4. Review of Relevant Data

4.1 Precipitation

Collection of precipitation data is an on-going activity by the District. Rainfall gauges are maintained at five sites across the watershed (Map 4.1). Data collection and reporting is currently implemented by the Washington Conservation District on behalf of the District. Rainfall data is recorded in 15-minute intervals, generally from March through November.

Rainfall data is also collected by other agencies at sites adjacent to the watershed. The closest rainfall data collection site is at the Minnesota River Lock and Dam #2 at Hastings (National Weather Service, station 213567). Also adjacent to the South Washington Watershed District is the rainfall data collection site at the St. Paul airport (National Weather Service, station 217377).

4.1.1 Past Analysis

A typical analysis performed regarding weather station data is calculation of a 30-year normal value, usually based on a period of 1971-2000. The 30-year normal annual precipitation depth at Hastings is approximately 29.9 inches. (Refer to Chapter 8 for more information on climate.)

The Minnesota DNR and State Climatology Office jointly maintain a publication documenting flash flood occurrences in the state since 1970. This publication documents nine flash floods that have occurred in the SWWD, beginning with the “never-to-be-forgotten flood” of August 1977 up through the most recent heavy rainfall of October 2005.

A very significant past analysis of rainfall is the U.S. Weather Bureau’s Technical Paper (TP) 40 published in 1961. The formal name of TP40 is Rainfall Frequency Atlas of the United States. The document is composed of rainfall charts for storm events of various return frequencies across the nation. This document is significant because nearly all designs for flood control are based on this publication and its analyses. The validity of this document in realistically representing rainfall recurrence intervals and rainfall depths is challenged by some. The challenge is based on analysis methodology as well as perceived outdated information (i.e., currently missing approximately 45 years of precipitation records).

Another significant rainfall analysis is Bulletin 71: Rainfall Frequency Atlas of the Midwest published by the Midwestern Climate Center (Huff and Angel, 1992). It addresses perceived flaws in the classification of heavy storms by TP40. Bulletin 71 provides customized rainfall frequency distributions charts for nine states including Minnesota. Detailed tables are included showing precipitation depths for a range of storm durations and recurrence intervals from 2 months to 100 years. These tables can be quite useful for water quality analyses which focus on controlling small (frequently recurring) storm events.

In summary, past rainfall analysis publications serve to guide design methods. Generally, TP40 and Bulletin 71 publications can both be used but the more conservative of the two should always supercede. The District should continue to collect and analyze local rainfall data over a significant time period to help refine hydrologic design criteria and flood control parameters.

Implication: The District prefers Bulletin 71 as a more robust reference for hydrologic analysis and has established an updated 100-year rain event based on this research (see Chapter 6).

4.1.2 Pattern Classification

The current 5-year period of record for local rainfall data collected by the District limits the ability to develop site-specific statistical classifications for annual precipitation patterns. Another limitation is that some gaps exist in rainfall data at some sites. Improved data collection will facilitate a stronger ability to develop classifications about rainfall patterns within the watershed. However, the distribution of the rainfall gauges provides adequate spatial coverage of the watershed. A Theissen polygon map is overlaid on Map 4.1, illustrates which gauges in the District contribute the most spatial influence to an overall watershed precipitation average.

Currently the rainfall data can be used as inputs to continuous simulation models which span the same temporal scale that the data is collected. As well, the District's rainfall gauge network can illustrate the spatial variability of rainfall at a micro-scale of the watershed.

Historical data was evaluated from the Hastings dam and other nearby stations to statistically classify annual precipitation patterns into wet, dry, or normal depths. This is especially valuable for water quality modeling purposes where the annual precipitation pattern will greatly influence the pollutant load from the watershed. Similar to the approach by NOAA (National Oceanic and Atmospheric Administration), precipitation patterns for dry, normal, and wet are based on the 10^{th}, 50^{th}, and 90^{th} exceedance percentiles respectively. Percentiles—also referred to as frequency distributions—for annual rainfall depths are shown on the next page in Table 4.1.

The table indicates that there is little overall variation between historical data for the Hastings dam and historical data for combined nearby stations. A year classified as "dry" would only total about 20.5 inches precipitation, a "wet" year would total about nearly 36.5 inches, and a "normal" year would total about 28.5 inches. There is roughly an 8-inch precipitation differential between dry, normal, and wet classifications.

Data from Hastings Dam and other stations indicates that 2002 is classified as a wet year (Appendix G). Data recorded within the SWWD reveals that the month of August 2002 can be classified as wet, and that the months of June and July approach this classification as well. Bar charts are also included in Appendix G which shows SWWD summer monthly precipitation depths versus NOAA normal 10^{th}, 50^{th}, and 90^{th} percentiles.

Implication: The rainfall network distribution is adequate. However, minor refinements to the data collection effort (e.g., synchronizing data loggers) should be pursued. Until a design manual is established, the SWWD should use the 10^{th}, 50^{th}, and 90^{th} percentiles as shown to reflect modeling uncertainty.

Table 4.1 – Frequency distribution of historical annual rainfall depth (inches) near the SWWD.

Percentile	Hastings Station (n=63)	Combined Stations* (n=86)	Classification
2.5%	16.0	15.2	
5%	19.1	18.7	
10%	**20.5**	**20.3**	**Dry**
25%	23.0	23.4	
50%	**28.3**	**28.9**	**Normal**
75%	32.7	32.8	
90%	**36.3**	**36.6**	**Wet**
95%	38.2	38.3	
97.5%	39.4	39.0	

*Combines data at Hastings, St. Paul, and Stillwater

4.1.3 Washoff/Buildup

The number of days between precipitation events can influence the level of pollutant accumulation in a watershed. Similarly, the accumulation or buildup of watershed pollutants can be reflected as elevated pollutant concentrations washed off the landscape during rainfall. Many continuous simulation water quality models incorporate an algorithm to account for the gradual buildup of watershed pollutants during periods without rainfall. Such models can mathematically adjust the pollutant washoff concentration according to the duration of the preceding dry period.

Monitoring efforts and resulting data collected within the SWWD do not currently facilitate a robust analysis of the time between precipitation events and pollutant runoff concentration. Some patchiness in the rainfall data record was an issue in the analysis. Most occurrences of water quality sampling had 3 or fewer prior dry days. This may suggest that water quality data presented in the following Section 4.2 slightly underestimates annual loads. However, where rainfall did occur immediately prior to the monitored event it was usually a small amount, often less than one-tenth of an inch recorded over 24 hours.

Implication: The SWWD should accept standard defaults for washoff/buildup dynamics in water quality modeling. The current water quality sampling locations (i.e., downstream of ponds and lakes) does not facilitate a robust analysis of this dynamic.

4.2 Runoff Quantity and Quality

General Note: Additional data and analysis (annual monitoring and analysis reports) is available on the SWWD website at www.swwdmn.org.

The District has been collecting data on runoff quantity and quality at intermittent stream sites since 1996. The data collection efforts from 1996-1999 are poorly documented and contain information of unknown reliability (as per discussions with the Washington Conservation District). Beginning in 2000, the Washington Conservation District was contracted by the District to oversee the data collection for runoff quantity and quality at intermittent stream sites.

Continuous data loggers and automated samplers are deployed at the end of winter. Flow stage and velocity are recorded and converted to discharge by use of a rating curve or area-velocity calculation. Snowmelt grab samples and storm flow composite samples are obtained for water quality analysis at certain stations. Generally, the current data collection program is technically sound and successful. However, a formal monitoring plan should be developed which guides long-term data collection by identifying goals and objectives for use of data and address how the data will be used to inform watershed planning and decision-making.

