1.0 INTRODUCTION

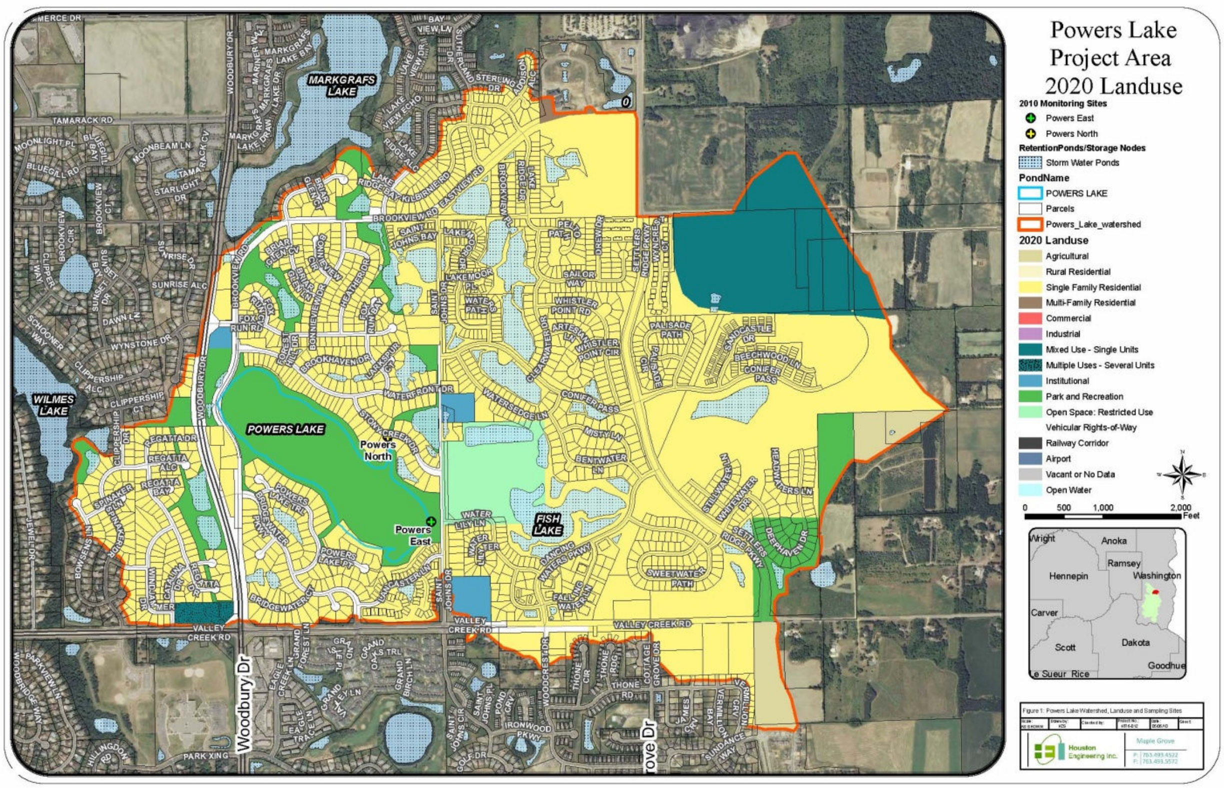
Powers Lake is an approximately 50-acre lake located in the City of Woodbury within southern Washington County. Washington County is located within the Minneapolis-St. Paul metropolitan area in eastern Minnesota (see **Figure 1**). The Powers Lake watershed is situated in the North Central Hardwood Forests ecoregion and the lake is in close proximity to the boundary with the Western Corn Belt Plains ecoregion.

Powers Lake has a drainage area of 1.93 square miles, much of which has been developed, and much of the runoff from those developed areas is directed into the lake. The lake identified by the Minnesota Department of Natural Resources (MnDNR) as Public Water No. 82-0092-00, has a public access and a managed sport fishery including pan fish and game fish weighing more than 3 pounds. The lake normally has no surface outlet so outflow likely occurs as recharge to the groundwater. The recorded lake elevation has ranged more than 23 feet (URL: http://www.dnr.state.mn.us/lakefind/showlevel.html?id=82009200, accessed April 29, 2010).

The Watershed Management Plan (WMP) implemented by the SWWD in 2007 suggested that Powers Lake is showing evidence of water quality degradation, with increased phosphorus concentrations and decreased clarity. In an effort to prevent continued degradation of Powers Lake, the SWWD requested the assistance of Houston Engineering, Inc. to evaluate existing data and develop models that would describe the stresses imposed upon Powers Lake. This information would be used to establish a load allocation serving as the basis to improve management of the lake and its watershed. It is anticipated that the successful completion of this study will result in similar studies conducted for other important lakes in the SWWD.

This report presents an assessment of the water quality for Powers Lake including the estimated water budgets and total phosphorus mass balances for two years of monitoring. These are used along with modeling to develop a phosphorus load allocation recommendation for the Powers Lake watershed to achieve the Minnesota Pollution Control Agency (MPCA) numeric water quality standard and SWWD water quality goal for total phosphorus.

Figure 1 – Map Showing Powers Lake Watershed, Land Use, and Sampling Sites



2.0 POWERS LAKE INFORMATION

2.1 Classification

Powers Lake is not specifically listed in Minnesota Rules (MR) 7050.0186 (wetlands) or 7050.0470 (lakes), which pertain to water body use classifications within the major drainage basins of the State. According to 7050.0430 unlisted waters are classified as Class 2B, 3C, 4A, 4B, 5, and 6 waters. Relative to the aquatic life and recreation classification for Powers Lake (i.e., 2B –see MR 7050.0220) the quality of surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface waters is also protected as a source of drinking water.

Although according to the MnDNR public waters map Powers Lake is classified as a protected wetland, Powers Lake is in fact a lake and required to meet the MPCA Class 2B standards. Powers Lake is a deep lake, as the maximum depth exceeds 15 feet and the lake thermally stratifies, based on data collected by the SWWD. Applicable conventional water quality standards that apply to Powers Lake include dissolved oxygen, pH, and temperature, but nutrients and specifically total phosphorus are of primary interest. The applicable MPCA eutrophication numeric standards expressed as the June through September average value for a near-surface (epilimnetic) sample are: total phosphorus (TP) should not exceed 40 micrograms per liter (ug/L); chlorophyll-*a* (chl-*a*) should not exceed 14 micrograms per liter (ug/L); and Secchi-disk transparency (SD) should be at least 1.4 meters.

The average values for TP, chl-*a*, and SD were computed for 2007 and 2008 using data obtained from the MPCA Environmental Data Access (EDA) Internet site. Those average values were used to compute trophic state indices using the formulas provided by Carlson (1977). The results of those data summaries are provided in **Table 1**. Lakes having TSIs between 40 and 50 are classified as mesotrophic, while lakes having TSIs between 50 and 70 are classified as eutrophic. During 2007 all measurements indicated that the lake was eutrophic. However, during 2008 all values had improved and the TSIs for TP and SD dropped into the mesotrophic category.

Table 1 – Average Values for Powers Lake Trophic State Indicators

	Chlorophyll *a* ug/L		Total Phosphorus, mg/L		Secchi-Disk, meters	
	2007	2008	2007	2008	2007	2008
	Values					
Mean	16.0	11.7	0.046	0.028	1.81	2.39
Median	14.0	11.0	0.031	0.028	1.76	2.15
	Trophic Status					
Mean	57.8	54.7	55.0	47.8	51.4	47.4
Median	56.5	54.1	49.3	47.8	51.8	49.0

Because of the complex hydrology of this lake, it is difficult to determine whether these changes resulted from improved water quality, dilution, or improved stability in the stratification discussed below, which could lead to reduced TP concentration near the surface.

Generally the lake is non-contributing to downstream flows. However, under high water conditions the Powers Lake can outlet via a lift station downstream to Wilmes Lake.

2.2 Water Quality

Powers Lake has been monitored by various agencies since 1994 and that monitoring continues. With some exception, this study used data that was collected by the SWWD during 2007-08, which includes monitoring of runoff to the lake. These data were used to calibrate and validate models used to establish the load allocation. Selecting this narrow time frame will reduce some of the variability that might result from mixing data from differing sampling efforts that might have used different sampling and analytical methods.

Powers Lake experiences strong thermal stratification which typically isolates warm, well oxygenated water near the surface in the epilimnion from colder, poorly oxygenated water near the bottom in the hypolimnion. These upper and lower waters are separated by a transitional layer called the thermocline where the temperature and dissolved oxygen concentration decrease rapidly with increasing depth. The thermocline in Powers Lake during 2008 occurred at about 8-10 meters depth early in the open-water season, and became shallower, about 4-6 meters deep, during most of the summer. This stratification breaks-up during the spring and fall when epilimnetic water is cooler. Persistent winds can cause the epilimnetic and hypolimnetic waters to mix during these seasons. Winter ice cover will cause reverse stratification with the coolest water (about zero degrees Celsius) near the surface, and the warmest water (about 4 degrees Celsius; water's maximum density) near the bottom.

Phosphorus concentrations in lake water often become elevated in the hypolimnion of stratified lakes, because the nearly anoxic conditions results in the release of dissolved phosphorus from enriched bottom sediments. This phosphorus remains isolated from epilimnetic waters while the lake is stratified except during extreme wind conditions. The isolation of the epilimnetic and hypolimnetic waters reduces use by phytoplankton and may otherwise cause algal blooms. However, that phosphorus-enriched water is mixed with the epilimnetic water during spring and/or fall turnover.

Figure 2 illustrates the change in total phosphorus concentrations near the surface of Powers Lake during 1994-2008. Starting about 2001 concentrations appeared to be sustained at a slightly higher concentration. At about the same time, unusually high concentrations of total phosphorus were measured that may have originated from the phosphorus-enriched hypolimnion, or phosphorus-enriched runoff water.

Figure 2 -- Powers Lake Epilimnetic Phosphorus Concentration, in milligrams per liter

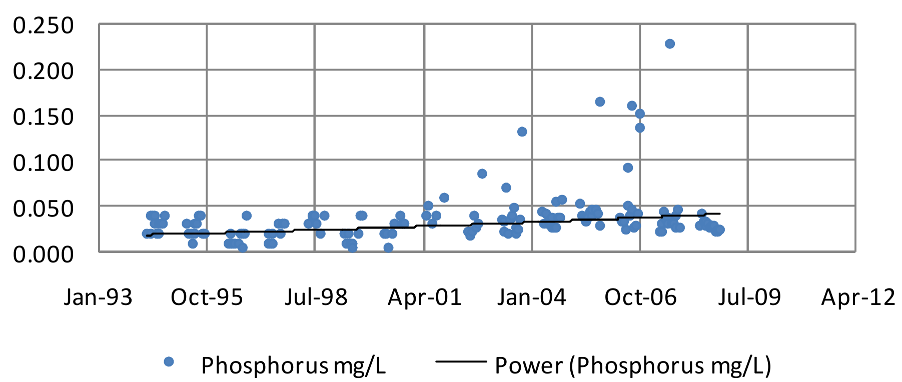


Table 2 shows hypolimnetic concentrations of phosphorus that were collected from Powers Lake during more recent sampling visits. Concentrations ranged from 0.029 milligrams per liter (mg/L) during April, 2007 (presumably a result of dilution during spring turnover or

snowmelt runoff) to more than 0.50 mg/L late in 2008. It is fortunate that the hypolimnetic phosphorus typically is "unavailable" during the growing season to augment and increase the growth of phytoplankton in the epilimnion of Powers Lake.

Table 2 -- Concentrations of Total Phosphorus in the Hypolimnion of Powers Lake.

Sample Date	Sample Depth	Phos-phorus mg/L
5/17/2006	10.7 m	0.265
6/1/2006	11.3 m	0.332
6/28/2006	11 m	0.499
7/25/2006	11.3 m	0.429
8/22/2006	11.3 m	0.329
9/19/2006	11.3 m	0.376
10/17/2006	10.7 m	0.164
4/23/2007	11 m	0.029
6/19/2007	12 m	0.544
8/15/2007	11 m	0.332
10/11/2007	12 m	0.439
5/21/2008	11 m	0.083
6/2/2008	12 m	0.168
6/17/2008	12 m	0.205
6/30/2008	11 m	0.252
7/14/2008	10 m	0.273
7/29/2008	12 m	0.340
8/13/2008	11 m	0.365
8/28/2008	11 m	0.556
9/9/2008	11 m	0.492
9/25/2008	10.5 m	0.597
10/8/2008	10 m	0.595
10/21/2008	9 m	0.577
Mean		0.358
Median		0.340
Minimum		0.029
Maximum		0.597

2.3 Current lake use and features

The fisheries report for Powers Lake prepared by the MnDNR indicates the fish species present in the lake during the last survey in 2007 included bluegill, black crappie, largemouth bass, northern pike, walleye, yellow perch, and bullhead. The MnDNR stocked the lake in 2007 with 2000 walleye yearling. The lake has a fishing pier, and the fish are tested for to ensure a fish consumption advisory is not warranted. The lake is part of the FIN – Fishing In the Neighborhood program. The information also indicates that Powers Lake is one of the best fishing lakes in Woodbury and has many species of game fish.

2.4 Watershed Characteristics and Land use

The Powers Lake watershed and the subwatersheds were delineated as part of previous modeling studies completed by the SWWD and presented in the 2006 SWWD WMP. Those boundaries are used in this report. Although the watershed consists of developed and undeveloped land the majority of the land is developed with the exception of a few scattered parcels on the eastern side of the watershed (**Figure 1**). The predominant land use is single-family residential. Some areas to the east are zoned as single-family residential, but are shown as being undeveloped. There are scattered areas of park land, especially near water bodies. According to the 2030 City of Woodbury Comprehensive Plan there are few areas not already classified as open space or natural land use that face the potential of being developed. For this report, the entire watershed will be considered "developed". Therefore, separate load allocations were not determined based on developed and undeveloped areas.

The Powers Lake watershed is situated on geologic materials that have a large hydraulic conductivity (Barr, 2005). Because of this, precipitation often infiltrates into the subsurface and moves as sub-surface (groundwater) flow rather than running off. Barr (2005) suggests that outflow from the lake goes to the local groundwater flow system as recharge. Impervious surfaces will produce runoff, but that often is conveyed to nearby catchment basins where the water will have the opportunity to infiltrate. The model used to estimate runoff to Powers Lake is capable of correctly simulating runoff through the application of curve numbers that take into account the pervious characteristics of the soils.

Powers Lake receives runoff enhanced by impervious surfaces, but has little or no outflow except during extreme runoff events. The outlet of Powers Lake is controlled by a lift station placed at an elevation of 890.0 MSL, but that has not been needed since installation in 1995 (SWWD, 2007).

Two subwatersheds to Powers Lake have been and continue to be sampled at sites for streamflow and concentrations of important constituents including TP as shown on **Figure 1**. These data are used to compute loads contributed to Powers Lake and provide input to the models used in this study. The data used for this study were collected during 2007-08, although the sampling period has been longer. Earlier data had uncertain quality, so it was decided that they would not be used to develop and calibrate the model for this study. However, the data were used as input to the model during the warm-up leading to 2007-08.

The sites sampled are believed to generally represent runoff and loads to Powers Lake. These data were used to extrapolate to other locations without measured data within the watershed. **Table 3** summarizes the areas and characteristics of the watersheds monitored compared to the total drainage area of Powers Lake.

Table 3 - Areas and Characteristics of Powers Lake Watersheds.

	Area (acres)	Average Slope (percent)	Percent Impervious Area
East Tributary	549	1.93	36.1
North Tributary	134	2.00	35.5
Total Drainage Area	1290	1.85	35.9

The total drainage area encompasses the entire watershed, whether it does or does not contribute runoff directly to the lake, and includes the area of Powers Lake. Based on slope and impervious area, the slope and amount of impervious area of the sampled subwatersheds are reasonably representative of the entire drainage system. These data collected from the subwatersheds were normalized by dividing by their area and used to construct the hydrologic budgets and mass balances.

2.7 Hydrologic Budget

2.7.1 Lake Evaporation

To provide the additional inputs needed to the Powers Lake receiving water model and to construct the water budget, evaporation from the lake was estimated. Evaporation accounts for an important component of the overall water budget of Powers Lake, making an estimate of this process essential. 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 for shallow lake evaporation. Three methods were analyzed that include the Lake Hefner #1 and #2 and the Meyer method. The average value for all methods was used to determine yearly evaporation.

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 Minneapolis St-Paul airport was used to compute evaporation for the 2007 and 2008 seasons. Data obtained from the weather station were on a daily time step; evaporation was computed for this daily time scale and summarized annually. The mean annual evaporation used in establishing the load capacity is an estimated 44.7 inches (2000 – 2008), compared to the estimate value of 65.2 inches for 2007 and 44.6 inches for 2008. The probability distribution for the annual mean evaporation is lognormal with a coefficient of variation of 26.5%.

2.7.2 Groundwater

An assessment of groundwater resources in Washington County determined that Powers Lake is a "recharge" waterbody with respect to interaction with groundwater (Barr, 2005). This indicates that the lake drains to groundwater. The Barr (2005) report indicates Powers Lake does not receive nutrient input from groundwater. The groundwater component of the water budget was not specifically measured, but determined by difference (along with error) by estimating the remaining terms.

2.7.3 Precipitation

Long-term precipitation records (1972 – 2008) from the Minneapolis-St. Paul airport were used to estimate the amount of precipitation reaching the lake surface and as a forcing function for the watershed model. The mean annual precipitation used in establishing the load capacity is an estimated 30.9 inches (1972-2008), compared to the estimate value of 27.4 inches for 2007 and 25.7 for 2008. The probability distribution for the annual mean precipitation depth is lognormal with a coefficient of variation of 25.7%.

2.7.4 Surface Runoff

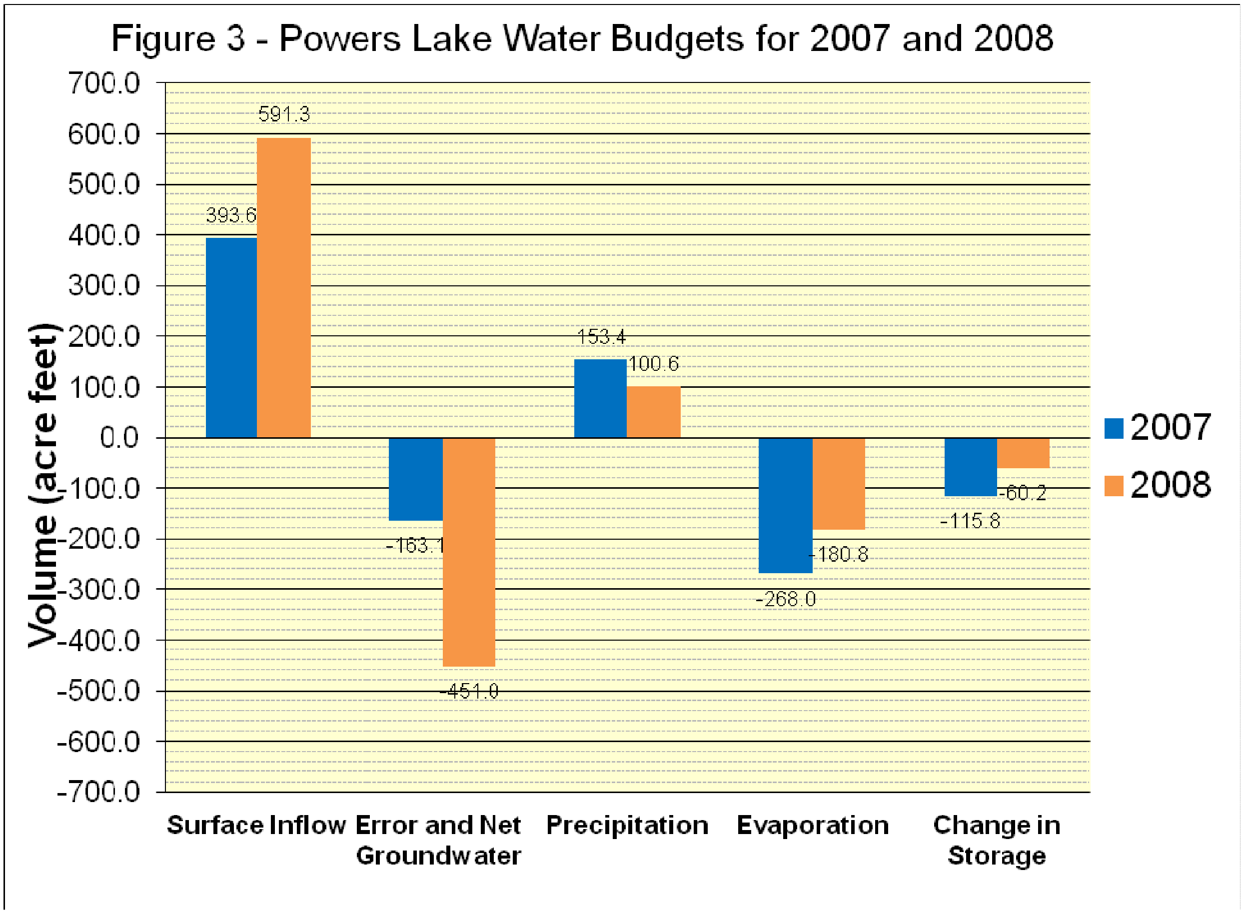
The amount of surface runoff for 2007 and 2008 was estimated based upon the Powers Lake North and East locations. Rating curves were applied to the daily stage estimates to compute estimated flows. These data were then applied to additional area contributing runoff directly to the lake and used to calibrate and validate the runoff volumes within the watershed model.

