4.0 Methodology and Results

4.1 Data Collection & Analysis

4.1.1 Historical Water Quality Data

Historical Wood Pond water quality monitoring data are available for basic parameters for the time period 1996-2007. These monitoring data have been collected by volunteers through the Metropolitan Council's Citizen Assisted Monitoring Program (CAMP). Water quality parameters analyzed in samples collected by CAMP for Wood Pond are: Secchi Disc, Total Kjeldahl Nitrogen, Total Phosphorus, Chlorophyll *a,* and water temperature.

As part of this analysis, an intensive water quality sampling program was conducted for Wood Pond during the open-water season of 2007. This data collection program was completed to evaluate current water quality conditions in the lake and to calibrate the water quality models developed as part of the UAA. There were six sampling events throughout the time period from mid-May to early September.

A total of ten water quality parameters were measured at each sampling stations. Table 4-1 lists the water quality parameters, and specifies when and at what depths samples or measurements were collected. Dissolved oxygen, temperature, specific conductance, and Secchi disc transparency were measured in the field; whereas, water samples were analyzed in the laboratory for total phosphorus, orthophosphate, dissolved phosphorus, pH, and chlorophyll *a*. The procedures for chemical analyses of the water samples are shown in Table 4-2. Generally, the methods can be found in *Standard Methods for Water and Wastewater Analysis* (American Water Works Association, 2005).

Table 4-1 Water Quality Sampling Parameters

Parameters	Depth (Meters)	Sampled or Measured During Each Sample Event
Dissolved Oxygen	Surface to bottom profile	X
Temperature	Surface to bottom profile	X
Specific Conductance	Surface to bottom profile	X
Secchi Disc	—	X
Total Phosphorus	0-2 Meter Composite Sample	X
Total Phosphorus	Profile at 1.0 meter intervals from 3 meters to 0.5 meters above lake bottom	X
Orthophosphate	0-2 Meter Composite Sample	X
Total Dissolved Phosphorus	0-2 Meter Composite Sample	X
pH	0-2 Meter Composite Sample	X
pH	Profile at 1.0 meter intervals from 3 meters to 0.5 meters above lake bottom	X
Chlorophyll *a*	0-2 Meter Composite Sample	X
Turbidity	0-2 Meter Composite Sample	X

Table 4-2 Procedures for Chemical Analyses Performed on Water Samples

Analysis	Procedure	Reference
Total Phosphorus	Automated persulfate digestion with ascorbic acid	Standard Methods, 18th Edition (1992) modified per Eisenreich, et al., Environmental Letters 9(1), 43-53 (1975) (EPA 365.2)
Orthophosphate	Ascorbic acid manual single reagent	EPA 365.2
Total Dissolved Phosphorus	Ascorbic acid manual single reagent	EPA 365.2
Chlorophyll *a*	Spectrophotometric	Standard Methods, 18th Edition, 1992, 10200 H
pH	Potentiometric measurement, glass electrode	Standard Methods, 16th Edition, 1985, 423
Specific Conductance	Wheatstone bridge	Standard Methods, 16th Edition, 1985, 205
Temperature	Thermometric	Standard Methods, 16th Edition, 1985, 212
Dissolved Oxygen	Electrode	Standard Methods, 16th Edition, 1985, 421F
Transparency	Secchi disc	
Chloride	Automated colorimetric with ferricyanide	EPA 325.1

For purposes of the UAA, the "summer-average" for each water quality parameter was calculated using data collected from May through September.

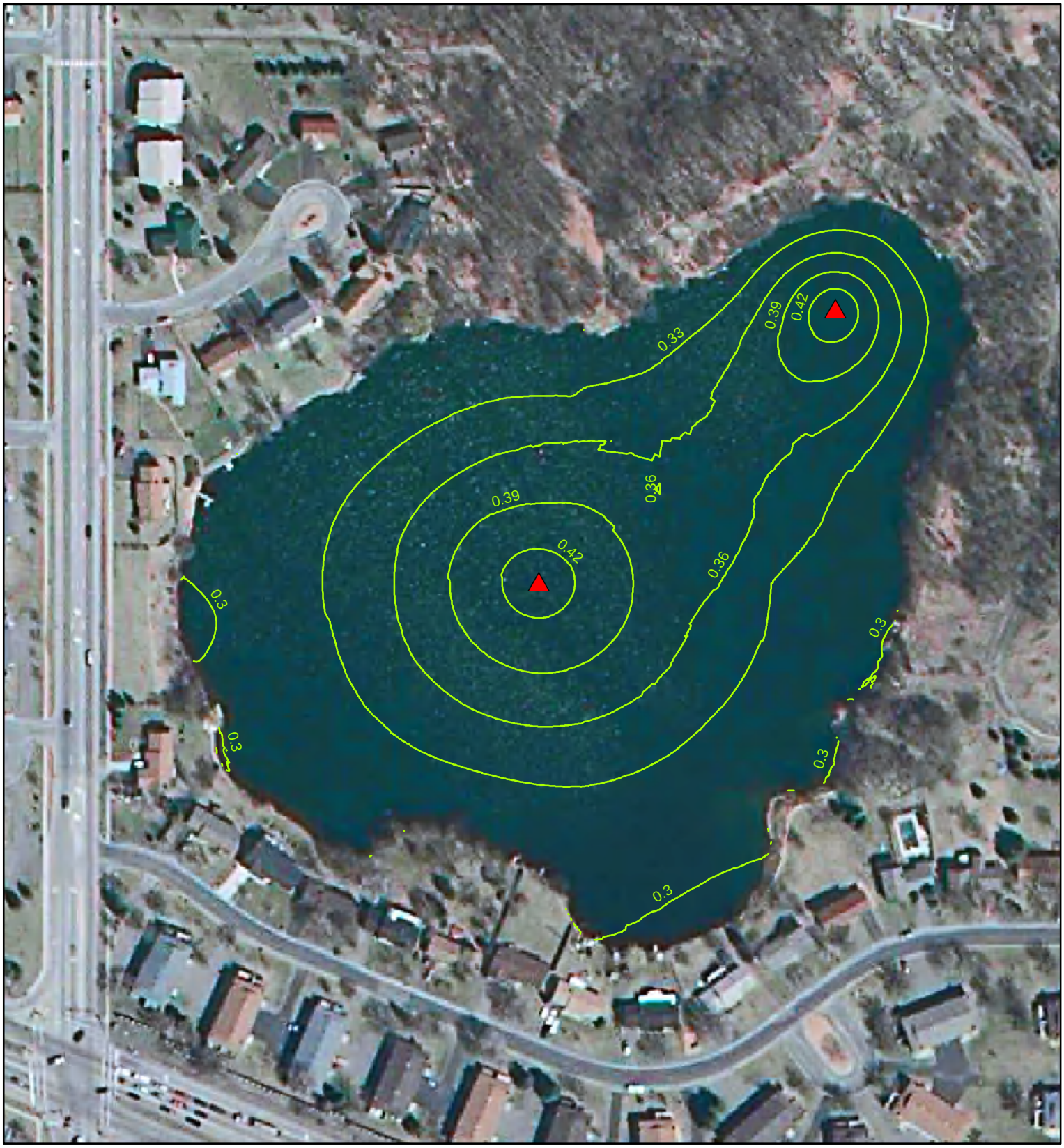
4.1.2 Sediment Core Samples

All lakes accumulate phosphorus (and other nutrients) in the sediment due to the settling of particles and dead organisms (plants, algae, fish, etc.). In some lakes this reservoir of phosphorus can be reintroduced in the lake water and become available again for uptake by algae and macrophytes. This resuspension or dissolution of nutrients from the sediment to the lake water is known as "internal loading". Sediment cores were collected from Wood Pond in May of 2007 to determine sediment phosphorus concentrations that can lead to internal phosphorus loading.

Three sediment cores were taken from Wood Pond and analyzed for mobile phosphorus (contributes directly to internal phosphorus loading) and organic bound phosphorus. Phosphorus fractions were determined according to a modified version of Psenner et al. (1988) and internal loading estimates were calculated according to the method developed by Pilgrim et al. (2007). After laboratory analysis, sediment phosphorus concentrations were modeled to determine lake wide internal phosphorus loading rates using Geostatistical Analyst within the ArcMap GIS program.

The sediment core locations and mobile phosphorus concentration contours created from the sediment core results are shown in Figure 4-1. Analysis of the sediment cores taken from Wood Pond in 2007 indicates that the maximum internal phosphorus loading rate ranges from 4.4 to 5.3 $mg/m^2/day$, with an average of 4.9 $mg/m^2/day$. Table 4-3 shows how this rate compares to the rates calculated for other Metro Area lakes, using the same methodology.

Wood Pond has a moderately high internal loading rate. However, because Wood Pond is shallow, any phosphorus released from the sediment is available for growth by algae instantly. This is different than what happens in a deep, strongly stratified lake (much of the internal load is available only after turnover) and is the reason why low to moderate levels of internal loading can have substantial negative impacts in shallow lakes. For example, Lake Harriet has an internal loading rate approximately double that of Wood Pond. However, only a portion of that Harriet's internal load reaches the surface (or active zone) during the summer via diffusion or mixing while the entire amount of phosphorus released from Wood Pond sediment reaches the active zone.



Barr Footer: Date: 7/9/2008 5:36:26 PM File: I:\Projects\23\19\A24\GIS\Maps\Figure_4-1_sed_core_loc.mxd User: sgw

Sediment Core Locations

Mobile Phosphorus Contours
(contours are in g/sq. m/cm)

0 100 200 400
Feet

Figure 4-1

WOOD POND SEDIMENT
CORE PHOSPHORUS ANALYSIS

Wood Pond Use
Attainability Analysis
City of Burnsville
Burnsville, Minnesota

Table 4-3 Comparison of Wood Pond Internal Phosphorus Loading Rate to Those of Other Metro Area Lakes

Lake	Internal P Load ($mg/m^2/d$)
Isles (pre-alum, deep hole) [1]	14.1
Harriett (pre-alum, deep hole) [1]	11.1
Calhoun (pre-alum, deep) [1]	10.8
Fish E[2]	10.5
Cedar (pre-alum) [1]	9.3
Fish W[2]	8.1
Como[2]	7.6
Harriet[2]	6.9
North Twin[3]	6.0
South Twin[3]	5.6
Como-litoral[2]	5.7
Calhoun (pre-alum, shallow) [2]	5.6
Wood Pond	4.9
Parkers[2]	3.5
Earley Lake[3]	2.9
Phalen[2]	2.3
McCarrons[2]	2.0
Bryant[2]	1.5
Nokomis[2]	1.0
Minnewashta[2]	0.2
Christmas[2]	0.0

Sources:
[1]Huser and Brezonik (2007)
[2]Pilgrim et al. (2007)
[3]Barr Engineering (2007)

4.1.3 Macrophytes

Aquatic plants (i.e., macrophytes and phytoplankton) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. They are among the primary producers in the aquatic food chain, providing food for other aquatic life. Macrophytes (aquatic plants growing in the shallow, or littoral, area of the lake) perform a number of valuable functions in Wood Pond. Specifically, macrophyte communities:

- Provide habitat for fish, insects, and small aquatic invertebrates
- Provide food for waterfowl, fish, and wildlife
- Provide oxygen
- Provide spawning areas for fish in early spring
- Help stabilize marshy borders of the lake; which help protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

