7.0 Water Quality Modeling for the UAA

Phosphorus levels in Lake Holiday, Wing Lake, and Lake Rose are high. The TP levels in these lakes will continue to be greatly affected by the amount of phosphorus loading each lake receives. For this study, a detailed analysis of current and future discharges was completed to determine phosphorus sources and management opportunities to reduce the amount of phosphorus added to each lake. Phosphorus typically moves either in water as soluble phosphorus (dissolved in the water) or attached to sediments carried by water. Therefore, the determination of the volume of water discharged annually to Lake Holiday, Wing Lake, and Lake Rose is integral to defining the amount of phosphorus discharged to the lake.

7.1 Use of the P8 Model

The P8 model was used (see Section 2.3) to estimate both the water and phosphorus loads introduced from the entire Lake Holiday, Wing Lake, and Lake Rose watersheds. The model requires hourly precipitation and daily temperature input data; long-term climatic data can be used so that watersheds and BMPs can be evaluated for varying hydrologic conditions.

Hourly precipitation data was obtained from NMCWD rain gages in Eden Prairie and Hopkins and from the National Weather Service (NWS) site at the Minneapolis-St. Paul International Airport (MSP), approximately 12 miles away from the lakes. The Eden Prairie gage is located between 2 and 3 miles from the lakes; the Hopkins gage is located about 4 miles from the lakes. Precipitation data for 1992-1993 includes data from the Eden Prairie gage for the periods from April through October and data from the MSP gage for all other periods. Data for average climatic conditions includes precipitation from the Eden Prairie gage for April 1998 through October 1998, precipitation from the Hopkins Gage for April 1999 through October 1999, and MSP data for the remainder of the period. MSP data was also used for specific storms in early-April 1998 and mid- to late-April 1999. Data for dry climatic conditions includes precipitation from the Hopkins gage for April 2007 through September 2007 and April 2008 through August 2008. Precipitation data for October 2007 is based on the Hopkins gage. All remaining precipitation data for 2007 and 2008 is derived from the MSP gage. Daily temperature data was obtained from the Minneapolis-St. Paul International Airport for all modeled periods.

When evaluating the results of P8 modeling, it is important to consider that the results provided are more accurate in terms of relative differences than in terms of absolute results. The model will predict the percent difference in phosphorus reduction between various BMP scenarios 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 can be expected to be typical of the region, given the watershed's respective land uses.

7.2 Water Quality Model (P8) Calibration

7.2.1 Climatic Conditions

The annual water and watershed phosphorus loadings for Lake Holiday, Wing Lake, and Lake Rose under existing land use conditions were estimated for three different years, each representing a distinct climatic pattern. The varying climatic conditions affect each lake's volume and hydrologic residence time, and thereby affect the phosphorus concentrations in the lake. Selection of average, wet, and dry years was based on summer precipitation relative to the average recorded at Minneapolis-St. Paul International Airport. The selection of wet, average, and dry summers was limited to those years for which observed water quality data from Lake Holiday, Wing Lake, and Lake Rose exists. The precipitation totals during the three years modeled are summarized in Table 7-1.

Table 7-1 Precipitation Amounts for Various Climatic Conditions

Climatic Condition	Water Year (Oct 1 through Sept 30) Precipitation (inches)	Growing Season (May 1 through Sept 30) Precipitation (inches)
Dry (2007-2008)	22.58	14.00
Average (1998-1999)	27.46	19.89
Wet (1992-1993)	34.41	24.42

As previously discussed, the external and internal loading for Lake Holiday, Wing Lake, and Lake Rose varies during different climatic conditions. Water quality data was available for all of these lakes in the summers of 1993, 1999, and 2008.

7.2.2 P8 Model Development

The P8 watershed model was developed used existing data, including watershed areas, land use types, soil types, and stormwater system data (e.g. detention basin sizes, pumping rates). A separate

P8 model was developed for each lake, including only watersheds tributary to that lake (e.g. the Wing Lake P8 model did not include watersheds tributary to Lake Holiday, or inflow from Lake Holiday). Thus, the P8 models calculate only the water load and TP load in the stormwater runoff arriving at each lake.

7.2.2.1 P8 Model – Stormwater Volume Calibration

The P8 models could not be directly calibrated based on stormwater volume. There is no stormwater outflow monitoring data within the Holiday-Wing-Rose watersheds, to which P8 model results could be compared. In addition, water surface elevations are not available for Lake Holiday (the only lake for which precipitation and stormwater runoff are the only water balance inputs). Water level data exists for Wing Lake and Lake Rose. Those lakes, however, are heavily influenced by the inflow from the upstream lakes, which complicates calibration of the P8 model to stormwater volumes. Instead, the P8 model calibration was based on an overall water balance developed for each lake (described in Section 7.2.3).

7.2.2.2 P8 Model – Phosphorus Loading Calibration

Because no data had been collected regarding the inflow water quantity or quality for Lake Holiday, Wing Lake, or Lake Rose, detailed calibration of the P8 model was not possible. Thus, the P8 model output, used as input for the in-lake model (see Section 7.3) is considered to be best-suited for evaluating relative changes in loading under varying watershed conditions.

7.2.3 Water Balance Development and Calibration

Accurately modeling water quantity and quality in Lake Holiday, Wing Lake, and Lake Rose is difficult due to the serial nature of the lakes. The water and TP balance in Lake Holiday impacts Wing Lake, which in turn impacts Lake Rose. Thus, water balances for these lakes must be developed sequentially, beginning with Lake Holiday.

7.2.3.1 Lake Holiday Water Balance

To translate the water loadings into water surface elevations, a water balance spreadsheet model was utilized for Lake Holiday. The model uses estimated daily inflows (predicted by the P8 model), daily precipitation, daily evaporation, and net groundwater flow in conjunction with an outlet rating curve and area-volume-elevation relationship to estimate total annual outflow. Evaporation data used in the water balance was based on observed pan evaporation data for St. Paul, Minnesota, obtained from the Minnesota Climatology Working Group. A coefficient of 0.7 was applied to estimate open water evaporation. The volume-area-elevation relationship was developed based on a bathymetric survey of Lake Holiday performed in April 2009. The outlet rating curve was based on the pumping strategy for Lake Holiday. The pumping capacity of the Lake Holiday outlet is 7.0 cfs. There are three pumps; one pump turns on when the water surface elevation reaches 936.7, a second when the water level reaches 937.2 feet, and the third when the water level is above 937.7 feet. Pumping to Wing Lake is automated based on water level.

There are no observed water surface elevations for Lake Holiday. Therefore, the water balance could not be directly calibrated. Instead, the Lake Holiday water balance was calibrated in conjunction with the Wing Lake water balance. That is, the Lake Holiday P8 and water balance models and Wing Lake P8 and water balance models were calibrated such that the Wing Lake water balance model approximates the observed water levels in Wing Lake.

A Lake Holiday water balance was developed for 1993 (wet conditions), 1999 (average conditions), and 2008 (dry conditions). The final calibrated water balance for Lake Holiday is presented in Figures 7-1, 7-2, and 7-3, for wet, average, and dry conditions, respectively. The water balance was initially developed with a net groundwater flow of zero. The calibration process resulted in a net groundwater outflow of about 0.1 inches per day (which corresponds to about 0.07 acre-feet per day) from Lake Holiday.

7.2.3.2 Wing Lake Water Balance

To translate the water loadings into water surface elevations, a water balance spreadsheet model similar to the one developed for Lake Holiday was utilized for Wing Lake. The Wing Lake water balance included the same inputs and outputs, with the addition of upstream inflow from Lake Holiday. The volume-area-elevation relationship was developed based on a bathymetric survey of Wing Lake performed in April 2009. The outlet rating curve for Wing Lake is based on hydraulic calculations developed for the Wing Lake outlet. It should be noted that the Wing Lake outlet has a small hole located about 1 foot below the design outlet elevation. The outlet rating curve accounts for the combined flow through the designed outlet and the small hole (which outlets first).

The Wing Lake water balance was calibrated for 1993 (wet conditions), 1999 (average conditions), and 2008 (dry conditions). The final calibrated water balance for Wing Lake is presented in Figures 7-4, 7-5, and 7-6, for wet, average, and dry conditions, respectively. The water balance was initially developed with a net groundwater flow of zero. The calibration process resulted in a net groundwater outflow of about 0.1 inches per day (which corresponds to about 0.11 acre-feet per day) from Wing Lake.

