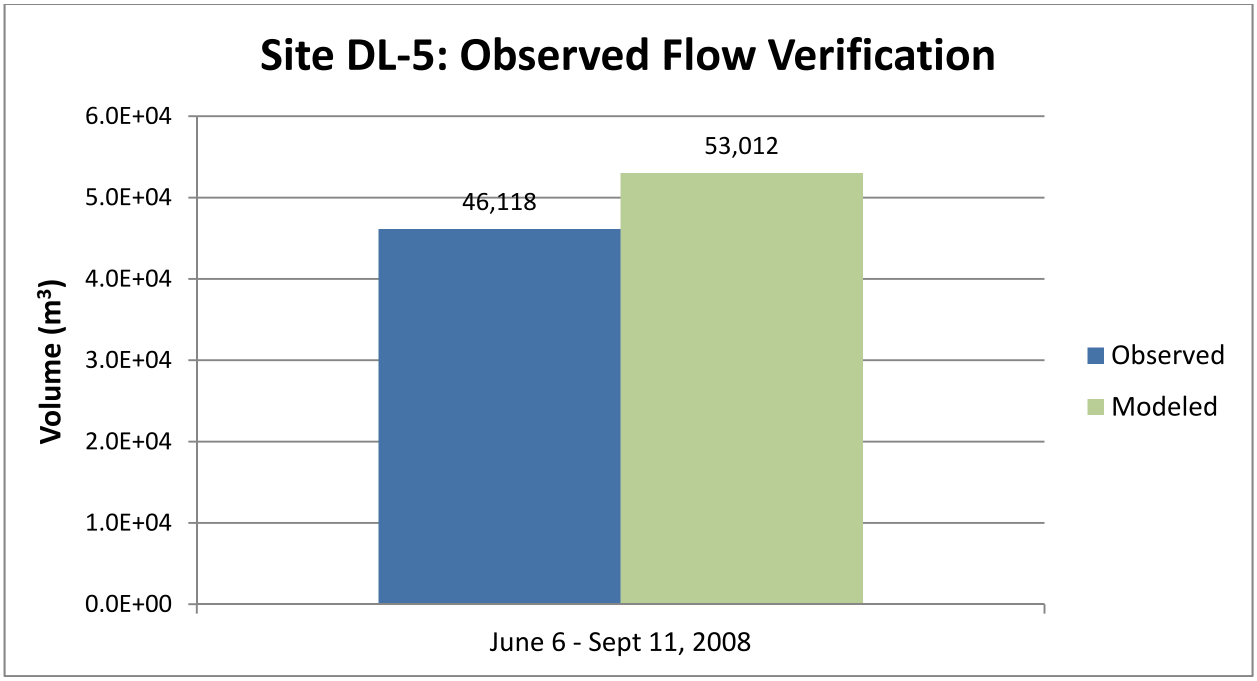
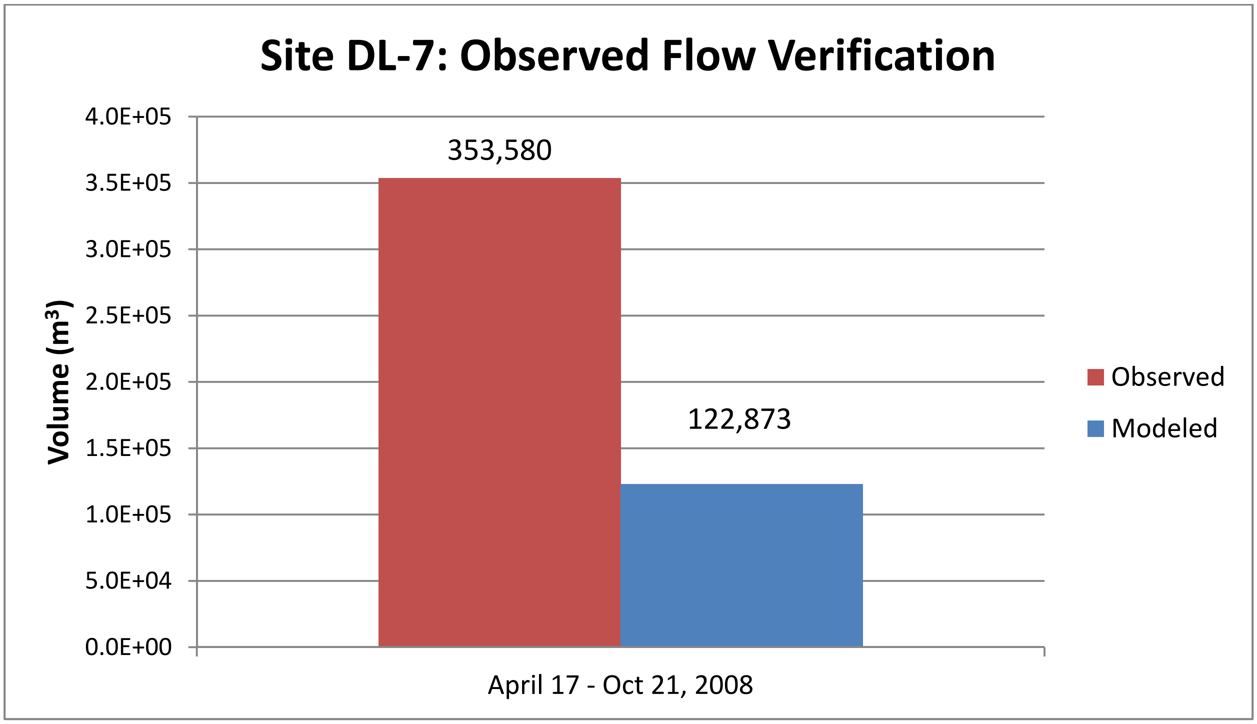


Figure 12: Streamflow Validation Results at Site DL-7



<u>Total Phosphorus Loading</u>

Similar to the streamflow validation, results of the TP loading validation show the model is under-predicting the phosphorus load to Diamond Lake. In this case, the difference between simulated and observed values is significant. When considering the total load simulated and observed at the three sites that flow directly into Diamond Lake (Sites DL-1, DL-5, and DL-7), the simulated load is 64.53% less than the observed. Again, potential errors in the 2008 observed values may contribute to these errors.

Table 5: Observed vs. Modeled TP Load at Validation Points

Site	Observed Load (lbs)	Modeled Load (lbs)	Absolute Error (lbs)	% Error
HL-2	394	363	-32	-8.03
DL-1	954	283	-671	-70.36
DL-5	54	30	-24	-45.09
DL-7	117	86	-31	-26.42

Figure 13: TP Loading Validation Results at Site HL-2

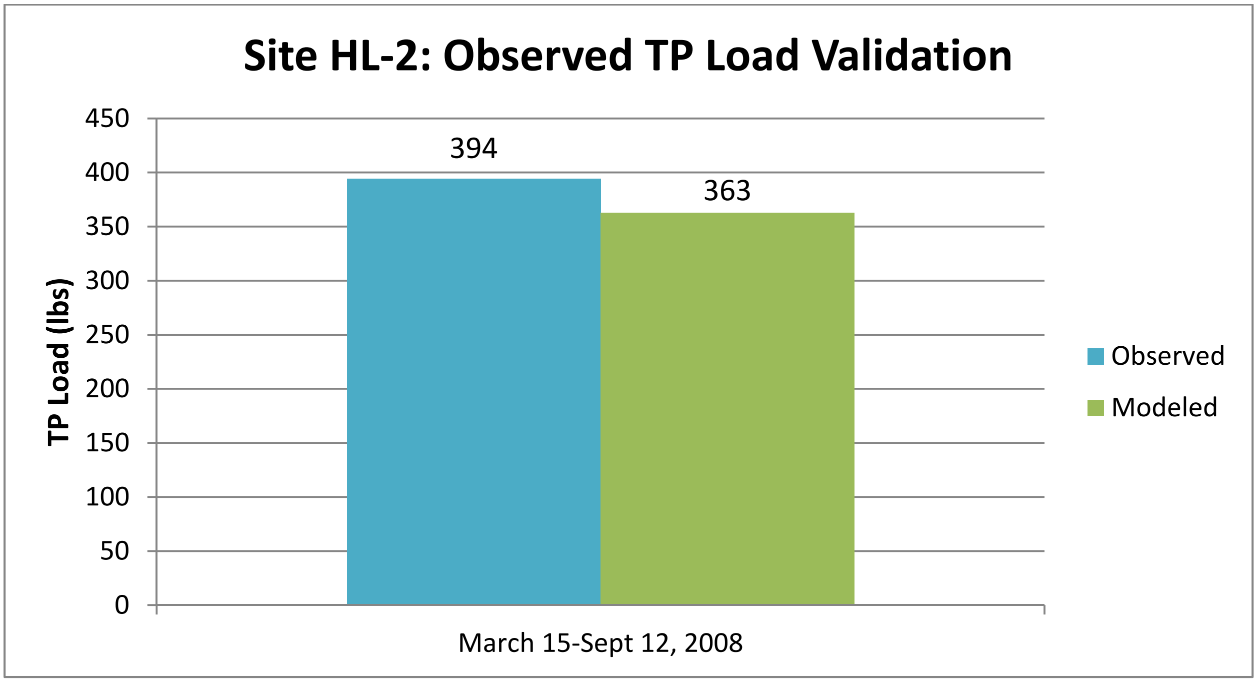


Figure 14: TP Loading Validation Results at Site DL-1

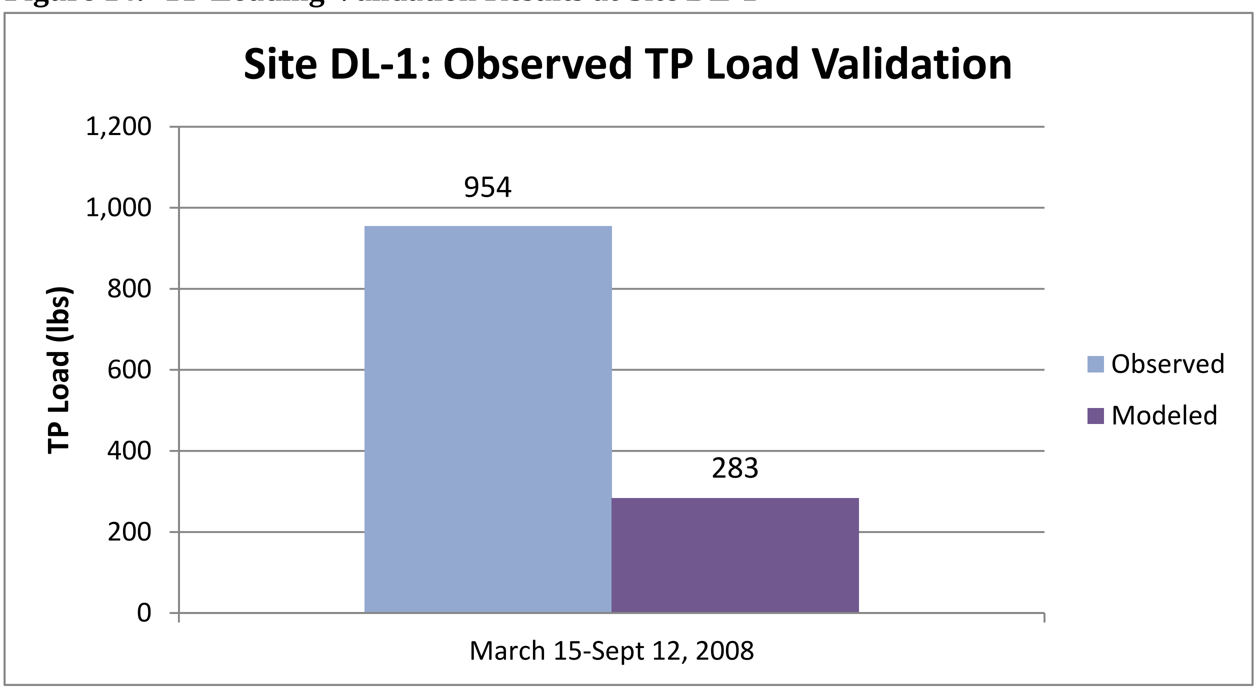


Figure 15: TP Loading Validation Results at Site DL-5

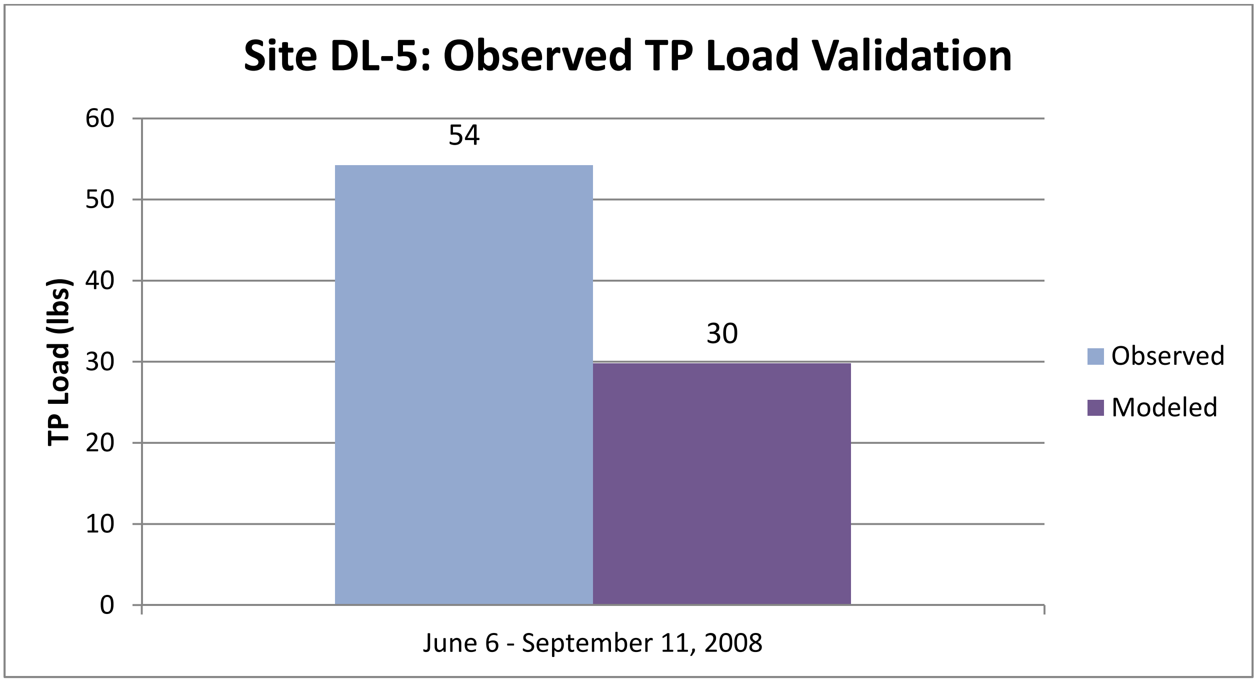
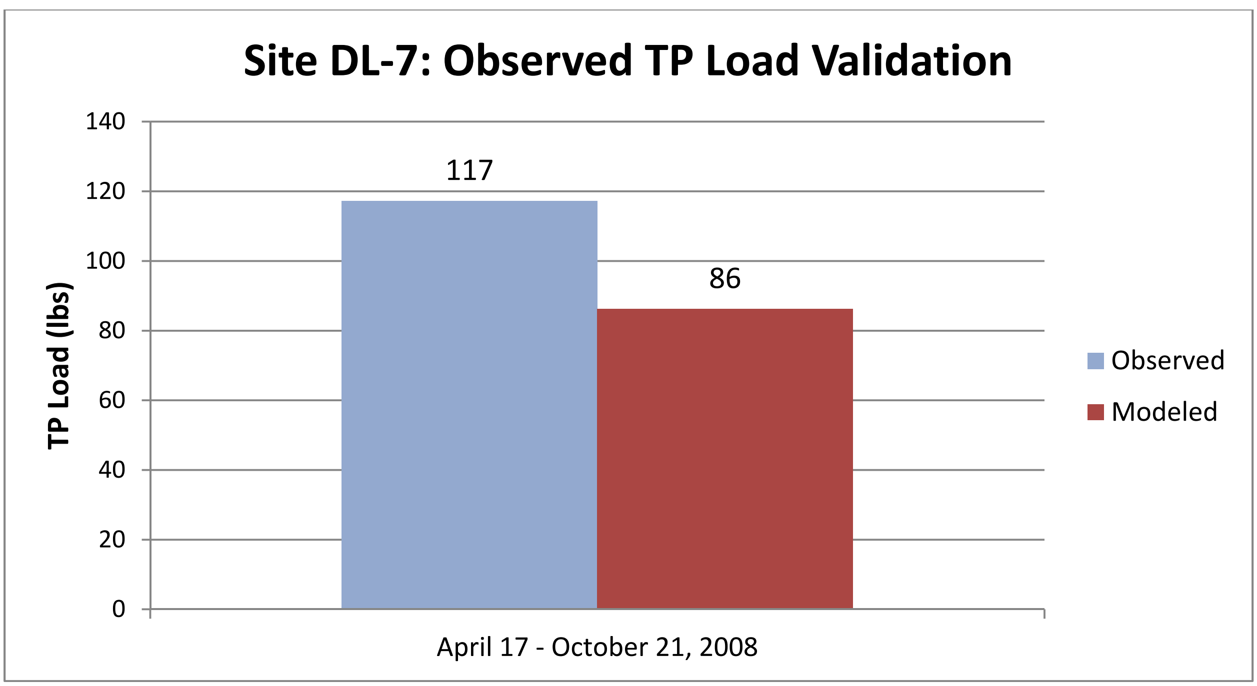


Figure 16: TP Loading Validation Results at Site DL-7



Model Application

Once the model calibration is complete, the SWAT model can then be used to give insight on hydrologic and water quality process in the study area. One application of the model is to view TP loading rates across the watershed, as shown in **Figure 17** *(attach map of TP loading rates)*. This map shows the annual average TP loading rate (in lbs/acre/year) from each modeled sub-basin, during the years 1980-2009. Results show high rates in three sub-basins immediately surrounding the lake (DL-15, DL-3, and DL-10) and low rates in other (DL-12, SL-11, DL-8, and DL-1). It is important to note that the TP loading rate shown in this map simulates the amount of TP contributed from each acre of land. Depending on that land's proximity to Diamond Lake and the features that its contribution flows through on the way to the lake (i.e., upstream lakes, wetlands), the actual TP load that reaches Diamond Lake may be much smaller. The information shown in **Figure 17**, however, is valuable for highlighting the portions of the watershed that are most susceptible to contributing TP to the system and useful in the eventual siting of BMPs.

Another valuable use of the calibrated SWAT model is the simulation of BMPs to quantify their effectiveness and aid in the design of implementation strategies for meeting the TMDL. Conversations were had with the staff of the MFCRWD to determine the most likely BMPs to be used for improving water quality in the Diamond Lake watershed. The BMPs chosen to address pollution from overland runoff and be simulated in the SWAT model are: filter strips (i.e., vegetative buffers) on agricultural land, the conversion of agricultural land to permanent cover, and the addition of temporary storage. The actual implementation of these BMPs could take many forms. To use the SWAT model to capture these forms, a range of potential implementation scenarios were run. The modeled scenarios are summarized in **Table 6**.

Table 6: BMP Scenarios Simulated in the Diamond Lake Watershed SWAT Model

BMP	Scenario Name	General Modeling Approach
20' Filter Strips	Filter20_over2	Apply a 20' filter strip to the edge of all HRUs that have agricultural land use and a slope >2%.
	Filter20_under2	Apply a 20' filter strip to the edge of all HRUs that have agricultural land use and a slope ≤2%.
	Filter20_all	Apply a 20' filter strip to the edge of all HRUs that have agricultural land use.
50' Filter Strips	Filter50_over2	Apply a 50' filter strip to the edge of all HRUs that have agricultural land use and a slope >2%.
	Filter50_under2	Apply a 50' filter strip to the edge of all HRUs that have agricultural land use and a slope ≤2%.
	Filter50_all	Apply a 50' filter strip to the edge of all HRUs that have agricultural land use.

Table 6: BMP Scenarios Simulated in the Diamond Lake Watershed SWAT Model (Cont.)

BMP	Scenario Name	General Modeling Approach
100' Filter Strips	Filter100_over2	Apply a 100' filter strip to the edge of all HRUs that have agricultural land use and a slope >2%.
	Filter100_under2	Apply a 100' filter strip to the edge of all HRUs that have agricultural land use and a slope ≤2%.
	Filter100_all	Apply a 100' filter strip to the edge of all HRUs that have agricultural land use.
Increase Temporary Storage by 10%	Pond10	In all subbasins with temporary storage, increase primary pond volume by 10% and increase fraction of subbasin draining to pond by 0%.
	Pond10a	In all subbasins with temporary storage, increase primary pond volume by 10% and increase fraction of subbasin draining to pond by 2%.
	Pond10b	In all subbasins with temporary storage, increase primary pond volume by 10% and increase fraction of subbasin draining to pond by 5%.
Increase Temporary Storage by 20%	Pond20	In all subbasins with temporary storage, increase primary pond volume by 20% and increase fraction of subbasin draining to pond by 0%.
	Pond20a	In all subbasins with temporary storage, increase primary pond volume by 20% and increase fraction of subbasin draining to pond by 2%.
	Pond20b	In all subbasins with temporary storage, increase primary pond volume by 20% and increase fraction of subbasin draining to pond by 5%.
	Pond20c	In all subbasins with temporary storage, increase primary pond volume by 20% and increase fraction of subbasin draining to pond by 7%.
	Pond20d	In all subbasins with temporary storage, increase primary pond volume by 20% and increase fraction of subbasin draining to pond by 10%.
Convert Ag Land to Permanent Cover	PermCover_over2	On HRUs with agricultural land use and slope >2%, change tilled crop to Alamo Switchgrass, remove management operations, and change CN to reflect permanent cover.
	PermCover_under2	On HRUs with agricultural land use and slope ≤2%, change tilled crop to Alamo Switchgrass, remove management operations, and change CN to reflect permanent cover.
	PermCover_all	On HRUs with agricultural land use, change tilled crop to Alamo Switchgrass, remove management operations, and change CN to reflect permanent cover.

The first scenario modeled was the use of filter strips on agricultural land. Filter strips are generally understood to be an effective agricultural management option and are widely accepted and employed. SWAT models filter strip trapping efficiency for sediment and nutrients as:

$$\text{Trap efficiency} = 0.367 \times (\text{width of strip (m)})^{0.2967}$$

where trap efficiency is the fraction of the constituent loading trapped by the filter strip, and width of strip is the width of the filter strip in meters.

For this project, we modeled 20-, 50- and 100-foot wide filter strip scenarios. As shown in **Table 6**, each of these scenarios was simulated by first applying the filter strips only to those agricultural lands with a slope greater than 2%. The scenarios were then repeated for agricultural lands with a slope equal to or less than 2% and for all agricultural lands, regardless of slope. Similar simulations were developed for each of the BMPs considered. The ultimate goal of modeling the BMPs in this manner was to quantify the range of pollutant reduction (per area of treated land) that can be expected from implementing them in the Diamond Lake watershed. To develop this range, modeling results were quantified at the four main field monitoring sites in the watershed (DL-1, HL-2, DL-5, and DL-7). Computing the pollutant reductions modeled at each of these sites gives insight to the effectiveness of the BMPs in the different soil, topography, and land use combinations. **Table 7** shows an example of the impact of filter strips on the average annual discharge, sediment load, and TP load observed at monitoring site DL-1. In this case, results reflect a 50-foot buffer being applied.

Table 7: Impact of Filter Strips at DL-1

	Current Conditions (1980-2009)	50’ filter strips on slopes ≤ 2%	50’ filter strips on slopes > 2%	50’ filter strips on all slopes
Avg Annual Discharge (AF/yr)	2,257	2,257	2,257	2,257
Avg Annual Sediment Load (tons/yr)	2.20	1.74	2.13	1.39
Avg Annual TP Load (lbs/yr)	1,158	355	1,020	218
Avg Annual Net Sediment Load Reduction per Area with BMP (tons/acre/yr)	---	0.0001	0.0002	0.0001
Avg Annual Net TP Load Reduction per Area with BMP (lbs/acre/yr)	---	0.16	0.30	0.17
Area Treated with BMP (acres)	---	5,155	460	5,615

The second column in **Table 7** shows the annual average discharge, sediment load, and TP load simulated at site DL-1 under current conditions in the Diamond Lake watershed. The simulation was averaged over 30-years (1980-2009). Columns three through five of **Table 7** show the simulate values under the three different BMP scenarios. By comparing the results of the BMP scenarios with the results of the current conditions (and taking into account the amount of land area that had the BMP applied), the effectiveness of each scenario can be gauged. Modeling 50-foot filter strips on all agricultural lands upstream of DL-1 with a slope of >2%, for example, resulted in an average net annual TP load reduction of 0.30 lbs/acre of treated land. Similar results were shown for the areas upstream of sites DL-5 and DL-7, with average net annual TP load reductions of 0.29 lbs/acre and 0.25 lbs/acre, respectively. Load reductions from ag land with slopes ≤2% were smaller, averaging 0.06 lbs/acre of treated land for the area upstream of DL-1. Since the vast majority of the land in the Diamond Lake watershed (including that upstream of DL-1) has a slope of ≤2%, simulating filter strips on all agricultural lands regardless of slope (column 5 of **Table 7**) results in a load reduction similar to that of the lands with low slope, with an average annual reduction of 0.17 lbs TP/acre with the BMP.

The results shown for the simulation of 50-foot filter strips in the area upstream of DL-1 (**Table 7**) are similar to those seen throughout the watershed, both at different monitoring points and for other filter strip widths. **Table 8** summarizes the overall impact of utilizing filter strips in the Diamond Lake watershed, showing the range of net sediment and TP load reductions observed for each width of filter strip applied. The values are reported as a net reduction in TP load (i.e., the load reduction observed at the various monitoring points; not the load reduction achieved at the field) per acre of agricultural land that the BMP was applied to. Detailed results of all the filter strip simulations are included at the end of this memo.

Table 8: Simulated Effectiveness of Filter Strips

	20' Filter Strips	50' Filter Strips	100' Filter Strips
Avg Annual Net Sediment Load Reduction per Area with BMP (tons/acre/yr)	0.0001-0.12	0.0001-0.16	0.0002-0.19
Avg Annual Net TP Load Reduction per Area with BMP (lbs/acre/yr)	0.09-0.42	0.12-0.55	0.14-0.67

Note: ranges of BMP effectiveness reflect the application of filter strips to different areas in the watershed and targeting different land slopes

Similar analyses were performed to quantify the impact of additional temporary storage in the Diamond Lake watershed. Adding more storage could take a number of forms, including wetland restoration or the installation of side inlet controls on agricultural fields that border drainage canals. Regardless of the type of temporary storage, the mechanism to model this storage in SWAT is the same; the model simulates all short-term water storage as ponds.

