1.0 INTRODUCTION

Colby Lake is an approximately 70-acre lake located in the City of Woodbury within southern Washington County. Washington County is located within the Minneapolis-St. Paul metropolitan area of eastern Minnesota (see **Figure 1**). The Colby Lake watershed is situated in the North Central Hardwood Forests ecoregion, though the lake itself is in close proximity to the boundary with the Western Corn Belt Plains ecoregion. Colby Lake is part of a multi-lake system, receiving water from Wilmes Lakes to its north and contributing water downstream to the Bailey wetland (see **Figure 1**). The total cumulative drainage area into Colby Lake is 10.6 square miles, 6.3 of which come through Wilmes Lake. The remaining 4.3 square miles of the drainage area contributes water directly into Colby Lake either through direct runoff or through a series of stormwater infrastructure. The majority of the area in the watershed is developed.

Colby Lake is identified by the Minnesota Department of Natural Resources (MnDNR) as Public Water No. 82-0094-00. The fishery within the lake is managed by the Fishing in the Neighborhood (FiN) program with the goal of providing shorefishing opportunities in the City of Woodbury. The outlet of Colby Lake is controlled by a 10-foot long weir with a crest elevation at 890.30 MSL (NGVD 29) and an ordinary high water level has been established at 891.8 MSL. Since 1980, lake levels have fluctuated by a maximum of 5 feet, averaging to within a foot and a half of the weir elevation (URL: http://www.dnr.state.mn.us/lakefind/showlevel.html?id=82009400 , accessed April 1, 2011).

In 2006, Colby Lake was placed on the Environmental Protection Agency's (EPA) List of Impaired Waters (i.e., 303(d) List) for Nutrient Eutrophication / Biological Indicators. It is currently listed in Category 5C with no Total Maximum Daily Load (TMDL) plan having been approved. In an effort to prevent continued degradation of Colby Lake, the South Washington Watershed District (SWWD) requested the assistance of Houston Engineering, Inc. (HEI) to evaluate existing data and develop models to describe the stresses imposed upon Colby Lake. This information would be used to establish the load capacity of the lake and allocate the allowable loads, providing a basis to improve management of the Colby Lake system. An additional goal of this study is to eventually pursue the re-listing of Colby Lake under EPA's Category 4b (impaired but not requiring a TMDL due to other pollution control requirements being in place).

This report presents an assessment of the water quality for Colby Lake including the estimated water budgets and total phosphorus mass balances for three years of monitoring data, 2008-2010. Watershed loading and in-lake eutrophication response models were created for the area, using the summer season (June 1through September 30) monitoring data for model calibration and validation. Once the models were calibrated and validated, a long-term precipitation record was input to the watershed model to simulate 50-years of runoff volume and load. These loads were then used as input to the receiving water model to develop the phosphorus loading capacity of Colby Lake, the allowable load to achieve both the Minnesota Pollution Control Agency's (MPCA) numeric water quality standard and SWWD's water quality goal for total phosphorus. Allowable loads were then allocated amongst the various sources in the watershed.

2.0 COLBY LAKE INFORMATION

2.1 Classification

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

With a maximum depth of 11-feet and most of the surface area littoral, Colby Lake is considered a shallow lake. It has an average hydraulic residence time of approximately 1.5 months. Colby Lake is managed as a Class C lake and is required to meet the MPCA Class 2B water quality standards for shallow lakes in the North Central Hardwood Forest Ecoregion. Based on the available data, the lake does not thermally stratify on a consistent basis. Applicable conventional water quality standards that apply to Colby Lake include dissolved oxygen, pH, and temperature, but nutrients and specifically total phosphorus (TP) are of primary interest as this is the stressor causing the use impairment. The applicable MPCA eutrophication numeric standards, expressed as the June 1 through September 30 average value for a near-surface (epilimnetic) sample, are: TP should not exceed 60 micrograms per liter (ug/L); chlorophyll-*a* (chl-*a*) should not exceed 20 micrograms per liter (ug/L); and Secchi-disk transparency (SD) should be not less than 1.0 meter. However, recent guidance from MPCA indicates that, based on the analysis of eutrophication causal and response variables during the standards development process, by meeting the TP water quality standard all other standards can likewise be assumed to be met (Zadak, 2011). So, while TP, chl-*a*, and SD data will all be presented in this report, the focus of the loading capacity calculation will be based solely on TP concentrations in the lake.

Water quality data has been collected in Colby Lake with varying degrees of frequency from 1994 to present. The mean and median TP, chl-*a*, and SD summer season values were computed for the most recent years of summer season data, 2008 and 2010 (Colby Lake's water quality was only monitored in May in 2009). The resultant 2008/2010 summer median values were used to compute trophic state indices (TSI) using the formulas provided by Carlson (1977). The results of those data summaries are provided in **Table 1**. A TSI value provides a single quantitative index to estimate the degree of eutrophication of a specific water body and is a unitless measurement. Lakes having TSIs between 55 and 65 are classified as eutrophic or nutrient rich, while lakes having TSIs between above 65 are classified as hypereutrophic, or very nutrient rich. TSI values from 2008 – 2010 indicate Colby Lake is a hypereutrophic lake.

Table 1: Summary of Summer Season Values for Colby Lake Trophic State Indicators

Year	n	Total Phosphorus, (ug/L)		Chlorophyll *a*, (ug/L)		Secchi Disk Transparency, (meters)	
		Mean	Median	Mean	Median	Mean	Median
Concentrations							
2008	7	181.4	175	52.9	47.0	0.30	0.30
2010	6	103.5	105	52.0	51.5	0.73	0.71
Trophic Status Index Computed from Mean Concentrations							
2008	7	---	78.6	---	68.4	---	77.3
2010	6	---	71.2	---	69.3	---	64.9

TP TSI = 14.42 x ln (TP) + 4.15
Chl-a TSI = 9.81 x ln (chl-*a*) + 30.6
SD TSI = 60 - 14.41 x ln (SD)

2.2 Water Quality

Colby Lake's water quality has been monitored by various agencies and volunteers since 1994 and that monitoring continues through support from the SWWD. For the purposes of this study, water quality and surface water flow data were needed to simulate conditions within the Colby Lake watershed and Colby Lake, itself. The time period from 2008 - 2010 was the most data rich period of time and was, therefore, focused on for model development, calibration, and validation.

Figure 2 illustrates the historic summer season TP concentrations monitored in Colby Lake. All samples were collected in the upper three feet of the lake. Although there is variability from season to season, phosphorus concentrations have remained relatively constant and are consistently over the State water quality standard. **Figures 3 and 4** shows the chl-*a* and SD data that have been collected in the lake. Similar to TP concentrations, chl-*a* concentrations and SD values have consistently exceeded the water quality standards.

Figure 2: Summer Season (June through September) Colby Lake TP Concentrations

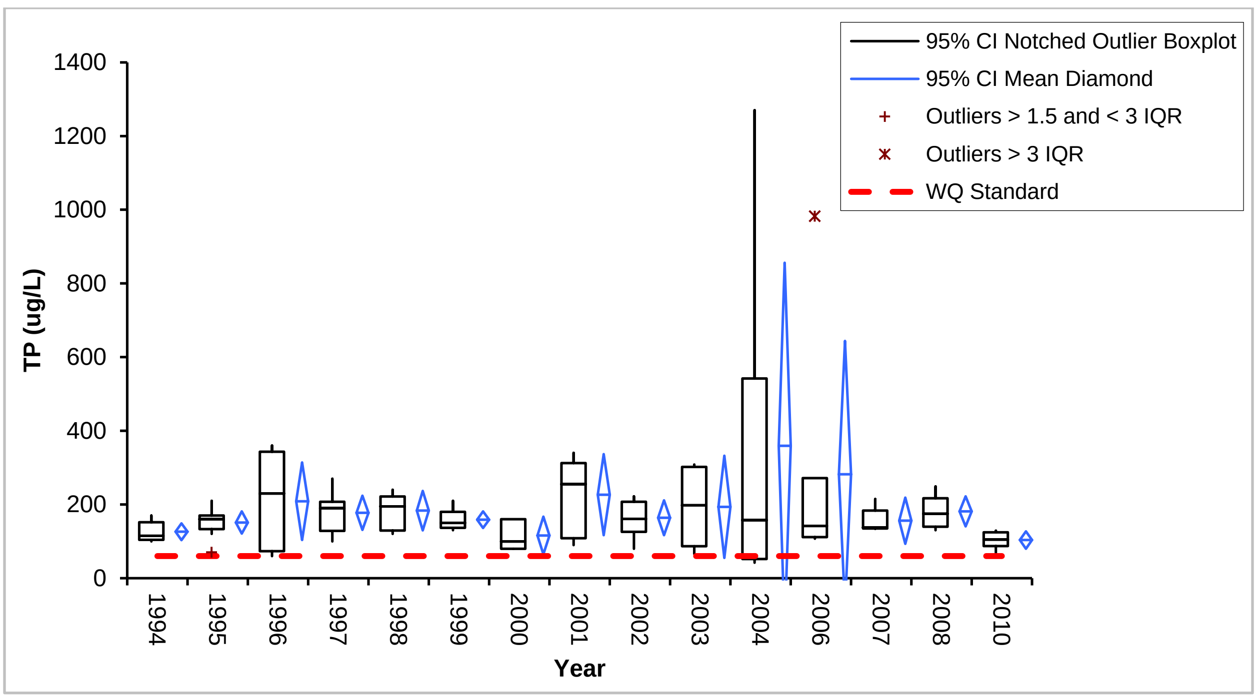


Figure 3: Summer Season (June through September) Colby Lake Chl-*a* Concentrations

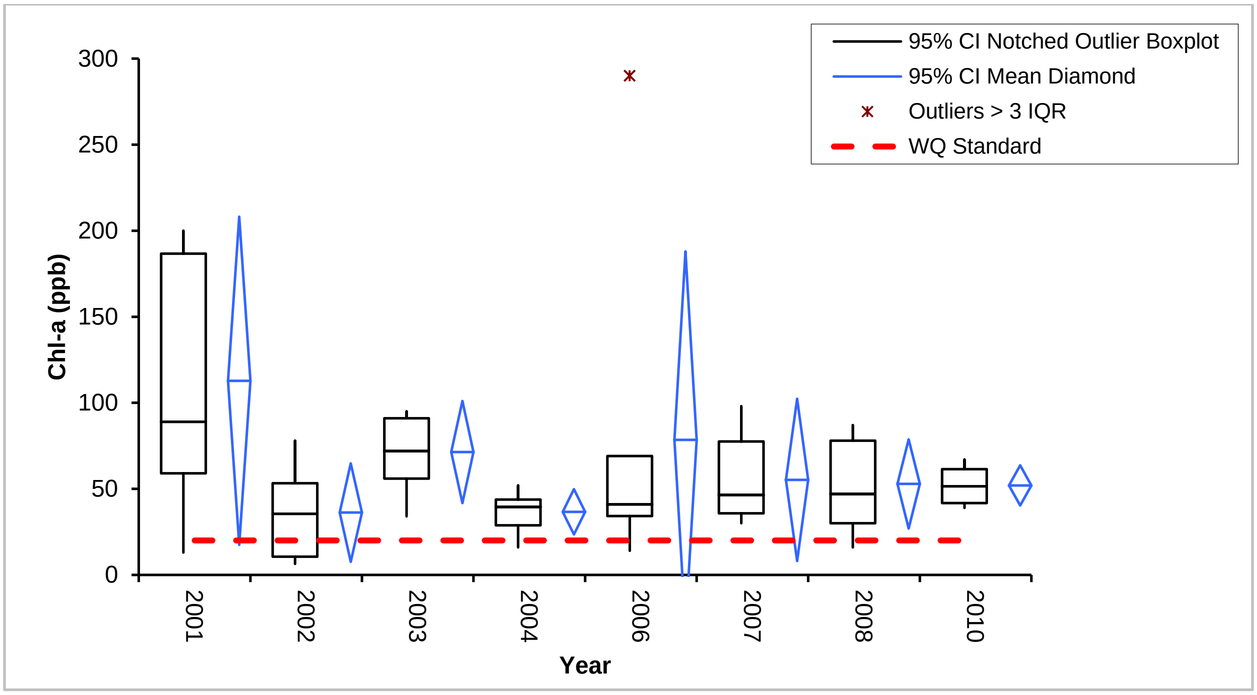
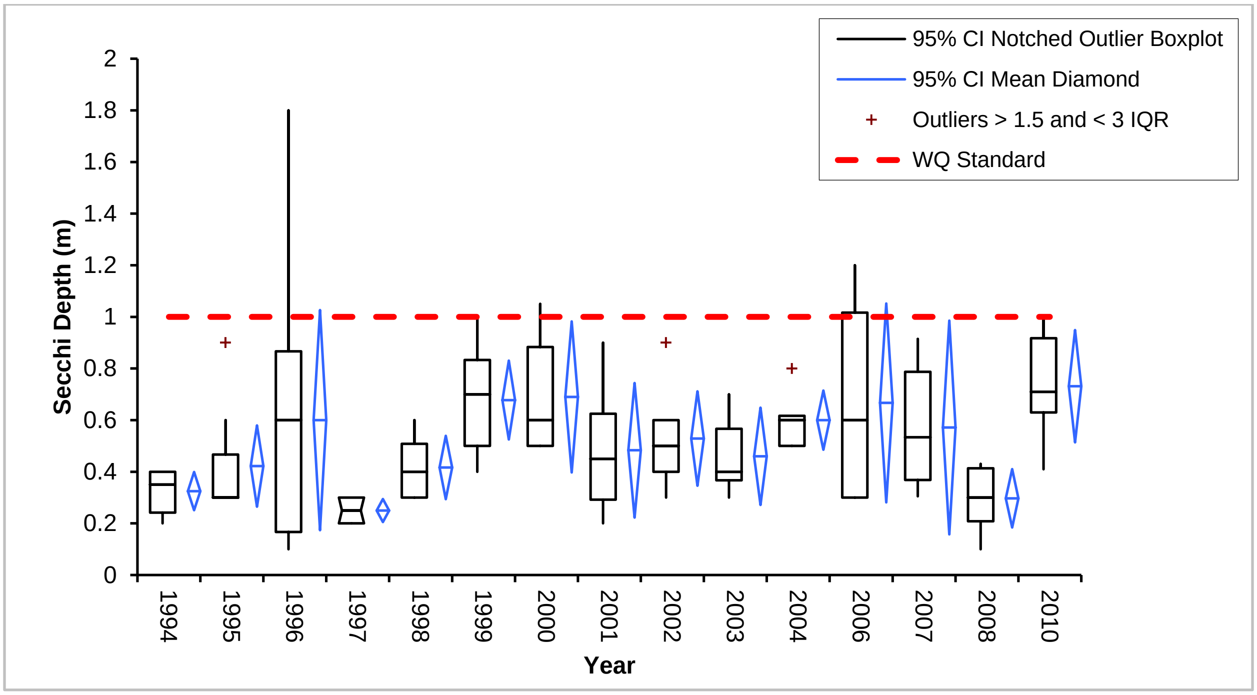


Figure 4: Summer Season (June through September) Secchi Depths in Colby Lake



2.3 Current Lake Use and Features

The fisheries report for Colby Lake prepared by the MnDNR in 2007 indicates the vast majority of fish in Colby Lake are black bullhead (*Ameiurus melas*). Additional species present include: black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), pumpkinseed (*Lepomis gibbosus*), hybrid sunfish (*Lepomis sp*.), largemouth bass (*Micropterus salmoides*), northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), and white sucker (*Catostomus commersonii*). The MnDNR stocked the lake in 2002-2003 with black crappie and bluegill, in 2005 with northern pike, bluegill and yellow perch, and in 2008 with northern pike and yellow perch. The lake has been managed by the Fishing in the Neighborhood (FiN) since 2002 with the goal of providing shorefishing opportunities for panfish and northern pike. Fish consumption guidelines of once per week have been placed on crappie and northern pike due to mercury. Also according to the 2007 MnDNR report, Colby Lake's submergent plant community has a number of species, including curly-leaf pondweed.

2.4 Watershed Characteristics and Land use

The Colby Lake watershed and subwatersheds were delineated as part of previous hydrologic modeling studies completed for the SWWD and presented in the 2006 SWWD Watershed Management Plan (WMP). Those boundaries are used in this report. The majority of the land use within the Colby Lake watershed is zoned as single-family residential (see **Figure 1**). Intermingled in the residential housing is a golf course and several parks scattered across the watershed. As such, the entire watershed is considered developed and separate load allocations are not determined for developed versus undeveloped areas.

As shown in **Figure 1**, three monitoring stations in the Colby Lake watershed have been and continue to measure streamflow and obtain the chemical concentrations of important constituents, including TP and Total Suspended Solids (TSS). At two of those stations streamflow and the quality of water entering Colby Lake are measured. The Wilmes Lake Outlet gauge reflects the 3,997-acre contributing drainage area from Armstrong, Markgrafs, and Wilmes watersheds. The Colby West Inlet gauge includes 384-acres on the west side of the Colby Lake watershed. The MS1 montioring station is located upstream of Wilmes Lake at I-94, it measures runoff from 1,200-acres in the upper portion of the watershed. Data collected at these three stations (along with pumping data at the Eagle Valley Pump Station) were used for calibrating and validating the watershed model, as discussed in the accompanying Colby Lake

Watershed P8 Model documentation (**Appendix A**). The data were also used to complete the surface water components of the hydrologic budget and nutrient mass balances around Colby Lake, as discussed below.

A large portion of the area contributing surface water runoff directly to Colby Lake is un-gauged (i.e., not measured) (see **Figure 1**). **Table 2** summarizes the areas and land use characteristics of the un-gauged areas as compared to those areas where gauges are present and used to measure streamflow. Since no data are available on surface water runoff and pollutant loading from un-gauged areas, assumptions must be made to estimate the amount of water and pollutants coming from those landscapes. As shown in **Table 2**, of the gauged areas in the watershed, the landuse characteristics of the un-gauged area is (arguably) most similar to those in the Colby West Inlet subwatershed. Therefore, unit runoff and pollutant loading values from the Colby West Inlet subwatershed were computed and applied in the un-gauged area to account for its contributions in the hydrologic budget and nutrient mass balance for Colby Lake.

