4.0 Methods

4.1 Data Collection

4.1.1 Lake Water Quality Data

Lake Owasso has historical water quality data for basic parameters from 1973 to 2008. This data has been collected by a variety of agencies and monitoring programs. The MDNR collected water quality data in the early 1970s and the Metropolitan Council (MetCouncil) collected data in the later 1970s through the early 1980s. Data collected in 1980 and 1984 were collected as part of the MetCouncil's Citizen-Assisted Monitoring Program (CAMP). Secchi depth data for Lake Owasso has been collected as part of the MPCA's Citizen Lake Monitoring Program (CLMP) from 1976 through the present. However, the majority of the water quality data for Lake Owasso (from 1984 through the present) has been collected by Ramsey County, including the more detailed sampling efforts in 2007 and 2008.

In 2007, and again in 2008, an intensive water quality sampling program was implemented for Lake Owasso during the open-water season. Because the recent summer average transparencies in Lake Owasso fell below the GLWMO "action level", the intensive data collection program was completed to evaluate current water quality conditions in the lakes. This data was used to calibrate the water quality models developed as part of the UAA. There were two monitoring sites on Lake Owasso (Figure 4-1). The first site (5401) was located in the deep area in the northwest corner of the lake. This site is also the location where sampling has historically occurred in Lake Owasso. The second site (5403) was located in the deeper area located in the southwest corner of the lake. There were nine sampling events from the end of March through late September in 2007. There were eight sampling events from early May through late September in 2008.

Table 4-1 lists the water quality parameters, and specifies when and at what depths samples or measurements were collected. Dissolved oxygen, temperature, specific conductance, and Secchi disc transparency were measured in the field; whereas, water samples were analyzed in the laboratory for total phosphorus, pH, chlorophyll *a*, chloride, hardness, and alkalinity. 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 4-1 Water Quality Sampling Parameters

Parameters	Depth (Meters)	Sampled or Measured During Each Sample Event
Dissolved Oxygen	Surface to bottom profile	X
Temperature	Surface to bottom profile	X
Specific Conductance	Surface to bottom profile	X
Secchi Disc	—	X
Total Phosphorus	0-2 Meter Composite Sample	X
Total Phosphorus	Profile at 1.0 meter intervals from 3 meters to 0.5 meters above lake bottom	X
Soluble Reactive Phosphorus	Profile at 1.0 meter intervals from 3 meters to 0.5 meters above lake bottom	X
Total Dissolved 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
Chloride	0.5 meters above lake bottom	X
Hardness	Surface to Bottom Profile	X
Alkalinity	Surface to Bottom Profile	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
Transparency	Secchi disc	
Chloride	Automated colorimetric with ferricyanide	EPA 325.1
Hardness		EPA 130.2
Alkalinity		SM2320 B-97

To define a "summer-average" for each water quality parameter, the typical averaging period was late May through early September to be consistent with the MPCA's method for evaluating lake water quality. For some years, the averaging period was June through early September if data for late May was not available.

4.1.2 Sediment Core Samples

All lakes accumulate phosphorus (and other nutrients) in the lake sediments from the settling of particles and dead organisms. In some lakes this reservoir of phosphorus can be reintroduced in the lake water and become available again for plant uptake. This resuspension or dissolution of nutrients from the sediments to the lake water is known as "internal loading". Sediment cores were collected from Lake Owasso in May of 2007 to determine sediment phosphorus concentrations that can lead to internal phosphorus loading.

Multiple sediment cores were taken from Lake Owasso (Figure 4-1) and were analyzed for mobile phosphorus (which potentially can contribute directly to internal phosphorus loading) and organic bound phosphorus. Phosphorus fractions were determined according to a modified version of Psenner et al. (1988) and internal loading estimates were calculated according to the method developed by Pilgrim et al. (2007). After laboratory analysis, sediment phosphorus concentrations were modeled to determine lake wide potential internal phosphorus loading rates using Geostatistical Analysis within the ArcMap GIS program.

4.1.3 Macrophyte Monitoring

Macrophyte (aquatic plant) monitoring for Lake Owasso has been completed for several years. Most recently, macrophytes in Lake Owasso were monitored in 2007 at the end of May by Ramsey County. A detailed map of the 2007 macrophyte monitoring results, specifically focusing on Curlyleaf pondweed coverage, is presented and discussed in this report. A brief summary of past monitoring results for the lake is also presented in this report.

4.1.4 Stormwater Runoff Monitoring

In 2007 and 2008, the Ramsey Washington Metro Watershed District (RWMWD) installed three watershed runoff monitoring stations around Lake Owasso (Figure 4-1). These stations monitored both flow and water quality. These stations collected flow data (area-velocity) every 10 minutes during operation. The water quality sampling was a composite sampling system triggered by changes in the observed water level during storm events.

In 2007, the first monitoring site was located on the south side of Owasso Bay, in the storm sewer running along Galtier Street. This site monitored runoff from subwatershed LO_E_1f. This watershed does not have any ponds or other treatment devices. The second monitoring station was located on the southside of Lake Owasso at downstream of the County Road C crossing at the outlet of Central Park Pond west. This station corresponds with the outlet of subwatershed LO_S_1. There are many stormwater ponds, wetlands, and lakes within this watershed including Westwood Village Pond, Bennett Lake, and the Central Park Ponds (east and west). The third site was located on the west side of Lake Owasso, just downstream of the CDS treatment structure at West Owasso Boulevard. This monitoring site corresponds to the combined outlet of subwatershed Dschg36 and LO_W_1c (Charlie Pond) . Runoff through this watershed passes through numerous lakes and ponds, including Lake Judy, Lake Emily, and the Charlie Pond system.

Because additional data was needed to verify the P8 model runoff predictions, watershed runoff flow and water quality modeling was continued in the summer of 2008. In 2008, the monitoring station from Galtier Street was moved to Dale Street where the Central Park - East wetland discharges into the Central Park – West wetland (at the outlet of subwatershed LO_S_2a). This site was selected to help monitor the potential water quality impacts of the City of Roseville Leaf Recycling Center. The other two monitoring stations installed in 2008 were located at the County Road C crossing at the outlet of Central Park Pond - West and just downstream of the CDS treatment structure at West Owasso Boulevard. These sites were the same as those monitored in 2007, although at County Road C, the 2008 monitoring station was located at the upstream end of the County Road C crossing while in 2007, it was located at the downstream end of the pipe. This station was moved to reduce the influence of Lake Owasso water level fluctuations on the flow monitoring data, as both the Central Park – East and Central Park – West wetlands can be impacted by Lake Owasso water levels.

In addition to the installation of the automatic flow and water quality sampling stations in 2008, RWMWD staff collected water quality grab samples at the Dale Street and County Road C stations to establish an understanding of the baseline (non-storm event) water quality in these two wetlands. These grab samples were typically collected between storm events by the RWMWD staff.

4.1.5 Discharge Location Survey (2007)

The *Water Quality Management Alternatives* study (Barr, 1991) considered 12 major inlet locations to Lake Owasso. These locations were typically larger inflow locations under the jurisdiction of the City or the County.

Concerns expressed by lake residents about untreated direct discharges to Lake Owasso were addressed by conducting a survey of all pipes, regardless of jurisdiction or size, discharging to the lake. The Cities of Shoreview and Roseville staff conducted these surveys in the early summer of 2007, recording the size and type of pipe, as well as using GPS and/or parcel address to locate the discharge to the lake. There are also photographs of each discharge to Lake Owasso in the City of Shoreview. The approximate location of each discharge as well as the party responsible for maintenance is included in Figure 3-1. This survey identified 23 discharges to Lake Owasso under public jurisdiction (City or County). However, a few of these pipes have been bulkheaded and no longer discharge to the lake. There were 32 discharges to the lake coming from residential properties to the lake. Appendix C includes additional information about the 2007 discharge survey.

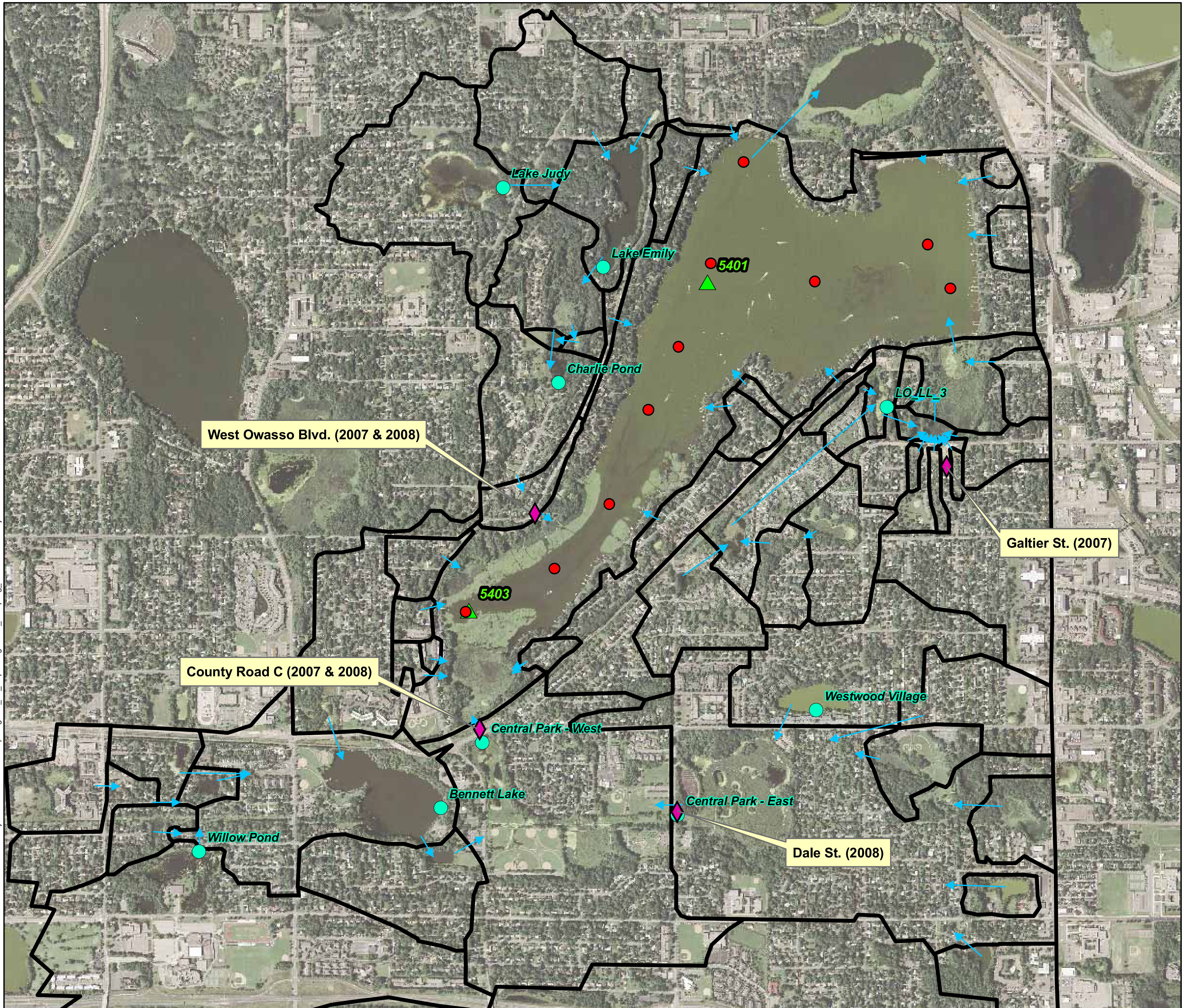
4.1.6 Pond Discharge Survey (2008)

The summer of 2007 experienced below average precipitation for much of the summer, making calibration of P8 model runoff difficult (see Section 4.2.2 for a more complete discussion). In 2007, there were several ponds within the Lake Owasso watershed whose water levels had dropped below the normal outlet and were not discharging (as observed on a single field visit in August). More detailed information about the discharges from some of the key lakes, ponds, and wetlands throughout the summer would aid in the model calibration and validation process. Therefore, in 2008, nine of the major ponds and wetlands in the Lake Owasso watershed were monitored approximately every two weeks during June and July. Monitoring was limited to observations of whether the water levels in the ponds were above or below the invert of the normal outlet structure. Ponds monitored included: Lake Judy (LO_W_4), Lake Emily (LO_W_2), Charlie Pond (LO_W_1c), Willow Pond (LO_S_8), Bennett Lake (LO_S_6a), Central Park Pond – East (LO_S_2a), Central Park Pond – West (LO_S_1), Westwood Village Pond (LO_S_5), and the wetland located in subwatershed LO_LL_3. Results of the pond discharge surveys can be found in Appendix D.