The table below (Table 4.2) illustrates the stream and runoff monitoring stations and their period of record (as of 2004). These stations are also shown on Map 4.2.

Table 4.2 – Stream and runoff monitoring locations and history within the SWWD.

Stream and Runoff Monitoring Station	Year Started*	Water Quality Data Collected	Subwatershed
Fox Run	2000	NO	Northern
Tamarack	2000	NO	Northern
MS1	2000	YES	Northern
MS2	2000	YES	Northern
Powers Lake**	2001	YES	Northern
100th Street	2001	YES	Central Ravine
80th Street	2002	NO	Central Ravine
90th Street	2002	NO	Central Ravine

*Indicates year when data collection was started by Washington Conservation District for SWWD.
**Powers Lake monitoring occurred at two different locations since 2001.

4.2.1 Past Analysis

Only limited use has been made of the monitored stream flow and chemistry data. Each year the Washington Conservation District delivers an annual report to the SWWD which presents a summary of data collected. However, synthesis and interpretation of data are generally outside of the scope of the annual report.

Monitored data relating to stormwater runoff flows and volume have been utilized by HDR Engineering to verify hydrologic and hydraulic models constructed for the SWWD. Although the data were utilized and generally discussed, no specific analysis was intended nor developed as part of the model verification exercise.

4.2.2 Monitored Flows

4.2.2.1 Overview

As noted in Table 4.2, there are eight stations where runoff flow is measured by the District. For this WMP, the analysis evaluated flows monitored at four stations where water quality data was also collected: MS1, MS2, 100th Street, and Powers Lake.

Flow regimes at these stations reflect a log-normal distribution which is typical for runoff data in an urban system. Box plots of flow data are presented in Appendix H. Flow data are based on monitored runoff volumes over a 24-hour period and are not tied to a specific hydrograph. Median daily discharge values indicate a typical volume of runoff passing a monitoring station during a 24-hour period when there is observed flow. Flow data are not collected for an entire 12-month period, so some snow melt events or light rains are not captured in the monitoring or the data analysis. This is not expected to significantly impact the median daily discharge values.

4.2.2.2 Discharge Recurrence Interval

The District intends to establish discharge assessment points at critical crossings and locations across the watershed. (A detailed discussion of regional assessment locations is presented in Section 6.8.) Monitoring data will be combined with hydrologic and hydraulic modeling to establish allowable limits for runoff. Continuous discharge records were utilized to begin compiling a recurrence interval for the 2-year, 10-year, and 100-year discharges. The period of record is generally 4-5 years and only captures data during free-flowing conditions (approximately March through October) through the year 2004. Based on the data, recurrence intervals are presented in Table 4.3 below. The discharge data is considered preliminary and should be updated annually as the District collects additional information. The data can also be used to calibrate hydrologic models.

Table 4.3 –Recurrence intervals for mean daily discharge (cfs) at monitoring stations.

Monitoring Station	*2-Year Recurrence*	*10-Year Recurrence*	*100-Year Recurrence*
MS1	0.3 cfs	2.4 cfs	11.4 cfs
MS2	1.0 cfs	17.7 cfs	60.0 cfs
100th Street	1.1 cfs	3.7 cfs	10.1 cfs
Powers Lake*	N/A	N/A	N/A

*Powers Lake monitoring occurred at two different locations since 2001; insufficient period of record.
**Multiply mean daily flows (cfs) by a factor of 2 to approximate units of acre-feet/day.

Implication: As longer periods of record are established at these sites, the District can use the data to set and assess allowable flows at critical crossings and for the calibration of hydrologic models.

4.2.2.3 Annual Runoff Coefficient

An annual runoff coefficient (Rv) is a unitless ratio of cumulative observed runoff at the watershed outlet versus cumulative precipitation depth upon a watershed area. It reflects the degree to which rainfall is infiltrated into the ground. A low annual runoff coefficient means that most rainfall does not leave the watershed as surface runoff.

The annual runoff coefficient is a valuable tool to aid in computing annual pollutant loads to receiving waters. The Rv can be mathematically combined with an annual precipitation depth and a pollutant mean concentration to estimate a total load. Continuing to monitor rainfall and runoff at established stations will enable the District to refine the most likely Rv for areas of the watershed as well as develop ranges for different precipitation patterns (i.e., wet, dry, normal). Annual runoff coefficients for the three of the four key monitoring stations are presented below in Table 4.4 and detailed in Appendix G. Drainage areas to Powers Lake monitoring stations (two separate sites monitored in different years) were not defined so a coefficient was not calculated.

Table 4.4 – Annual runoff coefficients at selected monitoring stations.

Monitoring Station	2000	2001	2002	2003	2004
MS1	0.05	0.13	0.12	0.11	0.09
MS2	0.09	0.03	0.22	0.09	0.01*
100th Street**	-	0.02	0.01	-	0.00

* Due to construction only periodic field state and discharge measurements were taken.
** The drainage area to 100th Street needs field verification; it may only be monitoring local runoff.

Implication: These data can be used to corroborate hydrologic components of water quality and quantity models. A more detailed analysis can be done to break down the temporal scale (e.g., monthly or discrete storms) to focus runoff management efforts.

4.2.3 Runoff Quality

4.2.3.1 Overview of Data

Four monitoring stations collect water quality data in the District: MS1, MS2, 100th Street, and Powers Lake inlet. With the exception of Powers Lake inlet, the stations have a minimum of four years of data. Watershed monitoring at Powers Lake has switched between two discharge sites, with 2001-2002 data collected at one site and 2004 data at the other site (see section 4.3.5 for more discussion on Powers Lake). As such, a long term record is still being developed and typical runoff quality data is not presented for Powers Lake in this WMP.

The information developed in the following two sections can be applied in numerous ways. The runoff quality measured through the watershed can be used to verify outputs of water quality models or to provide a basis for evaluating reasonableness. The data can be used to assess and set allowable conditions for runoff loads and concentrations at the monitoring locations. Another application is in characterizing watershed yield coefficients to contextualize potential loadings to the Mississippi River. However, a limitation is that the monitoring locations do not reflect raw (untreated) runoff conditions and so cannot be used directly as model inputs for land use runoff quality.

Monte Carlo simulations were performed to develop the event mean concentration and loading data presented in the next two sections. This approach incorporates the natural variability inherent in runoff quality and quantity. Monte Carlo modeling uses stochastic (random) calculations and mimics the observed distribution of monitored variables. This approach provides an excellent method for estimating typical runoff quality conditions when only a small portion of runoff events are actually sampled.

The District has collected runoff quality data on a wide range of constituents. Box plots which summarize the data are presented in Appendix I. Discrete results are tabulated are presented in Appendix J. Several of the metals, as well as ammonia, commonly exceeded water quality standards set by the MPCA (Rule 7050). Metals which exceeded standards (chronic and / or maximum) included copper, lead, zinc, cadmium, and chromium. The suitability to infiltrate waters which often exceed state standards is questionable.

4.2.3.2 Flow Weighted Mean Concentrations

Where long term data were available, flow weighted mean concentrations (FWMCs) were developed for three parameters: total phosphorus (TP), total suspended solids (TSS), and total kjeldahl nitrogen (TKN). These parameters represent variables which commonly influence the condition of receiving waters, especially lakes. Recognizing that variability is inherent in runoff water quality, a range of FWMCs is presented in Tables 4.5 – 4.7. In all cases, the average FWMC is above the 75th percentile FWMC, which illustrates that the water quality data are not normally distributed. The FWMCs were developed using the loads estimated through Monte Carlo (see next section) and dividing by the stochastically estimated flow.