7.2.3.3 Lake Rose Water Balance

Similar to Lake Holiday and Wing Lake, a water balance spreadsheet model was developed and calibrated for Lake Rose. The Lake Rose water balance includes similar inputs and outputs to the upstream lakes, with the addition of upstream inflow from Wing Lake. The volume-area-elevation relationship was developed based on a bathymetric survey of Lake Rose performed in April 2009. The outlet rating curve for Lake Rose is based on hydraulic calculations developed for the Lake Rose outlet as well as results from an XP-SWMM hydrologic/hydraulic model of Minnetonka. It should be noted that the Lake Rose outlet was lowered from 927.1 feet to 926.6 feet between 1993 and 1999. During model calibration, the Lake Rose outlet was set at the elevation corresponding to the period of observed water levels to which the model was calibrated (e.g. when evaluating model calibration with respect to wet climatic conditions, 1993 observed water level data were used, so the lake outlet elevation was set to 927.1 MSL).

The Lake Rose water balance was calibrated for 1993 (wet conditions), 1999 (average conditions), and 2008 (dry conditions). The final calibrated water balance for Lake Rose is presented in Figures 7-7, 7-8, and 7-9, for wet, average, and dry conditions, respectively. The water balance was initially developed with a net groundwater flow of zero. The calibration process resulted in a net groundwater outflow of about 0.14 inches per day (which corresponds to about 0.3 acre-feet per day) from Lake Rose.

7.2.3.4 Validation of P8 Runoff Results

Following the calibration of the net groundwater flow and the P8 runoff model using the water balances described above, the stormwater runoff volume calibration was then verified. The modeled surface runoff water load from the Lake Holiday watershed (assuming existing land use conditions) ranges from 158 to 199 acre-feet per year, which is equivalent to 6.8 to 8.6 inches of runoff over the watershed area tributary to Lake Holiday. The modeled surface runoff water load from the Wing Lake watershed (assuming existing land use conditions) ranges from 69 to 81 acre-feet per year, which is equivalent to 7.4 to 8.7 inches of runoff over the watershed area tributary to Wing Lake. The modeled surface runoff water load from the Lake Rose watershed (assuming existing land use conditions) ranges from 79 to 100 acre-feet per year, which is equivalent to 4.2 to 5.2 inches of runoff over the watershed area tributary to Lake Rose. The amount of runoff to Lake Rose is less than the other lakes (despite similar land use) because of a large wetland through which most of the runoff tributary to Lake Rose must pass. This wetland (in Subwatershed 700) allows an opportunity for infiltration, reducing the amount of runoff reaching the lake. The infiltration occurring in this wetland was estimated to occur at a rate of 0.008 inches per hour, or 0.19 inches per day; this rate was determined during the simultaneous calibration of the Lake Rose P8 model and water balance.

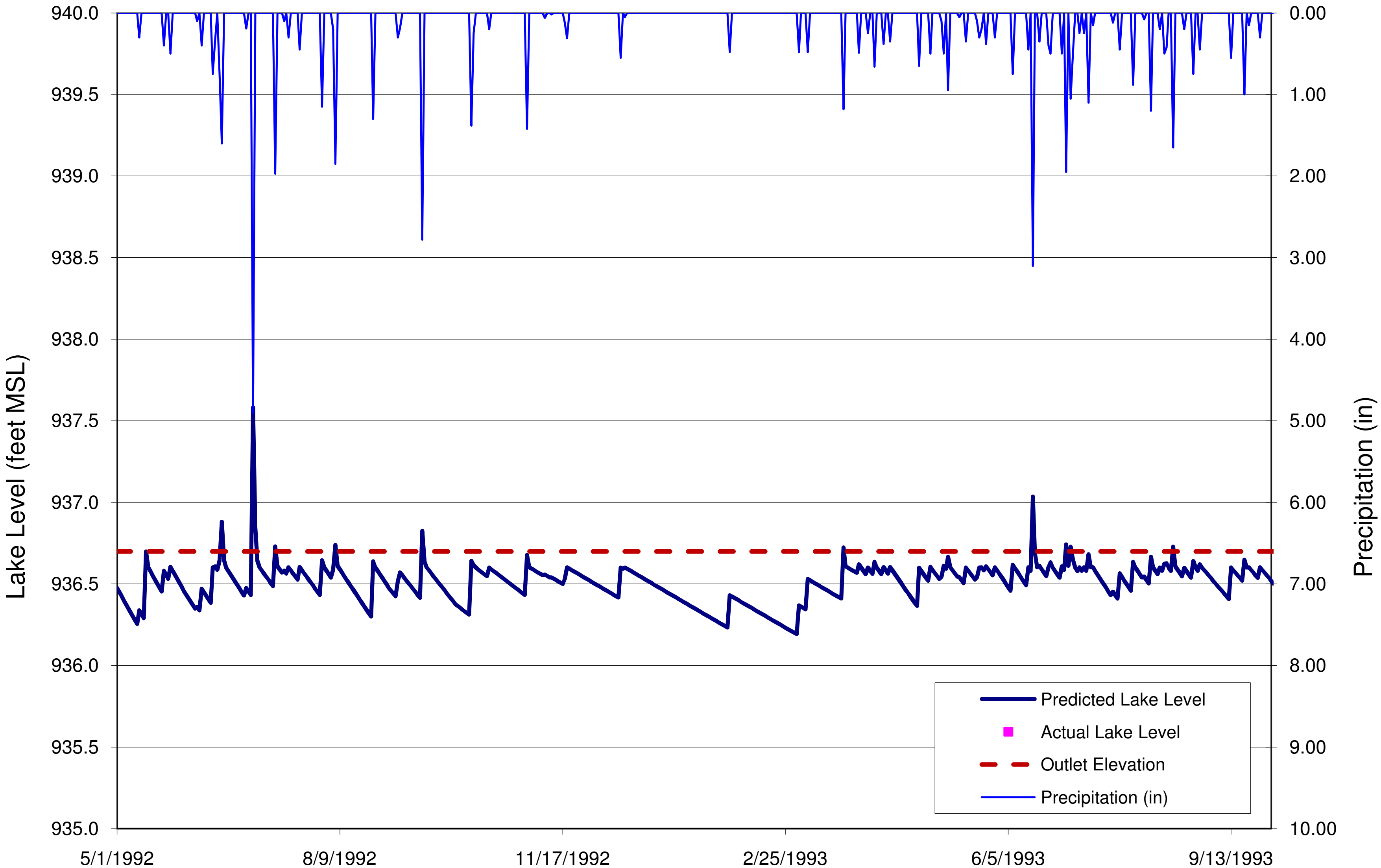


Figure 7-1
Lake Holiday Calibrated Water Balance Model
1992-1993 (Wet Conditions)