To simulate the addition of temporary storage in the Diamond Lake watershed, a number of scenarios were modeled. Scenarios were designed to assess the impact of increasing the existing amount of temporary storage by set percentages. One set of scenarios, for example, explores the impact of increasing the current amount of temporary storage upstream of monitoring site DL-1 by 10%, resulting in an additional 39.3 acre-feet (AF) of primary storage volume in this area of the watershed. (In SWAT, primary storage is defined as the volume of water stored when the pond is filled to the principal spillway – i.e., no flood storage is in use.) In addition to the volume of storage added, the placement of the additional storage on the landscape also has an impact on the effectiveness of this BMP. If the new storage is placed in an area that doesn't intercept much water, for example, minimal impact on loading will be seen since minimal loading is intercepted by the storage. To account for the impact of storage placement, each scenario of increased volume was simulated with multiple assumptions about how much of the watershed would contribute water (and load) to the BMP. For example, the scenarios that address a 10% increase in temporary storage run this additional volume assuming that the fraction of the subbasin that contributes flow to the storage is increased by 0, 2, and 5%. Results of the all the temporary storage BMP scenarios are presented in a series of tables at the end of this document. **Table 9** summarizes the information, noting ranges of effectiveness under two scenarios of storage increase.

Table 9: Simulated Effectiveness of Additional Temporary Storage

	10% Increase in Temporary Storage	**20% Increase in Temporary Storage**
Avg Annual Net Sediment Load Reduction per 1 AF Additional Storage (tons/AF/yr)	-0.02 – 0.56	-0.03 – 0.56
Avg Annual Net TP Load Reduction per 1 AF Additional Storage (lbs/AF/yr)	0.15 – 4.11	0.07 – 4.10

Note that under some circumstances, the model showed that adding temporary storage would increase the sediment load. This phenomenon was observed when additional ponding was added, but the fraction of the subbasin contributing flow to the pond was not increased. The increased sediment load is likely due to a shift in the water balance of the subbasin.

The last BMP considered in the model is the conversion of agricultural land to permanent cover, as may be done under a program like WHIP (Wildlife Habitats Improvement Program). Such a scenario simulates the elimination of tillage as an agricultural practice. For this scenario, switchgrass was selected as the permanent cover to be simulated, because it allows the harvesting of a biomass-rich cash crop that requires minimal maintenance. The only variety of switchgrass programmed into the SWAT model is Alamo Switchgrass, so it was used for these simulations. While Alamo Switchgrass is unlikely to be used in the Diamond Lake Watershed, it is expected to have more in common with the type of switchgrass that might be cultivated in the area than routinely-planted crops would have.

Similar to what was done with simulating the application of filter strips, the conversion of agricultural land to permanent cover was simulated by targeting the different slope characteristics of the watershed. As such, three different conversion scenarios were run: one on ag land with a slope ≤2%, one on ag land with a slope >2%, and one on agricultural land regardless of slope. **Table 10** summarizes the results of the analyses, showing a range of effectiveness for implementing this BMP. Similar to adding temporary storage, under some circumstances SWAT showed that converting agricultural land to permanent cover actually increases the sediment load. In this case, the phenomenon was observed only when the BMP was applied to land with slopes <2% and is likely due to an increase in flow, which (in turn) transports more sediment. The flow increase is likely due to a change in the Curve Number when converting from agricultural practices to permanent cover.

Table 10: Simulated Effectiveness of Converting Agricultural Land to Permanent Cover

	Convert Agricultural Land to Permanent Cover
Avg Annual Net Sediment Load Reduction per Area with BMP (tons/acre/yr)	-0.005-0.19
Avg Annual Net TP Load Reduction per Area with BMP (lbs/acre/yr)	0.13-0.65

Note: ranges of BMP effectiveness reflect the application of filter strips to different areas in the watershed and targeting different land slopes

Discussion

The Diamond Lake SWAT model was created to simulate the total phosphorus load to Diamond Lake from overland sources. Model performance was checked by calibrating and validating its outputs against streamflow and TP data collected during the 2008 and 2009 field seasons. Results of the model calibration at the three sites that feed directly in Diamond Lake, show that the model over-predicting flow (by 2.7%) and under-predicting TP loading (by -1.4%). Validation results at those three sites show that the model is under-predicting flow (by -57.4%) and also under-predicting TP loading (by -64.5%).

It is important to recognize that errors between modeled and observed values are the product of numerous considerations. All environmental data, including the observed discharge and water quality data used in this work, inherently has some error associated with it. This error results from natural variability, as well as sampling techniques, sample handling, and lab analysis of the samples. Models are simply a tool for simulating natural processes and also inherently have errors associated with their output. This error includes errors derived from the use of equations to simulate natural processes, as well as errors in the ‘driver’ data that’s put into the model. The overall goal of this type of project is to represent general trends in watershed processes and use these trends to predict what may occur under future modeling scenarios. Errors that are present in the calibrated base modeling results (such as under-predicting flows) will also occur during the modeled scenarios. Using the relative difference between the modeled and base scenarios to make management decisions is, therefore, justifiable.

Three different BMPs were simulated in the Diamond Lake SWAT model, using a variety of different scenarios. The goal of the BMP simulation was to develop a range of pollution reduction that can be expected from implementing each of the different BMPs. The expected values can then be used to help prioritize BMP installations and design implementation strategies to achieve the TMDL. Results of modeling the BMPs show that filter strips and land conversion (from agricultural to permanent cover) have similar load reduction efficiencies per acre of treated land. Temporary storage has a wide range of effectiveness depending on the specifics of how the BMP is applied. Combining this information with estimated costs, stakeholder desires, availability of funding, and practicality of installation will assist in choosing the best design.

References

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Supplemental Information

SWAT Input Parameters Adjusted

Parameter	Description	SWAT Range		SWAT Default	Range Evaluated		Modeled Value
		Low	High		Low	High	
Water Balance							
SMFMX	Melt factor for snow on June 21 (mm $H_2O/^oC$-day)	0	500	4.5	1.5	3.5	3.5
SMFMN	Melt factor for snow on Dec 21 (mm $H_2O/^oC$-day)	0	10	4.5	1.5	3.5	1.5
SFTMP	Snowfall temperature (^oC)	-5	5	1	1.5	1.5	1.5
SMTMP	Soil melt base temperature (^oC)	-5	5	0.5	0.8	0.8	0.8
SNOCOVMX	Min water content at 100% snow cover (mm H_2O)	0	500	1	30	30	30
SNO50COV	Fraction of SNOCOVMX snow vol at 50% snow cover	0	1	0.5	0.2	0.2	0.2
TIMP	Snow pack temperature lag factor	0	1	1	0.25	0.25	0.25
ESCO	Soil evaporation	0.01	1	0.95	0.6	0.7	0.7
SOL_AWC()	Available water capacity in soil layer	0	1	Computed in model	Default	Increase by 4%	Increase by 4%
Surface Runoff							
CN2	Initial SCS runoff Curve Number for AMC II	35	98	Computed in model	Reduce by 10%	Increase by 5%	Default for Sub-basins 1, 2, 3, 5 & 6; -8% in rest

Parameter	Description	SWAT Range		SWAT Default	Range Evaluated		Modeled Value
		Low	High		Low	High	
Groundwater							
GW_DELAY	Delay for aquifer recharge (days)	0	500	31	0	20	5 in Sub-basins 10, 11, 12; 20 in others
GWQMN	Threshold level for return flow from shallow aquifer (mm H_2O)	0	50,000	0	0	100	30
ALFA_BF	Baseflow recession constant (days)	0.1	1	0.048	0.02	0.8	0.7
RCHRG_DP	Deep aquifer percolation factor.	0	1	0.05	0	0.2	0
GW_REVAP	Revap coefficient	0.02	0.2	0.02	0.02	0.1	0.05 in Sub-basins 4 & 8; 0.02 in others
Reservoirs / Ponds							
NDTARGR	# of days to reach target storage from current storage	1	200	1	4	10	4
PND_K	Hydraulic conductivity of pond bottom (mm/hr)	0	50	0	0	1	Varies from 0 – 0.04
Water Quality							
PHOSKD	P soil partitioning coefficient (m^3/Mg)	0	500	175	20	500	500
RS5	Organic P settling rate in the reach at 20°C (day^{-1})	0.001	0.1	0.05	0.07	0.09	0.09
PSETLR1	P settling rate in a reservoir during settling months (m/yr)	<0	>16	10	-4	20	Res 2 &3 = 4; Res 1 = 1

Detailed Outputs of Various BMP Scenarios

Results of Filter Strip Scenarios at Site DL-1 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	20' Filter Strips on Slopes </= 2%	50' Filter Strips on Slopes </= 2%	100' Filter Strips on Slopes </= 2%	20' Filter Strips on Slopes >2%	50' Filter Strips on Slopes >2%	100' Filter Strips on Slopes >2%	20' Filter Strips on All Slopes	50' Filter Strips on All Slopes	100' Filter Strips on All Slopes
Average Annual Volume (m^3)	$2.78x10^6$	$2.78x10^6$	$2.78x10^6$	$2.78x10^6$	$2.78x10^6$	$2.78x10^6$	$2.78x10^6$	$2.78x10^6$	$2.78x10^6$	$2.78x10^6$
Average Annual Sediment Load (tons)	2.203	1.880	1.744	1.132	2.149	2.130	2.114	1.779	1.390	0.000
Average Annual TP Load (lbs)	1,158	546	355	183	1,053	1,020	990	441	218	15
Average TP Concentration (ug/L)	*188.60*	*88.93*	*57.85*	*29.83*	*171.51*	*166.18*	*161.37*	*71.89*	*35.48*	*2.40*
Average Annual Sediment Load Reduction per Acre of Ag with BMP (tons)	---	0.0001	0.0001	0.0002	0.0001	0.0002	0.0002	0.0001	0.0001	0.0004
Average Annual Net TP Load Reduction per Acre of Ag with BMP (lbs)	---	0.119	0.156	0.189	0.228	0.299	0.363	0.128	0.167	0.204
Subwatershed area simulated with BMPs - i.e., area with x slope (acres)	---	5,155			460			5,615		

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Filter Strip Scenarios at Site HL-2 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	**20' Filter Strips on Slopes </= 2%**	**50' Filter Strips on Slopes </= 2%**	**100' Filter Strips on Slopes </= 2%**	**20' Filter Strips on Slopes >2%**	**50' Filter Strips on Slopes >2%**	**100' Filter Strips on Slopes >2%**	**20' Filter Strips on All Slopes**	**50' Filter Strips on All Slopes**	**100' Filter Strips on All Slopes**
Average Annual Volume (m^3)	9.36x10^5	9.36x10^5	9.36x10^5	9.36x10^5	9.36x10^5	9.36x10^5	9.36x10^5	9.36x10^5	9.36x10^5	9.36x10^5
Average Annual Sediment Load (tons)	74.54	70.56	67.67	62.53	73.64	73.20	72.65	65.64	50.40	4.79
Average Annual TP Load (lbs)	916	520	397	285	751	700	653	355	180	22
Average Annual Sediment Load Reduction per Acre of Ag with BMP (tons)	---	0.0023	0.0040	0.0069	0.0023	0.0034	0.0049	0.0042	0.0113	0.0328
Average Annual Net TP Load Reduction per Acre of Ag with BMP (lbs)	---	0.228	0.299	0.363	0.423	0.555	0.674	0.264	0.346	0.420
Subwatershed area simulated with BMPs - i.e., area with x slope (acres)	---	1,739			391			2,130		

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Filter Strip Scenarios at Site DL-5 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	20' Filter Strips on Slopes </= 2%	50' Filter Strips on Slopes </= 2%	100' Filter Strips on Slopes </= 2%	20' Filter Strips on Slopes >2%	50' Filter Strips on Slopes >2%	100' Filter Strips on Slopes >2%	20' Filter Strips on All Slopes	50' Filter Strips on All Slopes	100' Filter Strips on All Slopes
Average Annual Volume (m^3)	6.20×10^5	6.20×10^5	6.20×10^5	6.20×10^5	6.20×10^5	6.20×10^5	6.20×10^5	6.20×10^5	6.20×10^5	6.20×10^5
Average Annual Sediment Load (tons)	133.27	62.25	40.07	20.09	120.81	116.92	113.41	49.79	23.71	0.23
Average Annual TP Load (lbs)	285	130	82	39	261	254	248	107	52	2
Average Annual Sediment Load Reduction per Acre of Ag with BMP (tons)	---	0.0509	0.0668	0.0811	0.1203	0.1579	0.1917	0.0557	0.0731	0.0888
Average Annual Net TP Load Reduction per Acre of Ag with BMP (lbs)	---	0.111	0.145	0.176	0.223	0.292	0.355	0.118	0.155	0.189
Subwatershed area simulated with BMPs - i.e., area with x slope (acres)	---		1,395			104			1,499	

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Filter Strip Scenarios at Site DL-7 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	20' Filter Strips on Slopes </= 2%	50' Filter Strips on Slopes </= 2%	100' Filter Strips on Slopes </= 2%	20' Filter Strips on Slopes >2%	50' Filter Strips on Slopes >2%	100' Filter Strips on Slopes >2%	20' Filter Strips on All Slopes	50' Filter Strips on All Slopes	100' Filter Strips on All Slopes
Average Annual Volume (m^3)	$6.57x10^5$	$6.57x10^5$	$6.57x10^5$	$6.57x10^5$	$6.57x10^5$	$6.57x10^5$	$6.57x10^5$	$6.57x10^5$	$6.57x10^5$	$6.57x10^5$
Average Annual Sediment Load (tons)	35.54	30.34	27.71	24.86	32.53	31.01	29.52	23.80	16.04	0.30
Average Annual TP Load (lbs)	305	179	140	105	240	220	202	115	56	2
Average Annual Sediment Load Reduction per Acre of Ag with BMP (tons)	---	0.0038	0.0057	0.0077	0.0090	0.0136	0.0181	0.0068	0.0113	0.0205
Average Annual Net TP Load Reduction per Acre of Ag with BMP (lbs)	---	0.090	0.119	0.144	0.193	0.254	0.308	0.110	0.145	0.176
Subwatershed area simulated with BMPs - i.e., area with x slope (acres)	---	1,385			333			1,718		

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Temporary Storage Scenarios at Site DL-1 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	+10% in Pond Primary Vol and +0% in PND_FR	+10% in Pond Primary Vol and +2% in PND_FR	+10% in Pond Primary Vol and +5% in PND_FR	+20% in Pond Primary Vol and +0% in PND_FR	+20% in Pond Primary Vol and +2% in PND_FR	+20% in Pond Primary Vol and +5% in PND_FR	+20% in Pond Primary Vol and +7% in PND_FR	+20% in Pond Primary Vol and +10% in PND_FR
Average Annual Volume (m^3)	2.78×10^6	2.79×10^6	2.77×10^6	2.76×10^6	2.79×10^6	2.78×10^6	2.76×10^6	2.75×10^6	2.73×10^6
Average Annual Sediment Load (tons)	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Average Annual TP Load (lbs)	1,158	1,152	1,124	1,081	1,148	1,118	1,076	1,047	1,006
Average TP Concentration (ug/L)	*188.6*	*187.5*	*183.8*	*177.9*	*186.6*	*182.7*	*176.8*	*172.9*	*167.2*
Average Annual Sediment Load Reduction per 1 AF added storage (tons)	---	0.0000	0.0003	0.0006	0.0000	0.0002	0.0003	0.0004	0.0007
Average Annual Net TP Load Reduction per 1 AF added storage (lbs)	---	0.150	0.854	1.943	0.122	0.499	1.035	1.401	1.927
Additional storage simulated in upstream subwatersheds (AF)	---		39.3				78.6		

* PND_FR = the fraction of a subbasin area that drains into the ponds.

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Temporary Storage Scenarios at Site HL-2 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	**+10% in Pond Primary Vol and +0% in PND_FR**	**+10% in Pond Primary Vol and +2% in PND_FR**	**+10% in Pond Primary Vol and +5% in PND_FR**	**+20% in Pond Primary Vol and +0% in PND_FR**	**+20% in Pond Primary Vol and +2% in PND_FR**	**+20% in Pond Primary Vol and +5% in PND_FR**	**+20% in Pond Primary Vol and +7% in PND_FR**	**+20% in Pond Primary Vol and +10% in PND_FR**
Average Annual Volume (m^3)	$9.36 x 10^5$	$9.46 x 10^5$	$9.39 x 10^5$	$9.26 x 10^5$	$9.60 x 10^5$	$9.51 x 10^5$	$9.40 x 10^5$	$9.30 x 10^5$	$9.18 x 10^5$
Average Annual Sediment Load (tons)	75	75	75	71	76	75	72	70	68
Average Annual TP Load (lbs)	916	912	868	798	908	862	794	748	681
Average Annual Sediment Load Reduction per 1 AF added storage (tons)	---	-0.0191	-0.0085	0.1357	-0.0261	-0.0073	0.0450	0.0771	0.1194
Average Annual Net TP Load Reduction per 1 AF added storage (lbs)	---	0.168	1.704	4.112	0.145	0.950	2.143	2.940	4.104
Additional storage simulated in upstream subwatersheds (AF)	---		28.7				57.3		

* PND_FR = the fraction of a subbasin area that drains into the ponds.

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Temporary Storage Scenarios at Site DL-5 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	+10% in Pond Primary Vol and +0% in PND_FR	+10% in Pond Primary Vol and +2% in PND_FR	+10% in Pond Primary Vol and +5% in PND_FR	+20% in Pond Primary Vol and +0% in PND_FR	+20% in Pond Primary Vol and +2% in PND_FR	+20% in Pond Primary Vol and +5% in PND_FR	+20% in Pond Primary Vol and +7% in PND_FR	+20% in Pond Primary Vol and +10% in PND_FR
Average Annual Volume (m^3)	6.20×10^5	6.05×10^5	6.04×10^5	6.02×10^5	5.96×10^5	5.92×10^5	5.88×10^5	5.89×10^5	5.89×10^5
Average Annual Sediment Load (tons)	133	133	124	111	133	124	111	102	89
Average Annual TP Load (lbs)	285	284	265	238	283	265	237	219	191
Average Annual Sediment Load Reduction per 1 AF added storage (tons)	---	0.0000	0.2247	0.5618	0.0000	0.1124	0.2809	0.3933	0.5618
Average Annual Net TP Load Reduction per 1 AF added storage (lbs)	---	0.025	0.484	1.175	0.023	0.252	0.599	0.833	1.177
Additional storage simulated in upstream subwatersheds (AF)	---		39.5				79.1		

* PND_FR = the fraction of a subbasin area that drains into the ponds.

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Temporary Storage Scenarios at Site DL-7 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	**+10% in Pond Primary Vol and +0% in PND_FR**	**+10% in Pond Primary Vol and +2% in PND_FR**	**+10% in Pond Primary Vol and +5% in PND_FR**	**+20% in Pond Primary Vol and +0% in PND_FR**	**+20% in Pond Primary Vol and +2% in PND_FR**	**+20% in Pond Primary Vol and +5% in PND_FR**	**+20% in Pond Primary Vol and +7% in PND_FR**	**+20% in Pond Primary Vol and +10% in PND_FR**
Average Annual Volume (m^3)	$6.57x10^5$	$6.64x10^5$	$6.54x10^5$	$6.45x10^5$	$6.75x10^5$	$6.68x10^5$	$6.57x10^5$	$6.48x10^5$	$6.39x10^5$
Average Annual Sediment Load (tons)	36	36	34	32	35	33	31	29	25
Average Annual TP Load (lbs)	305	302	274	233	299	271	230	203	170
Average Annual Sediment Load Reduction per 1 AF added storage (tons)	---	-0.0007	0.0385	0.0964	0.0049	0.0272	0.0592	0.0855	0.1346
Average Annual Net TP Load Reduction per 1 AF added storage (lbs)	---	0.076	0.820	1.896	0.070	0.443	0.988	1.340	1.775
Additional storage simulated in upstream subwatersheds (AF)	---		37.8				75.6		

* PND_FR = the fraction of a subbasin area that drains into the ponds.

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Conversion to Permanent Cover Scenarios at Site DL-1 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	**Permanent Cover on Ag w/ Slopes >2%**	**Permanent Cover on Ag w/ Slopes <2%**	**Permanent Cover on Ag w/ All Slopes**
Average Annual Volume (m^3)	2.78×10^5	2.86×10^5	7.1×10^5	7.4×10^5
Average Annual Sediment Load (tons)	2.20	2.12	1.78	0.30
Average Annual TP Load (lbs)	1,158	1,010	377	162
Average TP Concentration (ug/L)	*188.6*	*160.0*	*24.1*	*9.9*
Average Annual Sediment Load Reduction per Acre of Ag with BMP (tons)	---	0.0002	0.0001	0.0003
Average Annual Net TP Load Reduction per Acre of Ag with BMP (lbs)	---	0.322	0.151	0.177
Subwatershed area simulated with BMPs – i.e., area with x slope (acres)	---	460	5,155	5,615

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Conversion to Permanent Cover Scenarios at Site HL-2 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	**Permanent Cover on Ag w/ Slopes >2%**	**Permanent Cover on Ag w/ Slopes <2%**	**Permanent Cover on Ag w/ All Slopes**
Average Annual Volume (m^3)	$9.36x10^5$	$9.92x10^5$	$2.10x10^6$	$2.32x10^6$
Average Annual Sediment Load (tons)	75	74	84	13
Average Annual TP Load (lbs)	916	661	332	80
Average Annual Sediment Load Reduction per Acre of Ag with BMP (tons)	---	0.0004	-0.0054	0.0289
Average Annual Net TP Load Reduction per Acre of Ag with BMP (lbs)	---	0.654	0.336	0.392
Subwatershed area simulated with BMPs – i.e., area with x slope (acres)	---	391	1,739	2,130

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Conversion to Permanent Cover Scenarios at Site DL-5 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	**Permanent Cover on Ag w/ Slopes >2%**	**Permanent Cover on Ag w/ Slopes <2%**	**Permanent Cover on Ag w/ All Slopes**
Average Annual Volume (m^3)	6.21×10^5	6.36×10^5	2.08×10^6	2.14×10^6
Average Annual Sediment Load (tons)	133	114	22	3
Average Annual TP Load (lbs)	285	249	59	24
Average Annual Sediment Load Reduction per Acre of Ag with BMP (tons)	---	0.1889	0.0796	0.0871
Average Annual Net TP Load Reduction per Acre of Ag with BMP (lbs)	---	0.343	0.161	0.174
Subwatershed area simulated with BMPs – i.e., area with x slope (acres)	---	104	1,395	1,499

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Results of Conversion to Permanent Cover Scenarios at Site DL-7 (model simulations from 1/1/1980-12/31/2009)

	Current (Base Scenario)	**Permanent Cover on Ag w/ Slopes >2%**	**Permanent Cover on Ag w/ Slopes <2%**	**Permanent Cover on Ag w/ All Slopes**
Average Annual Volume (m^3)	6.57×10^5	7.24×10^5	1.79×10^6	2.02×10^6
Average Annual Sediment Load (tons)	36	31	43	3
Average Annual TP Load (lbs)	305	205	127	27
Average Annual Sediment Load Reduction per Acre of Ag with BMP (tons)	---	0.0134	-0.0052	0.0189
Average Annual Net TP Load Reduction per Acre of Ag with BMP (lbs)	---	0.298	0.128	0.161
Subwatershed area simulated with BMPs – i.e., area with x slope (acres)	---	333	1,385	1,718

Note: Reductions in load are net (i.e., represent the modeled load reduction at the site, not the load reduction from the acre of property)

Crystal Ball Report - Full
Simulation started on 12/8/2010 at 7:28 AM
Simulation stopped on 12/8/2010 at 7:28 AM

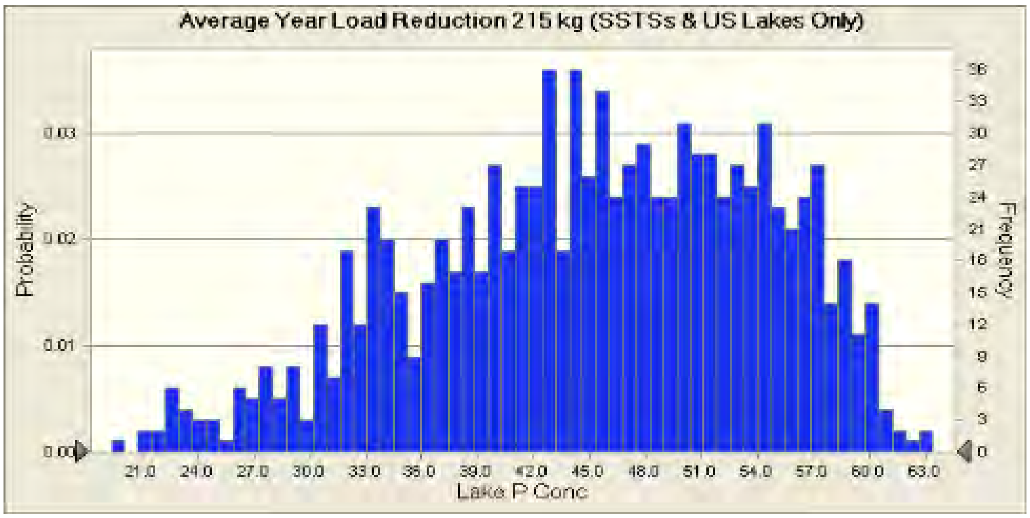
Run preferences:	
Number of trials run	1,000
Monte Carlo	
Random seed	
Precision control on	
Confidence level	95.00%
Run statistics:	
Total running time (sec)	5.46
Trials/second (average)	183
Random numbers per sec	7,691
Crystal Ball data:	
Assumptions	42
Correlations	35
Correlated groups	7
Decision variables	0
Forecasts	55

Forecasts

Worksheet: [CNET_Diamond_Lake_September1_2010.xls]MODEL

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) **Cell: I132**

Summary:
Entire range is from 12.9 to 63.4
Base case is 45.9
After 1,000 trials, the std. error of the mean is 0.3



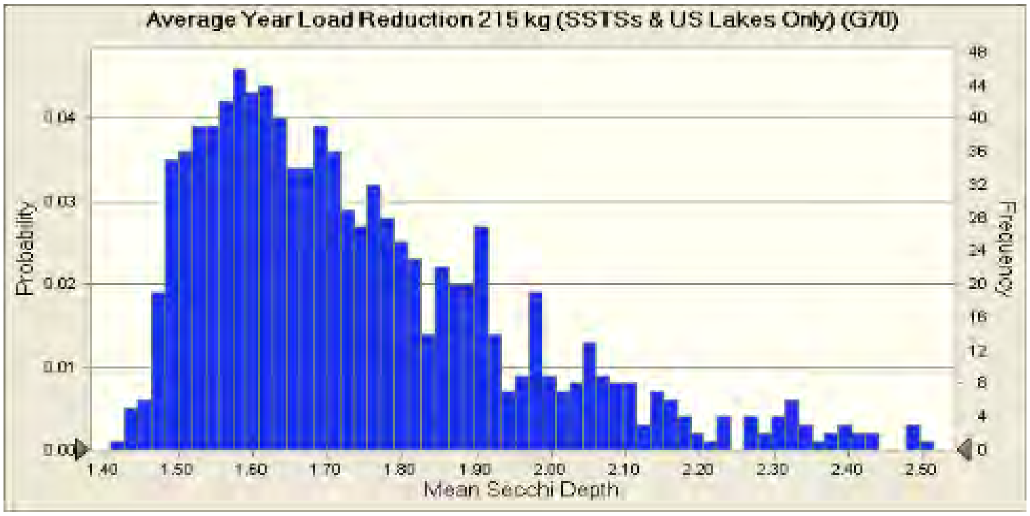
Statistics:	Forecast values
Trials	1,000
Base Case	45.9
Mean	45.0
Median	45.8
Mode	---
Standard Deviation	9.2
Variance	84.1
Skewness	-0.4231
Kurtosis	2.61
Coeff. of Variability	0.2037
Minimum	12.9
Maximum	63.4
Range Width	50.5
Mean Std. Error	0.3