Implication: The District should update FWMCs (potentially annually) because the continued addition of field data will make the analysis more robust. Modeling efforts should strive to be within the 25th – 75th percentiles for FWMCs at corresponding monitoring locations.

4.2.3.3 Loads

The estimation of loads at monitoring stations were developed using a Monte Carlo analysis of the monitoring data. This approach incorporates the probability distribution of the data as well as the natural variability inherent in both water quality concentration and flow volumes.

No significant relationship was found between mean daily flow and corresponding water quality concentration at the monitoring stations. Mean daily loads were stochastically calculated by multiplying pollutant concentration and mean daily flow. Summary statistics were used to develop a range of mean daily loads. These loads were then increased to an annual scale by multiplying against the average number of days with recorded discharge at each station. An illustration of a range of daily loads, and their associated probabilities, is shown in Figure 4.1.

Implication: The cumulative load impacts to downstream resources are likely driven by small, yet frequent, daily loads. However, flow records at the monitoring stations are influenced by upstream extended detention dynamics which affects the number of days with recorded discharge. Further investigation is needed to determine whether small storm hydrology (i.e., rains between 0.5 – 1.0 inches in depth) or other factors such as precipitation depth or total runoff volume are more influential in loading dynamics.

Table 4.5 – Characteristics of selected water quality parameters at MS1**.*

	Flow Weighted Mean Concentration (mg/L)			Mean Annual Load (pounds)		
	TP	TSS	TKN	TP	TSS	TKN
Median	0.318	77	1.37	75	18,029	320
Mean	0.611	869	1.84	514	731,590	1,533
25th Percentile	0.245	32	1.15	19	2,533	91
75th Percentile	0.407	179	1.54	280	123,670	1,065

*Based on Monte Carlo analysis of field data.

**Drainage area = 1,482 acres, estimated percent impervious = 24%

Table 4.6 – Characteristics of selected water quality parameters at MS2**.*

	Flow Weighted Mean Concentration (mg/L)			Mean Annual Load (pounds)		
	TP	TSS	TKN	TP	TSS	TKN
Median	0.155	17	1.53	166	18,648	1,648
Mean	0.193	25	1.61	1,288	160,944	10,293
25th Percentile	0.143	15	1.50	44	4,536	452
75th Percentile	0.169	20	1.55	648	75,264	5,966

*Based on Monte Carlo analysis of field data.

**Drainage area = 10,174 acres, estimated percent impervious = 25%

Table 4.7 – Characteristics of selected water quality parameters at 100th Street**.*

	Flow Weighted Mean Concentration (mg/L)			Mean Annual Load (pounds)		
	TP	TSS	TKN	TP	TSS	TKN
Median	0.090	8	0.76	66	5,480	556
Mean	0.115	12	0.92	145	14,659	1,167
25th Percentile	0.085	7	0.70	22	1,644	179
75th Percentile	0.099	9	0.82	169	15,344	1,388

*Based on Monte Carlo analysis of field data.

**Drainage area = 8,046 acres, estimated percent impervious = 28%. Note, however, that this monitoring station may only be capturing runoff from a localized watershed (not the storm sewer system)

Figure 4.1 – Stochastically estimated total phosphorus daily loads

4.3 Lakes

General Note: Additional data and analysis (annual monitoring and analysis reports) is available on the SWWD website at www.swwdmn.org.

Long-term records of lake water quality are critical for assessing trends or changes in the integrity of a lake system. The Metropolitan Council's Citizen Assisted Monitoring Program (CAMP) has been utilizing volunteers to help obtain information on the health of Twin Cities lakes since 1993. Volunteers collect water samples for analysis and record observational information.

As of 2004, there are currently 7 lakes in the District that are actively monitored as part of the CAMP. In addition to the CAMP, the District has utilized the Washington Conservation District (WCD) to annually collect more detailed water quality data on Powers Lake and Armstrong Lake. The WCD also currently collects water level information on 8 lakes. It is anticipated that lake monitoring efforts will increase across Washington County and the WCD takes the lead on developing a program to coordinate baseline monitoring.

Section 4.3 assesses the characteristics of District lakes whereas Section 6.5 provides management classifications and standards for these lakes.

This section is intended to present a characterization of the lakes found within the watershed. A discussion of the lake in the context of its surrounding drainage area is presented. Hydrologic behaviors (lake level fluctuations) of lakes are noted. The long-term and overall qualities of the lakes are assessed and supporting data is illustrated. Estimated phosphorus loads to lakes are provided. The classification of the lakes and proposed nutrient standards for management purposes are found in Section 6.5.

4.3.1 Past Analysis

The SWWD has completed lake management plans for Powers Lake and Ravine Lake. These plans focus on the impacts of future development to lake water quality. A summary of these management plans, and other District studies, is presented in Appendix B. The former Lower St. Croix Watershed Management Organization completed a management plan for O'Conners Creek and Lake with focus on protecting and restoring the unique water resource. The O'Conners Creek and Lake Management Plan included extensive review of available data and is available on the SWWD website at www.swwdmn.org.

In addition to the lake management plans, the Metropolitan Council prepares an annual report which evaluates water quality data collected by participants of the CAMP. Grades are assigned to each lake to reflect the quality of the lake and, where possible, long term trends of lake health. The Washington Conservation District prepares an annual report which includes a summary of data collected on lakes within the District. The scope of the annual report is not intended to include analysis or interpretation of data.

The MPCA provides technical assistance for lake management studies through their Lake Assessment Program. These studies provide basic insight regarding the interaction between a lake and its watershed. Currently no LAP studies have been performed in Washington County.

There currently is not an adequate level of past analyses on the priority lakes in the District to provide District-wide guidance for lake management or address regulatory program requirements.

4.3.2 Overview of District Lakes and Analysis

The following sections (4.3.3 through 4.3.10) discuss lake status and analyze data collected through 2004. New lakes (e.g., Fish Lake) were added to the District's monitoring efforts in 2005 but are not included in this WMP. A summary table for the eight lakes analyzed in this WMP is presented in Table 4.9. Additionally, the District analyzes data annually and reports findings on the SWWD website at www.swwdmn.org.

The most commonly collected information on lakes includes total phosphorus (TP), transparency, and chlorophyll *a*. Phosphorus is an essential nutrient for aquatic plant and algal growth. When TP is abundant in lake systems it can cause excessive growth of algae (referred to as blooms), leading to nuisance conditions in the lake. The amount of algae present in a lake is characterized by chlorophyll-*a*, a pigment which supports photosynthesis. As increased nutrient levels stimulate algal growth, the transparency of the lake water declines. Transparency indicates the level of water clarity and is measured by a Secchi disk. Other indicators of lake health or impacts include chloride levels (e.g., from road de-icing operations) or nitrogen concentrations.

Several tools and approaches are available to synthesize and evaluate lake water quality data. One of the most frequently used tools is the **Carlson Trophic State Index** (TSI). The TSI indicates the biological productivity and nutrient enrichment of a lake and is illustrated in Table 4.8. The elevation of nutrient levels in a lake is called eutrophication. This is a natural aging process of lakes but is often unnaturally accelerated due to human activities in the watershed. The condition of hypereutrophic lakes in particular is often a result of land use changes by humans, whether from agriculture, urbanization, or both.