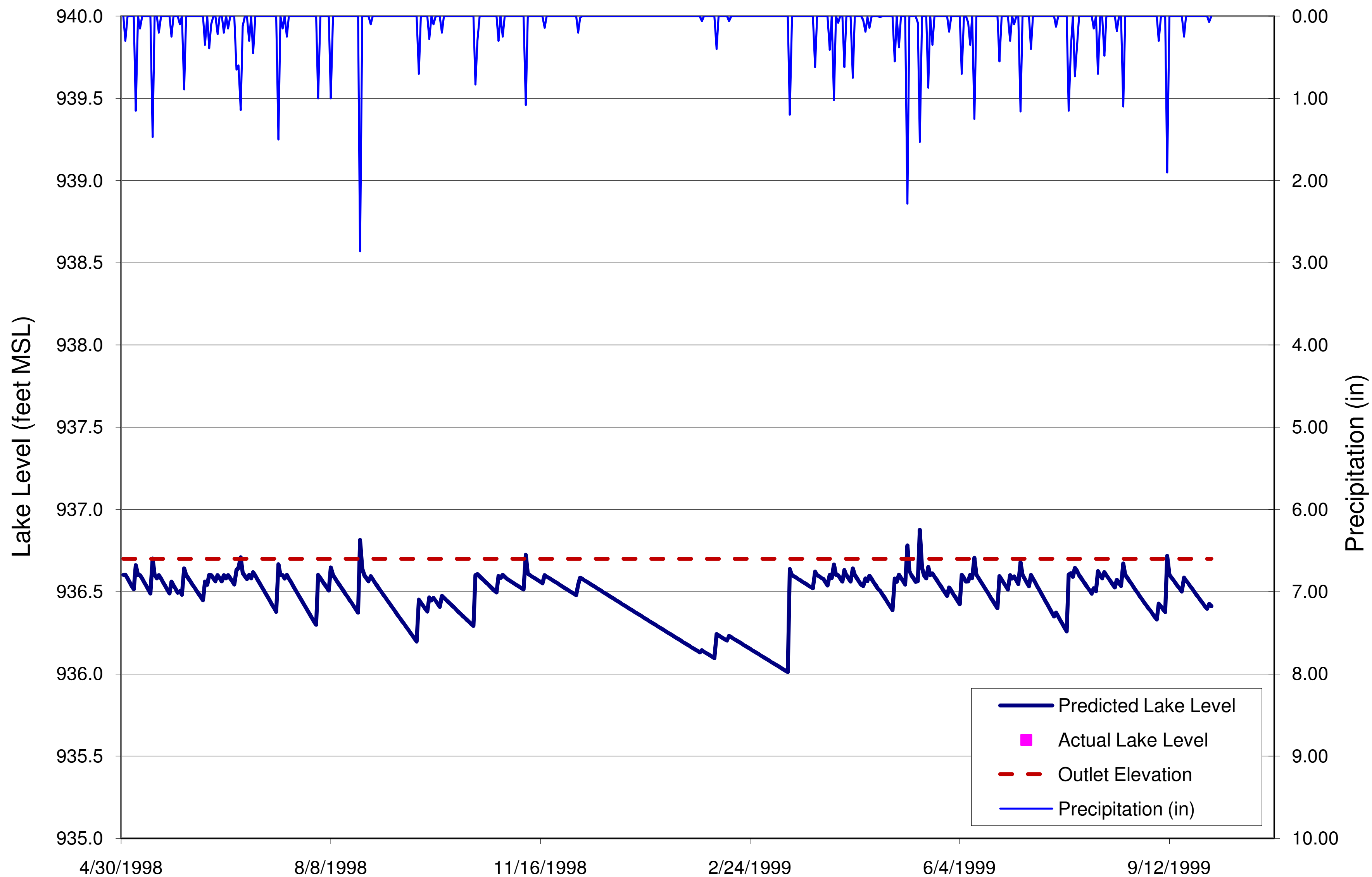


Figure 7-2
Lake Holiday Calibrated Water Balance Model
1998-1999 (Average Conditions)

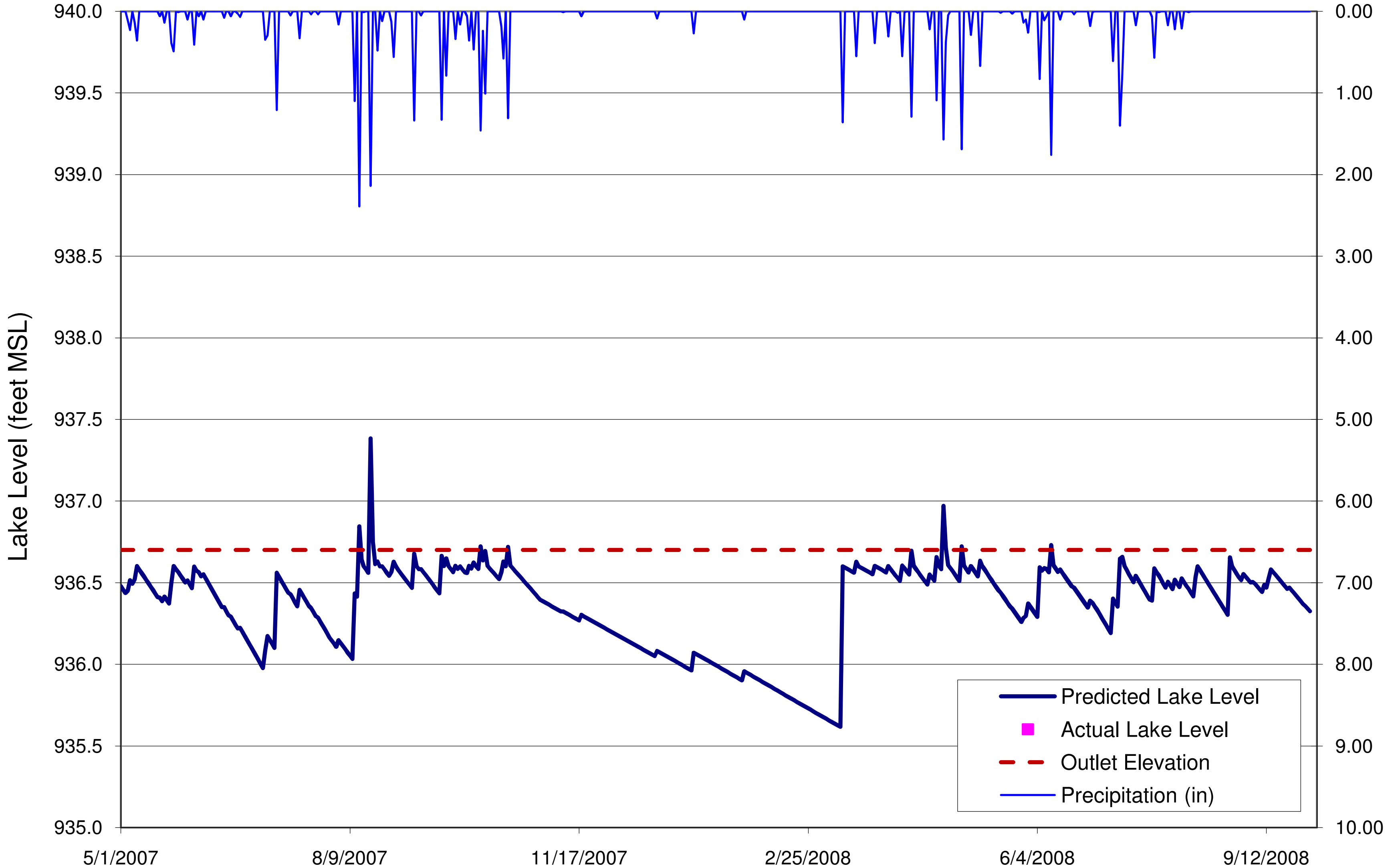


Figure 7-3
Lake Holiday Calibrated Water Balance Model
2007-2008 (Dry Conditions)