Results from the P8 model were used to determine the “surface inflow” term to Powers Lake for average long-term conditions. The model results were based on calibrated flow and concentration records for the years 2007 and 2008. Additional information regarding use of the P8 model is presented in Section 3.0.

The mean annual runoff used in establishing the load capacity is an estimated 796 ac-feet, compared to the estimate value of 393.6 ac-feet for 2007 and 591 ac-feet for 2008. The probability distribution for the annual mean surface runoff is lognormal with a coefficient of variation of 38.4%.

2.7.5 Estimated Hydrologic Budget

A hydrologic budget is an accounting of the amount of water entering and leaving a lake. The amount 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 water quality modeling. 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 affects the volume of water in the lake (storage). The hydrologic budget was estimated for Powers Lake using data from 2007 and 2008. The estimated hydrologic budgets are shown in **Figure 3**.



2.8 Total Phosphorus Budget

2.8.1 Surface Inflow

Surface inflow loads to Powers Lake in 2007 and 2008 were estimated based upon measured stream flow and grab and flow-weighted composite samples collected by the SWWD for the Powers East and Powers North monitoring locations. Annual loads from these data were estimated using the U.S. Army Corps of Engineer's FLUX model. These loads were then normalized by dividing by the contributing drainage area and the resulting yield applied to directly contributing portions of the contributing drainage area. These data were used to construct the surface inflow component of the total phosphorus mass balance. These data were also used to calibrate the P8 watershed model. The average surface inflow load was estimated using the P8 model for the period 1972-2008 using the Minneapolis-St. Paul precipitation data.

The mean annual TP runoff used in establishing the load capacity is an estimated 275 kg, compared to the estimate value of 154 kg for 2007 and 210 kg for 2008. The probability distribution for the annual mean surface runoff load is lognormal with a coefficient of variation of 53.2%.

2.8.2 Atmospheric Deposition

Atmospheric deposition to the Powers Lake watershed was determined to be 29 kilograms per square kilometer per year (Barr, 2007). The probability distribution for the atmospheric deposition was assumed to be lognormal with a coefficient of variation of 25.7%; equal to that of precipitation.

2.8.3 Internal Loading

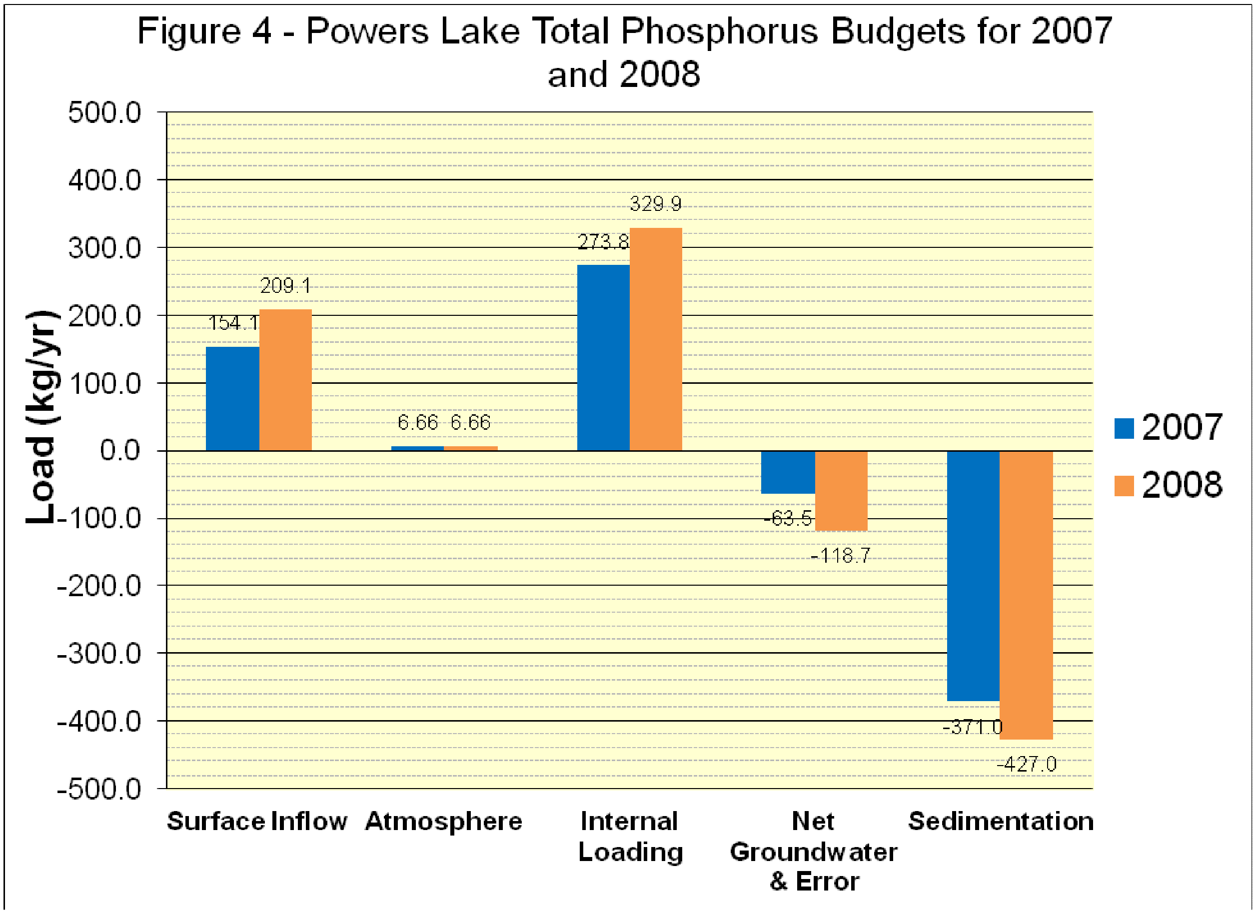
Internal loads were estimated by the SWWD using monitoring data from Powers Lake sampled during 2007 and 2008, the average depth of the surface mixed layer (to compute the volume of the hypolimnion and bottom surface area of the lake) and the duration of stratification. The temperature profiles show Powers Lake stratified for 171 days and 153 days in 2007 and 2008, respectively. The corresponding increase in total phosphorus concentration within the hypolimnion was 11.7 mg / cubic foot and 14.9 mg/cubic feet in 2007 and 2008, respectively. Estimated internal load rates during the period of thermal stratification were 6.97 and 9.39 mg/square meter /day. These estimated values are within the range of 1 to 10 mg/square meter /day characteristic of many lakes. The probability distribution for the internal loading rate was considered lognormal with a coefficient of variation of 129%.

2.8.3 Sedimentation

The estimated sedimentation rate came from the CNET receiving water model and is a function of the hydraulic residence time.

2.8.5 Estimated Total Phosphorus Nutrient Budget

Like a hydrologic budget, which is an accounting of water, a nutrient budget is an accounting of the amount or "load" of nutrients entering and leaving Powers Lake. 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 time period. The estimated TP budgets for Powers Lake are found in **Figure 4**.



3.0 MODEL DEVELOPMENT AND APPLICATION

3.1 Modeling 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. These 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 goals 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.

Modeling goals and objectives likely differ depending upon the type of modeling being performed. The two primary types of water quality modeling for this project can be broadly categorized as watershed (i.e., landscape) and receiving water modeling. The water quality goals and technical objectives for the Powers Lake Pilot Project are described in Tables 1 and 2 of a Technical Memorandum to the SWWD dated January 28, 2010. The goals and objects can be generally described as understanding the response of Powers Lake to excess nutrients, both in terms of the amount of algae and the clarity of the lake.

3.2 Watershed Modeling

The movement of water from the watershed into Powers Lake was determined using the P8 Urban Catchment Model calibrated to the 2008 monitoring data at Powers North and Powers East locations. P8 is described as a Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (URL: http://wwwalker.net/p8/, accessed April 27, 2010). The model incorporates a number of factors that encompass inflow, outflow, and the movement of sediment-related particles (including total phosphorus) through the watershed. The P8 model was run using data from 1978-2007 as a warm up which allowed the model compartments (soil moisture, particulate content, etc.) to “wash” the potential influence of initial conditions from the model results. The model then was calibrated using 2008 data and validated using the 2007 data.

The model is a good fit given the urban nature of the watershed and the model’s ability to discretely model constructed BMP’s within the watershed. The source watershed and geometric data was taken directly from the existing XP-SWMM model for Powers Lake through use of conversion software created by HEI. The "SWMM to P8" conversion was completed to provide consistency with the existing SWMM model and can be used as a tool for future analysis to evaluate "what if" scenarios for determining locations to install BMP's (i.e. rain gardens, infiltration basins) to meet TP reduction goals. Rainfall data used to generate P8 runoff volumes were taken from the Minneapolis-St. Paul airport. The data were found to be a good fit when compared to rainfall recorded for a similar time period taken at Powers Lake in 2007. The rainfall comparison can be found in **Appendix A**.

The P8 model was calibrated to measured runoff volume and phosphorus annual load at the two measurement locations as shown in **Figure 1**. The calibration was performed using 2008 and the validation using 2007. The results of the calibration and validation are found in **Table 4**.

Table 4 - Measured and Modeled Runoff to Powers Lake from Monitored Tributaries

Station	Year	Measured	Model
Runoff Volume in acre feet per Year			
Powers North	2007	15.5	12.9
	2008	18.9	13.7
Powers East	2007	85.0	79.7
	2008	80.5	79.7
Total Phosphorus Load in pounds per year			
Powers North	2007	8.4	17.0
	2008	10.3	11.4
Powers East	2007	62.8	69.5
	2008	60.2	53.3

[1]Criteria Used To Evaluate Quality

	Very Good	Good	Fair
Water Volume	<10%	10%-20%	20%-30%
Loading	<15%	15%-25%	25%-35%

When compared to the measured, the numbers generally were within the good- to very good-category. Powers North was shown to contain baseflow which could explain the higher degree of variability when compared to Powers East. The coefficients used for the P8 model were consistently applied for both Powers North and Powers East measurement locations. Loads were estimated using FLUX (URL: http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=watqual (accessed April 29, 2010). Detailed calibration information including P8 and FLUX model inputs, graphs depicting observed and P8 model flow data is located in **Appendix B**.

3.3 Receiving Water Modeling

Based upon the modeling goals and objectives we used the CNET model 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, accessed 4-27-10). CNET is a spreadsheet model currently available as a "beta" version from Dr. William W. Walker. The primary modifications to the CNET model implemented during this effort were to: 1) add an algorithm to model the surface mixed layer annual mean total phosphorus from a depth averaged annual mean total phosphorus concentration; 2) to use empirically derived regression relationships specific to Powers Lake derived from monitoring data to estimate the response of chlorophyll-a and Secchi disk depth to total phosphorus; and 3) implementing a Monte Carlo approach which allowed selected modeling parameters and inputs to vary based upon known statistical distributions and be reflected in the forecast results. The Monte Carlo approach generates a distribution of the annual mean concentrations reflecting the uncertainty in the model parameters and normal variability in inputs (e.g., annual total phosphorus load from surface runoff).

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. 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 TP, chl-*a*, and SD are allowed to vary according to their statistical distribution and therefore their probability of occurrence. This allows the effect of parameter uncertainty and normal variability in the inputs (e.g., amount of surface runoff which varies annually depending upon the amount of precipitation) to be quantified when computing the annual mean concentration of TP, chl-*a*, and SD.

The Crystal Ball software allowed for multiple probabilistic simulations of the model computations. Many trial values (10,000 trials in this study case) were generated, with each trial representing a different permutation of model parameters and input values within the bounds established by the statistical distributions. The many trials resulted in a computed distribution of annual mean concentrations rather than a single, fixed output that was based upon only one possible combination of model parameters and inputs. The stochastic approach reflects the variability in model parameters and inputs, and allows explicit determination of their effect on the mean values and the expression of model results as risk.

Prior to completing the Monte Carlo modeling analysis, the Powers Lake CNET model was calibrated using the annual water budget and TP mass balance for 2008 as described in **Section 2.7,** and validated using the annual water budget and total phosphorus mass balance for 2007 described in **Section 2.8**. 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 shows the results of model calibration using the 2008 data.

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

	Calibration Coefficient	Measured	Modeled	Absolute Difference	Percent Difference
Total Phosphorus (surface mixed layer)	0.78	46 ppb	46.2 ppb	0.2 ppb	< 1%
Chlorophyll-a	0.42	11.7 ppb	11.8 ppb	-0.1 ppb	< 1%
Secchi Disk	0.9	2.4 meters	2.4 meters	0 meters	< 1%

Table 6 shows the results of model validation using the 2007 data. The total phosphorus calibration coefficient adjusted the model results to match the observed depth averaged annual mean total phosphorus concentration. The depth averaged annual mean total phosphorus concentration was then reduced by 25% to match the observed mixed layer concentrations.

Table 6 - CNET model validation results for 2007 annual mean concentrations.

	Measured	Modeled	Absolute	Percent

			Difference	Difference
Total Phosphorus (surface mixed layer)	28 ppb	44.6 ppb	16.6 ppb	59.3%
Chlorophyll-a	16 ppb	11.8 ppb	-5.2 ppb	-32.5%
Secchi Disk	1.8 meters	2.4 meters	0.6 meters	33.3%

The validation results convey the challenges of modeling Powers Lake. A review of the monitoring data shows that the epilimnetic and hypolimnetic total phosphorus concentrations tend to differ by as much as an order of magnitude during the summer because of thermal stratification and hypolimnetic anoxic conditions. During September and October as thermal stratification decays, these high concentrations become mixed into the surface layer, elevating concentrations and the annual mean concentration. However, because of low fall water temperatures a corresponding increase in algae as reflected by the chlorophyll-a concentrations is absent. The validation results also reflect the uncertainty associated with the water budget and mass balances.

3.4 Modeling the Load Allocation

A water budget and total phosphorus mass balance for an "average year" was used to establish the TMDL. The annual mean and statistical distributions for the surface water runoff and total phosphorus load came from running the P8 model for a 30-year period. The annual mean internal load came from an average of the computed values for 2007 and 2008. Statistical distributions were generally assumed to be log normal. The CNET model spreadsheet is shown in **Appendix C** with the parameters and input values.

4.0 EUTROPHICATION RESPONSE AND LOAD ALLOCATION

4.1 Eutrophication Response

Figures 5-10 show the effects of reducing total phosphorus loads on the total phosphorus, chlorophyll-*a* and Secchi disk visibility within Powers Lake based on the CNET model, for the average condition. Loads were reduced incrementally within the CNET model and assumed to come from the surface runoff component of the mass balance. 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 annual mean values.

Figure 5 – Powers Lake Annual Mean Epilimnetic Total Phosphorus Concentrations Resulting from Selected Load-Reduction Scenarios,

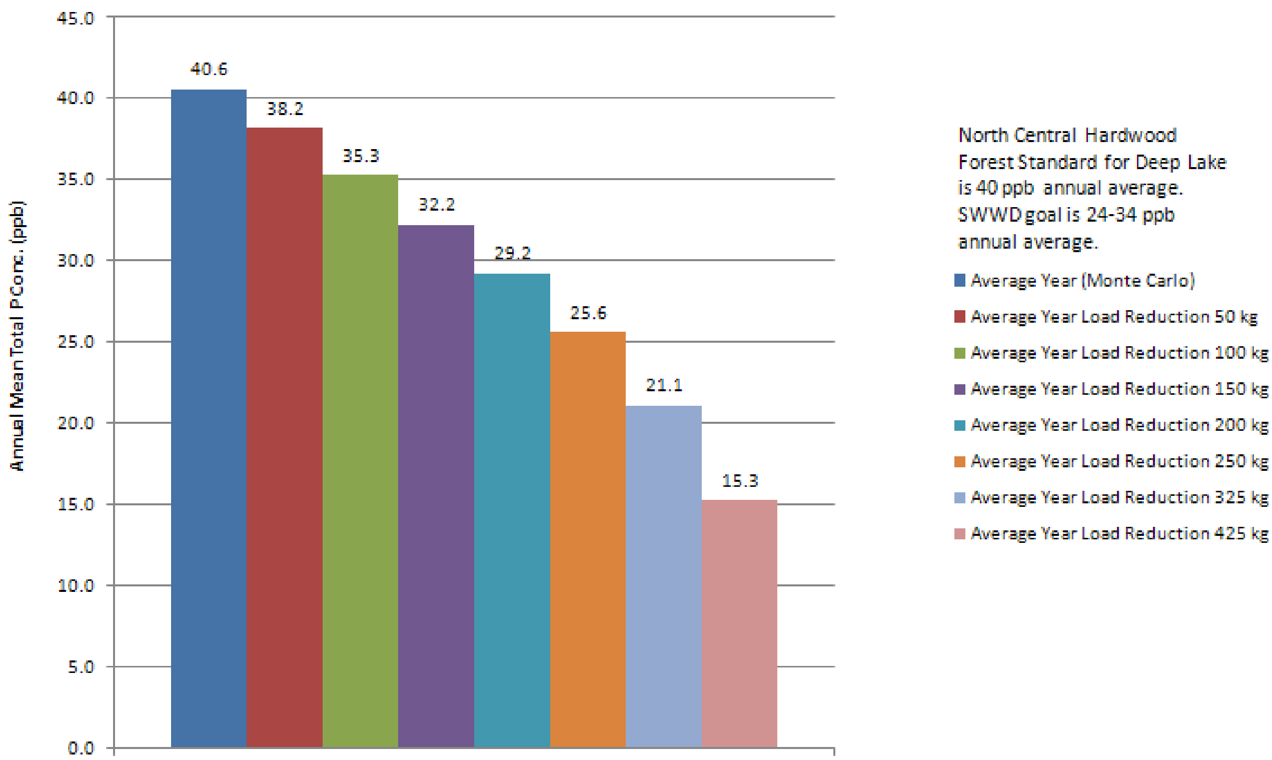
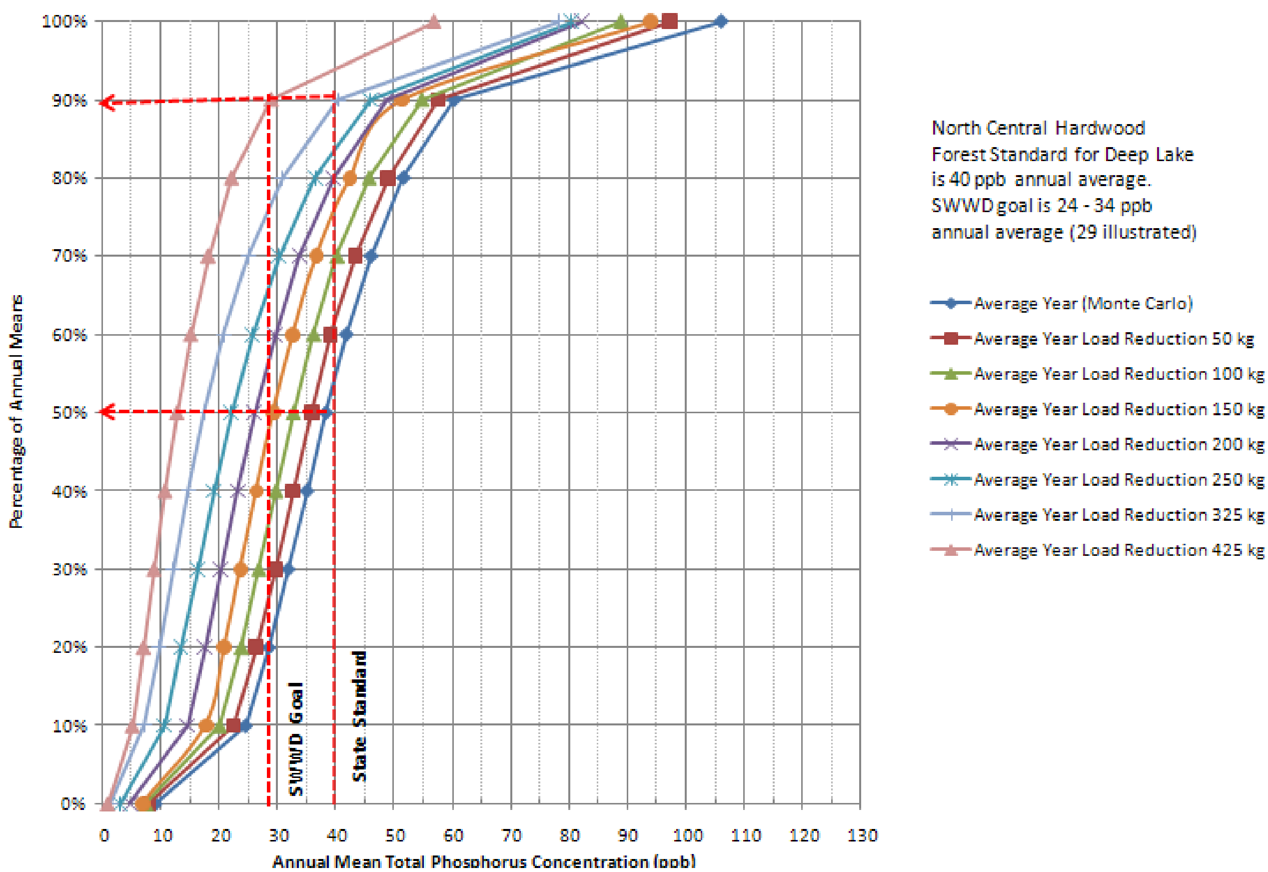