Table 4.8 – Lake trophic state and general characteristics

Trophic State	TSI Range	General Characteristics
Oligotrophic	0 – 40	Lakes, usually deep, with low nutrient levels with few or infrequent algal blooms. Water clarity is very high.
Mesotrophic	41 – 50	Lakes with moderate levels of nutrients and slightly depressed dissolved oxygen. Algal blooms are typically occasional or temporary.
Eutrophic	51 – 70	Lakes, often shallow, having high nutrient levels and correspondingly low dissolved oxygen. Designated uses are frequently impaired by persistent algal blooms.
Hypereutrophic	>70	Lakes characterized as very "green" with frequent winterkill and summer kill which limit aquatic life. Impacts from algal blooms are extreme.

Another tool to evaluate data and identify trends is a **rolling average** (also called a moving average). It is an average of data over a certain time period, by putting in the latest value and taking out oldest value of a previous period. This is useful because it helps to smooth irregularities in data and identify long-term trends. The larger the time period utilized, the more robust the smoothing effect. It is important to note that a rolling average is a “lagging indicator” and thus behind the current value. Four year rolling averages for lake nutrient concentration (TP) and Secchi depth (clarity) is presented in Figure 4.2 and Figure 4.3.

Table 4.9 – Summary of key information for SWWD lakes.

	Gables Lake	Ravine Lake	Markgrafs Lake	Wilmes Lake	Powers Lake	Colby Lake	La Lake	Armstrong Lake
DNR Lake ID Number	82-0082	82-0087	82-0089	82-0090	82-0092	82-0094	82-0097	82-0116
Monitoring Period	1998 - 1999	1998-present	1994-present	1994-present	1994-present	1994-present	1994-present	1998-present
Management Classification*	Class D	Class B	Class C	Class B	Class A	Class C	Class A	Class B
Trophic Status	Hyper-eutrophic	Eutrophic	Hyper-eutrophic	Eutrophic	Eutrophic	Hyper-eutrophic	Eutrophic	Eutrophic
Mean Total Phosphorus** (ppb)	204 (+/- 10)	88 (+/- 5)	130 (+/- 7)	86 (+/- 4)	30 (+/- 2)	153 (+/- 8)	88 (+/- 5)	86 (+/- 10)
Estimated Phosphorus Load^ (pounds)	N/C	238	350	455	92	1,461	134	202
Lake Management Plan Completed?	No	Yes	No	No	Yes	No	No	No
Invasive Macrophytes Present?	No	No	No	No	Yes	No	No	No
Listed on 303(d)# list?	No	Yes	Yes	Yes	No	Yes	No	No

*See Section 6.5 (Receiving Water Classification and Management) for more details regarding management classification.
** Parenthesis reflect standard error of the mean, a measure of the data spread around the mean.
^Aggregate load; does not distinguish between watershed and in-lake sources of phosphorus load.
#The 303(d) list is maintained by the MPCA. It tracks waters which have been identified as not meeting their designated use. See 5.1.1 for more details.

Figure 4.2 – Four year rolling average of mean total phosphorus (TP) concentration

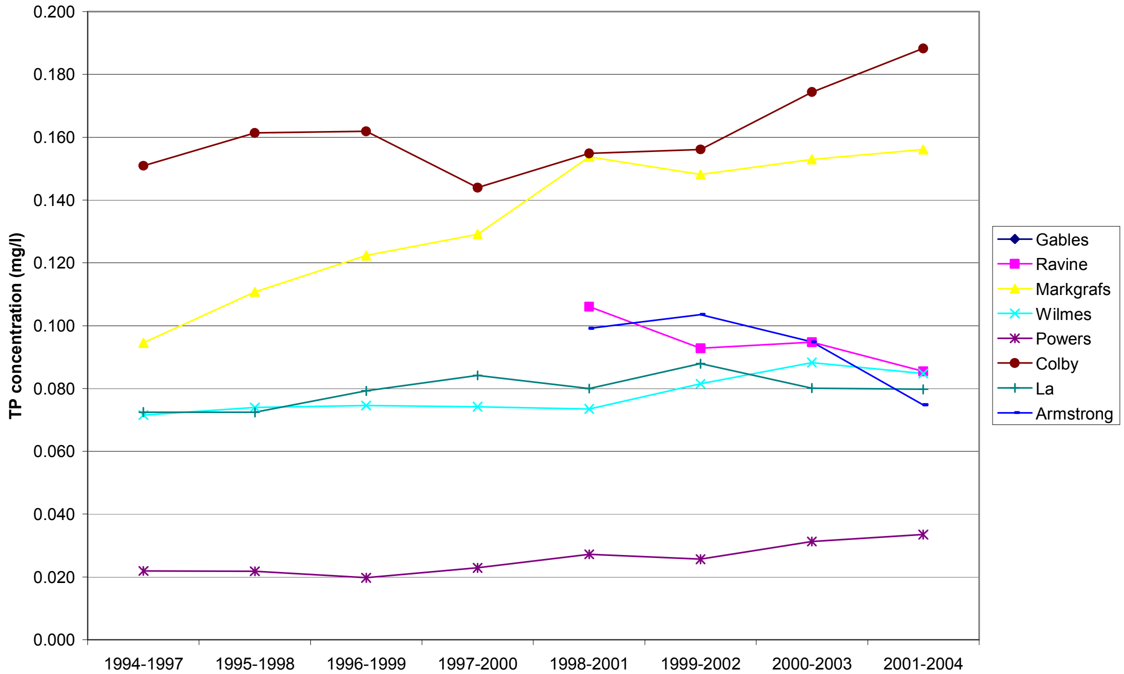
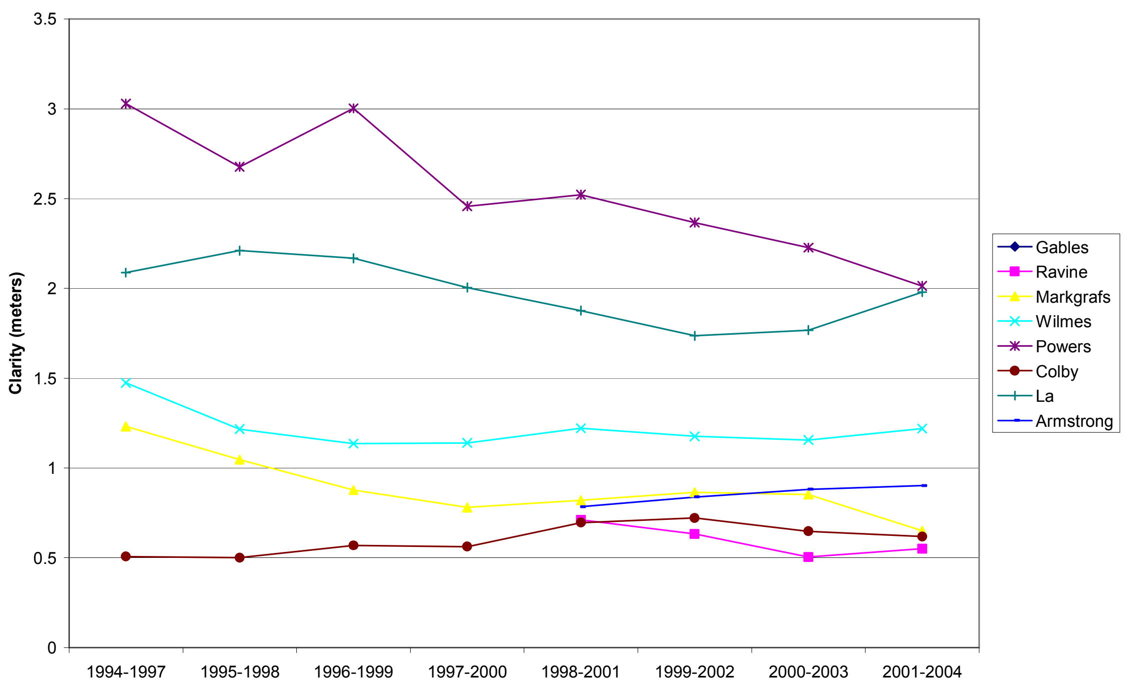