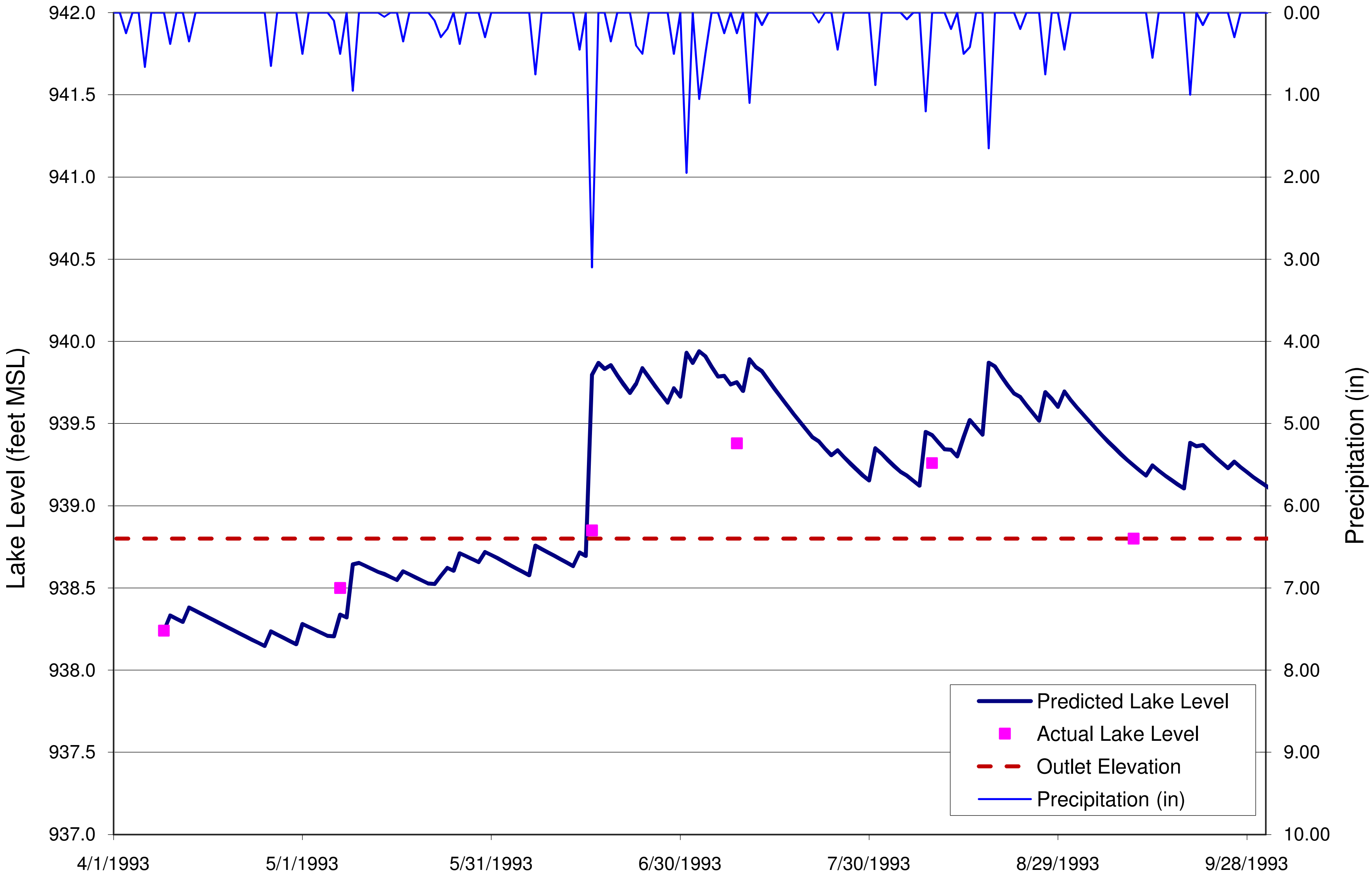


Figure 7-4
Wing Lake Calibrated Water Balance Model
Summer 1993 (Wet Conditions)

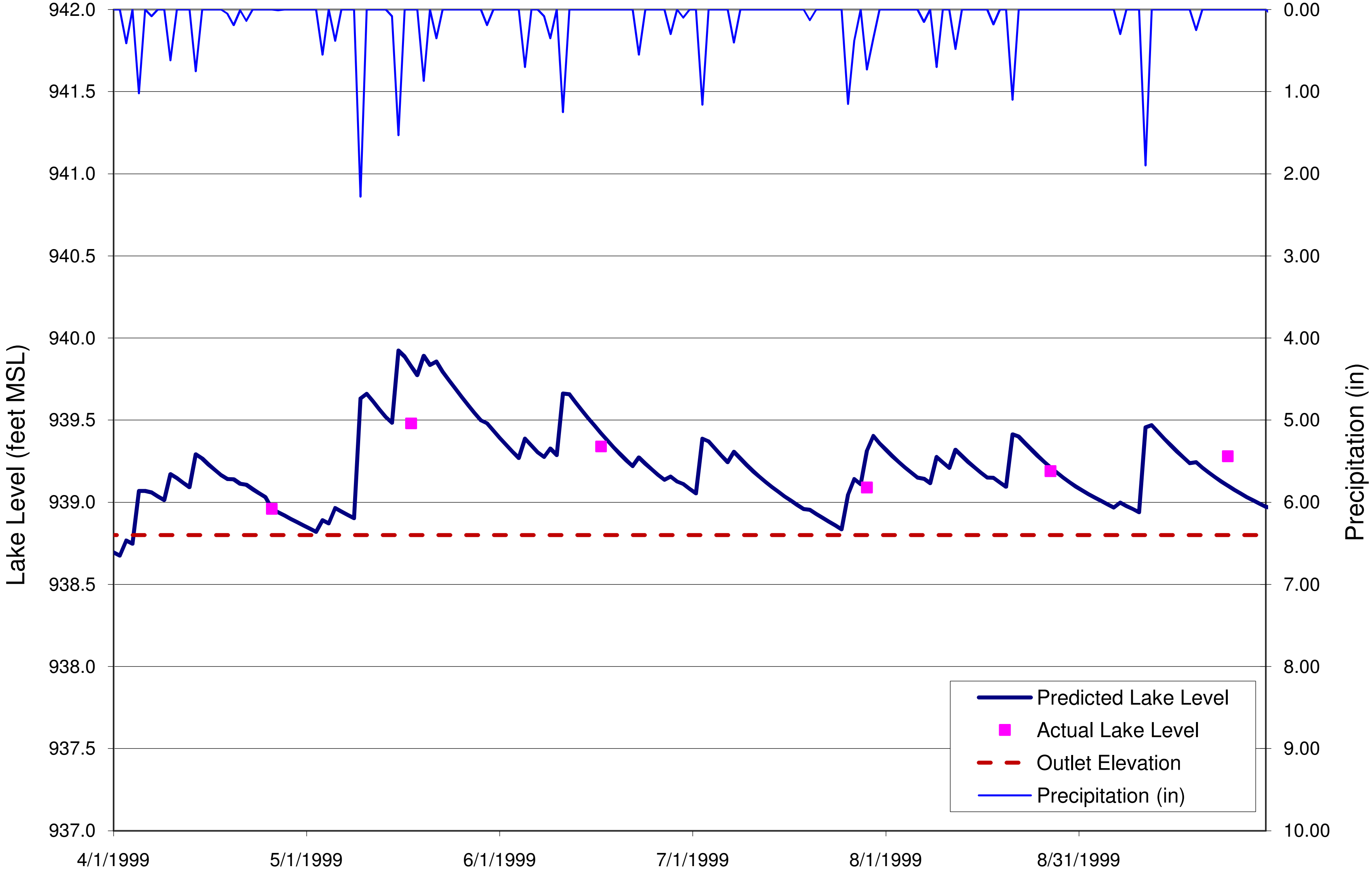


Figure 7-5
Wing Lake Calibrated Water Balance Model
Summer 1999 (Average Conditions)