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (cont'd) **Cell: I132**

Percentiles:	Forecast values
0%	12.9
10%	32.5
20%	36.9
30%	40.4
40%	43.1
50%	45.8
60%	48.3
70%	51.0
80%	53.5
90%	56.5
100%	63.4

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (G70) **Cell: G70**

Summary:
Entire range is from 1.41 to 3.34
Base case is 1.71
After 1,000 trials, the std. error of the mean is 0.01



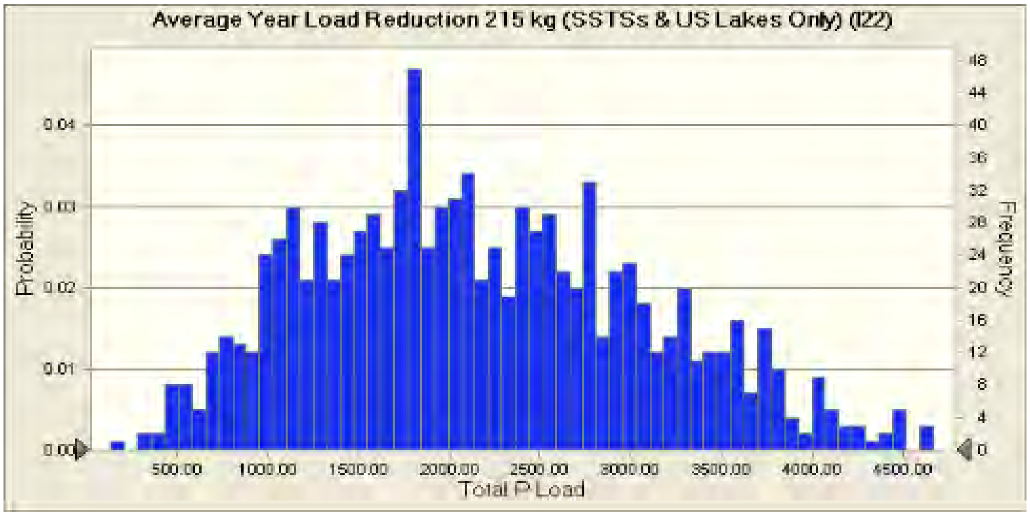
Statistics:	Forecast values
Trials	1,000
Base Case	1.71
Mean	1.77
Median	1.70
Mode	---
Standard Deviation	0.27
Variance	0.07
Skewness	1.99
Kurtosis	8.64
Coeff. of Variability	0.1511
Minimum	1.41
Maximum	3.34
Range Width	1.93
Mean Std. Error	0.01

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (G70) (cont'd) **Cell: G70**

Percentiles:	Forecast values
0%	1.41
10%	1.52
20%	1.56
30%	1.60
40%	1.65
50%	1.70
60%	1.76
70%	1.82
80%	1.91
90%	2.08
100%	3.34

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (I22) **Cell: I22**

Summary:
Entire range is from 135.74 to 4663.94
Base case is 2083.77
After 1,000 trials, the std. error of the mean is 28.84



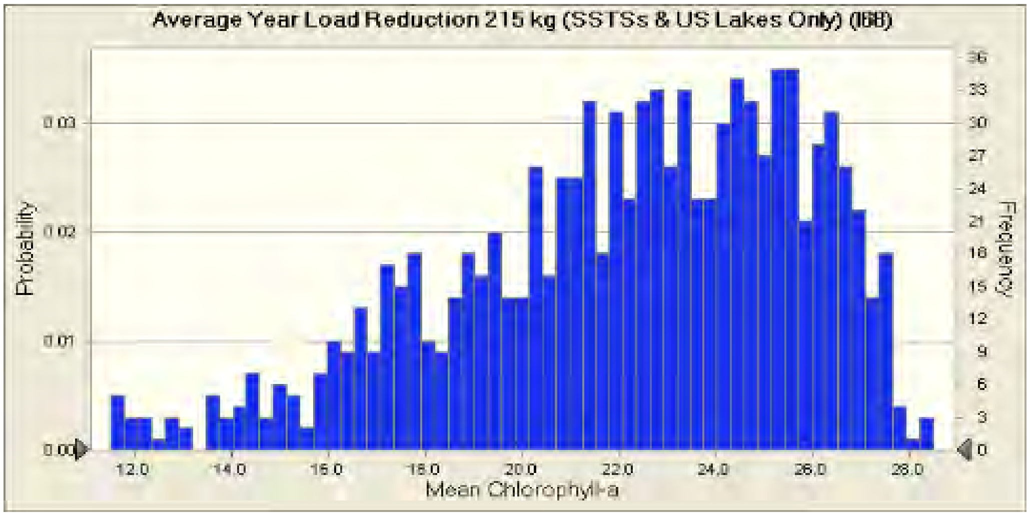
Statistics:	Forecast values
Trials	1,000
Base Case	2083.77
Mean	2163.43
Median	2074.35
Mode	---
Standard Deviation	912.03
Variance	831793.47
Skewness	0.3169
Kurtosis	2.45
Coeff. of Variability	0.4216
Minimum	135.74
Maximum	4663.94
Range Width	4528.20
Mean Std. Error	28.84

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (I22) (cont'd) **Cell: I22**

Percentiles:	Forecast values
0%	135.74
10%	1022.78
20%	1301.75
30%	1606.47
40%	1811.59
50%	2074.31
60%	2364.99
70%	2643.70
80%	2973.03
90%	3459.33
100%	4663.94

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (I68) **Cell: I68**

Summary:
Entire range is from 6.1 to 28.5
Base case is 22.7
After 1,000 trials, the std. error of the mean is 0.1



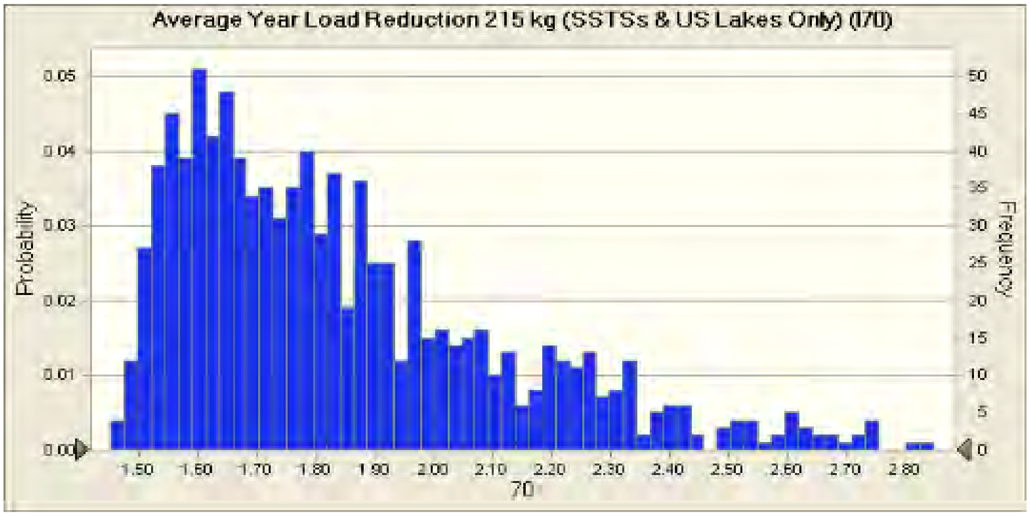
Statistics:	Forecast values
Trials	1,000
Base Case	22.7
Mean	22.0
Median	22.6
Mode	---
Standard Deviation	3.8
Variance	14.1
Skewness	-0.7759
Kurtosis	3.30
Coeff. of Variability	0.1707
Minimum	6.1
Maximum	28.5
Range Width	22.3
Mean Std. Error	0.1

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (I68) (cont'd) **Cell: I68**

Percentiles:	Forecast values
0%	6.1
10%	16.8
20%	18.9
30%	20.4
40%	21.6
50%	22.6
60%	23.6
70%	24.6
80%	25.4
90%	26.4
100%	28.5

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (I70) **Cell: I70**

Summary:
Entire range is from 1.45 to 4.93
Base case is 1.78
After 1,000 trials, the std. error of the mean is 0.01



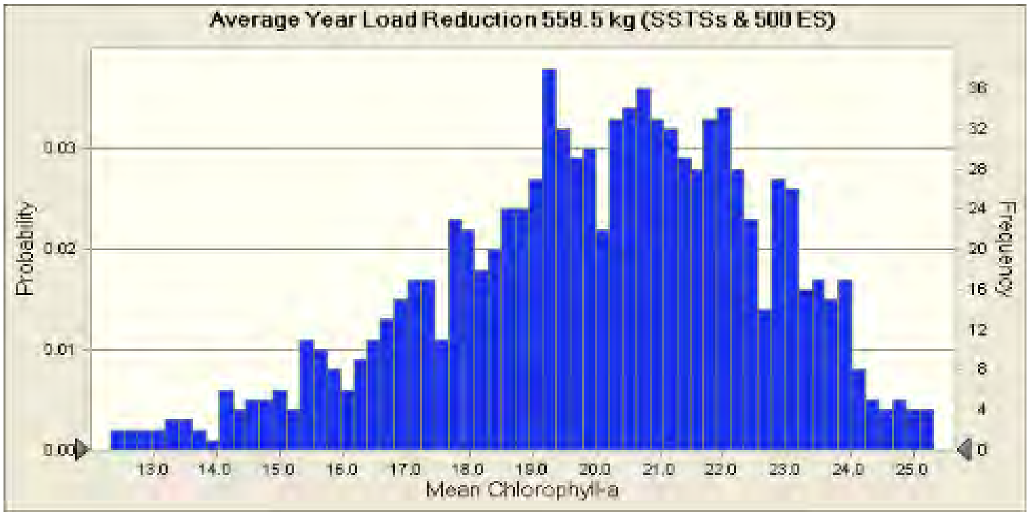
Statistics:	Forecast values
Trials	1,000
Base Case	1.78
Mean	1.87
Median	1.78
Mode	---
Standard Deviation	0.35
Variance	0.12
Skewness	2.23
Kurtosis	12.16
Coeff. of Variability	0.1857
Minimum	1.45
Maximum	4.93
Range Width	3.48
Mean Std. Error	0.01

Forecast: Average Year Load Reduction 215 kg (SSTSs & US Lakes Only) (I70) (cont'd) **Cell: I70**

Percentiles:	Forecast values
0%	1.45
10%	1.55
20%	1.61
30%	1.66
40%	1.72
50%	1.78
60%	1.86
70%	1.95
80%	2.08
90%	2.30
100%	4.93

Forecast: Average Year Load Reduction 559.5 kg (SSTSs & 500 ES) **Cell: J68**

Summary:
Entire range is from 9.8 to 25.3
Base case is 20.2
After 1,000 trials, the std. error of the mean is 0.1



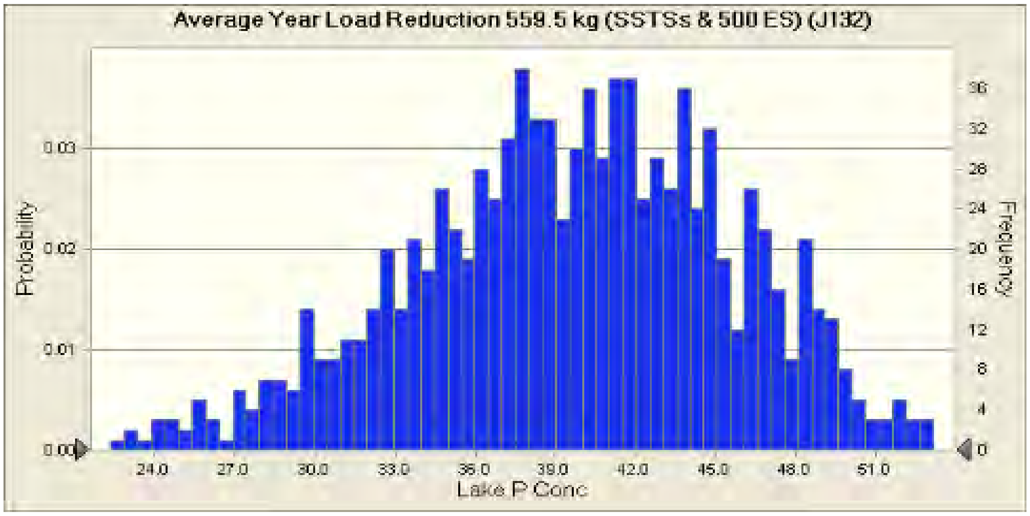
Statistics:	Forecast values
Trials	1,000
Base Case	20.2
Mean	19.9
Median	20.2
Mode	---
Standard Deviation	2.7
Variance	7.3
Skewness	-0.6732
Kurtosis	3.47
Coeff. of Variability	0.1359
Minimum	9.8
Maximum	25.3
Range Width	15.5
Mean Std. Error	0.1

Forecast: Average Year Load Reduction 559.5 kg (SSTSs & 500 ES) (cont'd) **Cell: J68**

Percentiles:	Forecast values
0%	9.8
10%	16.3
20%	17.8
30%	18.8
40%	19.5
50%	20.2
60%	20.9
70%	21.5
80%	22.2
90%	23.1
100%	25.3

Forecast: Average Year Load Reduction 559.5 kg (SSTSs & 500 ES) (J132) **Cell: J132**

Summary:
Entire range is from 19.3 to 53.2
Base case is 39.9
After 1,000 trials, the std. error of the mean is 0.2



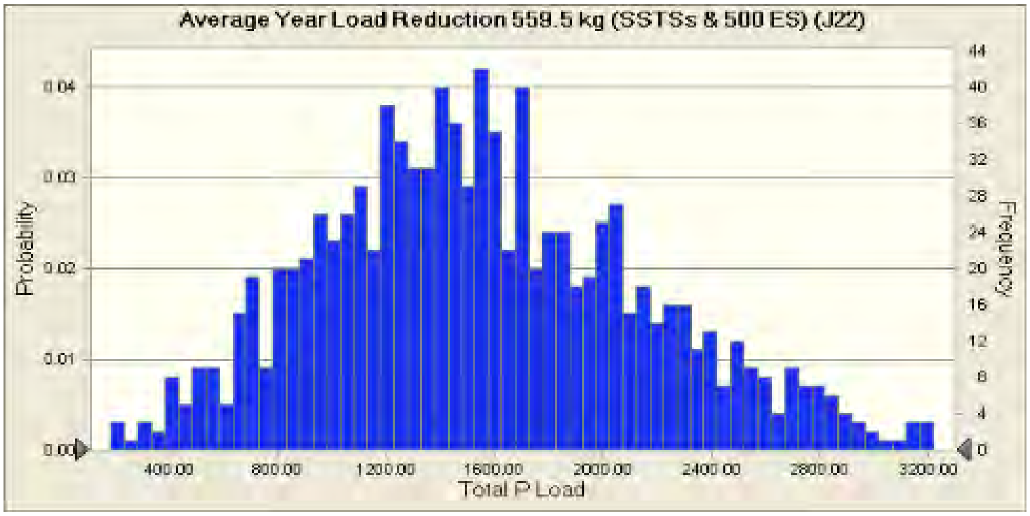
Statistics:	Forecast values
Trials	1,000
Base Case	39.9
Mean	39.5
Median	39.9
Mode	---
Standard Deviation	6.1
Variance	37.5
Skewness	-0.3866
Kurtosis	2.98
Coeff. of Variability	0.1550
Minimum	19.3
Maximum	53.2
Range Width	33.9
Mean Std. Error	0.2

Forecast: Average Year Load Reduction 559.5 kg (SSTSs & 500 ES) (J132) (cont'd) **Cell: J132**

Percentiles:	Forecast values
0%	19.3
10%	31.4
20%	34.5
30%	36.7
40%	38.1
50%	39.9
60%	41.4
70%	43.0
80%	44.8
90%	47.2
100%	53.2

Forecast: Average Year Load Reduction 559.5 kg (SSTSs & 500 ES) (J22) **Cell: J22**

Summary:
Entire range is from 186.95 to 3316.72
Base case is 1494.63
After 1,000 trials, the std. error of the mean is 18.79



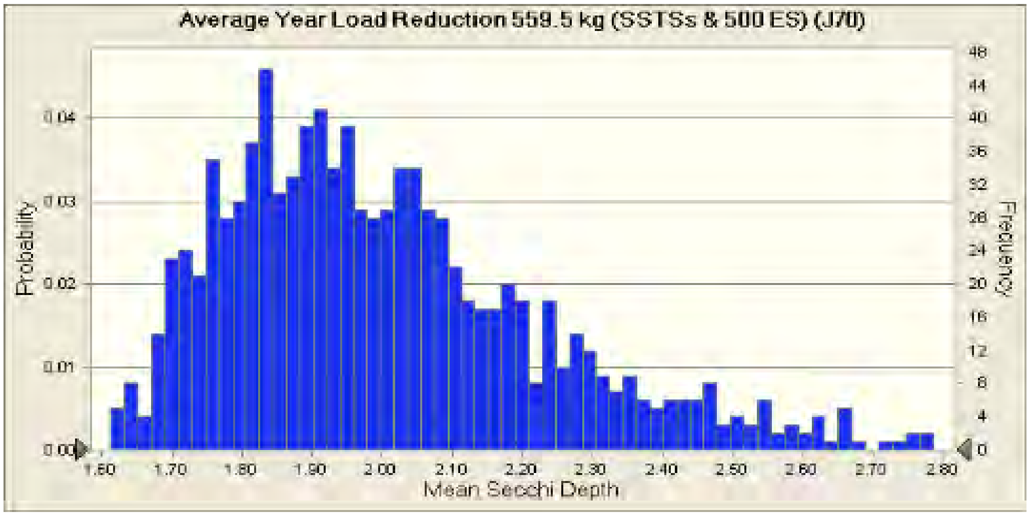
Statistics:	Forecast values
Trials	1,000
Base Case	1494.63
Mean	1550.86
Median	1506.91
Mode	---
Standard Deviation	594.05
Variance	352900.67
Skewness	0.3300
Kurtosis	2.73
Coeff. of Variability	0.3830
Minimum	186.95
Maximum	3316.72
Range Width	3129.77
Mean Std. Error	18.79

Forecast: Average Year Load Reduction 559.5 kg (SSTSs & 500 ES) (J22) (cont'd) **Cell: J22**

Percentiles:	Forecast values
0%	186.95
10%	814.17
20%	1037.93
30%	1209.87
40%	1367.97
50%	1506.73
60%	1649.12
70%	1844.68
80%	2054.10
90%	2354.22
100%	3316.72

Forecast: Average Year Load Reduction 559.5 kg (SSTSs & 500 ES) (J70) **Cell: J70**

Summary:
Entire range is from 1.61 to 3.54
Base case is 1.96
After 1,000 trials, the std. error of the mean is 0.01



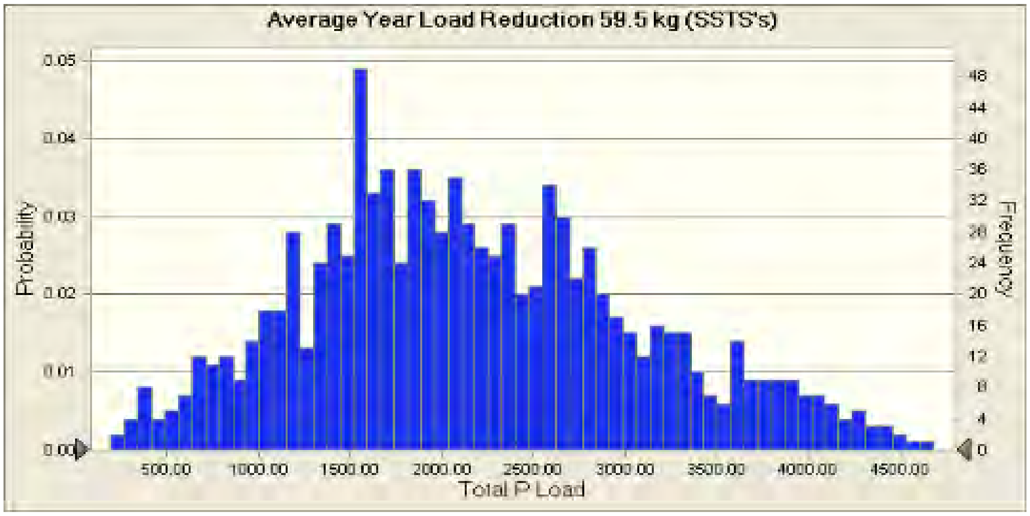
Statistics:	Forecast values
Trials	1,000
Base Case	1.96
Mean	2.02
Median	1.96
Mode	---
Standard Deviation	0.27
Variance	0.07
Skewness	1.66
Kurtosis	7.33
Coeff. of Variability	0.1345
Minimum	1.61
Maximum	3.54
Range Width	1.92
Mean Std. Error	0.01

Forecast: Average Year Load Reduction 559.5 kg (SSTSs & 500 ES) (J70) (cont'd) **Cell: J70**

Percentiles:	Forecast values
0%	1.61
10%	1.75
20%	1.81
30%	1.86
40%	1.91
50%	1.96
60%	2.03
70%	2.09
80%	2.19
90%	2.36
100%	3.54

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) **Cell: H22**

Summary:
Entire range is from 197.31 to 4677.85
Base case is 2083.77
After 1,000 trials, the std. error of the mean is 28.69



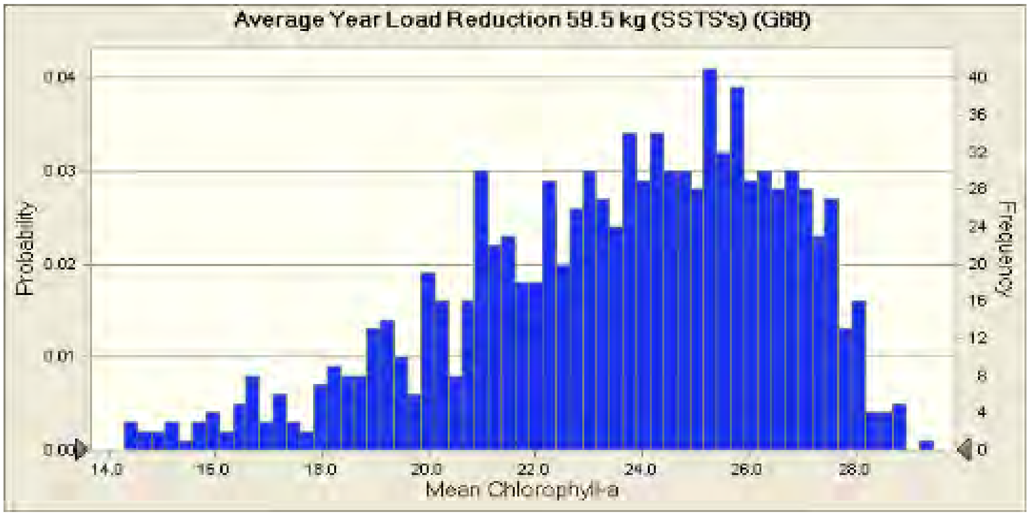
Statistics:	Forecast values
Trials	1,000
Base Case	2083.77
Mean	2168.19
Median	2084.54
Mode	---
Standard Deviation	907.33
Variance	823254.40
Skewness	0.3410
Kurtosis	2.62
Coeff. of Variability	0.4185
Minimum	197.31
Maximum	4677.85
Range Width	4480.55
Mean Std. Error	28.69

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (cont'd) **Cell: H22**

Percentiles:	Forecast values
0%	197.31
10%	1056.09
20%	1393.86
30%	1605.66
40%	1838.34
50%	2084.12
60%	2333.49
70%	2620.57
80%	2942.47
90%	3441.70
100%	4677.85

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (G68) **Cell: G68**

Summary:
Entire range is from 10.6 to 29.4
Base case is 23.7
After 1,000 trials, the std. error of the mean is 0.1



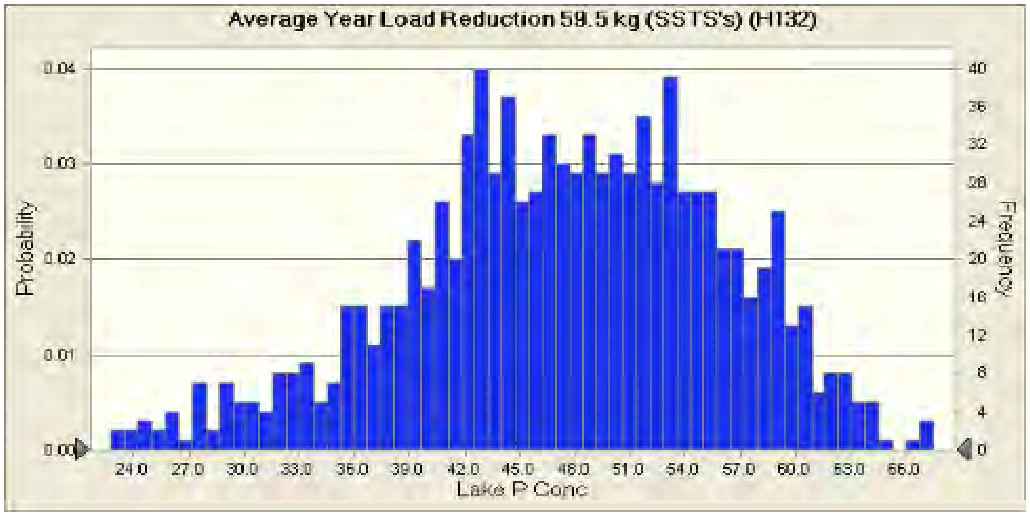
Statistics:	Forecast values
Trials	1,000
Base Case	23.7
Mean	23.3
Median	23.9
Mode	---
Standard Deviation	3.3
Variance	11.0
Skewness	-0.9164
Kurtosis	3.79
Coeff. of Variability	0.1422
Minimum	10.6
Maximum	29.4
Range Width	18.9
Mean Std. Error	0.1

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (G68) (cont'd) **Cell: G68**

Percentiles:	Forecast values
0%	10.6
10%	18.9
20%	20.9
30%	22.0
40%	23.0
50%	23.9
60%	24.7
70%	25.5
80%	26.2
90%	27.1
100%	29.4

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (H132) **Cell: H132**

Summary:
Entire range is from 20.0 to 67.4
Base case is 47.9
After 1,000 trials, the std. error of the mean is 0.3