Figure 6 – Powers Lake Frequency Distribution of Annual Mean Epilimnetic Total Phosphorus Concentrations Resulting from Selected Load-Reduction Scenarios, and Table of Data used to Produce the Graphical Illustration



		Load Reduction from Current Load for Average Year						
	Average Year (current)	50 kg	100kg	150kg	200 kg	250 kg	325 kg	425 kg
Mean	40.6	38.2	35.3	32.2	29.2	25.6	21.1	15.3
0%	9.1	8.1	7.5	7.0	4.8	3.1	1.5	1.0
10%	24.6	22.5	20.1	17.8	14.5	10.7	7.3	5.3
20%	28.6	26.4	23.8	21.0	17.6	13.5	9.8	7.2
30%	31.9	29.7	26.8	23.7	20.4	16.3	12.2	8.9
40%	35.1	32.7	29.7	26.5	23.2	19.1	14.8	10.8
50%	38.4	35.9	32.7	29.3	26.1	22.2	17.5	12.9
60%	41.9	39.1	36.2	32.8	29.7	25.8	20.9	15.2
70%	46.1	43.4	40.2	36.7	33.8	30.3	25.0	18.2
80%	51.6	49.0	45.7	42.5	39.7	36.6	30.9	22.2
90%	60.3	57.6	54.7	51.4	48.7	46.1	40.5	29.0

100%	106.0	97.3	88.8	94.0	82.2	80.5	78.1	56.8

Figure 7 – Powers Lake Annual Mean Chlorophyll *a* Concentrations Resulting from Selected Phosphorous Load-Reduction Scenarios

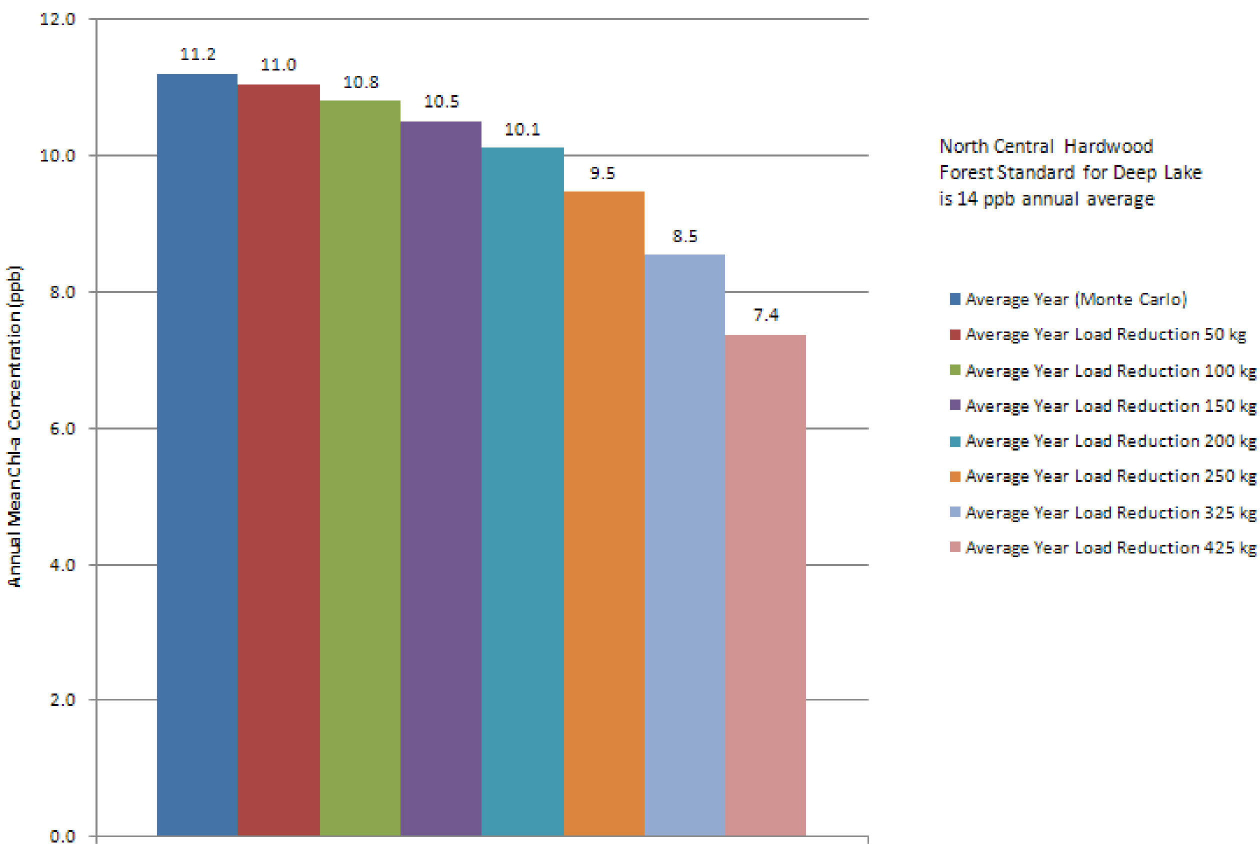


Figure 8 – Powers Lake Frequency Distribution of Annual Mean Chlorophyll *a* Concentrations Resulting from Selected Phosphorous Load-Reduction Scenarios

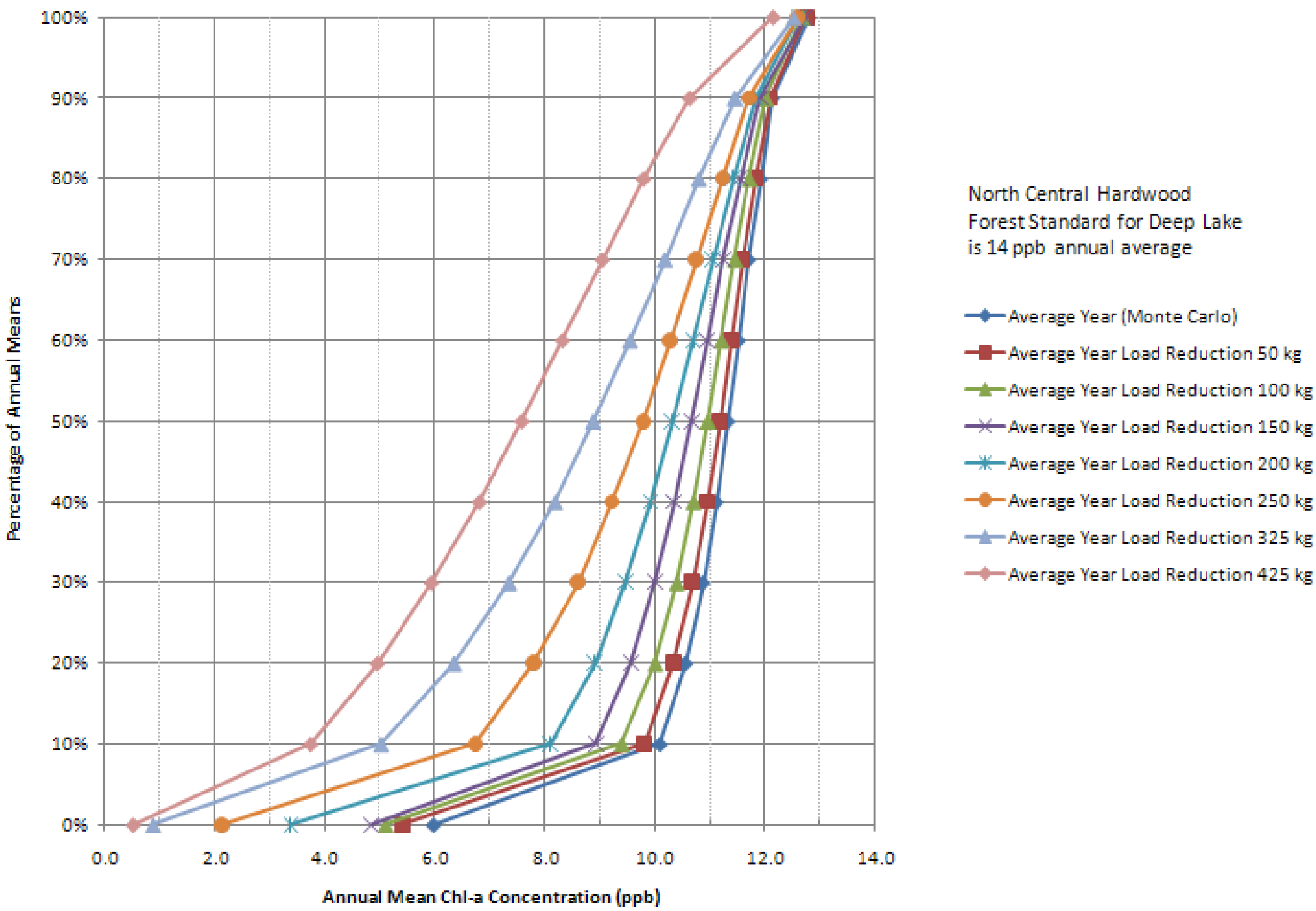


Figure 9 – Powers Lake Annual Mean Secchi-Disk Transparency Resulting from Selected Phosphorous Load-Reduction Scenarios

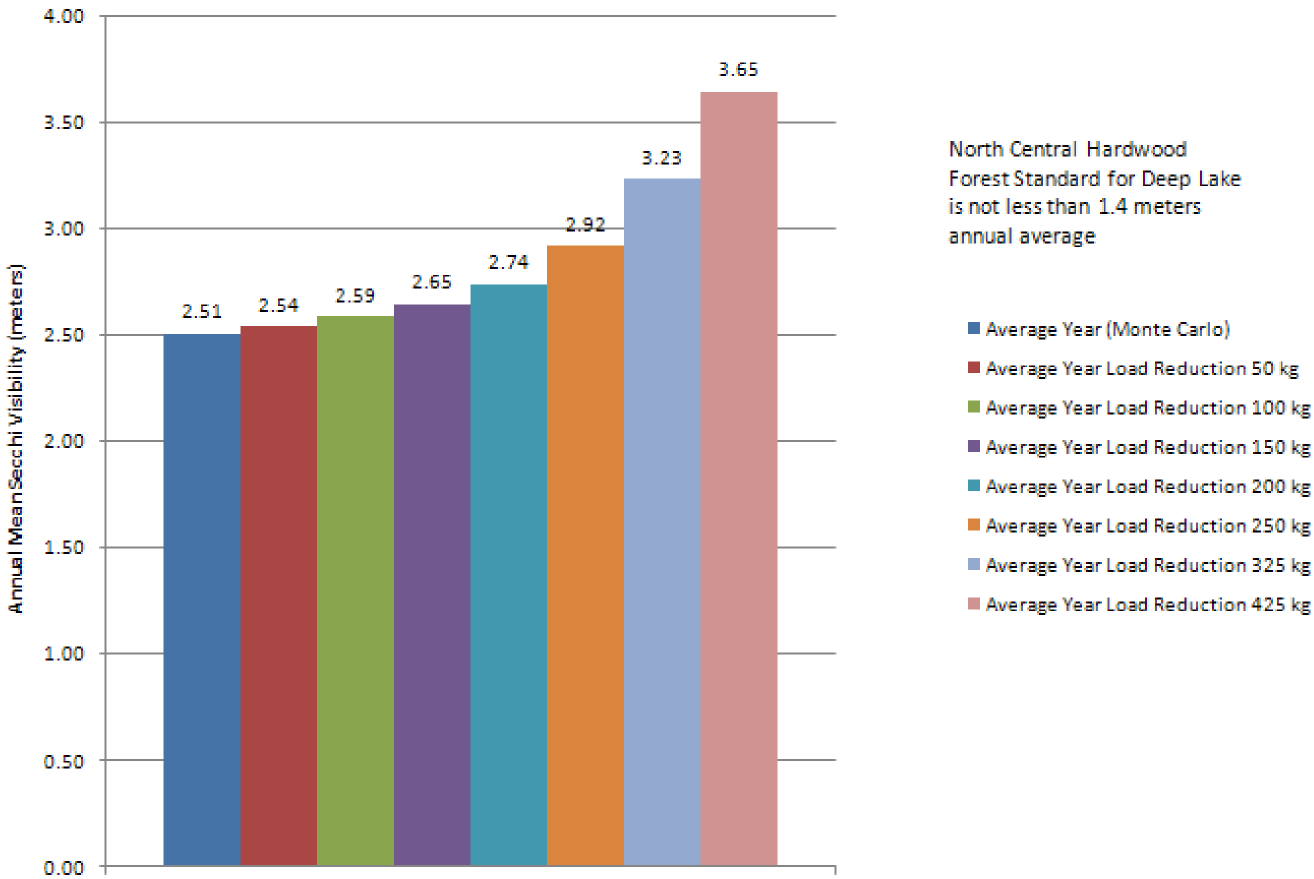
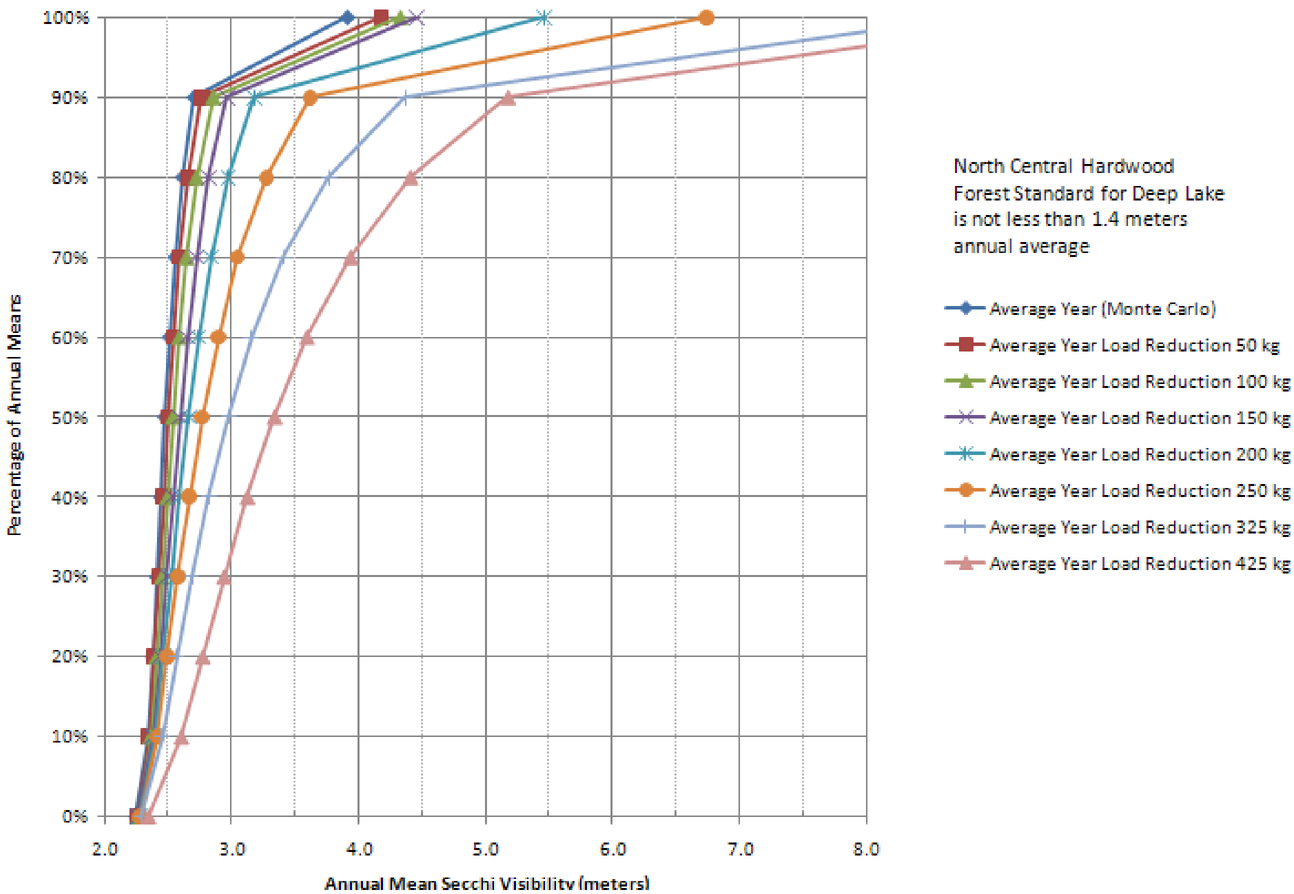


Figure 10 – Powers Lake Frequency Distribution of Annual Mean Secchi-Disk Transparency Resulting from Selected Phosphorous Load-Reduction Scenarios



4.2 Loading Capacity

The loading capacity (i.e., the TMDL) is the maximum allowable TP load to Powers Lake which can occur, while still achieving the water quality numeric standard of the MPCA (40 ug/l) and in this case, the water quality goal established by the SWWD (24-34 ug/l). 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 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 lack of knowledge in establishing the load capacity.

The loading capacity is the annual load reduction (expressed on a daily basis) for the average year, necessary to reduce the annual mean TP concentration for the 90th percentile nonexceedance value to the MPCA numeric standard (40 ug/l). A second loading capacity is computed in the same manner to achieve SWWD goal (24 – 34 ug/l; 29 is used for the loading capacity), The 90th percentile nonexceedance 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. The approach translates into one exceedance every 10 years and is consistent with the use of monitoring data for the purposes of placing a waterbody on the 303(d) list. 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 or the SWWD goal of 29 ug/l.