Table 2: Areas and Landuse Characteristics of Watersheds Contributing to Colby Lake

Watershed	Area (acres)	Primary Landuse (percentages)			
		Residential	Parks/ Open Space	Multiple Uses	Other
Wilmes Lake	3,997	60	11	10	19
Colby West Inlet	384	88	7	2	3
Ungauged Colby Lake	2,396	78	17	2	3
Total Drainage Area	6,777	68	13	6	13

2.7 Hydrologic Budget

A hydrologic budget is an accounting of the amount of water entering and leaving a lake over a given time period, in this case (given the short hydraulic residence time of Colby Lake and MPCA's guidance suggesting the approach) during the summer seasons of 2008-2010. The amount of water moving in and out of a system varies from year-to-year depending, primarily, on the amount of rainfall occurring in the area. The hydrologic budget is important to quantify since different sources of water can contain different quantities of pollutants (in this case, nutrients). The hydrologic budget is also important because it is used during hydrologic and water quality modeling for model calibration/validation purposes.

A hydrologic budget accounts for "gains" in water to the lake (*i.e.*, precipitation, runoff and groundwater inflow) as well as "losses" (*i.e.*, evaporation, surface outflow, and groundwater outflow). Each of these affects the volume of water in the lake (storage). The following sections describe how the various terms of the Colby Lake summer season hydrologic budget were computed. Final results are presented in **Section 2.7.7**.

2.7.1 Precipitation

Long-term precipitation records (1961-2010) from the first-order weather monitoring station at the Minneapolis St-Paul airport (MSP) were used for forcing functions in the models created under this study and to estimate the amount of water entering Colby Lake from precipitation during the study period. The mean summer season precipitation observed at MSP during this 50-year period (i.e., the time period used in setting the loading capacity of Colby Lake, discussed below) 14.6 inches. In comparison, a summer season total of 9.96 inches was observed in 2008, 11.9 inches was observed in 2009, and 19.7 inches was seen in 2010 (the years of the constructed hydrologic balance). The volumes associated with these rainfall depths were 57 acre-feet, 68 acre-feet, and 113 acre-feet, respectively.

2.7.2 Surface Runoff (Inflow)

The amount of surface runoff entering Colby Lake during the summer season for the years 2008-2010 was estimated based upon the data collected at the MS1, Wilmes Lake Outlet, and Colby West Inlet monitoring stations and the Eagle Valley Pump Station (**Figure 1**). SWWD staff applied site-specific rating curves to observed stage data at the Wilmes and Colby monitoring stations to compute estimated daily streamflows. Eagle Valley Pump Station data was provided by the City of Woodbury, who estimated daily flow volumes through each of the two pumps at this location based on recorded pump data. Although the majority of the summer season flows were available at these stations, some periods of data were missing and had to be estimated based on relationships between the hydrology at the sites and other observations during the time periods in question.

Flow data collection at the Wilmes Lake Outlet location began in 2009. To complete the 2008 hydrologic balance around Colby Lake it was, therefore, necessary to estimate surface water flow at the Wilmes Lake Outlet in 2008. To estimate these flows, regression analyses were completed between observed daily flows at the Wilmes Lake Outlet and the two other monitoring stations in the watershed in 2009 (this year was chosen based on its hydrologic similarity to 2008). The relationship between mean daily flows at MS1 and the Wilmes Lake Outlet were superior to those associated with the Colby West Inlet. The 2009 regression results were, therefore, applied to the 2008 MS1 flow data to estimate 2008 flow values at the Wilmes Lake Outlet gauging station.

In August 2009, the Colby West Inlet gauge was removed due to construction activities in the area of the monitoring location. Surface water flow data for the later portion of the 2009 monitoring season was, therefore, unavailable at this location. For purposes of developing the surface water term of the hydrologic budget, average daily flow values were estimated at the Colby West Inlet gauging location from August 7 – September 30, 2009 based on results of a regression analysis between flows at this location and MS1 during the 2008 season. The 2008 regression analysis results were applied to the August 7 – September 30, 2009 MS1 flow data to estimate flows at the Colby West Inlet gauging station during this time.

Seasonal surface water flows were used to compute runoff volumes at the Wilmes Lake Outlet and Colby West Inlet stations. Along with observed pump volumes at the Eagle Valley pump station, the results were used to construct the gauged inflow (i.e., surface water) portion of the Colby Lake hydrologic budget. Summer season daily unit runoff values were computed for the Colby West Inlet subwatershed and applied to the un-gauged portion of the Colby Lake watershed. Results of this analysis were used to construct the un-gauged surface water inflow portion of the hydrologic budget. Together the gauged and un-gauged inflow components create the total surface water inflow to Colby Lake during this time, which was computed as 505 acre-feet in 2008, 544 acre-feet in 2009, and 2,495 acre-feet in 2010. As expected from the large amount of precipitation received during the year, surface water runoff was excessive in 2010.

2.7.3 Groundwater

Information on groundwater within the Colby Lake watershed is limited. A large-scale assessment of groundwater resources in Washington County determined that Colby Lake is, on average, a “recharge” waterbody with respect to interaction with groundwater (Barr, 2005). This indicates that, during typical conditions, the lake drains to groundwater. Results of the Barr (2005) report indicate that Colby Lake (generally) does not receive nutrient input from groundwater. Given the qualitative nature of this information and the lack of more detailed data on groundwater interactions with Colby Lake, the groundwater term in the Colby Lake hydrologic balance was combined with the error term and computed by estimating the remaining terms in the balance equation (i.e., groundwater + error = inputs - outputs). Values for the groundwater+error term were computed at -177 acre-feet in 2008 (i.e., losses from the lake), -130 acre-feet in 2009, and 997 acre-feet in 2010.

2.7.4 Lake Evaporation

To provide the additional inputs needed to the Colby Lake receiving water model and to develop the hydrologic budget, evaporation from the lake was estimated. Evaporation accounts for an important component of the overall hydrologic budget of Colby Lake, making an estimate of this process essential. A method derived from both physical and empirical relationships, accounting for many of the influencing meteorological parameters, was used for estimating evaporation. The method is well accepted for the estimation of open water evaporation and is known specifically as the combined aerodynamic and energy balance method for shallow lake evaporation. Three methods were analyzed, including the Lake Hefner #1 and #2 and the Meyer method. The average value for all methods was used to determine yearly evaporation during the study period.

Each evaporation calculation method requires the following meteorological data: 1) air temperature; 2) wind speed; and 3) water vapor pressures (expressed as dew point). Data measured at the MSP station were used to compute evaporation for the 2008-2010 seasons. Data obtained from the weather station were on a daily time step; evaporation was computed for this daily time scale and summarized over the summer season. Summer season evaporation values were computed from 2000-2010. For use in developing a long-term hydrologic budget, this record was extended back to 1961 by developing a relationship between summer season precipitation and evaporation and using precipitation data to back-fill the evaporation values. The mean summer season evaporation used in establishing the long term hydrologic budget for Colby Lake (1961-2010) is an estimated 30.1 inches, compared to the estimated value of 23.3 inches for 2008, 20.8 inches for 2009, and 28.2 inches for 2010. The Colby Lake summer season water balance terms resulting from these evaporation rates were 134 acre-feet, 119 acre-feet, and 162 acre-feet, respectively.

2.7.5 Surface Outflow

The surface outflow volume was estimated by using measured lake levels, provided by the MnDNR lakefinder website (http://www.dnr.state.mn.us/lakefind/index.html, Accessed March 14, 2011), and the known weir crest lake and type of the dam on Colby Lake. Observed water level values were linearly interpolated between measurements to estimate daily values. A weir equation ($Q = C*L*H^{2/3}$; $C = 3$) was then used to convert the height of water above the crest of the dam (i.e., head) to an estimated mean daily flow. Total summer season outflow volume was estimated at 260 acre-feet in 2008, 379 acre-feet in 2009, and 3,468 acre-feet in 2010.

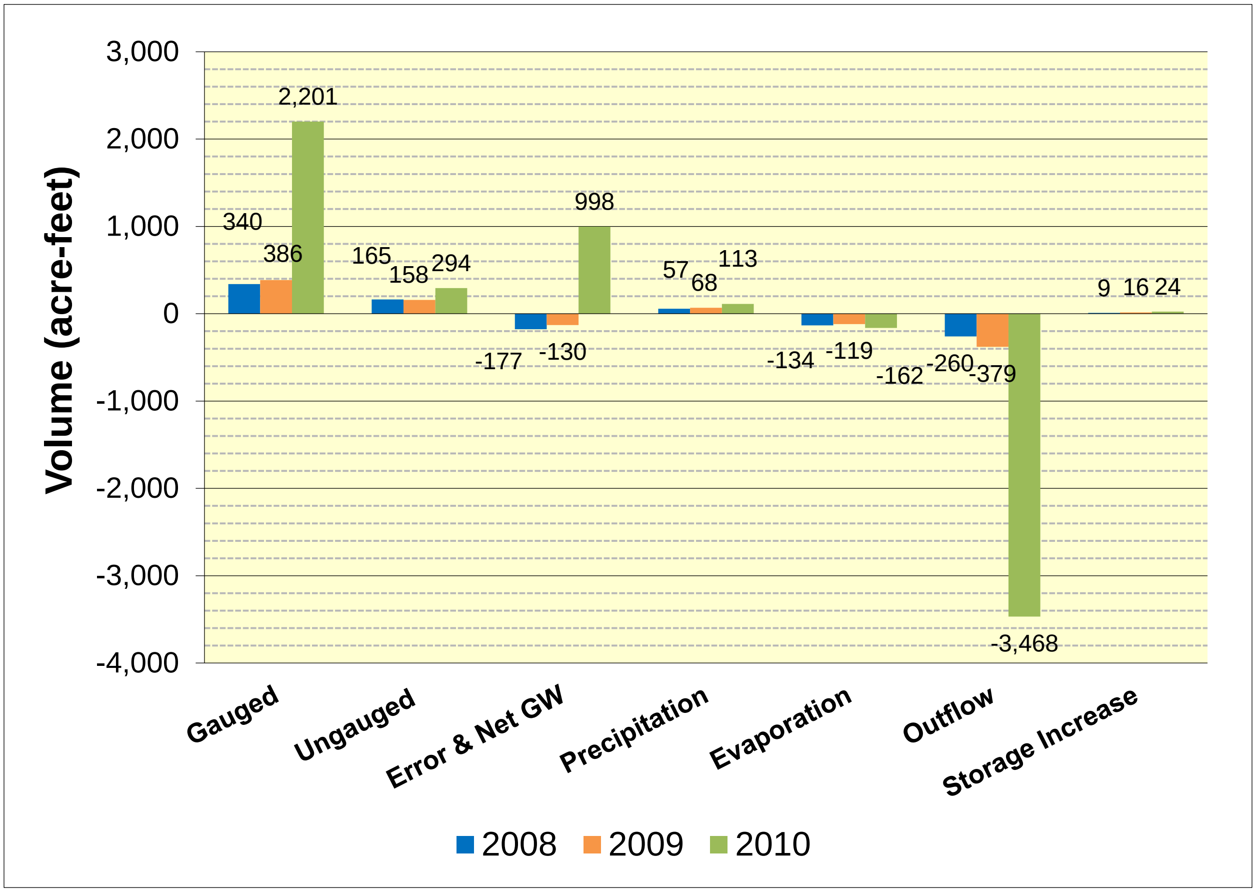
2.7.6 Storage Increase

Storage increase was also calculated using the MnDNR lake level data. Increases (or losses) over the summer season were estimated from the difference in lake level between June 1 and September 30 during each year. The estimated storage increases during the 2008-2010 summer seasons were 9, 16, and 24 acre-feet, respectively.

2.7.7 Estimated Hydrologic Budget

The hydrologic budget for Colby Lake during the summer seasons of 2008, 2009, and 2010 was computed as described above. **Figure 5** shows the result.

Figure 5: Colby Lake Summer Season (June through September) Hydrologic Budget: 2008, 2009, and 2010



2.8 Total Phosphorus Budget

Like a hydrologic budget, that is an accounting of water, a nutrient budget or “mass balance” is an accounting of the amount or "load" of nutrients entering and leaving Colby Lake. Loads are expressed in units of mass per time (e.g., kg/year or lb/year) and estimated by considering the concentration of a substance in the water and the amount of water over a time period. The following sections describe how the various terms in the Colby Lake summer season TP budgets were computed. The overall budget results are presented in **Section 2.8.6**.

2.8.1 Surface Inflow

Surface inflow loads to Colby Lake in 2008, 2009 and 2010 were estimated based upon measured stream flow and grab and flow-weighted composite samples collected by the SWWD for the Wilmes Lake Outlet and Colby Lake Inlet monitoring locations. **Table 3** summarizes the TP concentration data collected at these sites during this time, showing the number of samples collected during each summer season.

Table 3: Observed Summer Season TP Concentrations (ug/L) in Colby Lake Watershed

Site	2008		2009		2010	
	n	Mean	n	Mean	n	Mean
Wilmes Lake Outlet	0	N/A	3	90.3	9	94.1
Colby West Inlet	4	186.8	4	212.8	12	1998

Individual TP concentrations observed at the two monitoring stations were combined with mean daily flow data, through the U.S. Army Corps of Engineer’s FLUX model, to compute summer season total TP loads from surface water runoff. Similar to what was done to develop the hydrologic balance, unit TP loading values were computed for the Colby West Inlet subwatershed and applied to un-gauged areas around the lake to compute a value for un-gauged TP loadings during the summer seasons of 2008-2010. Unlike what was available in the water balance, however, no water quality data exists for the water being contributed from the subwatershed feeding into the Eagle Valley pump station. To estimate TP loading from this portion of the watershed, therefore, unit TP loading values from the Colby West Inlet subwatershed were applied to the Eagle Valley pump station subwatershed.

To further refine the estimated TP loading from this portion of the watershed, the Colby West Inlet subwatershed unit runoff values discussed in **Section 2.7.1** were used to compute a summer season surface water runoff value for the Eagle Valley pump station subwatershed. A ratio was then created between the estimated and observed surface water runoff volumes at the Eagle Valley Pump station. This ratio was then applied to the estimated TP loads from the Eagle Valley pump station subwatershed to compute a summer season TP load from this area in 2008-2010. No removal was accounted for in the ponds feeding into the Eagle Valley pump station, resulting in a conservative estimate of TP loading from this subwatershed.

As shown in **Table 3**, no data was collected at the Wilmes Lake Outlet station in 2008. Therefore, to estimate the amount of TP contributed from this site in the summer of that year, a relationship was developed between 2009 flows at MS1 and Wilmes Lake Outlet. The relationship was used to compute mean daily flows at the Wilmes Lake Outlet station during the summer of 2008. Equations developed in the 2009 Wilmes Lake Outlet FLUX runs were then used to compute the summer season TP load at the station based on the estimated flows.

The total 2008 summer season TP surface water loads to Colby Lake were computed as 82 kg. The 2009 and 2010 values were 92 kg and 340 kg, respectively. In addition their use in the TP nutrient balance on Colby Lake, results of the TP loading at the Wilmes Outlet and Colby Lake Inlet stations were also used to calibrate/validate the P8 watershed model, as discussed below.

2.8.2 Atmospheric Deposition

Annual atmospheric deposition to the Colby Lake watershed was determined to be 0.29 kilograms per hectare per year (Barr, 2007). To compute atmospheric deposition during the 2008-2010 summer seasons, it was assumed that the amount of TP from atmospheric deposition is driven solely by precipitation and that a constant precipitation TP concentration is maintained throughout the year. Using the 50-years of precipitation record (1961-2010), a long-term average annual precipitation amount of 28.5 inches was computed. A ratio of summer season: long-term annual average precipitation was then developed for the years 2008-2010 (for example, in 2008 the summer season total precipitation was 9.96 inches; the 2008 ratio is, therefore, 0.35). Summer season atmospheric loadings for 2008-2010 were computed as the product of these ratios and the annual atmospheric deposition rate of 0.29 kg/hectare/yr, resulting in a seasonal atmospheric TP loading to Colby Lake of 2.8, 3.3, and 5.5 kg for 2008 to 2010, respectively. Using the long-term average annual precipitation, the average of TP in the precipitation of the study area was computed as 0.049 kg/AF (this value was used in computing long-term atmospheric deposition in the CNET modeling, discussed below).

2.8.3 Internal Loading

Internal TP loads to Colby Lake were estimated using information developed by the Rice Creek Watershed District (RCWD). The RCWD retained the U.S. Army Corps of Engineer's Eau Galle Lab to measure the sediment phosphorus release rates in 30 of their lakes, in the laboratory, under oxic and anoxic conditions. Phosphorus release rates in Colby Lake were estimated assuming a long-term average summer season internal release rate of 1.62 milligrams per square meter per day (the median rate observed in 23 shallow lakes in the RCWD) over an area equal to the surface area of Colby Lake. As a result, the internal phosphorus loading to Colby Lake during the summer season was estimated at 55 kg (a constant internal loading was assumed for all years included in this work).

2.8.4 Other In-Lake Processes

Other in-lake processes, including sedimentation, were not explicitly accounted for in the Colby Lake TP nutrient balance, but rather estimated with the error term in the nutrient balance equation (i.e., sedimentation/in-lake = TP inputs – TP outputs). However, the CNET in-lake response model (discussed in **Section 3.3**) does account for this term in its simulations.