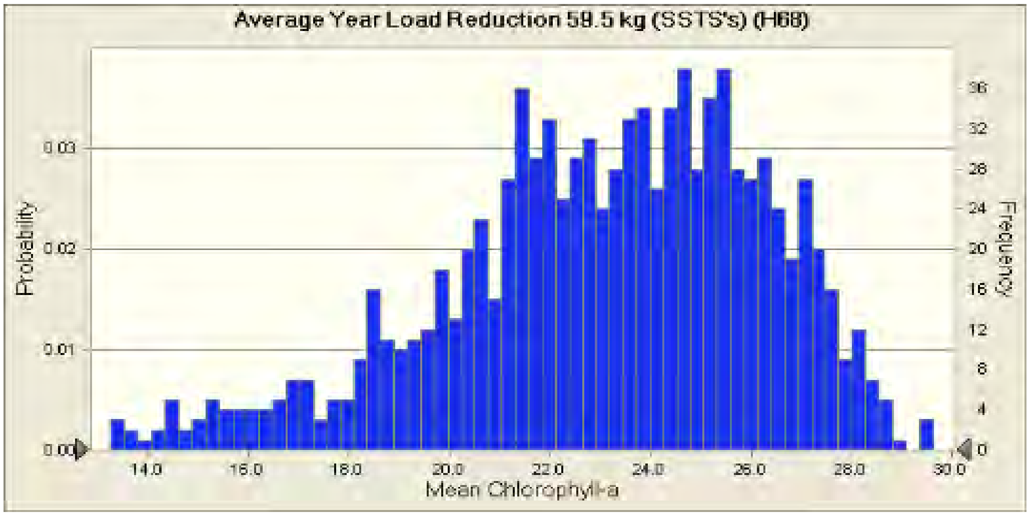
Statistics:	Forecast values
Trials	1,000
Base Case	47.9
Mean	47.2
Median	47.8
Mode	---
Standard Deviation	8.7
Variance	76.0
Skewness	-0.4215
Kurtosis	2.97
Coeff. of Variability	0.1847
Minimum	20.0
Maximum	67.4
Range Width	47.5
Mean Std. Error	0.3

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (H132) (cont'd) **Cell: H132**

Percentiles:	Forecast values
0%	20.0
10%	35.9
20%	40.4
30%	43.0
40%	45.2
50%	47.7
60%	50.2
70%	52.5
80%	54.8
90%	58.4
100%	67.4

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (H68) **Cell: H68**

Summary:
Entire range is from 10.2 to 29.6
Base case is 23.4
After 1,000 trials, the std. error of the mean is 0.1



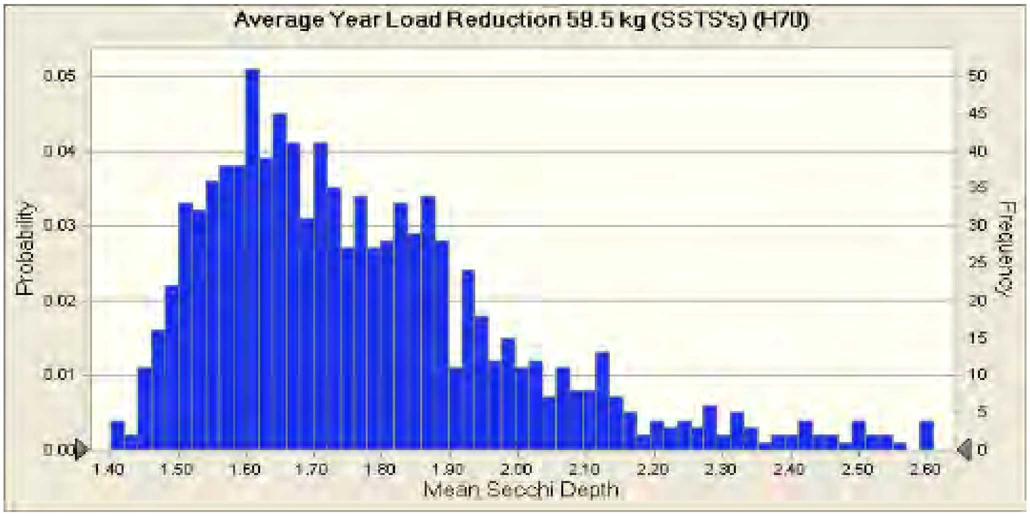
Statistics:	Forecast values
Trials	1,000
Base Case	23.4
Mean	22.9
Median	23.4
Mode	---
Standard Deviation	3.4
Variance	11.9
Skewness	-0.8478
Kurtosis	3.78
Coeff. of Variability	0.1503
Minimum	10.2
Maximum	29.6
Range Width	19.4
Mean Std. Error	0.1

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (H68) (cont'd) **Cell: H68**

Percentiles:	Forecast values
0%	10.2
10%	18.4
20%	20.4
30%	21.5
40%	22.4
50%	23.4
60%	24.3
70%	25.1
80%	25.9
90%	26.9
100%	29.6

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (H70) **Cell: H70**

Summary:
Entire range is from 1.40 to 3.43
Base case is 1.73
After 1,000 trials, the std. error of the mean is 0.01



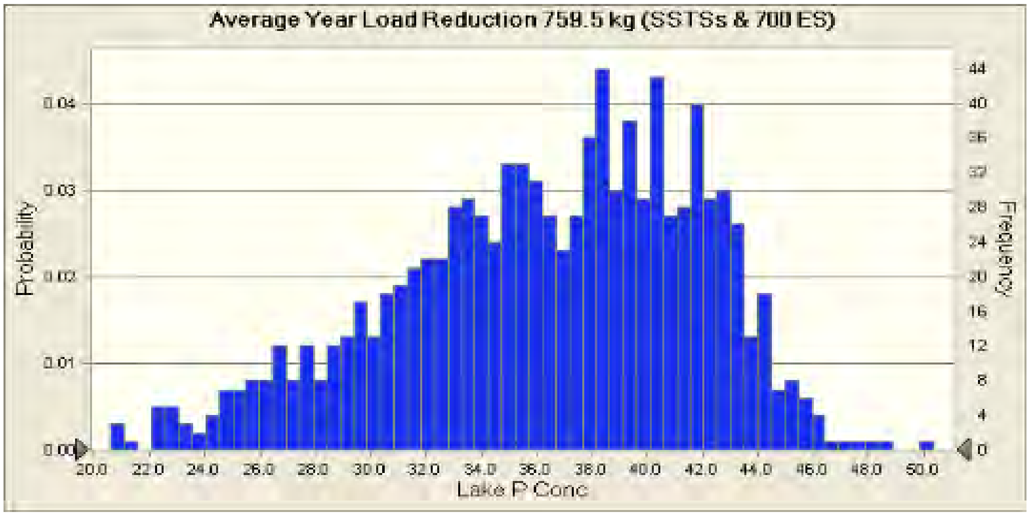
Statistics:	Forecast values
Trials	1,000
Base Case	1.73
Mean	1.80
Median	1.73
Mode	---
Standard Deviation	0.29
Variance	0.08
Skewness	2.02
Kurtosis	8.84
Coeff. of Variability	0.1607
Minimum	1.40
Maximum	3.43
Range Width	2.03
Mean Std. Error	0.01

Forecast: Average Year Load Reduction 59.5 kg (SSTS's) (H70) (cont'd) **Cell: H70**

Percentiles:	Forecast values
0%	1.40
10%	1.53
20%	1.58
30%	1.63
40%	1.68
50%	1.73
60%	1.79
70%	1.86
80%	1.95
90%	2.13
100%	3.43

Forecast: Average Year Load Reduction 759.5 kg (SSTSs & 700 ES) **Cell: K132**

Summary:
Entire range is from 18.1 to 50.3
Base case is 36.4
After 1,000 trials, the std. error of the mean is 0.2



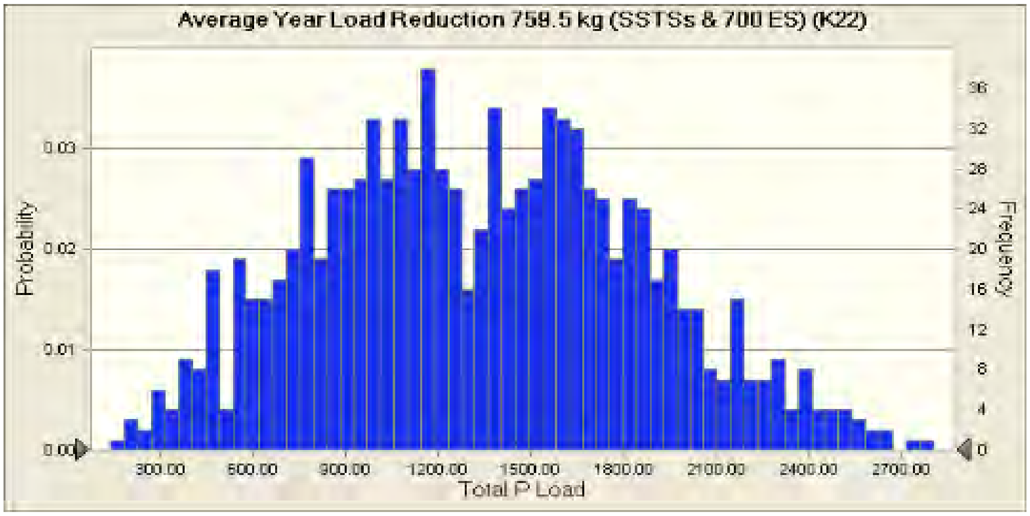
Statistics:	Forecast values
Trials	1,000
Base Case	36.4
Mean	36.2
Median	36.9
Mode	---
Standard Deviation	5.6
Variance	31.1
Skewness	-0.5398
Kurtosis	2.85
Coeff. of Variability	0.1539
Minimum	18.1
Maximum	50.3
Range Width	32.2
Mean Std. Error	0.2

Forecast: Average Year Load Reduction 759.5 kg (SSTSs & 700 ES) (cont'd) **Cell: K132**

Percentiles:	Forecast values
0%	18.1
10%	28.4
20%	31.6
30%	33.6
40%	35.3
50%	36.9
60%	38.4
70%	39.8
80%	41.3
90%	42.8
100%	50.3

Forecast: Average Year Load Reduction 759.5 kg (SSTSs & 700 ES) (K22) **Cell: K22**

Summary:
Entire range is from 140.13 to 2889.19
Base case is 1258.98
After 1,000 trials, the std. error of the mean is 16.57



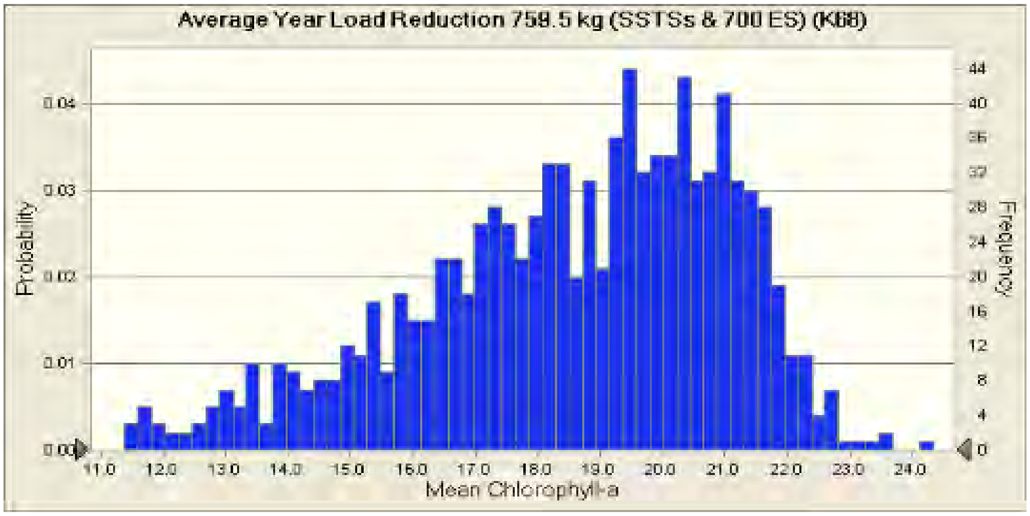
Statistics:	Forecast values
Trials	1,000
Base Case	1258.98
Mean	1334.35
Median	1323.45
Mode	---
Standard Deviation	524.00
Variance	274576.37
Skewness	0.1805
Kurtosis	2.47
Coeff. of Variability	0.3927
Minimum	140.13
Maximum	2889.19
Range Width	2749.06
Mean Std. Error	16.57

Forecast: Average Year Load Reduction 759.5 kg (SSTSs & 700 ES) (K22) (cont'd) **Cell: K22**

Percentiles:	Forecast values
0%	140.13
10%	652.61
20%	852.75
30%	1011.53
40%	1153.60
50%	1320.74
60%	1486.86
70%	1624.72
80%	1798.83
90%	2017.71
100%	2889.19

Forecast: Average Year Load Reduction 759.5 kg (SSTSs & 700 ES) (K68) **Cell: K68**

Summary:
Entire range is from 9.1 to 24.3
Base case is 18.7
After 1,000 trials, the std. error of the mean is 0.1



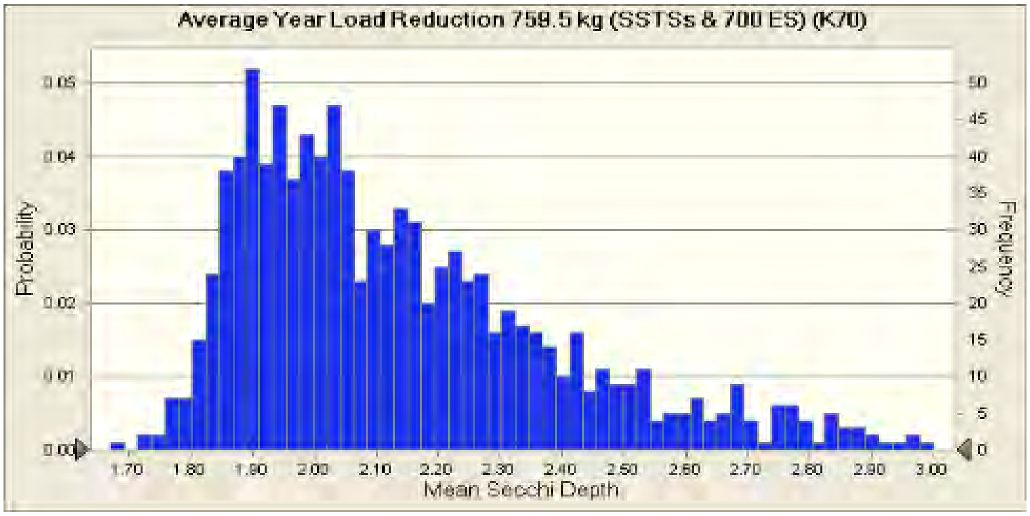
Statistics:	Forecast values
Trials	1,000
Base Case	18.7
Mean	18.5
Median	18.9
Mode	---
Standard Deviation	2.6
Variance	6.8
Skewness	-0.7505
Kurtosis	3.24
Coeff. of Variability	0.1412
Minimum	9.1
Maximum	24.3
Range Width	15.2
Mean Std. Error	0.1

Forecast: Average Year Load Reduction 759.5 kg (SSTSs & 700 ES) (K68) (cont'd) **Cell: K68**

Percentiles:	Forecast values
0%	9.1
10%	14.8
20%	16.4
30%	17.3
40%	18.1
50%	18.9
60%	19.6
70%	20.2
80%	20.8
90%	21.4
100%	24.3

Forecast: Average Year Load Reduction 759.5 kg (SSTSs & 700 ES) (K70) **Cell: K70**

Summary:
Entire range is from 1.67 to 3.73
Base case is 2.10
After 1,000 trials, the std. error of the mean is 0.01



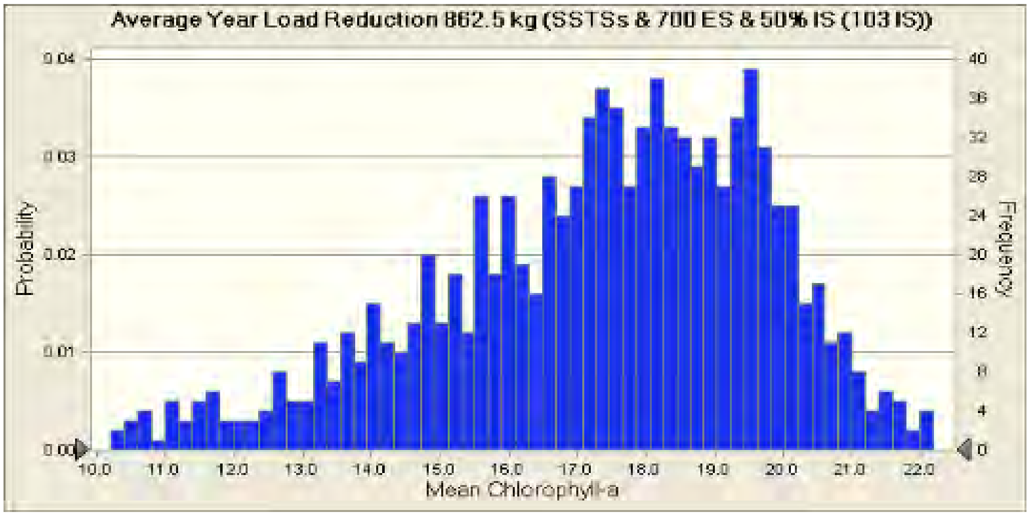
Statistics:	Forecast values
Trials	1,000
Base Case	2.10
Mean	2.16
Median	2.08
Mode	---
Standard Deviation	0.30
Variance	0.09
Skewness	1.56
Kurtosis	6.16
Coeff. of Variability	0.1389
Minimum	1.67
Maximum	3.73
Range Width	2.06
Mean Std. Error	0.01

Forecast: Average Year Load Reduction 759.5 kg (SSTSs & 700 ES) (K70) (cont'd) **Cell: K70**

Percentiles:	Forecast values
0%	1.67
10%	1.87
20%	1.92
30%	1.97
40%	2.02
50%	2.08
60%	2.16
70%	2.24
80%	2.35
90%	2.54
100%	3.73

Forecast: Average Year Load Reduction 862.5 kg (SSTSs & 700 ES & 50% IS (103 IS)) Cell: L68

Summary:
Entire range is from 8.1 to 22.2
Base case is 17.5
After 1,000 trials, the std. error of the mean is 0.1



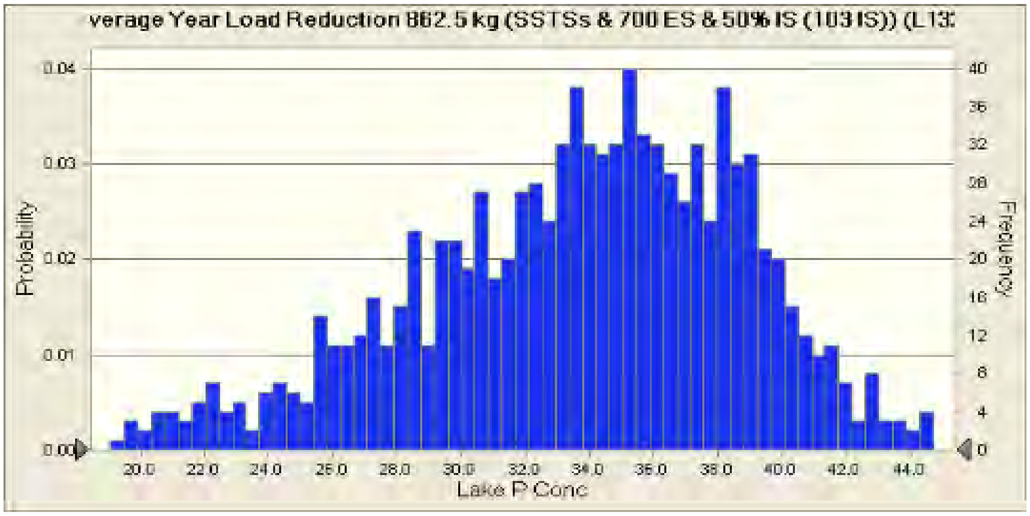
Statistics:	Forecast values
Trials	1,000
Base Case	17.5
Mean	17.2
Median	17.6
Mode	---
Standard Deviation	2.5
Variance	6.3
Skewness	-0.7328
Kurtosis	3.30
Coeff. of Variability	0.1457
Minimum	8.1
Maximum	22.2
Range Width	14.1
Mean Std. Error	0.1

Forecast: Average Year Load Reduction 862.5 kg (SSTSs & 700 ES & 50% IS (103 IS)) (cont'd) Cell: L68

Percentiles:	Forecast values
0%	8.1
10%	13.7
20%	15.2
30%	16.2
40%	17.0
50%	17.6
60%	18.2
70%	18.8
80%	19.4
90%	20.1
100%	22.2

Forecast: Average Year Load Reduction 862.5 kg (SSTSs & 700 ES & 50% IS (103 IS)) (L132) Cell: L132

Summary:
Entire range is from 16.2 to 44.7
Base case is 33.8
After 1,000 trials, the std. error of the mean is 0.2



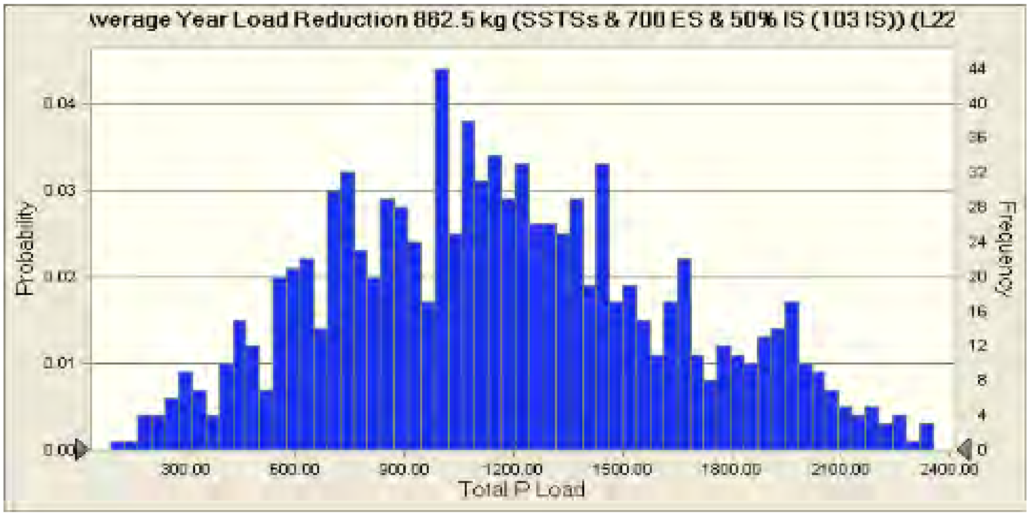
Statistics:	Forecast values
Trials	1,000
Base Case	33.8
Mean	33.6
Median	34.2
Mode	---
Standard Deviation	5.2
Variance	26.8
Skewness	-0.5322
Kurtosis	2.97
Coeff. of Variability	0.1541
Minimum	16.2
Maximum	44.7
Range Width	28.5
Mean Std. Error	0.2

Forecast: Average Year Load Reduction 862.5 kg (SSTSs & 700 ES & 50% IS (103 IS)) (LCell: L132

Percentiles:	Forecast values
0%	16.2
10%	26.4
20%	29.2
30%	31.2
40%	32.9
50%	34.2
60%	35.4
70%	36.7
80%	38.2
90%	39.6
100%	44.7

Forecast: Average Year Load Reduction 862.5 kg (SSTSs & 700 ES & 50% IS (103 IS)) (L22)Cell: L22

Summary:
Entire range is from 93.14 to 2351.73
Base case is 1097.75
After 1,000 trials, the std. error of the mean is 14.75



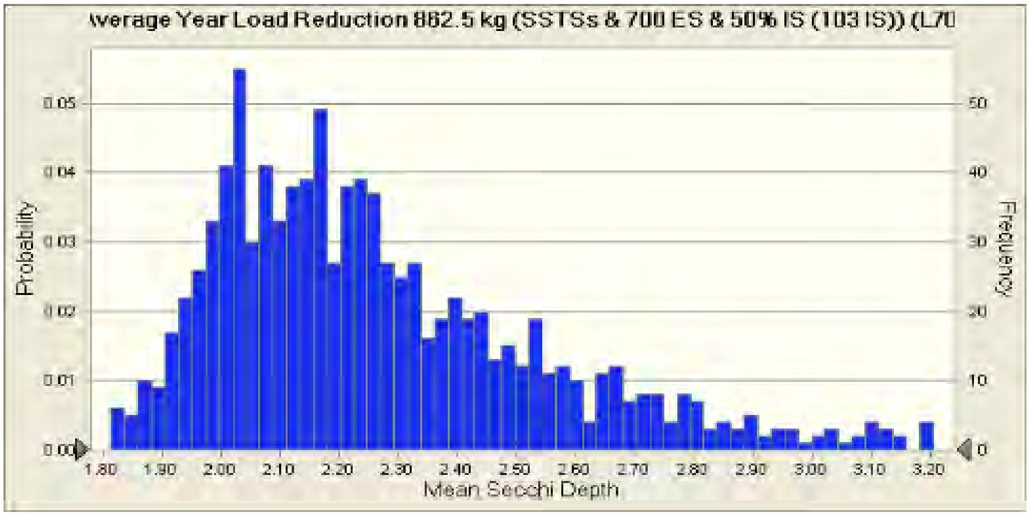
Statistics:	Forecast values
Trials	1,000
Base Case	1097.75
Mean	1161.33
Median	1132.64
Mode	---
Standard Deviation	466.36
Variance	217494.93
Skewness	0.2351
Kurtosis	2.47
Coeff. of Variability	0.4016
Minimum	93.14
Maximum	2351.73
Range Width	2258.59
Mean Std. Error	14.75

Forecast: Average Year Load Reduction 862.5 kg (SSTSs & 700 ES & 50% IS (103 IS)) (L22) Cell: L22

Percentiles:	Forecast values
0%	93.14
10%	574.36
20%	737.35
30%	879.17
40%	1011.38
50%	1132.05
60%	1253.10
70%	1386.41
80%	1567.87
90%	1849.88
100%	2351.73

Forecast: Average Year Load Reduction 862.5 kg (SSTSs & 700 ES & 50% IS (103 IS)) (L70) Cell: L70

Summary:
Entire range is from 1.81 to 4.08
Base case is 2.23
After 1,000 trials, the std. error of the mean is 0.01



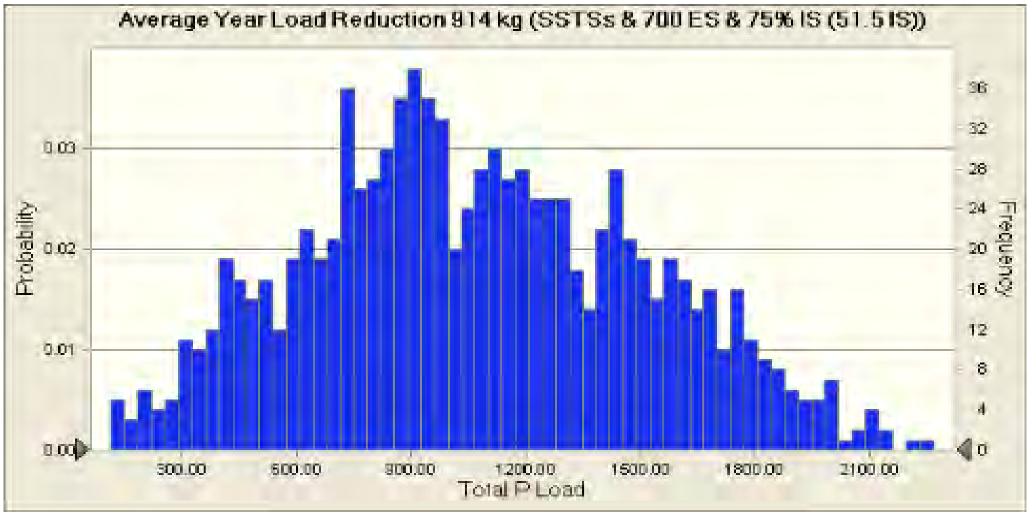
Statistics:	Forecast values
Trials	1,000
Base Case	2.23
Mean	2.29
Median	2.21
Mode	---
Standard Deviation	0.33
Variance	0.11
Skewness	1.58
Kurtosis	6.23
Coeff. of Variability	0.1424
Minimum	1.81
Maximum	4.08
Range Width	2.27
Mean Std. Error	0.01