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 stormwater runoff and phosphorus loads introduced from the entire Lake Owasso watersheds. P8 is a useful diagnostic tool for evaluating and designing watershed improvements and Best Management Practices (BMPs).

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



Sediment Core Locations (2007)

Runoff Monitoring (2007 & 2008)

In-Lake Water Quality Monitoring (2007 & 2008)

Pond Discharge Sites (2008)

Feet

1,250 0 1,250

N

Figure 4-1

LAKE OWASSO
MONITORING SITES

Lake Owasso UAA
Grass Lake Watershed Management Organization

4.2.1 Water Quality Modeling (P8) of Varying Hydrologic Conditions

The amount of stormwater runoff and associated pollutant loading from a watershed is dependent upon hydrologic conditions such as precipitation patterns and soil saturation conditions. To evaluate the watershed loading under differing hydrologic conditions, the P8 model was run for three time periods that represent average, wet, and dry climatic conditions.

- "Average" climatic conditions: May 2004- September 2005
- "Wet" climatic conditions: May 2001- September 2002
- "Dry" climatic conditions: May 2007 - September 2008

The P8 model requires hourly precipitation and daily temperature data for each of the modeled time periods. For model calibration, a continuous hourly precipitation file was developed based on data from the National Weather Service (NWS) Downtown Saint Paul Airport station for 2006 through 2008 and from the NWS Minneapolis-St. Paul International Airport station for years prior to 2006. The Downtown Saint Paul monitoring station is located approximately 7.5 miles from Lake Owasso while the Minneapolis-St. Paul Airport station is located approximately 10.5 miles from Lake Owasso. Local daily precipitation data from the Minnesota High Density Network of rain gages (Vadnais) were used to augment the observed hourly data from the Downtown Saint Paul Airport and Minneapolis-St. Paul International Airport NWS stations. Daily temperature data was obtained from the NWS station at the Minneapolis-St. Paul International Airport station. To model the various climatic conditions, the same hourly precipitation and temperature data were used. See Figure 4-2 for the location of the precipitation gages.

See Appendix E for additional information on the P8 model input files.

4.2.2 Water Quality Model (P8) Calibration

4.2.2.1 Stormwater Volume Calibration

The stormwater runoff model calibration process involved two phases. First was the calibration of the predicted P8 runoff volume to actual stormwater monitoring data. The second phase included developing a water balance model calibrated to lake level data to verify runoff volumes and estimate the expected groundwater exchange.

4.2.2.1.1 Stormwater Monitoring Sites (2007 and 2008)

Initially, the P8 model runoff volumes were calibrated to the 2007 observed flows at each of the runoff monitoring stations. Because there were no ponds or treatment devices within the watershed contributing runoff to the monitoring station on Galtier Street (outfall of subwatershed LO_E_1f), this station was used to estimate the watershed runoff parameters to be applied to all subwatersheds across the entire Lake Owasso watershed. It is important to note that there were few storm events during the summer of 2007 that contributed flows from the pervious surfaces in the watershed contributing to the monitoring station on Galtier Street. Figure 4-3a shows the results of the 2007 runoff volume calibration for the monitoring site at Galtier Street. The calibrated watershed parameters based on the 2007 Galtier Street site were applied to all watersheds contributing runoff to Lake Owasso.

The contributing watersheds to the County Road C (2007 and 2008 monitoring), the West Owasso Boulevard (2007 and 2008 monitoring), and the Dale Street (2008 monitoring) sites have several lakes and wetlands within them. Under default conditions in P8, treatment devices such as ponds do not lose water through infiltration (or excessive evaporation) and will remain at their normal water level, even during extended periods of little or no rainfall.

The summer of 2007 was very hot and dry during June July, and the first half of August, and a field inspection of ponds and wetlands in August 2007 indicated that many of these water bodies were below their normal water level and were not discharging downstream. Therefore, for all devices that were natural water bodies (ponds or wetlands), an “infiltration” rate was applied to calibrate the cumulative runoff volume predicted by P8 to the monitoring data from the County Road C and West Owasso Boulevard monitoring sites, respectively. This “infiltration” rate is not solely a loss to infiltration but represents losses to infiltration as well as excessive evaporation.

The summer of 2008 was also a very dry summer. The runoff monitoring data, in conjunction with the pond discharge survey data, indicated that similar to the summer of 2007, there were periods during which many of the major ponds within the watershed were not discharging runoff downstream. With this additional monitoring data, the P8 model runoff calibration was further refined. This included modifications to the estimated pond and wetland “infiltration” rates as well as developing modified discharge rating curves for both the Central Park Pond – East (Dale Street) and the Central Park Pond – West (County Road C) wetlands based on the 2008 flow monitoring data. Surveys of the inverts of the Central Park pond’s outlet (conducted in May 2008 by the City of Roseville) and review of the flow monitoring data indicates that the water levels and discharges from these water bodies are, at times, significantly impacted by the water levels in Lake Owasso. This results in rating curves for each of these ponds that vary with time, depending on the level of Lake Owasso. The outlet rating curves used in P8 were selected based on the conveyance system characteristic and best fit to the cumulative runoff volumes in 2007 and 2008 for the stations at Dale St. and County Road C.

Figures 4-3b, 4-3c, and 4-3d show the results of the P8 runoff volume calibration to the West Owasso Boulevard (2007 and 2008), County Road C (2007 and 2008), and Dale Street (2008) monitoring data, respectively. Table 4-3 summarizes the results of the runoff calibrated volume calibration. Appendix E includes more detailed information about the selection of the parameters used in P8.

Table 4-3 Summary of Lake Owasso P8 Runoff Calibration

Parameter	Site 1: Galtier Street (LO_E_1f)	Site 2: County Road C (LO_S_1)	Site 3: West Owasso Blvd. (Dschg36)	Site 4: Dale Street (LO_S_2a)
2007 Individual Site Predicted/Observed Volume Ratios[1]	1.03	0.97	1.87[2]	N/A
2008 Individual Site Predicted/Observed Volume Ratios[1]	N/A	0.97	1.03	1.04

1. Based on Cumulative Runoff Volume over the monitoring period.
2. This discrepancy is due to variation of a single storm event across the Lake Owasso watershed, as reviewed on the Minnesota Climatology Working Group website (http://climate.umn.edu/hidradius/HIDENmapFile.asp)

