4.0 Methods

4.1 Lake Water Quality Data Collection

In 2002, a representative water quality sampling station was selected for Keller Lake, the main Crystal Lake basin and each of the four bays of Crystal Lake (Figure 4-1). Bi-weekly water samples were collected from May through September. A total of 8 water quality parameters were measured at each sampling stations. Table 4-1a and 4-1b list the water quality parameters, and specifies when and at what depths samples or measurements were collected. Dissolved oxygen, temperature, specific conductance, and Secchi disc transparency were measured in the field; whereas, water samples were analyzed in the laboratory for total phosphorus, pH, chlorophyll *a*, and turbidity. The procedures for chemical analyses of the water samples are shown in Table 4-2. Generally, the methods can be found in Standard Methods for Water and Wastewater Analysis.

Table 4-1a Main Crystal Lake Basin Water Quality Parameters

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

Table 4-1b Keller Lake and Crystal Lake Bays Water Quality Parameters

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

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

Analysis	Procedure	Reference
Total Phosphorus	Persulfate digestion, manual ascorbic acid	Standard Methods, 18th Edition (1992) modified per Eisenreich, et al., Environmental Letters 9(1), 43-53 (1975)
Chlorophyll *a*	Spectrophotometric	Standard Methods, 18th Edition, 1992, 10200 H
pH	Potentiometric measurement, glass electrode	Standard Methods, 16th Edition, 1985, 423
Specific Conductance	Wheatstone bridge	Standard Methods, 16th Edition, 1985, 205
Temperature	Thermometric	Standard Methods, 16th Edition, 1985, 212
Dissolved Oxygen	Electrode	Standard Methods, 16th Edition, 1985, 421F
Secchi disc transparency	Secchi disc	

Figure 4-1 2002 Water Quality Sample Locations (2.0 MB)

4.2 Watershed Stormwater and Total Phosphorus Loadings

The computer model P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds, IEP, Inc., 1990) was used to estimate both the water and phosphorus loads introduced from the entire watershed of Crystal and Keller Lakes. P8 is a useful diagnostic tool for evaluating and designing watershed improvements and BMPs.

The model requires hourly precipitation and daily temperature data; long-term climatic data can be used so that watersheds and BMPs can be evaluated for varying hydrologic conditions. The P8 model requires a continuous hourly precipitation record for the period of interest (in this case May 1, 2001 through September 30, 2002). The closest National Weather Service (NWS) hourly data collection site was the Minneapolis-St. Paul International Airport, while the closest NWS daily precipitation data collection site was in the City of Farmington (Station 212737: Farmington 3NW), approximately 5 miles from Crystal Lake. Evaluation of the sum of the hourly snowfall water equivalent precipitation measured at the MSP Airport revealed that it does not match the daily totals for that station. As a result, the hourly snowfall water equivalent measurements at the Airport were suspect and do not accurately represent the actual hourly snowfall totals. Therefore, the hourly precipitation data was obtained from a gage operated by the Nine Mile Creek Watershed District located near T.H. 212 and I-494 (Eden Prairie gage) during the model calibration year (2001-2002). The 2001-2002 simulation period (May 1, 2001 through September 30, 2002) precipitation total was 40.97 inches at the Eden Prairie gage and 40.74 inches at the City of Farmington. Since the precipitation totals were similar no adjustments were required to compensate for the difference in precipitation between the Eden Prairie and NWS Farmington gages. Daily temperature data was obtained from the NWS site at the Minneapolis–St. Paul International Airport.

When evaluating the results of the modeling, it is important to consider that the results provided are more accurate in terms of relative differences than in absolute results. The model will predict the percent difference in phosphorus reduction between various BMP options in the watershed fairly accurately. It also provides a realistic estimate of the relative differences in phosphorus and water loadings from the various subwatersheds and major inflow points to the lake. However, since runoff quality is highly variable with time and location, the phosphorus loadings estimated by the model for a specific watershed may not necessarily reflect the actual loadings, in absolute terms. Various site-specific factors, such as lawn care practices, illicit point discharges and erosion due to construction are not accounted for in the model. The model provides values that are considered to be typical of the region, given the watershed's respective land uses.