Figure 4.3 – Four year rolling average of mean Secchi depth (water clarity)



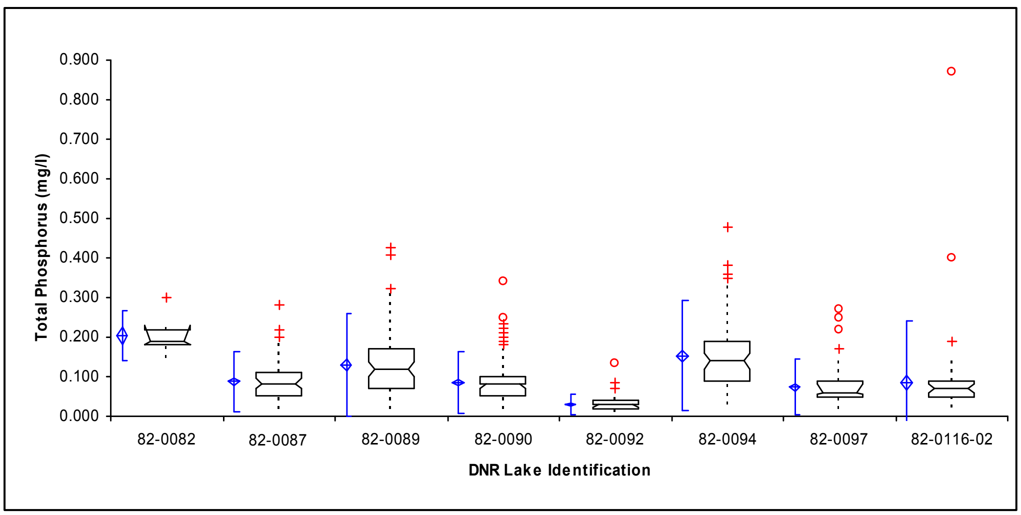
NOTE: Figures 4.2 and 4.3 reflect averages for the growing season of May 1 – September 30. Annual averages (April – October) are presented in the following sections.

Notched box plots are a graphical representation of data distribution and central tendency. They are used to compare dynamics between lakes in a region. They are especially useful when comparing data patterns between years for a particular lake. If the notches (which represent the confidence interval for the median value) in the box plot do not overlap, you can conclude that the true medians do differ. This shows significant difference between years for a variable such as TP.

A simple lake modeling tool is the **Minnesota Lake Eutrophication Analysis Procedure** model (MnLEAP), which has been modified by the MPCA for use on an ecoregion basis (Wilson and Walker 1989). This tool can be used to develop estimated phosphorus loads to lakes and estimate in-lake water quality and trophic status. Inputs to the model include watershed area, lake area and volume, and known lake water quality data for phosphorus, clarity, and chlorophyll. This tool is limited in that it does not distinguish watershed phosphorus loads from in-lake sources of phosphorus. As well, it is not able to account for watershed BMPs. However, it is useful to compare the condition of a lake against ecoregion benchmark conditions, provide a relative illustration of the quality of a lake, and a reasonable estimate of load.

The details of annual water quality conditions for lakes discussed in Section 4.3.3 through 4.3.10 are presented as notched box plots in Appendix K. Notched box plots summarize data by graphically illustrate the spread (variability) of the data as well as the central tendencies such as median or means. An example notched box plot taken from the appendix is presented below in Figure 4.4, showing all recorded total phosphorus concentration values.

Figure 4.4 – Notched box plot summarizing total phosphorus data for SWWD lakes.



The blue diamond shows the mean and the requested confidence interval around the mean. The blue line shows the percentile range such as 5th and 95th percentile. The notched box shows the median, lower and upper quartiles, and confidence interval around the median. Red crosses (+) and circles (o) indicate possible outliers - observations more than 1.5 IQRs (near outliers) and 3.0 IQRs (far outliers) from the quartiles.

4.3.3 Armstrong Lake

DNR ID #: 82-0116	*Municipality: Lake Elmo/Oakdale*
Surface area: 39 acres	*Watershed area: 566 acres*
Mean depth: 3-5 feet	*Maximum depth: 5 feet*
Total phosphorus: 86 ppb (annual average)	

4.3.3.1 Lake Description

Armstrong Lake is approximately 39 acres in size and has a contributing watershed of 487 acres (Map 4.3). This very shallow and flat lake is located in the headwaters of the Northern subwatershed. A majority of the drainage area to the lake is from Oakdale and is comprised mostly of low density residential land use with some farm areas; few undeveloped parcels remain. The lake is used for wildlife viewing and aesthetics. Non-motorized boating is possible.

The lake is divided in two by County Road 10 with a culvert under the road connecting the north and south basins. The northern portion of the lake is in Lake Elmo and has a maximum depth of 3 feet. The southern portion of the lake is in Oakdale and has a maximum depth of 5 feet. Water quality samples are taken in the southern basin because of its greater depth.

4.3.3.2 Water Levels

Water levels on Armstrong Lake are controlled by two 18-inch pipes set at invert elevations of 1017.35 and 1017.49. The Ordinary High Water Level (OHWL) set for Armstrong Lake is at elevation 1019.10. The lake shows an overall increasing trend in median water levels since 2000. Notched box plots indicate that rise in median water levels is statistically significant. However, the lake level shows minimal fluctuation in any given year. The range of median annual water level fluctuation for Armstrong Lake is slightly more than one foot.

4.3.3.3 Water Quality

The trophic status of Armstrong Lake is characterized as eutrophic (TSI = 67). The 2004 CAMP suggests the lake's water quality is described by a D+ / C- grade, relative to other lakes in the Metro area.

Based on monitoring data from 1998-2004, average annual TP concentrations range from 53 to 124 ppb over a seven year period. At 95% confidence, the average TP concentration will fall between 66 and 105 ppb. A sharp downward trend (improvement) is reflected in the 4-year rolling average of growing season mean TP.

Chloride concentrations have been sampled in Armstrong Lake since 2002. Chloride levels fluctuate dramatically in the lake but can be statistically summarized as a mean of 69 mg/L with a spread of plus or minus 28 mg/L. As an illustrative comparison, according to the Wisconsin DNR, chloride values of 50 to 100 mg/L are common in septic tank effluent.

The theoretical TP loading to Armstrong lake based on drainage area and ecoregion reference values is 101 pounds. This indicates the amount of TP entering the lake for a minimally disturbed watershed condition. However, the current likely overall annual phosphorus load to Armstrong Lake is estimated at 202 pounds based on summer monitoring data. Frequent and typically severe algal blooms in the summer are expected to occur. A management consideration for this lake should be to stabilize Armstrong Lake within the eutrophic range and minimize a transition into a hypereutrophic condition. Lake-specific maximum allowable nutrient loads for development and redevelopment can help stabilize this system.