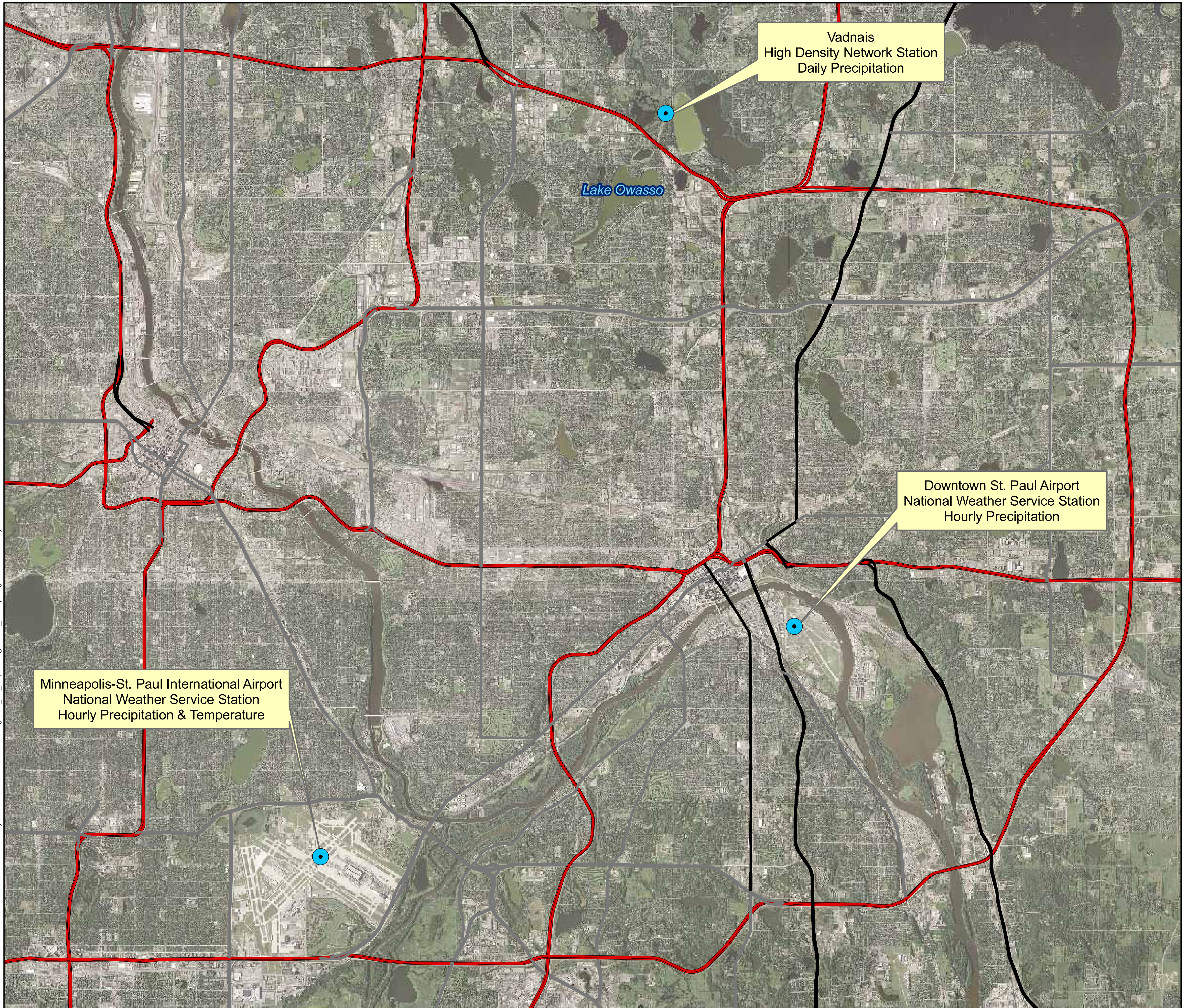


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Figure 4-2

PRECIPITATION GAGE LOCATIONS

Lake Owasso UAA
Grass Lake Watershed Management Organization

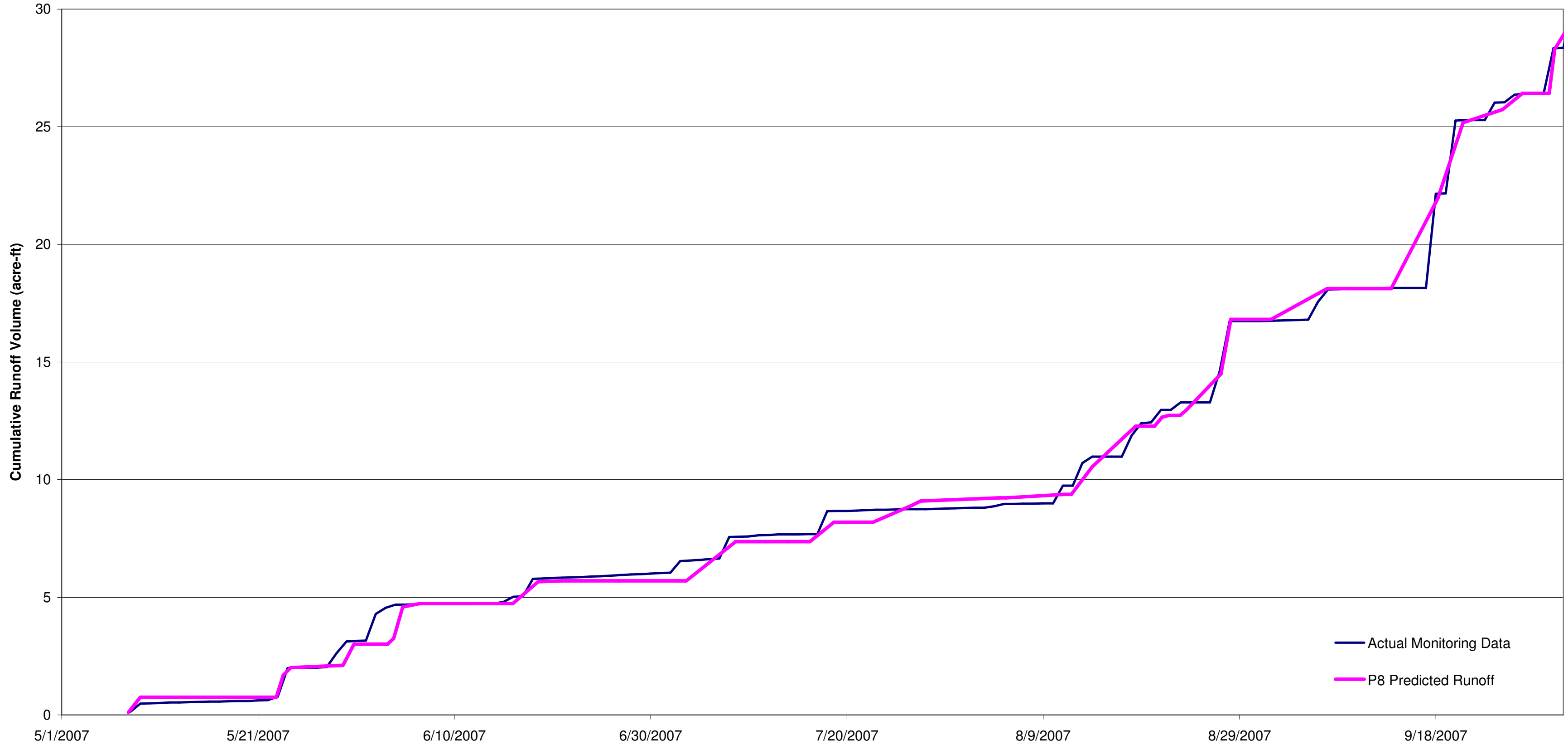
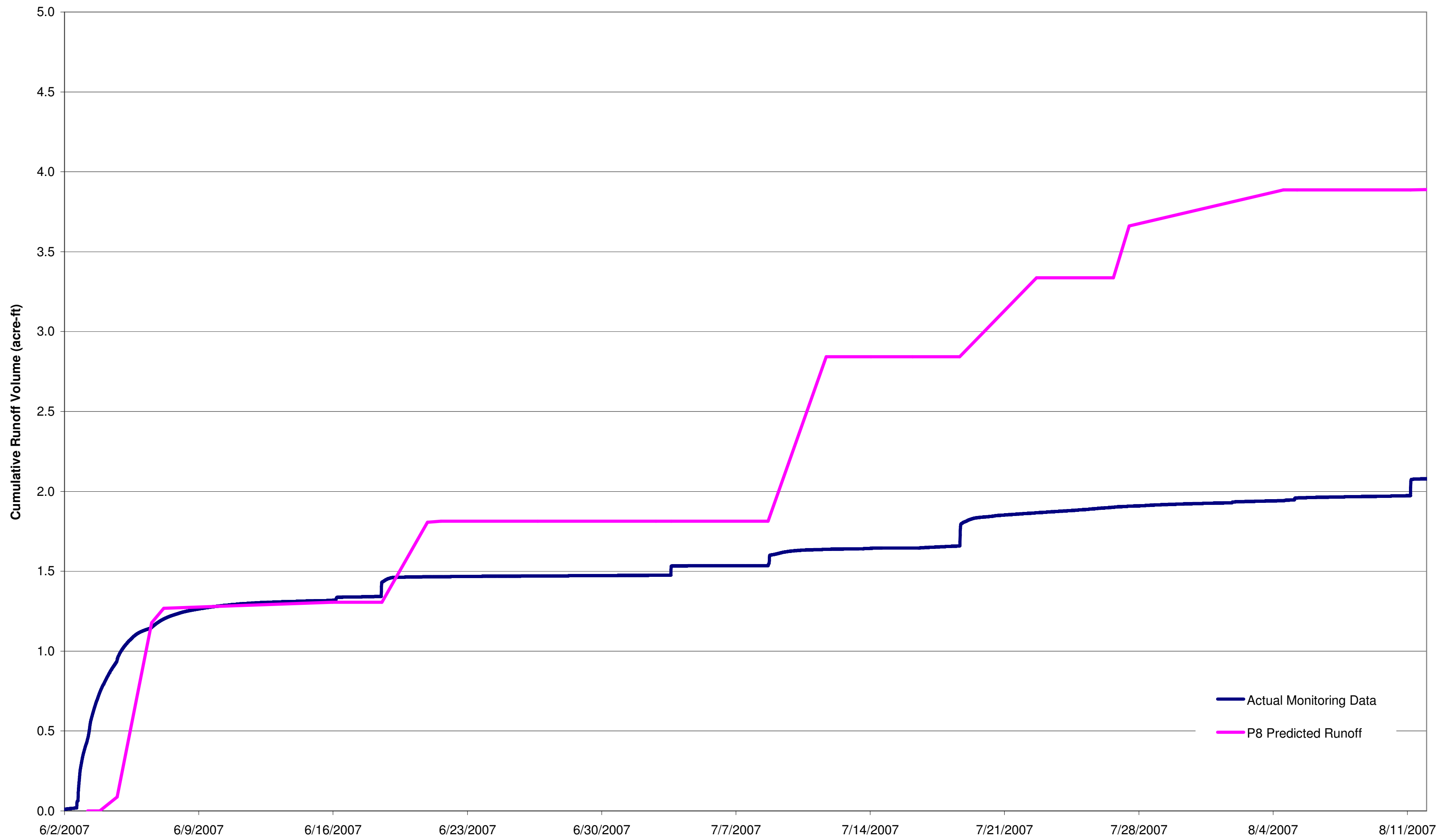
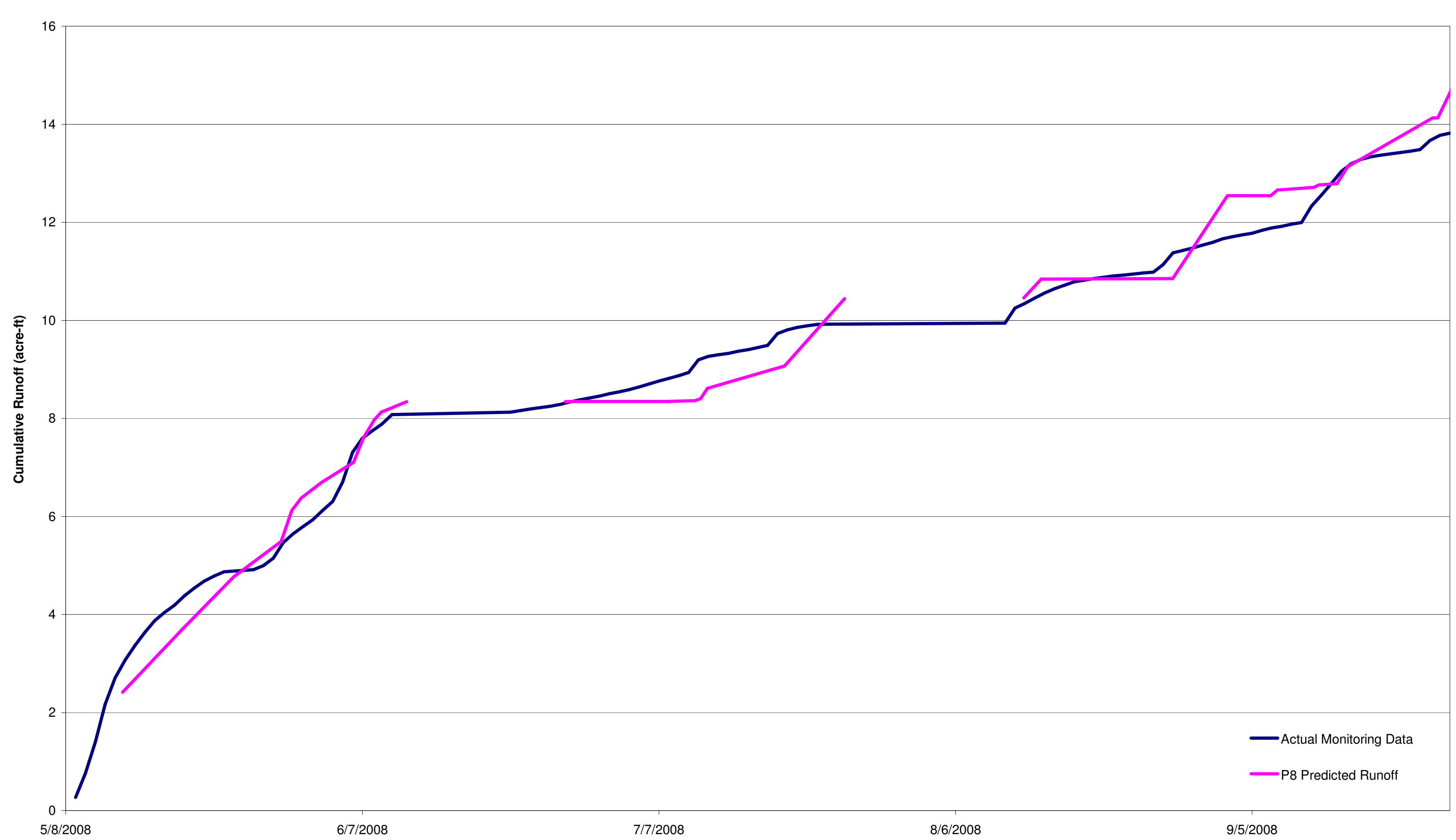


Figure 4-3a
Cumulative Runoff Volume for Monitoring Period
(5/8/2007 - 10/1/2007)
Station at Galtier St.