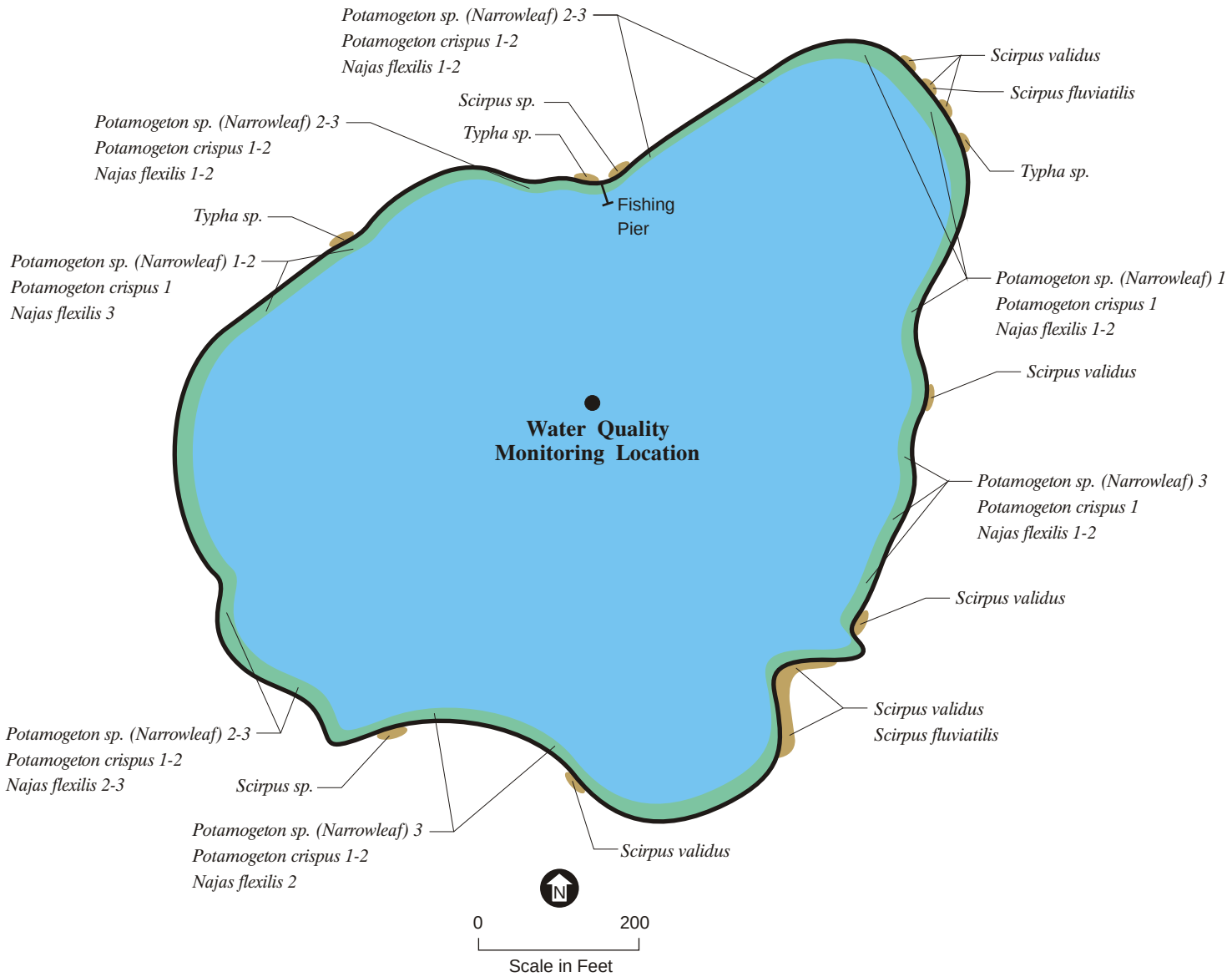
Macrophytes are an important component of the lake ecosystem (Ozimek, Gulati, and Van Donk 1990). However, the introduction of exotic (nonnative) aquatic plants into a lake may cause undesirable changes to the plant community and to the lake ecosystem. Dense stands of some mat-forming plant species reduce oxygen exchange, deplete available dissolved oxygen, increase water temperatures, and increase internal loading rates of nutrients (Frodge, Thomas, and Pauley 1991; Frodge et al. 1995; Seki, Takahashi, and Ichimura 1979). Dense canopies formed by some nonnative species (e.g., Curlyleaf pondweed and Eurasian watermilfoil) reduce native plant diversity and abundance, thereby reducing habitat complexity. This reduction in habitat complexity results in reduced macroinvertebrate diversity and abundance (Krull 1970, Keast 1984) and also reduces growth of fishes (Lillie and Budd 1992). The introduction of a nonnative plant species to a lake is not only deleterious to human use of aquatic systems, but is also detrimental to the native ecosystem.

Once a lake becomes infested with Curlyleaf pondweed, this plant typically replaces native vegetation, thereby increasing its coverage and density. Curlyleaf pondweed begins growing in late August, grows throughout the winter at a slow rate, grows rapidly in the spring, and dies in early summer (Madsen et al. 2002). Native plants that grow from seed in the spring are unable to grow in areas already occupied by Curlyleaf pondweed, and are displaced by this plant. Curlyleaf pondweed die-off in early summer releases phosphorus to the lake, causing increased algal growth for the remainder of the summer.

Eurasian watermilfoil is a nuisance non-native species that typically replaces native vegetation. It has a canopy style growth pattern that causes heavy growth near the surface, making it more visible and a greater nuisance for boating and fishing.

4.1.3.1 Wood Pond Macrophyte Surveys

The presence of nuisance-level macrophytes has not historically been a problem in Wood Pond. Qualitative macrophyte surveys were conducted for Wood Pond in June 2007 and August 2007 to characterize the presence and density of macrophyte populations in the lake. The results of the June 2007 and August 2007 surveys are depicted in Figures 4-2 and 4-3, respectively.



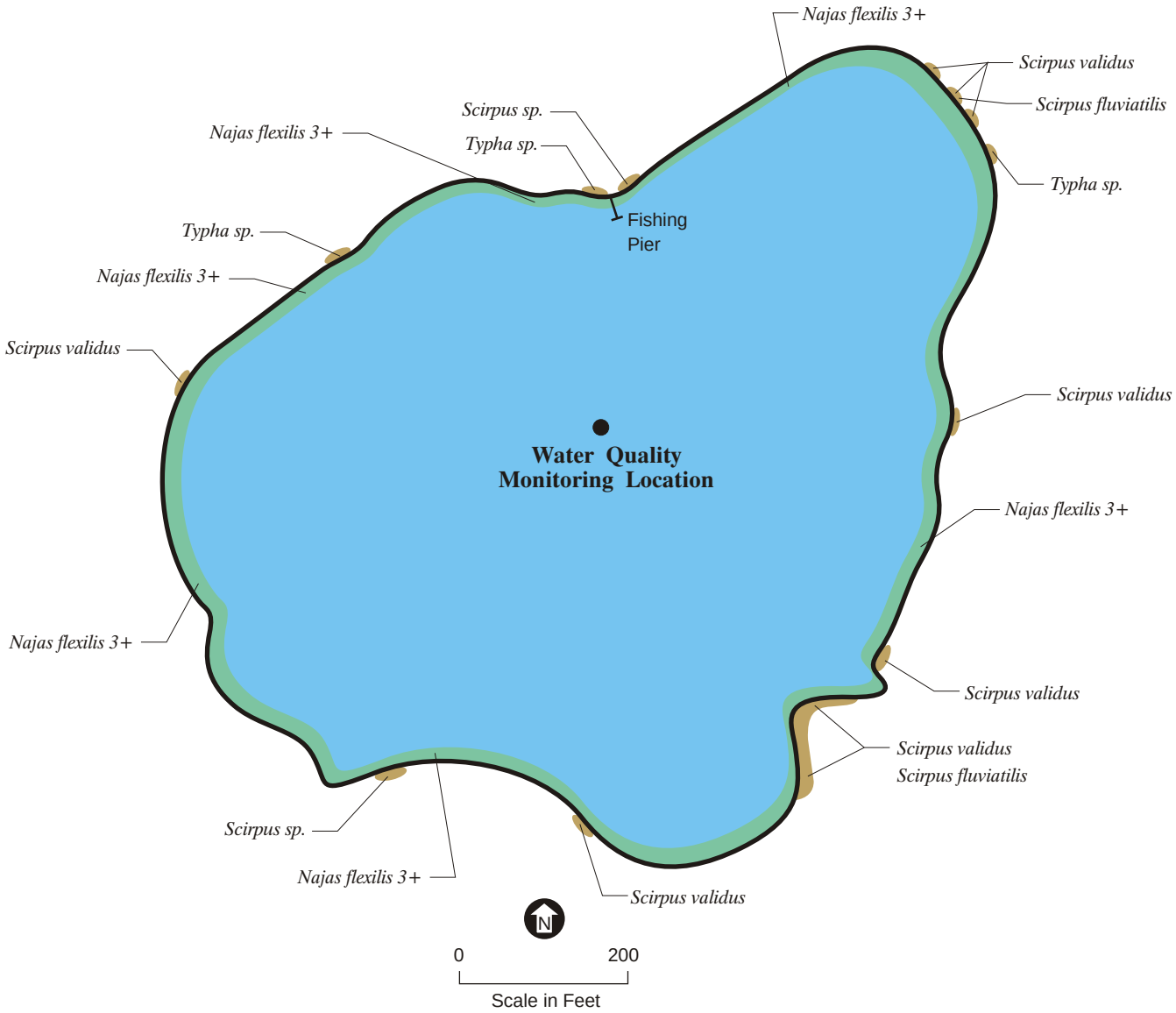
- Macrophytes Found Along Entire Perimeter of Pond. Macrophytes Observed 10'-15' Out From Shore and 8'-9' of Depth.
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy; + extremely dense.
- Algae Observed Growing on Rooted Macrophytes - Dense

	Common Name	Scientific Name
Submerged Aquatic Plants:	Narrowleaf Pondweed	*Potamogeton sp. (Narrowleaf)*
	Curlyleaf pondweed	*Potamogeton crispus*
	Elodea	*Elodea canadensis*
	Slender naiad	*Najas flexilis*
Floating Leaf:		
Emergent:	Bulrush	*Scirpus sp.*
	Softstem Bulrush	*Scirpus validus*
	Cattail	*Typha sp.*
	River Bulrush	*Scirpus fluviatilis*
No Aquatic Vegetation Found:		

Figure 4-2

WOOD POND
MACROPHYTE SURVEY
June 12, 2007

P:\Mpls\23 MN\19\2319A24\WorkFiles\Macrophytes\Lake Macrophyte Maps\Wood Park Pond June 2007.CDR RLG 07-30-08



- Macrophytes Found Along Entire Perimeter of Pond. Macrophytes Observed 20' Out From Shore and 8'-9' of Depth.
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy; + extreme dense.
- Najas flexilis Found Around Entire Pond Perimeter With a Density Rating of 3+.

		Common Name	Scientific Name
Submerged Aquatic Plants:		Elodea Slender Naiad	*Elodea canadensis* *Najas flexilis*
Floating Leaf:			
Emergent:		Bulrush Softstem Bulrush Cattail River Bulrush	*Scirpus sp.* *Scirpus validus* *Typha sp.* *Scirpus fluviatilis*
No Aquatic Vegetation Found:			

Figure 4-3

WOOD POND
MACROPHYTE SURVEY
August 13, 2007

P:\Mpls\23 MN\19\2319A24\WorkFiles\Macrophytes\Lake Macrophyte Maps\Wood Park Pond August 2007.CDR RLG 07-30-08

In general, the aquatic plants in Wood Pond are limited to the area along the perimeter of the lake; macrophytes were observed approximately 10 to 20 feet from the shore and limited to water depths of approximately 8 to 9 feet. During the June 12, 2007 macrophyte survey, Narrowleaf pondweed was one of the more prevalent submerged aquatic plants, observed along the shoreline at moderate to high densities. Slender Naiad was also observed fairly consistently along the shoreline, varying in density from light to heavy. Curlyleaf pondweed was also observed at light to moderate densities. The emergent vegetation observed included Bulrush, Softstem Bulrush, River Bulrush and Cattails.

The August 13, 2007 macrophyte survey identified Slender Naiad as the only submerged aquatic plant observed; it was found around the entire lake perimeter at extremely heavy densities. Emergent species identified include Bulrush, Softstem Bulrush, River Bulrush and Cattails. Although Slender Naiad does not have negative impacts on the water quality of the lake, the prevalence of the aquatic plant in the late-summer of 2007 was considered to be at nuisance levels.