4.3.4 Wilmes Lake

DNR ID #: 82-0090	*Municipality: City of Woodbury*
Surface area: 30 acres	*Watershed area: 3,242 acres*
Mean depth: 3-5 feet	*Maximum depth: 7-18 feet*
Total phosphorus: 86 ppb (annual average)	

4.3.4.1 Lake Description

Wilmes Lake is situated in the Northern subwatershed. Similar to Armstrong Lake, Wilmes lake is divided into two basins by a berm with a culvert connecting the north and south basins (Map 4.4). The southern portion of the lake has a maximum depth of 7 feet while the northern portion has a maximum depth of 18 feet. Wilmes Lake receives flows from Armstrong Lake and Markgrafs Lake, together adding approximately 1,000 acres of drainage. Powers Lake will also discharge into Wilmes at times when the Powers Lake lift station is operating.

4.3.4.2 Water Levels

The outlet structure for Wilmes Lake is a 7-foot weir at elevation 902.6 flowing to a 48-inch outlet pipe at invert elevation 899.73. Wilmes Lake has an OHWL set at elevation 902.6. The lake shows no rising or falling trends in median water levels since 2000. However, Wilmes Lake level shows the largest fluctuation in any given year compared to the five other lakes in the District with long-term lake level data. The median annual water level fluctuation for Wilmes Lake is slightly more than three feet.

4.3.4.3 Water Quality

Wilmes Lake reflects a eutrophic condition (TSI = 64). The 2004 CAMP suggests the lake's water quality is described by a D+ / C grade, slightly poorer than other Metro area lakes. The lake is listed on the MPCA's 303(d) list of impaired waters. Although monitoring data has been collected since 1994, water quality sampling was performed in the north basin (18 feet maximum depth) from 1994-1995 and since then has been performed in the shallow southern basin (7 feet maximum depth).

Based on monitoring data from 1996-2004, average annual TP concentrations range from 72 to 124 ppb over a 9 year period. At 95% confidence, the average TP concentration will fall between 78 and 93 ppb. Evaluation of a 4-year rolling average for TP indicates a slight upward trend (decline) in water quality.

The estimated loads to Wilmes Lake were below loads estimated under ecoregion reference conditions. The estimated loads corresponding to the observed mean TP are 455 pounds while the theoretical TP loading based on drainage area and ecoregion reference values is 559 pounds. Further, the mean summer secchi depth is 3.6 feet. It appears that lake conditions are slightly better than would be expected from nutrient concentrations.

A management consideration for Wilmes Lake would be to reduce the frequency and duration of algal blooms and shift the lake towards the lower end of eutrophic range. Lake-specific maximum allowable nutrient loads for development and redevelopment can be used to reduce inputs to this system. A lake management plan may outline further measures to improve water quality.

4.3.5 Powers Lake

DNR ID #: 82-0092	*Municipality: City of Woodbury*
Surface area: 56 acres	*Watershed area: 1,384 acres*
Mean depth: 16 feet	*Maximum depth: 41 feet*
Total phosphorus: 30 ppb (annual average)	

4.3.5.1 Lake Description

Powers Lake is a 56 acre lake in the Northern subwatershed. The District completed a lake management plan in 2000 for Powers Lake (by Bonestroo, Rosene, Anderlik & Associates). The historically high quality lake has several stormwater fed inlets and one natural inlet that receives runoff from developed areas. The natural watershed draining to this lake has been significantly expanded. In 1999, the contributing watershed was 430 acres. The storm sewer network expanded due to urbanization, increasing the total watershed area draining to Powers Lake to 1,384 acres (Map 4.5). Land cover in the watershed is actively transitioning to an impervious nature. The city of Woodbury has established a shore line preservation zone for the lake to ensure the lake has sufficient natural buffer around the perimeter.

Powers Lake has a maximum depth of 41 feet and a littoral zone (fringe area from 0 to 15 feet in depth where macrophytes grow) covering about 48 percent of its surface. A public access and fishing pier are located just east of County Road 19. The DNR has done fishery surveys in 1977, 1984, and 1992, but has not conducted fish stocking due to the lack of a public access. Fisheries management could begin following the construction of the public access. Eurasian water milfoil, an invasive aquatic plant, is present in the lake.

4.3.5.2 Water Levels

A lift station was installed at Powers Lake in 1995 and currently serves as the outlet for this previously land-locked lake. Water pumped from this lake is discharged to Wilmes Lake (south basin). The OHWL set for Powers Lake is at elevation 891.30. The lake shows substantial changes in water level throughout the five years that data was collected. This lake level fluctuation is likely in response to climatic influences (precipitation and evaporation) and the fact that the lake has no natural outlet. The undeveloped nature of the shoreline suggests that Powers Lake can experience more dramatic lake level fluctuations without significant risk to homes or property.

Groundwater interaction is likely a significant component of the lake's water budget, given the lakes' large volume and its pre-development drainage area. Powers Lake shows no rising or falling trends in median water levels since 2000. As alluded to in the previous paragraph, water levels at Powers Lake level show the second largest fluctuation compared to the five other lakes in the District with long-term lake level data. The median annual water level fluctuation for Powers Lake is 2.6 feet.

4.3.5.3 Water Quality

Powers Lake has historically been valued by residents in the watershed as a high quality lake. Powers is characterized as having a slightly eutrophic condition (average TSI = 53). The 2004 CAMP notes that the lake's water quality has received a variety of annual grades of A, B and C, although no distinct trend is acknowledged.

Based on monitoring data from 1994-2004, average annual TP concentrations range from 15 to 44 ppb. At 95% confidence, the average TP concentration will be between 27 and 33 ppb. A small but steady upward trend (decline) is reflected in the 4-year rolling average of growing season mean TP. However, the water clarity (as measured by Secchi depth) indicates a strong downward trend. Based on the 4-year rolling average, mean water clarity has decreased one meter (approximately 3.3 feet) since 1994. Median water clarity for 2004 showed a statistically significant decrease compared to 1994.

Chloride concentrations have been sampled in Powers Lake since 2003. Chloride levels are relatively stable in the lake and can be statistically summarized as a mean of 27 mg/L with a spread of plus or minus 7 mg/L.

The theoretical TP loading to Powers Lake based on *original* drainage area (430 acres) and ecoregion reference values is 88 pounds, resulting in a modeled in-lake TP concentration of 34 ppb. This slightly overestimates the observed TP concentration of 26 ppb averaged from 1994 – 2004, a period where the lake watershed was greatly expanded above 430 acres. In theory the ecoregion reference modeling should result in predicted values lower than observed concentrations for the urbanizing watershed. The discrepancy may be due to the naturally high degree of infiltration in the watershed (i.e., lower runoff volumes and loads) which is not accounted for in the MnLEAP model.

The lake management plan estimated that under fully developed watershed conditions with no runoff mitigation, the annual TP load would be 430 pounds (0.35 pounds per acre per year). Analysis of runoff monitoring at Powers Lake northeast inlet for 2001 and 2002 suggests TP loads of 185 pounds and 102 pounds, respectively. Estimated TP loads at the eastern inlet for 2004 were 287 pounds yet only 36 acre-feet of runoff was monitored (data was not collected in 2003). The drainage area near St. John's East was experiencing development and construction during 2003 and into 2004 and these factors likely influenced water quality conditions.

A key implication is that Powers Lake has a high capacity to assimilate TP inputs from the watershed. As such, it will be slow to observe changes of in-lake TP concentration resulting from increased watershed nutrient inputs. However, restoration improvements to the lake will be difficult and costly. A management consideration for the lake should be to keep watershed loads similar to pre-storm sewer expansion and move the lake towards a mesotrophic condition. Lake-specific maximum allowable nutrient loads for development and redevelopment will be a key to limiting nutrient inputs to the system.