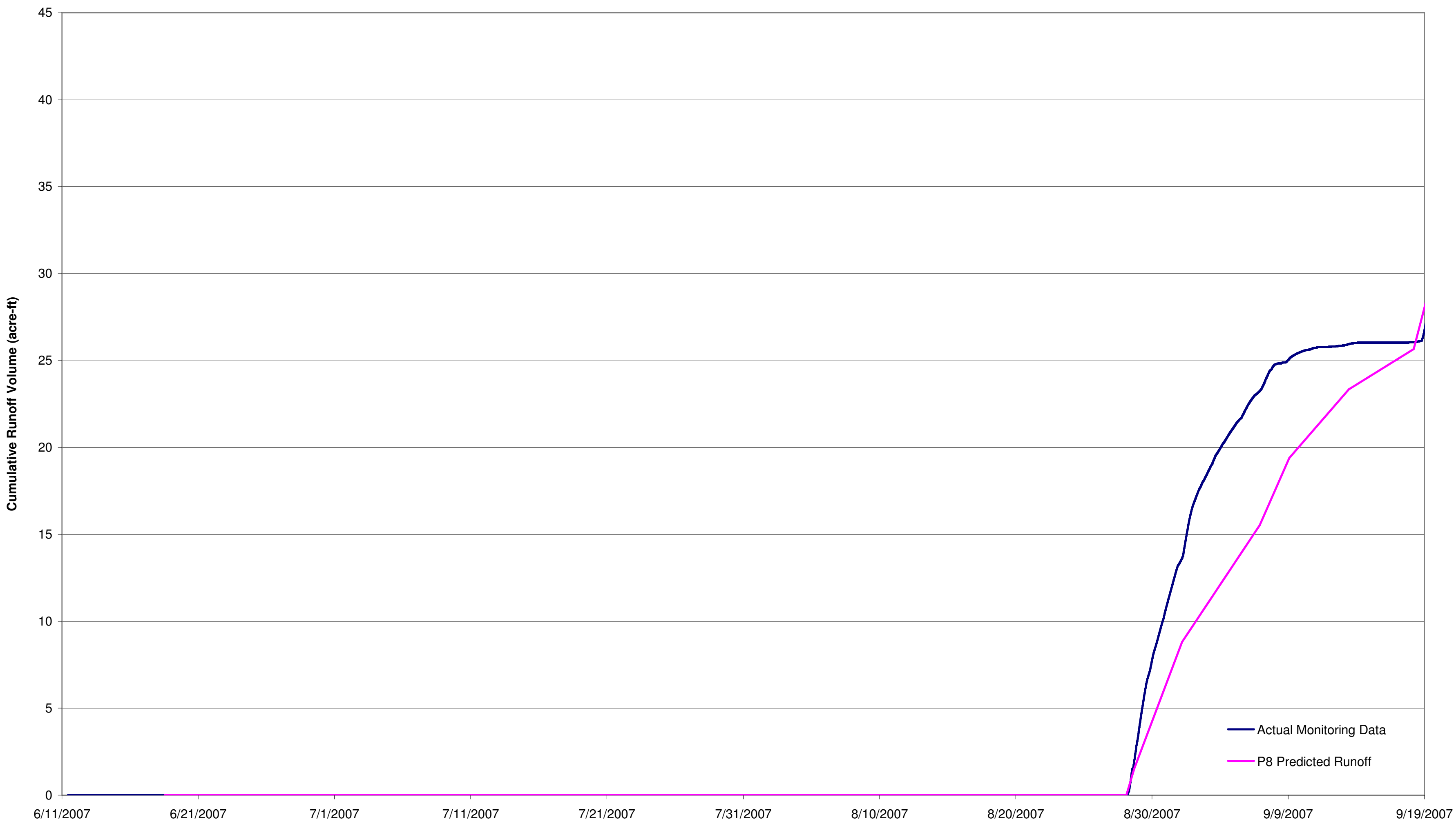


Cumulative Runoff Volume for Monitoring Period
(6/2/2007 - 8/14/2007)

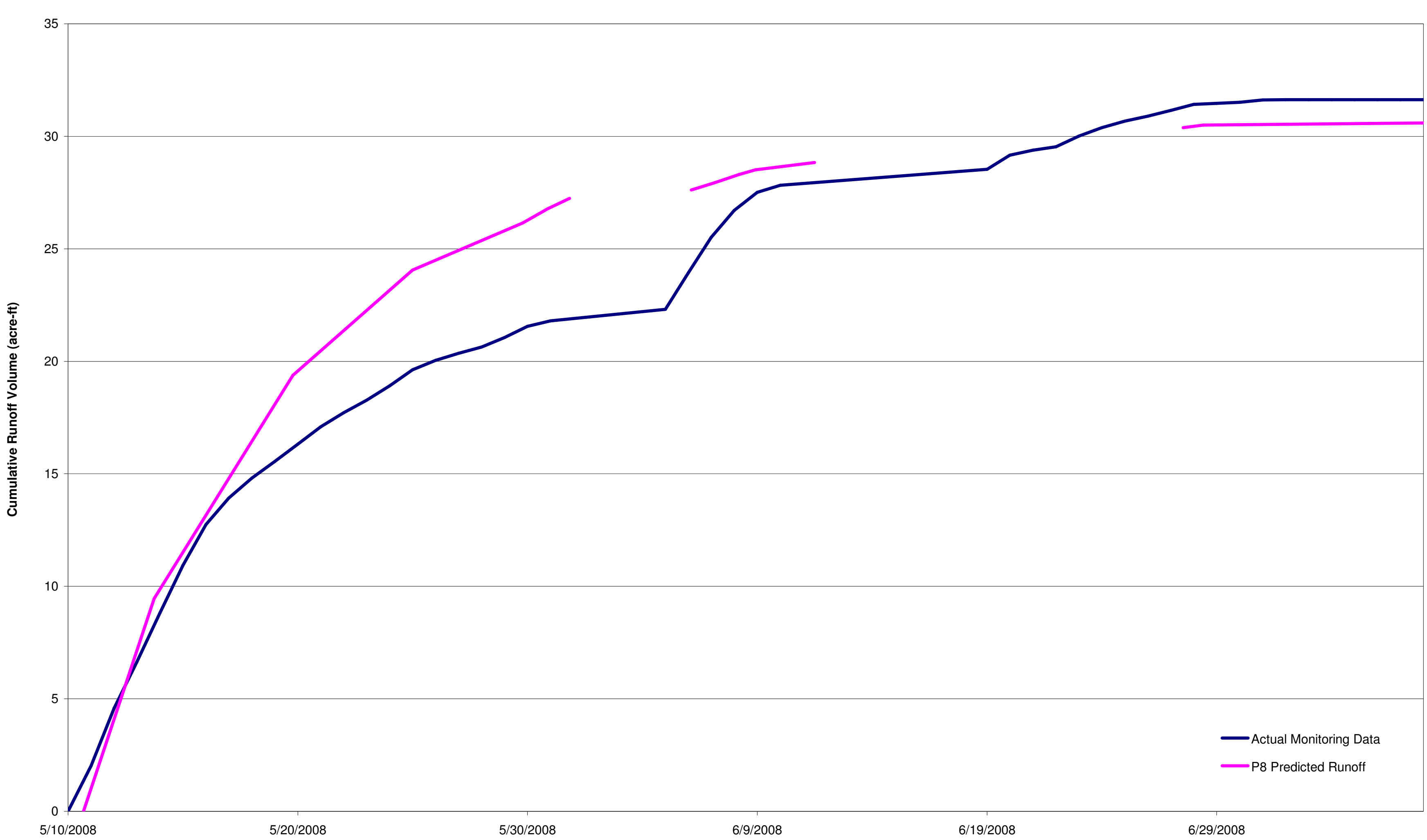


Cumulative Runoff Volume for Monitoring Period
(5/9-6/11/2008, 6/23-7/28/2008, 8/11-9/25/2008)

Figure 4-3b
Cumulative Runoff Volume for 2007 & 2008
Station at West Owasso Boulevard



Cumulative Runoff Volume for Monitoring Period
(6/11/2007 - 9/18/2007)



Cumulative Runoff Volume for Monitoring Period
(5/10/2008 - 5/31/2008, 6/5/2008 - 6/10/2008, 6/19/2008 - 7/8/2008)

Figure 4-3c
Cumulative Runoff Volume for 2007 & 2008
Station at County Road C

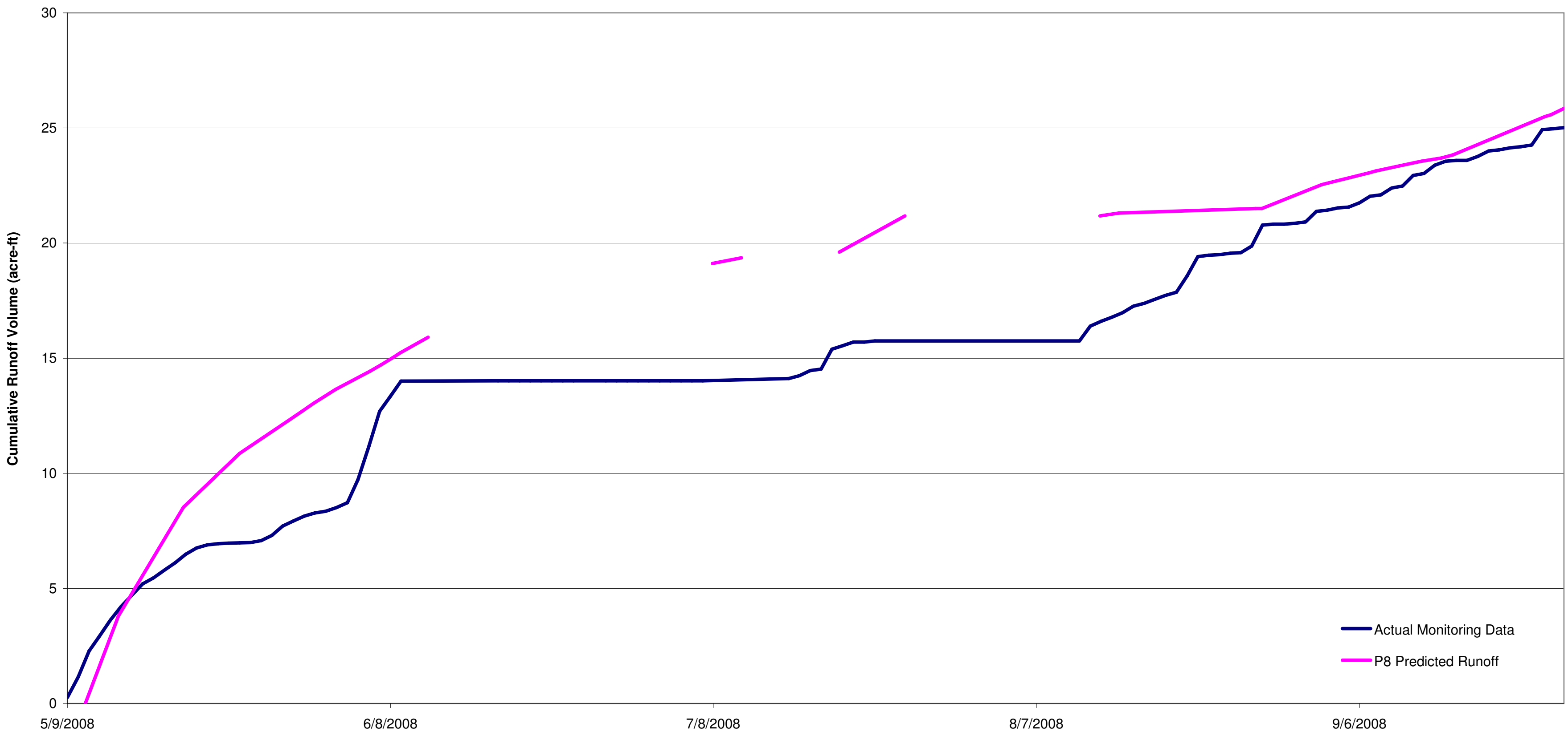


Figure 4-3d
Cumulative Runoff Volume for Monitoring Period
(5/9-6/8/2008, 6/22-6/27/2008, 6/28-7/10/2008, 7/17-7/25/2008, 8/12-9/25/2008)
Station at Dale Street

4.2.2.1.2 Water Balance Model

The daily precipitation. the total estimated daily watershed runoff to Lake Owasso from the calibrated P8 model, along with daily evaporation values (estimated by the Meyer Model for years prior to 2008 and daily values estimated from the St. Paul Campus Climatological Observatory for 2008) and the Lake Owasso discharge rating curve were used as inputs to the daily water balance model, WATBUD (developed by the MDNR), for 2008 (the calibration period). WATBUD was used to estimate the groundwater exchange for Lake Owasso, verify the runoff volumes predicted by P8, and simulate lake levels during this time period. The predicted lake levels were then compared to observed lake levels, and adjustments were made to the P8 and water balance model input parameters to obtain an optimal match between predicted and observed conditions.