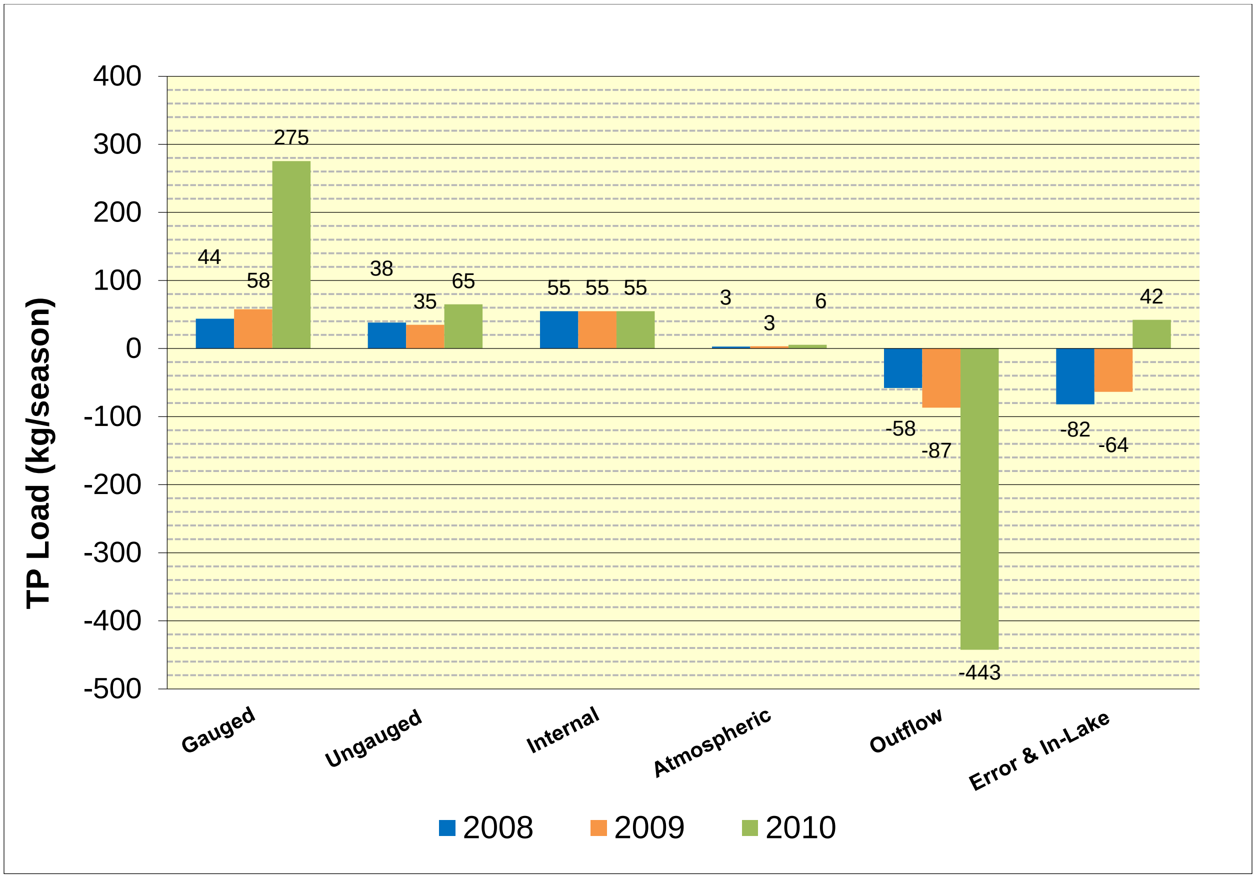
2.8.5 Surface Outflow

The TP load exiting Colby Lake as outflow for each year of the TP balance was estimated as the product of the average summer season in-lake TP concentration and the observed daily outflows during the summer season. Since in-lake water quality data was not collected during the summer season of 2009, the value for this year was estimated based on the long-term summer season average in-lake TP concentration (computed as the average of the mean summer season values over the period of record, 1994-2010). Summer season outflow loads for the years of 2008-2010 were estimated as 58, 87, and 443 kg, respectively.

2.8.6 Estimated Total Phosphorus Nutrient Budget

Using the results of **Sections 2.8.1 through 2.8.5**, the Colby Lake summer season TP mass balances for 2008-2010 were estimated. **Figure 6** shows the results.

Figure 6: Colby Lake Summer Season (June through September) TP Budget: 2008, 2009, and 2010



3.0 MODEL DEVELOPMENT AND APPLICATION

3.1 <u>Modeling Goals and Technical Objectives</u>

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

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

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

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

3.2 Watershed Modeling

The movement of water from the watershed into Colby Lake was determined using version 3.4 of the P8 model (Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (http://wwwalker.net/p8/)). The P8 model incorporates a number of factors that encompass inflow, outflow, and the movement of sediment-related particles (including TP) through a watershed. The goal of creating the Colby Lake P8 watershed model was to simulate long-term hydrology and TP loading in the study area. Results of these simulations were then used as inputs to the receiving water model, which was developed to compute the loading capacity of Colby Lake. The Colby Lake watershed P8 model was run using data from 1949-2010. The period from 1949-1960 was used as a warm up, allowing the model compartments (soil moisture, particulate content, etc.) to "wash" the potential influence of initial conditions from the model results. The model then was calibrated to observed 2008/2009 summer season hydrology and water quality at the MS1, Wilmes Outlet, and Colby West Inlet monitoring locations. The model was validated with summer season data from 2010. Given the variability in the hydrology (and associated water quality) of 2008/2009 versus that of 2010, using these years for model calibration and validation gave an excellent check of the performance under both normal and wet weather conditions.

Considering the Colby Lake watershed's urban setting, the P8 model is a good fit for modeling its hydrology and water quality given the model's ability to discretely model constructed BMPs within its model domain. The routing information and most other required inputs for the Colby Lake watershed P8 model were adopted from an existing SWWD hydrologic and hydraulic XPSWMM model through the use of the proprietary "SWMM to P8" software (developed by HEI), as discussed in the Colby Lake Watershed Modeling Report (HEI, 2011). Rainfall data used to generate P8 runoff volumes were taken from the MSP weather station discussed in **Section 2.7.3**. The main reason for using these data was the availability of a long-term record, allowing for simulation of long-term pollutant loading in the Colby Lake watershed. A similar modeling exercise performed for Powers Lake (just northwest of Colby Lake in the SWWD) compared portions of the MSP record to shorter periods of data observed in the SWWD (HEI, 2010). Results showed that, overall, the MSP data were a good fit.

The Colby Lake watershed P8 model was calibrated to observed summer season surface water runoff volumes, TSS loads, and TP loads at the three measurement locations shown in **Figure 1**. Complete details of this process and its results are included in the accompanying Colby Lake Watershed P8 Modeling Report (**Appendix A**). Model calibration was performed using data from 2008 and 2009. Model validation was performed using data from 2010. **Table 4** shows the final results of this analysis.

Table 4: Volume, TSS, and TP Yields Predicted by the P8 Model for Calibration and Validation (June 1 to September 30)

STATION		YEAR	OBSERVED			P8 MODELED			DIFFERENCE MODELED VS. MEASURED			% DIFFERENCE MODELED VS. MEASURED		
			Volume (ac-ft)	TSS (lbs)	TP (lbs)	Volume (ac-ft)	TSS (lbs)	TP (lbs)	Volume (ac-ft)	TSS (lbs)	TP (lbs)	Volume (%)	TSS (%)	TP (%)
MS1 Monitoring Station		2008	73	7,816	35	65	6,700	29	-8	-1,116	-5			
		2009	57	5,698	24	104	8,013	42	46	2,315	17			
	Calibration		130	13,514	59	169	14,713	71	38	1,200	12	29%	9%	20%
	Validation	2010	359	38,311	154	255	16,993	98	-104	-21,318	-56	-29%	-56%	-36%
Wilmes Outlet Monitoring Station		2008	282	8,678	67	306	7,977	91	23	-701	24			
		2009	255	4,296	64	470	10,357	137	215	6,062	73			
	Calibration		537	12,974	131	776	18,335	228	239	5,361	97	44%	41%	74%
	Validation	2010	2,005	50,741	512	1,072	24,590	318	-933	-26,151	-194	-47%	-52%	-38%
Colby Lake West Monitoring Station		2008	37	4,012	19	21	5,046	14	-16	1,034	-4			
		2009	35	10,811	17	37	6,648	21	1	-4,163	4			
	Calibration		72	14,822	36	58	11,693	36	-14	-3,129	0	-20%	-21%	-1%
	Validation	2010	66	19,125	32	87	16,148	51	21	-2,977	19	32%	-16%	59%
Eagle Valley		2008	21	2,286	11	58	621	16	37	-1,665	5			
(Colby East 12)		2009	95	28,866	46	83	838	22	-12	-28,028	-23			
Pump Station	Calibration		116	31,153	57	141	1,459	38	26	-29,693	-18	22%	n/a*	n/a
	Validation	2010	129	37,585	63	171	2,178	48	42	-35,407	-15	33%	n/a	n/a

* The quality of the measured TSS and TP data are unknown at the pump station, and therefore an assessment of the calibration at this location was not made

During calibration years, errors in the simulated surface water runoff volume (in terms of the percent difference of predicted volume versus observed volume) range from -20% to +44%. In general, the model over predicts the 2008/2009 volume to Colby Lake from the northern watersheds, which are assessed at the MS1 and Wilmes Outlet monitoring stations. The 2008/2009 outflow volume from the Eagle Valley Pump Station, located east of Colby Lake, is also over predicted, whereas the volume at the Colby Lake West monitoring station, to the west of the lake, is under predicted during this time. Likewise, the model over predicts TSS and TP loading in the same northern subwatersheds and under predicts them in the subwatersheds associated with the Colby Lake West monitoring station. As shown in **Table 4**, these errors range from -21% to +41% for TSS loading and from -1% to +74% for TP loads.

Model validation was performed for the summer months of 2010. Again, results are presented in **Table 4.** For the most part, the Colby Lake watershed model validation errors tend to be negative under the scenarios where calibration errors were positive and vice versa. For example, whereas the model over predicts the runoff volumes at the MS1 and Wilmes Outlet monitoring stations during 2008/2009, it under predicts the volumes during 2010. Given the limited data available for model calibration/validation and the precipitation patterns during these years (2008 and 2009 had an average 11 inches of rainfall during those summers, while 2010 had nearly 20 inches), this over- and under prediction pattern is to be expected. Further discussion of the modeling errors, potential contributors to those errors, and their implications are included in the Colby Lake Watershed P8 Modeling Report (**Appendix A**).

3.3 Receiving Water Modeling

Based upon the stated modeling goals and objectives (discussed above), the CNET model was used to simulate the eutrophication response within Colby Lake itself. CNET is a modified version of the receiving water model BATHTUB (http://wwwalker.net/bathtub/index.htm), which was created by the Army Corps of Engineers. CNET is a spreadsheet model currently available as a "beta" version from Dr. William W. Walker. The primary modifications to the CNET model implemented during this effort were to: 1) to use empirically derived regression relationships specific to Colby Lake derived from monitoring data to estimate the response of chl-*a* and SD to TP (used primarily to double check/confirm the responses values predicted by the CNET equations); and 2) implementing a Monte Carlo approach which allowed selected modeling parameters and inputs to vary based upon known statistical distributions and be reflected in the forecast results. The Monte Carlo approach generates a distribution of the annual mean concentrations reflecting the uncertainty in the model parameters and normal variability in inputs (*e.g.*, seasonal TP load from surface runoff).

To complete the Monte Carlo modeling the CNET model was linked with a program called Crystal Ball. Crystal Ball is proprietary software developed by Oracle (http://www.oracle.com/us/products/applications/crystalball/index.html) and is applicable to Monte Carlo or stochastic simulation and analysis. Stochastic modeling is an approach where model parameters and input values (*e.g.*, precipitation) used in the equations to compute the annual mean concentration of TP, chl-*a*, and SD are allowed to vary according to their statistical distribution and therefore their probability of occurrence. This allows the effect of parameter uncertainty and normal variability in the inputs (*e.g.*, amount of surface runoff which varies annually depending upon the amount of precipitation) to be quantified when computing the summer season mean concentration of TP, chl-*a*, and SD.

The Crystal Ball software allowed for multiple probabilistic simulations of the model computations. Many trial values (1,000 trials in this study case) were generated, with each trial representing a different permutation of model parameters and input values within the bounds established by the statistical distributions. The many trials resulted in a computed distribution of annual mean concentrations rather than a single, fixed output that was based upon only one possible combination of model parameters and inputs. The stochastic approach reflects the variability in model parameters and inputs, and allows explicit determination of their effect on the mean values and the expression of model results as risk. **Table 5** shows the values allowed to vary in the Monte Carlo simulation and the statistical distribution for each parameter allowed to vary within the model. The other necessary inputs to the CNET model (the internal loading and groundwater + error terms, for example) were held constant throughout all model simulations.

Table 5: Model Inputs used in the Monte Carlo Analysis

Model Input	Statistical Distribution	Basis for Distribution	Distribution Truncated at Extreme Values?	Correlation	
				Considered?	Input Correlated With
Precipitation	Beta	1961 – 2010 MSP National Weather Service Station	Yes (low)	Yes	Evaporation (0.38) Surface runoff (0.86) Surface load (0.45) Atmospheric Load (1.0)
Evaporation	Beta	2000 – 2010; 1961 – 2009 computed from precipitation data	Yes (low)	Yes	Precipitation (0.38)
Atmospheric Load	Beta	Distribution Assumed Same as Precipitation	No	No	Precipitation (1)
Surface Water Runoff Volume	Lognormal	1961 – 2010 calibrated P8 model	Yes (low)	Yes	Precipitation (0.86) Surface Load (0.80)
Surface Runoff Load	Lognormal	1961 – 2010 calibrated P8 model	Yes (low)	Yes	Precipitation (0.45) Surface Runoff Volume (0.80)

Notes:

Distributions generally were best fit for the 50-year period (1961-2010) of seasonal values.
Correlation coefficients were derived from actual data.
Atmospheric TP load distribution assumed to be the same as precipitation with equal coefficient of variation.
Value in parentheses is correlation coefficient.
See **Appendix B** for the statistical distribution parameters.
Statistical distributions were the "best fit" distribution, as determined by the Crystal Ball software.

Prior to completing the Monte Carlo modeling analysis, the Colby Lake CNET model was calibrated to summer season mean TP, chl-*a*, and SD for 2008 and validated for 2010. The modeling using the seasonal water budget and TP mass balance around the Lake as described in **Sections 2.7 and 2.8**. The following CNET models were used in the simulations:

- Total phosphorus sedimentation model: Canfield & Bachman, Natural Lakes
- Chlorophyll-*a* response model: P, Light, Flushing
- Secchi-disk Transparency response model: Chlorophyll-*a* and turbidity.

Similar to what was done with the P8 model, the goal of the CNET model calibration was to adjust each sedimentation and response models' calibration coefficient to reduce the errors between observed and simulated values. Given the hydrologic (and associated water quality) differences between the calibration and validation years, an approach of "splitting the difference" between the calibration and validation errors was used. This approach ensures an in-lake response model that best represents long-term average conditions in Colby Lake, which is appropriate for computing the allowable load. **Table 6** shows the results of model calibration using the 2008 data. **Table 7** shows the results of model validation using the 2010 data.

Table 6: **CNET Model Calibration Results for 2008 Summer Season (June through September) Mean Concentrations**

	Calibration Coefficient	Measured	Modeled	Absolute Difference	Percent Difference
Total Phosphorus	0.56	181.4 ppb	201.3 ppb	19.9 ppb	11.0 %
Chlorophyll-a	1.15	52.9 ppb	65.3 ppb	12.4 ppb	23.4 %
Secchi Disk	0.92	0.30 meters	0.38 meters	0.08 meters	26.7 %

Table 7: CNET Model Validation Results for 2010 Summer Season (June through September) Mean Concentrations

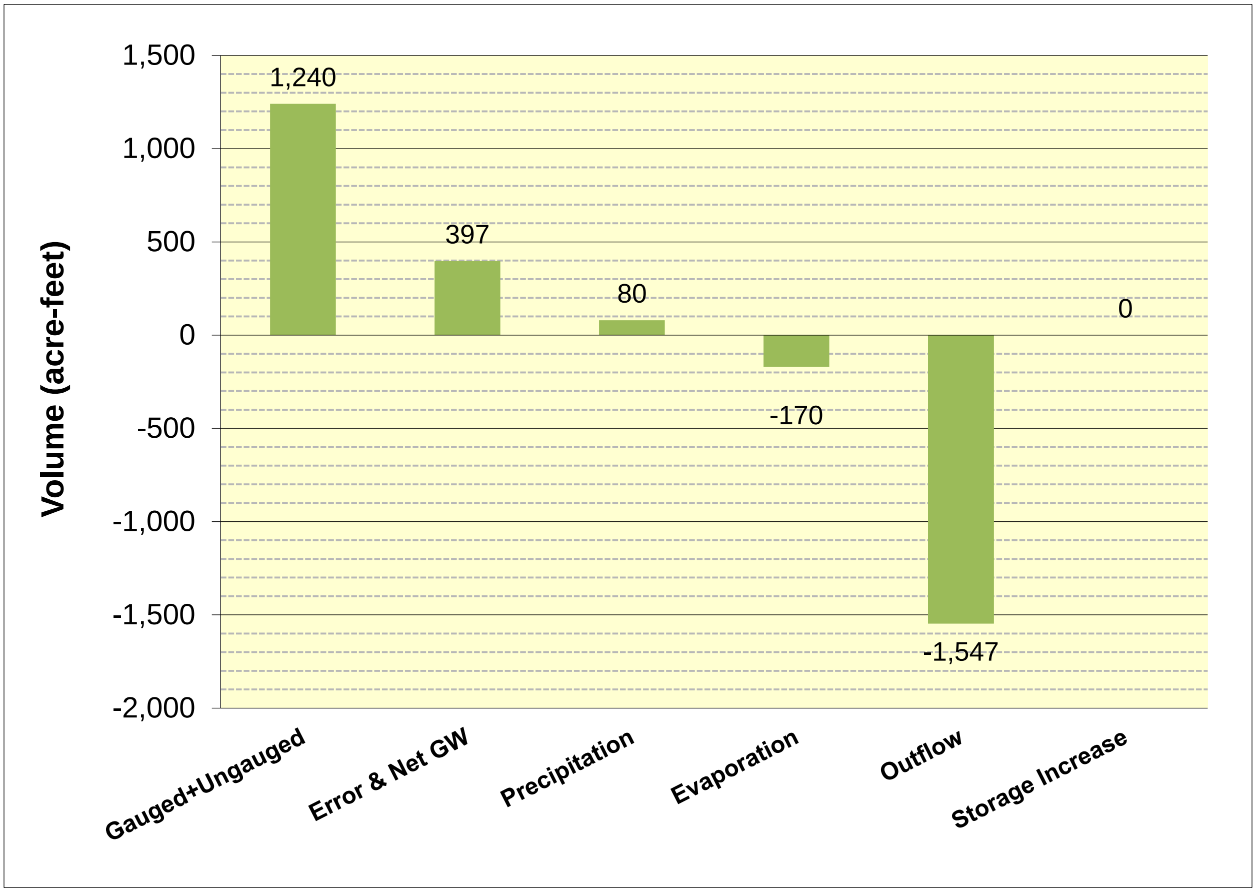
	Measured	Modeled	Absolute Difference	Percent Difference
Total Phosphorus	103.5 ppb	89.3 ppb	-14.2 ppb	-13.7 %
Chlorophyll-a	52.0 ppb	38.7 ppb	-13.3 ppb	-25.6 %
Secchi Disk	0.73 meters	0.52 meters	-0.21 meters	-28.8 %

Given the difference in the hydrology and associated water quality in the Colby Lake system during the years of 2008 and 2010, the general approach taken during the model calibration/validation was to adjust the model to best represent "average" conditions in the system (i.e., equalize the errors between the drier year of 2008 and wetter year of 2010). Using this approach the Colby Lake CNET model is setup to simulate anticipated long-term water quality goals.