Forecast: Average Year Load Reduction 862.5 kg (SSTSs & 700 ES & 50% IS (103 IS)) (L70) Cell: L70

Percentiles:	Forecast values
0%	1.81
10%	1.98
20%	2.03
30%	2.09
40%	2.15
50%	2.21
60%	2.27
70%	2.37
80%	2.50
90%	2.71
100%	4.08

Forecast: Average Year Load Reduction 914 kg (SSTSs & 700 ES & 75% IS (51.5 IS)) Cell: M22

Summary:
Entire range is from 114.54 to 2266.00
Base case is 1017.14
After 1,000 trials, the std. error of the mean is 13.86



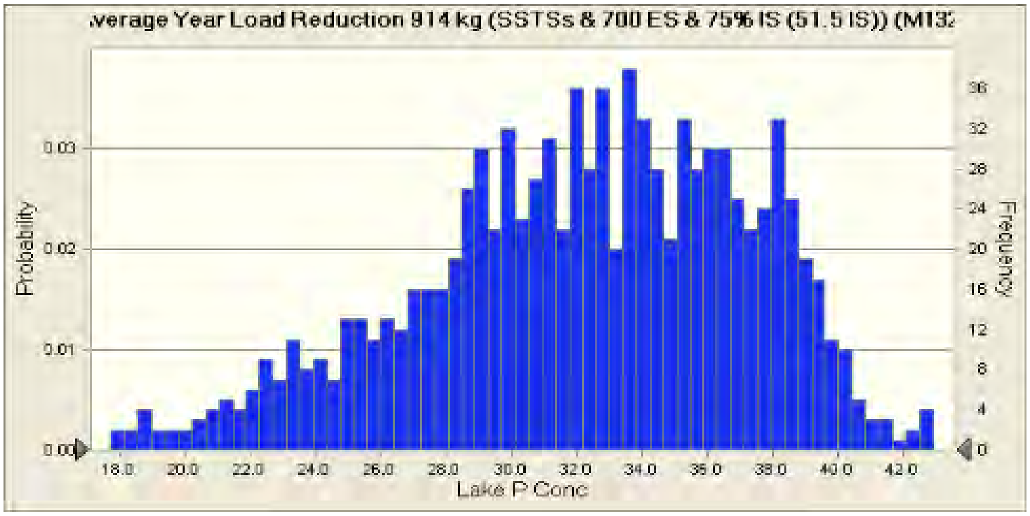
Statistics:	Forecast values
Trials	1,000
Base Case	1017.14
Mean	1067.66
Median	1033.87
Mode	---
Standard Deviation	438.16
Variance	191986.97
Skewness	0.1841
Kurtosis	2.40
Coeff. of Variability	0.4104
Minimum	114.54
Maximum	2266.00
Range Width	2151.46
Mean Std. Error	13.86

Forecast: Average Year Load Reduction 914 kg (SSTSs & 700 ES & 75% IS (51.5 IS)) (cont'd) Cell: M22

Percentiles:	Forecast values
0%	114.54
10%	490.05
20%	684.92
30%	810.92
40%	919.22
50%	1033.57
60%	1164.56
70%	1298.00
80%	1462.72
90%	1671.74
100%	2266.00

Forecast: Average Year Load Reduction 914 kg (SSTSs & 700 ES & 75% IS (51.5 IS)) (M132) Cell: M132

Summary:
Entire range is from 16.0 to 42.9
Base case is 32.5
After 1,000 trials, the std. error of the mean is 0.2



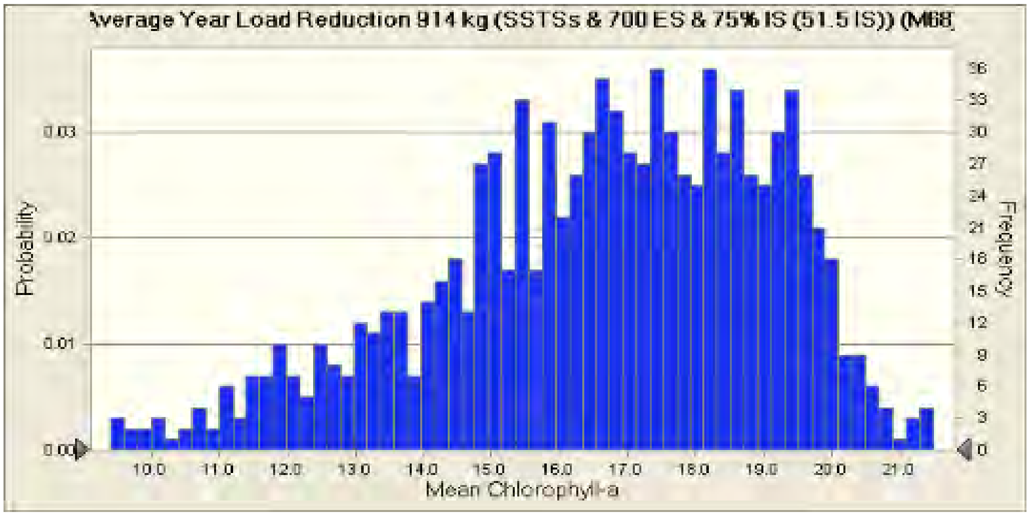
Statistics:	Forecast values
Trials	1,000
Base Case	32.5
Mean	32.1
Median	32.6
Mode	---
Standard Deviation	5.1
Variance	26.4
Skewness	-0.5070
Kurtosis	2.85
Coeff. of Variability	0.1599
Minimum	16.0
Maximum	42.9
Range Width	26.9
Mean Std. Error	0.2

Forecast: Average Year Load Reduction 914 kg (SSTSs & 700 ES & 75% IS (51.5 IS)) (M132) (Cell: M132

Percentiles:	Forecast values
0%	16.0
10%	25.0
20%	27.9
30%	29.7
40%	31.2
50%	32.6
60%	33.9
70%	35.4
80%	36.8
90%	38.4
100%	42.9

Forecast: Average Year Load Reduction 914 kg (SSTSs & 700 ES & 75% IS (51.5 IS)) (M68) Cell: M68

Summary:
Entire range is from 7.9 to 21.5
Base case is 16.8
After 1,000 trials, the std. error of the mean is 0.1



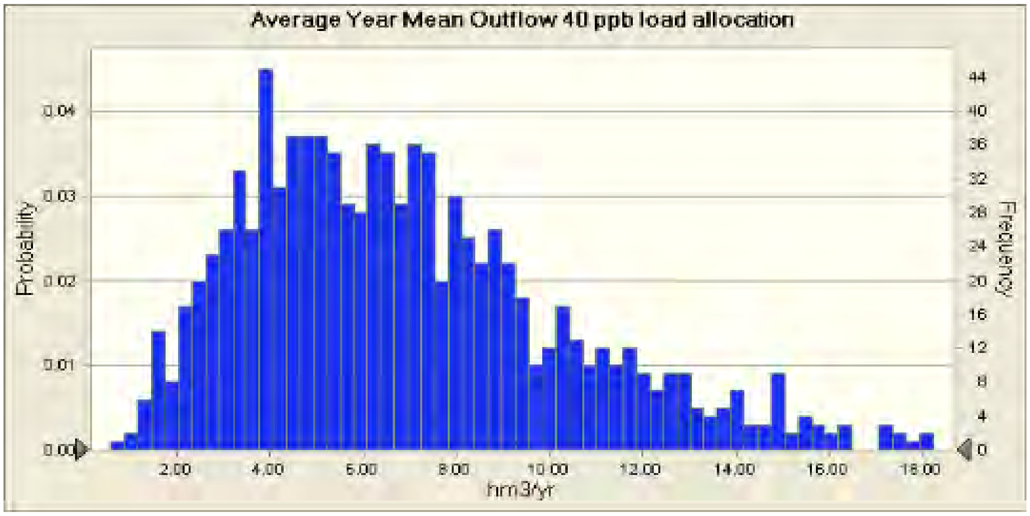
Statistics:	Forecast values
Trials	1,000
Base Case	16.8
Mean	16.5
Median	16.9
Mode	---
Standard Deviation	2.5
Variance	6.5
Skewness	-0.6863
Kurtosis	3.15
Coeff. of Variability	0.1539
Minimum	7.9
Maximum	21.5
Range Width	13.6
Mean Std. Error	0.1

Forecast: Average Year Load Reduction 914 kg (SSTSs & 700 ES & 75% IS (51.5 IS)) (M68) Cell: M68

Percentiles:	Forecast values
0%	7.9
10%	13.0
20%	14.5
30%	15.4
40%	16.2
50%	16.9
60%	17.5
70%	18.2
80%	18.9
90%	19.5
100%	21.5

Forecast: Average Year Mean Outflow 40 ppb load allocation **Cell: I89**

Summary:
Entire range is from 0.59 to 24.57
Base case is 6.41
After 1,000 trials, the std. error of the mean is 0.12



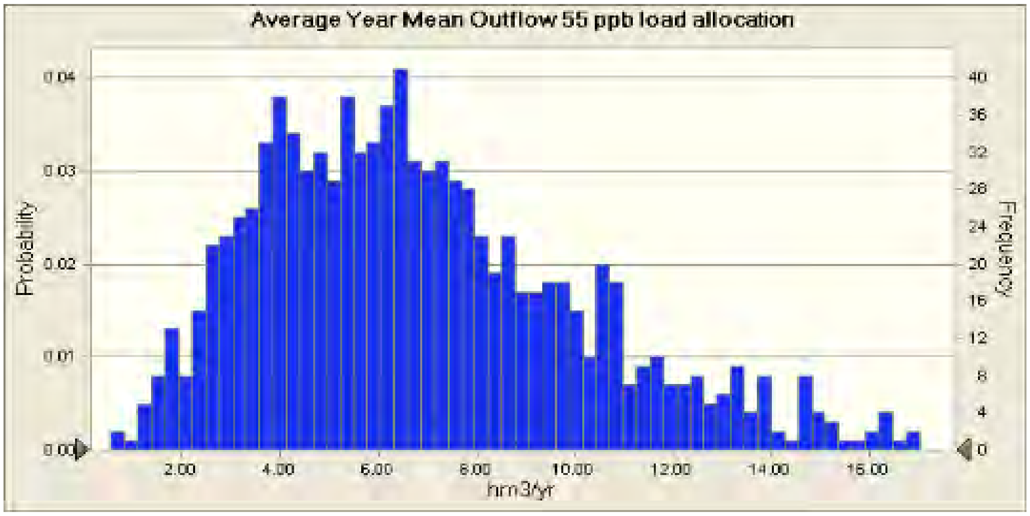
Statistics:	Forecast values
Trials	1,000
Base Case	6.41
Mean	7.18
Median	6.45
Mode	---
Standard Deviation	3.94
Variance	15.55
Skewness	1.25
Kurtosis	4.99
Coeff. of Variability	0.5497
Minimum	0.59
Maximum	24.57
Range Width	23.98
Mean Std. Error	0.12

Forecast: Average Year Mean Outflow 40 ppb load allocation (cont'd) **Cell: I89**

Percentiles:	Forecast values
0%	0.59
10%	3.01
20%	3.92
30%	4.70
40%	5.52
50%	6.45
60%	7.30
70%	8.37
80%	9.91
90%	12.43
100%	24.57

Forecast: Average Year Mean Outflow 55 ppb load allocation **Cell: J89**

Summary:
Entire range is from 0.57 to 22.07
Base case is 6.41
After 1,000 trials, the std. error of the mean is 0.12



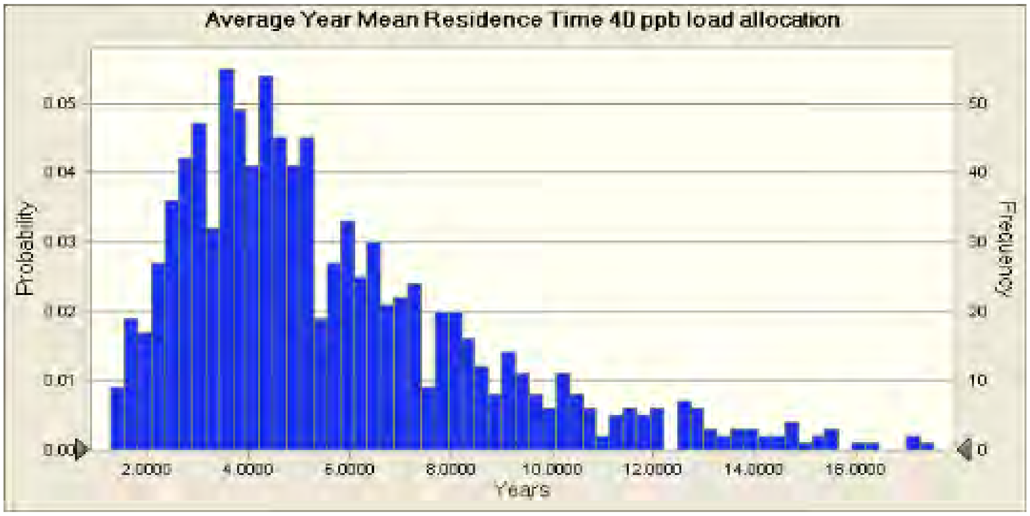
Statistics:	Forecast values
Trials	1,000
Base Case	6.41
Mean	7.07
Median	6.47
Mode	---
Standard Deviation	3.65
Variance	13.30
Skewness	1.09
Kurtosis	4.50
Coeff. of Variability	0.5160
Minimum	0.57
Maximum	22.07
Range Width	21.50
Mean Std. Error	0.12

Forecast: Average Year Mean Outflow 55 ppb load allocation (cont'd) **Cell: J89**

Percentiles:	Forecast values
0%	0.57
10%	3.10
20%	3.94
30%	4.80
40%	5.64
50%	6.46
60%	7.26
70%	8.26
80%	9.68
90%	11.82
100%	22.07

Forecast: Average Year Mean Residence Time 40 ppb load allocation **Cell: I113**

Summary:
Entire range is from 1.2876 to 53.8559
Base case is 4.9349
After 1,000 trials, the std. error of the mean is 0.1297



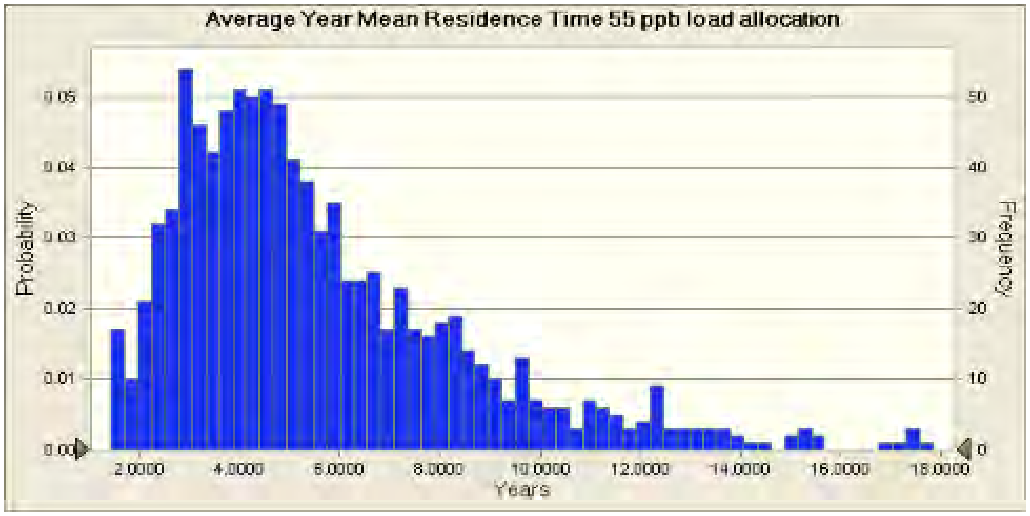
Statistics:	Forecast values
Trials	1,000
Base Case	4.9349
Mean	6.0310
Median	4.9044
Mode	---
Standard Deviation	4.1004
Variance	16.8131
Skewness	3.24
Kurtosis	25.20
Coeff. of Variability	0.6799
Minimum	1.2876
Maximum	53.8559
Range Width	52.5683
Mean Std. Error	0.1297

Forecast: Average Year Mean Residence Time 40 ppb load allocation (cont'd) **Cell: I113**

Percentiles:	Forecast values
0%	1.2876
10%	2.5456
20%	3.1723
30%	3.7706
40%	4.3247
50%	4.9005
60%	5.7189
70%	6.7147
80%	8.0571
90%	10.4915
100%	53.8559

Forecast: Average Year Mean Residence Time 55 ppb load allocation **Cell: J113**

Summary:
Entire range is from 1.4337 to 55.5220
Base case is 4.9349
After 1,000 trials, the std. error of the mean is 0.1335



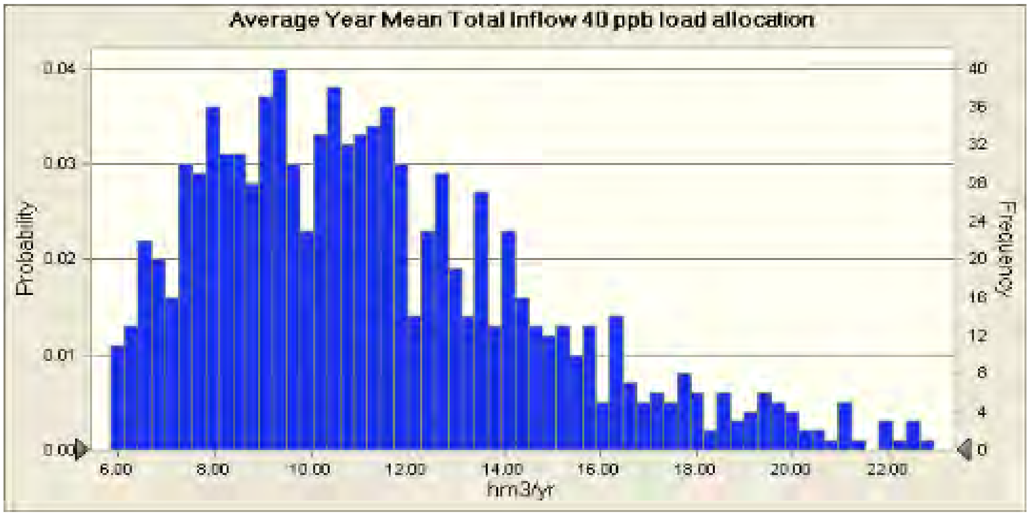
Statistics:	Forecast values
Trials	1,000
Base Case	4.9349
Mean	6.0151
Median	4.8935
Mode	---
Standard Deviation	4.2219
Variance	17.8247
Skewness	3.86
Kurtosis	31.26
Coeff. of Variability	0.7019
Minimum	1.4337
Maximum	55.5220
Range Width	54.0883
Mean Std. Error	0.1335

Forecast: Average Year Mean Residence Time 55 ppb load allocation (cont'd) **Cell: J113**

Percentiles:	Forecast values
0%	1.4337
10%	2.6673
20%	3.2599
30%	3.8308
40%	4.3548
50%	4.8919
60%	5.6069
70%	6.5580
80%	8.0262
90%	10.1985
100%	55.5220

Forecast: Average Year Mean Total Inflow 40 ppb load allocation **Cell: I87**

Summary:
Entire range is from 5.85 to 28.88
Base case is 10.93
After 1,000 trials, the std. error of the mean is 0.13



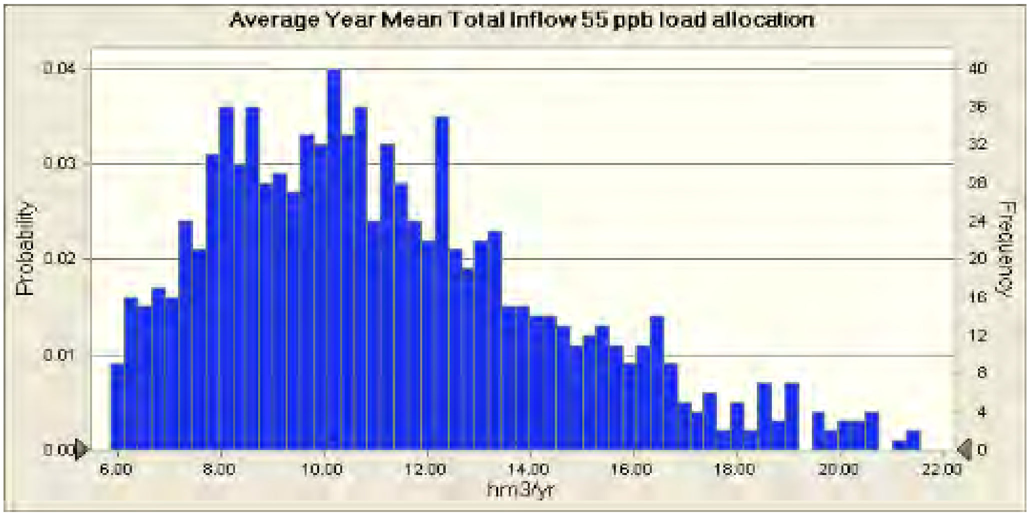
Statistics:	Forecast values
Trials	1,000
Base Case	10.93
Mean	11.66
Median	10.88
Mode	---
Standard Deviation	4.01
Variance	16.11
Skewness	1.29
Kurtosis	5.08
Coeff. of Variability	0.3443
Minimum	5.85
Maximum	28.88
Range Width	23.03
Mean Std. Error	0.13

Forecast: Average Year Mean Total Inflow 40 ppb load allocation (cont'd) **Cell: I87**

Percentiles:	Forecast values
0%	5.85
10%	7.43
20%	8.29
30%	9.18
40%	10.06
50%	10.87
60%	11.69
70%	12.85
80%	14.29
90%	16.82
100%	28.88

Forecast: Average Year Mean Total Inflow 55 ppb load allocation **Cell: J87**

Summary:
Entire range is from 5.87 to 27.20
Base case is 10.93
After 1,000 trials, the std. error of the mean is 0.12



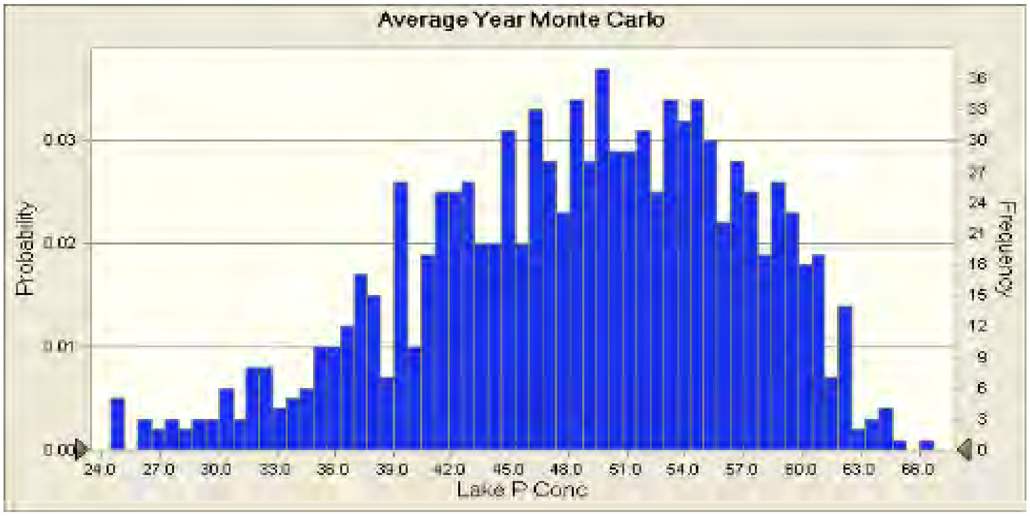
Statistics:	Forecast values
Trials	1,000
Base Case	10.93
Mean	11.49
Median	10.74
Mode	---
Standard Deviation	3.68
Variance	13.53
Skewness	1.13
Kurtosis	4.52
Coeff. of Variability	0.3201
Minimum	5.87
Maximum	27.20
Range Width	21.32
Mean Std. Error	0.12

Forecast: Average Year Mean Total Inflow 55 ppb load allocation (cont'd) **Cell: J87**

Percentiles:	Forecast values
0%	5.87
10%	7.47
20%	8.33
30%	9.18
40%	10.04
50%	10.72
60%	11.71
70%	12.72
80%	14.18
90%	16.33
100%	27.20

Forecast: Average Year Monte Carlo **Cell: G132**

Summary:
Entire range is from 20.6 to 66.7
Base case is 48.7
After 1,000 trials, the std. error of the mean is 0.3



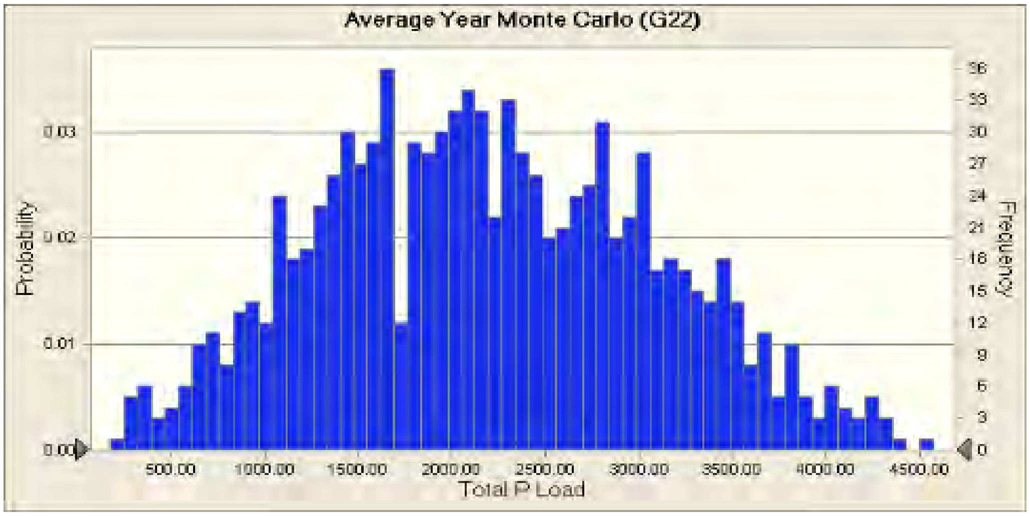
Statistics:	Forecast values
Trials	1,000
Base Case	48.7
Mean	48.3
Median	49.2
Mode	---
Standard Deviation	8.5
Variance	72.4
Skewness	-0.5289
Kurtosis	2.92
Coeff. of Variability	0.1761
Minimum	20.6
Maximum	66.7
Range Width	46.1
Mean Std. Error	0.3