Table 4-4 summarizes the stage-storage-discharge relationship developed for Lake Owasso based on basin bathymetry data (see Figure 3-2) and outlet characteristics: As previously mentioned, Lake Owasso is a groundwater lake that experiences periods of seepage and recharge, throughout the year. Also, during the winter months, discharge from Lake Owasso is reduced due to the accumulation of ice around the outlet structure, as confirmed by the City of Shoreview (Shoreview Public Works Director, personal communication, 1/18/2008).

Table 4-4 Stage-Storage-Discharge for Lake Owasso

Elevation	Water Surface Area	Cumulative Storage Volume (acre-feet)	Discharge (cfs)
851.6	13.1	0.0	0
861.6	52.2	326.2	0
866.6	68.8	628.5	0
871.6	86.3	1016.2	0
876.6	115.8	1521.6	0
881.6	270.3	2486.9	0
886.6	374.4	4098.7	0
886.7	376.2	4120.4	0.7
886.8	379.5	4162.4	2.1
886.9	382.5	4200.1	3.4
887.0	386.5	4250.8	5
888.0	416.8	4652.6	35
890.0	440.8	5510.2	60

Use of the WATBUD model indicates that the expected groundwater exchange in Lake Owasso typically varies throughout the year and also varies from year to year, especially during the winter months. To account for the variability of the groundwater exchange throughout the year as well as the change in the lake's rating curve during the winter months, the WATBUD modeling was separated into several periods throughout 2008 to account for groundwater and discharge variability. For calibration of the groundwater exchange to the 2008 lake level data, the WATBUD model was separated into the following groundwater exchange periods:

- Winter (December 2007 through March 2008) – this assumes there was no discharge from Lake Owasso during this period.
- May 2008 through June 2008
- July 2008 through August 2008
- September 2008

April 2008 was not evaluated as part of the WATBUD analysis as the ice out dates for other lakes in the region occurred in mid- to late April, resulting in an expected change in the Lake Owasso rating curve sometime during this month (Minnesota Climatology Working Group website, accessed 1/5/2009). It was assumed that the groundwater exchange predicted from the winter months (December 2007 through March 2008) would also be applicable during April.2008. October and November, in both 2007 and 2008, could not be evaluated due to limited lake level data during these months. It was assumed that groundwater exchange during October would be similar to that during September, while in November, groundwater would be similar to the expected groundwater exchange during the winter months.

Review of lake level data during the winter months (January and February during periods without thaw events) for the past decade (1998 through 2008), indicates that during some years, there is groundwater inflow into Lake Owasso while other years, there is seepage from the lake during the winter. This seepage analysis assumes that during the months of January and February, there is no discharge from Lake Owasso as the result of ice build-up around the outlet structure, and that the changes in water levels during these months are the results of groundwater exchange only. Table 4-5 summarizes the estimated daily winter groundwater exchange for 1998 through 2008.

Table 4-5 Estimated Winter Groundwater Exchange in Lake Owasso based on Lake Level Data (1998 to 2008)

Year	Winter Groundwater Exchange[1] (ft/d)
1998	-0.001
1999	0.002
2000	-0.003
2001[2]	-0.009
2002	N/A[3]
2003	N/A[3]
2004	0.001
2005	N/A[3]
2006	No Data
2007	-0.007
2008	0.001

1 – Winter is defined as January and February, assuming that there is no discharge from Lake Owasso due to accumulation of ice around the outlet. Groundwater exchange estimates do not include thawing events during these periods.

2 – Seepage estimate is based on lake level data for February and March.

3 – Groundwater exchange not able to be calculated due to thawing events during this period.

Figure 4-4a illustrates the results of the water balance modeling results for Lake Owasso, including the groundwater exchange estimated by WATBUD as well as the assumption that there is no discharge from Lake Owasso from December 15 through April 15 (based on average ice on and ice off conditions for the region). Additionally, the estimated groundwater exchanges for the periods evaluated are summarized on the figure. According to the 2008 WATBUD calibration, during the winter and spring, Lake Owasso received groundwater inflow at a rate ranging from 0.003 feet/day to 0.043 feet/day. During the summer and fall, Lake Owasso lost water to seepage at a rate ranging from 0.004 feet/ day to 0.008 feet/day. The estimated 2008 groundwater exchange rates were assumed to apply to the same periods in 2006 and 2007 to verify the groundwater exchange.

The predicted water levels for the calibration period closely match the actual lake level data. Applying the same groundwater exchange to 2006 and 2007 conditions yields a predicted lake level pattern similar to the observed pattern but with a slightly different magnitude. This is likely the result of the combination of several factors. The first factor is related to the variability in the Lake Owasso discharge rating curve as the result of ice accumulation around the outlet structure. The water balance model results (as shown on Figure 4-4a) are based on the assumption that discharge from Lake Owasso is zero from December 15 through April 15 (based on regional average ice on and ice off conditions). However, historical records show that there can be a significant amount of variability (on the order of several weeks in either direction) for the timing of the ice on and ice off conditions, impacting the predicted lake levels.

The second factor is the variability in the groundwater exchange throughout the year as well as from year to year. Previous studies of Lake Owasso suggest that the lake experiences periods of recharge as well as discharge. This was also seen during the WATBUD modeling. The variability of the groundwater exchange between years was also demonstrated by the estimation of groundwater exchange during the winter months, as summarized in Table 4-5.

Figure 4-4b shows the comparison of the predicted to the actual lake levels for the 2008 calibration period, including the regression equation and coefficient for these data. The regression indicates a close relationship between actual lake levels and the model results.

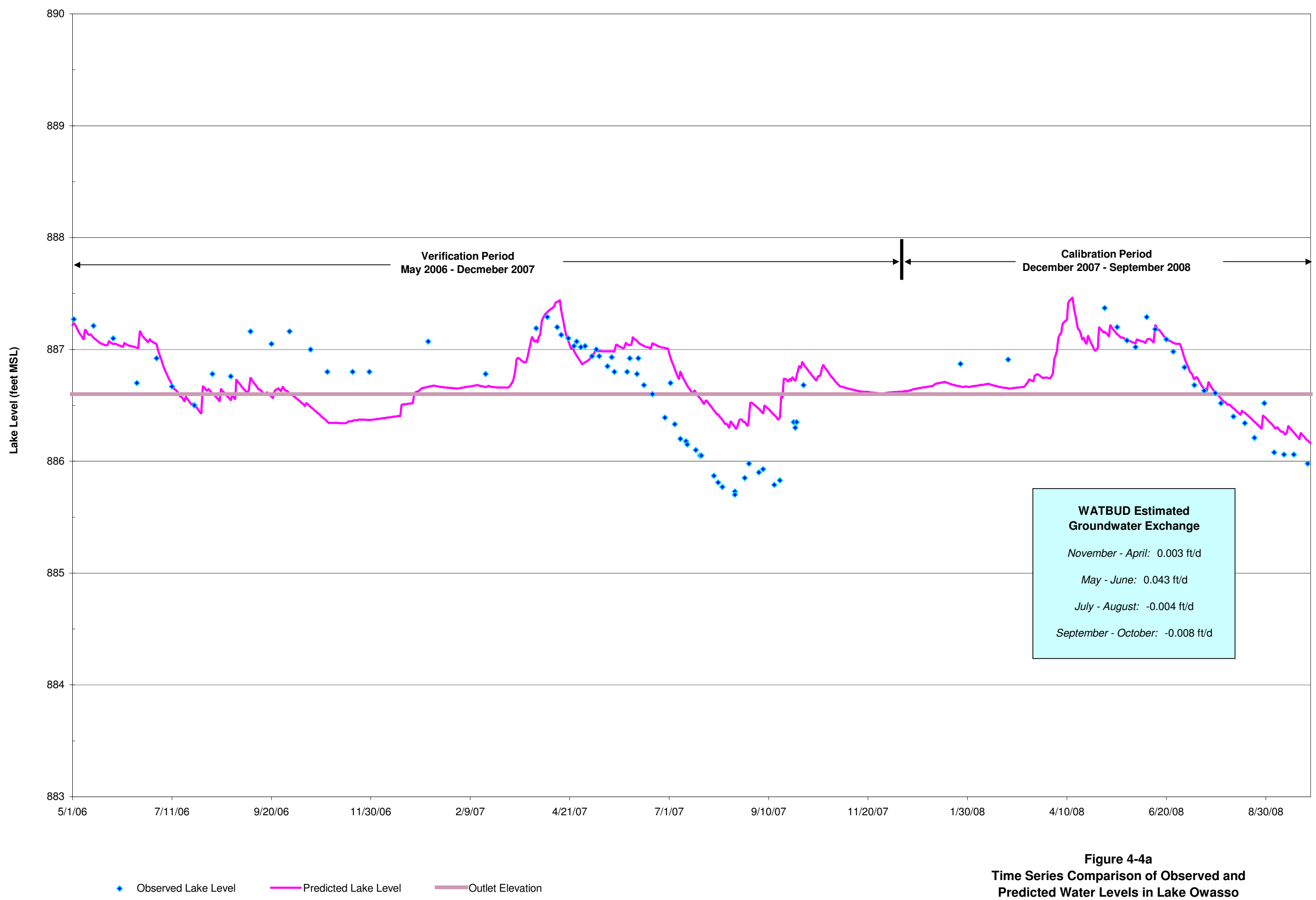


Figure 4-4a
Time Series Comparison of Observed and Predicted Water Levels in Lake Owasso from the 2006 through 2008 Water Balance

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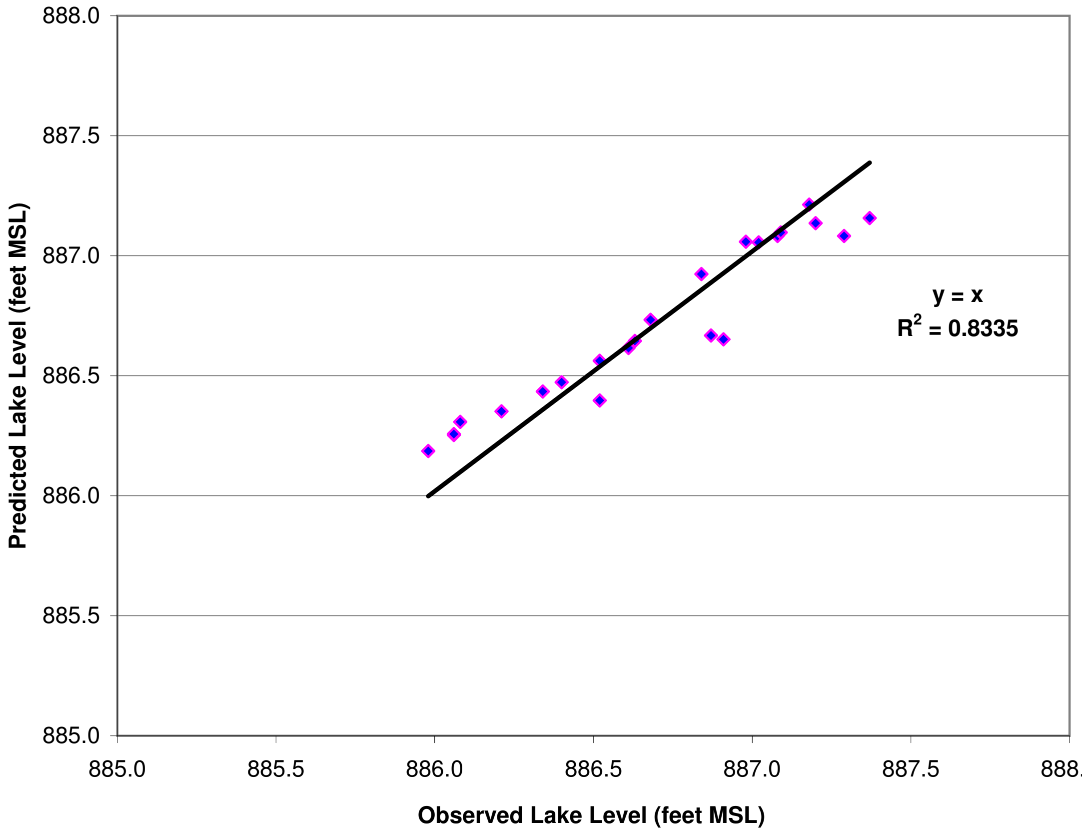

2007 - 2008 Calibration Period

Figure 4-4b
Regression Analysis of the Observed and Predicted Water Levels

4.2.2.2 Pollutant Loading Calibration

Because actual monitoring data related to the quantity and quality (total suspended solids (TSS) and total phosphorus (TP)) of stormwater runoff was available at monitoring locations around Lake Owasso in 2007, a detailed calibration of the particle and pollutant relationship in P8 was performed so that model results would closely mimic the actual monitoring data from each of the sites. However, because total dissolved phosphorus was not measured, the model was not calibrated to the dissolved fraction.