3.4 Modeling the Load Allocation

The hydrologic budget and TP mass balance used to develop the TMDL for Colby Lake used the average values and statistical distributions for a 50-year period of record to represent the long-term condition. Fifty-years of precipitation data was used as input to the watershed model to compute long-term summer season surface water runoff and TP load. Additional methods were used to estimate the long-term evaporation, precipitation and atmospheric loading, as shown in **Table 5**. Internal TP loading rates were simulated as the long-term average of 55 kg/season, as discussed in **Section 2.8.3**. The log-term average change in storage was assumed to zero and the groundwater + error term was assumed to be an average of values computed during the hydrologic budget in **Section 2.7**. The surface water outlet from the lake was computed by the CNET model. The long-term average hydrologic budget for Colby Lake is shown in **Figure 7**. Results of the modeling and the impacts of various load reductions are discussed below.

Figure 7: Long-Term Average Colby Lake Summer Season (June through September) Hydrologic Budget

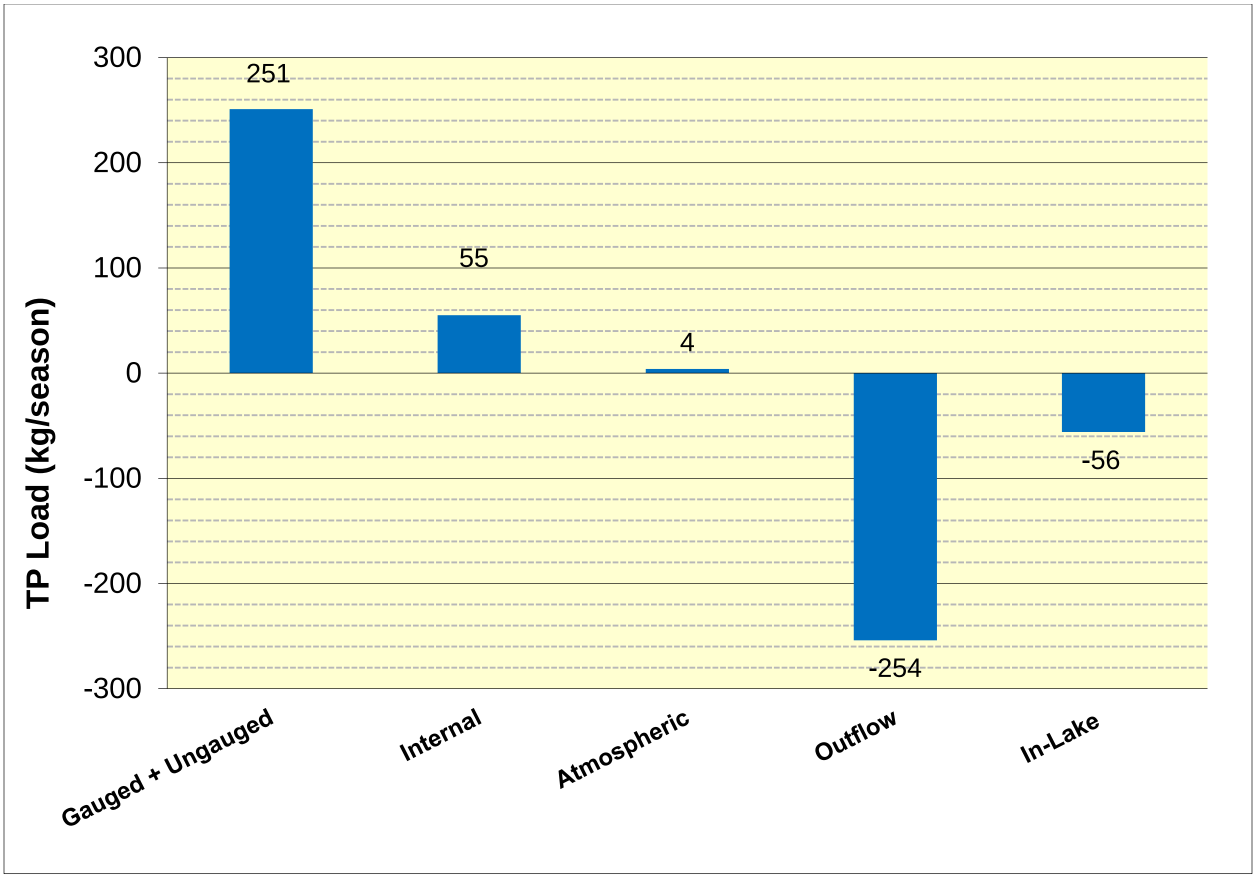


4.0 EUTROPHICATION RESPONSE AND LOAD ALLOCATION

To simulate the load reductions and therefore the maximum allowable load (i.e., loading capacity) needed to achieve the State water quality standard in Colby Lake, a series of model simulations were performed. Each simulation reduced the total amount of TP entering Colby Lake during the summer season, computing the anticipated response within the Lake. The goal of the modeling was to identify the loading capacity of Colby Lake (i.e., the maximum allowable load to the system, while allowing it to meet water quality standards) during the June 1 – September 30 summer season. Consistent with recent MPCA guidance, it was assumed that if Colby Lake meets the State's TP water quality standard that chl-*a* and SD within the system will respond accordingly and eventually also reach the State-defined goals (even if the results of the CNET modeling don't predict that they will). This approach assumes that data collected and extensively analyzed by the MPCA during standards development provides a more accurate estimate of how lakes will respond when moved from an impaired to unimpaired state than the relationships that exist within the CNET program.

Figure 8 shows the long-term average TP mass balance of Colby Lake (i.e., the current condition scenario) as simulated in the CNET model. Results show that Colby Lake currently receives a total summer season TP loading of approximately 310 kg. About 250 kg of that TP comes from surface water runoff; the other major source of TP is from internal load. As mentioned, the CNET model computes in-lake processes through its sedimentation term; in this case removing (on average) 56 kg/season TP from the system.

Figure 8: Long-Term Average Colby Lake Summer Season (June through September) TP Mass Balance



4.1 Eutrophication Response

Figures 9-14 show the effects of reducing summer season TP loads to Colby Lake on the summer mean TP, chl-*a* and Secchi disk depth within the lake (based on the CNET model). Loads were reduced incrementally within the CNET model and assumed to come from the surface runoff and internal loading components of the mass balance. Results are presented both in terms of the seasonal mean concentrations as shown by the column graphs and the results of the Monte Carlo analysis. The Monte Carlo analysis results are presented as a series of lines, where each line represents a statistical distribution of the seasonal mean values.

Figure 9: Colby Lake Seasonal Mean (June through September) TP Concentrations under Select Load Reduction Scenarios; Current Conditions = 310 kg/season

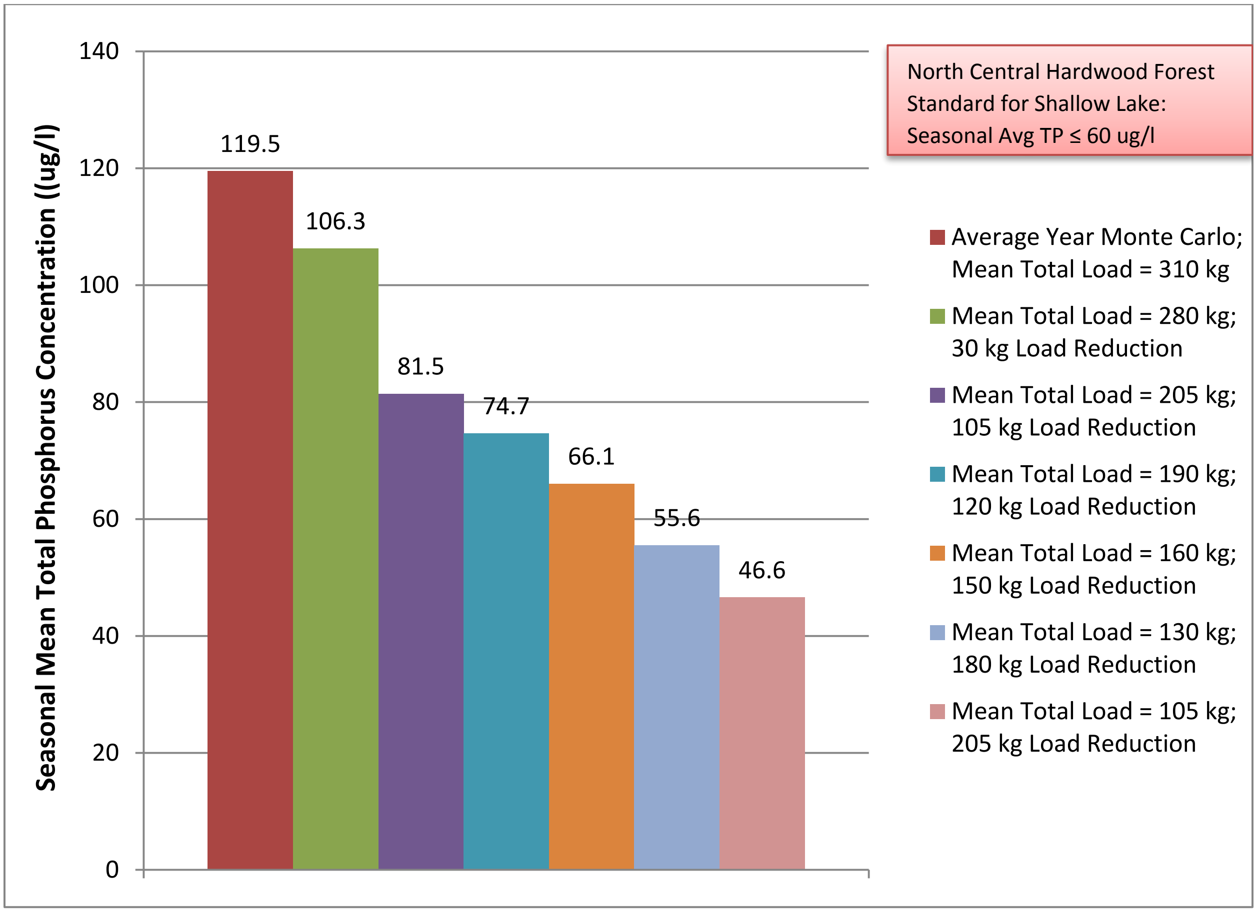
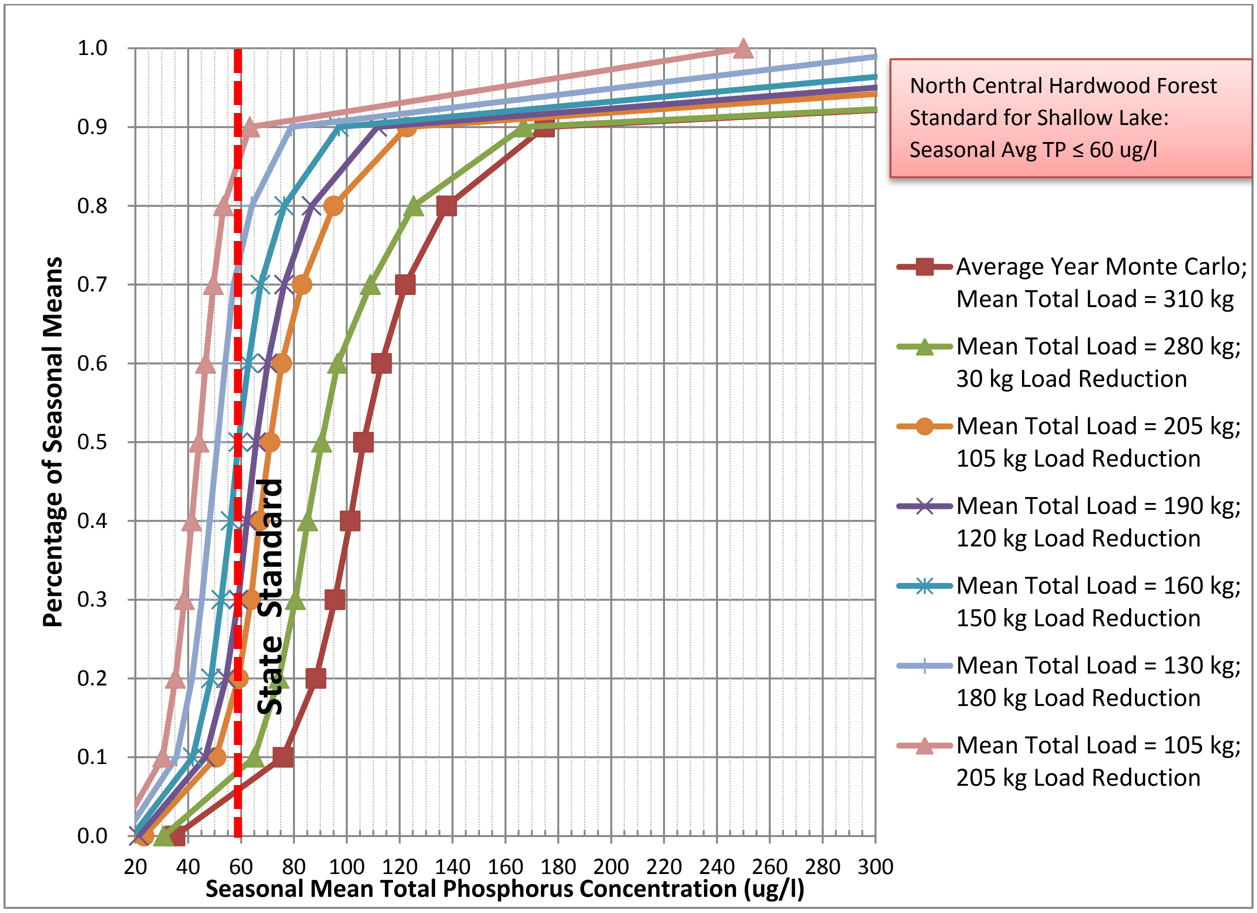


Figure 10: Colby Lake Frequency Distribution of Seasonal (June through September) Mean TP Concentrations Resulting from Select Load Reduction Scenarios and Table of Data used to Produce the Graphical Illustration; Current Conditions = 310 kg/season



		Load Reduction from Current Load for Average Summer Season					
Non-exceedance Percentile	Average Year (current)	30 kg	105 kg	120 kg	150 kg	180 kg	205 kg
Mean	119.5	106.3	81.5	74.7	66.1	55.6	46.6
0%	35.0	30.7	23.3	21.3	18.9	15.9	13.4
10%	75.9	65.0	50.6	46.5	41.7	35.5	30.4
20%	88.3	74.4	59.0	54.3	48.6	41.5	35.2
30%	95.5	80.6	63.8	59.0	52.5	45.2	38.6
40%	101.3	85.2	67.0	62.2	56.0	48.1	41.4
50%	106.3	90.5	71.0	65.7	59.0	51.1	44.1
60%	113.1	96.6	75.4	70.1	62.8	54.0	46.6
70%	122.2	109.0	83.1	76.3	67.4	57.2	49.5
80%	137.7	125.3	95.1	86.7	76.3	64.0	53.4
90%	174.8	166.9	122.8	111.6	97.0	78.9	63.3
100%	756.3	753.9	545.6	488.4	415.7	326.4	250.1

Figure 11: Colby Lake Seasonal (June through September) Mean Chl-*a* Concentrations under Select Load Reduction Scenarios; Current Conditions = 310 kg/season

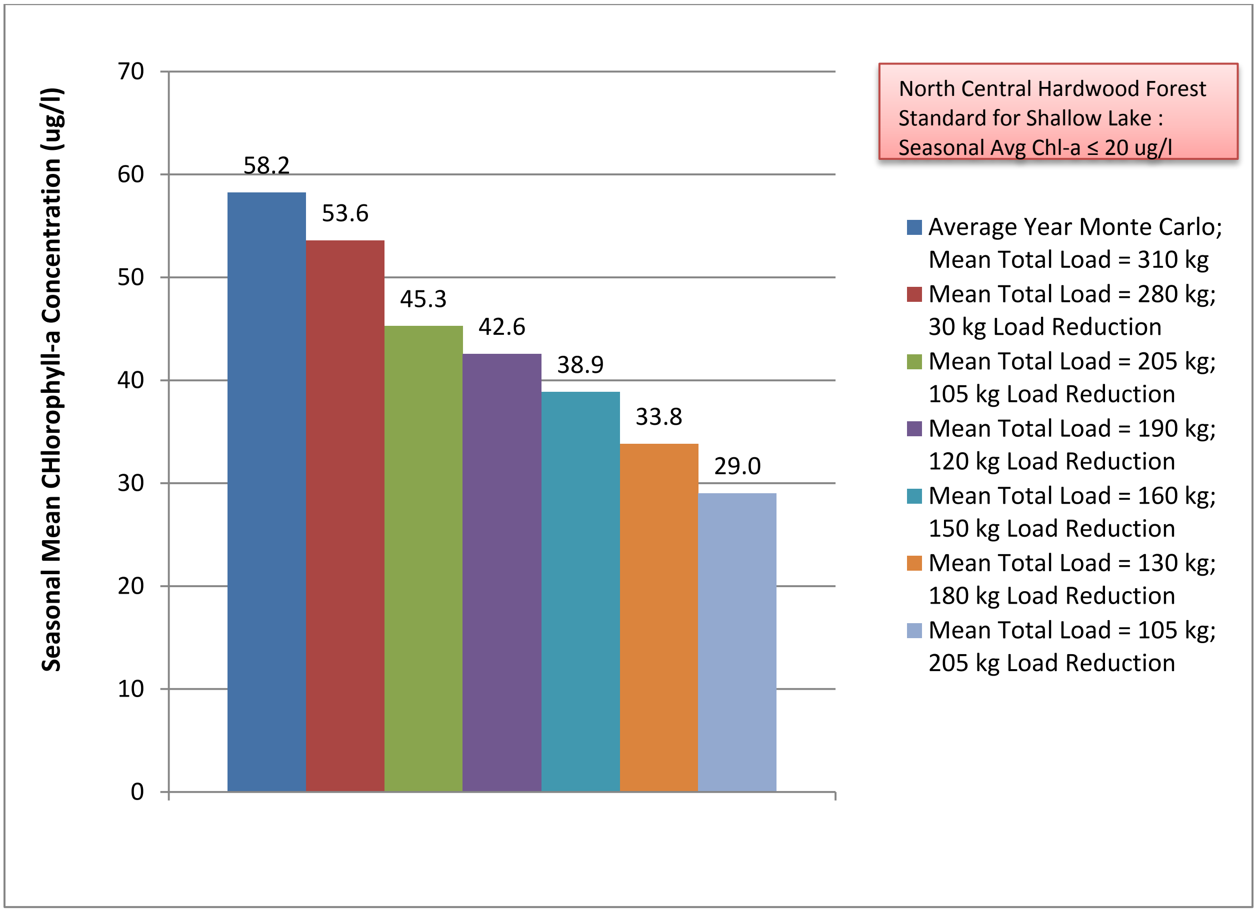


Figure 12: Colby Lake Frequency Distribution of Seasonal Mean Chl-*a* Concentrations under Select Load Reduction Scenarios; Current Conditions = 310 kg/season