4.2 Baseline/Current Lake Water Quality

4.2.1 Wood Pond Historical Water Quality

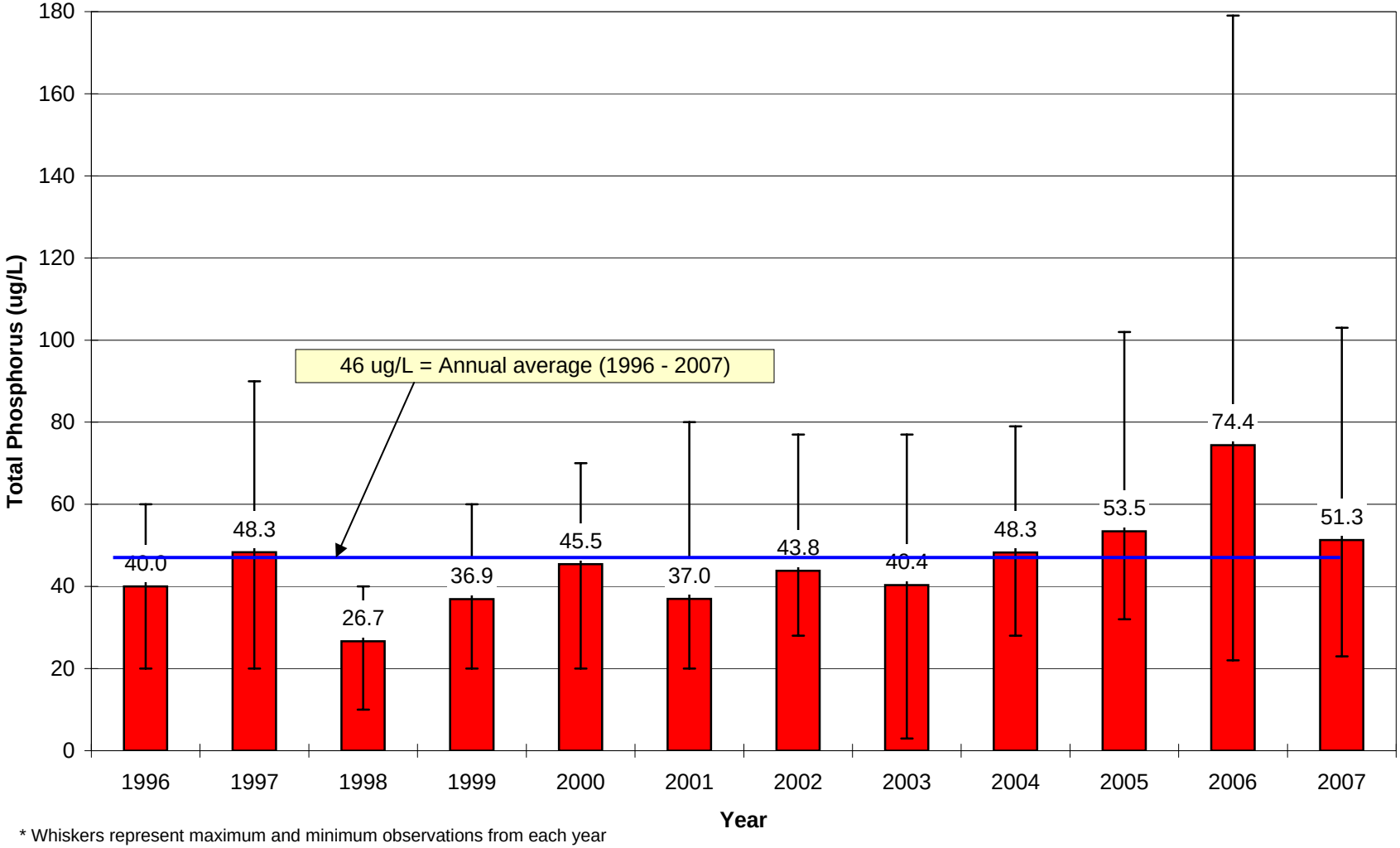
Water quality monitoring data has been collected from Wood Pond by volunteers through the Metropolitan Council's Citizen Assisted Monitoring Program (CAMP) since 1996. Water quality parameters analyzed in samples collected by CAMP for Wood Pond are: Secchi Disc, Total Kjeldahl Nitrogen, Total Phosphorus, Chlorophyll *a,* and water temperature. The results of the historical monitoring of total phosphorus, Secchi disc transparency, and chlorophyll *a* are summarized below.

4.2.1.1 Total Phosphorus

Phosphorus is the plant nutrient that most often limits the growth of algae. Phosphorus-rich lake water indicates a lake has the potential for abundant algal growth, which can lead to lower water transparency and a decline in hypolimnetic oxygen levels in a lake. According to previous studies (Heiskary and Wilson, 1990) summer-average phosphorus concentrations of 60 µg/L typically result in nuisance algal bloom conditions (greater than 20 µg/L chlorophyll *a*) for approximately 70 percent of the summer.

Figure 4-4 shows the historic "summer-average" total phosphorus concentrations for the time period of record (1996-2007) for Wood Pond, using the averaging interval of May through September. The average over the period of record is also noted on Figure 4-4. This information, along with the MPCA's phosphorus standard for shallow lakes and the City of Burnsville's phosphorus goal, based on a lake-specific relationship between Secchi depth and total phosphorus concentrations (see Section 4.2.3) is summarized in Table 4-4.

Wood Pond Summer-Average (May through September)
Total Phosphorus Concentrations
1996-2007



* Whiskers represent maximum and minimum observations from each year

Figure 4-4

Table 4-4 Wood Pond Summary of Historical Water Quality Data

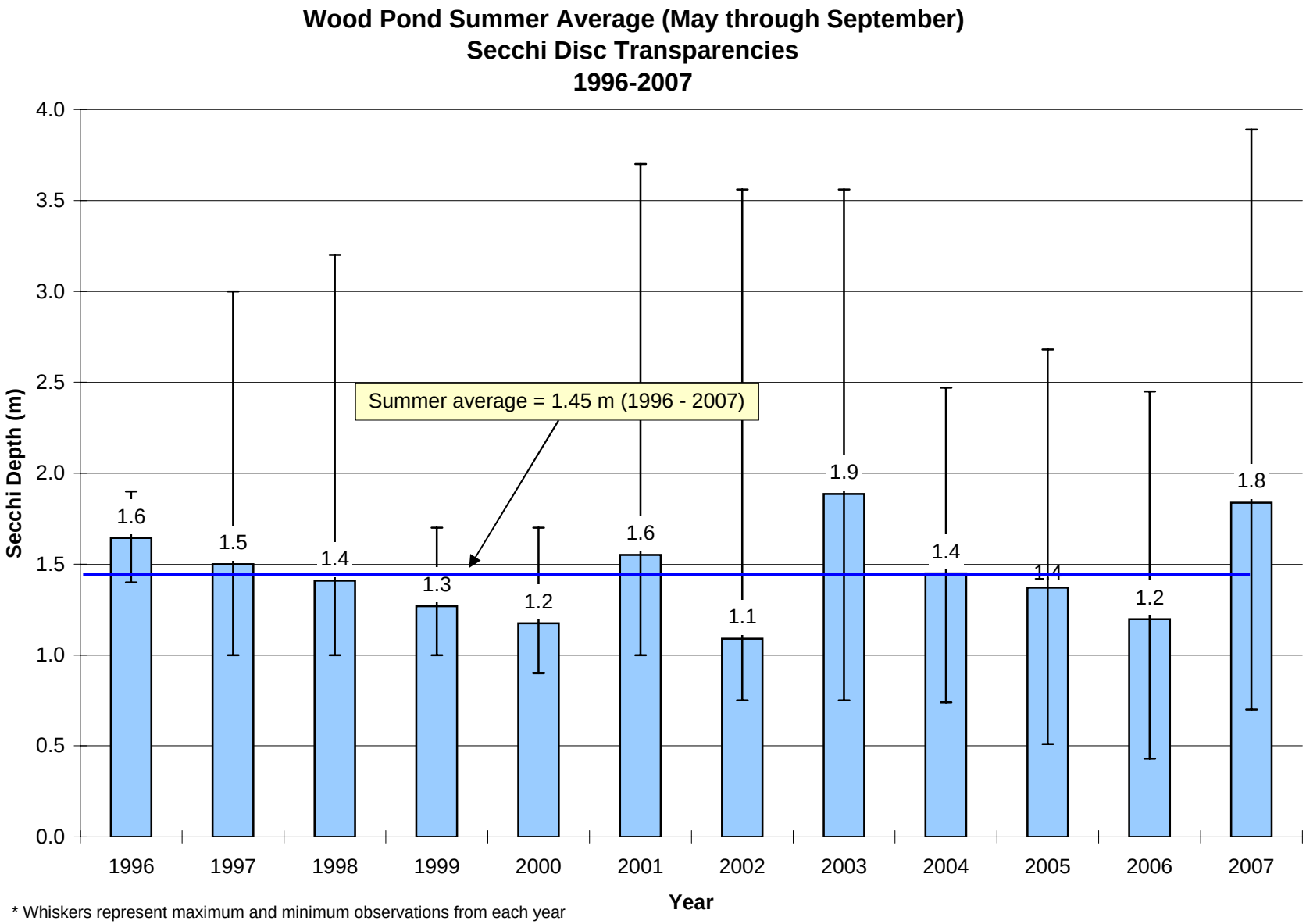
Water Quality Parameter	Mean Summer-average for Period of Record (1996-2007)	City of Burnsville Existing Goal	MPCA's Deep Lake Standard[1]	MPCA's Shallow Lake Standard[1]
Total Phosphorus	46 µg/L	31 µg/L	40 µg/L	60 µg/L
Secchi Disc	4.8 ft (1.45 m)	5.6 ft (1.7 m)	4.0 ft (1.2 m)	3.2 ft (1.0 m)
Chlorophyll *a*	17.3 µg/L	9.6 µg/L	15 µg/L	20 µg/L
[1] Eutrophication standards for North Central Hardwood Forest ecoregion				

4.2.1.2 Secchi Disc Transparency

Secchi disc transparency is a measure of water clarity. Perceptions and expectations of people using a lake are generally correlated with water clarity. Results of a survey completed by the Metropolitan Council (Osgood, 1989) revealed the following relationship between a lake's recreational use impairment and Secchi disc transparencies:

- Moderate to severe use-impairment occurs at Secchi disc transparencies less than 1 meter (3.3 feet).
- Moderate impairment occurs at Secchi disc transparencies of 1 to 2 meters.
- Minimal impairment occurs at Secchi disc transparencies of 2 to 4 meters.
- No impairment occurs at Secchi disc transparencies greater than 4 meters

Figure 4-5 shows the historic "summer-average" Secchi disc transparency for the time period of record (1996-2007) for Wood Pond, using the averaging interval of May through September. Figure 4-5 also shows the average over the period of record. This information, along with the MPCA's Secchi depth transparency standard for shallow lakes and the City of Burnsville's water clarity goal, is summarized in Table 4-4.



* Whiskers represent maximum and minimum observations from each year

Figure 4-5

4.2.1.3 Chlorophyll *a*

Chlorophyll *a* is a measure of algal abundance within a lake. High chlorophyll concentrations indicate excessive algal abundance (i.e., algal blooms), which can lead to recreational use impairment. As stated above, chlorophyll *a* measurements greater than 20 µg/L indicate "nuisance conditions."

Figure 4-6 shows the historic "summer-average" chlorophyll *a* concentrations for the time period of record (1996-2007) for Wood Pond, using the averaging interval of May through September, as well as the average over the period of record. This information, along with the MPCA's chlorophyll *a* standard for shallow lakes, is summarized in Table 4-4.

4.2.2 Wood Pond 2007 Water Quality Monitoring Program

Figure 4-7 shows the total phosphorus, Secchi disc, and chlorophyll *a* monitoring results for Wood Pond in 2007. Two sources of data were available for Wood Pond in 2007: Barr data collected for this UAA and CAMP data. A summary of all the data collected by Barr for the 2007 monitoring period, including temperature and dissolved oxygen, are provided in Appendix A.

The 2007 water quality data were evaluated according to the trophic status categories, which use the lake's total phosphorus concentration, chlorophyll *a* concentration, and Secchi disc transparency measurements to assign the lake to a water quality category that best describes its water quality. Water quality categories include oligotrophic (i.e., excellent water quality), mesotrophic (i.e., good water quality), eutrophic (i.e., poor water quality), and hypereutrophic (i.e., very poor water quality). Total phosphorus, chlorophyll *a*, and Secchi disc transparency are key water quality indicators for the following reasons:

- Phosphorus generally controls the growth of algae in lake systems. Of all the substances need for biological growth, phosphorus is typically the limiting nutrient.
- Chlorophyll *a* is the main photosynthetic pigment in algae. Therefore, the amount of chlorophyll *a* in the water indicates the abundance of algae present in the lake.
- Secchi disc transparency is a measure of water clarity, and is inversely related to the abundance of algae. Water clarity determines recreational-use impairment.