The report "P8 Enhancements and Calibration to Wisconsin Sites", Walker (1997) was used as a guide for the steps used to calibrate the Lake Owasso P8 model. The calibration steps outlined by Walker were followed with a few exceptions.

Calibration was originally focused on data collected at the Galtier Street monitoring station, as this station reflected only watershed runoff (there was no treatment in the watershed upstream of the monitoring station). This would allow for the calibration of the watershed pollutant loading parameters. Calibration at this site was for both TSS and TP event flow-weighted concentration, event loads, and cumulative loads. These watershed pollutant loading parameters were applied to all subwatersheds in the Lake Owasso watershed. Because there was no data related to the dissolved phosphorus concentration collected in 2007, the dissolved fraction was not calibrated.

The P8 model was calibrated to the average event flow-weighted concentration for total suspended solids (TSS) and total phosphorus (TP), as well as total event loads and cumulative loads (for the storm events selected for calibration). The pollutant calibration process began with the NURP50% particle file as developed by Walker for the median NURP monitoring site.

4.2.2.2.1 Total Suspended Solids Calibration

Following Walker's calibration steps, suspected monitored outliers were eliminated from the calibration process (Step 5). After completing the water volume calibration, Walker recommends calibrating the TSS (Step 14). Because all other pollutant concentrations are dependent on the amount of solids, TSS calibration is a critical step.

Similar to the runoff volume calibration method, the monitoring site at Galtier Street was used to first calibrate the pollutant parameters related to watershed build-up, wash-off, decay, and impervious and pervious runoff concentrations, as there are no treatment devices such as ponds or wetlands in the contributing watershed.

Five storm events were used for the TSS calibration at Galtier Street. Initial P8 runs applied the NURP50% particle file. Results indicated that P8 both over- and under-predicted TSS concentrations for the various calibration storm events. Based on the cumulative TSS load for the calibration events, P8 resulted in an overall under-prediction of the TSS loads.

P8 predicts TSS loads based on both pervious and impervious surfaces. To address the runoff TSS concentration from the pervious areas, the pervious runoff concentration and the pervious runoff exponent were adjusted for the various particle classes. According to *P8 Urban Catchment Model Program Documentation, Version 2.4* (Walker, 2000) based on typical sediment rating curves the pervious runoff exponent ranges between 0.1 and 1.6 for rivers. Other particle files supplied with the P8 model (NURP90.par, Monroe.par, and Lincoln.par) were reviewed to determine a range for the pervious runoff concentration since no pervious area monitoring data were available. Based on this review the P10% to P50% concentrations were found to range between 100 and 400 mg/L while the P80% concentration ranged between 200 and 800 mg/L. Numerous combinations of the pervious runoff concentration and exponent were examined. A pervious runoff concentration for the P10%-P50% of 100 mg/L and 200 mg/L for the P80% with a runoff exponent of 0.1 produced the best results for pervious runoff concentrations. (50 ppm/1).

According to *P8 Urban Catchment Model Program Documentation, Version 1.1* (Walker, 1990) any of the buildup/washoff parameters can be adjusted for calibration. Rescaling the impervious area particle loading for the different particle classes (P10% - P80%) as recommended in Step 14 of Walker's report was done to reduce the impervious runoff concentration. The NURP50 accumulation rates (1.75 and 3.5 lb/ac/day for P10%-P50% and P80% respectively) were reduced to 1.6 lb/ac/day for the P10%-P50% particle classes and 2.8 lb/ac/day for the P80% particle class. These adjustments alone did not sufficiently reduce the impervious runoff concentration.

The P8 documentation states that the exponential washoff relationship used by the model is similar to that employed by the EPA's Stormwater Management Model (SWMM). Therefore, documentation for SWMM (Huber et al., 1988) was reviewed to determine acceptable values for the washoff parameters. The documentation revealed that the impervious washoff coefficient could range between 1 and 10. It also mentions that this coefficient can vary by almost five orders of magnitude. The SWMM documentation also indicates that the impervious washoff exponent typically ranges between 1.1 and 2.6, with most values near 2.0. The SWMM documentation states that both of the parameters can be varied to calibrate the model to observed data. In addition to the ranges supplied by the SWMM documentation, the other particle files supplied with P8 were reviewed for typical ranges in the buildup/washoff parameters.

Again various combinations for the buildup/washoff parameters were simulated with the best results produced from the following parameters:

- Accumulation rates: 1.6 lb/ac/day (P10%-P50%) and 2.8 lb/ac/day (P80%)
- Accumulation Decay Rate : 0.35 day^{-1}
- Impervious Washoff Coefficient : 5
- Impervious Washoff Exponent : 3.0

Using the buildup/washoff and pervious runoff parameters listed above resulted in the overall arithmetic mean predicted to observed ratio of the flow weighted mean TSS concentration to equal 100 percent based on the representative monitoring site data. Table 4-6 summarizes the results of the TSS (and TP) calibration procedure.

Table 4-6 TSS & TP Calibration Results (LkOwasso.par)

Parameter Adjusted	Calibrated Value
Accumulation Rate (lb/ac/day) (P10%-P50%/P80%)	1.6 / 2.8
Accumulation Decay Rate (1/day)	0.35
Impervious Runoff Coefficient	5
Impervious Runoff Exponent	3
Pervious Runoff Concentration (mg/L) (P10%-P50%/P80%)	50
Pervious Runoff Exponent	1
TP P0% Particle Composition (mg TP/kg TSS)	99000
TP P10%-P80% Particle Composition (mg TP/kg TSS)	3850
TSS Scale Factor	1
TP Scale Factor	0.7

Figure 4-5 shows the TSS (and TP) pollutant loading results for the Galtier Street monitoring station when calibrated to 2007 data.

4.2.2.2.2 Total Phosphorus Calibration

The water quality data at the monitoring sites was limited to total phosphorus data, therefore it was not possible to calibrate the dissolved fraction of phosphorus (TP associated with P0%). It was assumed that the P0 particle composition was equal to that used in the NURP50 particle file (99,000 mg/kg). The remaining TP particle compositions for the other particle fractions (P10%-P80%) were also maintained from the NURP50 particle file. However, the TP scale factor was adjusted to best match the 2007 Galtier Street monitoring data. The TP scale factor was set to 0.7. Table 4-6 summarizes the pollutant loading and water quality component information for the Lake Owasso particle file. Figure 4-5 also shows the pollutant loading calibration results at the Galtier Street monitoring station, which reflects the calibration of the watershed runoff pollutant load (with no water quality improvement practices in place in the watershed).

The next step in the calibration of the P8 model was to calibrate the predicted TP load to the actual monitored loads at the County Road C and West Owasso Boulevard (2007 & 2008) monitoring stations as well as the Dale Street (2008) monitoring stations. The watersheds contributing to these sites have many natural and constructed ponds and wetlands that provide some pollutant removal as water passes through them. See Appendix E for more discussion about the selection of the P8 parameters as well as a summary of the P8 devices.

Grab samples collected in between storm events at County Road C (Central Park – West wetland) during the summer of 2008 indicated that the concentration of the wetland was significantly higher between storm events than the concentrations observed during actual storm events, indicating the potential “internal” loading of TP within the wetland. This internal loading may be the result of a variety of factors, such as the resuspension of sediments due to activity of carp (observed in the wetland during the summer of 2008), phosphorus release from sediments, and other biological activity in the wetland.

Grab samples were also collected at the Dale Street monitoring station (Central Park – East wetland) in 2008, just upstream from the County Road C wetland. However, unlike the grab samples collected at the County Road C wetland, the TP concentrations of the grab samples from the Dale Street site were lower than the TP concentrations observed during storm events. Also, the Dale Street monitoring site was located just downstream from the City of Roseville Leaf Recycling Center. However, the observed TP concentrations at the Dale Street site were similar to typical urban stormwater runoff TP concentrations, indicating that the City of Roseville Leaf Recycling Center may not be a significant source of TP to Lake Owasso.

One of the limitations of the P8 model is that it does not account for particle resuspension or loading as the result of other chemical or biological activity. As a result, a modeling method was developed to estimate a rate of internal TP loading for each waterbody located immediately upstream of the County Road C (Central Park – West wetland), Dale Street (Central Park – East), and West Owasso Boulevard (Charlie Ponds) monitoring stations.