Forecast: Average Year Monte Carlo (cont'd) **Cell: G132**

Percentiles:	Forecast values
0%	20.6
10%	36.9
20%	41.4
30%	44.3
40%	46.7
50%	49.2
60%	51.4
70%	53.7
80%	56.0
90%	58.8
100%	66.7

Forecast: Average Year Monte Carlo (G22) **Cell: G22**

Summary:
Entire range is from 182.13 to 4570.01
Base case is 2083.77
After 1,000 trials, the std. error of the mean is 27.94



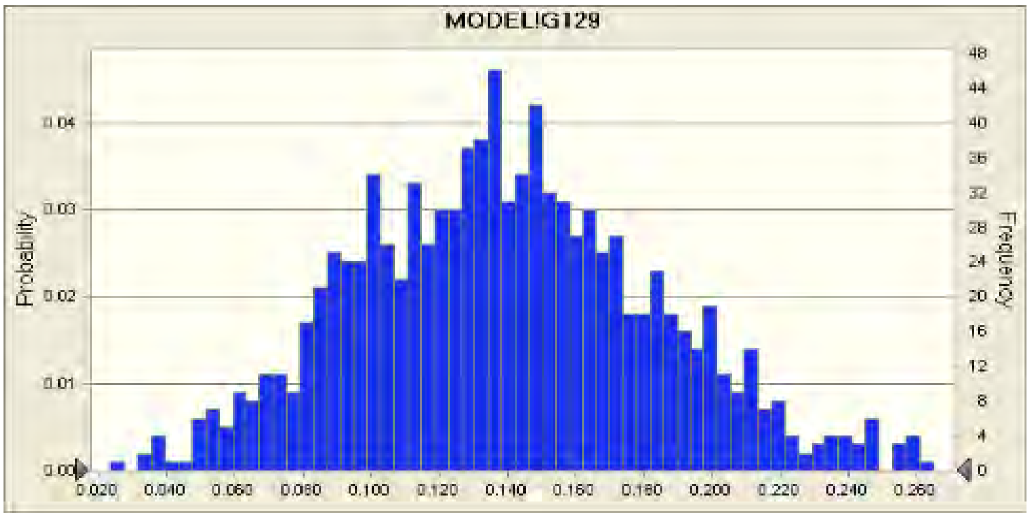
Statistics:	Forecast values
Trials	1,000
Base Case	2083.77
Mean	2194.09
Median	2141.43
Mode	---
Standard Deviation	883.51
Variance	780594.65
Skewness	0.1428
Kurtosis	2.39
Coeff. of Variability	0.4027
Minimum	182.13
Maximum	4570.01
Range Width	4387.88
Mean Std. Error	27.94

Forecast: Average Year Monte Carlo (G22) (cont'd) **Cell: G22**

Percentiles:	Forecast values
0%	182.13
10%	1074.44
20%	1392.68
30%	1641.35
40%	1915.90
50%	2140.45
60%	2402.84
70%	2706.38
80%	3002.30
90%	3403.69
100%	4570.01

Forecast: G129 **Cell: G129**

Summary:
Entire range is from 0.024 to 0.296
Base case is 0.134
After 1,000 trials, the std. error of the mean is 0.001



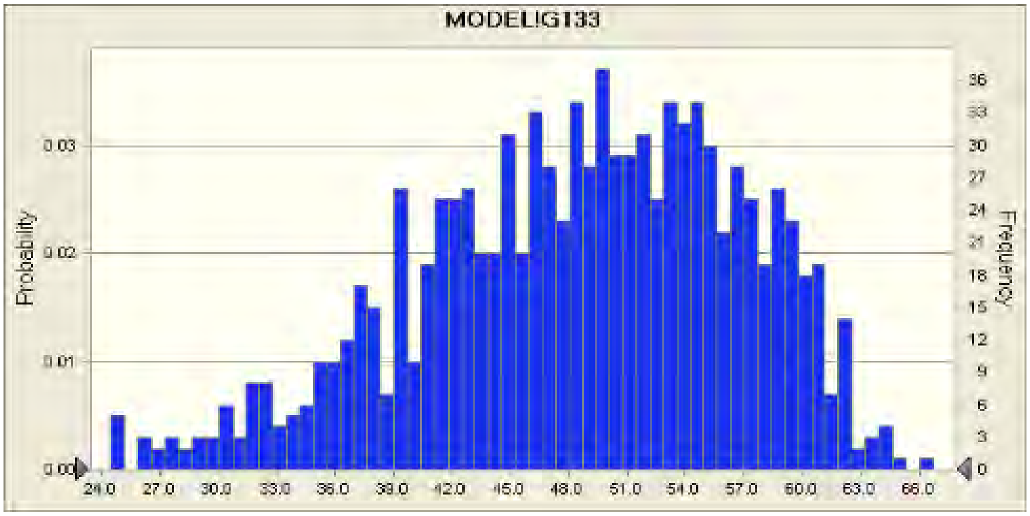
Statistics:	Forecast values
Trials	1,000
Base Case	0.134
Mean	0.140
Median	0.138
Mode	---
Standard Deviation	0.045
Variance	0.002
Skewness	0.2813
Kurtosis	3.00
Coeff. of Variability	0.3195
Minimum	0.024
Maximum	0.296
Range Width	0.272
Mean Std. Error	0.001

Forecast: G129 (cont'd) **Cell: G129**

Percentiles:	Forecast values
0%	0.024
10%	0.084
20%	0.100
30%	0.114
40%	0.128
50%	0.138
60%	0.148
70%	0.161
80%	0.176
90%	0.199
100%	0.296

Forecast: G133 **Cell: G133**

Summary:
Entire range is from 20.6 to 66.7
Base case is 48.7
After 1,000 trials, the std. error of the mean is 0.3



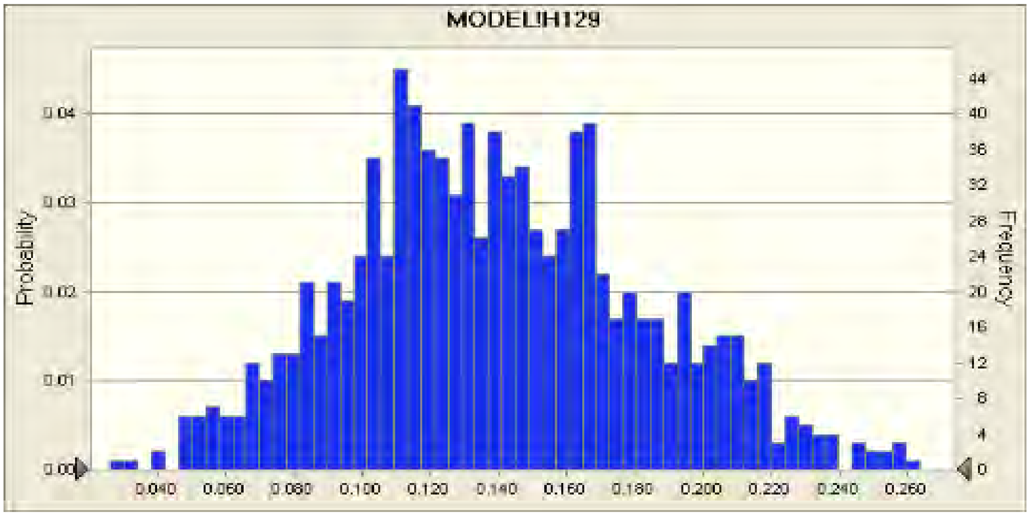
Statistics:	Forecast values
Trials	1,000
Base Case	48.7
Mean	48.3
Median	49.2
Mode	---
Standard Deviation	8.5
Variance	72.4
Skewness	-0.5289
Kurtosis	2.92
Coeff. of Variability	0.1761
Minimum	20.6
Maximum	66.7
Range Width	46.1
Mean Std. Error	0.3

Forecast: G133 (cont'd) **Cell: G133**

Percentiles:	Forecast values
0%	20.6
10%	36.9
20%	41.4
30%	44.3
40%	46.7
50%	49.2
60%	51.4
70%	53.7
80%	56.0
90%	58.8
100%	66.7

Forecast: H129 **Cell: H129**

Summary:
Entire range is from 0.027 to 0.297
Base case is 0.135
After 1,000 trials, the std. error of the mean is 0.001



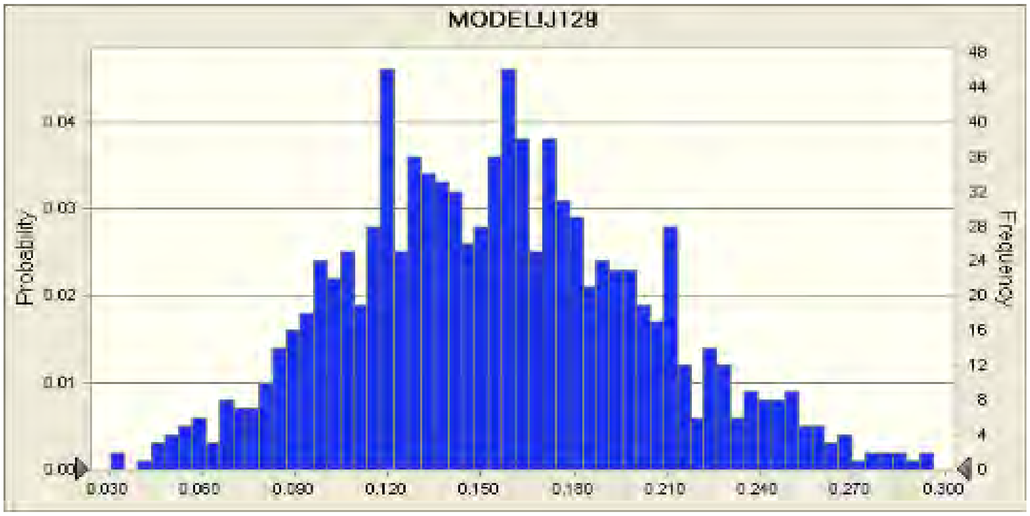
Statistics:	Forecast values
Trials	1,000
Base Case	0.135
Mean	0.141
Median	0.137
Mode	---
Standard Deviation	0.045
Variance	0.002
Skewness	0.4147
Kurtosis	3.17
Coeff. of Variability	0.3204
Minimum	0.027
Maximum	0.297
Range Width	0.271
Mean Std. Error	0.001

Forecast: H129 (cont'd) **Cell: H129**

Percentiles:	Forecast values
0%	0.027
10%	0.085
20%	0.103
30%	0.114
40%	0.125
50%	0.137
60%	0.149
70%	0.163
80%	0.177
90%	0.202
100%	0.297

Forecast: J129 **Cell: J129**

Summary:
Entire range is from 0.031 to 0.310
Base case is 0.152
After 1,000 trials, the std. error of the mean is 0.002



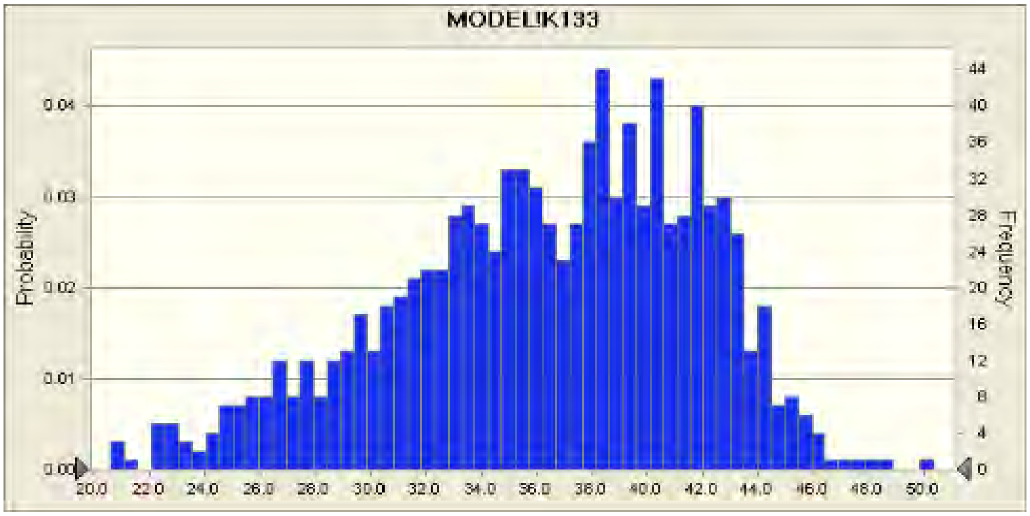
Statistics:	Forecast values
Trials	1,000
Base Case	0.152
Mean	0.156
Median	0.155
Mode	---
Standard Deviation	0.050
Variance	0.002
Skewness	0.3501
Kurtosis	3.03
Coeff. of Variability	0.3200
Minimum	0.031
Maximum	0.310
Range Width	0.279
Mean Std. Error	0.002

Forecast: J129 (cont'd) **Cell: J129**

Percentiles:	Forecast values
0%	0.031
10%	0.095
20%	0.114
30%	0.127
40%	0.140
50%	0.155
60%	0.165
70%	0.179
80%	0.197
90%	0.223
100%	0.310

Forecast: K133 **Cell: K133**

Summary:
Entire range is from 18.1 to 50.3
Base case is 36.4
After 1,000 trials, the std. error of the mean is 0.2



Statistics:	Forecast values
Trials	1,000
Base Case	36.4
Mean	36.2
Median	36.9
Mode	---
Standard Deviation	5.6
Variance	31.1
Skewness	-0.5398
Kurtosis	2.85
Coeff. of Variability	0.1539
Minimum	18.1
Maximum	50.3
Range Width	32.2
Mean Std. Error	0.2

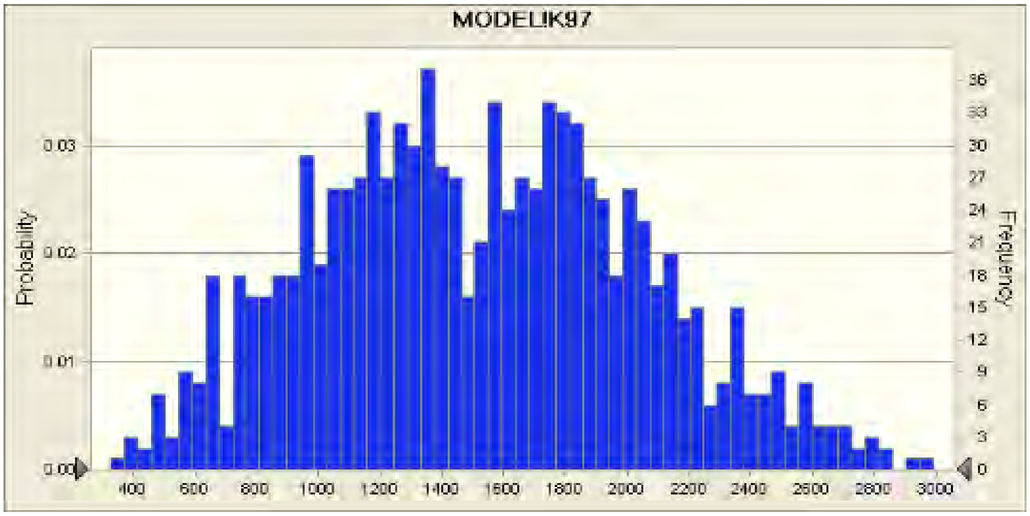
Forecast: K133 (cont'd)

Cell: K133

Percentiles:	Forecast values
0%	18.1
10%	28.4
20%	31.6
30%	33.6
40%	35.3
50%	36.9
60%	38.4
70%	39.8
80%	41.3
90%	42.8
100%	50.3

Forecast: K97 **Cell: K97**

Summary:
Entire range is from 329 to 3078
Base case is 1447
After 1,000 trials, the std. error of the mean is 17



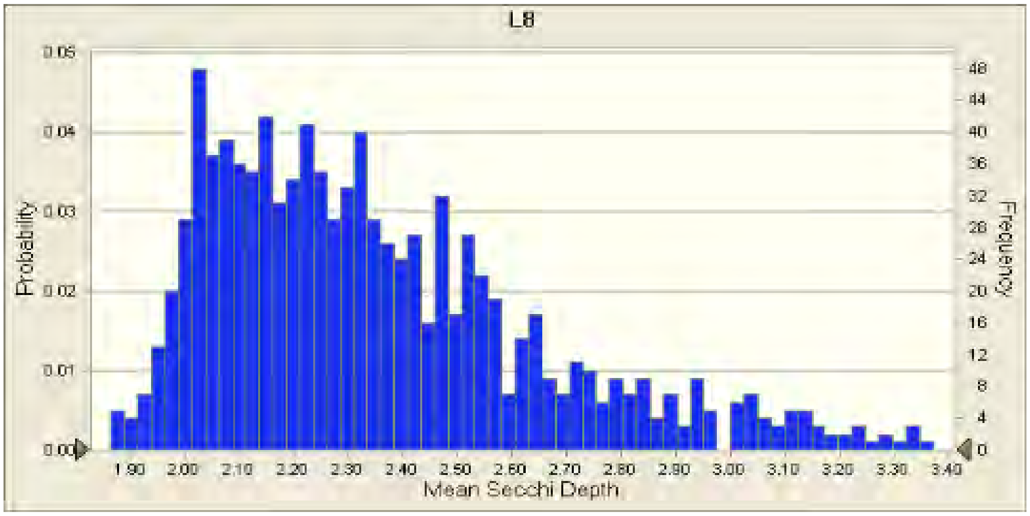
Statistics:	Forecast values
Trials	1,000
Base Case	1447
Mean	1522
Median	1512
Mode	---
Standard Deviation	524
Variance	274571
Skewness	0.1808
Kurtosis	2.47
Coeff. of Variability	0.3442
Minimum	329
Maximum	3078
Range Width	2749
Mean Std. Error	17

Forecast: K97 (cont'd) **Cell: K97**

Percentiles:	Forecast values
0%	329
10%	841
20%	1041
30%	1199
40%	1342
50%	1509
60%	1673
70%	1814
80%	1987
90%	2205
100%	3078

Forecast: L8 **Cell: M70**

Summary:
Entire range is from 1.86 to 4.14
Base case is 2.30
After 1,000 trials, the std. error of the mean is 0.01



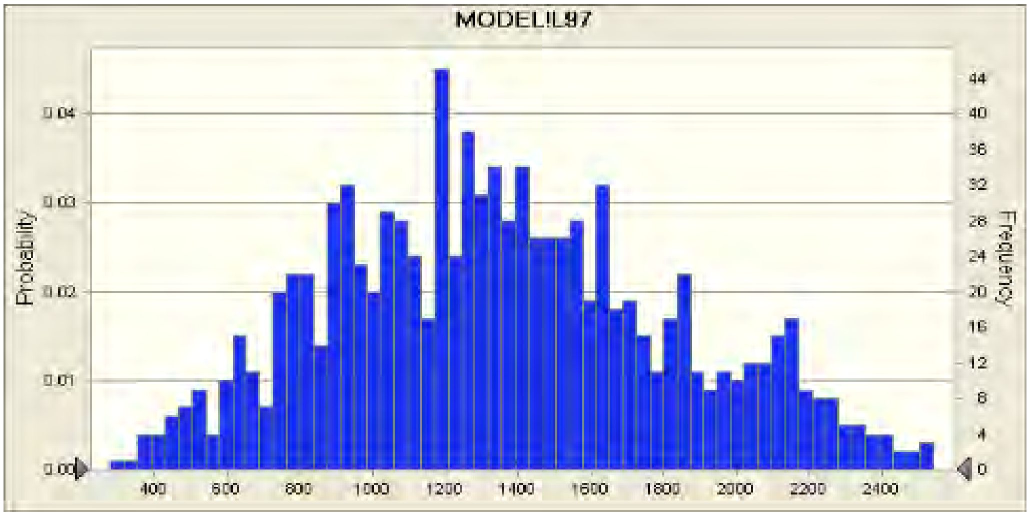
Statistics:	Forecast values
Trials	1,000
Base Case	2.30
Mean	2.38
Median	2.29
Mode	---
Standard Deviation	0.36
Variance	0.13
Skewness	1.55
Kurtosis	6.10
Coeff. of Variability	0.1496
Minimum	1.86
Maximum	4.14
Range Width	2.27
Mean Std. Error	0.01

Forecast: L8 (cont'd) **Cell: M70**

Percentiles:	Forecast values
0%	1.86
10%	2.02
20%	2.09
30%	2.15
40%	2.22
50%	2.29
60%	2.37
70%	2.47
80%	2.60
90%	2.84
100%	4.14

Forecast: L97 **Cell: L97**

Summary:
Entire range is from 281 to 2540
Base case is 1286
After 1,000 trials, the std. error of the mean is 15



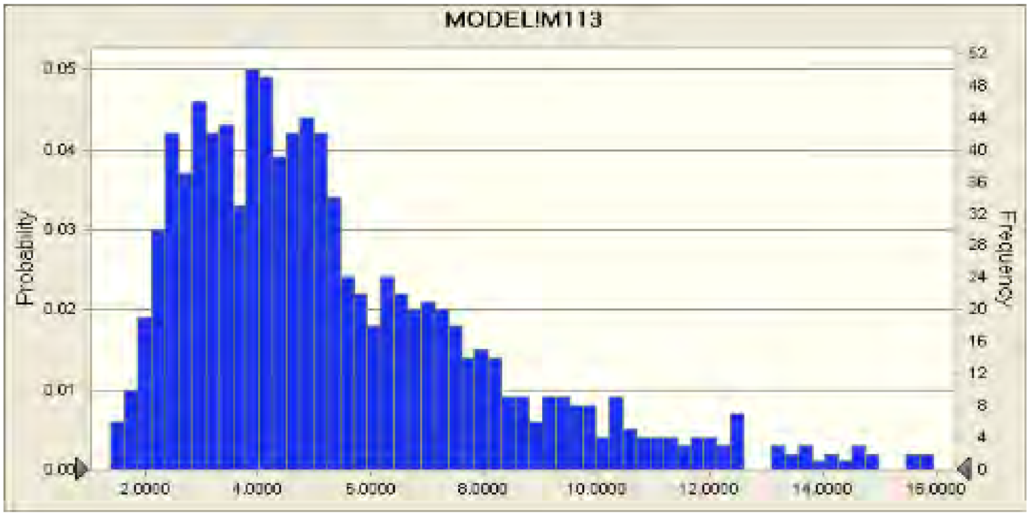
Statistics:	Forecast values
Trials	1,000
Base Case	1286
Mean	1349
Median	1320
Mode	---
Standard Deviation	466
Variance	217504
Skewness	0.2351
Kurtosis	2.47
Coeff. of Variability	0.3456
Minimum	281
Maximum	2540
Range Width	2259
Mean Std. Error	15

Forecast: L97 (cont'd) **Cell: L97**

Percentiles:	Forecast values
0%	281
10%	763
20%	926
30%	1067
40%	1199
50%	1320
60%	1440
70%	1576
80%	1757
90%	2039
100%	2540

Forecast: M113 **Cell: M113**

Summary:
Entire range is from 1.4108 to 27.2616
Base case is 4.9349
After 1,000 trials, the std. error of the mean is 0.1145



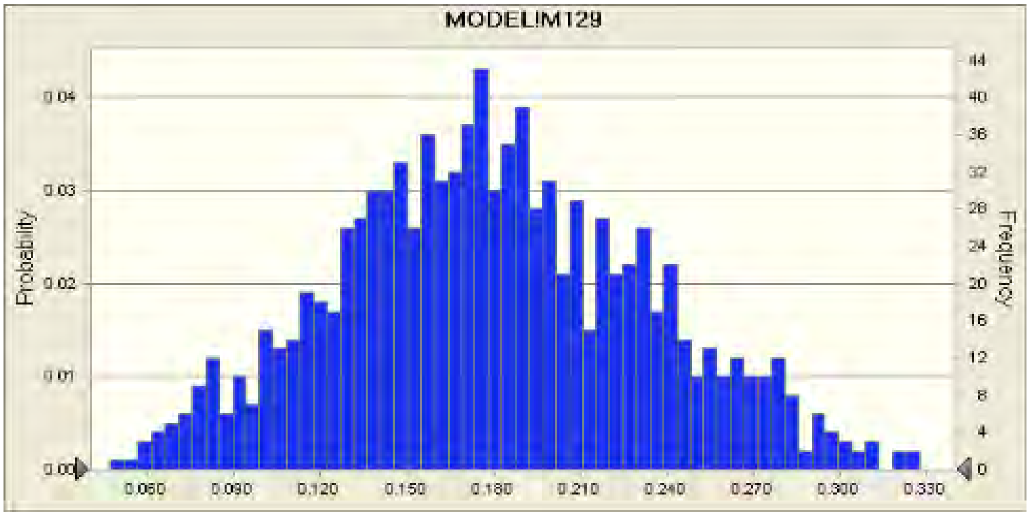
Statistics:	Forecast values
Trials	1,000
Base Case	4.9349
Mean	5.8023
Median	4.7928
Mode	---
Standard Deviation	3.6218
Variance	13.1176
Skewness	2.09
Kurtosis	8.67
Coeff. of Variability	0.6242
Minimum	1.4108
Maximum	27.2616
Range Width	25.8509
Mean Std. Error	0.1145

Forecast: M113 (cont'd) **Cell: M113**

Percentiles:	Forecast values
0%	1.4108
10%	2.5538
20%	3.1199
30%	3.7428
40%	4.2323
50%	4.7914
60%	5.3949
70%	6.4531
80%	7.6393
90%	10.1074
100%	27.2616

Forecast: M129 **Cell: M129**

Summary:
Entire range is from 0.048 to 0.348
Base case is 0.173
After 1,000 trials, the std. error of the mean is 0.002



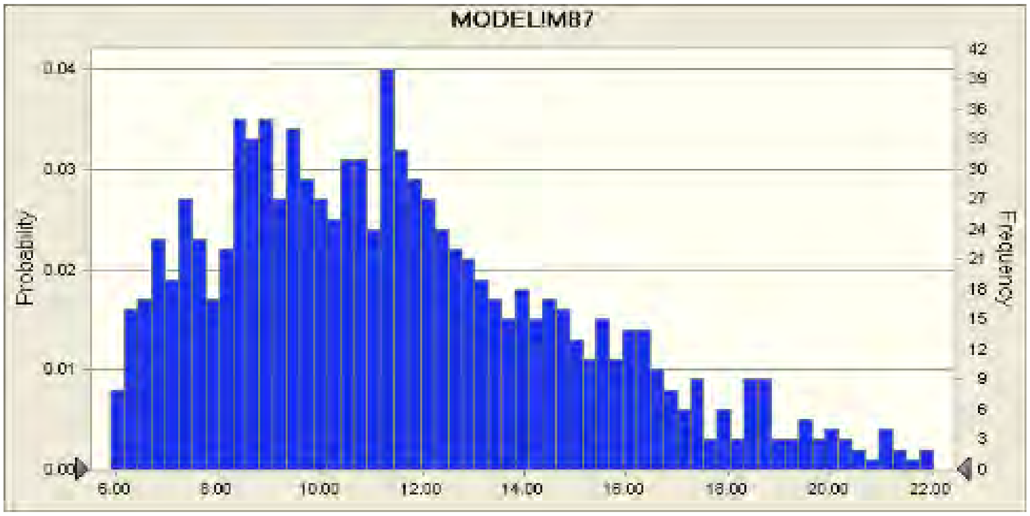
Statistics:	Forecast values
Trials	1,000
Base Case	0.173
Mean	0.180
Median	0.177
Mode	---
Standard Deviation	0.054
Variance	0.003
Skewness	0.1992
Kurtosis	2.74
Coeff. of Variability	0.3020
Minimum	0.048
Maximum	0.348
Range Width	0.300
Mean Std. Error	0.002