Figure 6 shows a line at 40 ug/L representing the average summer epilimnetic TP concentration eutrophication standard provided in MR 7050.0222 for the protection of lake quality in Class 2 surface waters in the North Central Hardwood Forest ecoregion. Another line at 29 ug/L represents the average summer epilimnetic TP concentration standard chosen by the

SWWD (2007) for the protection of lake quality. These lines were used to determine the level of phosphorus load reduction (i.e., loading capacity) that would be needed to achieve the desired quality of Powers Lake. A table accompanying **Figure 6** shows the values for the nodes used to produce the figure.

Shown below is the loading capacity table (**Table 7**) that would be employed if Powers Lake were to be evaluated as a TMDL-listed water body. Approximating from **Figure 6** and using the values from the accompanying table**,** the following load allocation was developed:

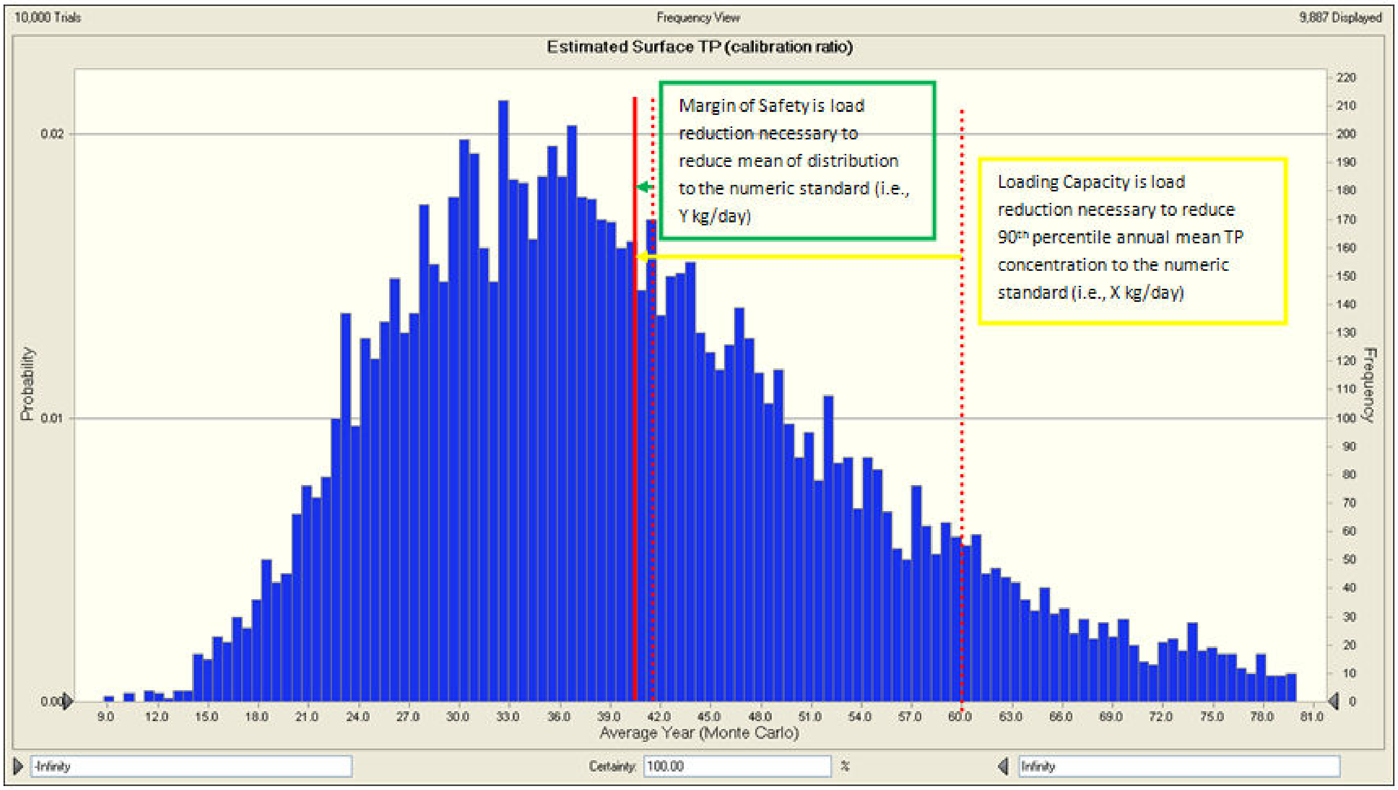
Table 7 - Powers Lake Loading Capacity to Meet MPCA Standard of 40 ug/l Total Phosphorus Annual Mean Concentration for average conditions. Values are in kilograms per day (numbers in parentheses are current average loads).

	Loading Capacity	=	Load Allocation	+	Wasteload Allocation	+	Margin of Safety
Current Condition	1.59	=	0.84	+	0.75	+	0
Future Goal: 40 ug/L	0.71	=	0.12	+	0.56	+	0.03

It is estimated that the current 1.59 kg/d phosphorus load to Powers Lake would have to be reduced to 0.71 kg/d. It is estimated that the wasteload allocation, which is storm-sewered runoff from the watershed, would have to be reduced by 25%; from 0.75 to 0.56 kg/d. The remainder would have to come from the load allocation which is comprised of both atmospheric and internal loading from the phosphorus-laden bottom sediments. The atmospheric loading of 0.018 kg/d is beyond the control of the SWWD, so the reduction would need to come from internal TP loading. The approximately 0.82 kg/d internal TP load would have to be reduced 88% to achieve the 0.10 kg/d internal load needed to meet the 40 ug/L goal 90% of the time. In reality any combination of waste load allocation and load allocation equaling 0.68 kg/d is able to achieve the loading capacity.

Figure 11 shows the probability distribution of the mean summer TP concentration for Powers Lake. The solid red vertical line shows the current annual mean of the TP 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 TP concentration that would occur about once every 10 years (the 90th percentile; about 60 ug/L). To achieve the 40 ug/L goal 90% of the time, the distribution needs to be shifted (yellow 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.

Figure 11 -- Probability Distribution of the Mean Summer Total Phosphorus Concentration for Powers Lake



A loading capacity table (**Table 8**) also was prepared for the SWWD lake TP goal of 55 ug/L. A compliance of 90% also was assumed for this scenario. Approximating from **Figure 6** and using the values from the accompanying table, the following loading capacity was developed:

Table 8 - Powers Lake Loading Capacity to Meet SWWD Goal of 29 ug/l Total Phosphorus Mean Annual Concentration. (Values in kilograms per day).

Loading Capacity SWWD Goal: 29 ug/L		=	Load Allocation	+	Wasteload Allocation	+	Margin of Safety
Current Condition	1.59	=	0.84	+	0.75	+	0
Future Goal: 29 ug/L	0.43	=	0.002	+	0. 38	+	0.03

It is estimated that the current 1.59 kg/d phosphorus load to Powers Lake would have to be reduced to 0.43 kg/d. It is estimated that the wasteload allocation, which is storm-sewered runoff from the watershed, would need to be reduced by 50%; from 0.75 to 0.38 kg/d. The remainder would have to come from the load allocation which is comprised of both atmospheric and internal loading from the phosphorus-laden bottom sediments. The reduction would need to come from internal TP loading. The approximately 0.82 kg/d internal TP load would have to be reduced effectively by 100% to achieve the 0.002 kg/d internal load needed to meet the 29 ug/L goal 90% of the time. In reality any combination of waste load allocation and load allocation equaling

There are no other NPDES permitted facilities in the watershed. There are a few MPCA permitted facilities that might contribute runoff from construction and storage tanks in the watershed. Because they are permitted, it can be assumed that discharges that may occur are controlled and will not directly affect the quality of Powers Lake.

Potential pollution sources that could contribute wasteload to Powers Lake were categorized in the current Watershed Management Plan (SWWD, 2007). It identifies no pollution sources within the Powers Lake watershed and therefore confirms zero wasteload. Waste loads from Subsurface Sewage Treatment Systems (SSTS), previously referred to as Individual Sewage Treatment Systems are also assumed to be zero because the vast majority (over 95% based on land coverage) of the watershed is serviced by municipal sanitary sewer. In addition, future development will require connections to the municipal sanitary system.

The LA portion of the loading capacity equation includes internal loading and atmospheric deposition. The loading capacity equation assumes that the internal load would be reduced by an estimated 88% to achieve the 40 ug/L standard. Because the internal TP load to

Powers Lake would have to be reduced in the MPCA-based load-allocation scenario (and to a greater degree using the SWWD 24-34 ug/L goal), some form of phosphorus sequestration would be needed. Various methods can be employed, but one of the more common methods is alum treatment.

5.0 IMPLEMENTATION TO ACHIEVE THE LOADING CAPACITY

5.1 Priority Implementation Areas

The P8 model provides information to determine existing storage-node (retention pond) performance for the Powers Lake watershed. The storage node locations and contributing watersheds have been identified in **Figures 12** and **13**, respectively. Using the results from the 30-year simulation of the P8 model, the following storage node and watershed terms were analyzed. They include:

- TP Removal Efficiency,
- TSS Removal Efficiency, and
- Direct Watershed Yield

Figure 12 -- Map Showing Powers Lake Watershed Model: Removal Efficiency

Figure 13 -- Map Showing Powers Lake Watershed Model: Existing Conditions Total Phosphorus Yield

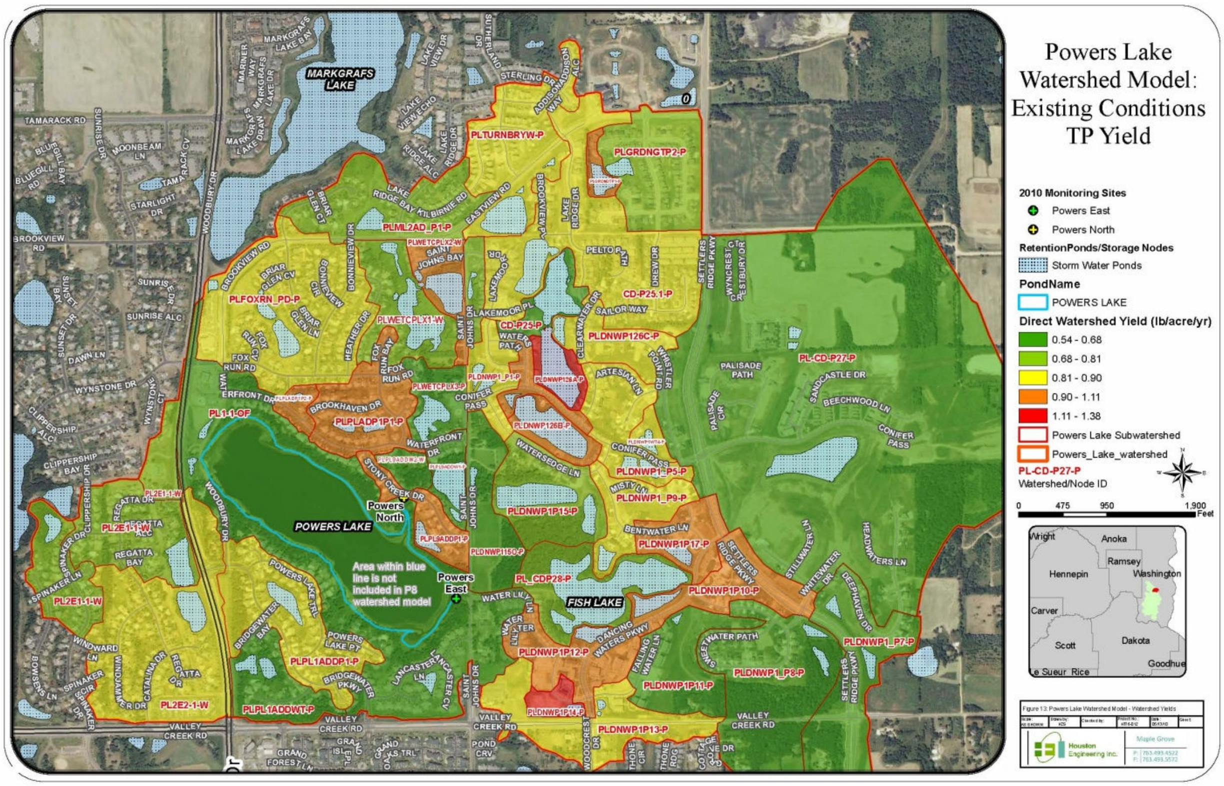


Figure 12 displays the TSS removal efficiency as an annual percent for each of the ponds modeled. The P8 model estimates removal efficiencies generally based on particulate removals, therefore TP removals are directly related and commensurate to TSS removals. **Figure 13** displays the existing conditions TP yield from each of the modeled sub-watersheds. The SWWD considers a yield of 0.06 lb/ac/year acceptable (SWWD, 2007). **Table 9** shows the storage nodes sorted by decreasing watershed yield, with the twelve nodes having the lowest removal efficiency highlighted. The order and highlighting shown in **Table 9** suggests higher priority areas which could be targeted for additional BMP implementation. The highlighted nodes represent storage nodes that achieve less than 50% TSS removal and 15% TP removal based on P8 modeling.

Table 9 - Powers Lake Estimated Watershed Yield and Pond Performance based on the P8 model.

Watershed or Storage Node	Direct Watershed Yield lb/acre/yr	TSS Efficiency % rem.	TP Efficiency % rem.
PLDNWP1P14-P	1.37	34.5	8.5
PLDNWP126A-P	1.23	47.3	6.1
PLDNWP126B-P	1.12	47.5	5.6

PLDNWP1P12-P	1.08	64.4	21.4
PLWETCPLX2-W	1.02	85.4	32.9
PLDNWP1P10-P	0.99	53.6	16.2
PLDNWP1P17-P	0.98	87.0	36.3
PLDNWP1_P2-P	0.96	62.1	15.1
PLPL9ADDP1-P	0.96	81.1	31.9
PLPLADP1P1-P	0.96	82.5	33.6
PLPLADP1P2-P	0.95	78.9	31.0
PLGRDNGTP1-P	0.94	46.5	11.2
PLTURNBRYW-P	0.90	73.3	26.1
PLDNWP1_P9-P	0.90	72.2	20.6
PL2E2-1-W	0.90	72.6	25.2
CD-P25.1-P	0.89	74.0	23.4
PLDNWP126C-P	0.89	84.8	35.0
PLPL1ADDP1-P	0.88	66.8	21.8
PLDNWP1P13-P	0.87	44.4	10.4
PLDNWP1_P1-P	0.85	81.1	32.1
PLDNWP1_P5-P	0.84	75.2	27.0
PLDNWP1WT4-P	0.82	80.1	30.5
PLFOXRN_PD-P	0.82	77.7	29.7
PLML2AD_P1-P	0.81	79.6	31.1
PLWETCPLX4-P	0.79	59.2	16.8
PL2E1-1-W	0.78	69.4	19.8
PLWETCPLX1-W	0.77	77.0	19.1
PLGRDNGTP2-P	0.74	68.8	23.5
PLDNWP1P15-P	0.73	60.8	7.9
PL_CDP28-P	0.71	44.4	7.7
PLDNWP1_P8-P	0.68	63.7	21.6
PLWETCPLX3-P	0.66	37.9	3.9
PL-CD-P27-P	0.66	85.0	35.5
PLPL1ADDWT-P	0.65	70.4	24.4
PLPL9ADDW1-P	0.65	20.3	1.5
PLPL9ADDW2-W	0.65	6.4	0.3
PLDNWP1P11-P	0.65	59.5	19.5
PLDNWP1_P7-P	0.63	48.6	10.5
PLDNWP115O-P	0.58	27.2	1.8
CD-P25-P	0.54	45.6	7.1

The numbers for removal efficiency and exports are based on 30-year averages for the years 1978 through 2008. The P8 model-run included a pre-flush out period starting in 1960. The **Table 9** results serve as a guide in determining implementation areas for additional treatment. Although the P8 model has been calibrated based on observed flow and concentration data, the P8 model was calibrated without altering or auditing the existing XP-SWMM hydraulic model inputs. The XP-SWMM model was used primarily for hydraulic analysis only and was not considered or adapted for future water quality modeling. When evaluating the results of the P8 model it is important to consider:

- The impervious areas entered into P8 that were directly converted from the XP-SWMM model considered areas occupied by water as impervious. Therefore, TP loads may be higher than expected due to the P8 model that calculates loads based on runoff volume multiplied by an event-mean-concentration for areas with high surface water areas as a function of overall watershed area (i.e. nodes PLDNWP126B-P, PLDNWP126A-P).

- The existing XP-SWMM model appears to have inconsistencies when estimating the amount of "dead-storage" provided by each storage node. The model appears to underestimate the storage provided by natural wetlands and ponding areas when compared to constructed ponds within the watershed. The end result will be lower than anticipated removal efficiencies and greater than expected load runoff rates for those natural ponding areas (i.e. nodes PLDNWP126A-P, PLWETCPLX2-W).

Figure 12 and **Figure 13** have been provided in a GIS format and are placed in a geodatabase. Additional watershed and storage node information can be found within the geodatabase including removal efficiencies, unit loads, rank in terms of performance, additional hydraulic information, sedimentation rates, and other storage node and watershed characteristics.

5.2 Implementation Mechanism

SWWD utilizes a Subwatershed Retrofit Assessment Protocol as developed by the Metro Conservation Districts to meet the wasteload allocation portion of the loading capacity. Starting with priority implementation areas identified in this report, the Protocol uses a systematic approach to identifying individual properties and projects with the greatest potential water quality benefit, maximizing the benefit of implementation funding. The assessment will identify projects and associated costs required to meet the WLA for both the current MPCA standard (69.4 kg/yr total reduction) and SWWD goal (135.1 kg/yr total reduction). The Powers Lake Subwatershed Assessment Report will be completed separate of this report and represent the bulk of the implementation plan.

To achieve the load allocation portion of the loading capacity, SWWD will investigate the use of various in-lake phosphorus sequestration methods in cooperation with the City of Woodbury. Implementation of in-lake sequestration will only be considered upon meeting the wasteload allocation through implementation of the Subwatershed Retrofit Assessment Protocol. This phased approach will maximize and prolong the benefits of any in-lake treatment.

All implementation will be a cooperative effort between SWWD and the City of Woodbury, both of whom have funding dedicated to improving the water quality of Powers Lake.

6.0 REFERENCES

Barr, 2005, Integrating Groundwater & Surface Water Management: Southern Washington County, Barr Engineering, August 2005.

Barr, 2007, Technical Memorandum - Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Atmospheric Deposition: 2007 Update, Barr Engineering, June 2007.