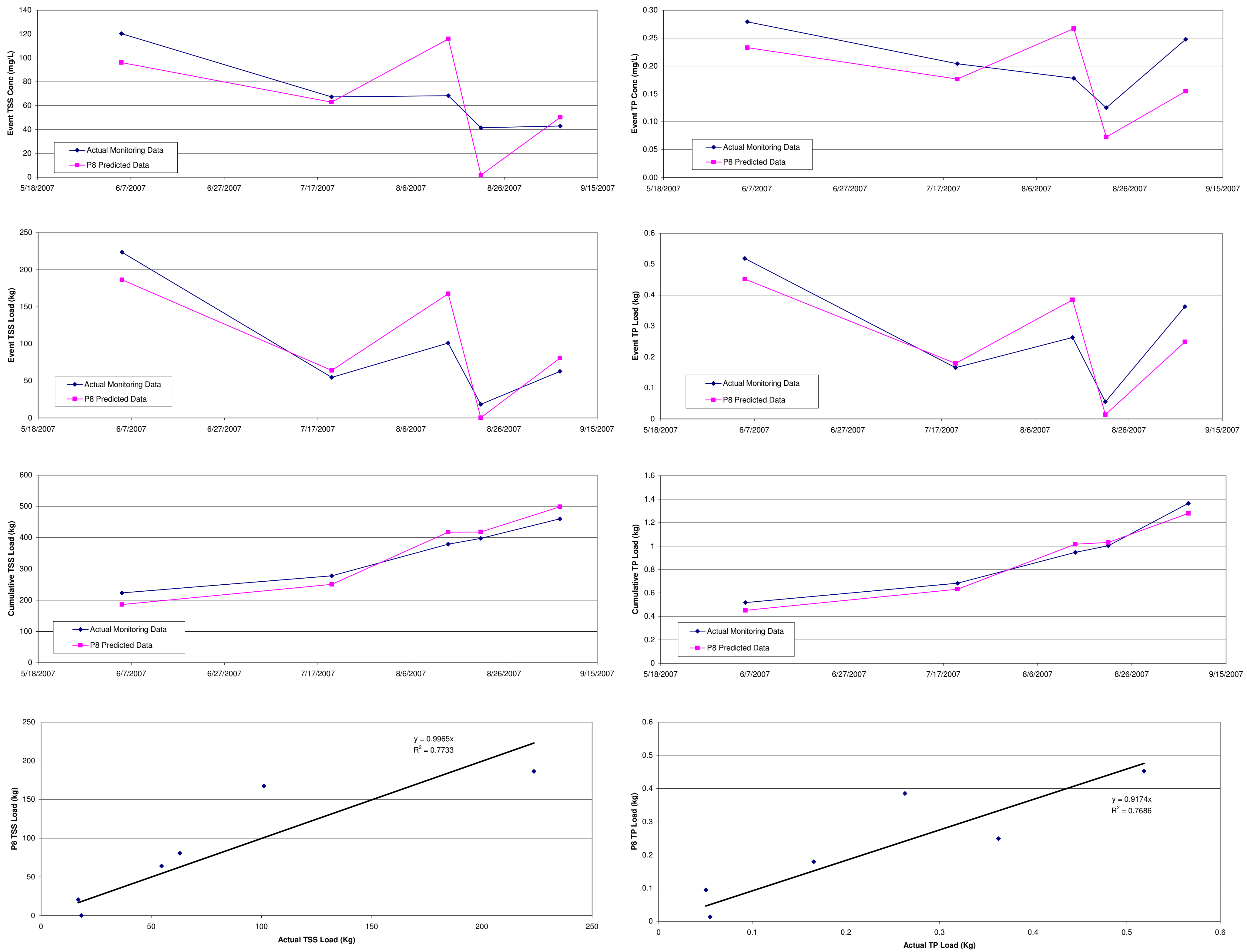

Figure 4-5
2007 Pollutant Calibration at Galtier Street

4.2.2.2.2.1 FLUX Modeling

To help estimate the internal TP loading rate in the water bodies immediately upstream of the County Road C (Central Park – West wetland), Dale Street (Central Park – East wetland), and West Owasso Boulevard (Charlie Pond system) monitoring stations, the FLUX model was used to estimate the actual TP load at each of the runoff water quality monitoring stations.

FLUX is an interactive computer program designed for use in estimating the loadings of water quality components from tributary sampling. FLUX (Walker 1986) uses continuous flow records and parameter concentrations from sampled events to develop flow weighted mean concentrations and loading (in kg/yr) for sites where both flow and sample analysis data are available. For more information about the FLUX model, see Appendix E.

FLUX was used at all the runoff monitoring stations including the County Road C (2008), Dale Street (2008), and West Owasso Boulevard (2007 & 2008) monitoring stations as well as the Galtier Street (2007) monitoring station which was originally used to calibrate the P8 watershed runoff volume and water quality parameters.

TP loads were estimated for the period of record (both flow and water quality) available for each of the sites. Table 4-7 summarizes the estimated TP loads estimated by FLUX at each of the monitoring sites. Also summarized in the table is the P8-predicted TP load for the same period of time as well as the estimated daily "internal" TP loading rate (the difference between the FLUX load and the P8 load divided by the days in the period used for the FLUX modeling). It was assumed the internal loading only occurred during the months of May through September (the growing season).

Table 4-7 FLUX Results and Estimated Internal TP Loading in the Central Park Wetlands (County Road C and Dale St.) and the Charlie Pond System (West Owasso Blvd.)

Monitoring Station	Period	FLUX TP Load (lbs)	P8 TP Load (lbs)[1]	Pond Area @ NWL (acres)	Internal TP Loading Rate ($mg/m^2/d$)
Galtier St	5/7/2007 – 10/3/2007	14.3	12.3	N/A	N/A
Dale Street (Central Park – East)	5/10/2008 – 9/29/2008	31.2	6.6	20.3	1.0
County Road C (Central Park – West)	5/10/2008 – 7/3/2008	40.3	9.0	11.6	5.1
West Owasso Blvd. (Charlie Ponds)[2]	5/10/2007 – 10/3/2007	21.3	4.7	3.5	2.9
	5/10/2008 – 9/29/2008	12.1	2.5	3.5	

1 – P8 loads based on existing land use conditions

2 – Internal TP loading rate in the Charlie Pond System was based on the average of the rates estimated for 2007 and 2008.

4.2.2.2.2.2 Total Phosphorus Mass Balance Model of the Central Park – West Wetland (County Road C)

The internal TP load in each wetland was originally estimated based on the application of the daily internal loading rate (as estimated by the comparison of the FLUX and P8 modeling results) and the period of each P8 storm event. However, applying the daily internal TP loading rate alone makes the assumption that the internal TP load from each water body reaches the lake during each storm event.

Actual flow monitoring data for the County Road C and Dale Street monitoring stations indicate that there are periods during both the summers of 2007 and 2008 where the water levels in the wetlands are below the normal water levels and were not discharging downstream into Lake Owasso. During these periods with low water levels (water levels below the normal water level),, any internal phosphorus load would accumulate in the wetlands until the water levels rise and the water body begins to discharges downstream (to Lake Owasso).

In order to account for the accumulation of the internal phosphorus load in the wetland during low water levels and the discharge from the wetland when water levels rose above the outlet elevation, a phosphorus mass balance model was developed for the Central Park – West wetland (County Road C). This model considers both the water and phosphorus loads and losses as predicted by the P8 model, the available storage available in the wetland, and the daily internal TP load (the sum of the load from the Central Park – East and Central Park – West wetlands).

The mass balance model calculated the TP mass (and concentration) in the Central Park – West wetland for each storm event period through the summer of 2008, using the following equation:

Wetland P = Observed P + Runoff P + Upstream Device P + Internal P – Infiltration P – Discharge P

For the first iteration of this TP mass balance, the internal TP load in each wetland was estimated based on the application of the daily internal loading rate (as estimated by the comparison of the FLUX and P8 modeling results) and the period of each P8 storm event. The estimated daily internal phosphorus load from the Central Park - East wetland (Dale St) was also adjusted to reflect periods when the wetland was not discharging downstream to the Central Park – West (County Road C) wetland.

Grab samples collected from the Central Park – West wetland between storm events during the summer of 2008 indicated a maximum observed TP concentration of 580 µg/L. In the mass balance model, it was assumed that the maximum wetland TP concentration (as the result of accumulating phosphorus loads) could not exceed 600 µg/L. Using the original internal TP load numbers resulted in wetland TP concentrations greater than 600 µg/L. Therefore, the threshold TP concentration of 600 µg/L and the phosphorus loads and losses predicted by P8 were used to back-calculate the maximum internal TP load within the wetland. If the back-calculated internal TP load was less than the load originally predicted based on the daily internal loading rate predicted by the FLUX modeling, the back-calculated load was used; otherwise, the original internal TP load was used in the mass balance. The mass balance was then used to estimate the TP concentration within the Central Park – West wetland.

The estimated wetland TP concentration (as predicted from the mass balance) and discharge volume (as predicted by the calibrated P8 model) were used to calculate the actual TP load reaching Lake Owasso as the result of the internal loading in the Central Park – East and West wetlands.

For the Charlie Pond system (West Owasso Blvd), a TP mass balance was not used to estimate the internal TP load to Lake Owasso from this system as was done for the Central Park – West Wetland. Unlike the Central Park – West wetland, continuous flow was observed at the West Owasso Blvd. monitoring station for the majority of both the summers of 2007 and 2008. As a result, only the estimated daily internal loading rate from the P8/FLUX comparison was applied for each storm event.

The internal TP loads estimated for waterbodies upstream of both the County Road C and West Owasso Blvd. discharges were then used inputs into the in-lake water quality model. The TP loads input into the in-lake water quality model were adjusted to differentiate between the dissolved phosphorus and the phosphorus associated with particulates (that would settle out more quickly and have less impact on the overall water quality in Lake Owasso). The TP load was adjusted by a factor of 0.44 (the ratio of dissolved phosphorus to total phosphorus based on the 2008 grab samples collected the County Road C site). See Section 4.3 for a more complete discussion of the Lake Owasso in-lake water quality modeling.

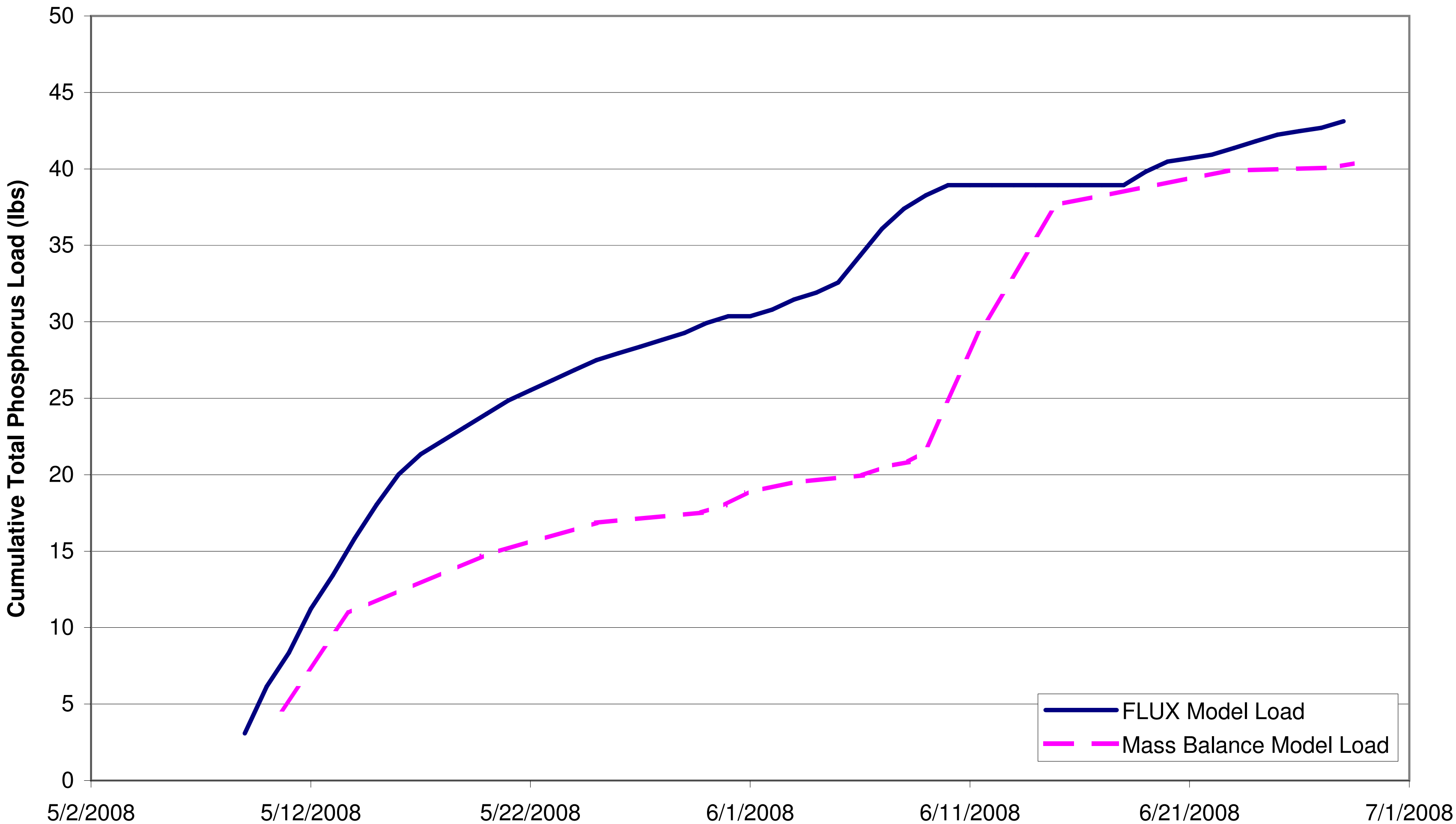

Figure 4-6
Total Phosphorus
Mass Balance Loads vs. FLUX Loads
for Central Park - West (County Road C) Wetland - 2008

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4.3 In-Lake Water Quality Model

4.3.1 In-lake Water Quality Modeling Methodology

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

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

- "Dry" climatic conditions: May 2007 - September 2008
- "Average" climatic conditions: May 2004- September 2005
- "Wet" climatic conditions: May 2001- September 2002

Water quality data has been collected in Lake Owasso since the early 1970's. The monitoring location was in the northern portion of the lake (site 5401). However, in 2007 and 2008, the detailed in-lake water quality monitoring data was collected at two different locations within Lake Owasso (Site 5401 in the north and Site 5403 in the south). For the initial calibration of the Lake Owasso in-lake water quality model, the 2007 and 2008 water quality and the 2007 macrophyte survey data were used. The in-lake model was developed as a two basin model. Figure 4-7 shows the division of Lake Owasso as modeled in the two-basin in-lake model for 2007 and 2008.