Forecast: M129 (cont'd) **Cell: M129**

Percentiles:	Forecast values
0%	0.048
10%	0.110
20%	0.133
30%	0.149
40%	0.164
50%	0.177
60%	0.191
70%	0.207
80%	0.228
90%	0.253
100%	0.348

Forecast: M87 **Cell: M87**

Summary:
Entire range is from 5.89 to 27.40
Base case is 10.93
After 1,000 trials, the std. error of the mean is 0.12



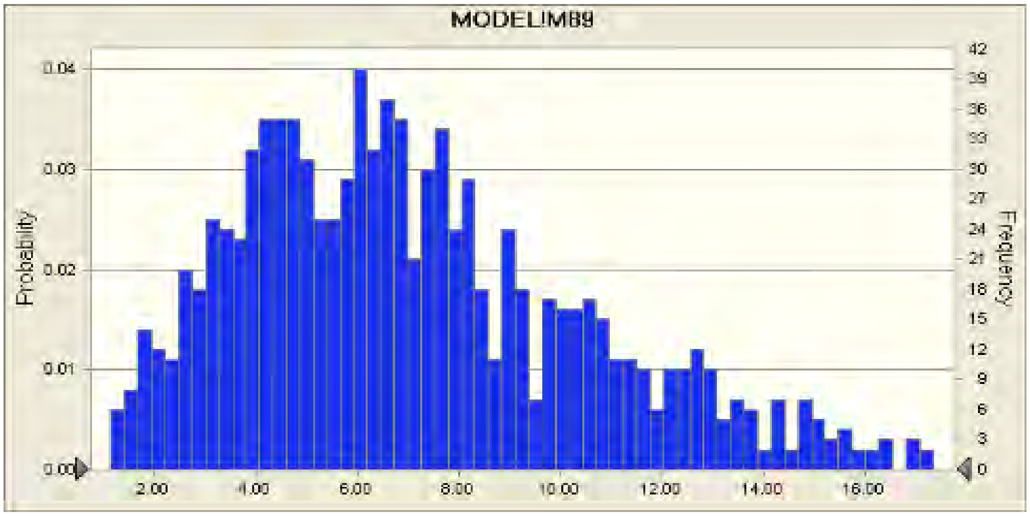
Statistics:	Forecast values
Trials	1,000
Base Case	10.93
Mean	11.67
Median	11.11
Mode	---
Standard Deviation	3.69
Variance	13.63
Skewness	0.9261
Kurtosis	3.92
Coeff. of Variability	0.3163
Minimum	5.89
Maximum	27.40
Range Width	21.51
Mean Std. Error	0.12

Forecast: M87 (cont'd) **Cell: M87**

Percentiles:	Forecast values
0%	5.89
10%	7.37
20%	8.48
30%	9.30
40%	10.21
50%	11.10
60%	11.86
70%	13.04
80%	14.62
90%	16.61
100%	27.40

Forecast: M89 **Cell: M89**

Summary:
Entire range is from 1.16 to 22.43
Base case is 6.41
After 1,000 trials, the std. error of the mean is 0.11



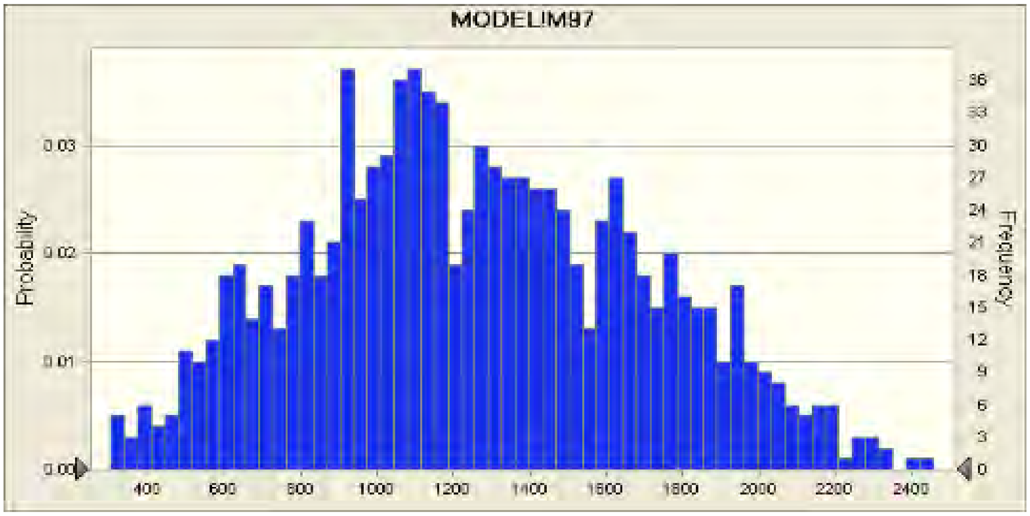
Statistics:	Forecast values
Trials	1,000
Base Case	6.41
Mean	7.22
Median	6.60
Mode	---
Standard Deviation	3.61
Variance	13.04
Skewness	0.9076
Kurtosis	3.85
Coeff. of Variability	0.5005
Minimum	1.16
Maximum	22.43
Range Width	21.27
Mean Std. Error	0.11

Forecast: M89 (cont'd) **Cell: M89**

Percentiles:	Forecast values
0%	1.16
10%	3.13
20%	4.12
30%	4.90
40%	5.86
50%	6.60
60%	7.47
70%	8.45
80%	10.12
90%	12.33
100%	22.43

Forecast: M97 **Cell: M97**

Summary:
Entire range is from 303 to 2455
Base case is 1205
After 1,000 trials, the std. error of the mean is 14



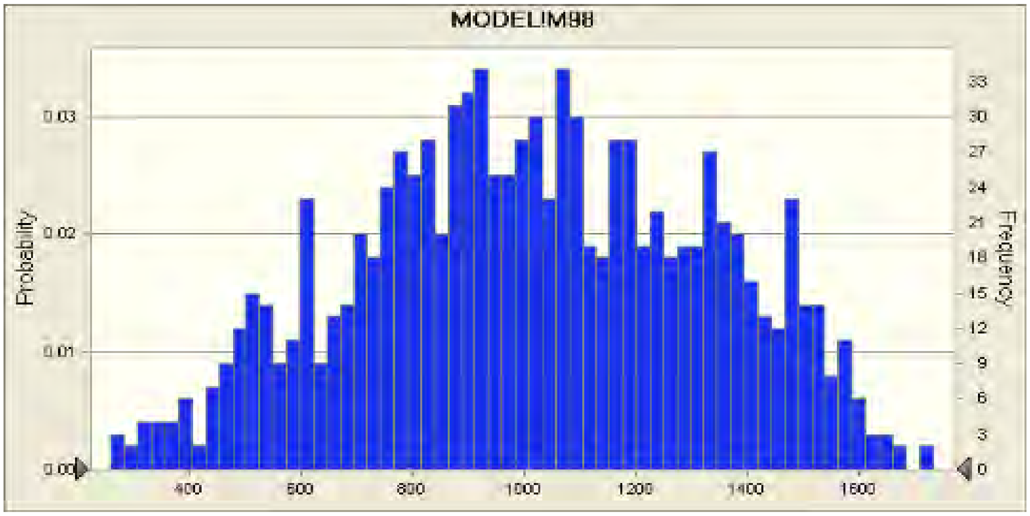
Statistics:	Forecast values
Trials	1,000
Base Case	1205
Mean	1256
Median	1221
Mode	---
Standard Deviation	438
Variance	191981
Skewness	0.1839
Kurtosis	2.40
Coeff. of Variability	0.3489
Minimum	303
Maximum	2455
Range Width	2152
Mean Std. Error	14

Forecast: M97 (cont'd) **Cell: M97**

Percentiles:	Forecast values
0%	303
10%	679
20%	873
30%	999
40%	1106
50%	1221
60%	1353
70%	1486
80%	1651
90%	1859
100%	2455

Forecast: M98 **Cell: M98**

Summary:
Entire range is from 260 to 1731
Base case is 997
After 1,000 trials, the std. error of the mean is 10



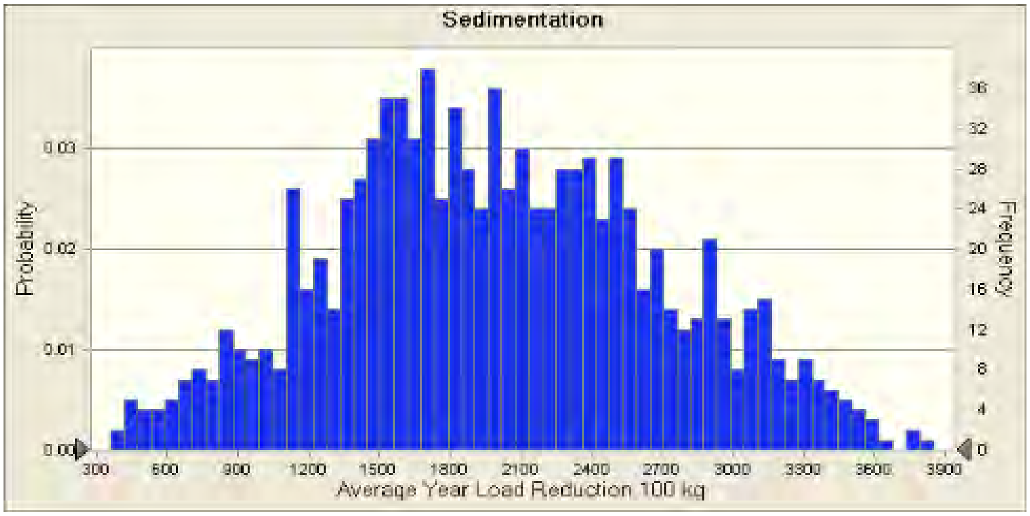
Statistics:	Forecast values
Trials	1,000
Base Case	997
Mean	1013
Median	1011
Mode	---
Standard Deviation	310
Variance	96133
Skewness	-0.0678
Kurtosis	2.30
Coeff. of Variability	0.3061
Minimum	260
Maximum	1731
Range Width	1471
Mean Std. Error	10

Forecast: M98 (cont'd) **Cell: M98**

Percentiles:	Forecast values
0%	260
10%	593
20%	743
30%	836
40%	924
50%	1011
60%	1093
70%	1197
80%	1314
90%	1440
100%	1731

Forecast: Sedimentation **Cell: H98**

Summary:
Entire range is from 363 to 3845
Base case is 1965
After 1,000 trials, the std. error of the mean is 22



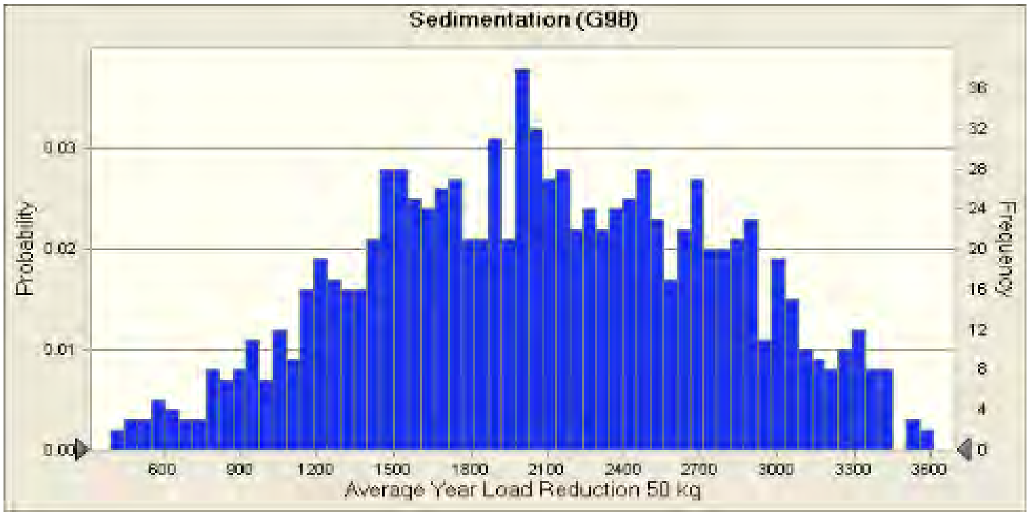
Statistics:	Forecast values
Trials	1,000
Base Case	1965
Mean	1994
Median	1965
Mode	---
Standard Deviation	693
Variance	480519
Skewness	0.1291
Kurtosis	2.50
Coeff. of Variability	0.3476
Minimum	363
Maximum	3845
Range Width	3482
Mean Std. Error	22

Forecast: Sedimentation (cont'd) **Cell: H98**

Percentiles:	Forecast values
0%	363
10%	1130
20%	1399
30%	1592
40%	1764
50%	1962
60%	2148
70%	2376
80%	2588
90%	2942
100%	3845

Forecast: Sedimentation (G98) **Cell: G98**

Summary:
Entire range is from 395 to 3607
Base case is 2019
After 1,000 trials, the std. error of the mean is 22



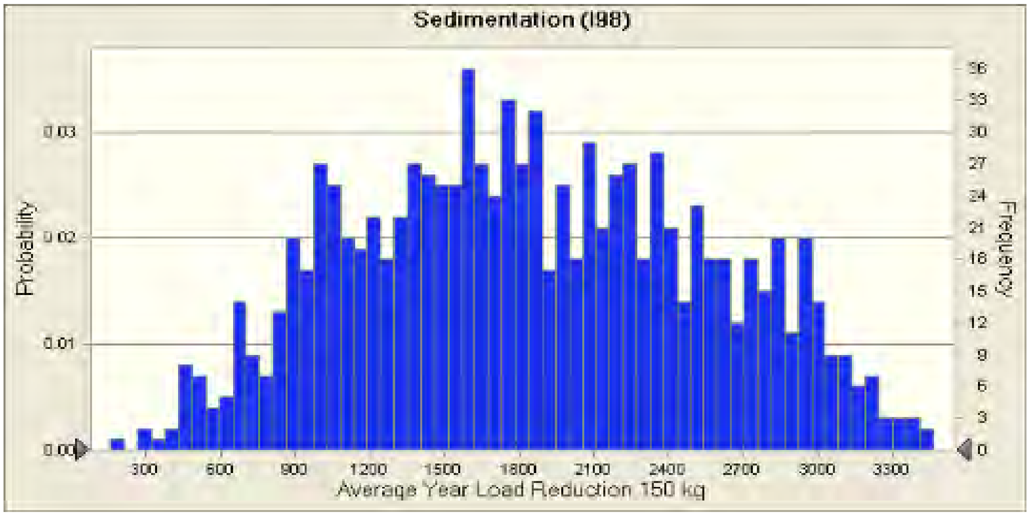
Statistics:	Forecast values
Trials	1,000
Base Case	2019
Mean	2072
Median	2062
Mode	---
Standard Deviation	680
Variance	462761
Skewness	-0.0523
Kurtosis	2.32
Coeff. of Variability	0.3282
Minimum	395
Maximum	3607
Range Width	3212
Mean Std. Error	22

Forecast: Sedimentation (G98) (cont'd) **Cell: G98**

Percentiles:	Forecast values
0%	395
10%	1173
20%	1465
30%	1667
40%	1894
50%	2062
60%	2269
70%	2480
80%	2703
90%	2984
100%	3607

Forecast: Sedimentation (I98) **Cell: I98**

Summary:
Entire range is from 160 to 3462
Base case is 1822
After 1,000 trials, the std. error of the mean is 22



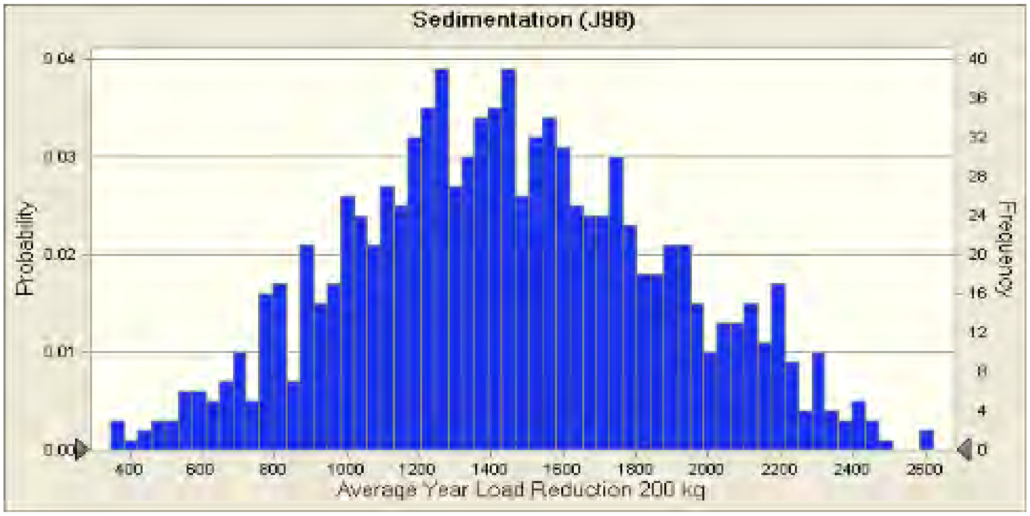
Statistics:	Forecast values
Trials	1,000
Base Case	1822
Mean	1848
Median	1809
Mode	---
Standard Deviation	697
Variance	485728
Skewness	0.0778
Kurtosis	2.20
Coeff. of Variability	0.3771
Minimum	160
Maximum	3462
Range Width	3302
Mean Std. Error	22

Forecast: Sedimentation (I98) (cont'd) **Cell: I98**

Percentiles:	Forecast values
0%	160
10%	946
20%	1182
30%	1431
40%	1615
50%	1809
60%	2037
70%	2257
80%	2505
90%	2836
100%	3462

Forecast: Sedimentation (J98) **Cell: J98**

Summary:
Entire range is from 349 to 2621
Base case is 1427
After 1,000 trials, the std. error of the mean is 14



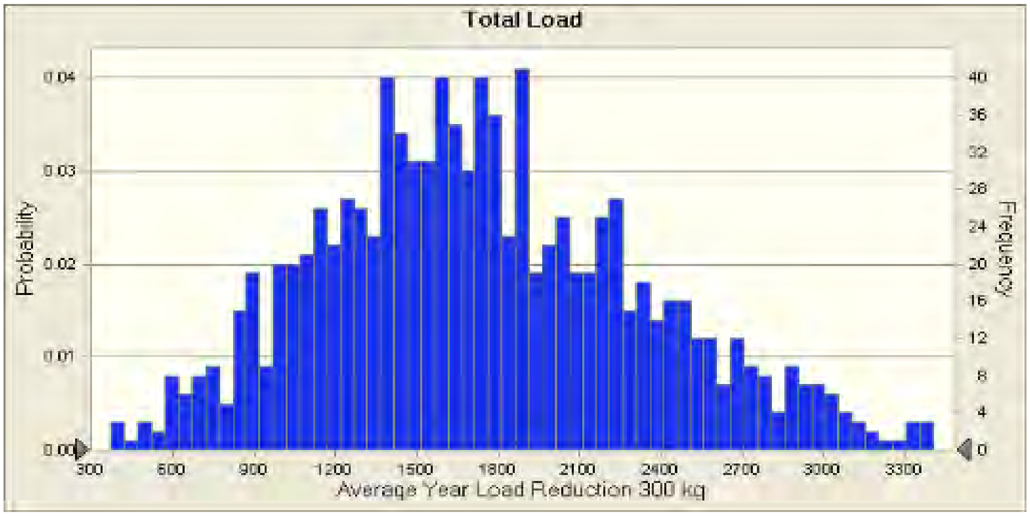
Statistics:	Forecast values
Trials	1,000
Base Case	1427
Mean	1446
Median	1430
Mode	---
Standard Deviation	434
Variance	188785
Skewness	0.0875
Kurtosis	2.55
Coeff. of Variability	0.3005
Minimum	349
Maximum	2621
Range Width	2271
Mean Std. Error	14

Forecast: Sedimentation (J98) (cont'd) **Cell: J98**

Percentiles:	Forecast values
0%	349
10%	888
20%	1065
30%	1207
40%	1317
50%	1430
60%	1546
70%	1672
80%	1823
90%	2048
100%	2621

Forecast: Total Load **Cell: J97**

Summary:
Entire range is from 374 to 3505
Base case is 1683
After 1,000 trials, the std. error of the mean is 19



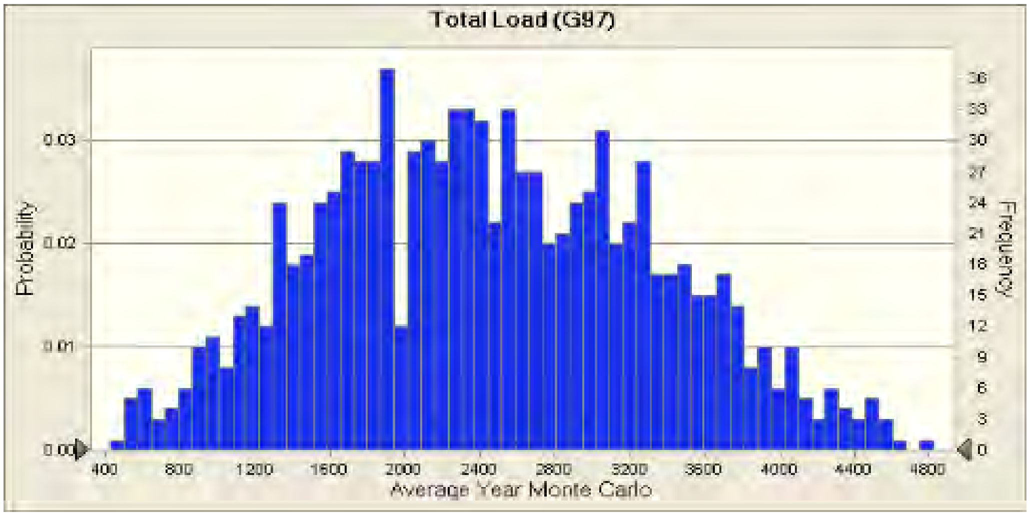
Statistics:	Forecast values
Trials	1,000
Base Case	1683
Mean	1739
Median	1694
Mode	---
Standard Deviation	594
Variance	352994
Skewness	0.3299
Kurtosis	2.73
Coeff. of Variability	0.3416
Minimum	374
Maximum	3505
Range Width	3130
Mean Std. Error	19

Forecast: Total Load (cont'd) **Cell: J97**

Percentiles:	Forecast values
0%	374
10%	1002
20%	1226
30%	1397
40%	1556
50%	1694
60%	1836
70%	2033
80%	2243
90%	2543
100%	3505

Forecast: Total Load (G97) **Cell: G97**

Summary:
Entire range is from 430 to 4816
Base case is 2331
After 1,000 trials, the std. error of the mean is 28



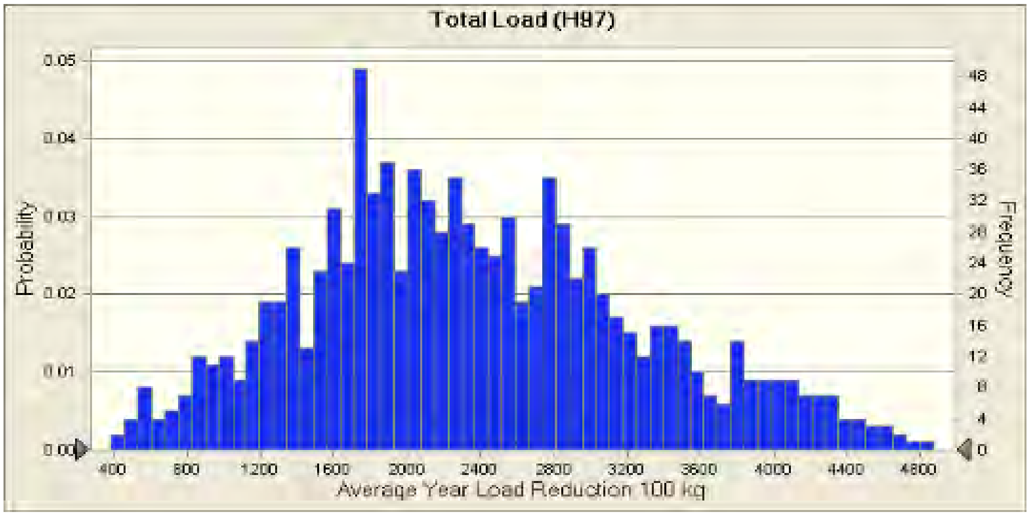
Statistics:	Forecast values
Trials	1,000
Base Case	2331
Mean	2442
Median	2389
Mode	---
Standard Deviation	883
Variance	780548
Skewness	0.1428
Kurtosis	2.39
Coeff. of Variability	0.3618
Minimum	430
Maximum	4816
Range Width	4386
Mean Std. Error	28

Forecast: Total Load (G97) (cont'd) **Cell: G97**

Percentiles:	Forecast values
0%	430
10%	1324
20%	1640
30%	1888
40%	2164
50%	2387
60%	2650
70%	2954
80%	3250
90%	3651
100%	4816

Forecast: Total Load (H97) **Cell: H97**

Summary:
Entire range is from 385 to 4867
Base case is 2272
After 1,000 trials, the std. error of the mean is 29



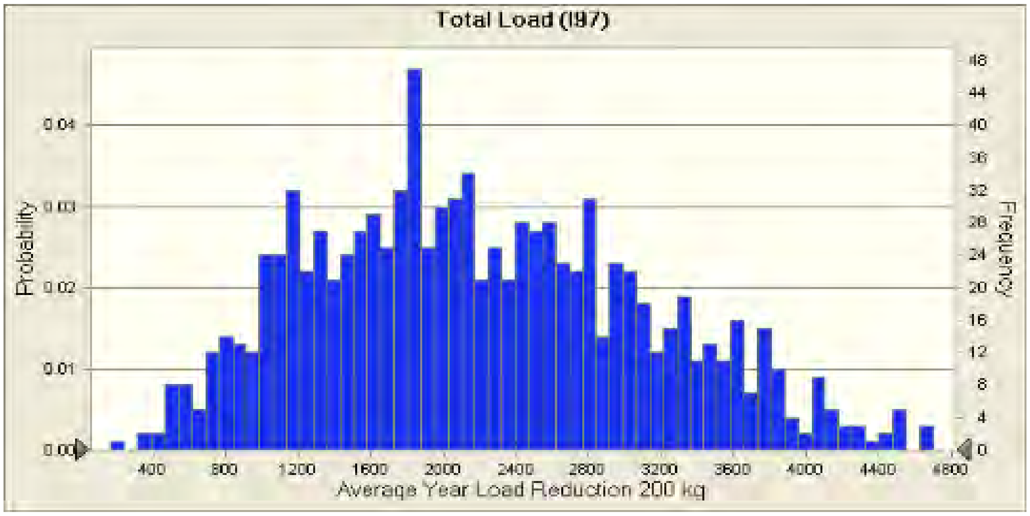
Statistics:	Forecast values
Trials	1,000
Base Case	2272
Mean	2356
Median	2273
Mode	---
Standard Deviation	907
Variance	823265
Skewness	0.3409
Kurtosis	2.62
Coeff. of Variability	0.3851
Minimum	385
Maximum	4867
Range Width	4481
Mean Std. Error	29