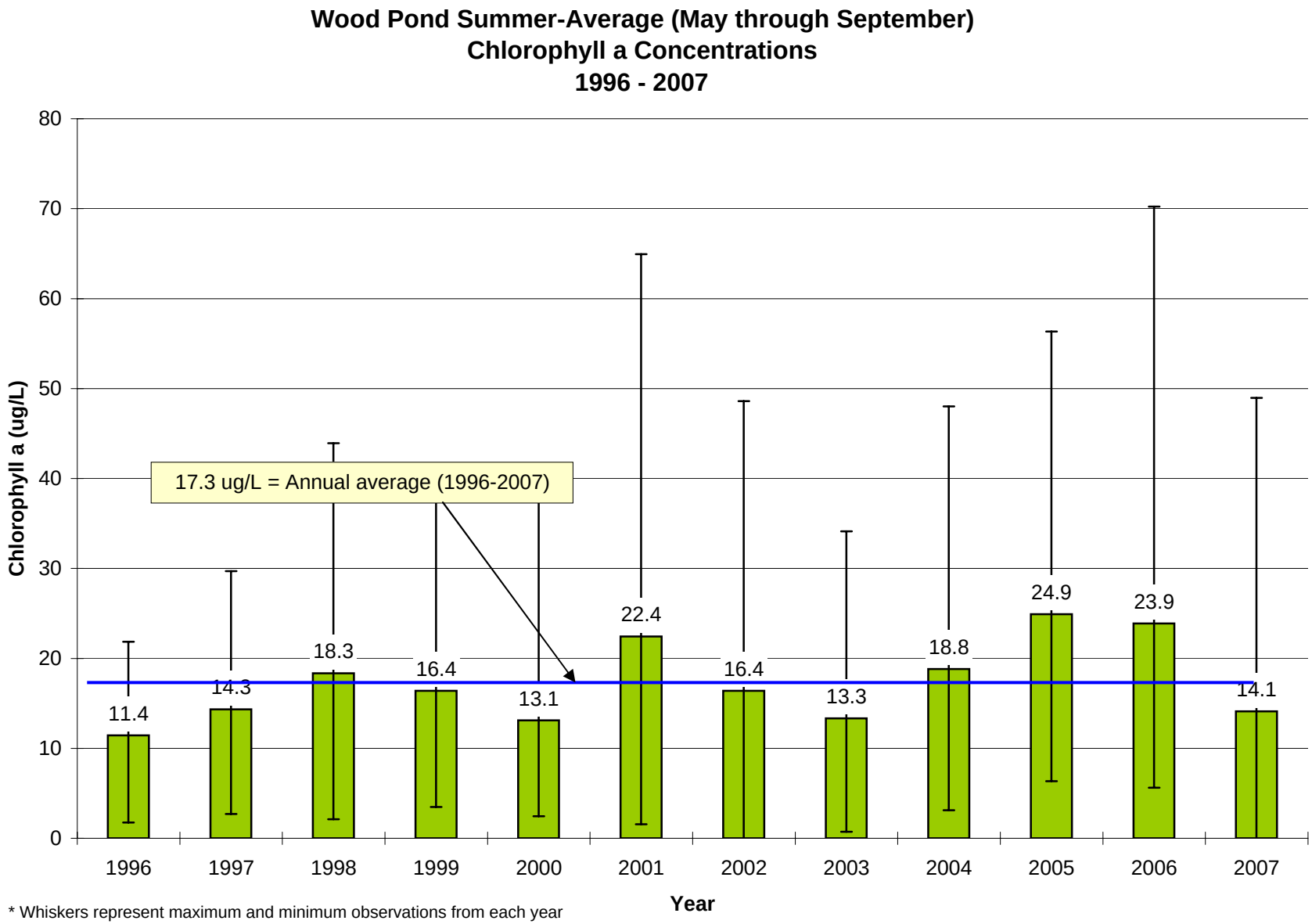
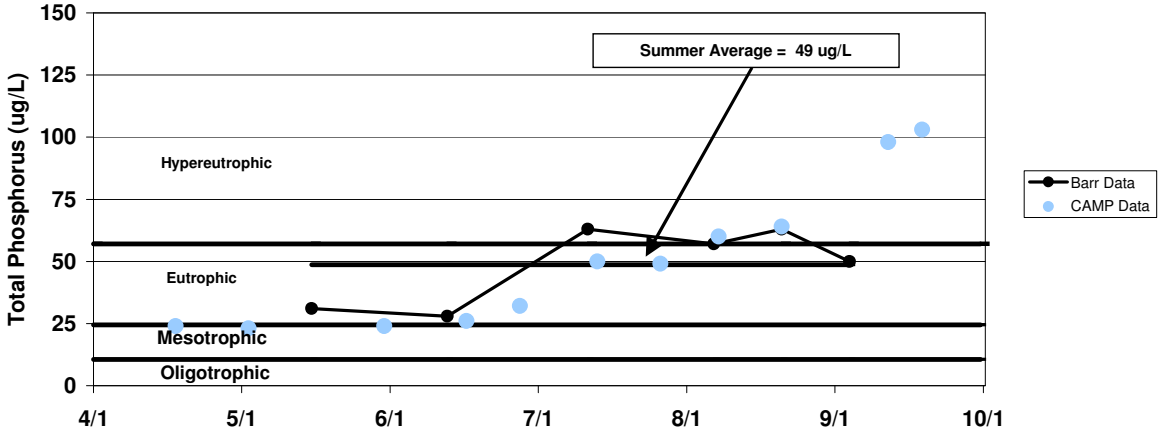
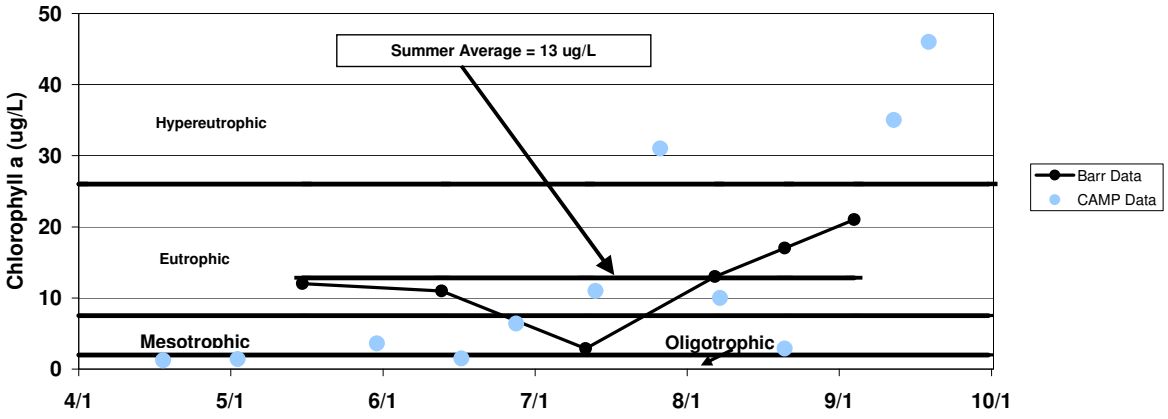

Wood Pond Summer-Average (May through September)
Chlorophyll a Concentrations
1996 - 2007
Chlorophyll a (ug/L)
80
70
60
50
40
30
20
10
0
17.3 ug/L = Annual average (1996-2007)
11.4
14.3
18.3
16.4
13.1
22.4
16.4
13.3
18.8
24.9
23.9
14.1
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year
* Whiskers represent maximum and minimum observations from each year

Figure 4-6

Wood Pond--2007
Total Phosphorus Concentrations



Wood Pond--2007
Chlorophyll a



Wood Pond--2007
Secchi disc

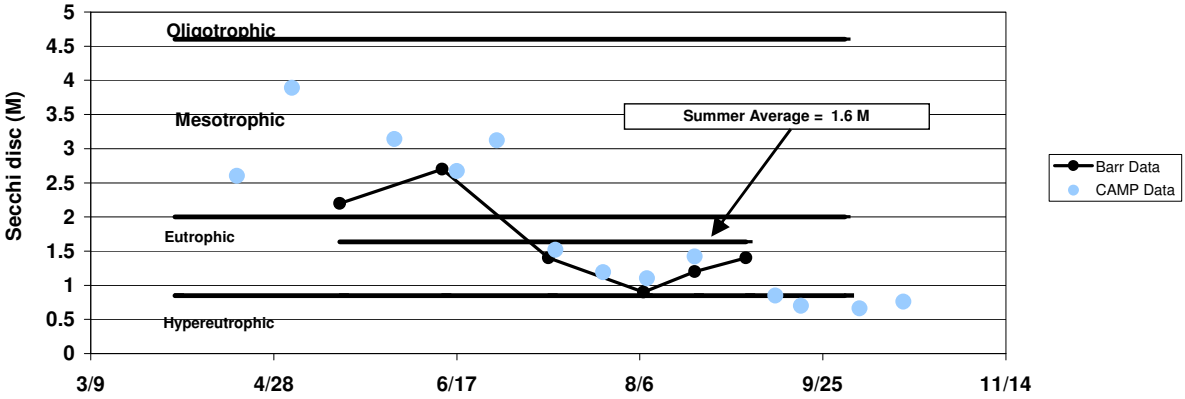


Figure 4-7

Phosphorus

The 2007 spring total phosphorus concentration in Wood Pond was 31 µg/L (May 16, 2007 observation), which placed the lake at the lower end of the eutrophic status category. However, due to summer inputs of phosphorus, primarily from watershed runoff and internal load from the lake's sediments, the summer total phosphorus concentration rose to 63 µg/L by mid-summer and remained in the upper-eutrophic and hypereutrophic status category for the remainder of the summer. Monitoring data collected in mid- to late-September by the CAMP program showed particularly high phosphorus concentrations, indicating a significant algal bloom likely occurred at that time. The 2007 summer-average total phosphorus concentration (49 µg/L) exceeds the total phosphorus concentration (31 µg/L) that corresponds to the City's 1.7 meter transparency goal, based on the lake-specific relationship developed between total phosphorus and Secchi depth.

Chlorophyll *a*

The 2007 spring chlorophyll *a* concentration in Wood Pond was 12 µg/L (May 16, 2007 observation), which placed the lake in the lower portion of the eutrophic status category (Figure 4-7). The chlorophyll *a* concentrations in Wood Pond remained in the lower-eutrophic or mesotrophic status category until mid-July. For the remainder of the summer, the chlorophyll *a* concentrations remained in the upper-eutrophic or hypereutrophic status categories, due to summer inputs of phosphorus, primarily from watershed runoff and internal load from the lake's sediments. Monitoring data collected in mid- to late-September by the CAMP program showed particularly high chlorophyll *a* concentrations, indicating a significant algal bloom likely occurred at that time. The 2007 summer-average chlorophyll *a* concentration (13 µg/L) exceeds the chlorophyll *a* concentration (9.6 µg/L) that corresponds to the City's 1.7 meter transparency goal, calculated based on the MPCA's relationship between total phosphorus and chlorophyll *a* for phosphorus-limited lakes.

Secchi Disc Transparency

The 2007 spring Secchi disc transparency in Wood Pond was 2.2 meters (May 16, 2007 observation), which placed the lake in the middle of the mesotrophic status category. The lake remained in the mesotrophic status category for Secchi depth throughout May and June, with Secchi disc transparency gradually decreasing throughout the remainder of the summer, bringing the lake into the eutrophic and hypereutrophic categories. The 2007 summer-average Secchi disc transparency (1.6 meters) does not meet the City's goal of 1.7 meters.

Temperature and Oxygen

Temperature and oxygen measurements throughout the water column in Wood Pond indicate that the lake did stratify several times throughout the monitoring period, with thermocline depths varying between 2-3 meters. This is consistent with the presumption of frequent mixing (polymixis) in Wood Pond because the lake is shallow and has exposure to the wind. Dissolved oxygen levels were low in the lower portions of the water column (often less than 3 mg/L) during several sampling events indicating that Wood Pond likely experienced periods of anoxic sediments resulting in internal phosphorus loading. Phosphorus released from the sediments during these periods of oxygen depletion accumulated in the hypolimnion and made its way (in part) up to the surface waters, increasing the lake's surface phosphorus concentration. The low dissolved oxygen levels in the lake also have the effect of reducing the available habitat for organisms (e.g., fish and zooplankton), as a dissolved oxygen concentration of 5.0 mg/L is considered the minimum desirable level for fish.

4.2.3 Relationships between TP, SD, and Chlorophyll *a*

4.2.3.1 Relationship between Total Phosphorus and Secchi Disc Transparency

The MPCA has developed several approximate relationships between summer average total phosphorus and summer average Secchi depth based on data collected from numerous lakes in Minnesota. The MPCA relationship for phosphorus-limited lakes in Minnesota best describes the observed summer-average conditions for Wood Pond. The relationship is described below, in which Secchi depth is expressed in meters (m) and total phosphorus in micrograms per liter (µg/L):

$$SD = 38.57*(TP)^{-0.856}$$

However, the MPCA's relationship (shown in red in Figure 4-8)does not represent a great fit for the observed data, with much of the Wood Pond summer-average data falling below the MPCA curve. This indicates that similar TP values result in less Secchi disc transparency in Wood Pond than in other shallow lakes within the region. The deviation between the MPCA relationship and Wood Pond observed data prompted further analysis to determine a relationship more accurately representative of Wood Pond.