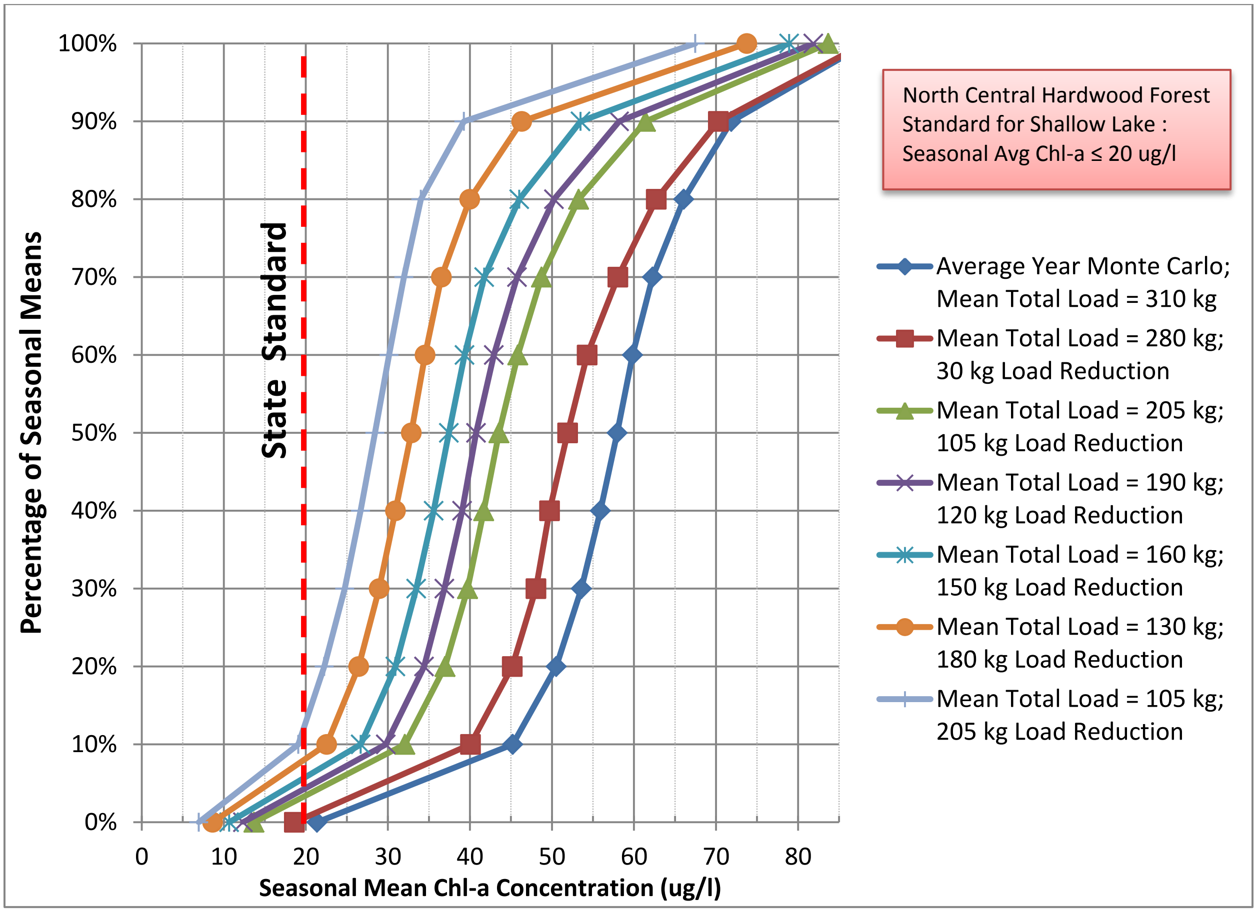


Figure 13: Colby Lake Seasonal Mean Secchi Disk Depth under Select Load Reduction Scenarios; Current Conditions = 310 kg/season

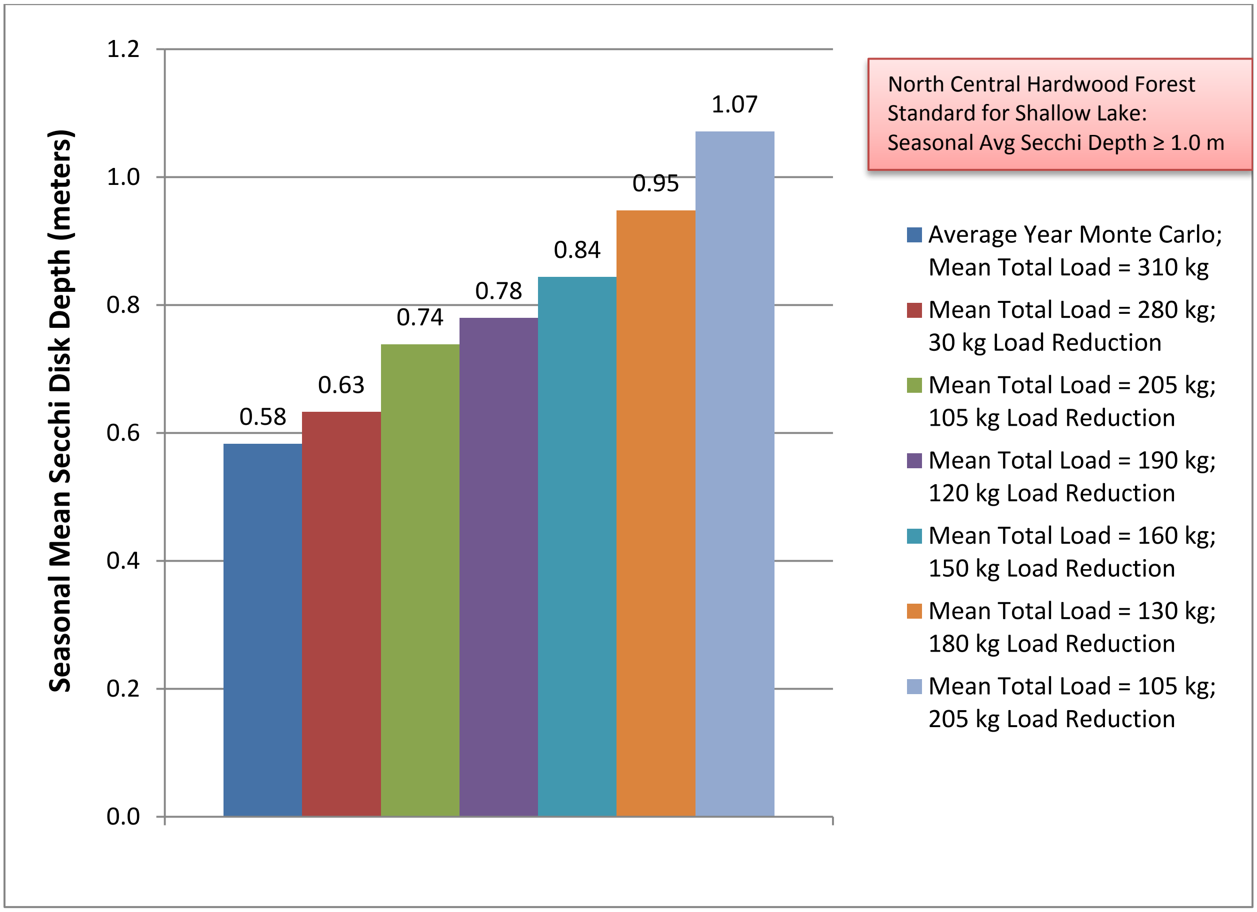
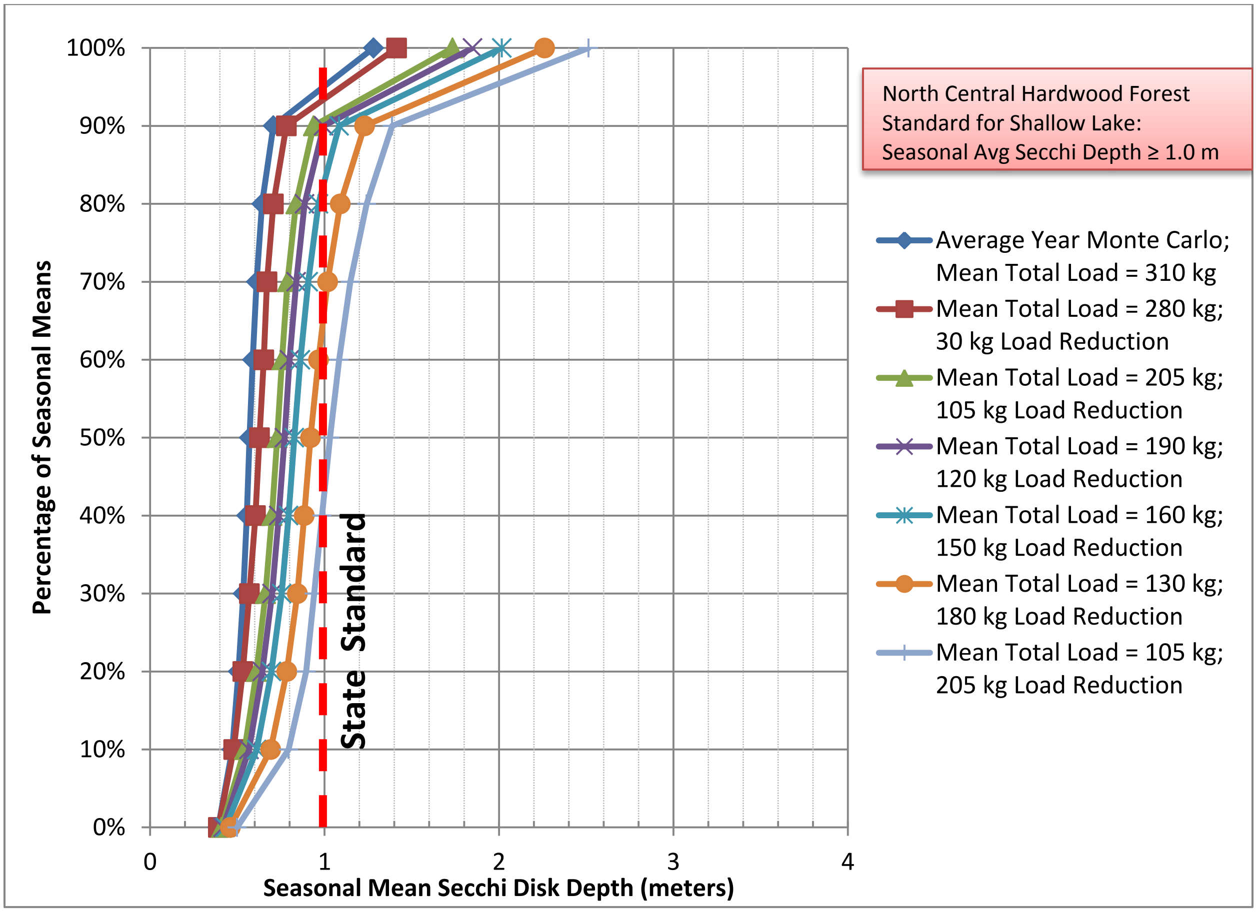


Figure 14: Colby Lake Frequency Distribution of Seasonal Mean Secchi Disk Depth under Select Load Reduction Scenarios; Current Conditions = 310 kg/season



4.2 Loading Capacity

The loading capacity is the maximum allowable TP load to Colby Lake which can occur, while still achieving the in-lake TP water quality numeric standard of the MPCA, 60 ug/l. The SWWD also has goal for Colby Lake that the TP Trophic State Index (TSI) value will range between 70 and 73. Since a TSI value of 70-73 correlates to a TP concentration of 96-118 ug/l, in this case, the State standard is more stringent and will be the basis for computing the allowable load. Although this study is not, technically a Total Maximum Daily Load (TMDL) study, the function of a loading capacity defined here replicates that developed under a TMDL. Given the similarity between this work and a TMDL, the loading capacity computed for Colby Lake is allocated between non-point sources (i.e., the load allocation – LA – in a TMDL study), point sources (i.e., the wasteload allocation – WLA – in a TMDL study), and a margin of safety (MOS). The LA component of the loading capacity includes existing and future nonpoint sources (i.e., atmospheric deposition and internal load); the WLA component includes storm-sewered and overland runoff from the Colby Lake watershed. The MOS used is an explicit expression, intended to reflect the lack of knowledge and uncertainty in establishing the load capacity.

In this study, the loading capacity of Colby Lake was computed using a stochastic approach based on the hydrology and water quality simulated by the P8/CNET modeling. The loading capacity (allowable load) of the Lake was defined as that which reduces the seasonal mean TP concentration for the 50th percentile non-exceedance value to the MPCA numeric standard (60 ug/l). Given that the SWWD's lake-specific standards for Colby Lake are less conservative than the MPCA's, achieving the State standard will satisfy those of the District. Since the loading capacity of Colby Lake is computed using a stochastic approach (which takes uncertainty and variability into consideration), the MOS was computed as 5% of the allowable load.

Results of the loading capacity analysis are shown in **Figure 10**. A line at 60 ug/L represents the average summer season TP concentration eutrophication standard for the protection of lake quality in Class 2 surface waters in the North Central Hardwood Forest ecoregion. A table accompanying **Figure 10** shows the values for the values used to produce the figure. Results of this analysis show that a 150 kg summer season TP load reduction is needed to achieve the water quality standard. **Table 8** shows the load allocations that would be employed if Colby Lake were to be evaluated as a TMDL-listed water body. The summer season daily values presented in **Table 8** were computed based on seasonal values shown in **Figure 10** and its accompanying table.

Table 8: Colby Lake Loading Capacity to Meet State Standards

	Loading (kg/day)	=	Load Allocation (kg/day)	+	Wasteload Allocation (kg/day)	+	Margin of Safety (kg/day)
Current Condition	2.54	=	0.48	+	2.06	+	0
Goal: 60 ug/L	1.31	=	0.23	+	1.02	+	0.06

As summarized in **Table 8**, it is estimated that the current 2.54 kg/d summer season TP load to Colby Lake would have to be reduced to 1.31 kg/d. Under this scenario, the wasteload allocation (storm-sewered runoff from the watershed) would have to be reduced by 51%; from 2.06 to 1.02 kg/d (250 to 124 kg/season). The wasteload allocation represents what is considered a technically feasible reduction through the installation of BMPs as the fully developed watershed redevelops. The remainder would have to come from the load allocation which is comprised of both atmospheric and internal loading from the phosphorus-laden bottom sediments. The load allocation represents what is considered a technically feasible reduction associated with changing Colby Lake from the turbid to clear phase. The atmospheric loading of 0.03 kg/d is beyond the control of the SWWD, so the reduction would need to come from internal TP loading. The approximately 0.45 kg/d internal TP load would have to be reduced 55% to achieve the 0.20 kg/d internal load needed to meet the 60 ug/L goal 50% of the time. In reality any combination of waste load allocation and load allocation equaling 1.31 kg/d is able to achieve the loading capacity.