4.2.1 Water Quality Model (P8) Calibration

4.2.1.1 Stormwater Volume Calibration

The runoff volume in the model was calibrated to the observed water surface elevation of Crystal Lake during the period May 1999 through September 2000. To translate the water loadings into water surface elevations, the MDNR WATBUD computer model was utilized. The model uses estimated daily inflows (i.e., predicted by the P8 model), daily precipitation, daily evaporation, an outlet rating curve, and observed lake levels to estimate total annual outflow. The following stage-storage-discharge relationship was developed based on basin bathymetry data (see Table 4-3) and outlet characteristics:

Table 4-3 Stage-Storage-Discharge for Crystal Lake

Elevation	Water Surface Area (acres)	Cumulative Storage Volume (acre-feet)	Discharge (cfs)
895.4	0	0	0
898.4	0.91	1.37	0
903.4	8.88	25.84	0
908.4	32.79	130.02	0
913.4	46.68	328.69	0
918.4	67.19	613.37	0
923.4	106.65	1047.97	0
924.4	114.28	1158.43	0
925.4	127.32	1279.23	0
926.4	144.04	1414.91	0
928.4	182.97	1741.92	0
933.4	292.53	2930.67	0
933.6	293.10	2989.23	2.9
933.8	293.68	3047.91	8.2
934.0	294.25	3106.71	15.1
934.2	294.83	3165.61	23.2
934.4	295.40	3224.64	32.0
934.6	295.98	3283.77	35.0
934.8	296.55	3343.03	38.0
935.0	297.13	3402.40	42.0
935.2	297.70	3461.88	46.0
935.4	298.28	3521.48	51.0
935.6	298.85	3581.19	54.0
935.8	299.43	3641.02	56.0
936.0	300.00	3700.96	60.0
938.0	331.00	4331.96	80.0

Figure 4-2 illustrates the results of the WATBUD modeling assuming no net gain or loss due to groundwater. The predicted water levels, shown by the line on the plot, closely matched (within 0.2 feet) the observed water levels (the open diamonds). In addition to the WATBUD modeling, two individual periods (July 9-10 and July 27-29, 2000) of approximately constant outflow (i.e., constant lake levels) were investigated and the results are summarized in the Table 4-4.

Table 4-4 Constant Flow Comparison for Crystal Lake

<table>
<tr><th>Date</th><th>Observed Water Surface Elevation</th><th>Estimated Outflow based on Observed Water Surface Elevation (cfs)</th><th>Estimated Inflow based on P8 Model Results (cfs)</th><th>Relative Difference (percent)</th></tr>
<tr><td>July 9, 2000</td><td>934.55</td><td rowspan="2">34.4</td><td rowspan="2">34.5</td><td rowspan="2">0.3</td></tr>
<tr><td>July 10, 2000</td><td>934.57</td></tr>
<tr><td>July 27, 2000</td><td>934.07</td><td rowspan="2">19.0</td><td rowspan="2">18.0</td><td rowspan="2">5</td></tr>
<tr><td>July 29, 2000</td><td>934.04</td></tr>
</table>

Since there was essentially no change in the water surface elevation the inflow to Crystal Lake must approximately equal the outflow from the lake. Based on the two periods listed above the P8 model is accurately simulating the watershed's hydrology.

The modeled water load from Crystal Lake's watershed assuming existing (2002) land use conditions during the May 2001 to April 2002 (1,775 acre-feet) is equivalent to 6.4 inches of runoff over the 3,315-acre urbanized watershed (excluding the 292-acre Crystal Lake and 55-acre Keller Lake water surface areas according the 2000 aerial photos).