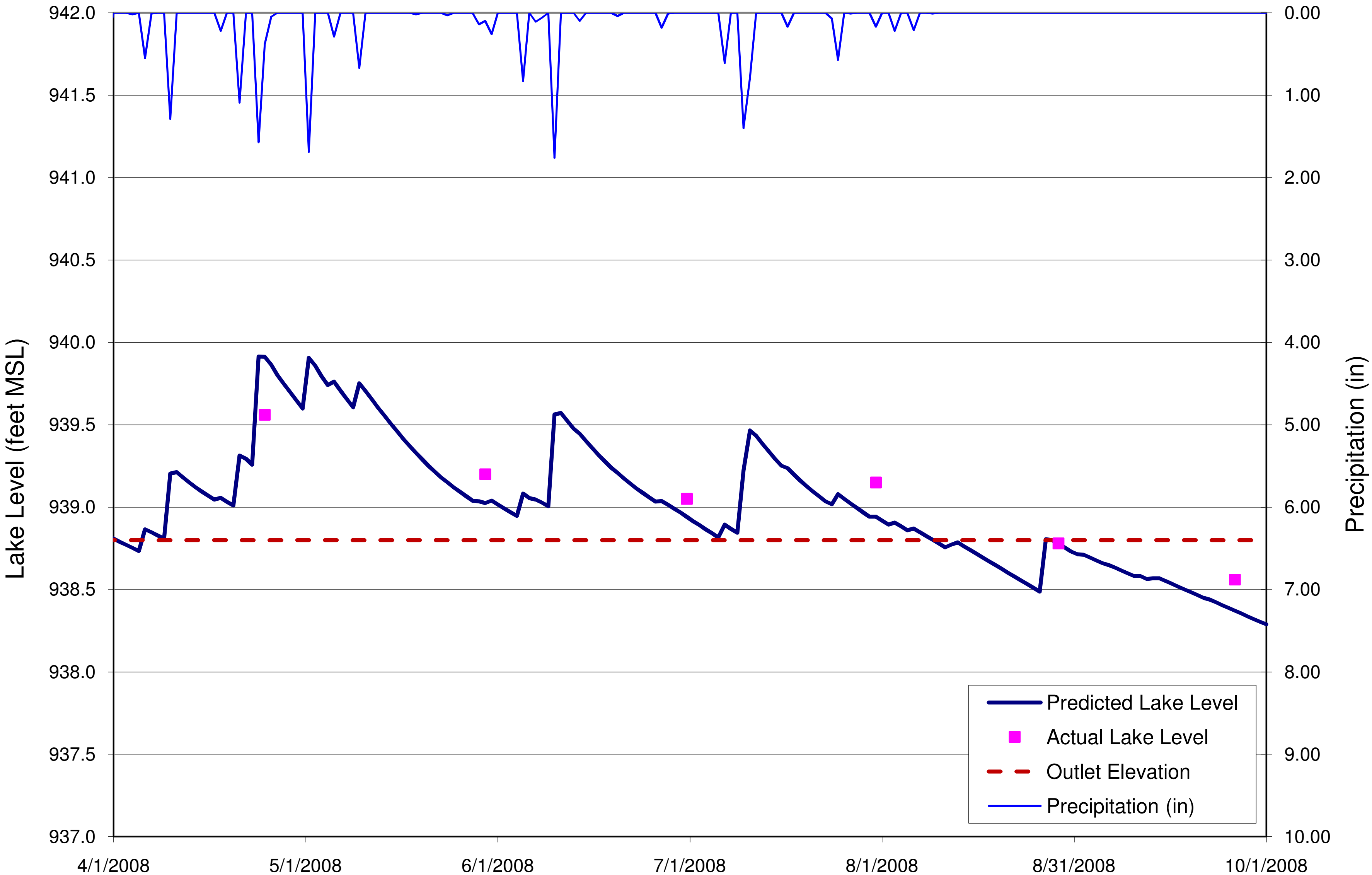


Figure 7-6
Wing Lake Calibrated Water Balance Model
Summer 2008 (Dry Conditions)

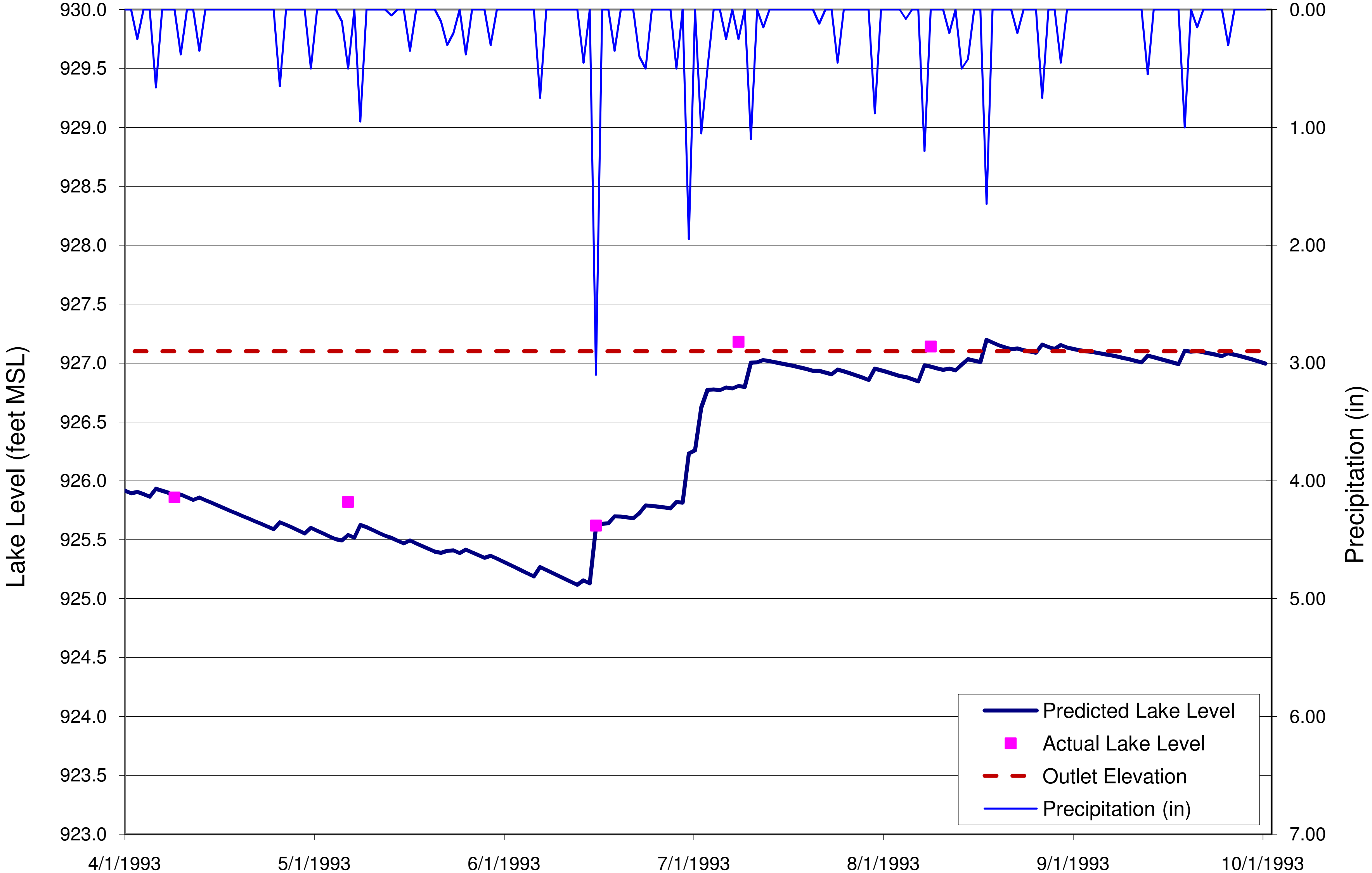


Figure 7-7
Lake Rose Calibrated Water Balance Model
Summer 1993 (Wet Conditions)

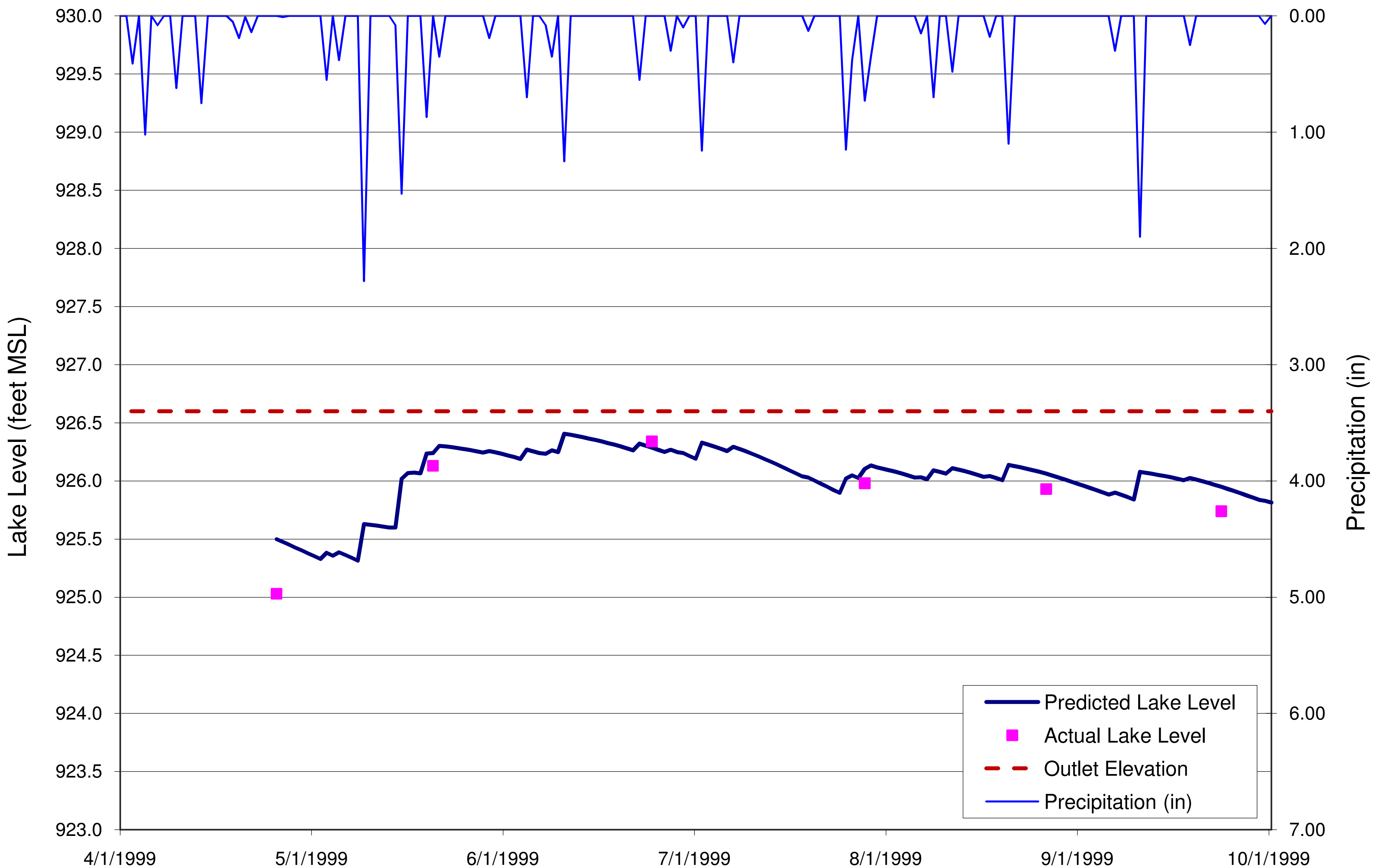


Figure 7-8
Lake Rose Calibrated Water Balance Model
Summer 1999 (Average Conditions)