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1.0 INTRODUCTION

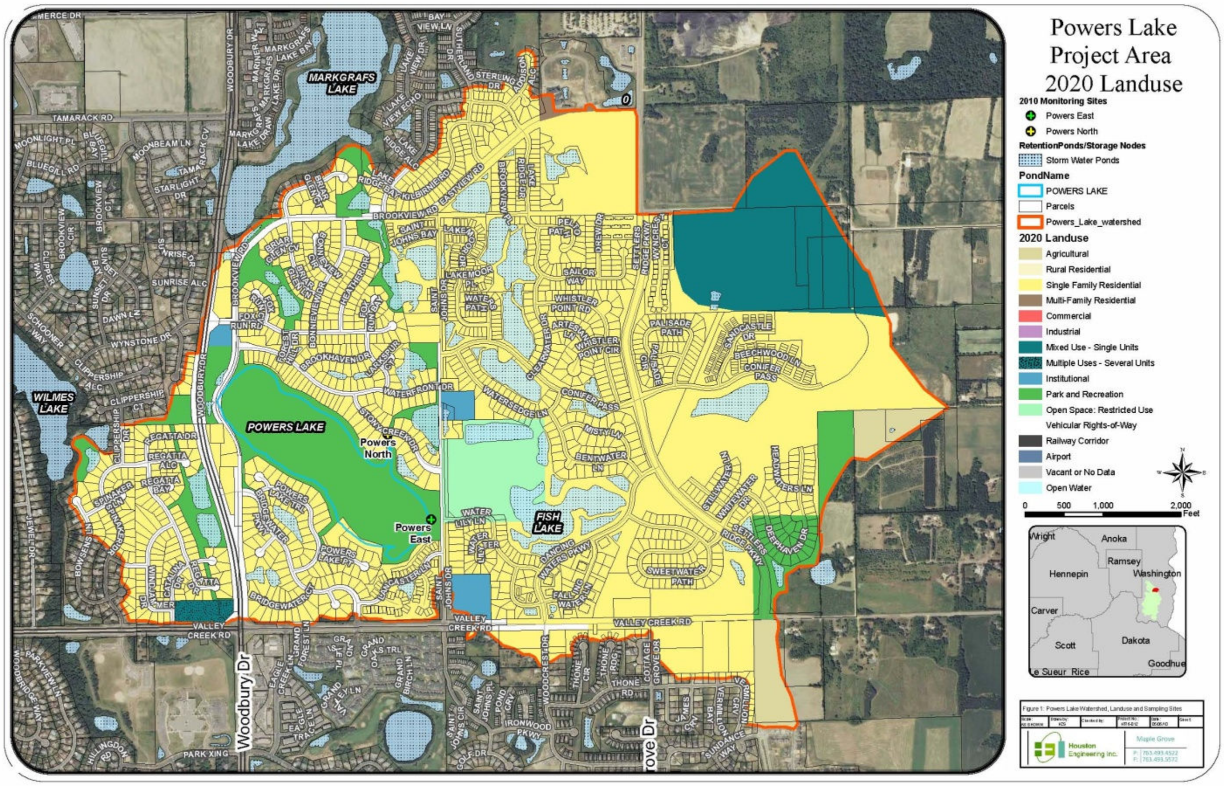
Powers Lake is an approximately 50-acre lake located in the City of Woodbury within southern Washington County. Washington County is located within the Minneapolis-St. Paul metropolitan area in eastern Minnesota (see **Figure 1**). The Powers Lake watershed is situated in the North Central Hardwood Forests ecoregion and the lake is in close proximity to the boundary with the Western Corn Belt Plains ecoregion.

Powers Lake has a drainage area of 1.93 square miles, much of which has been developed, and much of the runoff from those developed areas is directed into the lake. The lake identified by the Minnesota Department of Natural Resources (MnDNR) as Public Water No. 82-0092-00, has a public access and a managed sport fishery including pan fish and game fish weighing more than 3 pounds. The lake normally has no surface outlet so outflow likely occurs as recharge to the groundwater. The recorded lake elevation has ranged more than 23 feet (URL: http://www.dnr.state.mn.us/lakefind/showlevel.html?id=82009200, accessed April 29, 2010).

The Watershed Management Plan (WMP) implemented by the SWWD in 2007 suggested that Powers Lake is showing evidence of water quality degradation, with increased phosphorus concentrations and decreased clarity. In an effort to prevent continued degradation of Powers Lake, the SWWD requested the assistance of Houston Engineering, Inc. to evaluate existing data and develop models that would describe the stresses imposed upon Powers Lake. This information would be used to establish a load allocation serving as the basis to improve management of the lake and its watershed. It is anticipated that the successful completion of this study will result in similar studies conducted for other important lakes in the SWWD.

This report presents an assessment of the water quality for Powers Lake including the estimated water budgets and total phosphorus mass balances for two years of monitoring. These are used along with modeling to develop a phosphorus load allocation recommendation for the Powers Lake watershed to achieve the Minnesota Pollution Control Agency (MPCA) numeric water quality standard and SWWD water quality goal for total phosphorus.

Figure 1 – Map Showing Powers Lake Watershed, Land Use, and Sampling Sites



2.0 POWERS LAKE INFORMATION

2.1 Classification

Powers Lake is not specifically listed in Minnesota Rules (MR) 7050.0186 (wetlands) or 7050.0470 (lakes), which pertain to water body use classifications within the major drainage basins of the State. According to 7050.0430 unlisted waters are classified as Class 2B, 3C, 4A, 4B, 5, and 6 waters. Relative to the aquatic life and recreation classification for Powers Lake (i.e., 2B –see MR 7050.0220) the quality of surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface waters is also protected as a source of drinking water.

Although according to the MnDNR public waters map Powers Lake is classified as a protected wetland, Powers Lake is in fact a lake and required to meet the MPCA Class 2B standards. Powers Lake is a deep lake, as the maximum depth exceeds 15 feet and the lake thermally stratifies, based on data collected by the SWWD. Applicable conventional water quality standards that apply to Powers Lake include dissolved oxygen, pH, and temperature, but nutrients and specifically total phosphorus are of primary interest. The applicable MPCA eutrophication numeric standards expressed as the June through September average value for a near-surface (epilimnetic) sample are: total phosphorus (TP) should not exceed 40 micrograms per liter (ug/L); chlorophyll-*a* (chl-*a*) should not exceed 14 micrograms per liter (ug/L); and Secchi-disk transparency (SD) should be at least 1.4 meters.

The average values for TP, chl-*a*, and SD were computed for 2007 and 2008 using data obtained from the MPCA Environmental Data Access (EDA) Internet site. Those average values were used to compute trophic state indices using the formulas provided by Carlson (1977). The results of those data summaries are provided in **Table 1**. Lakes having TSIs between 40 and 50 are classified as mesotrophic, while lakes having TSIs between 50 and 70 are classified as eutrophic. During 2007 all measurements indicated that the lake was eutrophic. However, during 2008 all values had improved and the TSIs for TP and SD dropped into the mesotrophic category.

Table 1 – Average Values for Powers Lake Trophic State Indicators

	Chlorophyll *a* ug/L		Total Phosphorus, mg/L		Secchi-Disk, meters	
	2007	2008	2007	2008	2007	2008
	Values					
Mean	16.0	11.7	0.046	0.028	1.81	2.39
Median	14.0	11.0	0.031	0.028	1.76	2.15
	Trophic Status					
Mean	57.8	54.7	55.0	47.8	51.4	47.4
Median	56.5	54.1	49.3	47.8	51.8	49.0

Because of the complex hydrology of this lake, it is difficult to determine whether these changes resulted from improved water quality, dilution, or improved stability in the stratification discussed below, which could lead to reduced TP concentration near the surface.

Generally the lake is non-contributing to downstream flows. However, under high water conditions the Powers Lake can outlet via a lift station downstream to Wilmes Lake.

2.2 Water Quality

Powers Lake has been monitored by various agencies since 1994 and that monitoring continues. With some exception, this study used data that was collected by the SWWD during 2007-08, which includes monitoring of runoff to the lake. These data were used to calibrate and validate models used to establish the load allocation. Selecting this narrow time frame will reduce some of the variability that might result from mixing data from differing sampling efforts that might have used different sampling and analytical methods.

Powers Lake experiences strong thermal stratification which typically isolates warm, well oxygenated water near the surface in the epilimnion from colder, poorly oxygenated water near the bottom in the hypolimnion. These upper and lower waters are separated by a transitional layer called the thermocline where the temperature and dissolved oxygen concentration decrease rapidly with increasing depth. The thermocline in Powers Lake during 2008 occurred at about 8-10 meters depth early in the open-water season, and became shallower, about 4-6 meters deep, during most of the summer. This stratification breaks-up during the spring and fall when epilimnetic water is cooler. Persistent winds can cause the epilimnetic and hypolimnetic waters to mix during these seasons. Winter ice cover will cause reverse stratification with the coolest water (about zero degrees Celsius) near the surface, and the warmest water (about 4 degrees Celsius; water's maximum density) near the bottom.

Phosphorus concentrations in lake water often become elevated in the hypolimnion of stratified lakes, because the nearly anoxic conditions results in the release of dissolved phosphorus from enriched bottom sediments. This phosphorus remains isolated from epilimnetic waters while the lake is stratified except during extreme wind conditions. The isolation of the epilimnetic and hypolimnetic waters reduces use by phytoplankton and may otherwise cause algal blooms. However, that phosphorus-enriched water is mixed with the epilimnetic water during spring and/or fall turnover.

Figure 2 illustrates the change in total phosphorus concentrations near the surface of Powers Lake during 1994-2008. Starting about 2001 concentrations appeared to be sustained at a slightly higher concentration. At about the same time, unusually high concentrations of total phosphorus were measured that may have originated from the phosphorus-enriched hypolimnion, or phosphorus-enriched runoff water.

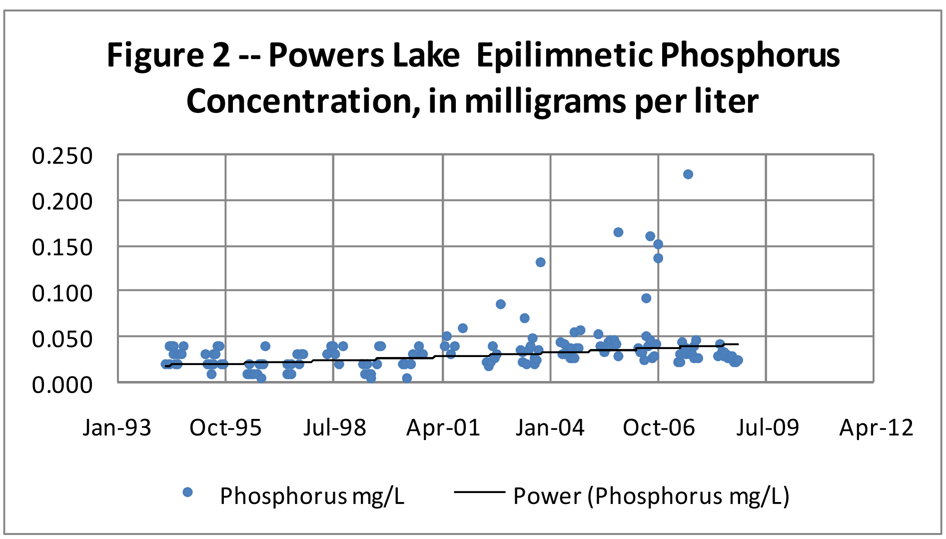


Table 2 shows hypolimnetic concentrations of phosphorus that were collected from Powers Lake during more recent sampling visits. Concentrations ranged from 0.029 milligrams per liter (mg/L) during April, 2007 (presumably a result of dilution during spring turnover or

snowmelt runoff) to more than 0.50 mg/L late in 2008. It is fortunate that the hypolimnetic phosphorus typically is "unavailable" during the growing season to augment and increase the growth of phytoplankton in the epilimnion of Powers Lake.

Table 2 -- Concentrations of Total Phosphorus in the Hypolimnion of Powers Lake.

Sample Date	Sample Depth	Phos-phorus mg/L
5/17/2006	10.7 m	0.265
6/1/2006	11.3 m	0.332
6/28/2006	11 m	0.499
7/25/2006	11.3 m	0.429
8/22/2006	11.3 m	0.329
9/19/2006	11.3 m	0.376
10/17/2006	10.7 m	0.164
4/23/2007	11 m	0.029
6/19/2007	12 m	0.544
8/15/2007	11 m	0.332
10/11/2007	12 m	0.439
5/21/2008	11 m	0.083
6/2/2008	12 m	0.168
6/17/2008	12 m	0.205
6/30/2008	11 m	0.252
7/14/2008	10 m	0.273
7/29/2008	12 m	0.340
8/13/2008	11 m	0.365
8/28/2008	11 m	0.556
9/9/2008	11 m	0.492
9/25/2008	10.5 m	0.597
10/8/2008	10 m	0.595
10/21/2008	9 m	0.577
Mean		0.358
Median		0.340
Minimum		0.029
Maximum		0.597

2.3 Current lake use and features

The fisheries report for Powers Lake prepared by the MnDNR indicates the fish species present in the lake during the last survey in 2007 included bluegill, black crappie, largemouth bass, northern pike, walleye, yellow perch, and bullhead. The MnDNR stocked the lake in 2007 with 2000 walleye yearling. The lake has a fishing pier, and the fish are tested for to ensure a fish consumption advisory is not warranted. The lake is part of the FIN – Fishing In the Neighborhood program. The information also indicates that Powers Lake is one of the best fishing lakes in Woodbury and has many species of game fish.

2.4 Watershed Characteristics and Land use

The Powers Lake watershed and the subwatersheds were delineated as part of previous modeling studies completed by the SWWD and presented in the 2006 SWWD WMP. Those boundaries are used in this report. Although the watershed consists of developed and undeveloped land the majority of the land is developed with the exception of a few scattered parcels on the eastern side of the watershed (**Figure 1**). The predominant land use is single-family residential. Some areas to the east are zoned as single-family residential, but are shown as being undeveloped. There are scattered areas of park land, especially near water bodies. According to the 2030 City of Woodbury Comprehensive Plan there are few areas not already classified as open space or natural land use that face the potential of being developed. For this report, the entire watershed will be considered “developed”. Therefore, separate load allocations were not determined based on developed and undeveloped areas.

The Powers Lake watershed is situated on geologic materials that have a large hydraulic conductivity (Barr, 2005). Because of this, precipitation often infiltrates into the subsurface and moves as sub-surface (groundwater) flow rather than running off. Barr (2005) suggests that outflow from the lake goes to the local groundwater flow system as recharge. Impervious surfaces will produce runoff, but that often is conveyed to nearby catchment basins where the water will have the opportunity to infiltrate. The model used to estimate runoff to Powers Lake is capable of correctly simulating runoff through the application of curve numbers that take into account the pervious characteristics of the soils.

Powers Lake receives runoff enhanced by impervious surfaces, but has little or no outflow except during extreme runoff events. The outlet of Powers Lake is controlled by a lift station placed at an elevation of 890.0 MSL, but that has not been needed since installation in 1995 (SWWD, 2007).

Two subwatersheds to Powers Lake have been and continue to be sampled at sites for streamflow and concentrations of important constituents including TP as shown on **Figure 1**. These data are used to compute loads contributed to Powers Lake and provide input to the models used in this study. The data used for this study were collected during 2007-08, although the sampling period has been longer. Earlier data had uncertain quality, so it was decided that they would not be used to develop and calibrate the model for this study. However, the data were used as input to the model during the warm-up leading to 2007-08.

The sites sampled are believed to generally represent runoff and loads to Powers Lake. These data were used to extrapolate to other locations without measured data within the watershed. **Table 3** summarizes the areas and characteristics of the watersheds monitored compared to the total drainage area of Powers Lake.

Table 3 - Areas and Characteristics of Powers Lake Watersheds.

	Area (acres)	Average Slope (percent)	Percent Impervious Area
East Tributary	549	1.93	36.1
North Tributary	134	2.00	35.5
Total Drainage Area	1290	1.85	35.9

The total drainage area encompasses the entire watershed, whether it does or does not contribute runoff directly to the lake, and includes the area of Powers Lake. Based on slope and impervious area, the slope and amount of impervious area of the sampled subwatersheds are reasonably representative of the entire drainage system. These data collected from the subwatersheds were normalized by dividing by their area and used to construct the hydrologic budgets and mass balances.

2.7 Hydrologic Budget

2.7.1 Lake Evaporation

To provide the additional inputs needed to the Powers Lake receiving water model and to construct the water budget, evaporation from the lake was estimated. Evaporation accounts for an important component of the overall water budget of Powers Lake, making an estimate of this process essential. 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 for shallow lake evaporation. Three methods were analyzed that include the Lake Hefner #1 and #2 and the Meyer method. The average value for all methods was used to determine yearly evaporation.

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 Minneapolis St-Paul airport was used to compute evaporation for the 2007 and 2008 seasons. Data obtained from the weather station were on a daily time step; evaporation was computed for this daily time scale and summarized annually. The mean annual evaporation used in establishing the load capacity is an estimated 44.7 inches (2000 – 2008), compared to the estimate value of 65.2 inches for 2007 and 44.6 inches for 2008. The probability distribution for the annual mean evaporation is lognormal with a coefficient of variation of 26.5%.

2.7.2 Groundwater

An assessment of groundwater resources in Washington County determined that Powers Lake is a “recharge” waterbody with respect to interaction with groundwater (Barr, 2005). This indicates that the lake drains to groundwater. The Barr (2005) report indicates Powers Lake does not receive nutrient input from groundwater. The groundwater component of the water budget was not specifically measured, but determined by difference (along with error) by estimating the remaining terms.

2.7.3 Precipitation

Long-term precipitation records (1972 – 2008) from the Minneapolis-St. Paul airport were used to estimate the amount of precipitation reaching the lake surface and as a forcing function for the watershed model. The mean annual precipitation used in establishing the load capacity is an estimated 30.9 inches (1972-2008), compared to the estimate value of 27.4 inches for 2007 and 25.7 for 2008. The probability distribution for the annual mean precipitation depth is lognormal with a coefficient of variation of 25.7%.

2.7.4 Surface Runoff

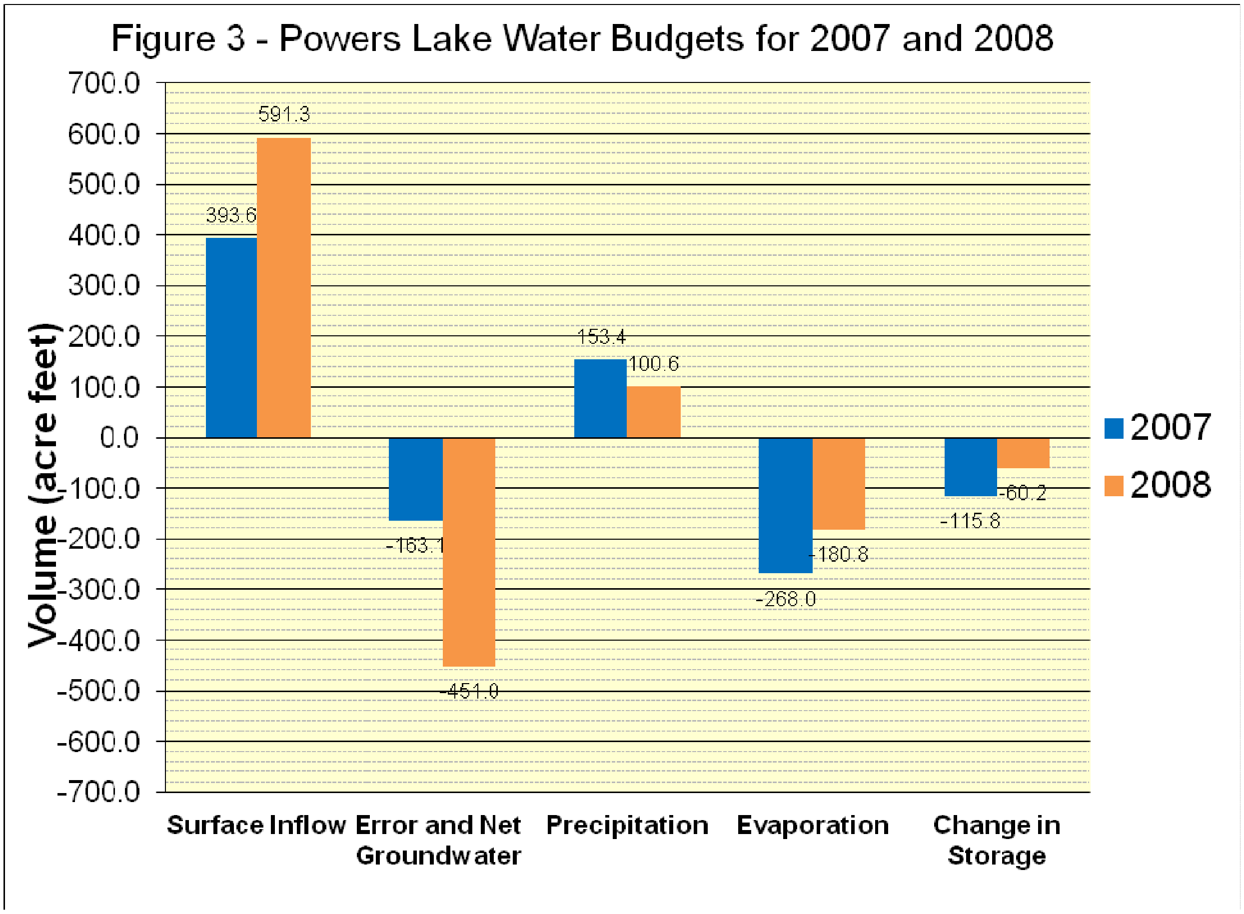
The amount of surface runoff for 2007 and 2008 was estimated based upon the Powers Lake North and East locations. Rating curves were applied to the daily stage estimates to compute estimated flows. These data were then applied to additional area contributing runoff directly to the lake and used to calibrate and validate the runoff volumes within the watershed model.