4.2.1.2 Phosphorus Loading Calibration

Because no 2002 data had been collected regarding inflow water quantity or quality, detailed calibration of the P8 model was not possible. It was assumed that the adjustments made to the model calibration parameters for Lake Marion and Orchard Lake in Lakeville, two other metropolitan lakes, (see *Lake Marion Diagnostic-Feasibility Study*, Barr 1997) would be generally suited for modeling Crystal and Keller Lakes. The Lake Marion phosphorus loading was calibrated as follows:

> "The 1995 phosphorus loads predicted by the P8 model were calibrated using the stormwater monitoring data collected during 1995. The monitoring data record for Station T2 was most complete (and was felt to be the most reliable); the mean phosphorus concentration in stormwater runoff at T2 during the monitoring period (May 24 through November 4, 1995) was 105 ppb. The NURP 50th percentile particle file (i.e., National Urban Runoff Program, particle size distribution observed within the 50th percentile confidence interval) was used as the basis of the calibration. Particle and phosphorus accumulation and runoff parameters were modified within the P8 model during the calibration. The average runoff phosphorus concentration at Station T2 simulated by the P8 model for the period of monitoring (May 24 through November 4, 2002) was 105 ppb."

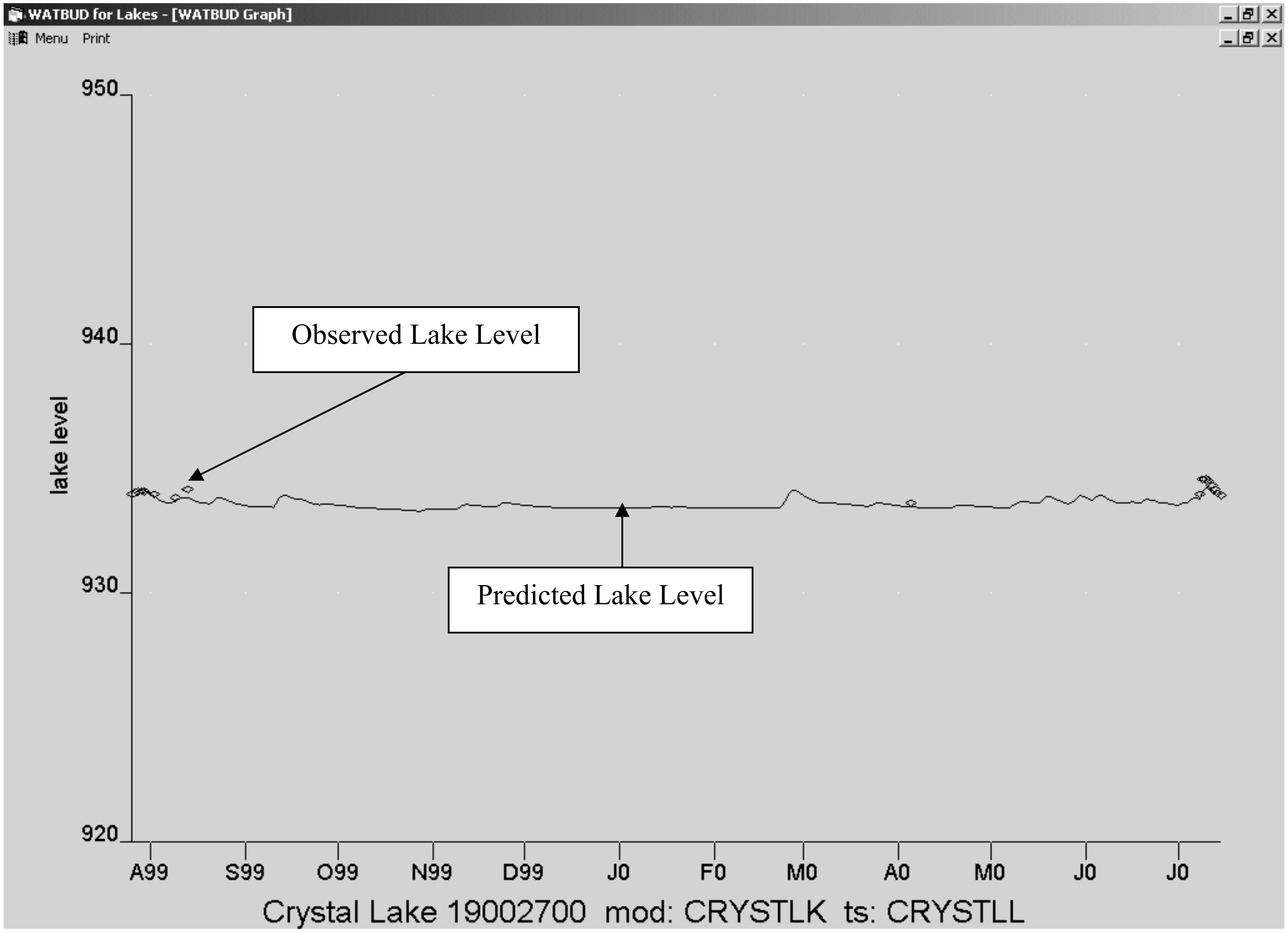

Figure 4-2. Stormwater Volume Calibration Results: WATBUD Model assuming No Net Gain or Loss due to Groundwater

4.3 In-Lake Water Quality Model

Typically, an empirical model such as the Dillon and Rigler phosphorus model (1974) is used to reconcile the phosphorus loadings from a watershed with the phosphorus concentrations observed in the lake. Most of the empirical phosphorus models assume that the lake to be modeled is well-mixed, meaning that the phosphorus concentrations in the lake are uniform across the surface of the lake regardless of the locations of the storm sewer inlets or the lake outlet. For modeling purposes, Crystal Lake was divided into the five basins described previously: Bluebill Bay, Mystic Bay, Maple Island Bay, Buckhill Bay and the main Crystal Lake basin. In addition to the five basins in Crystal Lake, Keller Lake was modeled with an empirical in-lake model. To calibrate the Dillon and Rigler water quality model for existing land use conditions, phosphorus loads for 2002 were predicted using the P8 model and then used with the 2002 in-lake water quality data to calculate the internal phosphorus load (described in more detail in Section 5.4.3).