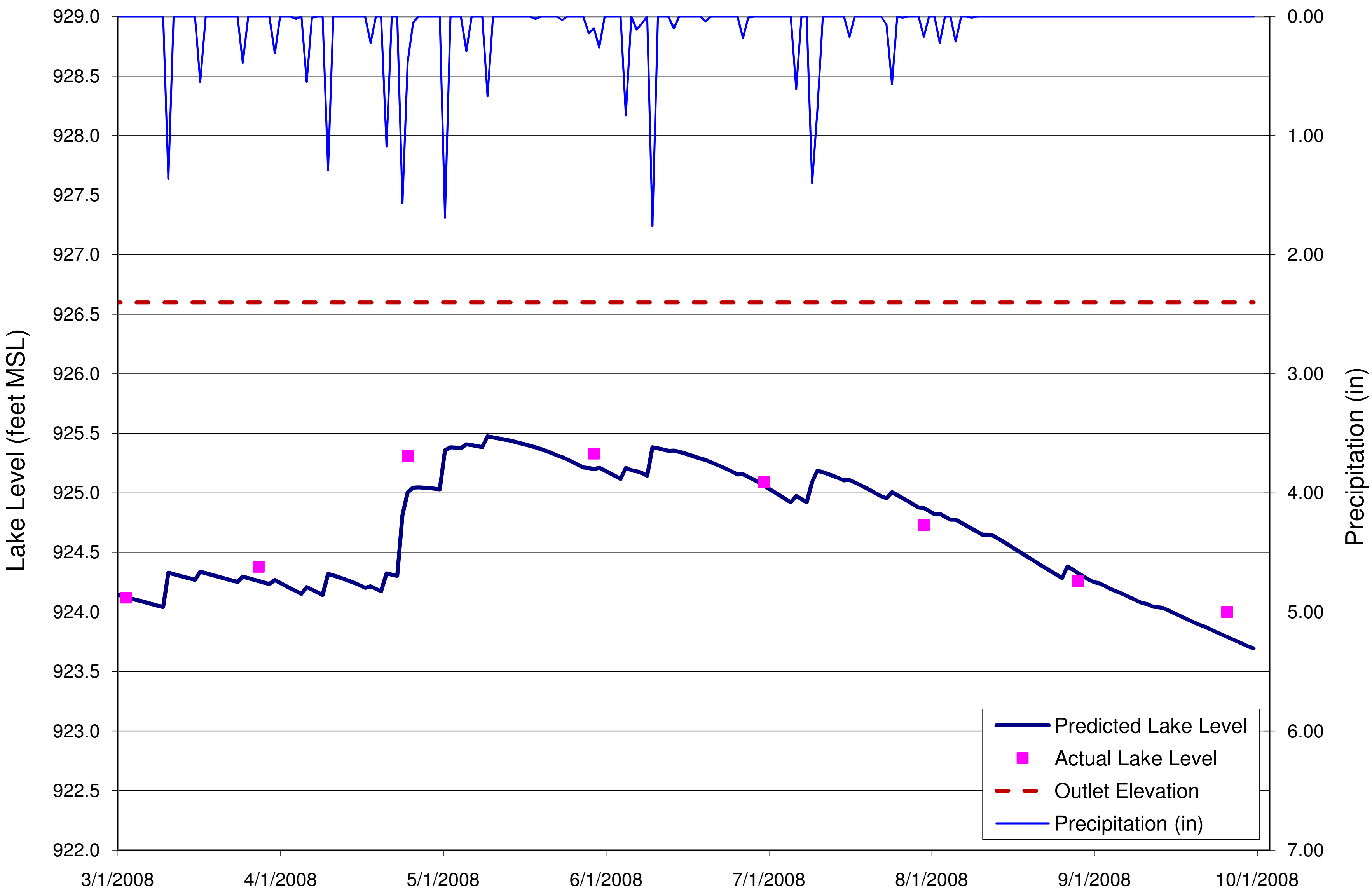


Figure 7-9
Lake Rose Calibrated Water Balance Model
Summer 2008 (Dry Conditions)

7.3 In-Lake Modeling

While the P8 model is a useful tool for evaluating runoff volumes and pollutant concentrations from a watershed, a separate method is required for predicting the in-lake phosphorus concentrations that are likely to result from both external and internal phosphorus loads. For evaluating the resultant in-lake concentrations for Lake Holiday, Wing Lake, and Lake Rose, a spreadsheet water quality model based on the empirical equation set forth by Dillion and Rigler (1974) was developed for each basin. This model is generally referred to as the "in-lake" model in this report.

To calibrate the mass balance in-lake water quality model for existing land use conditions, phosphorus loads for each climatic condition were predicted using the P8 model and then used with the observed in-lake water quality data during that same time period to calculate the internal phosphorus load (described in more detail in Section 7.3.1.3).

7.3.1 Calibrating the In-Lake Models to Existing Water Quality

Observed water quality data, including total phosphorus concentrations, was used to calibrate and verify the in-lake water quality mass balance model for each climatic condition. Water quality data is available for Lake Holiday, Wing Lake, and Lake Rose for the summers of 1993 (wet conditions), 1999 (average conditions), and 2008 (dry conditions).

Model calibration for Lake Holiday utilized data collected by the City of Minnetonka for 1993 (wet conditions), 1999 (average conditions), and 2008 (dry conditions). For Wing Lake model calibration, data collected by the City of Minnetonka was used to calibrate to wet conditions, NMCWD data was used to calibrate to average conditions, and City of Minnetonka and CAMP data were used to calibrate to dry conditions. Model calibration for Lake Rose included City of Minnetonka data for wet and average conditions, and City of Minnetonka and CAMP data for dry conditions.

7.3.1.1 Estimating Spring-time Phosphorus Concentrations

Water quality data were used to determine the empirical model that would best predict the spring concentration in the lake in each lake for each climactic condition. The Dillon and Rigler model with the Numberg phosphorus retention term (Numberg, 1984) was used to predict the spring total phosphorus concentration of Wing Lake and Lake Rose during all climatic conditions and for Lake Holiday during average and dry conditions. For wet conditions in Lake Holiday, the Dillon and Rigler model with the Larson and Mercier phosphorus retention term (Larson and Mercier, 1976) was used to predict the spring total phosphorus concentration of the lake. The use of a different calculation for wet conditions in Lake Holiday is due to a very high springtime phosphorus concentration (113 µg/L) observed in 1993.

The following steady-state mass balance equation was used for modeling the springtime total phosphorus concentration of Lake Holiday, Wing Lake, and Lake Rose:

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

…where:

P_{SPRING}	=	spring total phosphorus concentration (µg/L)
L	=	areal total phosphorus loading rate ($mg/m^2/yr$)
z	=	lake mean depth (m)
ρ	=	hydraulic flushing rate (1/yr), or 1/(t_d)
t_d	=	hydraulic residence time = (V/Q)
Q	=	annual outflow (m^3/yr)
V	=	lake volume (m^3)
R_p	=	retention coefficient

…in these models, the retention coefficient (R_p) is based on the following two methods:

$$R_p = 0.426(e^{-0.271*qs}) + 0.574(e^{-0.00949*qs}) \qquad \text{(Kirchner and Dillion, 1975)}$$

$$R_p = \frac{15}{(18 + q_s)} \qquad \text{(Numberg, 1984)}$$

…where:

q_s	=	annual areal water outflow load (m/yr) = (Q/A)
A	=	lake surface area (m^2)
Q	=	annual outflow (m^3/yr)

While these empirical models adequately predicted the spring steady-state concentration of phosphorus in each lake, early-summer, summer-average and fall overturn concentrations were not accounted for in the above model. Based on the limited data available, the observed phosphorus concentrations varied during the summer time. These variations are the result of additional watershed runoff, gains and losses from macrophytes, and internal loading due to the release of phosphorus from anoxic bottom sediments (see Section 7.3.2 for the in-lake calibration results).