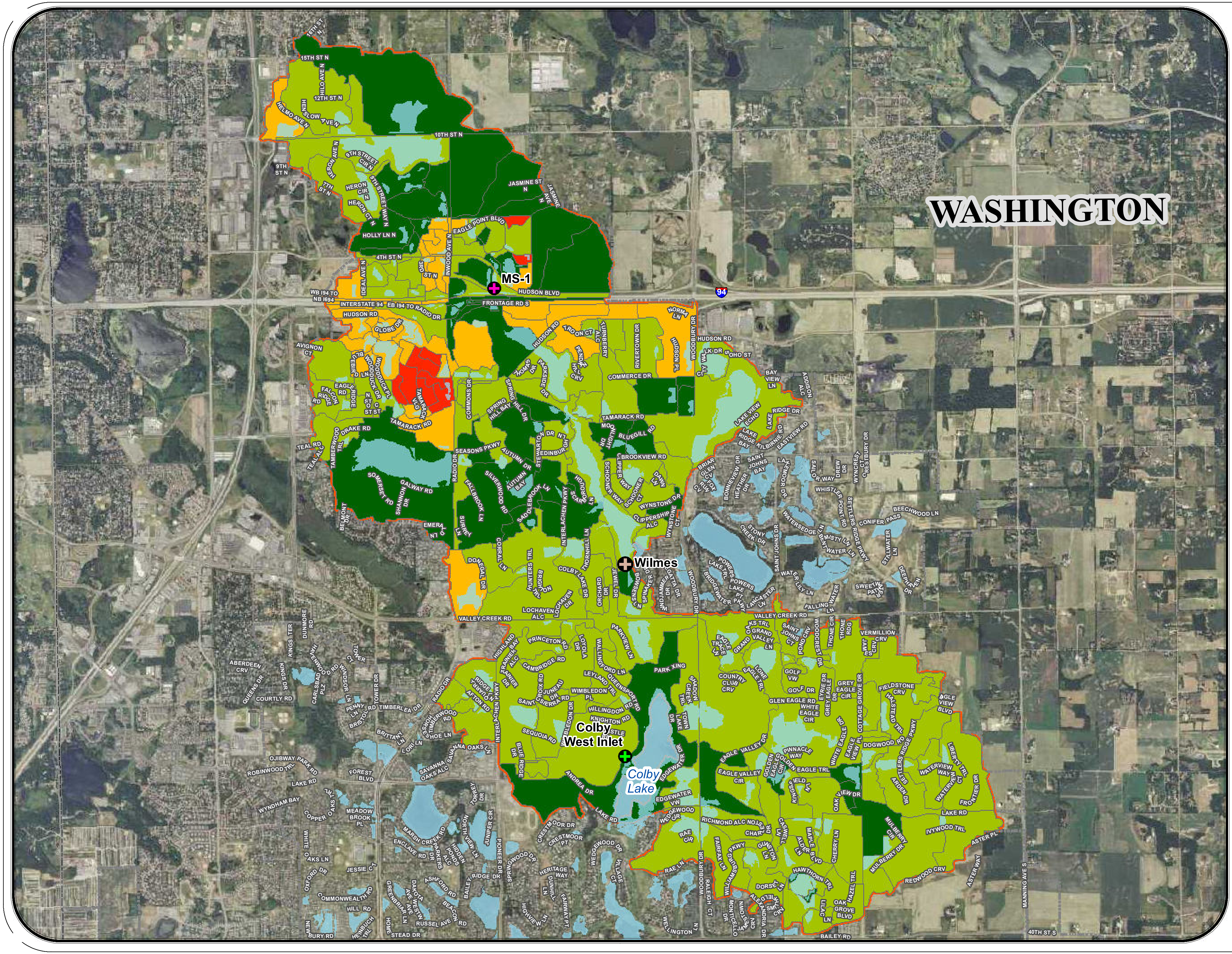
5.0 IMPLEMENTATION TO ACHIEVE THE LOADING CAPACITY

There are any number of implementation scenarios that could be employed in the Colby Lake system to reduce the TP loading to the Lake and (eventually) attain the water quality standard. A companion study to this work is being completed by the SWWD and the Washington Conservation District (WCD) to target specific watershed-based BMPs that would reduce TP loading to the lake due to surface water runoff. To reduce internal TP loadings to Colby Lake some form of phosphorus sequestration would be needed. Various methods can be employed toward that goal; one of the more common methods is alum treatment. Alternatively and perhaps more probable, is that the internal load reduction can be realized by transitioning the lake from the turbid to clear state, though a combination of curly leaf pond weed control, fish management and the establishment of native aquatic vegetation. Data from Lake Christina in west-central Minnesota collected by the MnDNR shows a 50% reduction in TP when the lake is in the clear than turbid state (Deutschman, 2011).

5.1 Priority Implementation Areas

The work of the SWWD/WCD will rely heavily upon the results of the Colby Lake Watershed P8 model, using its results to determine existing storage-node (retention pond) performance for the Colby Lake watershed and identifying areas where further improvements can be made. Details on the (estimated) storage-node performance under current conditions is included in the Colby Lake P8 Watershed Modeling Report, which is included as Appendix A.

Other results of the Colby Lake Watershed P8 model that will be useful when identifying areas for improved TP load reductions are the simulated TP yield values, shown by (modeled) subwatershed in **Figure 15**. The SWWD Watershed Plan identifies an annual yield of 0.34 lbs/ac/year acceptable with the Colby Lake watershed and 0.10 lbs/ac/year acceptable with the Wilmes Lake area (SWWD, 2007).



Colby Lake P8 Watershed Model: Existing Conditions TP Yield

2010 Monitoring Sites
- Colby West Inlet
- MS-1
- Wilmes
- Retention Ponds/Storage Nodes

TP Yield (lbs/acre/yr)
- 0.18 - 0.35
- 0.35 - 0.55
- 0.55 - 0.75
- 0.75 - 0.95
- Colby Lake Watershed

0 1,750 3,500 7,000 Feet

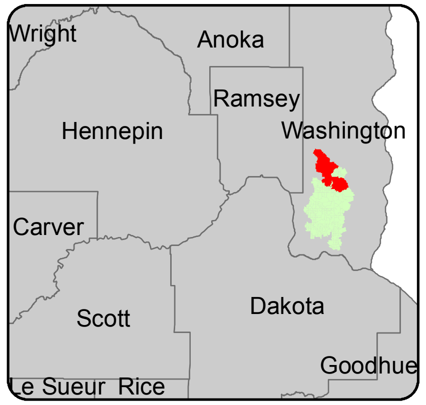


Figure 15: Existing Conditions Annual TP Yield by Subwatershed (Colby Lake Watershed P8 Model)

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APPENDIX A

Colby Lake P8 Watershed Modeling

1 Introduction

The Colby Lake watershed encompasses the northern portion of the South Washington Watershed District (SWWD), as shown in **Figure 1**. Watershed modeling of the Colby Lake watershed was performed using version 3.4 of the P8 model – Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (http://wwalker.net/p8) - to develop the surface water runoff, total suspended sediment (TSS), and total phosphorus (TP) components of the long-term hydrologic budget and mass balance, respectively. The P8 model was originally developed using National Urban Runoff Program (NURP) data and provides pollutant loading estimates based on data collected as part of the NURP program. The model tracks pollutant loading by building up particles on impervious surfaces, washing off the particles through runoff resulting from precipitation, and routing the loads and runoff volume downstream through treatment devices (representing ponds, infiltration basins, pipes, etc.). The pollutant removal efficiency of each device is then evaluated and pollutants not removed are routed downstream through the simulated watershed. This report serves as documentation for development of the Colby Lake watershed P8 model, including the modeling methods and data sources.

2 Derivation of Model Inputs

The P8 model requires user input relative to local precipitation and temperature, watershed characteristics, water quality parameters, and treatment device geometry. For the Colby Lake watershed P8 model, the routing information and most other required inputs were adopted from a hydrologic and hydraulic XPSWMM model[1] which was developed for the SWWD as part of the Central Draw Project.[2] The XPSWMM model was converted to a EPA Storm Water Management Model[3] (hereafter referred to as the SWMM model), and the watershed characteristics, hydrologic parameters, and device geometry data for the P8 model were adopted through the use of the proprietary "SWMM to P8" software, which was developed by Houston Engineering, Inc. (HEI). This "SWMM to P8" conversion software was used to

[1] http://www.xpsoftware.com/products/xpswmm/
[2] XP-SWMM model developed for the "Central Draw Project and Flood Storage Area Maps," by HDR Engineering, Inc., June 2002.
[3] http://www.epa.gov/athens/wwqtsc/html/swmm.html

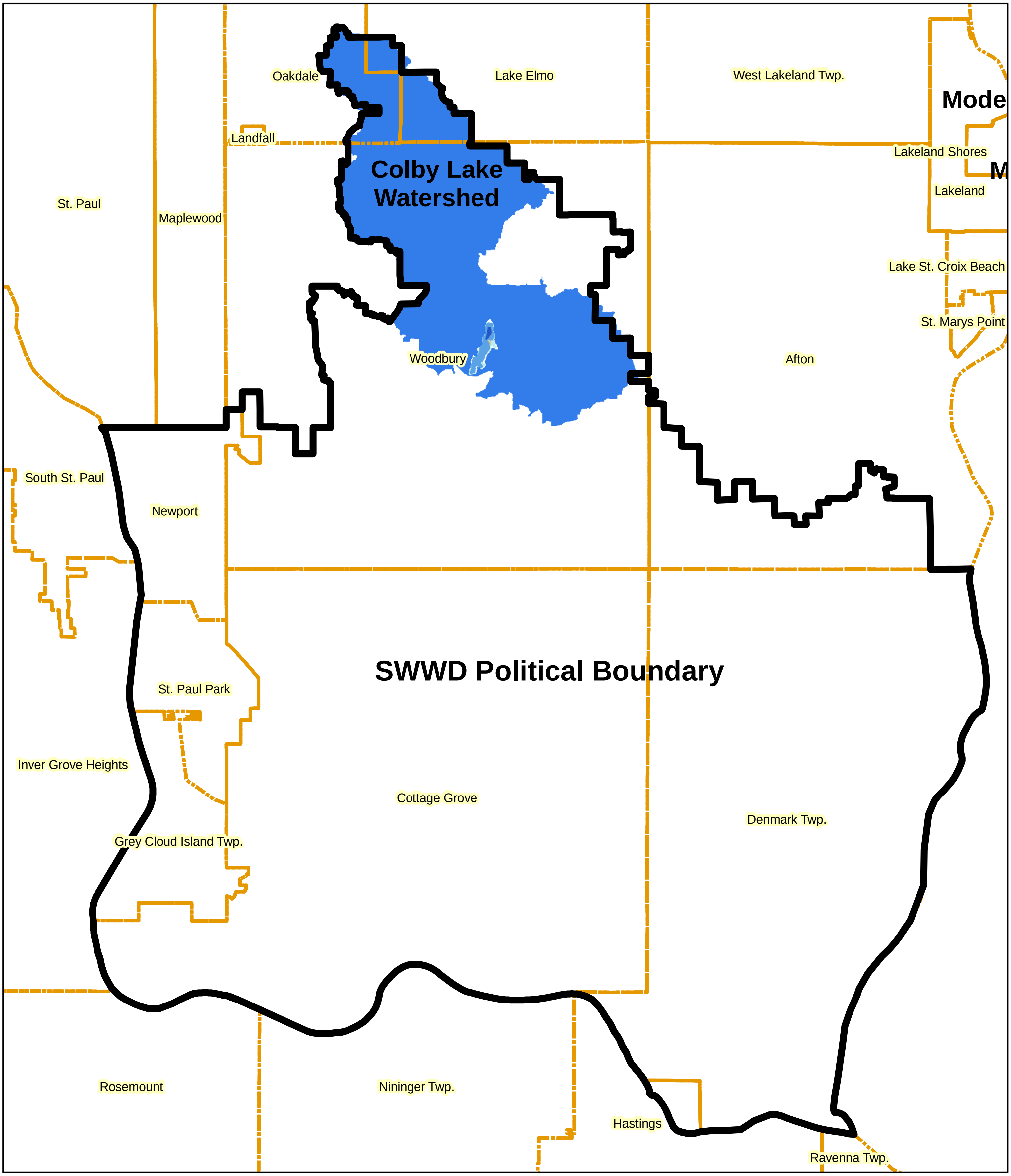

Figure 1: Colby Lake Watershed

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provide consistency with regard to the watershed characteristics, routing, and devices (e.g., ponds) with the existing SWMM model. The following paragraphs discuss the input data used from the SWMM model, as well as the selection of other input parameters specific to the P8 model during the model calibration process. Any input parameters not specifically discussed within this report remain the same as the P8 model default values.

2.1 Precipitation and Temperature

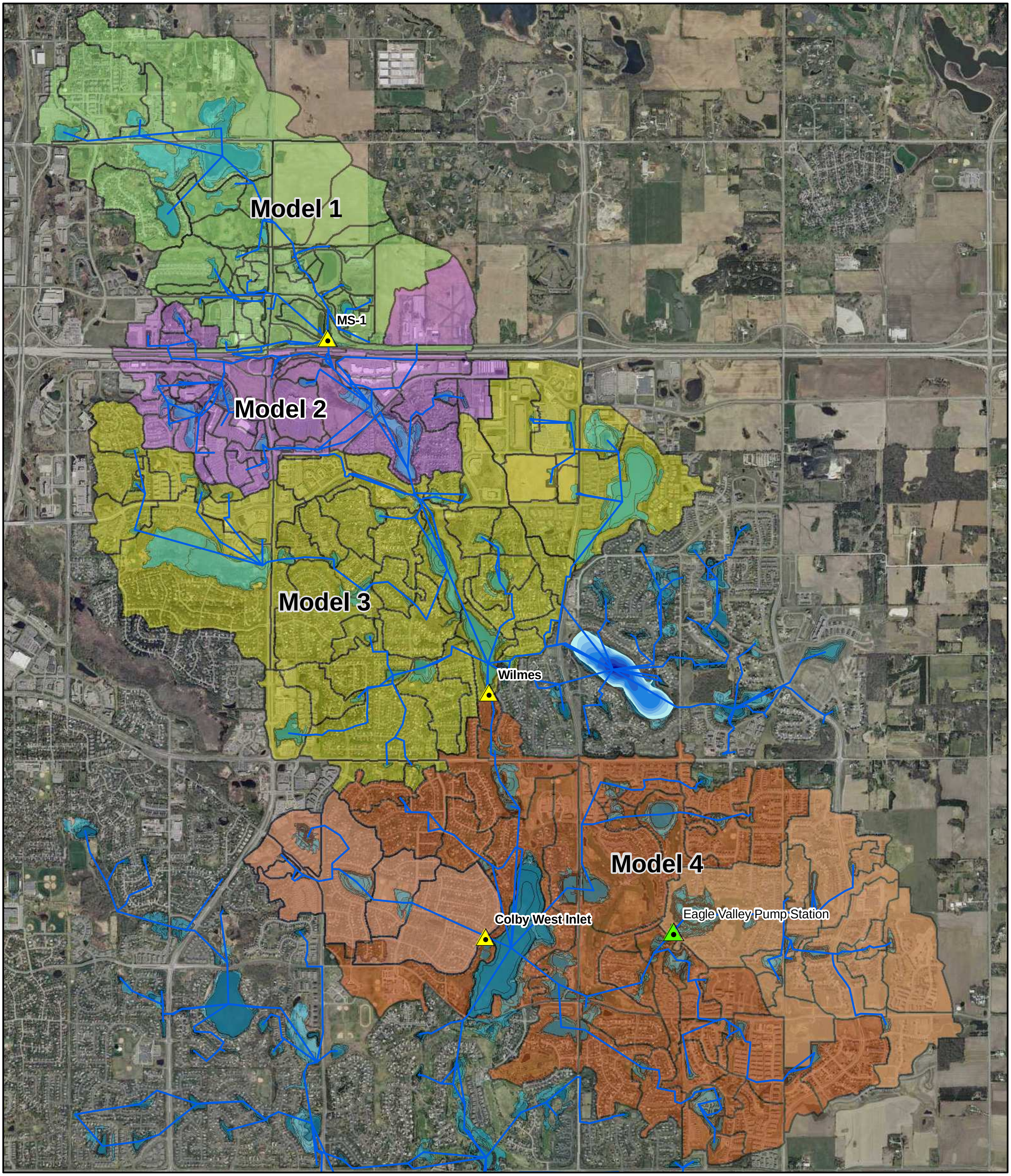
The P8 model requires hourly precipitation and daily temperature data to be input for hydrologic simulation. For the Colby Lake watershed model, these data were obtained at the Minneapolis-St. Paul airport, as it was the closest station (approximately 20 miles away) with sufficient data to perform long-term model simulations. For this work, data from 1949 to 2010 were used.

2.2 Watershed Characteristics

The Colby Lake watershed boundaries were adopted from the aforementioned SWMM model. Due to limitations on the number of nodes in the P8 modeling framework, it was necessary to divide the SWMM model up into four separate P8 models, i.e. Model 1, Model 2, Model 3, and Model 4 (see **Figure 2**). Model 1 encompasses the subwatersheds which drain through the MS1 monitoring station north of I-94. Model 2 generally consists of the subwatersheds draining to the northern segment of Wilmes Lake. Model 3 encompasses the subwatersheds draining to the southern segment of Wilmes Lake. Model 4 consists of the remaining subwatersheds downstream of Wilmes Lake, many of which drain directly to Colby Lake. There are a total of 199 subwatersheds modeled within these four separately developed P8 watershed models. The total surface water runoff volume and pollutant loading to Colby Lake was computed by adding the simulated results at the outlets of Models 1, 2, 3, and 4.

The imperviousness fractions for each subwatershed were adopted from the SWWD SWMM model. These fractions were determined reasonable by comparing them to impervious surface datasets obtained from the University of Minnesota's Remote Sensing and Geospatial Analysis Laboratory.[4]

[4] http://land.umn.edu/



Legend

- SWWD_Monitoring_Sites
- Eagle Valley Pump Station

Figure 2: P8 Models for Colby Lake Watershed

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The SWMM model was developed using Horton's Infiltration Method for pervious surfaces with depression storage. In contrast, P8 model calculations use Curve Number Method to generate pervious surface runoff without depression storage. A conversion between methods is, therefore, necessary. However, the calibration process (described in Section 3) revealed that the majority of the runoff from land surfaces in the Colby Lake watershed is from impervious area, and therefore the P8 pervious Curve Number (in this case) is not a critical model parameter. As such, a pervious Curve Number of 61, a commonly used value in P8 modeling, was selected. This value represents grassed areas in good condition on soils of the Hydrologic Soil Group B which according the SWWD Watershed Management Plan,[5] is found throughout the majority of the Colby Lake watershed.

The impervious area runoff coefficient, impervious depression storage, and portion of the total impervious area assumed to be directly-connected (e.g. to a curb, storm sewer, or other stormwater conveyance facility) were used as calibration parameters while simulating runoff volumes. All impervious surfaces were assumed to be un-swept. The drainage areas include open water, such as lakes, which were explicitly modeled in order to account for precipitation falling directly on the open water.