Water quality data, consisting of total phosphorus data from 2002, were used to determine the best in-lake water quality model to use for this analysis. The best fit proved to be the Dillon and Rigler model (Dillon and Rigler, 1974) with several different retention terms depending on the basin analyzed (see Table 4-5). Therefore, this model was used for predicting the spring total phosphorus concentration of the individual basin.

Table 4-5 Selected Basin Retention Terms

Basin	**Retention Term Utilized**
Keller Lake	Kirchner and Dillon (1975)
Main Crystal Lake Basin	Kirchner and Dillon (1975)
Bluebill Bay	Chapra (1975)
Mystic Bay	Chapra (1975)
Maple Island Bay	Kirchner and Dillon (1975)
Buckhill Bay	Kirchner and Dillon (1975)

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

where:

P_{SPRING} = spring total phosphorus concentration (µg/L)
L = areal total phosphorus loading rate (mg/m²/yr)
R = retention coefficient
= Chapra (1975) = $16/(16+q_s)$ or
= Kirchner and Dillon (1975) = 0.426*e^(-0.271*qs)+0.574*e^(-0.00949*qs)
q_s = annual areal water outflow load (m/yr)
= Q/A
z = lake mean depth (m)
ρ = hydraulic flushing rate (1/yr)
= 1/(hydraulic residence time) = 1/(V/Q)
Q = annual outflow (m^3/yr)
V = lake volume (m^3)
A = lake surface area (m^2)

While this model, supplied with the May 1, 2001 to April 30, 2002 total phosphorus loading predicted by P8 for existing land use conditions, adequately predicted the spring steady-state concentration of phosphorus in the individual basins, early-summer, summer average and fall overturn concentrations were not accounted for in the above model. It was determined, after analyzing historical water quality data; that the early-summer, summer average and fall overturn phosphorus concentration were typically higher than the observed spring concentrations. The increase was the result of additional watershed runoff and internal loading due to: (1) the mid-season die-back of curlyleaf pondweed; and (2) the release of phosphorus from anoxic bottom sediments (see Section 5.4.4 for the in-lake calibration results).