A total phosphorus and Secchi disc transparency relationship was developed based on equivalent probabilities. The average value and standard distribution of TP and 1/SD in Wood Pond were determined assuming a normal distribution of the summer averages. Based on the assumption that an inverse relationship between Secchi depth and total phosphorus exists, it was assumed that the probability of observing a given percentile of TP in Wood Pond is equal to the probability of

observing the same percentile of 1/SD. For example, the 90th percentile of observed TP corresponds to the 90th percentile of 1/SD. This yields a one-to-one relationship between 1/SD and TP, and therefore a one-to-one relationship between SD and TP. These pairings were plotted and the resulting relationship is shown (in bold black line) in Figure 4-8 and described below (SD in meters, TP in µg/L):

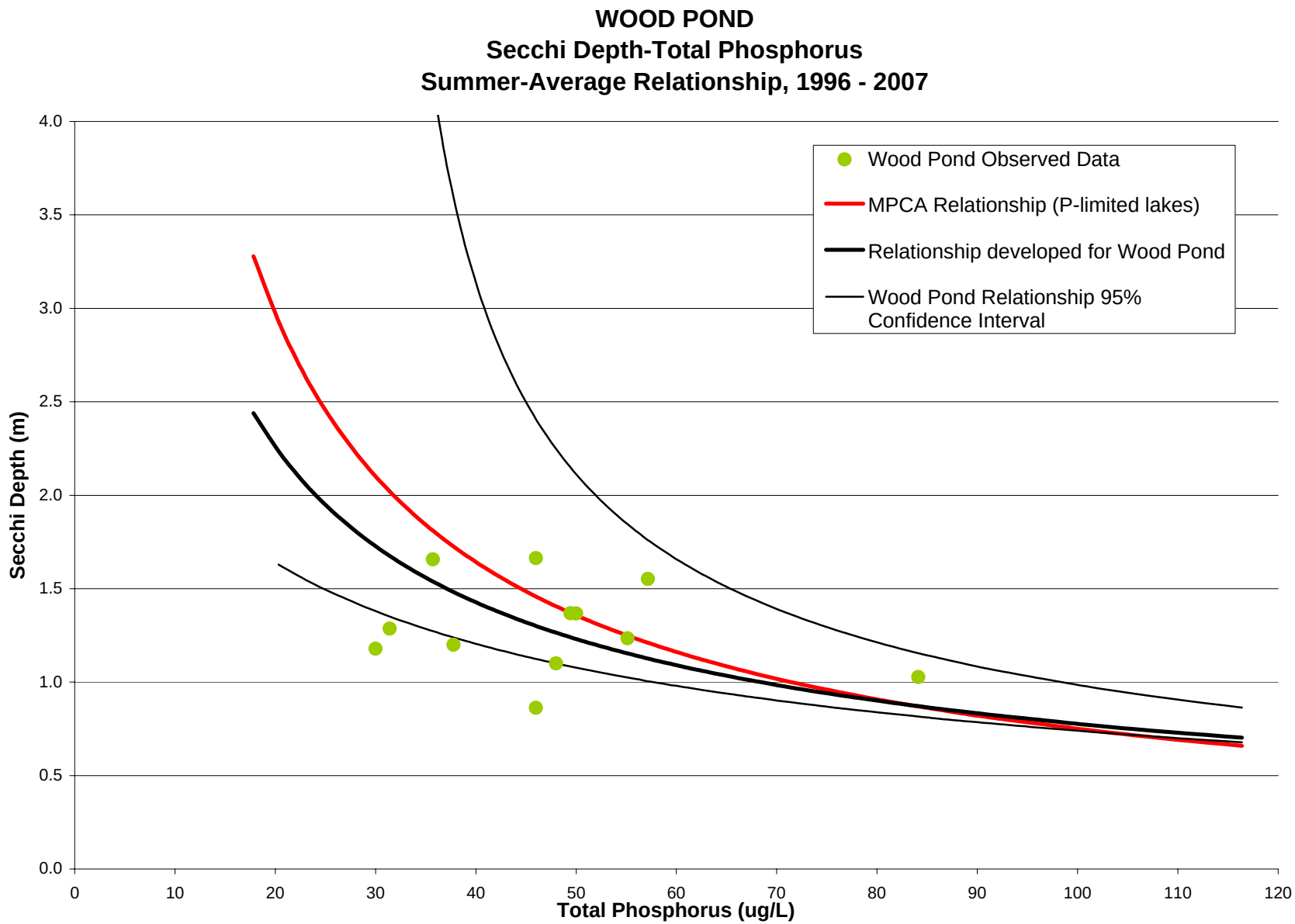
$$SD = 16.51*(TP)^{-0.664}$$

This relationship fits the observed Wood Pond data more accurately than the MPCA relationship. In addition, the standard deviation of the TP (the independent variable, in this case) can be used to estimate the 95% confidence intervals of the corresponding observed SD. For example, if the observed summer average TP is 60 µg/L, the corresponding summer average SD is expected to be 1.1 meters. However, there is a 95% likelihood that the actual observed SD will be between 0.86 meters and 1.66 meters.

4.2.3.2 Relationship between Total Phosphorus and Chlorophyll *a* Concentrations

The observed summer-average total phosphorus and chlorophyll *a* concentrations for Wood Pond were evaluated in an effort to develop a lake-specific regression relationship, but a good fit to the data was not obtained. In the absence of a good lake-specific correlation, the MPCA's regression equation for shallow lakes was used to describe the relationship between total phosphorus and chlorophyll *a* concentrations in Wood Pond (Figure 4-9). The relationship is described below, in which chlorophyll *a* and total phosphorus are expressed in micrograms per liter (µg/L):

$$1/\text{Chl } a = 15.136*TP^{-1.45}$$



P:\Mpls\23 MN\19\2319A24 Wood Pond Management Plan\WorkFiles\Historic_WQData\Wood Pond WQ Analysis_052608

Figure 4-8

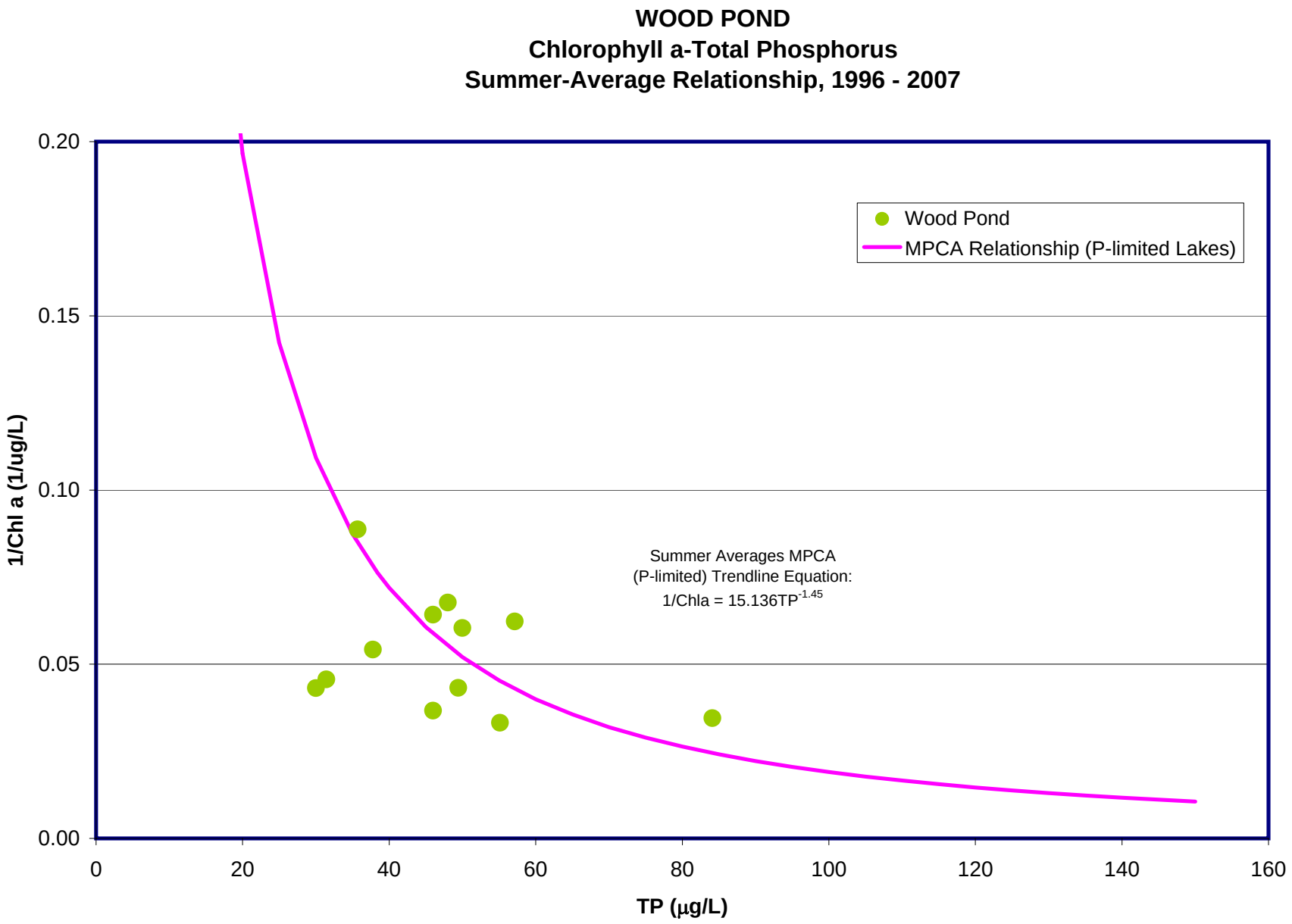


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Figure 4-9

4.2.4 Baseline Water Quality Status

The Minnesota Lake Eutrophication Analysis Procedure (MnLEAP) is intended to be used as a screening tool for estimating lake conditions and for identifying "problem" lakes. MnLEAP is particularly useful for identifying lakes requiring "protection" versus those requiring "restoration" (Heiskary and Wilson, 1990). In addition, MnLEAP is used for estimating 'minimally impacted' lake conditions based on location, watershed area, lake basin morphometry, and observed summer-average water quality conditions. MnLEAP predicts a total phosphorus concentration of approximately 41 µg/L for Wood Pond, with a standard error of 15 µg/L. Comparison of the predicted MnLEAP concentration and observed annual average phosphorus concentrations indicates that the lake is achieving water quality that is generally similar to what it "should be" based on its location, watershed area lake basin morphometry.

Vighi and Chiaudani (1985) developed another method to estimate the phosphorus concentrations in lakes that are not affected by anthropogenic (human) inputs. As a result, the phosphorus concentration in a lake resulting from natural, background phosphorus loadings can be calculated from information about the lake's mean depth and alkalinity or conductivity. Alkalinity is considered more useful for this analysis because it is less influenced by development of the watershed. Alkalinity was measured in Wood Pond in September 2007.

Using the September 2007 alkalinity measurement from Wood Pond (40 mg/L as $CaCO_3$) and the Vighi and Chiaudani equation, the predicted phosphorus concentration from natural, background loadings is estimated to be 18 µg/L. This predicted concentration is lower than the total phosphorus concentration (31 µg/L) that corresponds to the City's water clarity goal for Wood Pond (1.7 meters), indicating that improvement of the lake may be attainable. However, it is important to note that achieving this phosphorus concentration predicted using the Vighi and Chiaudani equation is unlikely in an urban setting.

4.3 Modeling Watershed Runoff and Total Phosphorus Loadings

The computer model P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds, IEP, Inc., 1990) was used to estimate both the stormwater runoff and phosphorus loads introduced from the entire Wood Pond watershed. P8 is a useful diagnostic tool for evaluating and designing watershed improvements and Best Management Practices (BMPs).

When evaluating the results of the modeling, it is important to consider that the results provided are more accurate in terms of relative differences than in absolute results. The model will predict the percent difference in phosphorus reduction between various BMP options in the watershed fairly