7.3.1.2 Estimating Loading and Loss from Aquatic Macrophytes

Most of the empirical phosphorus models (including Kirchner and Dillon) assume that a lake can be modeled as a well-mixed system, meaning that the phosphorus concentrations within the lake are uniform. This approach, does not account for the seasonal changes in phosphorus concentrations that can occur in a lake. As has been discussed, these changes can also occur seasonally as a result of internal loading, watershed runoff from storm events, and macrophyte life cycles.

7.3.1.2.1 Phosphorus Uptake from Coontail (Ceratophyllum demersum)

Coontail (*Ceratophyllum demersum*) is a submerged aquatic macrophyte present within Wing Lake and Lake Rose. Coontail obtains nutrients for growth (including phosphorus) directly from the water column through a method known as foliar uptake, thereby acting as a phosphorus sink for the lake (Lombardo and Cooke, 2003). Foliar uptake has also been observed and documented for *Elodea* species (Eugelink, 1998), which were also observed in Lake Holiday and Wing Lake in 2008. Aquatic macrophyte surveys of Wing Lake and Lake Rose in June and August of 2008 demonstrated high densities of coontail in both lakes throughout the summer (see Section 6.3.3). For the purposes of calibrating the in-lake model for average and wet conditions, it was assumed that the aquatic macrophyte communities observed in 2008 were present in 1999 and 1993.

The in-lake mass balance spreadsheet model includes algorithms to estimate the foliar uptake of coontail based on the plant density in the lake and nutrient availability in the water column (i.e. TP concentration). A high plant density (1.32 kg per square meter) was estimated for Wing Lake and Lake Rose based on the aquatic macrophyte surveys and density measurements collected at Rice Marsh Lake (Newman, 2004). An average foliar uptake rate of 2.51 $\mu g/g_{plant}$/day was used in the in-lake mass balance model; this rate was determined with a medium TP concentration (about 50 to 100 µg/L) in the water column (Lombardo and Cooke, 2003).

For in-lake model calibration, it was assumed that 20 percent of Wing Lake is covered with coontail when uptake begins on May 15th. The area of the lake where coontail is present is assumed to increase to 80 percent by June 1st (the date of the first aquatic macrophyte survey) and remains at 80 percent through August 15th (the date of the second aquatic macrophyte survey). Twenty percent of Lake Rose is covered with coontail when uptake beings on May 15th; the coverage increases to

60 percent by June 1st and further increases to 80 percent by August 15th. There is no coontail present in Lake Holiday.

Because coontail obtains its nutrients from the water column, it is likely that changes in in-lake phosphorus concentrations will affect the coontail population. For the analysis performed as part of this UAA, it was assumed that any modeled reduction in in-lake phosphorus concentrations would result in a proportional reduction in phosphorus uptake by coontail present in the lake. For example, if future changes to the Wing Lake watershed reduce the phosphorus concentration from 100 µg/L to 80 µg/L, the modeled phosphorus uptake due to coontail would be reduced by 20 percent from current conditions.

7.3.1.2.2 Phosphorus Loading from Curlyleaf Pondweed (Potamogeton crispus)

Curlyleaf pondweed (*Potamogeton crispus*) begins growing in late-August and grows throughout the winter at a slow rate, grows rapidly in the spring, and dies early in the summer (Madsen et al. 2002). When Curlyleaf pondweed dies, the subsequent decay releases phosphorus into the lake, thus acting as a source of phosphorus. Aquatic macrophyte surveys in 2008 revealed high concentrations of Curlyleaf pondweed in Lake Holiday and Wing Lake, and moderate concentrations in Lake Rose (see Section 6.3.3).

The in-lake mass balance spreadsheet model includes algorithms to estimate the release of phosphorus from Curlyleaf pondweed according to plant density and phosphorus release rate. A plant density of 150 stems per square meter (with a mass of 0.35 grams per stem) was estimated for all areas where Curlyleaf was present. The portion of the lake covered with Curlyleaf pondweed was estimated to be 80 percent for Lake Holiday, 70 percent for Wing Lake, and 40 percent for Lake Rose. For the purposes of calibrating the in-lake model for average and wet conditions, it was assumed that the Curlyleaf pondweed coverages observed in 2008 were present in 1999 and 1993. The phosphorus release rate was set at 2.2 mg/m2/day based on a study of Half Moon Lake (James et al., 2001). The die-back start date was originally set at June 1st and adjusted during calibration. During calibration, the start date of die-back was moved later in the summer to prevent negative internal loading rates resulting from too much phosphorus loading early in the summer. The die-back start date was ultimately set as July 1st for all lakes and all climatic conditions.

7.3.1.3 Calculating Internal Loading from Lake Sediment

The initial springtime phosphorus concentration, combined with runoff from surface watersheds, inflow from upstream lakes, atmospheric phosphorus deposition, and macrophyte activity cannot account for the total amount of phosphorus present in Lake Holiday, Wing Lake, and Lake Rose. As has been discussed (see Section 6.2.2), the cause of the increase in summer phosphorus concentrations in these lakes is internal loading from lake sediments.

Based on observed temperature and dissolved oxygen profiles in Lake Holiday and Wing Lake throughout the summer months of 2008, both Lake Holiday and Wing Lake appear to be "polymictic" (normally well-mixed). Lake Rose exhibited stratification on some sampling dates and well-mixed conditions on other sampling dates in 2008. While Lake Rose demonstrated a greater tendency to stratify than either Lake Holiday or Wing Lake, it may be classified as polymictic due to the frequency of mixing. During periods of stratification the bottom waters can become anoxic (devoid of oxygen), even for short periods, and internal phosphorus load from the lake sediments may occur. The phosphorus released from the sediments can build up in the hypolimnion during periods of stratification, especially during periods of high temperatures and low wind. This internal load of phosphorus can be transported to the entire water column as wind increases and causes lake circulation or as fall approaches and mixing typically begins to occur.

Conceptually, the in-lake mass balance model calculates the internal loading of phosphorus in Lake Holiday, Wing Lake, and Lake Rose using the following mass balance equation:

$$P_{Internal} = P_{Observed} + P_{Outflow} + P_{Coontail} - P_{Runoff} - P_{Atmos.} - P_{CurlyLeaf}$$

where…

$P_{Internal}$ = Mass of P from anoxic sediments (internal loading)