Results from the P8 model were used to determine the “surface inflow” term to Powers Lake for average long-term conditions. The model results were based on calibrated flow and concentration records for the years 2007 and 2008. Additional information regarding use of the P8 model is presented in Section 3.0.

The mean annual runoff used in establishing the load capacity is an estimated 796 ac-feet, compared to the estimate value of 393.6 ac-feet for 2007 and 591 ac-feet for 2008. The probability distribution for the annual mean surface runoff is lognormal with a coefficient of variation of 38.4%.

2.7.5 Estimated Hydrologic Budget

A hydrologic budget is an accounting of the amount of water entering and leaving a lake. The amount 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 water quality modeling. 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 affects the volume of water in the lake (storage). The hydrologic budget was estimated for Powers Lake using data from 2007 and 2008. The estimated hydrologic budgets are shown in **Figure 3**.



2.8 Total Phosphorus Budget

2.8.1 Surface Inflow

Surface inflow loads to Powers Lake in 2007 and 2008 were estimated based upon measured stream flow and grab and flow-weighted composite samples collected by the SWWD for the Powers East and Powers North monitoring locations. Annual loads from these data were estimated using the U.S. Army Corps of Engineer's FLUX model. These loads were then normalized by dividing by the contributing drainage area and the resulting yield applied to directly contributing portions of the contributing drainage area. These data were used to construct the surface inflow component of the total phosphorus mass balance. These data were also used to calibrate the P8 watershed model. The average surface inflow load was estimated using the P8 model for the period 1972-2008 using the Minneapolis-St. Paul precipitation data.

The mean annual TP runoff used in establishing the load capacity is an estimated 275 kg, compared to the estimate value of 154 kg for 2007 and 210 kg for 2008. The probability distribution for the annual mean surface runoff load is lognormal with a coefficient of variation of 53.2%.

2.8.2 Atmospheric Deposition

Atmospheric deposition to the Powers Lake watershed was determined to be 29 kilograms per square kilometer per year (Barr, 2007). The probability distribution for the atmospheric deposition was assumed to be lognormal with a coefficient of variation of 25.7%; equal to that of precipitation.

2.8.3 Internal Loading

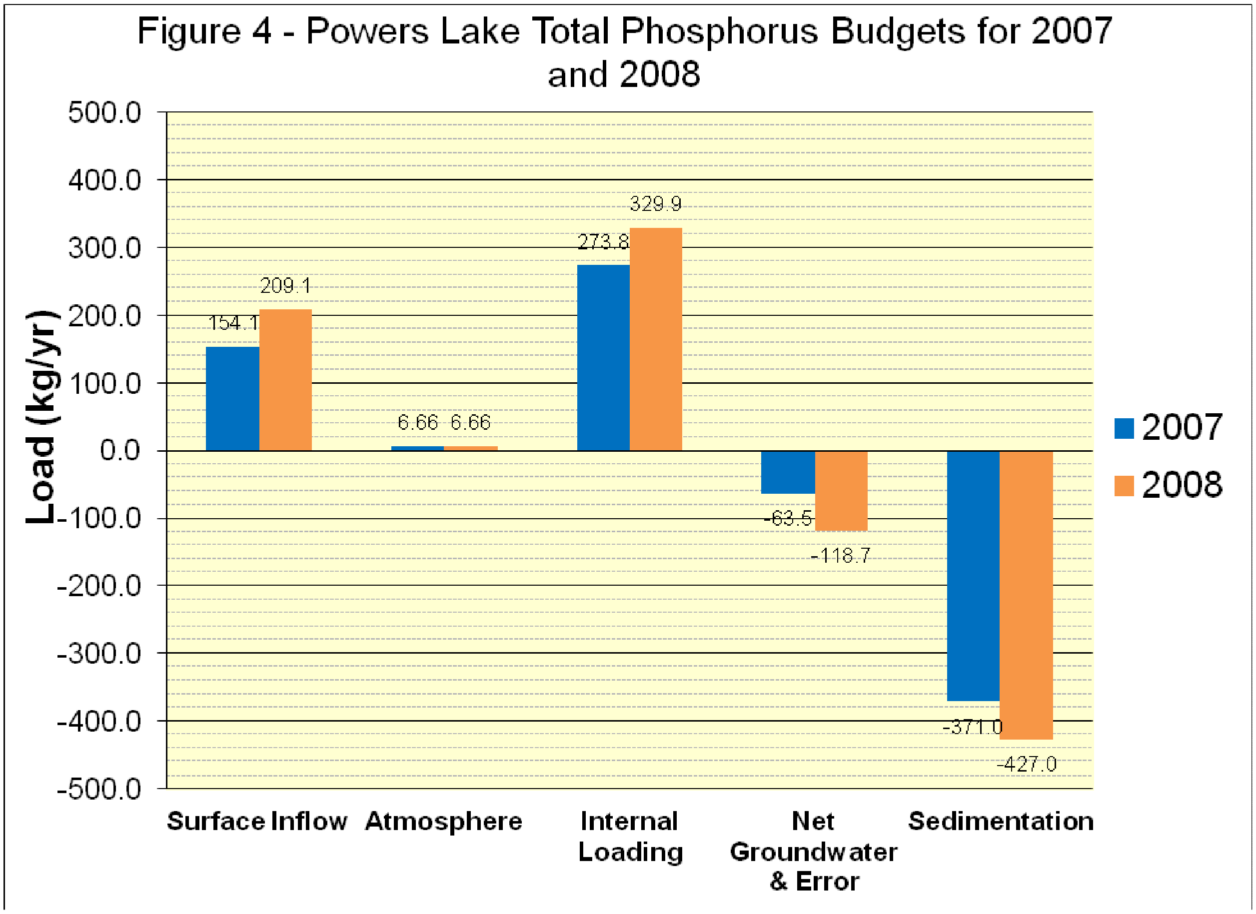
Internal loads were estimated by the SWWD using monitoring data from Powers Lake sampled during 2007 and 2008, the average depth of the surface mixed layer (to compute the volume of the hypolimnion and bottom surface area of the lake) and the duration of stratification. The temperature profiles show Powers Lake stratified for 171 days and 153 days in 2007 and 2008, respectively. The corresponding increase in total phosphorus concentration within the hypolimnion was 11.7 mg / cubic foot and 14.9 mg/cubic feet in 2007 and 2008, respectively. Estimated internal load rates during the period of thermal stratification were 6.97 and 9.39 mg/square meter /day. These estimated values are within the range of 1 to 10 mg/square meter /day characteristic of many lakes. The probability distribution for the internal loading rate was considered lognormal with a coefficient of variation of 129%.

2.8.3 Sedimentation

The estimated sedimentation rate came from the CNET receiving water model and is a function of the hydraulic residence time.

2.8.5 Estimated Total Phosphorus Nutrient Budget

Like a hydrologic budget, which is an accounting of water, a nutrient budget is an accounting of the amount or "load" of nutrients entering and leaving Powers Lake. 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 time period. The estimated TP budgets for Powers Lake are found in **Figure 4**.



3.0 MODEL DEVELOPMENT AND APPLICATION

3.1 Modeling 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. These 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 goals 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.

Modeling goals and objectives likely differ depending upon the type of modeling being performed. The two primary types of water quality modeling for this project can be broadly categorized as watershed (i.e., landscape) and receiving water modeling. The water quality goals and technical objectives for the Powers Lake Pilot Project are described in Tables 1 and 2 of a Technical Memorandum to the SWWD dated January 28, 2010. The goals and objects can be generally described as understanding the response of Powers Lake to excess nutrients, both in terms of the amount of algae and the clarity of the lake.

3.2 Watershed Modeling

The movement of water from the watershed into Powers Lake was determined using the P8 Urban Catchment Model calibrated to the 2008 monitoring data at Powers North and Powers East locations. P8 is described as a Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (URL: http://wwwalker.net/p8/, accessed April 27, 2010). The model incorporates a number of factors that encompass inflow, outflow, and the movement of sediment-related particles (including total phosphorus) through the watershed. The P8 model was run using data from 1978-2007 as a warm up which allowed the model compartments (soil moisture, particulate content, etc.) to “wash” the potential influence of initial conditions from the model results. The model then was calibrated using 2008 data and validated using the 2007 data.

The model is a good fit given the urban nature of the watershed and the model’s ability to discretely model constructed BMP’s within the watershed. The source watershed and geometric data was taken directly from the existing XP-SWMM model for Powers Lake through use of conversion software created by HEI. The "SWMM to P8" conversion was completed to provide consistency with the existing SWMM model and can be used as a tool for future analysis to evaluate "what if" scenarios for determining locations to install BMP's (i.e. rain gardens, infiltration basins) to meet TP reduction goals. Rainfall data used to generate P8 runoff volumes were taken from the Minneapolis-St. Paul airport. The data were found to be a good fit when compared to rainfall recorded for a similar time period taken at Powers Lake in 2007. The rainfall comparison can be found in **Appendix A**.

The P8 model was calibrated to measured runoff volume and phosphorus annual load at the two measurement locations as shown in **Figure 1**. The calibration was performed using 2008 and the validation using 2007. The results of the calibration and validation are found in **Table 4**.

Table 4 - Measured and Modeled Runoff to Powers Lake from Monitored Tributaries

Station	Year	Measured	Model
Runoff Volume in acre feet per Year			
Powers North	2007	15.5	12.9
	2008	18.9	13.7
Powers East	2007	85.0	79.7
	2008	80.5	79.7
Total Phosphorus Load in pounds per year			
Powers North	2007	8.4	17.0
	2008	10.3	11.4
Powers East	2007	62.8	69.5
	2008	60.2	53.3

[1]Criteria Used To Evaluate Quality

	Very Good	Good	Fair
Water Volume	<10%	10%-20%	20%-30%
Loading	<15%	15%-25%	25%-35%

When compared to the measured, the numbers generally were within the good- to very good-category. Powers North was shown to contain baseflow which could explain the higher degree of variability when compared to Powers East. The coefficients used for the P8 model were consistently applied for both Powers North and Powers East measurement locations. Loads were estimated using FLUX (URL: http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=watqual (accessed April 29, 2010). Detailed calibration information including P8 and FLUX model inputs, graphs depicting observed and P8 model flow data is located in **Appendix B**.

3.3 Receiving Water Modeling

Based upon the modeling goals and objectives we used the CNET model 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, accessed 4-27-10). CNET is a spreadsheet model currently available as a "beta" version from Dr. William W. Walker. The primary modifications to the CNET model implemented during this effort were to: 1) add an algorithm to model the surface mixed layer annual mean total phosphorus from a depth averaged annual mean total phosphorus concentration; 2) to use empirically derived regression relationships specific to Powers Lake derived from monitoring data to estimate the response of chlorophyll-a and Secchi disk depth to total phosphorus; and 3) implementing a Monte Carlo approach which allowed selected modeling parameters and inputs to vary based upon known statistical distributions and be reflected in the forecast results. The Monte Carlo approach generates a distribution of the annual mean concentrations reflecting the uncertainty in the model parameters and normal variability in inputs (e.g., annual total phosphorus load from surface runoff).

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. 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 TP, chl-*a*, and SD are allowed to vary according to their statistical distribution and therefore their probability of occurrence. This allows the effect of parameter uncertainty and normal variability in the inputs (e.g., amount of surface runoff which varies annually depending upon the amount of precipitation) to be quantified when computing the annual mean concentration of TP, chl-*a*, and SD.

The Crystal Ball software allowed for multiple probabilistic simulations of the model computations. Many trial values (10,000 trials in this study case) were generated, with each trial representing a different permutation of model parameters and input values within the bounds established by the statistical distributions. The many trials resulted in a computed distribution of annual mean concentrations rather than a single, fixed output that was based upon only one possible combination of model parameters and inputs. The stochastic approach reflects the variability in model parameters and inputs, and allows explicit determination of their effect on the mean values and the expression of model results as risk.

Prior to completing the Monte Carlo modeling analysis, the Powers Lake CNET model was calibrated using the annual water budget and TP mass balance for 2008 as described in **Section 2.7,** and validated using the annual water budget and total phosphorus mass balance for 2007 described in **Section 2.8**. 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 shows the results of model calibration using the 2008 data.

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

	Calibration Coefficient	Measured	Modeled	Absolute Difference	Percent Difference
Total Phosphorus (surface mixed layer)	0.78	46 ppb	46.2 ppb	0.2 ppb	< 1%
Chlorophyll-a	0.42	11.7 ppb	11.8 ppb	-0.1 ppb	< 1%
Secchi Disk	0.9	2.4 meters	2.4 meters	0 meters	< 1%

Table 6 shows the results of model validation using the 2007 data. The total phosphorus calibration coefficient adjusted the model results to match the observed depth averaged annual mean total phosphorus concentration. The depth averaged annual mean total phosphorus concentration was then reduced by 25% to match the observed mixed layer concentrations.

Table 6 - CNET model validation results for 2007 annual mean concentrations.

	Measured	Modeled	Absolute	Percent

			Difference	Difference
Total Phosphorus (surface mixed layer)	28 ppb	44.6 ppb	16.6 ppb	59.3%
Chlorophyll-a	16 ppb	11.8 ppb	-5.2 ppb	-32.5%
Secchi Disk	1.8 meters	2.4 meters	0.6 meters	33.3%

The validation results convey the challenges of modeling Powers Lake. A review of the monitoring data shows that the epilimnetic and hypolimnetic total phosphorus concentrations tend to differ by as much as an order of magnitude during the summer because of thermal stratification and hypolimnetic anoxic conditions. During September and October as thermal stratification decays, these high concentrations become mixed into the surface layer, elevating concentrations and the annual mean concentration. However, because of low fall water temperatures a corresponding increase in algae as reflected by the chlorophyll-a concentrations is absent. The validation results also reflect the uncertainty associated with the water budget and mass balances.

3.4 Modeling the Load Allocation

A water budget and total phosphorus mass balance for an "average year" was used to establish the TMDL. The annual mean and statistical distributions for the surface water runoff and total phosphorus load came from running the P8 model for a 30-year period. The annual mean internal load came from an average of the computed values for 2007 and 2008. Statistical distributions were generally assumed to be log normal. The CNET model spreadsheet is shown in **Appendix C** with the parameters and input values.

4.0 EUTROPHICATION RESPONSE AND LOAD ALLOCATION

4.1 Eutrophication Response

Figures 5-10 show the effects of reducing total phosphorus loads on the total phosphorus, chlorophyll-*a* and Secchi disk visibility within Powers Lake based on the CNET model, for the average condition. Loads were reduced incrementally within the CNET model and assumed to come from the surface runoff component of the mass balance. 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 annual mean values.

Figure 5 – Powers Lake Annual Mean Epilimnetic Total Phosphorus Concentrations Resulting from Selected Load-Reduction Scenarios,

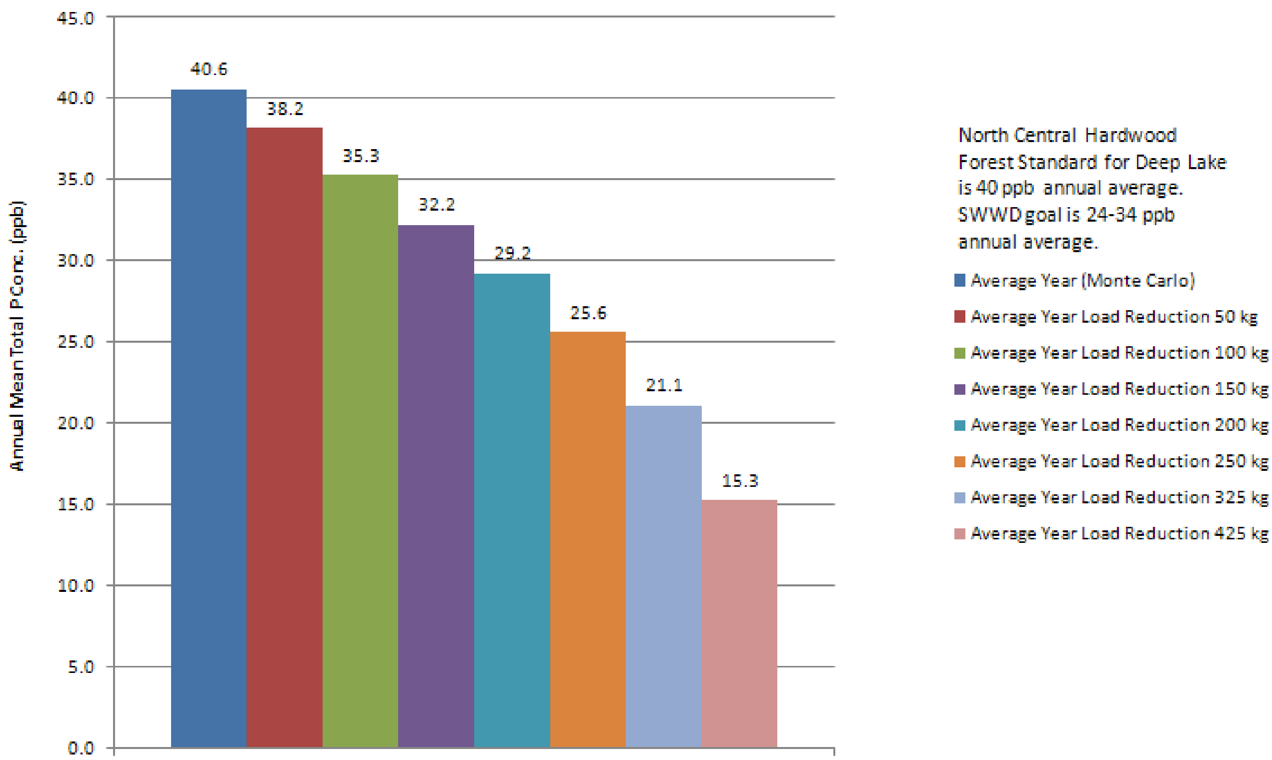
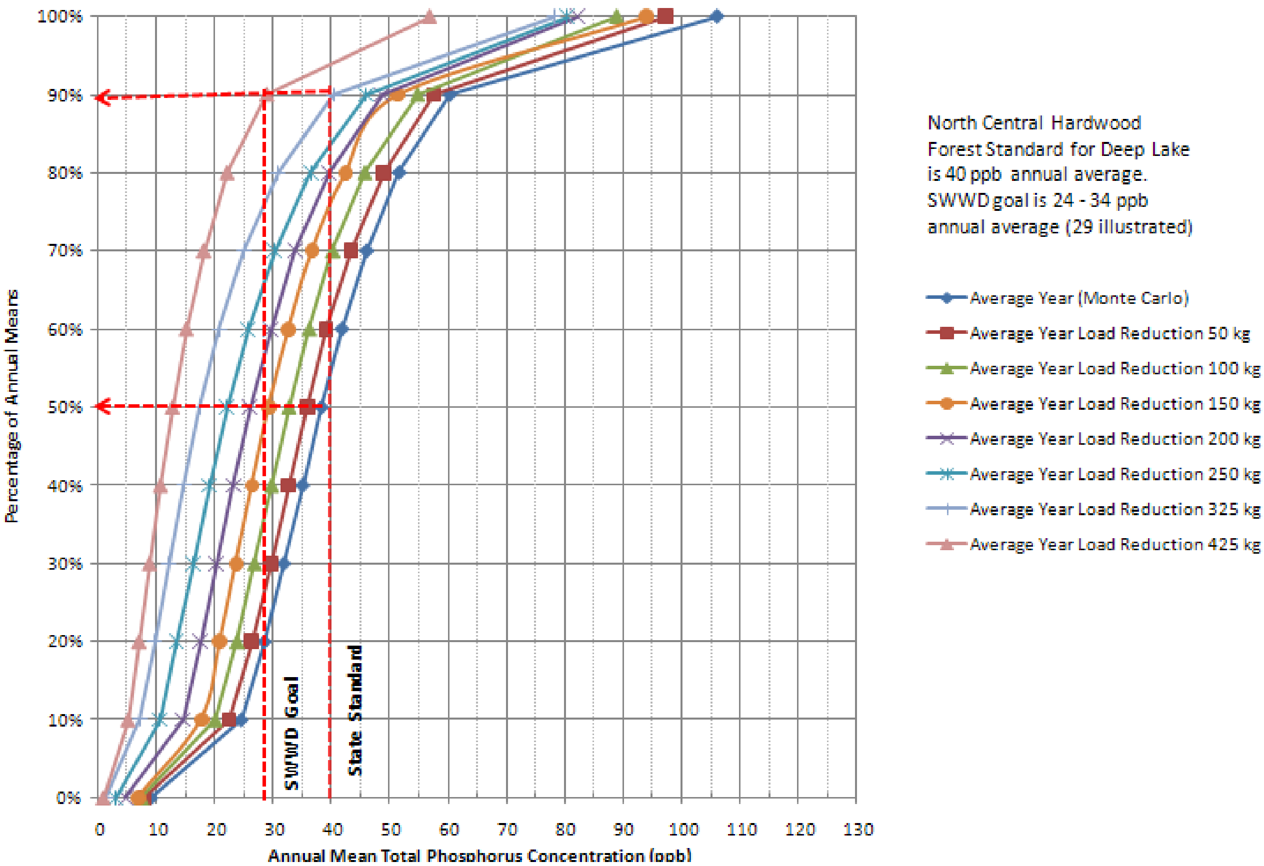