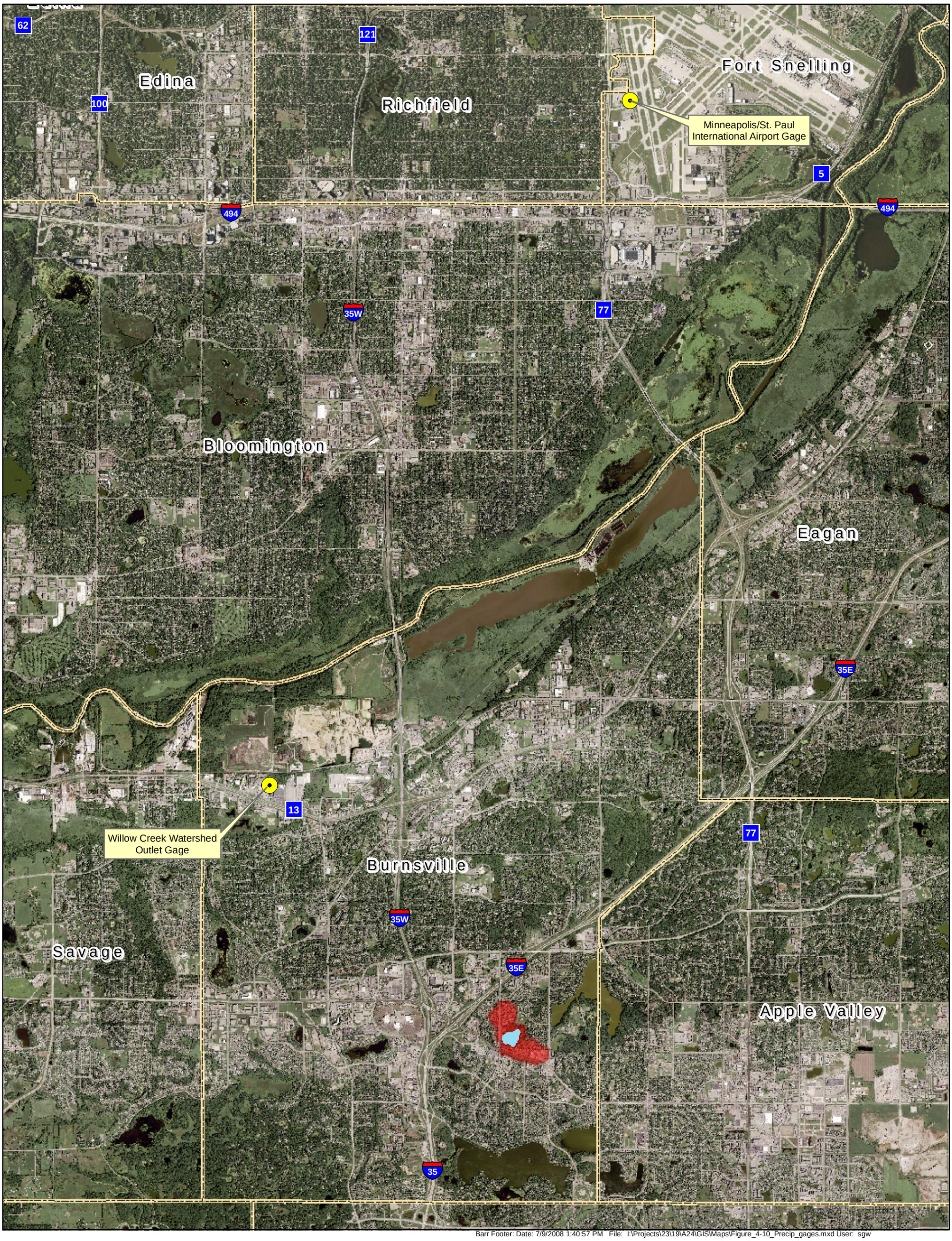
accurately. It also provides a realistic estimate of the relative differences in phosphorus and water loadings from the various subwatersheds and major inflow points to the lake. However, since runoff quality is highly variable with time and location, the phosphorus loadings estimated by the model for a specific watershed may not necessarily reflect the actual loadings, in absolute terms. Various site-specific factors, such as lawn care practices, illicit point discharges, and erosion due to construction are not accounted for in the model. The model provides values that are considered to be typical of the region, given the watershed's respective land uses.

4.3.1 Water Quality Modeling (P8) of Varying Hydrologic Conditions

The amount of stormwater runoff and associated pollutant loading from a watershed is dependent upon hydrologic conditions such as precipitation patterns and soil saturation conditions. To evaluate the watershed loading under differing hydrologic conditions, the P8 model was run for three time periods that represent varying climatic conditions, in addition to the calibration year (May 2006-September 2007):

- "Average" climatic conditions: May 2000- September 2001
- "Wet" climatic conditions: May 2001- September 2002
- "Dry" climatic conditions: May 2005 - September 2006

The P8 model requires hourly precipitation and daily temperature data for each of the modeled time periods. Continuous hourly precipitation files were developed for each time period based on data from the National Weather Service (NWS) Minneapolis-St. Paul International Airport data collection site and the Willow Creek Watershed Outlet Monitoring Program (WOMP) station in Burnsville (Figure 4-10). The Willow Creek WOMP station is located approximately 1 mile upstream from the confluence of the Minnesota River and Willow Creek, which flows through an underground box culvert. Local daily precipitation data from the Minnesota High Density Network of rain gages and results of the model calibration process were used to corroborate the observed data from the NWS and WOMP stations. Daily temperature data was obtained from the NWS site at the Minneapolis–St. Paul International Airport. See Appendix B for additional information on the P8 model input files.



Barr Footer: Date: 7/9/2008 1:40:57 PM File: I:\Projects\23\19\A24\GIS\Maps\Figure_4-10_Precip_gages.mxd User: sgw

Precipitation Gage
Wood Pond
Wood Pond Watershed
City Boundary

N

0 0.5 1 2
Miles

Figure 4-10

LOCATION OF PRECIPITATION GAGES
USED FOR P8 MODELING

Wood Pond Use
Attainability Analysis
City of Burnsville
Burnsville, Minnesota

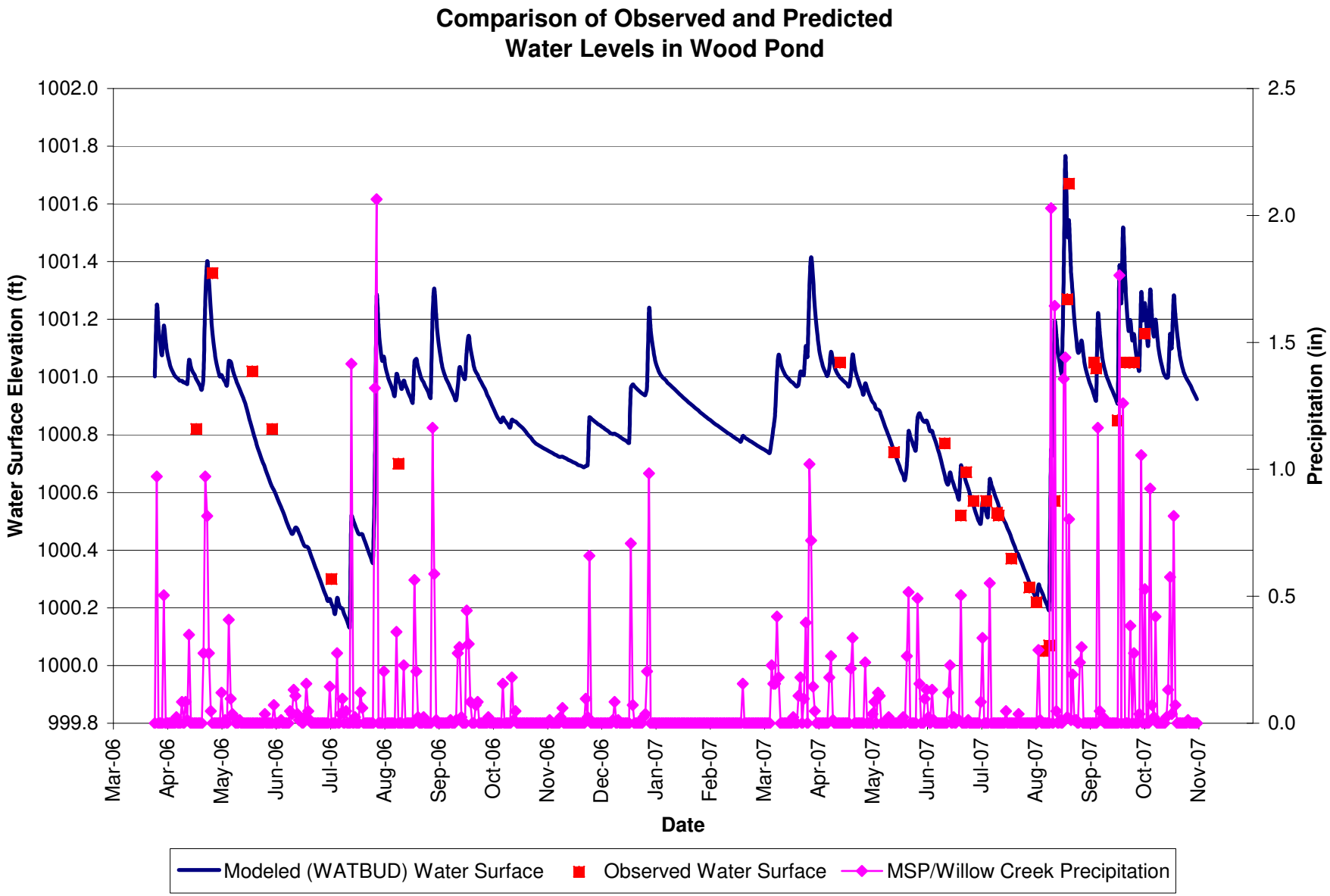
4.3.2 Water Quality Model (P8) Calibration

4.3.2.1 Stormwater Volume Calibration

The predicted runoff volumes from the P8 model were calibrated to the observed water surface elevations of Wood Pond during the period of April 2006 through October 2007. To translate the water loadings into water surface elevations, the Minnesota Department of Natural Resources (MDNR) WATBUD computer model was utilized. The model uses estimated daily watershed inflows (i.e., predicted by the P8 model), daily inflows from upstream water bodies, daily precipitation, daily evaporation, and an outlet rating curve to estimate lake levels. The predicted lake levels are then compared to observed lake levels, and adjustments are made to the model input parameters to obtain an optimal match between predicted and observed conditions.

The water level of Wood Pond is controlled at Elevation 1000.9 ft MSL by an 18-inch inlet/outlet pipe located on the west side of the lake. Discharge from the lake is conveyed southward through the trunk storm sewer system beneath Portland Avenue and eventually flows into Twin Lake. The stage-storage-discharge relationship provided in Table 4-5 was developed for Wood Pond based on basin bathymetry data (see Figure 3-2) and outlet characteristics:

Figure 4-11 illustrates the results of the WATBUD modeling for Wood Pond assuming no net gain or loss due to groundwater. The predicted water levels, shown by the line on the plot, closely matched the observed water levels (the open diamonds).



P:\Mpls\23 MN\19\2319A24 Wood Pond Management Plan\WorkFiles\WaterBalance\Observed_vs_Predicted_WSE.xls

Figure 4-11

Table 4-5 Stage-Storage-Discharge for Wood Pond

Elevation	Water Surface Area (acre-feet)	Cumulative Storage Volume (acre-feet)	Discharge (cfs)
987.0	0.0	0.0	0
988.0	3.1	1.8	0
989.0	6.8	7.6	0
990.0	8.1	15.1	0
991.0	8.8	23.6	0
992.0	9.3	32.6	0
993.0	9.8	42.2	0
994.0	10.2	52.2	0
995.0	10.7	62.7	0
996.0	11.1	73.6	0
997.0	11.5	84.9	0
998.0	12.0	96.6	0
999.0	12.5	108.9	0
1000.0	13.0	121.6	0
1001.0	13.5	134.7	0.04
1002.0	14.0	148.4	3.9
1003.0	14.3	162.6	11.1
1004.0	14.6	177.1	21.0

4.3.2.2 Phosphorus Loading Calibration

Because no field data was collected pertaining to the quantity or quality of stormwater runoff from the Wood Pond watershed, detailed calibration of the P8 model was not feasible. Similar studies completed for lakes in the area (Crystal Lake and Keller Lake [Barr, 1990], Lake Marion [Barr, 1997], Orchard Lake [Barr, 1999]) used phosphorus loading assumptions based on the stormwater monitoring data collected as part of the *Lake Marion Diagnostic-Feasibility Study* (Barr, 1997). However, due of the developed nature of the land use in the Wood Pond watershed, the phosphorus loading assumptions from the Lake Marion study were not deemed most appropriate. Instead, particle and phosphorus accumulation and runoff parameters used in the P8 model for the Wood Pond watershed were based on the NURP 50th Percentile particle file (i.e., National Urban Runoff Program, particle size distribution observed within the 50th percentile confidence interval). This is consistent with the modeling completed for the Twin and Earley Lake UAAs.

4.3.3 P8 Water Quality Modeling Results

Using the calibration discussed in Section 4.2.2.1, the P8 model was used to simulate the flow and treatment of stormwater throughout the Wood Pond watershed for each of the modeled climatic conditions. The following two general scenarios were modeled (full-development land use conditions were assumed to be consistent with existing land use conditions):

- Existing (2007) land use conditions with no additional best management practices (BMPs).
- Full-development land use conditions with various watershed and in lake BMPs (these scenarios are discussed in Section 6.0).

For each scenario, the stormwater runoff volume and phosphorus mass load to the lake was predicted using the P8 model. The predicted runoff and loadings were then used as input into the in-lake model to predict in-lake phosphorus concentrations.