4.3.6 Markgrafs Lake

DNR ID #: 82-0089	*Municipality: City of Woodbury*
Surface area: 46 acres	*Watershed area: 436 acres*
Mean depth: 5 feet	*Maximum depth: 8 feet*
Total phosphorus: 130 ppb (annual average)	

4.3.6.1 Lake Description

Markgrafs Lake is approximately 46 acres in surface area and has a contributing watershed of 413 acres. The lake is situated at the east boundary divide of the Northern subwatershed (Map 4.6). The watershed is almost fully developed. Commercial land use dominates the upper part of the watershed. Dense residential units surround the lake but the shoreline remains wooded. Stormwater treatment ponds receive runoff from the developments prior to flowing into Markgrafs.

4.3.6.2 Water Levels

The outlet structure for Markgrafs lake was installed in 1990. The outlet structure controlling water levels is a 12-inch pipe set at elevation 924.94 which is slightly below the OHWL set at 925.30. A valve device exists downstream from the outlet so that discharge can be split to Powers or Wilmes lakes. The lake shows no rising or falling trends in median water levels since 2000. The median annual water level fluctuation for Markgrafs Lake is slightly more than one foot.

4.3.6.3 Water Quality

The trophic state of Markgrafs Lake is borderline hypereutrophic (TSI = 70). The 2004 CAMP report notes that the lake's water quality has fluctuated generally between a C- / D grade, compared to other Metro area lakes. This report also notes that the MPCA has identified a statistically significant decrease in recent transparency (secchi depth). The lake is listed on the MPCA's 303(d) list of impaired waters.

The range of average annual TP concentrations for Markgrafs is from 52 to 193 ppb, based on monitoring from 1994-2004. At 95% confidence, the average TP concentration will fall between 116 and 143 ppb. A very dramatic upward trend (decline) is reflected in the 4-year rolling average of growing season mean TP, increasing more by roughly 60 ppb.

The likely overall annual phosphorus load to Markgrafs Lake is about 350 pounds. This is more than four times higher that the load of TP entering the lake given minimally disturbed watershed conditions. The theoretical TP loading to Markgrafts lake based on drainage area and ecoregion reference values is 79 pounds.

Algal blooms and nuisance conditions are severe and persistent. A management consideration for this lake is to maintain the lake at its current trophic level and prevent a decline into hypereutrophic conditions. At the same time, it will be important to use long term water quality data to set societal expectations for reasonable use and value of this shallow lake. Lake-specific maximum allowable nutrient loads for development and redevelopment can help stabilize this system. A lake management plan would provide further clarity as to reasonably attainable water quality conditions.

4.3.7 Colby Lake

DNR ID #: 82-0094	*Municipality: City of Woodbury*
Surface area: 68 acres	*Watershed area: 2,839 acres*
Mean depth: 7 feet	*Maximum depth: 11 feet*
Total phosphorus: 153 ppb (annual average)	

4.3.7.1 Lake Description

Colby Lake is located in the south-central portion of the Northern subwatershed (Map 4.7). It receives flows from Wilmes Lake, so Colby Lake receives approximately 4,240 acres of additional upstream drainage. Almost the entire shoreline is owned by the City of Woodbury. A park is located at the south end of the lake. Although there is no fishing pier, the lake is actively stocked by the DNR.

4.3.7.2 Water Levels

Water levels on Colby Lake are controlled by a 10-foot weir at elevation 890.30. The Colby Lake OHWL is established at elevation 891.80. Median annual water levels for the lake do not show rising or falling trends since 2000. The median annual water level fluctuation for Colby Lake is about 21 inches.

4.3.7.3 Water Quality

Colby Lake is classified as hypereutrophic (TSI = 74). The typical water quality condition is reflected as D / F grade according to the 2004 CAMP report, placing Colby among the worst relative to other Metro area lakes. The lake is listed on the MPCA's 303(d) list of impaired waters.

Over the last eleven seasons (1994-2004), the range of average annual TP concentrations for Colby has been from 103 to 282 ppb. At 95% confidence, the average TP concentration will fall between 138 and 168 ppb. A very dramatic upward trend (decline) is reflected in the 4-year rolling average of growing season mean TP, increasing by roughly 40 ppb.

Phosphorus loading to Colby Lake based on drainage area and minimally impacted ecoregion reference values is 493 pounds. However, the likely overall annual phosphorus load to Colby is estimated at 1,461 pounds. A management consideration will be to illustrate long term water quality data—and a watershed to lake ratio of over 100:1— to set societal expectations for reasonable use and value of the lake.

4.3.8 Gables Lake

DNR ID #: 82-0082	*Municipality: City of Cottage Grove*
Surface area: 5 acres	*Watershed area: 450*
Mean depth: unknown	*Maximum depth: 5 feet*
Total phosphorus: 204 ppb (annual average)	

Gables Lake is located in the upper portion of the East Ravine subwatershed. As such, it is an important long term management feature of the East Ravine itself. The lake is approximately 5 acres in size with an estimated drainage area of 450 acres. The surrounding land use is agricultural. The estimated maximum depth is about 5 feet.

No outlet exists for Gables Lake, natural or constructed. The OHWL is set at elevation 856.10. Water levels in this lake are not monitored. Water quality conditions for the lake are currently only available for 1998-1999, a total of 13 measurements. No loading estimate was developed for this lake and a 4-year rolling TP average was not possible.

4.3.9 La Lake

DNR ID #: 82-0097 *Municipality: City of Woodbury*
Surface area: 45 acres *Watershed area: 81 acres*
Mean depth: 6 feet *Maximum depth: 10 feet*
Total phosphorus: 73 ppb (annual average)

4.3.9.1 Lake Description

La Lake is a landlocked shallow basin within the East Mississippi subwatershed (Map 4.8). The less than 2-to-1 ratio of drainage area to lake surface area implies that inputs to the lake will be relatively straightforward to manage. The lake's drainage area is predominantly undeveloped with a mix of natural habitat areas and some agricultural land use. The watershed is privately owned and not expected to undergo development. No storm sewer outfalls discharge to the lake. Previous existence of septic systems for the few residences around the lake is likely of little concern to the lake. This lake is classified as a wetland by the Minnesota DNR, and DNR Fisheries uses the lake as a walleye rearing pond.

4.3.9.2 Water Levels

Data collection on water levels for La Lake has recently been implemented. The average water level during 2004 was calculated as elevation 999.70 with an overall fluctuation of about one foot. The OHWL for La Lake is established at elevation 1000.60. Given the undeveloped status of the shoreline, lake level fluctuation does not present an immediate concern for management.

4.3.9.3 Water Quality

La Lake is a eutrophic system. Over the last eleven seasons (1994-2004), the range of average annual TP concentrations for La Lake has been from 54 to 91 ppb. At 95% confidence, the average TP concentration will fall between 64 and 82 ppb. Frequency of lake sampling has tapered off in recent years, reducing the robustness of the data. The 4-year rolling average of growing season mean TP reveals a slight increase in summer phosphorus values since 1994 but no substantial pattern is evident.

The likely overall annual phosphorus load to La Lake is estimated at 134 pounds. The theoretical TP loading to La Lake based on drainage area and ecoregion reference values is 26 pounds annually. Given the nature of the land use and watershed size, the loading data suggests that internal nutrient cycling may play a strong role in La Lake.

La Lake is in a stable state of high productivity with clear water conditions supported by the existence of aquatic plant communities.