Figure 6 – Powers Lake Frequency Distribution of Annual Mean Epilimnetic Total Phosphorus Concentrations Resulting from Selected Load-Reduction Scenarios, and Table of Data used to Produce the Graphical Illustration



	Average Year (current)	Load Reduction from Current Load for Average Year 50 kg	100kg	150kg	200 kg	250 kg	325 kg	425 kg
Mean	40.6	38.2	35.3	32.2	29.2	25.6	21.1	15.3
0%	9.1	8.1	7.5	7.0	4.8	3.1	1.5	1.0
10%	24.6	22.5	20.1	17.8	14.5	10.7	7.3	5.3
20%	28.6	26.4	23.8	21.0	17.6	13.5	9.8	7.2
30%	31.9	29.7	26.8	23.7	20.4	16.3	12.2	8.9
40%	35.1	32.7	29.7	26.5	23.2	19.1	14.8	10.8
50%	38.4	35.9	32.7	29.3	26.1	22.2	17.5	12.9
60%	41.9	39.1	36.2	32.8	29.7	25.8	20.9	15.2
70%	46.1	43.4	40.2	36.7	33.8	30.3	25.0	18.2
80%	51.6	49.0	45.7	42.5	39.7	36.6	30.9	22.2
90%	60.3	57.6	54.7	51.4	48.7	46.1	40.5	29.0

100%	106.0	97.3	88.8	94.0	82.2	80.5	78.1	56.8

Figure 7 – Powers Lake Annual Mean Chlorophyll *a* Concentrations Resulting from Selected Phosphorous Load-Reduction Scenarios

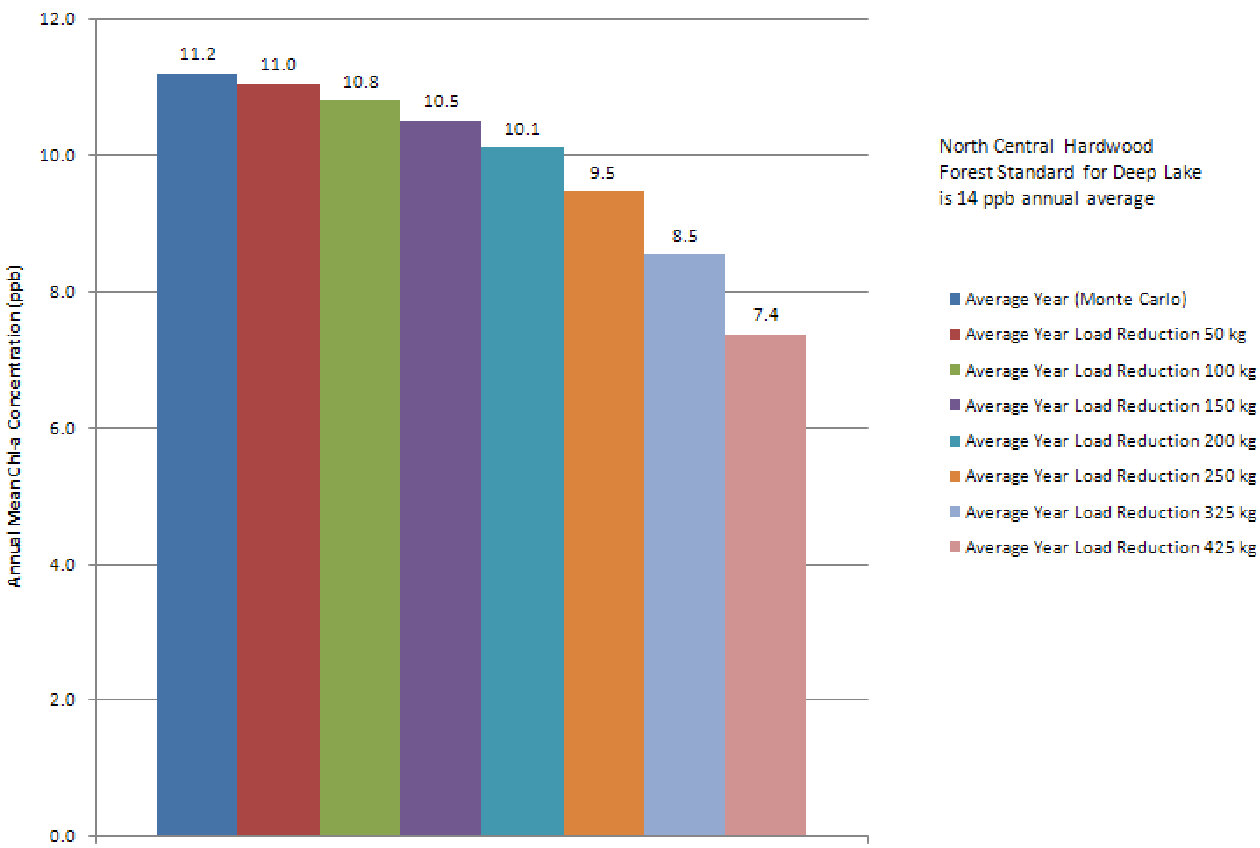


Figure 8 – Powers Lake Frequency Distribution of Annual Mean Chlorophyll *a* Concentrations Resulting from Selected Phosphorous Load-Reduction Scenarios

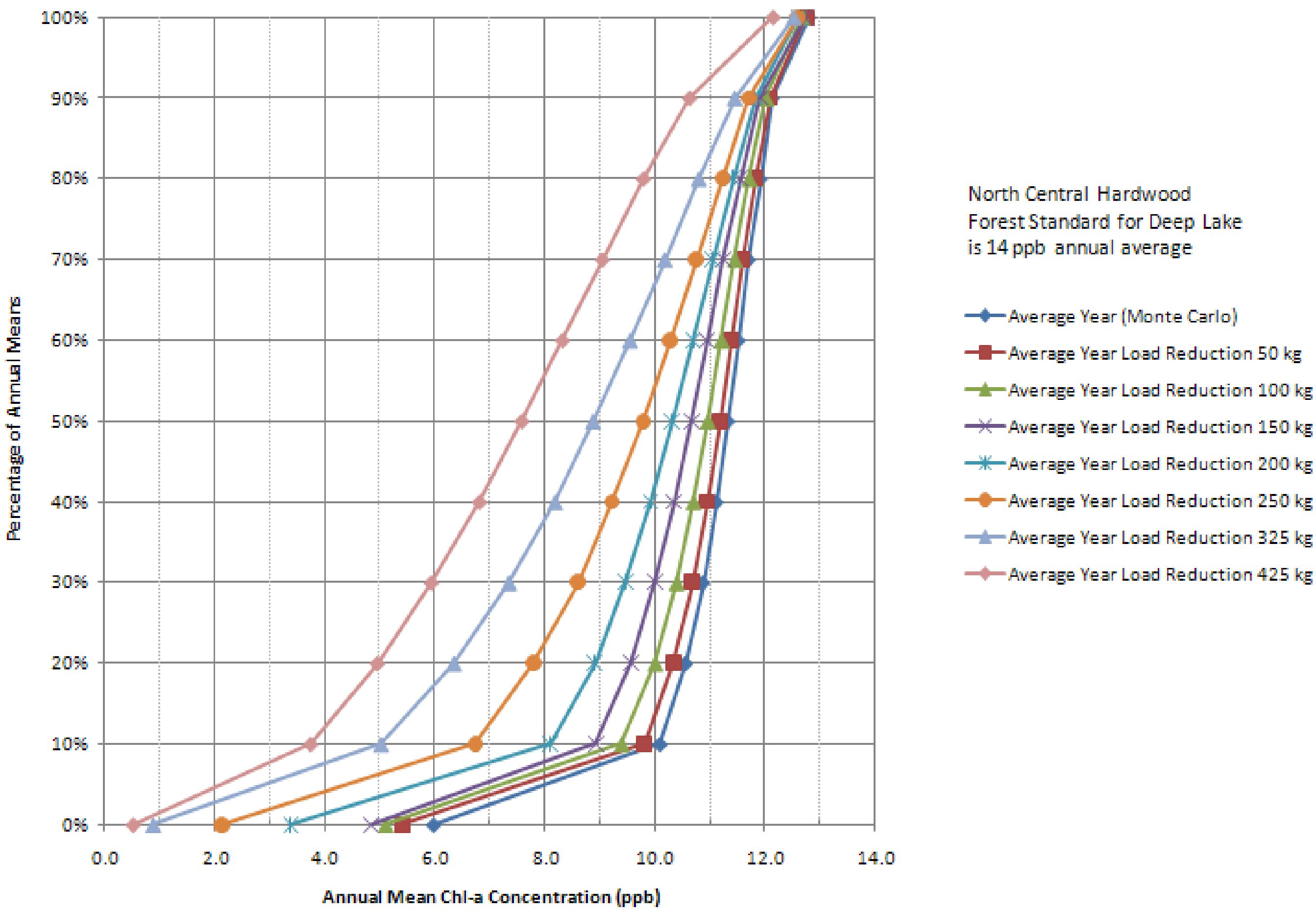


Figure 9 – Powers Lake Annual Mean Secchi-Disk Transparency Resulting from Selected Phosphorous Load-Reduction Scenarios

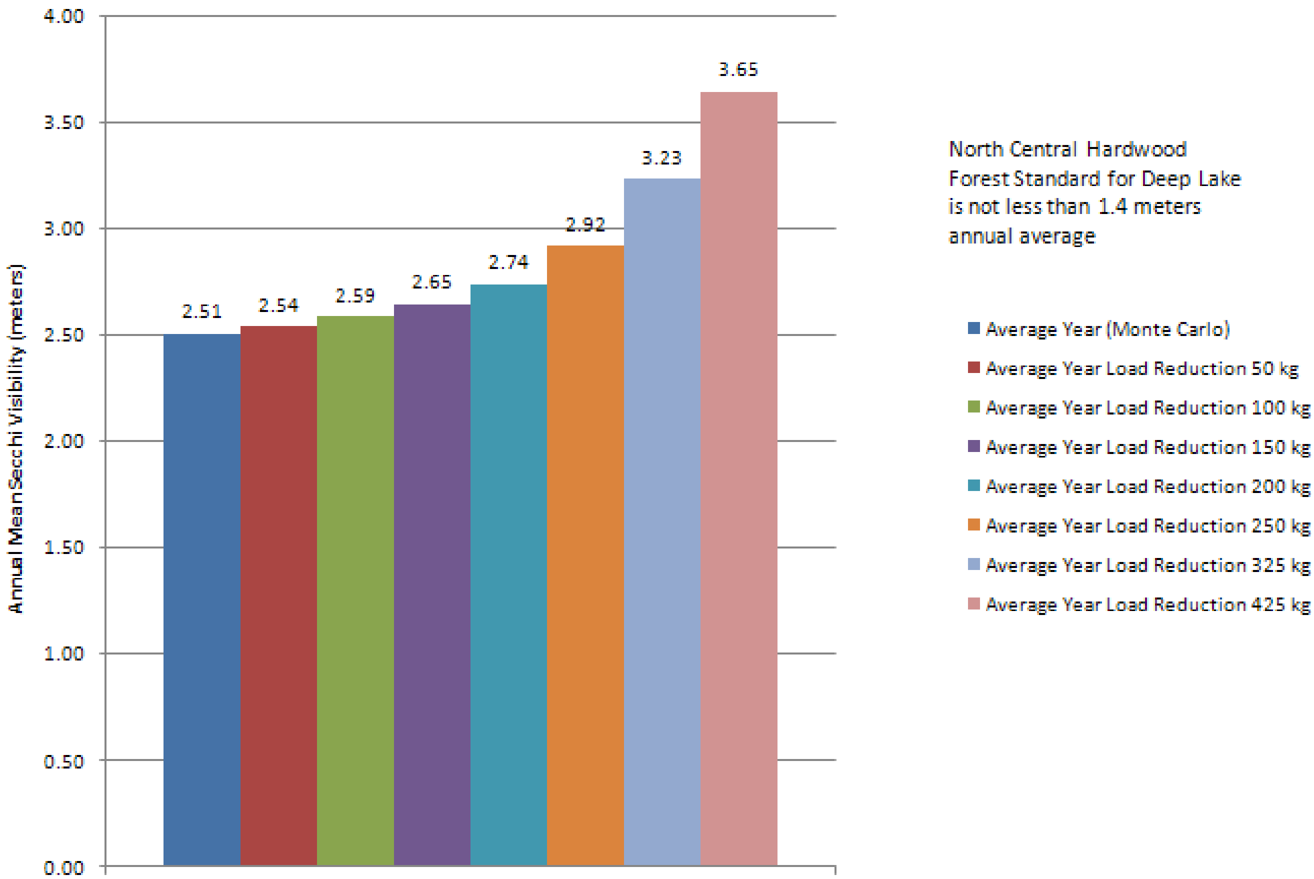
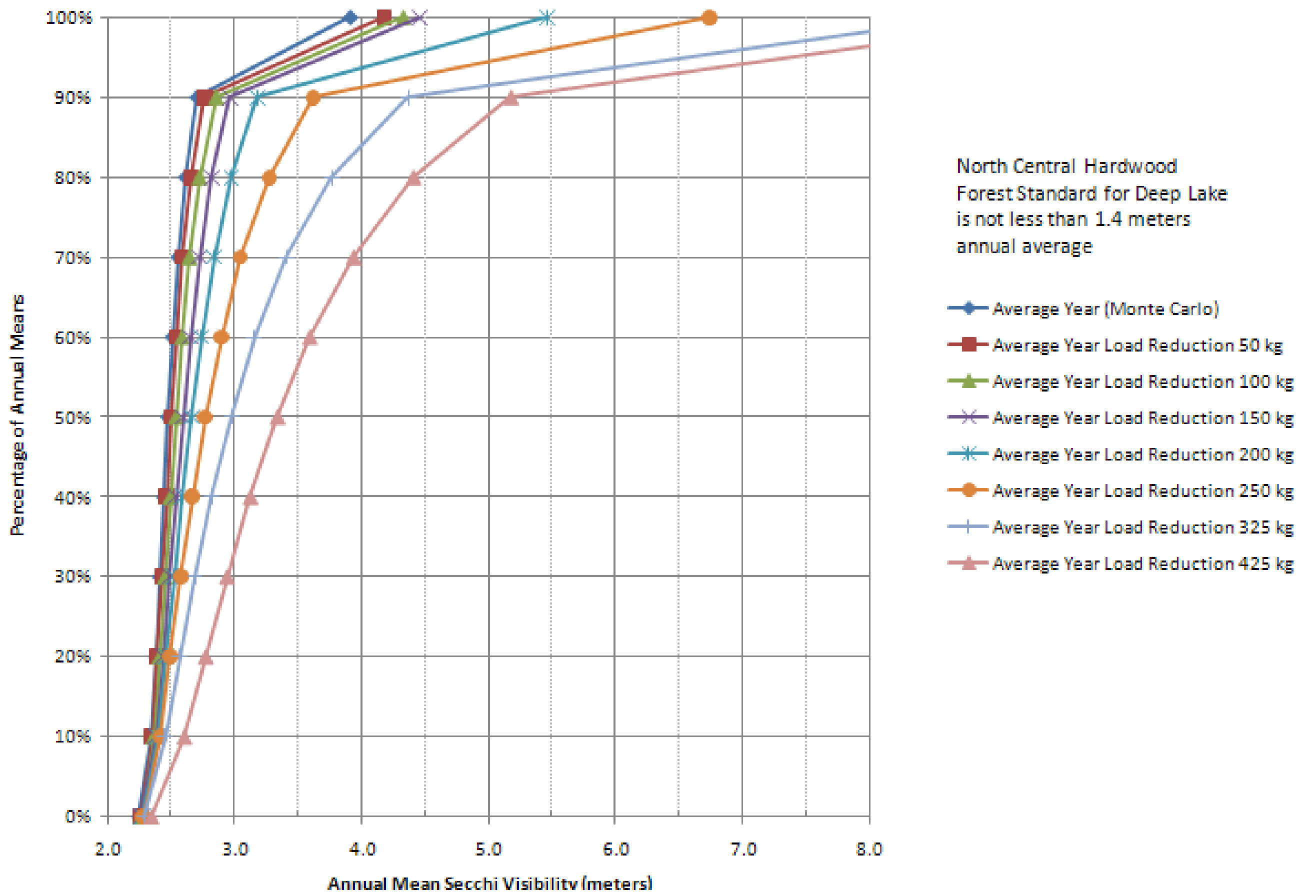


Figure 10 – Powers Lake Frequency Distribution of Annual Mean Secchi-Disk Transparency Resulting from Selected Phosphorous Load-Reduction Scenarios



4.2 Loading Capacity

The loading capacity (i.e., the TMDL) is the maximum allowable TP load to Powers Lake which can occur, while still achieving the water quality numeric standard of the MPCA (40 ug/l) and in this case, the water quality goal established by the SWWD (24-34 ug/l). 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 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 lack of knowledge in establishing the load capacity.

The loading capacity is the annual load reduction (expressed on a daily basis) for the average year, necessary to reduce the annual mean TP concentration for the 90th percentile nonexceedance value to the MPCA numeric standard (40 ug/l). A second loading capacity is computed in the same manner to achieve SWWD goal (24 – 34 ug/l; 29 is used for the loading capacity), The 90th percentile nonexceedance 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. The approach translates into one exceedance every 10 years and is consistent with the use of monitoring data for the purposes of placing a waterbody on the 303(d) list. 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 or the SWWD goal of 29 ug/l.

Figure 6 shows a line at 40 ug/L representing the average summer epilimnetic TP concentration eutrophication standard provided in MR 7050.0222 for the protection of lake quality in Class 2 surface waters in the North Central Hardwood Forest ecoregion. Another line at 29 ug/L represents the average summer epilimnetic TP concentration standard chosen by the

SWWD (2007) for the protection of lake quality. These lines were used to determine the level of phosphorus load reduction (i.e., loading capacity) that would be needed to achieve the desired quality of Powers Lake. A table accompanying **Figure 6** shows the values for the nodes used to produce the figure.