The Wood Pond watershed was divided into six subwatershed areas to facilitate hydrologic and phosphorus modeling (Figure 3-3). Stormwater and phosphorus contributions to the lake were estimated for each subwatershed using the P8 model. Each subwatershed is described below:

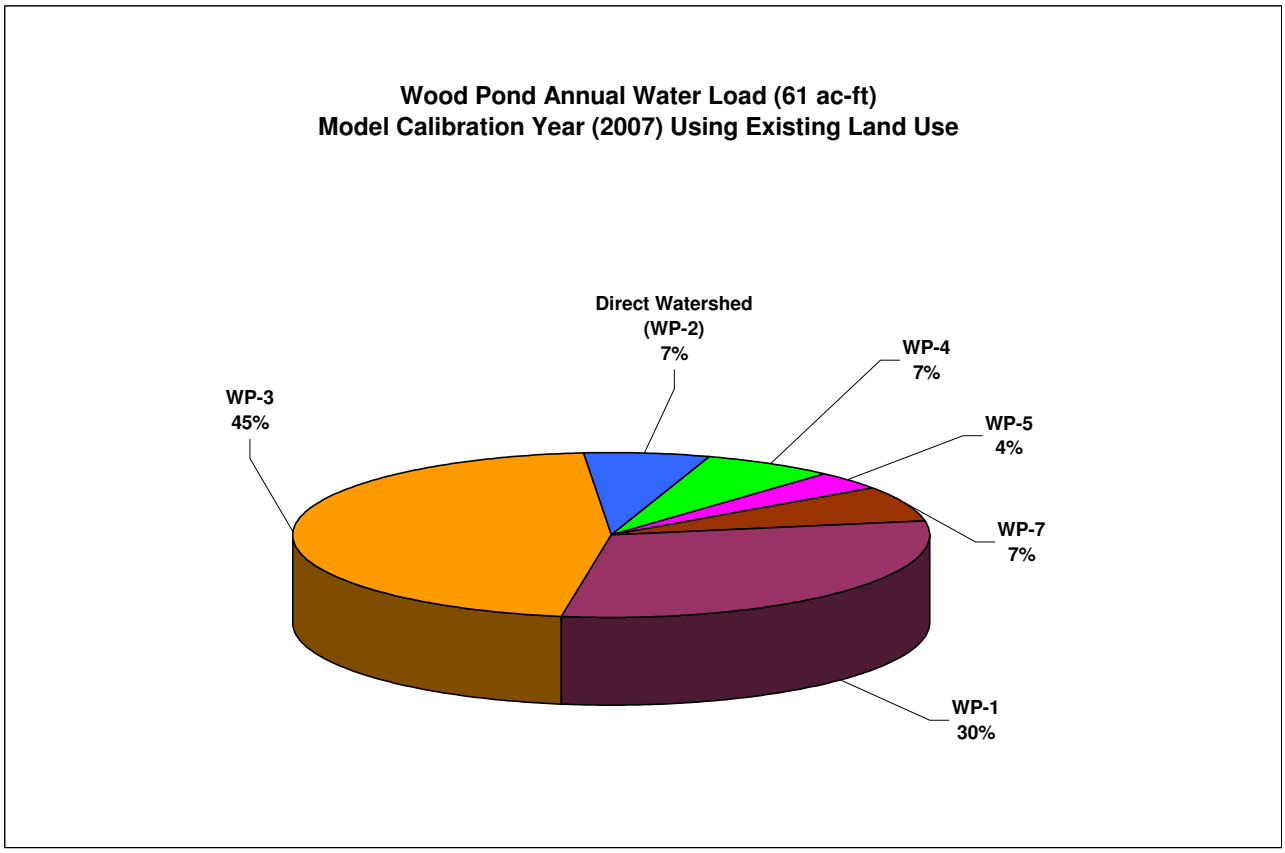
- **WP-1 Subwatershed—**The 27-acre drainage area represents approximately 25 percent of the Wood Pond watershed, and is located northwest of the lake. The WP-1 subwatershed is primarily medium density residential and right-of-way land use. Runoff from this subwatershed currently receives no water quality treatment prior to being conveyed to Wood Pond via a 24-inch RCP storm sewer.
- **WP-2 Subwatershed—**The 21-acre drainage area covers approximately 19 percent of the Wood Pond watershed and includes the land area that surrounds the lake. The subwatershed is primarily city-owned open space/parkland (Wood Park), with low density residential land use along the southern and northwestern shoreline of the lake. Runoff from this subwatershed reaches Wood Pond via overland flow.
- **WP-3 Subwatershed—**The 32-acre drainage area represents about 29 percent of the Wood Pond watershed. The subwatershed is primarily commercial, medium density residential and right-of-way land use, with some low density residential and open space land use on the north side of 145th Street. Runoff from this subwatershed currently receives no water quality treatment prior to being conveyed to Wood Pond via a 36-inch RCP storm sewer.

- **WP-4 Subwatershed—** The drainage area covers approximately 6 acres, which represents about 5 percent of the Wood Pond watershed. The subwatershed primarily consists of medium density residential and right-of-way land use. Runoff from this subwatershed currently receives no water quality treatment prior to being conveyed to Wood Pond via an 18-inch RCP storm sewer.
- **WP-5 Subwatershed—** This drainage area is approximately 3 acres, which approximately 3 percent of the Wood Pond watershed. The subwatershed consists of medium density residential and right-of-way land use. Runoff from this subwatershed currently receives no water quality treatment prior to being conveyed to Wood Pond via an 18-inch RCP storm sewer.
- **WP-7 Subwatershed—** The 6-acre subwatershed, representing approximately 5 percent of the Wood Pond watershed, consists entirely of the medium density residential and right-of-way land use. Runoff from this subwatershed is collected by the 18-inch RCP trunk storm sewer system beneath Portland Avenue. This system connects with the inlet/outlet pipe from Wood Pond, such that stormwater in the system will be discharged to Wood Pond if the lake level is below 1000.9 ft MSL, but will flow southward to Twin Lake if lake levels exceed this elevation. For purposes of the P8 modeling, it was assumed that all runoff from this subwatershed would be directed to Wood Pond.

4.3.3.1 Watershed Loading for Existing (2007) Land Use Conditions

Annual stormwater and phosphorus contributions to Wood Pond were estimated for each subwatershed using the P8 model. These loadings were then combined to determine the stormwater and phosphorus budgets for 2007 land use and hydrologic conditions (Figure 4-12). Modeling simulations indicate a total phosphorus load of 84 lbs from the Wood Pond watershed during 2007, and a watershed stormwater runoff volume of 61 acre-feet.

As indicated in Figure 4-12, the largest percentage (45 percent) of the annual water load to Wood Pond comes from subwatershed WP-3, which is the largest and most impervious subwatershed within the Wood Pond drainage area. Subwatershed WP-1, the second largest in the Wood Pond drainage area, produces approximately 30 percent of the annual water load to Wood Pond. The remaining 25 percent of the annual water load comes from the remaining subwatersheds (WP-2, WP-4, WP-5, WP-7).


Wood Pond Annual Water Load (61 ac-ft)
Model Calibration Year (2007) Using Existing Land Use
Direct Watershed (WP-2) 7%
WP-4 7%
WP-5 4%
WP-7 7%
WP-1 30%
WP-3 45%

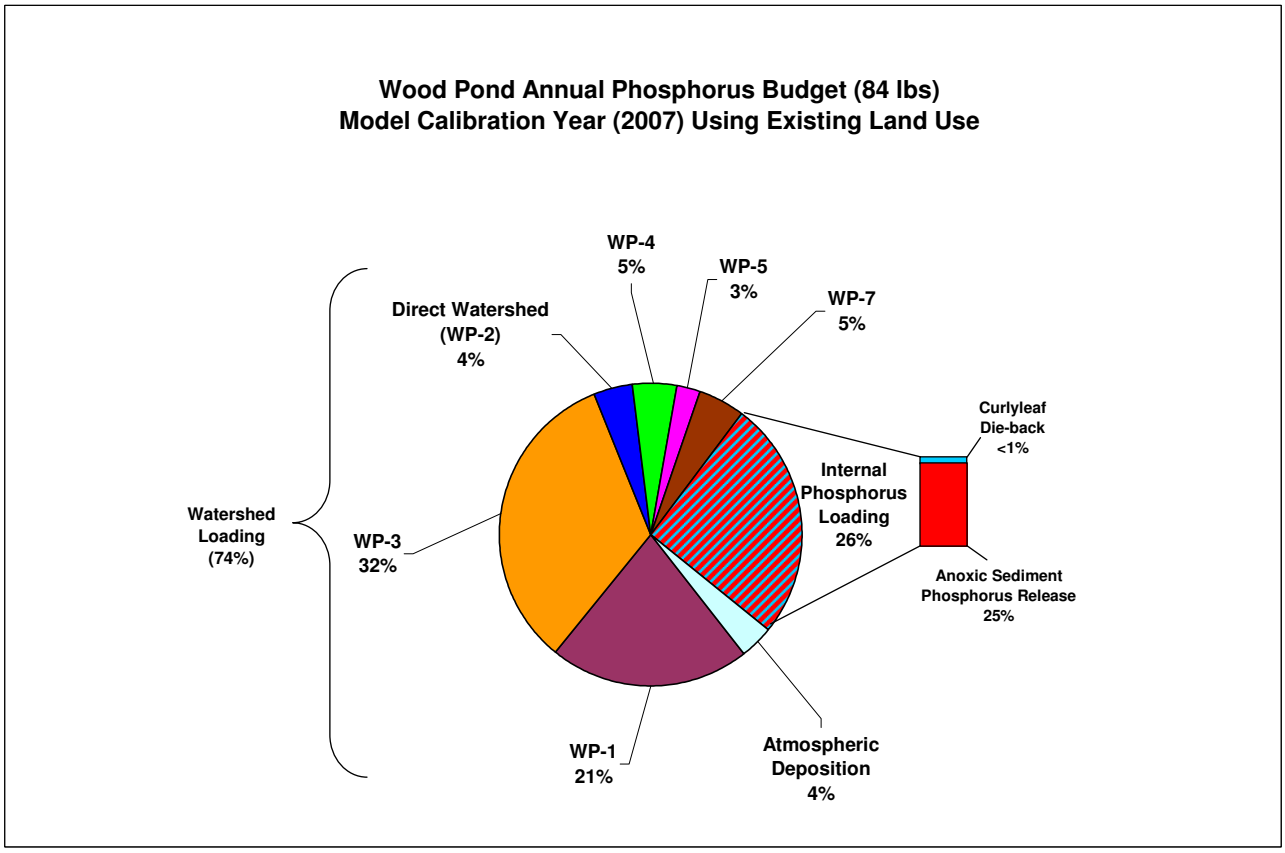

Wood Pond Annual Phosphorus Budget (84 lbs)
Model Calibration Year (2007) Using Existing Land Use
WP-4 5%
WP-5 3%
WP-7 5%
Direct Watershed (WP-2) 4%
Curlyleaf Die-back <1%
Internal Phosphorus Loading 26%
Watershed Loading (74%)
WP-3 32%
Anoxic Sediment Phosphorus Release 25%
WP-1 21%
Atmospheric Deposition 4%

Figure 4-12

Figure 4-12 also depicts the distribution of annual phosphorus loading to Wood Pond for the model calibration year (2007). Approximately 74 percent of the annual phosphorus loading was from external watershed sources. Of the external loading, the largest percentage (32 percent) comes from subwatershed WP-3, with 21 percent from subwatershed WP-1, 17 percent from the remaining subwatersheds (WP-2, WP-4, WP-5, and WP-7) and approximately 4 percent from atmospheric deposition. Internal phosphorus loading was estimated to contribute approximately 26 percent of the annual load to Wood Pond, the primary source being anoxic sediment phosphorus release (see Section 4.4 for additional information).

4.3.3.2 Watershed Loading for Full-Development Land Use Conditions

The Wood Pond watershed is considered fully developed, with no significant changes in land use classification expected for the foreseeable future. Therefore, the watershed runoff and phosphorus loading under full-development conditions was assumed to be the same as under existing land use conditions.

4.4 In-Lake Water Quality Modeling

4.4.1 In-lake Water Quality Modeling Methodology

While the P8 model is a useful tool for evaluating runoff volumes and pollutant concentrations from a watershed, another method is needed to predict the in-lake phosphorus concentrations that are likely to result from the various phosphorus loads.

To evaluate the lake's response to watershed and internal loads of phosphorus under a range of precipitation conditions, in-lake water quality models were created to route the P8 generated watershed loads through the lake for the following time periods:

- "Average" climatic conditions: May 2000- September 2001
- "Wet" climatic conditions: May 2001- September 2002
- "Dry" climatic conditions: May 2005 - September 2006

The in-lake modeling methodology used for the Wood Pond UAA is two-fold: First, the spring concentration is estimated with a steady-state, annual empirical lake model. Second, a spreadsheet mass balance model based on Dillon and Rigler (1974) is used that starts with the estimated spring concentration (from the empirical model) and routes external and internal phosphorous loads through the lake over many timesteps throughout the summer season (May through September).

The method described in the following sections was used first with existing land use and BMP conditions, and then, once internal loading rates had been calculated, the model could be used predictively, to evaluate lake phosphorus concentrations under future BMP scenarios under each hydrologic condition.

4.4.1.1 Predicting Springtime Concentration in Wood Pond

Water quality monitoring data from each lake was used to determine the empirical model that could best predict the spring concentration in each lake. The Dillon and Rigler model with a phosphorus retention term from Chapra (1975) was used to predict the spring total phosphorus concentration of each lake.

$$P_{SPRING} = \frac{L(1-R)}{z\rho}$$

where:

P_{SPRING} = spring total phosphorus concentration (µg/L)

L = areal total phosphorus loading rate (mg/m²/yr)

R = retention coefficient as defined by Chapra (1975)

= $16/(16+q_s)$

q_s = annual areal water outflow load (m/yr)

= Q/A

z = lake mean depth (m)

ρ = hydraulic flushing rate (1/yr)

= 1/(hydraulic residence time) = 1/(V/Q)

Q = annual outflow (m³/yr)

V = lake volume (m³)

A = lake surface area (m²)

The areal loading rate of total phosphorus (from the watershed) was obtained from P8 model output (May through April) for wet (2001-02), dry (2005-06), and average (2000-01) water years. Other values were obtained from P8 output and bathymetric information collected for each lake.