Forecast: Total Load (H97) (cont'd) **Cell: H97**

Percentiles:	Forecast values
0%	385
10%	1244
20%	1583
30%	1794
40%	2027
50%	2272
60%	2521
70%	2809
80%	3132
90%	3629
100%	4867

Forecast: Total Load (I97) **Cell: I97**

Summary:
Entire range is from 168 to 4697
Base case is 2116
After 1,000 trials, the std. error of the mean is 29



Statistics:	Forecast values
Trials	1,000
Base Case	2116
Mean	2196
Median	2107
Mode	---
Standard Deviation	912
Variance	831878
Skewness	0.3168
Kurtosis	2.45
Coeff. of Variability	0.4153
Minimum	168
Maximum	4697
Range Width	4529
Mean Std. Error	29

Forecast: Total Load (I97) (cont'd) **Cell: I97**

Percentiles:	Forecast values
0%	168
10%	1054
20%	1335
30%	1639
40%	1844
50%	2106
60%	2398
70%	2677
80%	3005
90%	3492
100%	4697

End of Forecasts

Assumptions

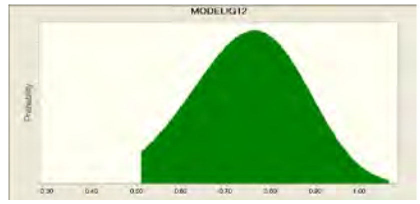
Worksheet: [CNET_Diamond_Lake_September1_2010.xls]MODEL

Assumption: G12 **Cell: G12**

Weibull distribution with parameters:

Location	0.22
Scale	0.57
Shape	4.6750019

Selected range is from 0.51 to Infinity



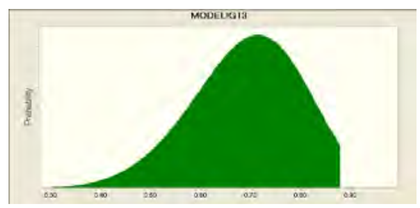
Correlated with:	Coefficient
G21 (G21)	0.74
G24 (G24)	0.56
G13 (G13)	0.19
G23 (G23)	0.56

Assumption: G13 **Cell: G13**

Weibull distribution with parameters:

Location	0.21
Scale	0.52
Shape	4.865325151

Selected range is from 0.30 to 0.88



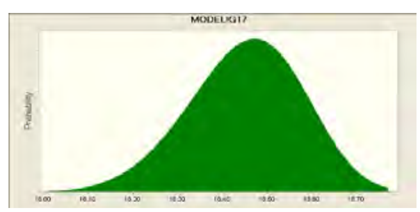
Correlated with:	Coefficient
G12 (G12)	0.19

Assumption: G17 **Cell: G17**

Weibull distribution with parameters:

Location	17.93
Scale	0.57
Shape	4.675

Selected range is from 18.01 to 18.77

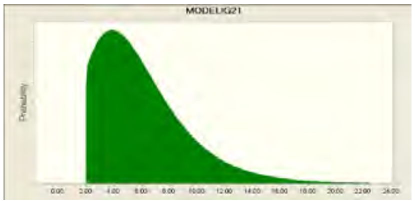


Assumption: G21 **Cell: G21**

Lognormal distribution with parameters:

Location	-3.67	
Mean	5.58	(='SWAT Total Surface Inflow'!$B$41)
Std. Dev.	3.55	

Selected range is from 2.00 to 22.42



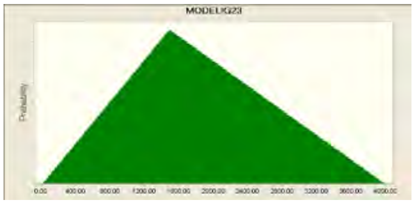
Correlated with:	Coefficient
G23 (G23)	0.89
G12 (G12)	0.74

Assumption: G23 **Cell: G23**

Triangular distribution with parameters:

Minimum	19.27	(='SWAT Total TP Surface Inflow'!$C$41)
Likeliest	1490.23	(='SWAT Total TP Surface Inflow'!$C$40)
Maximum	3986.65	(='SWAT Total TP Surface Inflow'!$C$42)

Selected range is from 19.27 to 3986.65

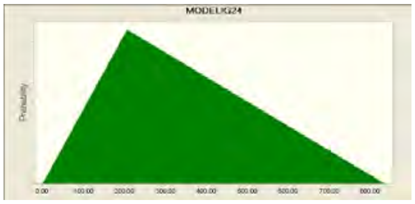


Correlated with:	Coefficient
G21 (G21)	0.89
G12 (G12)	0.56

Assumption: G24 **Cell: G24**

Triangular distribution with parameters:

Minimum	0.00	
Likeliest	206.00	(='Internal Loads from RCWD'!E42)
Maximum	834.67	(='Internal Loads from RCWD'!F44)



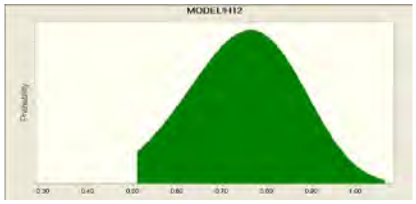
Correlated with:	Coefficient
G12 (G12)	0.56

Assumption: H12 **Cell: H12**

Weibull distribution with parameters:

Location	0.22
Scale	0.57
Shape	4.6750019

Selected range is from 0.51 to Infinity



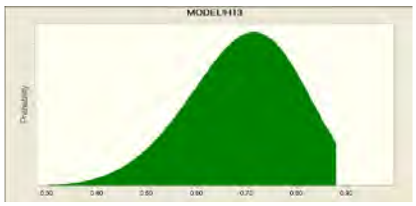
Correlated with:	Coefficient
H24 (H24)	0.56
H21 (H21)	0.74
H13 (H13)	0.19
H23 (H23)	0.56

Assumption: H13 **Cell: H13**

Weibull distribution with parameters:

Location	0.21
Scale	0.52
Shape	4.865325151

Selected range is from 0.30 to 0.88



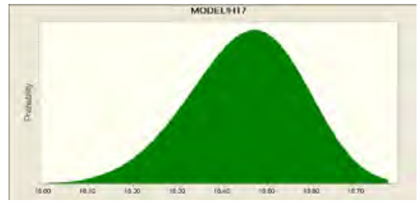
Correlated with:	Coefficient
H12 (H12)	0.19

Assumption: H17 **Cell: H17**

Weibull distribution with parameters:

Location	17.93
Scale	0.57
Shape	4.675

Selected range is from 18.01 to 18.77

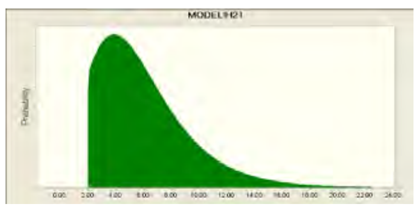


Assumption: H21 **Cell: H21**

Lognormal distribution with parameters:

Location	-3.67	
Mean	5.58	(='SWAT Total Surface Inflow'!$B$41)
Std. Dev.	3.55	

Selected range is from 2.00 to 22.42



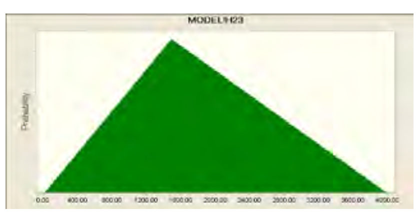
Correlated with:	Coefficient
H12 (H12)	0.74
H23 (H23)	0.89

Assumption: H23 **Cell: H23**

Triangular distribution with parameters:

Minimum	19.27	(='SWAT Total TP Surface Inflow'!$C$41)
Likeliest	1490.23	(='SWAT Total TP Surface Inflow'!$C$40)
Maximum	3986.65	(='SWAT Total TP Surface Inflow'!$C$42)

Selected range is from 19.27 to 3986.65



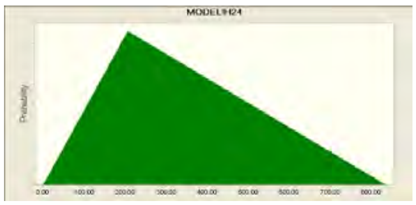
Assumption: H23 (cont'd) **Cell: H23**

Correlated with:	Coefficient
H21 (H21)	0.89
H12 (H12)	0.56

Assumption: H24 **Cell: H24**

Triangular distribution with parameters:

Minimum	0.00	
Likeliest	206.00	(='Internal Loads from RCWD'!E42)
Maximum	834.67	(='Internal Loads from RCWD'!F44)



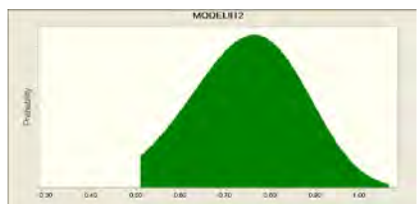
Correlated with:	Coefficient
H12 (H12)	0.56

Assumption: I12 **Cell: I12**

Weibull distribution with parameters:

Location	0.22
Scale	0.57
Shape	4.6750019

Selected range is from 0.51 to Infinity



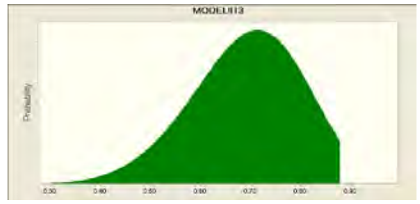
Correlated with:	Coefficient
I24 (I24)	0.56
I23 (I23)	0.56
I21 (I21)	0.74
I13 (I13)	0.19

Assumption: I13 **Cell: I13**

Weibull distribution with parameters:

Location	0.21
Scale	0.52
Shape	4.865325151

Selected range is from 0.30 to 0.88



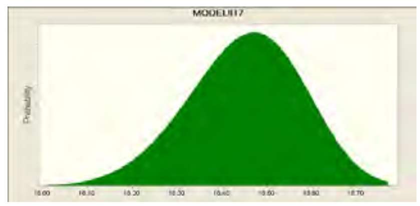
Correlated with:	Coefficient
I12 (I12)	0.19

Assumption: I17 **Cell: I17**

Weibull distribution with parameters:

Location	17.93
Scale	0.57
Shape	4.675

Selected range is from 18.01 to 18.77

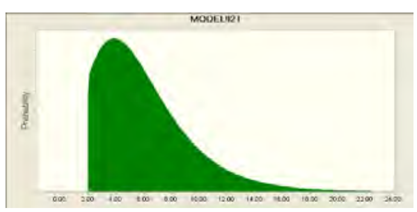


Assumption: I21 **Cell: I21**

Lognormal distribution with parameters:

Location	-3.67	
Mean	5.58	(='SWAT Total Surface Inflow'!$B$41)
Std. Dev.	3.55	

Selected range is from 2.00 to 22.42



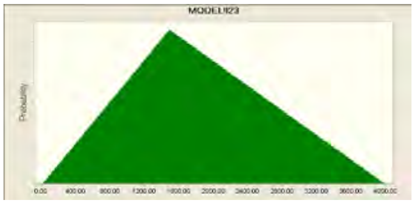
Correlated with:	Coefficient
I12 (I12)	0.74
I23 (I23)	0.89

Assumption: I23 **Cell: I23**

Triangular distribution with parameters:

Minimum	19.27	(='SWAT Total TP Surface Inflow'!$C$41)
Likeliest	1490.23	(='SWAT Total TP Surface Inflow'!$C$40)
Maximum	3986.65	(='SWAT Total TP Surface Inflow'!C42)

Selected range is from 19.27 to 3986.65

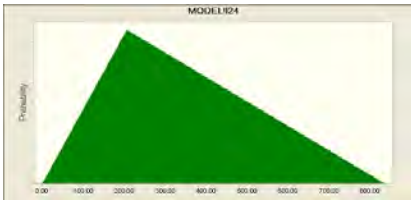


Correlated with:	Coefficient
I12 (I12)	0.56
I21 (I21)	0.89

Assumption: I24 **Cell: I24**

Triangular distribution with parameters:

Minimum	0.00	
Likeliest	206.00	(='Internal Loads from RCWD'!E42)
Maximum	834.67	(='Internal Loads from RCWD'!F44)



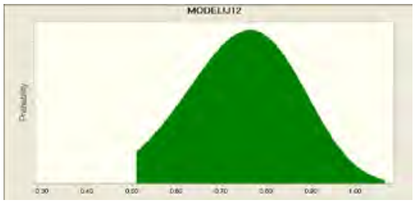
Correlated with:	Coefficient
I12 (I12)	0.56

Assumption: J12 **Cell: J12**

Weibull distribution with parameters:

Location	0.22
Scale	0.57
Shape	4.6750019

Selected range is from 0.51 to Infinity



Assumption: J12 (cont'd) **Cell: J12**

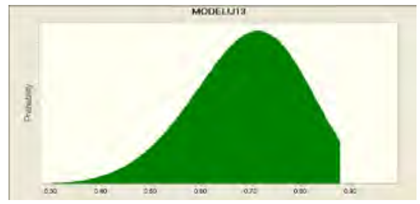
Correlated with:	Coefficient
J21 (J21)	0.74
J23 (J23)	0.56
J24 (J24)	0.56
J13 (J13)	0.19

Assumption: J13 **Cell: J13**

Weibull distribution with parameters:

Location	0.21
Scale	0.52
Shape	4.865325151

Selected range is from 0.30 to 0.88



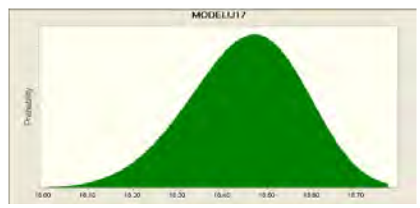
Correlated with:	Coefficient
J12 (J12)	0.19

Assumption: J17 **Cell: J17**

Weibull distribution with parameters:

Location	17.93
Scale	0.57
Shape	4.675

Selected range is from 18.01 to 18.77



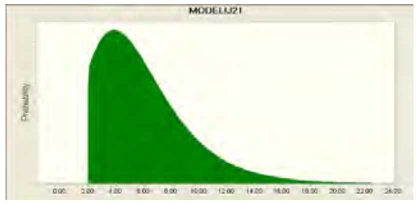
Assumption: J21 **Cell: J21**

Lognormal distribution with parameters:

Location	-3.67	
Mean	5.58	(='SWAT Total Surface Inflow'!$B$41)
Std. Dev.	3.55	

Selected range is from 2.00 to 22.42

Assumption: J21 (cont'd) **Cell: J21**



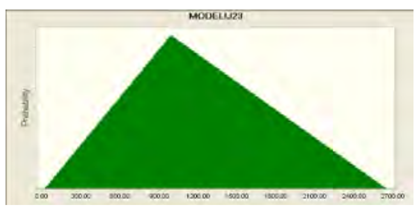
Correlated with:	Coefficient
J23 (J23)	0.89
J12 (J12)	0.74

Assumption: J23 **Cell: J23**

Triangular distribution with parameters:

Minimum	19.27	(='SWAT Total TP Surface Inflow'!$C$41)
Likeliest	990.23	(='SWAT Total TP Surface Inflow'!J54)
Maximum	2649.06	(='SWAT Total TP Surface Inflow'!K54)

Selected range is from 19.27 to 2649.06



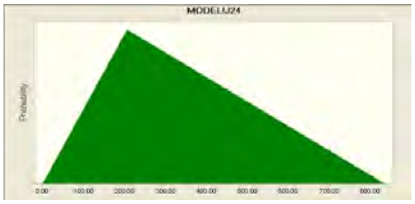
Correlated with:	Coefficient
J21 (J21)	0.89
J12 (J12)	0.56

Assumption: J24 **Cell: J24**

Triangular distribution with parameters:

Minimum	0.00	
Likeliest	206.00	(='Internal Loads from RCWD'!E42)
Maximum	834.67	(='Internal Loads from RCWD'!F44)

Assumption: J24 (cont'd) **Cell: J24**



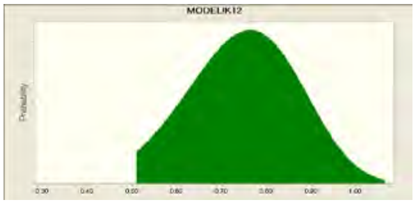
Correlated with:	Coefficient
J12 (J12)	0.56

Assumption: K12 **Cell: K12**

Weibull distribution with parameters:

Location	0.22
Scale	0.57
Shape	4.6750019

Selected range is from 0.51 to Infinity



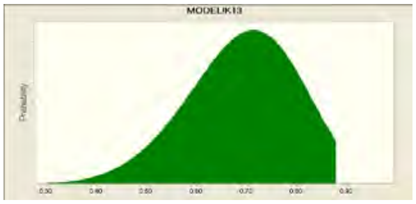
Correlated with:	Coefficient
K13 (K13)	0.19
K24 (K24)	0.56
K23 (K23)	0.56
K21 (K21)	0.74

Assumption: K13 **Cell: K13**

Weibull distribution with parameters:

Location	0.21
Scale	0.52
Shape	4.865325151

Selected range is from 0.30 to 0.88



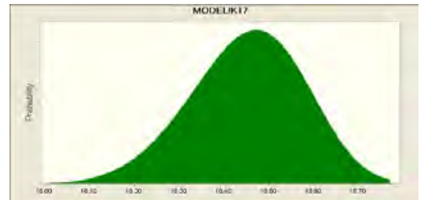
Correlated with:	Coefficient
K12 (K12)	0.19

Assumption: K17 **Cell: K17**

Weibull distribution with parameters:

Location	17.93
Scale	0.57
Shape	4.675

Selected range is from 18.01 to 18.77

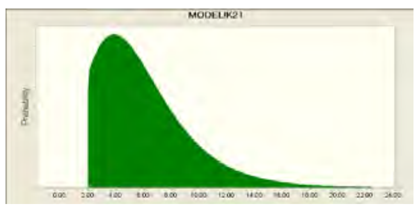


Assumption: K21 **Cell: K21**

Lognormal distribution with parameters:

Location	-3.67	
Mean	5.58	(='SWAT Total Surface Inflow'!$B$41)
Std. Dev.	3.55	

Selected range is from 2.00 to 22.42



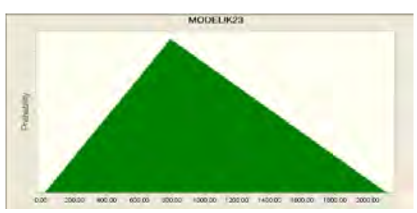
Correlated with:	Coefficient
K23 (K23)	0.89
K12 (K12)	0.74

Assumption: K23 **Cell: K23**

Triangular distribution with parameters:

Minimum	19.27	(='SWAT Total TP Surface Inflow'!$C$41)
Likeliest	790.23	(='SWAT Total TP Surface Inflow'!J55)
Maximum	2114.02	(='SWAT Total TP Surface Inflow'!K55)

Selected range is from 19.27 to 2114.02



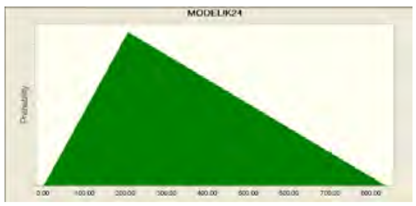
Assumption: K23 (cont'd) **Cell: K23**

Correlated with:	Coefficient
K21 (K21)	0.89
K12 (K12)	0.56

Assumption: K24 **Cell: K24**

Triangular distribution with parameters:

Minimum	0.00	
Likeliest	206.00	(='Internal Loads from RCWD'!E42)
Maximum	834.67	(='Internal Loads from RCWD'!F44)



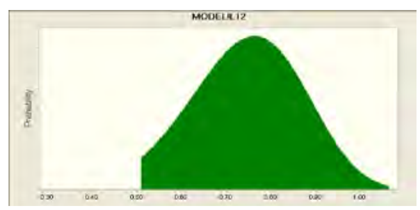
Correlated with:	Coefficient
K12 (K12)	0.56

Assumption: L12 **Cell: L12**

Weibull distribution with parameters:

Location	0.22
Scale	0.57
Shape	4.6750019

Selected range is from 0.51 to Infinity



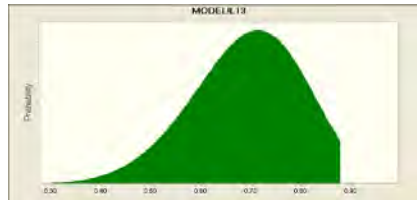
Correlated with:	Coefficient
L23 (L23)	0.56
L24 (L24)	0.56
L13 (L13)	0.19
L21 (L21)	0.74

Assumption: L13 **Cell: L13**

Weibull distribution with parameters:

Location	0.21
Scale	0.52
Shape	4.865325151

Selected range is from 0.30 to 0.88



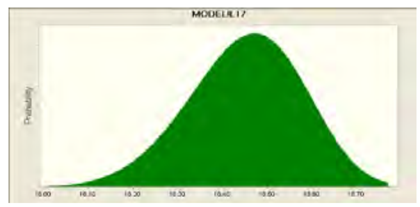
Correlated with:	Coefficient
L12 (L12)	0.19

Assumption: L17 **Cell: L17**

Weibull distribution with parameters:

Location	17.93
Scale	0.57
Shape	4.675

Selected range is from 18.01 to 18.77

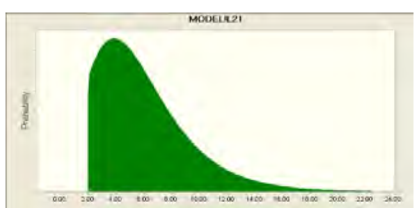


Assumption: L21 **Cell: L21**

Lognormal distribution with parameters:

Location	-3.67	
Mean	5.58	(='SWAT Total Surface Inflow'!$B$41)
Std. Dev.	3.55	

Selected range is from 2.00 to 22.42



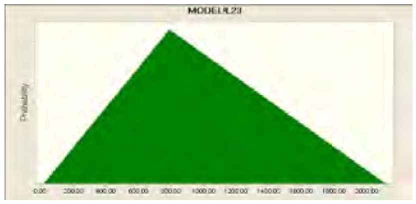
Correlated with:	Coefficient
L23 (L23)	0.89
L12 (L12)	0.74

Assumption: L23 **Cell: L23**

Triangular distribution with parameters:

Minimum	19.27	(='SWAT Total TP Surface Inflow'!$C$41)
Likeliest	790.23	(='SWAT Total TP Surface Inflow'!J56)
Maximum	2114.02	(='SWAT Total TP Surface Inflow'!K56)

Selected range is from 19.27 to 2114.02

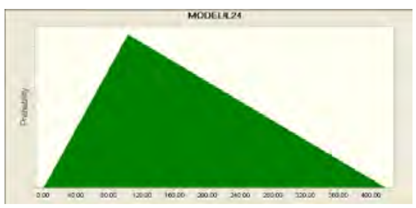


Correlated with:	Coefficient
L12 (L12)	0.56
L21 (L21)	0.89

Assumption: L24 **Cell: L24**

Triangular distribution with parameters:

Minimum	0.00	
Likeliest	103.00	(='Internal Loads from RCWD'!F48)
Maximum	417.33	(='Internal Loads from RCWD'!F48*'Internal



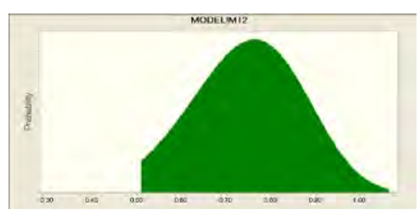
Correlated with:	Coefficient
L12 (L12)	0.56

Assumption: M12 **Cell: M12**

Weibull distribution with parameters:

Location	0.22
Scale	0.57
Shape	4.6750019

Selected range is from 0.51 to Infinity



Assumption: M12 (cont'd) **Cell: M12**

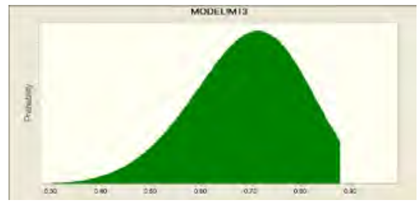
Correlated with:	Coefficient
M21 (M21)	0.74
M23 (M23)	0.56
M24 (M24)	0.56
M13 (M13)	0.19

Assumption: M13 **Cell: M13**

Weibull distribution with parameters:

Location	0.21
Scale	0.52
Shape	4.865325151

Selected range is from 0.30 to 0.88



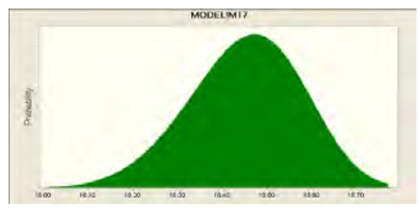
Correlated with:	Coefficient
M12 (M12)	0.19

Assumption: M17 **Cell: M17**

Weibull distribution with parameters:

Location	17.93
Scale	0.57
Shape	4.675

Selected range is from 18.01 to 18.77



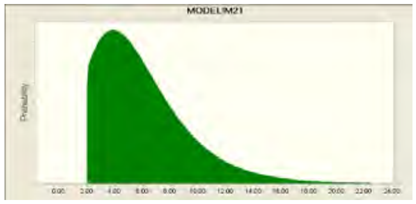
Assumption: M21 **Cell: M21**

Lognormal distribution with parameters:

Location	-3.67	
Mean	5.58	(='SWAT Total Surface Inflow'!$B$41)
Std. Dev.	3.55	

Selected range is from 2.00 to 22.42

Assumption: M21 (cont'd) **Cell: M21**



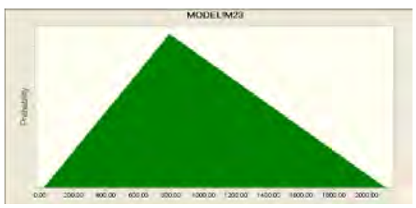
Correlated with:	Coefficient
M23 (M23)	0.89
M12 (M12)	0.74

Assumption: M23 **Cell: M23**

Triangular distribution with parameters:

Minimum	19.27	(='SWAT Total TP Surface Inflow'!$C$41)
Likeliest	790.23	(='SWAT Total TP Surface Inflow'!J57)
Maximum	2114.02	(='SWAT Total TP Surface Inflow'!K57)

Selected range is from 19.27 to 2114.02



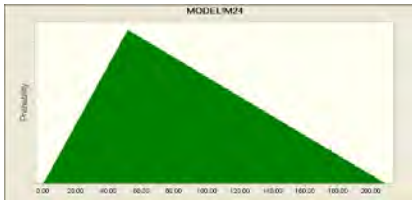
Correlated with:	Coefficient
M21 (M21)	0.89
M12 (M12)	0.56

Assumption: M24 **Cell: M24**

Triangular distribution with parameters:

Minimum	0.00	
Likeliest	51.50	(='Internal Loads from RCWD'!F49)
Maximum	208.67	(='Internal Loads from RCWD'!F49*'Internal

Assumption: M24 (cont'd) **Cell: M24**



Correlated with:	Coefficient
M12 (M12)	0.56

End of Assumptions