Although nutrient levels may be perceived as elevated in La Lake compared to deeper lakes, the water clarity of La Lake is good. The overall average secchi depth during summer is 5.6 feet. This suggests the lake is in a stable state of high productivity with clear water conditions supported by the existence of aquatic plant communities. External nutrient inputs to lake should be held in check by setting allowable nutrient loads for developments. A lake management plan should stress characterizing the aquatic plant community. Disturbances to the aquatic plant community should be prevented. Introduction of rough fish, such as common carp, should be prevented

4.3.10 Ravine Lake

DNR ID #: 82-0087 Municipality: City of Cottage Grove*
*Surface area: 25 acres Watershed area: 802 acres***
Mean depth: 7 feet Maximum depth: 16 feet
Total phosphorus: 88 ppb (annual average)

*Water quality data for this lake is improperly stored and reported under # ID 82-0086.
**Current watershed area, not ultimate development drainage area estimated at about 3,400 acres.

4.3.10.1 Lake Description

Ravine Lake is located in the East Ravine subwatershed and is situated in the Cottage Grove Regional Park. A lake management plan was completed for this lake in 2003. The watershed is predominantly wooded / park or agricultural land. As noted in the management plan, the lake has a contributing watershed of about 800 acres but planned urbanization will increase this watershed to about 3,400 total acres (Map 4.9). Further, the SWWD is pursuing a watershed overflow conveyance which will route through this system (see section 3.2.2.6 for more information). The lake has a strong groundwater influx in addition to surface inputs.

4.3.10.2 Water Levels

An 18-inch corrugated metal pipe exists for Ravine Lake but the invert is approximately at elevation 770 and is submerged. Minnesota DNR information reflects that the runout for Ravine Lake is the bottom of an outlet swale approximately 100 feet downstream of the road crossing at an elevation of 772.0. (An open channel was also constructed to help convey flows from the lake to the crossing under Highway 61.) The OHWL set for Ravine Lake is at elevation 770.70. The lake shows an overall increasing trend in median water levels since 2000. Notched box plots indicate that rise in median water levels is statistically significant. However, the lake level shows the lowest median annual fluctuation compared to the five other lakes where lake level information is available. The range of median annual water level fluctuation for Ravine Lake is roughly 9 inches. The anticipated drainage area expansion to Ravine Lake may change peak discharge rates thereby affecting downstream properties. Permissible future water level fluctuation on the lake and downstream discharges rates should be evaluated prior to watershed expansion projects.

4.3.10.3 Water Quality

Ravine Lake displays a eutrophic state (TSI = 69) but is very close to hypereutrophic conditions. The overall water quality condition is considered D+/C in the 2004 CAMP report. The lake is listed on the MPCA's 303(d) list of impaired waters. The average annual TP concentrations have ranged from 58 to 153 ppb. At 95% confidence, the mean

TP concentration is between 77 and 97 ppb. A 4- year rolling average shows a consistent downward trend (improvement) in lake quality as reflected by growing season average TP.

The lake management plan for Ravine Lake estimated an annual TP load of 205 pounds to the lake. This is similar to loads to Ravine Lake estimated by MnLEAP at 238 pounds annually, based on the current 800 acre watershed and water quality conditions. However, the annual phosphorus load given minimally impacted conditions is estimated at 143 pounds, in agreement with the lake management plan reference value of 149 pounds. Even at these levels, the lake will still be eutrophic.

As noted in the lake management plan, Ravine Lake will have midsummer algae blooms and probably not be a desirable lake for swimming. However, the water quality can promote indirect recreational use such as fishing and wildlife viewing. A management consideration for this lake will be to move away from potentially hypereutrophic conditions, and stabilize the lake towards a low to moderately eutrophic condition by establishing maximum allowable nutrient loads for development activities.

4.4 Groundwater and Infiltration

General Note: Additional data and analysis (annual monitoring and analysis reports) is available on the SWWD website at www.swwdmn.org.

The District has monitored groundwater levels at seven observation wells since the year 2000. These wells are situated at the undeveloped areas in or near basins CDP-85 and CDP-86 (Map 4.2). Water level and chemistry data is collected approximately once per month throughout the year. Generally the observation wells are situated in the middle of the watershed. The purpose of the monitoring is to begin establishing a baseline record for water levels and typical fluctuations based on seasonality.

The District has monitored surface water levels since 1999 at various basins in the watershed which serve as natural or constructed infiltration systems. Water level data is collected by continuous data loggers or by periodic observations of staff gauges. Generally, the purpose of the monitoring is to better understand the unique infiltration dynamics within the watershed and develop information for modeling use.

4.4.1 Past Analysis

Several significant studies have recently been completed within Washington County to characterize groundwater dynamics in the region. The studies have generally focused groundwater condition, movement, and interaction with surface waters. The scope of effort and level of detail in the past analyses is much greater than can be presented here; the reader is referred to Appendix B for an annotated listing of past analyses.

A report prepared by Emmons & Olivier Resources (2004 Infiltration Monitoring Program Final Report, 2005) summarizes monitoring data relating to stormwater infiltration at various basins within the watershed. The report presents ranges of infiltration rates (referred to as envelopes), calculated curve numbers of drainages areas contributing to infiltration basins, and water quality data for various parameters in runoff and groundwater. The report concluded that “infiltrating surface water is not negatively affecting the groundwater”. The presented data illustrated declines in infiltration rates over time.

Implication: The District should consider a hypothesis-oriented approach when studying interactions and dynamics in natural systems. Collected data can be further analyzed to provide specific (normalized) infiltration rates to serve as design standards. Trends in infiltration rate over time at constructed infiltration trenches such as CD-P85 can provide a basis for water quality modeling and potentially establishing guidelines for periodic maintenance activities.

4.4.2 Monitored Groundwater Levels

Generally, the SWWD groundwater levels fluctuate in response to precipitation patterns. Annual time series of groundwater notched box plots (shown in Appendix L) reflect differences in median groundwater elevations across years. Interquartile ranges in groundwater levels can vary from only 1-3 feet during normal years to 10 to almost 20 feet during wet years.

As discussed in Section 4.1.2, precipitation for 2002 overall reflects a "wet" year, with summer rainfall depths well above normal. The CDP-85 basin was inundated seven times in 2002 with water depths ranging from 6 feet to roughly 28 feet. The annual box plots suggest that groundwater wells MW-3S, MW-3D, MW-4, and MW-5 (all within CD-P85) appear to respond very quickly to the heavy rainfall depths while there is a dampened response in wells MW-1, MW-2, and MW-3 near, but outside, the CDP-85 basin.

Monthly variability in groundwater wells is reflected in clock diagrams in Appendix L. These diagrams generally indicate that winter months typically have lower groundwater levels due to limited precipitation and recharge. Groundwater levels rebound (rise) during spring months due to snowmelt. Line charts of groundwater elevations through time are also shown in Appendix L.

The temporal scale of groundwater monitoring is imprecise for accurately understanding relationships between surface water hydrology and groundwater. Overall, groundwater levels at the monitoring wells appear strongly influenced by immediate climate factors. Water supply needs do not seem to affect the groundwater in this area, either seasonally or annually. The monitoring indicates that groundwater recharge at the CD-P85 basin is high. Infiltrated water very quickly reaches the local water table but does not sustain groundwater levels; the infiltrated water moves elsewhere. The spring rebound in groundwater levels emphasizes the need for the District to understand snowmelt infiltration dynamics during spring in the watershed. The potential for snowmelt (with accumulated sediment, nutrients, and other compounds such as chloride) to reach deep groundwater during spring illustrates the importance of investigating alternative snow management and road de-icing efforts.