2.3 Treatment Devices

The P8 model network (which is used to route water from upstream to downstream), the locations and characteristics of treatment devices and BMPs, as well as outlet locations and characteristics were also adopted from the SWMM model. However, due to P8 model requirements, some assumptions were necessary to estimate the available storage in the BMPs, ponds, wetlands, and other nodes where pollutant removal would occur. Because the hydraulic component of the SWMM model only needs the flood pool defined (i.e., in the form of an elevation – area curve) and does not need a permanent storage volume (volume below the outlet) methods to estimate the permanent pool for the P8 model were necessary. Each individual storage node in the SWMM model was examined to determine whether or not a permanent pool was included in its elevation-area curve (or storage curve) and, if so, whether all or just a portion

[5] South Washington Watershed District Watershed Management Plan, Chapter 8, prepared by Houston Engineering, Inc. June 2007.

of that pool was defined. This determination was made using the elevation-area curve, the invert elevation of the outlet structure, and a shape file (provided by the SWWD) of the stage-area curves used in the model, which was examined against aerial photographs. If it appeared as though no permanent pool (or only a portion of the permanent pool) was included in a particular storage node in the SWMM model, 3-feet of permanent pool was assumed to exist below the elevation indicated by the aerial photos to be the top of the water surface. Where bathymetry was available for the larger lakes, it was used to determine the permanent pool for the P8 model.

The flood pool elevation for the storage nodes in the P8 models were estimated by running a 10-year, 24-hour duration precipitation event in the SWMM model. The" SWMM to P8" conversion program then determines the flood pool volume using the elevation resulting from the 10-year, 24-hour duration event from the stage-area curve. The flood storage volume is the difference in volume between the flood pool and the top of the permanent pool elevations. Wetlands controlled by an outlet structure were modeled as ponds in the P8 model and assigned a particle removal scale factor of 3, as recommended in the P8 documentation to account for the effects of vegetation on particle removal rates. The P8 model lacks a term for the evaporative losses from the lake surfaces. Evaporative losses are accounted for in the model by adding infiltration at a rate of 0.003 inches per hour, approximately equal to the long-term average expected evaporation, to the P8 storage nodes encompassing 1 acre or more of surface area.

2.4 Water Quality Particle Parameters

The NURP50.PAR (i.e., NURP 50 particle file), the P8 model default, was selected for model development. The NURP50.PAR represents typical concentrations and the distribution of particle settling velocities for a number of stormwater pollutants. The component concentrations in the file were calibrated by the original model developers to the 50th percentile (median) values compiled in the EPA's Nationwide Urban Runoff Program (NURP). [6]

2.5 Water Quality Components

P8 provides particle compositions (mg/kg) for various particle classes. During calibration, the scale factor for TSS and TP were adjusted as the mechanism for calibrating to the measured June through September TP and TSS loads.

[6] "P8 Urban Catchment Model Program Documentation ," William W. Walker, October 1990.

3 Model Calibration and Validation

Model calibration, the process of evaluating the behavior of the model and adjusting input parameters to reduce the error between simulated and observed data, is an important component of the model development process. In this work, three years (2008-2010) of observed watershed hydrology and water quality data were available for use in the calibration/validation effort. The Colby Lake watershed P8 model was calibrated to summer season (June 1 – September 30) runoff volumes, TP loads, and TSS loads during the years of 2008 and 2009. The June 1 through September 30 calibration period was selected to coincide with the applicable lake water quality standard for TP, which addresses the June through September average TP concentration.

Parameters determined through the calibration process remained unchanged and were used to validate the model by simulating the same June through September period in 2010. As a final assessment of the quality of the model results, the calibrated/validated P8 model was run for a 50-year period, and annual unit volumes and pollutant yields were evaluated for reasonability by comparison to other values computed from long-term empirical data.

3.1 Seasonal Calibration (June 1 to September 30)

The SWWD operates three monitoring stations in the Colby Lake watershed that had sufficient data for use in the P8 model calibration/validation effort (see **Figure 2**). The MS1 monitoring station is located on the north side of I-94 within the City of Lake Elmo. The Wilmes monitoring station is located at the outlet of Wilmes Lake. The Colby West Inlet monitoring station measures the discharge from approximately 384 acres west of Colby Lake. Also used in the calibration process were pumping records from the Eagle Valley Pump Station (also known as Colby 12 East Pump Station), which receives runoff from approximately 679 acres east of Colby Lake.

The surface water runoff volume, TP load, and TSS load to MS1 is simulated in Model 1. The volume and loading to the Wilmes Lake Outlet monitoring station is determined by adding together the model results at the MS1 location in Models 1, the most downstream node within the limits of Model 2, and the model results at the node corresponding to the Wilmes Lake outlet in Model 3. Note that the discharge from Models 1 and 2 were not routed through Wilmes Lake because the treatment capacity in the lake, without receiving the inflow from the watersheds simulated in Model 3, would be unrealistically large. Only the runoff from Model 3 drains to and is treated in Wilmes Lake.

The P8 model results were compared to observed runoff volume (in acre-feet), as well as TP and TSS loads (in total pounds) during the June 1 to September 30 calibration period in 2008 and 2009. Model parameters were optimized to reduce the error between simulated and observed values at the four calibration/validation points (**Table 1)**. The selected calibration parameters for the P8 model were impervious runoff coefficient, percent of impervious surface directly and indirectly connected, impervious depression storage, infiltration rate from lakes to simulate evaporation loss, and the TP and TSS loading scale factors.

Initial P8 model runs indicated an over prediction of runoff volume as compared to observed volume. The first parameter adjusted was the impervious runoff coefficient. In P8, runoff from impervious areas equals precipitation in excess of depression storage. The runoff coefficient was reduced from 1.0 to 0.9, which allows 10% of the excess rainfall to infiltrate. Also, because much of the impervious area within the Colby Lake watershed is residential, as opposed to commercial, disconnecting 50% of the impervious surface was considered a reasonable assumption and further improved the calibration results. Indirectly connected impervious areas are assumed to drain onto pervious areas, as opposed to a curb, storm sewer, or other stormwater conveyance facility. The Curve Number used in the simulation is an area-weighted average of the specified Curve Number for pervious areas and a Curve Number of 98 for the indirectly connected impervious areas. For one region of Model 4, the Colby West watershed (area west of Colby Lake draining to the Colby West Inlet on **Figure 2**), 75% of the impervious area was disconnected during the calibration process to reduce modeled runoff volume. Rational for this adjustment is based on findings of a previous study that showed this region has generally higher infiltration rates than most of the Colby Lake watershed.[7] Examining the model results on a daily basis indicated that the model was still over predicting runoff volume for very small storm events. To alleviate this issue, the impervious area depression storage was increased from the P8 default of 0.02 inches to 0.1 inch.

[7] "Integrating Groundwater & Surface Water Management, Southern Washington County," prepared for Washington County and the Washington Conservation District by Barr Engineering Company, August 2005

Table 1: Volume, TSS, and TP Yields Predicted by the P8 Model for Calibration and Validation (June 1 through September 30)

STATION		YEAR	OBSERVED			P8 MODELED			DIFFERENCE MODELED VS. MEASURED			% DIFFERENCE MODELED VS. MEASURED		
			Volume (ac-ft)	TSS (lbs)	TP (lbs)	Volume (ac-ft)	TSS (lbs)	TP (lbs)	Volume (ac-ft)	TSS (lbs)	TP (lbs)	Volume (%)	TSS (%)	TP (%)
MS1		2008	73	7,816	35	65	6,700	29	-8	-1,116	-5			
Monitoring Station		2009	57	5,698	24	104	8,013	42	46	2,315	17			
	Calibration		130	13,514	59	169	14,713	71	38	1,200	12	29%	9%	20%
	Validation	2010	359	38,311	154	255	16,993	98	-104	-21,318	-56	-29%	-56%	-36%
Wilmes Outlet		2008	282	8,678	67	306	7,977	91	23	-701	24			
Monitoring Station		2009	255	4,296	64	470	10,357	137	215	6,062	73			
	Calibration		537	12,974	131	776	18,335	228	239	5,361	97	44%	41%	74%
	Validation	2010	2,005	50,741	512	1,072	24,590	318	-933	-26,151	-194	-47%	-52%	-38%
Colby Lake West		2008	37	4,012	19	21	5,046	14	-16	1,034	-4			
Monitoring Station		2009	35	10,811	17	37	6,648	21	1	-4,163	4			
	Calibration		72	14,822	36	58	11,693	36	-14	-3,129	0	-20%	-21%	-1%
	Validation	2010	66	19,125	32	87	16,148	51	21	-2,977	19	32%	-16%	59%
Eagle Valley		2008	21	2,286	11	58	621	16	37	-1,665	5			
(Colby East 12)		2009	95	28,866	46	83	838	22	-12	-28,028	-23			
Pump Station	Calibration		116	31,153	57	141	1,459	38	26	-29,693	-18	22%	n/a*	n/a
	Validation	2010	129	37,585	63	171	2,178	48	42	-35,407	-15	33%	n/a	n/a

* The quality of the measured TSS and TP data are unknown at the pump station, and therefore an assessment of the calibration at this location was not made.

As explained in Section 2.3 (Treatment Devices), the P8 model lacks a term for the evaporative losses from the lake surfaces. To account for the evaporative losses from lakes in the Colby Lake watershed, an infiltration rate of 0.003 inches per hour, approximately equal tothe long-term average expected evaporation, was added to all P8 storage nodes with more than one-acre of surface area. This increase in infiltration rate could potentially require lowering the particle removal factor in the storage nodes to account for increased mass loss; but, in this case, adjusting the factor was found to be unnecessary. Once the volume calibration was completed, adjustments to the TSS and TP scale factor from 1 to 1.2 and 0.9, respectively, resulted in the loads which best matched the observed loads at the monitoring sites. The final hydrologic parameters determined through the calibration process are presented in **Table 2**.

Table 2: Model Parameters Selected during P8 Model Calibration

Watershed Hydrologic Parameter	Selected Value
Impervious Area Runoff Coefficient	0.9
Impervious Area Depression Storage	0.1 inch
Percent of Impervious Area disconnected*	50%
Infiltration rate from lakes to simulate evaporation loss	0.003 inches/hour
TSS loading scale factor	1.2
TP loading scale factor	0.9

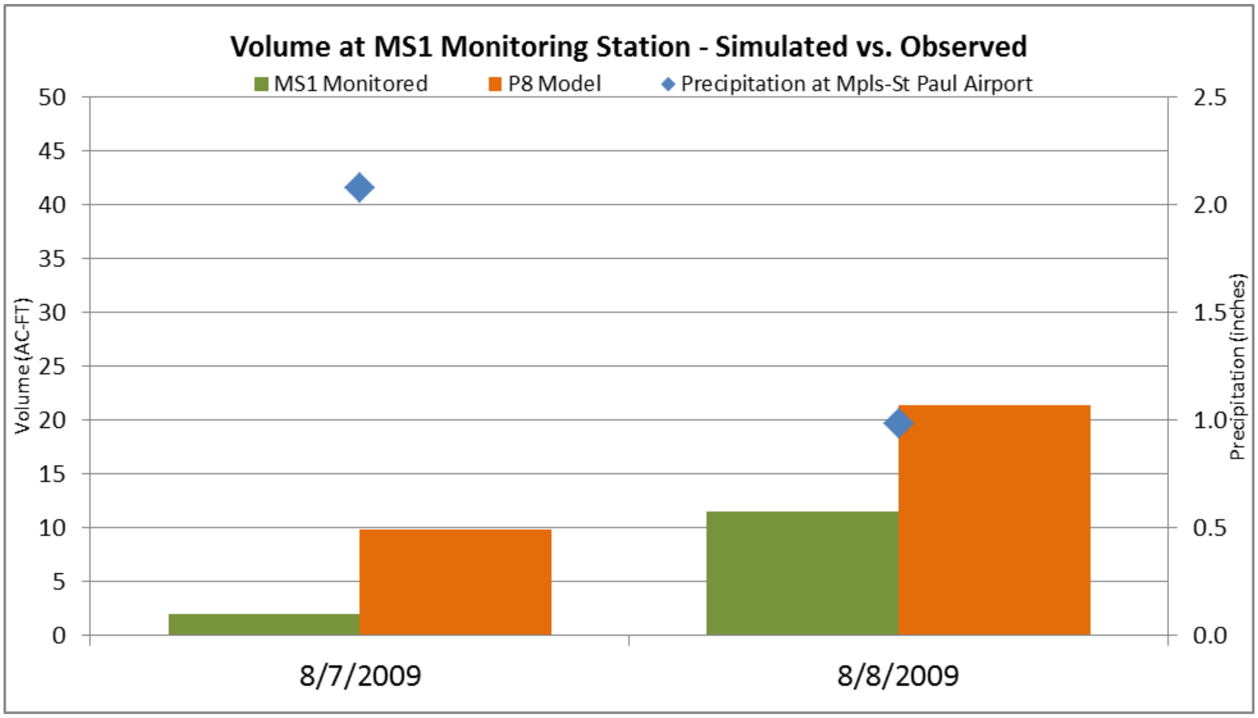
* For one region of Model 4, the Colby West watershed (area west of Colby Lake draining to the Colby West Inlet on Figure 2), 75% of the impervious area was disconnected during the calibration process.

A final judgment of model calibration was performed by combining runoff volumes and pollutant loads at the four calibration locations for the years of 2008/2009 and comparing the simulations to observed data. **Table 1** shows the results of this analysis. Errors in volume, in terms of the percent difference of predicted volume versus observed volume, range from -20% to +44%. In general, the model over predicts the 2008/2009 volume to Colby Lake from the northern watersheds, which are assessed at the MS1 and Wilmes Outlet monitoring stations. The 208/2009 outflow volume from the Eagle Valley Pump Station, located east of Colby Lake, is also over predicted, whereas the volume at the Colby Lake West monitoring station, to the west of the lake, is under predicted during this time. Likewise, the model over predicts TSS and TP loading in the same northern subwatersheds and under predicts them in the subwatersheds associated with the Colby Lake West monitoring station. As shown in **Table 1**, these errors range from -21% to +41% for TSS loading and from -1% to +74% for TP loads.

Model validation was performed for the summer months of 2010. Again, results are presented in **Table 1.** For the most part, the Colby Lake watershed model validation errors tend to be negative under the scenarios where calibration errors were positive and vice versa. For example, whereas the model over predicts the runoff volumes at the MS1 and Wilmes Outlet monitoring stations during 2008/2009, it under predicts the volumes during 2010. Given the limited data available for model calibration/validation and the precipitation patterns during these years (2008 and 2009 had an average 11 inches of rainfall during those summers, while 2010 had nearly 20 inches), this over- and under prediction pattern is to be expected.

One critical assumption that must be taken into account when considering calibration results of the Colby Lake watershed P8 model, is the precipitation dataset that was used. As stated, P8 requires an hourly precipitation record as input. In this case, the closest available long-term hourly precipitation records available were observed at the Minneapolis-St. Paul airport, over twenty miles away from the Colby Lake watershed. Given this distance, while compared data between the two sites showed that precipitation events during the modeling period were often very similar, there was also times when events varied significantly between the two locations. In hydrologic modeling, the quality of model calibration over a relatively short time period can sometimes be driven by even a single event, particularly when the precipitation used in the model differs significantly from that which actually occurred in the study area. For example, **Figure 3** shows runoff volume at the MS1 Monitoring Station, both observed and predicted by the P8 model over a period of two days. The recorded precipitation at the Minneapolis-St. Paul Airport over those two days totals 3.06 inches. However, National Weather Service NEXRAD data at the point nearest MS1 lists a total of 2.02 inches of precipitation across the same two days. As expected, the model overpredicts runoff on these two days due to the discrepancy in the precipitation data. Although short-term model performance is important, the purpose of this modeling exercise is to assess long-term trends in the Colby Lake watershed. When compared over a longer period of time (i.e., monthly and seasonally), the differences in the precipitation at the two locations reduce. As a result, the value of the Colby Lake watershed model calibration is increased, as shown in **Table 1** and discussed below.

Figure 3: Model Overprediction with Discrepancy in Precipitation Data



3.2 50-Year Assessment of the P8 Model

In order to understand the long-term variability in simulated hydrology and pollutant loading in the Colby Lake watershed, a 50-year model simulation was carried out. P8 model results were compiled from 1961 through 2010. The years 1949-1960 were modeled as a warm up period, which allowed the model compartments (soil moisture, particulate content, etc.) to "wash" the potential influence of initial conditions from the model results. The simulated weighted average annual unit runoff depth leaving the landscape, as well as pollutant yields and concentrations, as predicted by the P8 model, are shown in **Table 3.** The resulting values at the monitoring locations are presented in **Table 4**. For comparison to the results in **Table 4**, **Table 5** lists flow weighted mean concentrations (FWMCs) of TSS and TP which were determined from a Monte Carlo analysis of field data for the SWWD Watershed Management Plan.[8] Recognizing that variability is inherent in runoff water quality, a range of FWMCs was estimated through Monte Carlo and divided by the stochastically estimated flow.

Table 3: Annual Average Watershed Unit Runoff and Yields (leaving the landscape) Predicted by the P8 Model over a 50-year Period of Record (1961 – 2010)

Runoff Coeff.	Unit Runoff	TSS Yield	TSS Conc.	TP Yield	TP Conc.
(volume/precip.)	(in./yr.)	(lbs./ac./yr.)	(ppm)	(lbs./ac./yr.)	(ppm)
0.19	5.4	172	141	0.41	0.30

Table 4: Annual Average Unit Volume, Loads, and Yields Predicted at the Monitoring Locations by the P8 Model over a 50-year Period of Record (1961 – 2010)

Monitoring Location	Drainage Area (acres)	P8 Results at Subwatershed Outlet						
		Volume	TSS			TP		
		Unit Vol. (in./yr)	TSS Conc. (ppm)	TSS Load (lbs/yr)	TSS Yield (lbs/ac/yr)	TP Conc. (ppm)	TP Load (lbs/yr)	TP Yield (lbs/ac/yr)
MS1	1,200	3.7	46	46,161	38	0.20	192	0.16
Wilmes Outlet	3,997	4.5	24	92,730	23	0.13	596	0.15
Colby West	384	4.2	78	28,368	74	0.20	88	0.23
Eagle Valley Pump	2,396	4.7	8	5,832	9	0.10	81	0.12

Table 5: Flow Weighted Mean Concentrations at Monitoring Station MS1

	Flow Weighted Mean Concentration (ppm)		Mean Annual Load (lbs.)	
	TSS	TP	TSS	TP
Median	77	0.318	18,029	75
Mean	869	0.611	731,590	514
25th Percentile	32	0.245	2,533	19
75th Percentile	179	0.407	123,670	280

The results presented in **Table 3** and **Table 4** can be used to assess the reasonableness of the long-term model performance. The watershed unit runoff of 5.4 inches/year, shown **Table 3**, matches very closely with that presented for this region in the Minnesota Hydrology Guide of

[8] South Washington Watershed District Watershed Management Plan, June 2007, prepared by Houston Engineering, Inc.

about 5.5 inches/year.[9] The weighted average of the annual unit volumes simulated at each monitoring location shown in **Table 4** for the entire 10.6 square mile drainage area is 4.4 inches/year. As a comparison, the USGS Gage 05287890 (Elm Creek Near Champlin, MN), a larger watershed of 86 square miles, but of somewhat similar land use, has an annual unit volume of 6.0 inches/year.