Early summer, summer-average and fall overturn concentrations, however, are often not well represented in steady state empirical models such as Dillon and Rigler. Most empirical phosphorus models assume that the lake to be modeled is well-mixed, meaning that the phosphorus concentrations within the lake are uniform. This assumption is useful in providing a general

prediction of lake conditions (especially for springtime concentrations), but it accounts for neither the seasonal changes in phosphorus concentrations nor the effect of internal phosphorus load that can occur in a lake throughout the summer and fall. Therefore, mass balance models are needed that look at the effect of the P8-generated total phosphorus loads at different timesteps throughout the year to provide reasonable predictions of summer-average epilimnetic lake phosphorus concentrations.

Historical water quality data for Wood Pond shows that the phosphorus concentrations vary significantly during the summer as a result of additional watershed runoff and internal loading of phosphorus. For this reason, the Dillon and Rigler equation was used to calculate a spring concentration in the lake, but a mass balance model that built off of this predicted spring concentration was used to calculate the in-lake phosphorus concentrations at various times throughout the growing season.

4.4.1.2 Accounting for Seasonal Variation of Watershed Loads and Internal Loading in the In-Lake Water Quality Models

A spreadsheet mass balance model based on Dillon and Rigler (1974) was used to reconcile phosphorus loadings from the watershed with phosphorus concentrations observed in the lake. The in-lake mass balance model uses the estimated spring concentration (from the empirical model) as a starting point and routes external and internal phosphorous loads through the lake over many timesteps throughout the summer season (May through September).

In the mass balance model, internal load from the lake sediments was calculated by deduction, using the following equation, calculated at time intervals varying from a few days to two weeks:

$$\text{Internal P} = \text{Observed P} + \text{Outflow P} - \text{Runoff P} - \text{P from Curlyleaf Pondweed} - \text{Atmospheric P}$$

In addition, sediment cores from Wood Pond were collected and analyzed for mobile phosphorus (mobile P) in order to measure the maximum potential for internal loading rate of phosphorus from the lake sediments. This was helpful in verifying the amount of internal load deduced by the mass balance model.

Internal load from Curlyleaf pondweed was calculated within the mass balance model, using an estimated stem density (based on visual observation during macrophyte monitoring events), an estimated grams dry weight per stem and an estimated phosphorus content per dry weight (these values were measured as a part of a study of Big Lake in Wisconsin (Barr, 2001).

Uptake of phosphorus from coontail was not estimated in the modeling for the Wood Pond UAA, as was done with the modeling of Twin and Earley Lakes, because coontail was not observed in Wood Pond in 2007.

4.4.1.3 Internal Phosphorus Load Calculation Results

Phosphorus enters Wood Pond from watershed runoff, atmospheric deposition, macrophyte senescence and sediment release. The latter two sources are referred to as "internal loading".

The internal release of phosphorus from the lake sediments is often a significant source of phosphorus in lakes that have a history of high phosphorus loads from their watershed. Phosphorus released from the sediments is typically in a dissolved form, which can be quickly utilized by algae, leading to intense algal blooms. Internal loading is influenced by the lake's mixing and stratification patterns. Based on the monitoring data collected in 2007, Wood Pond appears to be a "polymictic" lake, with frequent mixing resulting from the shallow depths and exposure to the wind. Because of the frequent mixing, Phosphorus released from the sediments, therefore, does not typically build up in the hypolimnion. If, however, the bottom waters become anoxic (devoid of oxygen), even for short periods, internal phosphorus load from the lake sediments may occur. This is likely to occur during periods of high temperatures, low wind, and low oxygen concentrations in the lake (conditions that occurred in Wood Pond during several periods of the 2007 monitoring program). In addition, elevated pH can cause the phosphorus that is bound to the iron compounds to be replaced with the abundant hydroxyl ions, thus releasing the phosphorus into the water column. The internal load of phosphorus can be transported to the entire lake as the wind increases and causes the lake to circulate.

The phosphorus mass balance for Wood Pond was calculated based on existing land use conditions and phosphorus concentrations measured from May through September of 2001 ("average" year), 2002 ("wet" year), 2006 ("dry" year), and 2007 ("calibration" year). Using the mass balance equation, the estimated net internal phosphorus loadings from sediment release for these years are provided in Table 4-6.

Table 4-6 Net Internal Phosphorus Loading from Sediments in Wood Pond Based on In-Lake Modeling for 2001, 2002, 2006 and 2007 summer seasons (lbs/year).

Internal Phosphorus Load Source	2001 ("Average" Year)	2002 ("Wet" Year)	2006 ("Dry" Year)	2007 ("Calibration" Year)
Internal Load from Sediments (lbs)	4	4	75	21

Another source of internal phosphorus loading is senescence (die-back) of Curlyleaf pondweed. After Curlyleaf pondweed dies out in early July, it may sink to the bottom of the lake and decay. When dense colonies of the aquatic plant decay, oxygen depletion and release of phosphorus may occur. Although Curlyleaf pondweed was present in Wood Pond in 2007, it was observed at only light to moderate densities along portions of the lake's shoreline. The estimated phosphorus loading from the Curlyleaf die-back is relatively insignificant (see Section 4.4.2 for more information).

4.4.2 In-Lake Water Quality Modeling Results

The estimated atmospheric, internal and watershed phosphorus loads were applied to the in-lake water quality model to predict the associated summer-average phosphorus concentration in Wood Pond during 2001 ("Average" year), 2002 ("Wet" year), 2006 ("Dry" year), and 2007 (calibration year). The in-lake phosphorus model of the existing conditions scenario was essentially used to validate the estimated watershed and internal loads and to calibrate the in-lake model to actual in-lake data that were collected from Wood Pond for each of the years of interest.

Figure 4-13 shows how internal sediment load, internal load from die-back of Curlyleaf pondweed, watershed load, atmospheric deposition, and the effect of springtime concentrations contributed to the lake's summer-average phosphorus concentration for 2001 ("Average" year), 2002 ("Wet" year), 2006 ("Dry" year), and 2007 (calibration year). Detailed calibration results for each of these model years are presented in Appendix C. It should be noted that the summer-average concentrations reported by the calibrated in-lake model are not always equal to the summer-average concentrations reported in the historical water quality data figures (see Section 4.2). This variation in reported summer-average phosphorus concentrations reflects differences in the data sets used to calculate the summer-average concentrations. The water quality data points used for the in-lake modeling typically did not include early-May samples, as did the historical analysis. The data set used for the in-lake modeling also excluded some CAMP data points collected on or near the same day as samples collected by Barr in 2007.

In 2006 ("Dry" year), Wood Pond was at the highest summer-average phosphorus concentration of the 4 years evaluated (79 µg/L). Due to the dry conditions during the summer of 2006, the watershed loading contribution to Wood Pond was lower than that of the other evaluated years. However, there was a significant internal sediment load of phosphorus to the lake that year that largely contributed to the high summer-average phosphorus concentration (see Figure 4-13). The predicted phosphorus loading contribution from atmospheric deposition and die-back of Curlyleaf pondweed were insignificant.

Contributing Factors in Wood Pond's Summer-Average Total Phosphorus Concentration for a Variety of Scenarios: 2006 (Dry Year), 2002 (Wet Year), 2001 (Average Year) and 2007 (Calibration Year) Model Results

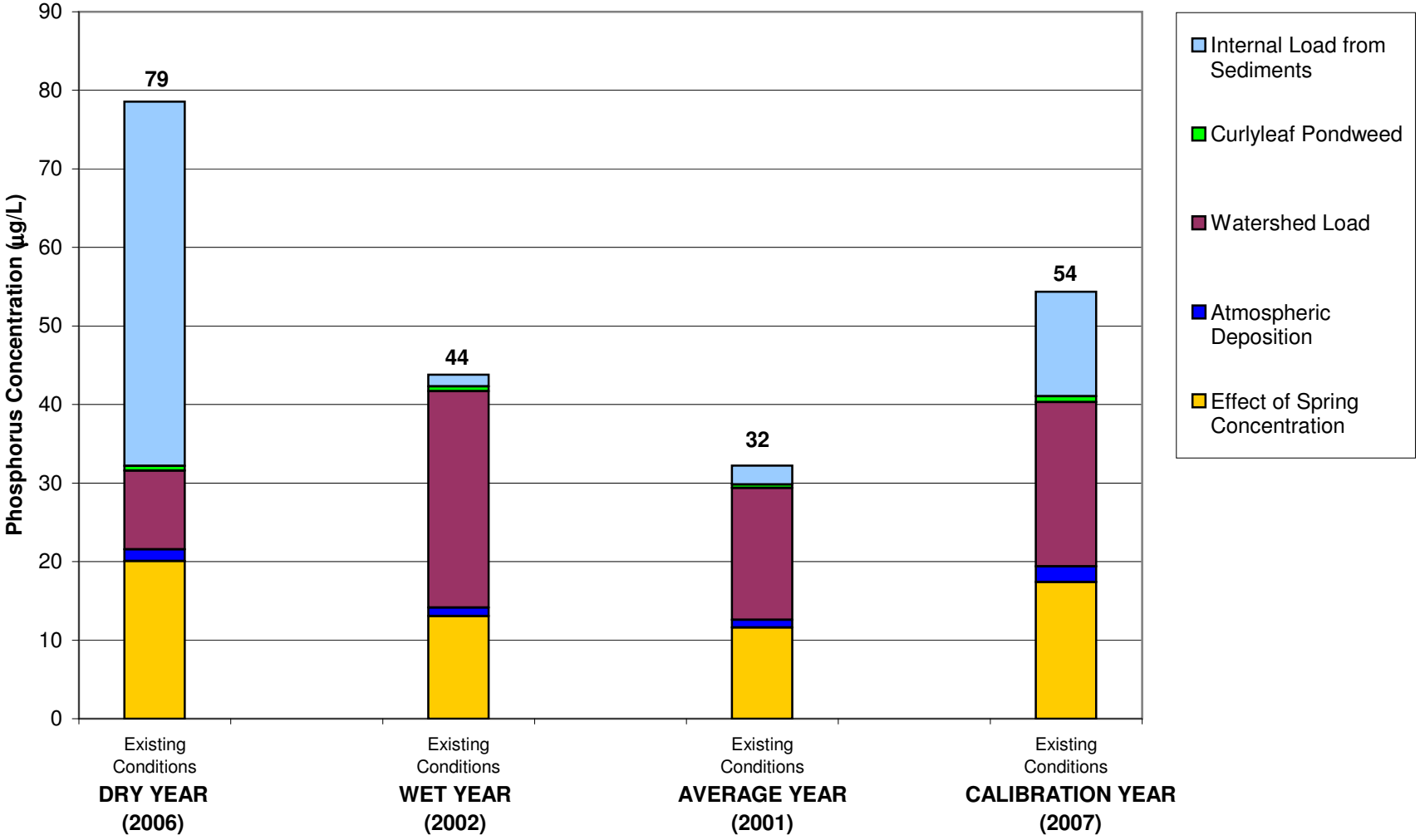


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Figure 4-13

In 2002 ("Wet" year), the summer-average phosphorus concentration in Wood Pond was 44 µg/L. Due to the wet conditions during the summer of 2002, the largest contribution to the observed summer-average phosphorus concentration was from stormwater runoff from the Wood Pond watershed. Under the wet conditions, the contribution of internal phosphorus loading from the lake's sediments was relatively insignificant, as were the loading contributions from atmospheric deposition and die-back of Curlyleaf pondweed.

In 2001 ("Average" year), Wood Pond was at the lowest summer-average phosphorus concentration of all 4 years evaluated—32 µg/L. This low concentration is in part due to low springtime phosphorus concentrations in Wood Pond. The phosphorus contribution from watershed runoff was moderate, reflecting "average" precipitation conditions during the summer of 2001. The contribution of internal phosphorus loading from the lake's sediments was relatively insignificant, as were the loading contributions from atmospheric deposition and die-back of Curlyleaf pondweed.

In 2007 (the calibration year), the summer-average phosphorus concentration in Wood Pond was 54 µg/L. The summer of 2007 exhibited two distinct precipitation patterns: dry in the early summer and wet in late-summer. As a result, lake conditions were affected by both a significant internal phosphorus load from the lake's sediments and a large phosphorus contribution from watershed runoff. The predicted phosphorus loading contributions from atmospheric deposition and die-back of Curlyleaf pondweed were insignificant.