Because there was a significant amount of historic water quality data available at depth for Lake Owasso, in-lake modeling was performed for each climatic condition to estimate the internal loading (from sediments and macrophyte senescence) within Lake Owasso. Parameters calibrated to the 2007 and 2008, such as the macrophyte coverage and estimated growth and die-back dates, were applied to all climatic condition models. Watershed runoff loads as predicted by P8, as well as the estimated watershed wetland "internal" loads, were developed specifically for each climatic condition.

The 2008 calibration year was selected to be representative of the dry climatic conditions for Lake Owasso, and was modeled as a two-basin in-lake model. For the wet (2002) and average (2005) climatic conditions, water quality data was only available at the northern sampling site (site 5401) and the in-lake water quality model was developed as a single basin.

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

The method described in the following sections was used for existing land use conditions under a variety of climatic conditions. Once the internal loading rates have been calculated, the model could be used predictively, to evaluate lake phosphorus concentrations under a variety of BMP scenarios for each hydrologic condition. Impacts as the result of futures changes in land use were not evaluated as the Lake Owasso watershed is already fully-developed, the expected changes are minimal. As a result, the changes in the pollutant loads to the lake will not have a significant impact on the overall lake water quality.

4.3.1.1 Predicting Springtime Concentration in Lake Owasso

4.3.1.1.1 Predicting Springtime Concentration in Lake Owasso – Dry Conditions (2008) – Two Basin Model

Water quality monitoring data from Lake Owasso was used to determine the empirical model that could best predict the spring concentration in the lake. For the southern portion of Lake Owasso (Station 5403), the Dillon and Rigler model with a phosphorus retention term from Nurnberg (1984) was used to predict the spring total phosphorus concentration.

$$\mathrm{P}_{SPRING} = \frac{L(1-R)}{z\rho}$$

where:

P_{SPRING} = spring total phosphorus concentration (µg/L)
L = areal total phosphorus loading rate (mg/m²/yr)
R = retention coefficient as defined by Nurnberg (1984)
= $15/(18+q_s)$
q_s = annual areal water outflow load (m/yr)
= Q/A
z = lake mean depth (m)
ρ = hydraulic flushing rate (1/yr)
= 1/(hydraulic residence time) = 1/(V/Q)
Q = annual outflow (m³/yr)
V = lake volume (m³)
A = lake surface area (m²)

For the northern portion of Lake Owasso (Station 5401), the Dillon and Rigler model with a phosphorus retention term from Larsen and Mercier (1976) was used to predict the spring total phosphorus concentration.

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

where:

P_{SPRING} = spring total phosphorus concentration (µg/L)
L = areal total phosphorus loading rate (mg/m²/yr)
R = retention coefficient as defined by Larsen and Mercier (1976)
= $1/(1+\rho^{(1/2)})$
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)

4.3.1.1.2 Predicting Springtime Concentration in Lake Owasso – Wet and Average Conditions (2002 & 2005) – One Basin Model

For the wet (2002) and average (2005) climatic scenarios where Lake Owasso is modeled as a single basin, the Dillon and Rigler empirical model with a phosphorus retention from Larsen and Mercier (1976) was used to predict the spring total phosphorus concentration.

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

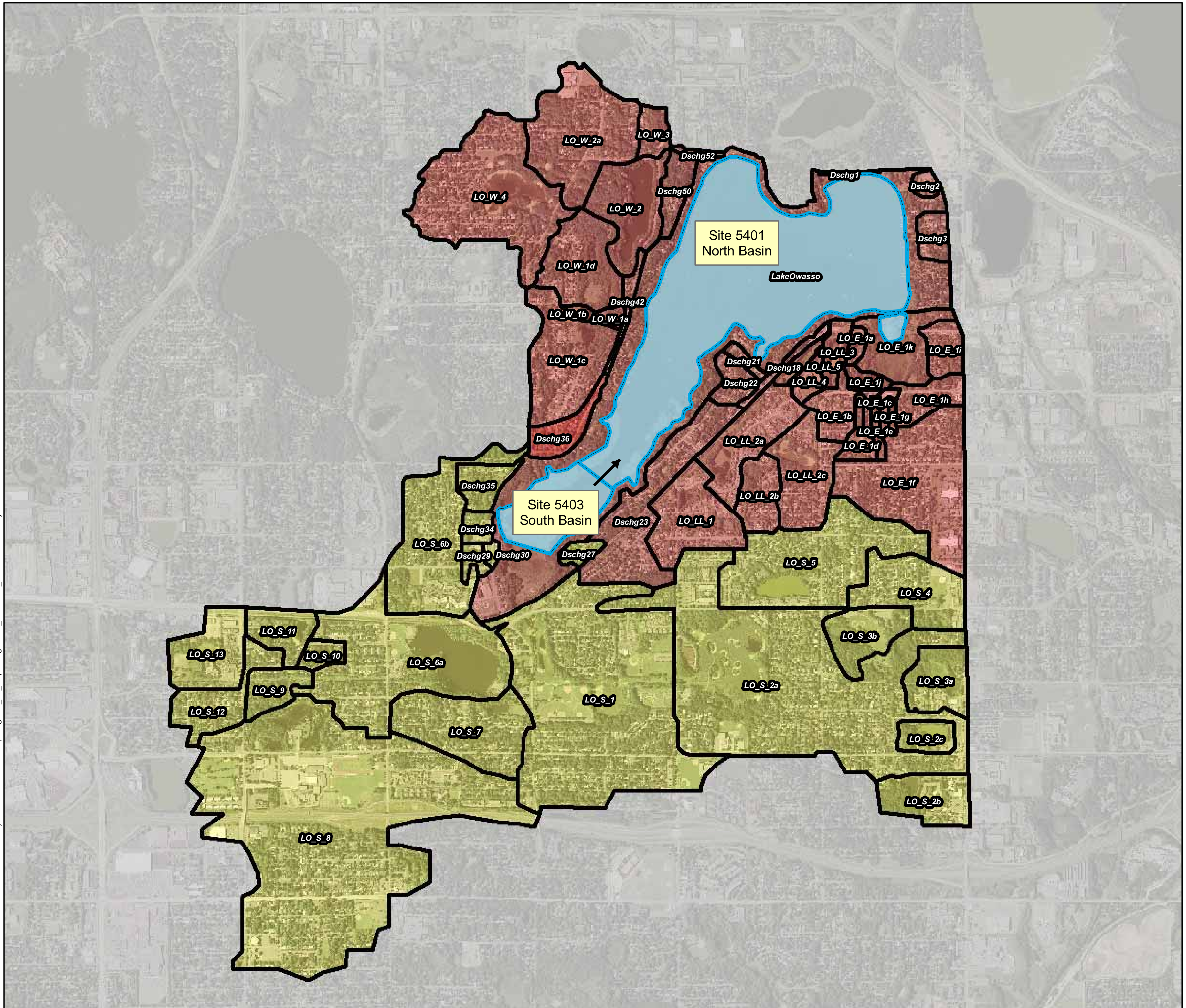
where:

P_{SPRING} = spring total phosphorus concentration (μg/L)
L = areal total phosphorus loading rate (mg/m²/yr)
R = retention coefficient as defined by Larsen and Mercier (1976)
= $1/(1+\rho^{(1/2)})$
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)

For all the in-lake water quality models (both the single-basin and two-basin models), the areal loading rate to Lake Owasso was based on the watershed loads (as predicted by the P8 model) as well as the internal loads from the Central Park wetlands (County Road C) and Charlie Pond system (predicted by the TP mass balance on the Central Park – West wetland and by the TP loading rate estimated by the FLUX modeling, respectively), For the two basin in-lake model, the watershed loads to the southern basin (5403) included the P8 watershed loads as well as the internal loads from the Central Park – East and Central Park – West wetlands. The loading rate to the northern basin (5401) was based on the P8 predicted watershed loads, the internal loads from the Charlie Pond system, as well as loads from the southern basin (5403). Additionally, in all cases, the in-lake water quality model also included the load associated with groundwater inflows (predicted by the water loads from the WATBUD model and the Lake Owasso water balance along with an assumed TP concentration of 25 μg/L, a value typical in groundwater in the Twin Cities metropolitan area (USGS, 2005)).

Early summer, summer-average and fall overturn concentrations, however, are often not well represented in steady state empirical models such as Dillon and Rigler. Most empirical phosphorus models assume that the lake to be modeled is well-mixed, meaning that the phosphorus concentrations within the lake are uniform. This assumption is useful in providing a general prediction of lake conditions (especially for springtime concentrations), but it accounts for neither the seasonal changes in phosphorus concentrations nor the effect of internal phosphorus load that can occur in a lake throughout the summer and fall. Therefore, mass balance models are needed that look at the effect of the total phosphorus loads at different timesteps throughout the year to provide reasonable predictions of summer-average epilimnetic lake phosphorus concentrations.

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



Division of Lake Owasso into Two-Basins for In-Lake Water Quality Modeling

To Site 5401 (North Basin)

To Site 5403 (South Basin)

Subwatersheds

Note: The area directly tributary to Lake Owasso (subwatershed "Lake Owasso") was routed directly to the north basin for in-lake water quality modeling purposes.

Feet

1,750 0 1,750

N

Figure 4-7

LAKE OWASSO
TWO-BASIN IN-LAKE
WATER QUAILTY MODEL (2008)

Lake Owasso UAA
Grass Lake Watershed Management Organization

Barr Footer: Date: 3/22/2009 5:35:47 PM File: I:\Projects\23\62\946\GIS\Maps\Figures_for_Report\Figure4-7_TwoBasin_Model.mxd User: jak2

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

As previously mentioned, a spreadsheet mass balance model based on Dillon and Rigler (1974) was used to reconcile phosphorus loadings from the watershed with phosphorus concentrations observed in the lake. The in-lake mass balance model routes external and internal phosphorous loads through the lake over the summer season (May through September).

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

Internal P = Observed P + Outflow P + Coontail Uptake P – Watershed Runoff P – P from Curlyleaf Pondweed - Atmospheric P ± Groundwater P

In the above mass balance model, the watershed runoff P term includes both the watersheds runoff (as predicted by the P8 model) as well as the estimated internal TP load from wetlands and waterbodies within the Lake Owasso watershed.

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

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

Uptake of phosphorus by coontail was also estimated in the model, using the following equation from Lombardo and Cooke (2003):

$$\mu g\ TP/g\ (plant\ ww)/d=1/(.0927\cdot(weeks)-.0097)$$

Where

ww = Plant wet weight per m^2, estimated based on a qualitative density measurement (range of 1 to 3, based on macrophyte monitoring on the lakes). The qualitative density measurements were related to wet weight based on data by Vidakoviae et al. 2002, and Newman, 2004.