The TSS and TP concentrations and loads in **Table 4** for MS1 are within the 25th and 75th percentiles shown in **Table 5** and, therefore, considered realistic. **Table 4** shows the TSS and TP concentrations leaving the Eagle Valley (Colby East 12) pump station to be significantly lower than the other locations. This could be explained by the large pollutant removal taking place in the large wetland complex where the pump station is located. Overall, the model data comparisons demonstrate that the P8 model reasonably simulates the average annual yields and loads in the long-term 50-year model, taking into consideration that hourly precipitation records applied in the modeling were approximately 20 miles from Colby Lake watershed.

4 Treatment Device Removal Efficiencies

The average annual TSS and TP removal efficiencies for each storage node in the P8 model, based on the results from the 50-year simulation, are presented in **Tables 5 – 9** in **Appendix A.** These values are provided as a planning tool only and could be used to prioritize whether additional investigation of pond performance is warranted for those ponds with low (~ < 40%) removal efficiencies.

[9] Hydrology Guide for Minnesota, U.S. Department of Agriculture, Figure 7-1, "Aveage Annual Runoff in Inches (1961 – 1990). Data gathered by U.S.G.S and prepared by MnDNR.

Appendix A

Removal Efficiencies as Predicted by the Colby Lake P8 Model

Notes:

Device names ending in –P are modeled as ponds
Devices names ending in –W are wetlands (modeled with increased particle removal scale factor)
Devices names ending in –PI are modeled as junction nodes with no storage

Table 5: Model 1- Predicted Removal Efficiencies

Storage Node	TSS Removal (%)	TP Removal (%)
1301-P	21	5
BLAshwd_P1-P	79	52
BLBAr1_P2-P	89	71
BLBAr1_P8-P	88	71
BLBAr1345e-P	86	58
BLBAr1345s-P	81	56
BLBAr2_P12-P	66	34
BLFwyMdwP1-P	69	40
BL_CDP42-P	65	36
BLFwyMdwP4-P	76	46
BLFwyMdwW5-P	18	6
BLHgKnolP2-P	77	49
BL_CDP49-W	73	41
BLKingFdP2-P	62	32
BLSMil1_P6-P	72	44
BLSMil1P20-P	77	51
BLSMil1_P3-P	33	13
BLSMil1_P4-P	44	19
BLSMil2P10-P	74	45
BLSMil2_P2-P	81	55
BLSMil3_P8-P	70	41
BLSMil1_P5-P	69	39
BLSMil1_P7-P	38	16
BLSMil3_P9-P	81	56
BLSMil9A-P	69	39
BLBAr2_P11-P	70	39
BLBAr2_P13-P	21	8
BLBAr3_P10-P	37	12
BLKingFdP1-P	38	15

Storage Node	TSS Removal (%)	TP Removal (%)
CL1E10_1-P	24	7
CL1E5_1-W	72	37
BLBAr1_P6-P	12	2
BLBAr1_P7-P	18	4
CL1E4_1-P	58	26
CL1E3_1A-P	58	28
CL1E3_1-P	69	38
CL1E6_2-P	69	37
CL1E9_1-W	85	43
CL1E8_1-P	20	4
CL1E7_1-P	9	1
CL1E6_1-P	22	6
CL1E2_1-P	40	14
CL1N3_1-P	55	22
CL1N6_1-W	83	56
CL1N5_1-W	51	16
CL1N2_1-P	50	20
CL1N1_1-P	61	33
CL2_1-P	62	32
CL3_1-P	51	19
CLHghHt1P1-P	65	37
CLCL1Ad12-PI	0	0
CLBLdCDP38-W	48	16
CLQryRdgPA-P	72	41
CLWdCrsP3-P	72	43
CLWdCrsP2-P	68	36
CLWdCrsP1-P	53	24
CL1W2_1-W	84	54
CL1W1_1-P	43	12

Table 6: Model 2- Predicted Removal Efficiencies

Storage Node	TSS Removal (%)	TP Removal (%)
EP2_3-PI	0	0
I94_6-P	48	19
Id_hud_1-P	87	58
I94_4-PI	0	0
I94_5-PI	0	0
OM1_1-P	89	73
GA1_2-P	81	56
I94_1-PI	0	0
RadI94Dtch-P	37	10
RadI94P1_1-P	61	30
RadioI94P1-P	88	56
WL_PdV1-P	85	57
WL_PdV2-P	81	49
WL_RT_P1-P	82	53
WL_WL_21-PI	0	0
WL_WL117-PI	0	0
WL_WL_2-PI	0	0
WL3W3_4-PI	0	0
WL3W3_3-PI	0	0
WL3W3_2-P	83	56
WL3W3_1-P	64	32
WL3W2_3-P	50	17
WL3W2_2-W	39	12
WL3W2_1-P	44	11

Storage Node	TSS Removal (%)	TP Removal (%)
WL4N2_1-P	72	41
446-PI	0	0
WL5_5-PI	0	0
WL5S1_1-P	81	55
WL5W3_5-PI	0	0
WL5W3_4-PI	0	0
WL5W4_3-PI	0	0
WL5W4_2-PI	0	0
WL5W4_1-P	83	53
WL5W3_2-PI	0	0
WL5W5_1-W	92	64
GlbColPd-P	86	54
WL5W5_2-W	80	44
WL5W3_1-P	72	36
WL5W2_1-P	2	0
WL5W1_3-PI	0	0
WL5W1_2-P	8	1
WL5W1_1-P	7	1
RadioI94P2-P	24	9
WL5_10-P	3	1
RadioI94P3-P	23	9
WL5_1-P*	70	35
WL4_1-P*	58	23

* Accuracy questionable. Located along mainstem of Wilmes Lake. Model 2 does not receive drainage from Model 1 to the north.

Table 7: Model 3- Predicted Removal Efficiencies

Storage Node	TSS Removal (%)	TP Removal (%)	Storage Node	TSS Removal (%)	TP Removal (%)
2857-PI	0	0	WL2N2_1-P	82	56
2949-PI	0	0	WL2N1_1-P	60	28
ML_STP1-P	89	63	WL2W11_1-P	73	45
ML_ST_1-PI	0	0	WL2W10_1-P	55	28
ML1W1_1-P	56	27	WL2W13_1-P	78	49
ML1W2_1-P	70	44	WL2W14_1-P	84	55
ML2_1-W	95	81	WL2W15_1-P	65	36
WL_SamPd-P	81	52	WL2W9_1-PI	0	0
ML1_1-P	92	68	WL2W8_1-P	47	21
WL1E3_1-PI	0	0	WL2W7_1-P	73	42
WL1E2_1-PI	0	0	WL2W6_1-P	40	17
WL1E1_1-P	46	14	WL2W5_1A-PI	0	0
WL1N3_2-P	71	43	WL2W4_1-P	30	10
WL1N3_1-W	72	40	WL2W3_1-P	44	17
WL1N2_1-P	78	51	WL2W2_1-P	2	0
1072-PI	0	0	WL2W1_1-PI	0	0
WL1W3_2-P	69	38	WL3_1-P*	38	9
WL1W3_3P-P	81	53	WL3W1_1-P	18	3
WL1W3_4P-P	59	29	WL2_2-P*	36	15
WL1W3_5P-P	39	14	WL6W2_1-W	82	57
WL1W4_1-P	93	72	WL6W1_1-P	64	35
WL1W3_1-P	58	31	WL2_1-P*	65	35
WL1W2_1-P	54	28	WL1_1-P*	44	17
WL1W1_1-PI	0	0			

* Accuracy questionable. Located along mainstem of Wilmes Lake. Model 2 does not receive drainage from Models 1 or 2 to the north.

Table 8: Model 4- Predicted Removal Efficiencies

Storage Node	TSS Removal (%)	TP Removal (%)	Storage Node	TSS Removal (%)	TP Removal (%)
1301-P*	21	5	CL1E10_1-P	24	7
BLAshwd_P1-P	79	52	CL1E5_1-W	72	37
BLBAr1_P2-P	89	71	BLBAr1_P6-P	12	2
BLBAr1_P8-P	88	71	BLBAr1_P7-P	18	4
BLBAr1345e-P	86	58	CL1E4_1-P	58	26
BLBAr1345s-P	81	56	CL1E3_1A-P	58	28
BLBAr2_P12-P	66	34	CL1E3_1-P	69	38
BLFwyMdwP1-P	69	40	CL1E6_2-P	69	37
BL_CDP42-P	65	36	CL1E9_1-W	85	43
BLFwyMdwP4-P	76	46	CL1E8_1-P	20	4
BLFwyMdwW5-P	18	6	CL1E7_1-P	9	1
BLHgKnolP2-P	77	49	CL1E6_1-P	22	6
BL_CDP49-W	73	41	CL1E2_1-P	40	14
BLKingFdP2-P	62	32	CL1N3_1-P	55	22
BLSMil1_P6-P	72	44	CL1N6_1-W	83	56
BLSMil1P20-P	77	51	CL1N5_1-W	51	16
BLSMil1_P3-P	33	13	CL1N2_1-P	50	20
BLSMil1_P4-P	44	19	CL1N1_1-P	61	33
BLSMil2P10-P	74	45	CL2_1-P	62	32
BLSMil2_P2-P	81	55	CL3_1-P	51	19
BLSMil3_P8-P	70	41	CLHghHt1P1-P	65	37
BLSMil1_P5-P	69	39	CLCL1Ad12-PI	0	0
BLSMil1_P7-P	38	16	CLBLdCDP38-W	48	16
BLSMil3_P9-P	81	56	CLQryRdgPA-P	72	41
BLSMil9A-P	69	39	CLWdCrsP3-P	72	43
BLBAr2_P11-P	70	39	CLWdCrsP2-P	68	36
BLBAr2_P13-P	21	8	CLWdCrsP1-P	53	24
BLBAr3_P10-P	37	12	CL1W2_1-W	84	54
BLKingFdP1-P	38	15	CL1W1_1-P	43	12

* Accuracy questionable. Located along mainstem. Model 4 does not receive drainage from Models 1, 2, or 3 to the north.

Table 8: Southeast Watershed of Clearwater Creek- Predicted Removal Efficiencies

Storage Node	TSS Removal (%)	TP Removal (%)
SJ3BR1_002-P	89	61
SJ3BR1_005-P	91	63
SJ3BR1_007-P	88	61
SJ3BR1_008-P	77	47
SJ3BR1_006-P	93	61
SJ3BR1_003-P	70	32
SJ3BR2_002-P	73	43
SJ3BR2_005-P	62	30
SJ3BR2_006-P	61	32
SJ3BR2_009-P	53	26
SJ3BR2_010-P	93	65
SJ3BR2_011-P	87	50
SJ3BR2_013-P	76	48
SJ3BR2_014-P	95	68
SJ3BR2_017-P	89	60
J3BR2_008-PI	0	0
SJ3BR2_018-P	73	42
SJ3BR2_019-P	75	44
J3BR2_006-PI	0	0
J3BR2_003-PI	0	0
J3BR2_002-PI	0	0
SJ3MT_067-P	78	49
SJ3MT_068-PI	0	0
SJ3MT_069-P	41	17
SJ3MT_072-P	66	39
SJ3MT_073-N	78	49

Storage Node	TSS Removal (%)	TP Removal (%)
SJ3MT_076-P	58	31
SJ3MT_077-P	75	48
SJ3MT_075-P	75	44
SJ3MT_074-P	24	7
SJ3MT_078-P	82	55
SJ3MT_079-P	72	45
SJ3MT_081-P	51	23
SJ3MT_082-P	62	36
SJ3MT_083-P	80	52
SJ3MT_087-P	84	54
SJ3MT_088-P	49	16
SJ3MT_090-W	94	67
SJ3MT_089-W	51	17
SJ3MT_092-N	57	29
SJ3MT_095-P	70	42
SJ3MT_091-P	59	31
J3MT_071-PI	0	0
SJ3MT_085-P	28	9
J3MZL_007-PI	0	0
J3MT_048-PI	0	0
SJ3MT_096-P	85	58
J3MT_043-PI	0	0
J3MT_042-PI	0	0
J3MT_038-PI	0	0
J3MT_036-PI	0	0

Table 9: West Watershed of Clearwater Creek- Predicted Removal Efficiencies

Storage Node	TSS Removal (%)	TP Removal (%)
J3MT_023-PI	0	0
J3P1_015-PI	0	0
SA55MT_001-P	80	52
SA55MT_002-P	78	49
SA55MT_003-P	56	24
SA55MT_004-P	56	23
SA55MT_005-P	46	19
SA55MT_011-W	68	36
SA55MT_014-P	78	50
SA55MT_013-W	54	21
SA55MT_019-P	65	36
SA55MT_017-P	60	32
SA55MT_015-P	49	23
SA55MT_016-P	32	12
SA55MT_020-P	56	27
SA55MT_022-P	39	16
SA55MT_023-P	42	18
SA55MT_021-P	17	8
SA55MT_025-P	43	17
SA55MT_009-P	85	56
SA55MT_051-P	81	52
SA55MT_012-P	83	53
SA55MT_010-P	72	39
SA55MT_008-P	48	16

Storage Node	TSS Removal (%)	TP Removal (%)
SA55MT_007-P	23	5
SA55MT_006-P	15	4
SJ3MT_002-P	80	51
SJ3MT_007-P	96	68
SJ3MT_008-P	76	45
SJ3MT_009-P	62	30
SJ3MT_010-P	79	50
SJ3MT_011-P	48	18
SJ3MT_013-P	93	65
SJ3MT_015-P	61	32
SJ3P1_006-P	89	61
SJ3P1_008-P	81	53
SJ3P1_007-P	61	27
SJ3P1_009-P	83	54
SJ3P1_014-W	43	16
J3P1_012-PI	0	0
J3P1_009-PI	0	0
J3P1_006-PI	0	0
SJ3P1_005-P	49	22
J3P1_005-PI	0	0
J3P1_002-PI	0	0
SJ3P1_016-P	55	23
J3P1_001-PI	0	0
J3MT_012-PI	0	0
J3MT_005-PI	0	0

APPENDIX B

Crystal Ball Report - Assumptions

No Simulation Data

Assumptions

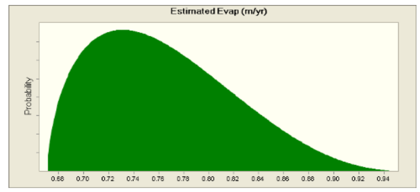
Worksheet: [CNET_Colby_lake_(slj)_loads_final.xls]MODEL

Assumption: Estimated Evap (m/summer) **Cell: F16**

Beta distribution with parameters:

Minimum	0.67
Maximum	0.96
Alpha	1.62192883
Beta	3.351923318

Selected range is from 0.00 to Infinity



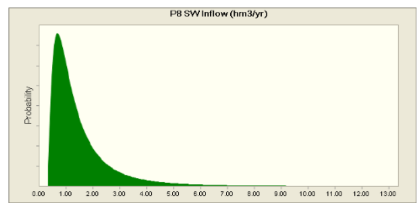
Correlated with:	Coefficient
Summer Precip (in/summer) (F15)	0.38 (='precip evap co

Assumption: P8 SW Inflow (hm3/summer) **Cell: F24**

Lognormal distribution with parameters:

Location	0.27
Mean	1.52
Std. Dev.	1.34

Selected range is from 0.00 to Infinity



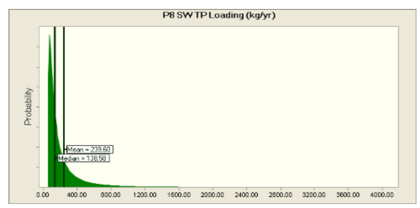
Correlated with:	Coefficient
Summer Precip (in/summer) (F15)	0.86 (='P8 Model Resu
P8 SW TP Loading (kg/summer) (F26)	0.80 (='P8 Model Resu

Assumption: P8 SW TP Loading (kg/summer) **Cell: F26**

Lognormal distribution with parameters:

Location	51.56
Mean	239.60
Std. Dev.	360.19

Selected range is from 0.00 to Infinity

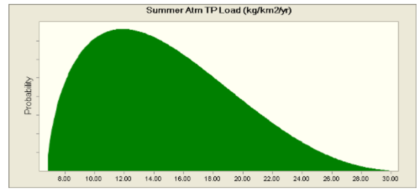


Correlated with:	Coefficient
Summer Precip (in/summer) (F15)	0.45 (='P8 Model Resu
P8 SW Inflow (hm3/summer) (F24)	0.80 (='P8 Model Resu

Assumption: Summer Atm TP Load (kg/km2/summer) **Cell: F20**

Beta distribution with parameters:

Minimum	6.83
Maximum	31.02
Alpha	1.62192883
Beta	3.351923318



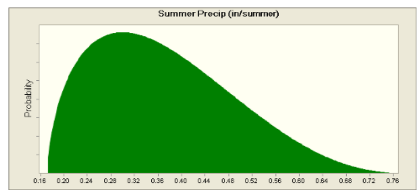
Selected range is from 0.00 to Infinity

Correlated with:	Coefficient
Summer Precip (in/summer) (F15)	1.00

Assumption: Summer Precip (in/summer) **Cell: F15**

Beta distribution with parameters:

Minimum	0.17
Maximum	0.78
Alpha	1.62192883
Beta	3.351923318



Selected range is from 0.00 to Infinity

Correlated with:	Coefficient	
Estimated Evap (m/summer) (F16)	0.38	(='precip evap co
Summer Atm TP Load (kg/km2/summer) (F20)	1.00	
P8 SW Inflow (hm3/summer) (F24)	0.86	(='P8 Model Resu
P8 SW TP Loading (kg/summer) (F26)	0.45	(='P8 Model Resu

End of Assumptions