Shown below is the loading capacity table (**Table 7**) that would be employed if Powers Lake were to be evaluated as a TMDL-listed water body. Approximating from **Figure 6** and using the values from the accompanying table**,** the following load allocation was developed:

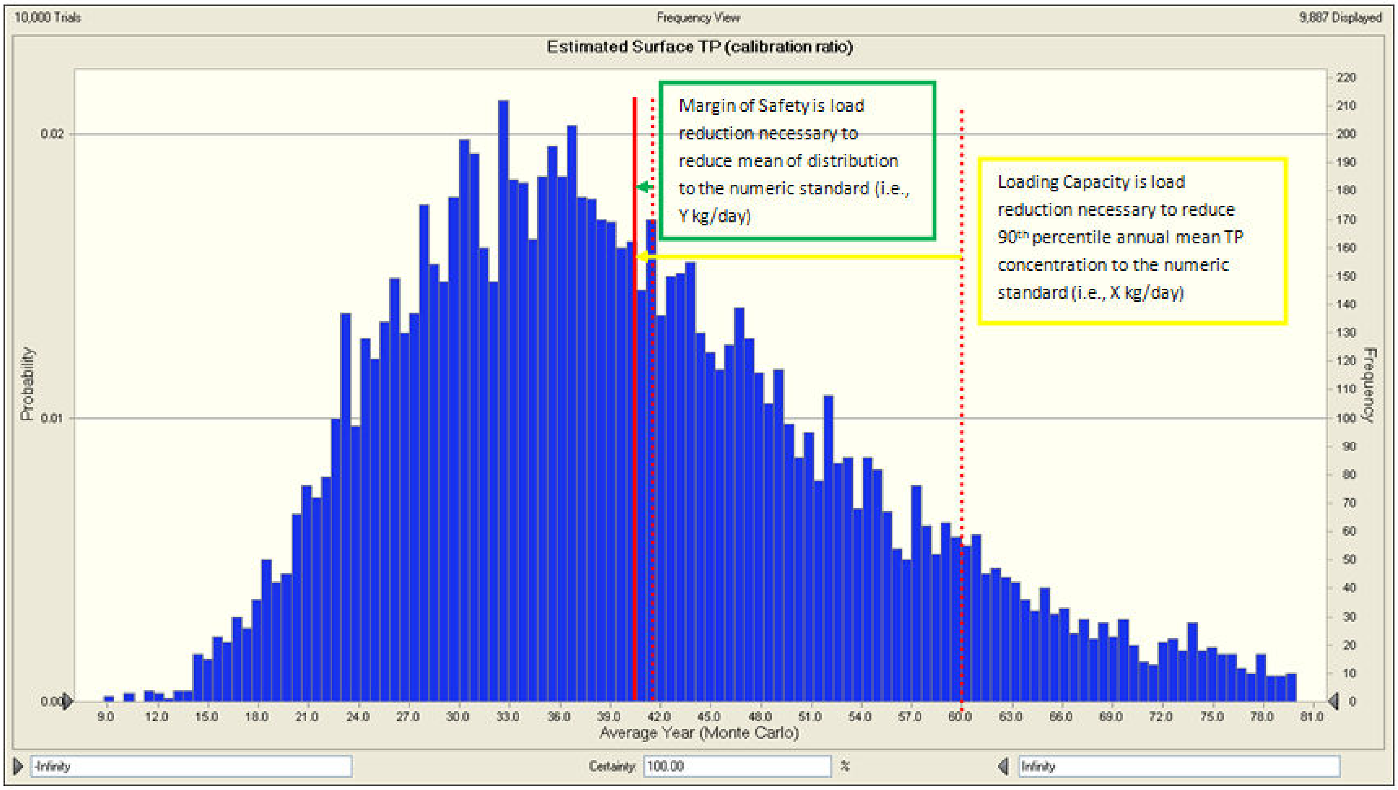
Table 7 - Powers Lake Loading Capacity to Meet MPCA Standard of 40 ug/l Total Phosphorus Annual Mean Concentration for average conditions. Values are in kilograms per day (numbers in parentheses are current average loads).

	Loading Capacity	=	Load Allocation	+	Wasteload Allocation	+	Margin of Safety
Current Condition	1.59	=	0.84	+	0.75	+	0
Future Goal: 40 ug/L	0.71	=	0.12	+	0.56	+	0.03

It is estimated that the current 1.59 kg/d phosphorus load to Powers Lake would have to be reduced to 0.71 kg/d. It is estimated that the wasteload allocation, which is storm-sewered runoff from the watershed, would have to be reduced by 25%; from 0.75 to 0.56 kg/d. The remainder would have to come from the load allocation which is comprised of both atmospheric and internal loading from the phosphorus-laden bottom sediments. The atmospheric loading of 0.018 kg/d is beyond the control of the SWWD, so the reduction would need to come from internal TP loading. The approximately 0.82 kg/d internal TP load would have to be reduced 88% to achieve the 0.10 kg/d internal load needed to meet the 40 ug/L goal 90% of the time. In reality any combination of waste load allocation and load allocation equaling 0.68 kg/d is able to achieve the loading capacity.

Figure 11 shows the probability distribution of the mean summer TP concentration for Powers Lake. The solid red vertical line shows the current annual mean of the TP 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 TP concentration that would occur about once every 10 years (the 90th percentile; about 60 ug/L). To achieve the 40 ug/L goal 90% of the time, the distribution needs to be shifted (yellow 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.

Figure 11 -- Probability Distribution of the Mean Summer Total Phosphorus Concentration for Powers Lake



A loading capacity table (**Table 8**) also was prepared for the SWWD lake TP goal of 55 ug/L. A compliance of 90% also was assumed for this scenario. Approximating from **Figure 6** and using the values from the accompanying table, the following loading capacity was developed:

Table 8 - Powers Lake Loading Capacity to Meet SWWD Goal of 29 ug/l Total Phosphorus Mean Annual Concentration. (Values in kilograms per day).

Loading Capacity SWWD Goal: 29 ug/L		=	Load Allocation	+	Wasteload Allocation	+	Margin of Safety
Current Condition	1.59	=	0.84	+	0.75	+	0
Future Goal: 29 ug/L	0.43	=	0.002	+	0. 38	+	0.03

It is estimated that the current 1.59 kg/d phosphorus load to Powers Lake would have to be reduced to 0.43 kg/d. It is estimated that the wasteload allocation, which is storm-sewered runoff from the watershed, would need to be reduced by 50%; from 0.75 to 0.38 kg/d. The remainder would have to come from the load allocation which is comprised of both atmospheric and internal loading from the phosphorus-laden bottom sediments. The reduction would need to come from internal TP loading. The approximately 0.82 kg/d internal TP load would have to be reduced effectively by 100% to achieve the 0.002 kg/d internal load needed to meet the 29 ug/L goal 90% of the time. In reality any combination of waste load allocation and load allocation equaling

There are no other NPDES permitted facilities in the watershed. There are a few MPCA permitted facilities that might contribute runoff from construction and storage tanks in the watershed. Because they are permitted, it can be assumed that discharges that may occur are controlled and will not directly affect the quality of Powers Lake.

Potential pollution sources that could contribute wasteload to Powers Lake were categorized in the current Watershed Management Plan (SWWD, 2007). It identifies no pollution sources within the Powers Lake watershed and therefore confirms zero wasteload. Waste loads from Subsurface Sewage Treatment Systems (SSTS), previously referred to as Individual Sewage Treatment Systems are also assumed to be zero because the vast majority (over 95% based on land coverage) of the watershed is serviced by municipal sanitary sewer. In addition, future development will require connections to the municipal sanitary system.

The LA portion of the loading capacity equation includes internal loading and atmospheric deposition. The loading capacity equation assumes that the internal load would be reduced by an estimated 88% to achieve the 40 ug/L standard. Because the internal TP load to

Powers Lake would have to be reduced in the MPCA-based load-allocation scenario (and to a greater degree using the SWWD 24-34 ug/L goal), some form of phosphorus sequestration would be needed. Various methods can be employed, but one of the more common methods is alum treatment.

5.0 IMPLEMENTATION TO ACHIEVE THE LOADING CAPACITY

5.1 Priority Implementation Areas

The P8 model provides information to determine existing storage-node (retention pond) performance for the Powers Lake watershed. The storage node locations and contributing watersheds have been identified in **Figures 12** and **13**, respectively. Using the results from the 30-year simulation of the P8 model, the following storage node and watershed terms were analyzed. They include:

- TP Removal Efficiency,
- TSS Removal Efficiency, and
- Direct Watershed Yield

Figure 12 -- Map Showing Powers Lake Watershed Model: Removal Efficiency

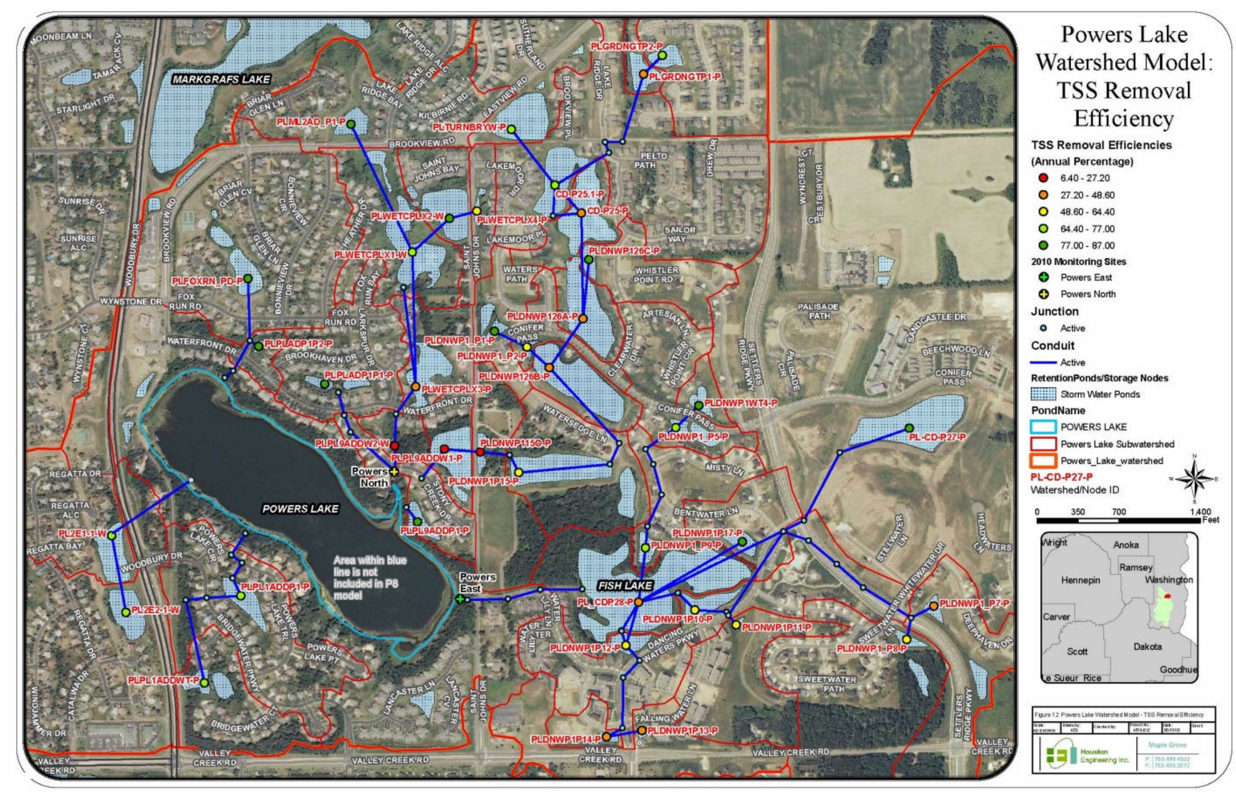


Figure 13 -- Map Showing Powers Lake Watershed Model: Existing Conditions Total Phosphorus Yield

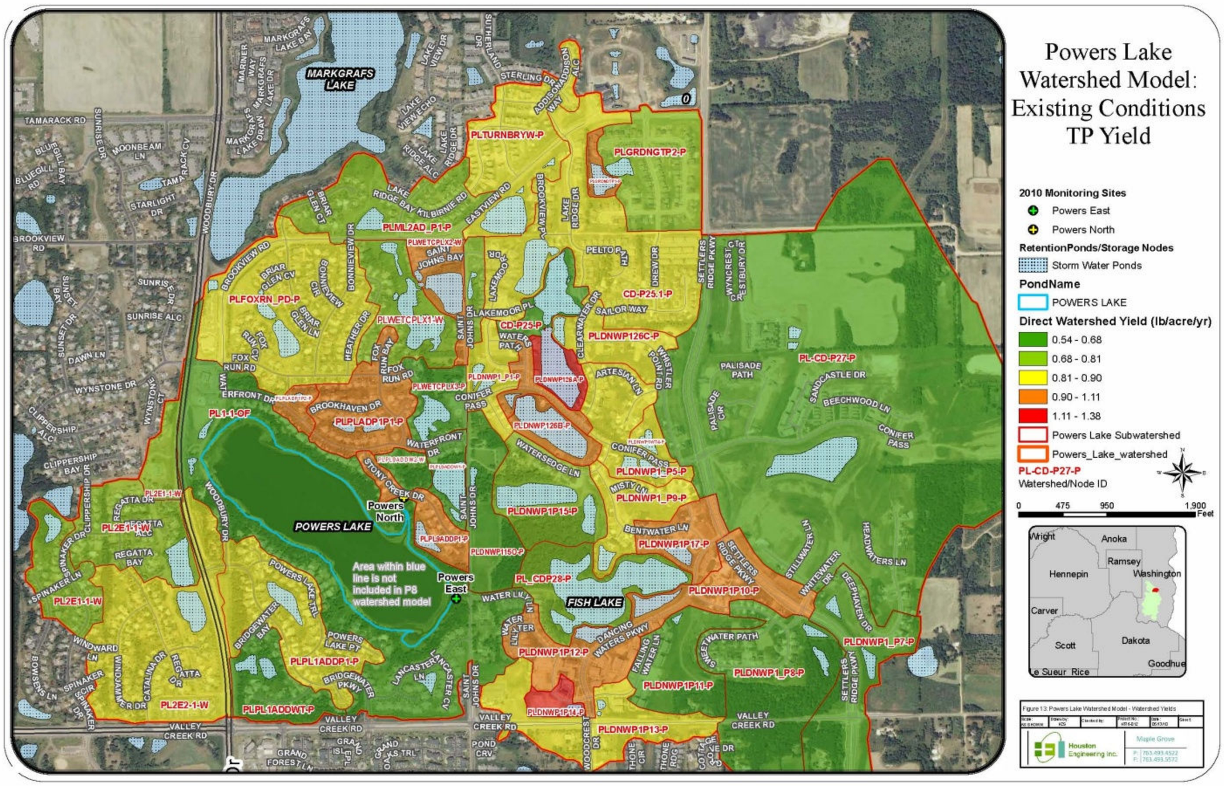


Figure 12 displays the TSS removal efficiency as an annual percent for each of the ponds modeled. The P8 model estimates removal efficiencies generally based on particulate removals, therefore TP removals are directly related and commensurate to TSS removals. **Figure 13** displays the existing conditions TP yield from each of the modeled sub-watersheds. The SWWD considers a yield of 0.06 lb/ac/year acceptable (SWWD, 2007). **Table 9** shows the storage nodes sorted by decreasing watershed yield, with the twelve nodes having the lowest removal efficiency highlighted. The order and highlighting shown in **Table 9** suggests higher priority areas which could be targeted for additional BMP implementation. The highlighted nodes represent storage nodes that achieve less than 50% TSS removal and 15% TP removal based on P8 modeling.

Table 9 - Powers Lake Estimated Watershed Yield and Pond Performance based on the P8 model.

Watershed or Storage Node	Direct Watershed Yield lb/acre/yr	TSS Efficiency % rem.	TP Efficiency % rem.
PLDNWP1P14-P	1.37	34.5	8.5
PLDNWP126A-P	1.23	47.3	6.1
PLDNWP126B-P	1.12	47.5	5.6

PLDNWP1P12-P	1.08	64.4	21.4
PLWETCPLX2-W	1.02	85.4	32.9
PLDNWP1P10-P	0.99	53.6	16.2
PLDNWP1P17-P	0.98	87.0	36.3
PLDNWP1_P2-P	0.96	62.1	15.1
PLPL9ADDP1-P	0.96	81.1	31.9
PLPLADP1P1-P	0.96	82.5	33.6
PLPLADP1P2-P	0.95	78.9	31.0
PLGRDNGTP1-P	0.94	46.5	11.2
PLTURNBRYW-P	0.90	73.3	26.1
PLDNWP1_P9-P	0.90	72.2	20.6
PL2E2-1-W	0.90	72.6	25.2
CD-P25.1-P	0.89	74.0	23.4
PLDNWP126C-P	0.89	84.8	35.0
PLPL1ADDP1-P	0.88	66.8	21.8
PLDNWP1P13-P	0.87	44.4	10.4
PLDNWP1_P1-P	0.85	81.1	32.1
PLDNWP1_P5-P	0.84	75.2	27.0
PLDNWP1WT4-P	0.82	80.1	30.5
PLFOXRN_PD-P	0.82	77.7	29.7
PLML2AD_P1-P	0.81	79.6	31.1
PLWETCPLX4-P	0.79	59.2	16.8
PL2E1-1-W	0.78	69.4	19.8
PLWETCPLX1-W	0.77	77.0	19.1
PLGRDNGTP2-P	0.74	68.8	23.5
PLDNWP1P15-P	0.73	60.8	7.9
PL_CDP28-P	0.71	44.4	7.7
PLDNWP1_P8-P	0.68	63.7	21.6
PLWETCPLX3-P	0.66	37.9	3.9
PL-CD-P27-P	0.66	85.0	35.5
PLPL1ADDWT-P	0.65	70.4	24.4
PLPL9ADDW1-P	0.65	20.3	1.5
PLPL9ADDW2-W	0.65	6.4	0.3
PLDNWP1P11-P	0.65	59.5	19.5
PLDNWP1_P7-P	0.63	48.6	10.5
PLDNWP115O-P	0.58	27.2	1.8
CD-P25-P	0.54	45.6	7.1

The numbers for removal efficiency and exports are based on 30-year averages for the years 1978 through 2008. The P8 model-run included a pre-flush out period starting in 1960. The **Table 9** results serve as a guide in determining implementation areas for additional treatment. Although the P8 model has been calibrated based on observed flow and concentration data, the P8 model was calibrated without altering or auditing the existing XP-SWMM hydraulic model inputs. The XP-SWMM model was used primarily for hydraulic analysis only and was not considered or adapted for future water quality modeling. When evaluating the results of the P8 model it is important to consider:

- The impervious areas entered into P8 that were directly converted from the XP-SWMM model considered areas occupied by water as impervious. Therefore, TP loads may be higher than expected due to the P8 model that calculates loads based on runoff volume multiplied by an event-mean-concentration for areas with high surface water areas as a function of overall watershed area (i.e. nodes PLDNWP126B-P, PLDNWP126A-P).

- The existing XP-SWMM model appears to have inconsistencies when estimating the amount of “dead-storage” provided by each storage node. The model appears to underestimate the storage provided by natural wetlands and ponding areas when compared to constructed ponds within the watershed. The end result will be lower than anticipated removal efficiencies and greater than expected load runoff rates for those natural ponding areas (i.e. nodes PLDNWP126A-P, PLWETCPLX2-W).

Figure 12 and **Figure 13** have been provided in a GIS format and are placed in a geodatabase. Additional watershed and storage node information can be found within the geodatabase including removal efficiencies, unit loads, rank in terms of performance, additional hydraulic information, sedimentation rates, and other storage node and watershed characteristics.

5.2 Implementation Mechanism

SWWD utilizes a Subwatershed Retrofit Assessment Protocol as developed by the Metro Conservation Districts to meet the wasteload allocation portion of the loading capacity. Starting with priority implementation areas identified in this report, the Protocol uses a systematic approach to identifying individual properties and projects with the greatest potential water quality benefit, maximizing the benefit of implementation funding. The assessment will identify projects and associated costs required to meet the WLA for both the current MPCA standard (69.4 kg/yr total reduction) and SWWD goal (135.1 kg/yr total reduction). The Powers Lake Subwatershed Assessment Report will be completed separate of this report and represent the bulk of the implementation plan.

To achieve the load allocation portion of the loading capacity, SWWD will investigate the use of various in-lake phosphorus sequestration methods in cooperation with the City of Woodbury. Implementation of in-lake sequestration will only be considered upon meeting the wasteload allocation through implementation of the Subwatershed Retrofit Assessment Protocol. This phased approach will maximize and prolong the benefits of any in-lake treatment.

All implementation will be a cooperative effort between SWWD and the City of Woodbury, both of whom have funding dedicated to improving the water quality of Powers Lake.

6.0 REFERENCES

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