$P_{Observed}$ = Mass of P observed in the lake

$P_{Outflow}$ = Mass of P lost in discharge from the lake

$P_{Coontail}$ = Mass of P removed from the lake by coontail growth

P_{Runoff} = Mass of P in stormwater runoff to the lake

$P_{Atmos.}$ = Mass in P deposited on the lake from the atmosphere

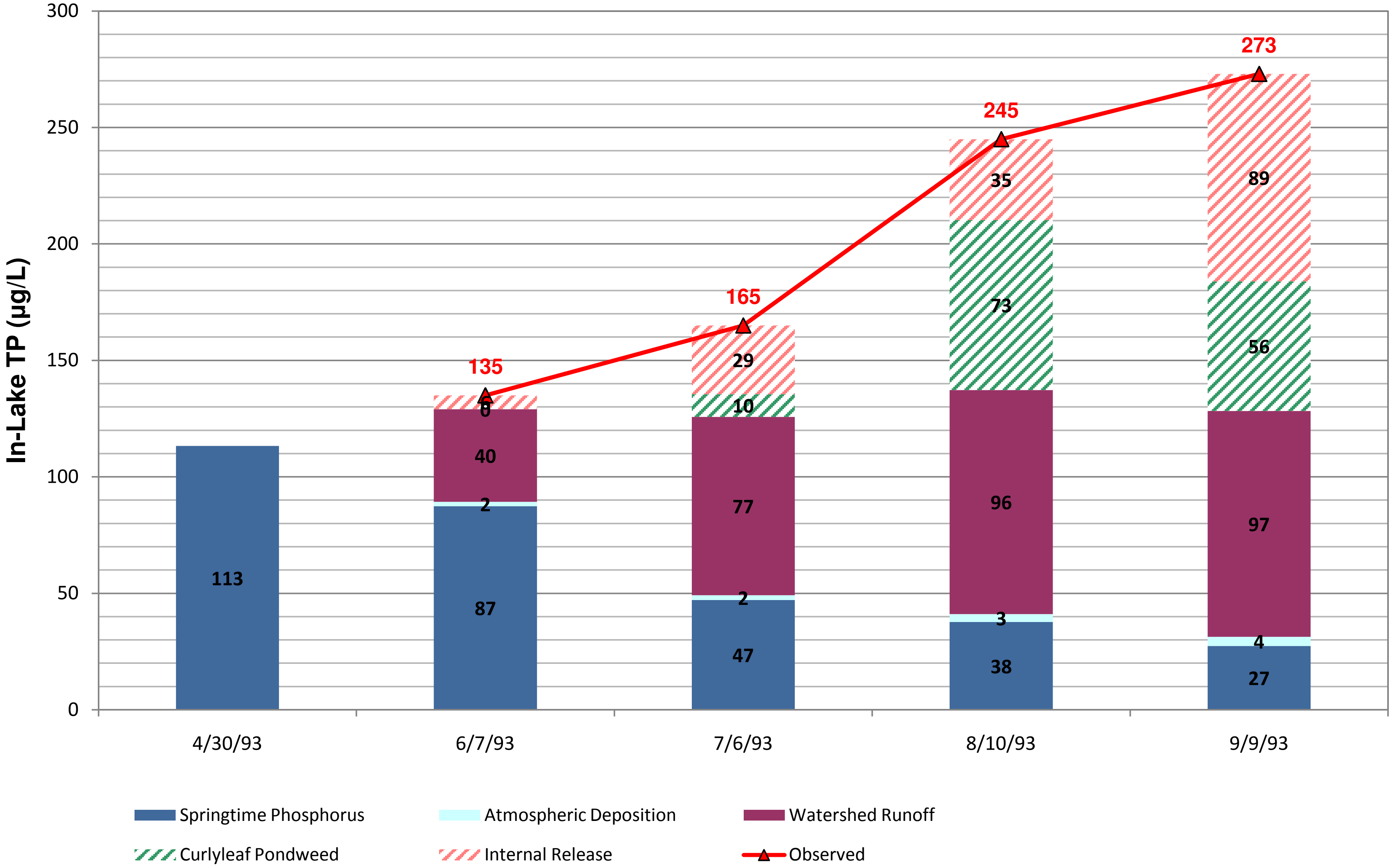
$P_{Curlyleaf}$ = Mass in P released into the lake by Curlyleaf pondweed dieback

The phosphorus mass balance was calculated for Lake Holiday, Wing Lake, and Lake Rose for each climatic condition. Model inputs listed in the above equation were calculated using observed TP data, runoff estimates from the P8 models (based on existing land use conditions), the atmospheric deposition rate described in Section 6.2.1.3, the water balances described in Section 7.2.3, and macrophyte loading and loss described in Section 7.3.1.2. The estimated internal loads using the mass balance equation are summarized in Section 6.2.2.

7.3.2 Results of the In-Lake Water Quality Model Calibration

Since observed water quality data is available for 1993, 1999, and 2008, the in-lake phosphorus model simulations of existing watershed conditions were essentially used to validate the estimated watershed loads, macrophyte loads, and internal loads for wet, average, and dry climatic conditions. Figures 7-10, 7-11 and 7-12 compare the simulated and the actual in-lake phosphorus concentrations for spring steady-state, early-summer peak, summer-average and fall overturn in Lake Holiday for wet, average, and dry years, respectively. Figures 7-13, 7-14 and 7-15 compare the simulated and the actual in-lake phosphorus concentrations for spring steady-state, early-summer peak, summer-average and fall overturn in Wing Lake for wet, average, and dry years, respectively. Figures 7-16, 7-17 and 7-18 compare the simulated and the actual in-lake phosphorus concentrations for spring steady-state, early-summer peak, summer-average and fall overturn in Lake Rose for wet, average, and dry years, respectively. The modeling results accurately predict the observed total phosphorus concentrations for the individual lakes for the time periods of interest.

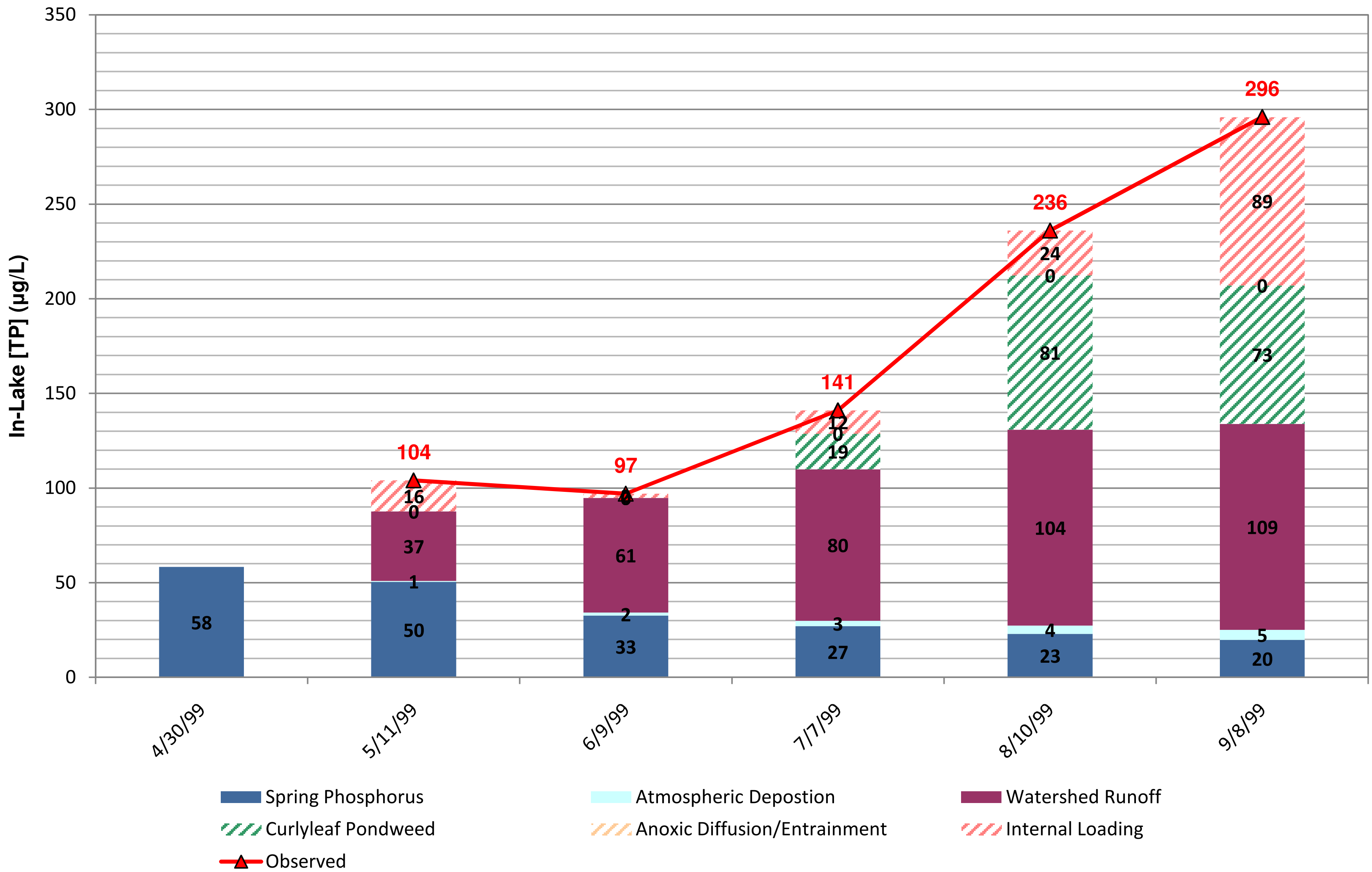
Figure 7-10
In-Lake Model Calibration for Holiday Lake
Wet Climatic Conditions



P:\Mpls\23 MN\27\2327634\WorkFiles\Holiday_Wing_Rose UAA\InLake_Modeling\Holiday_InLake_1993: ReportPlot

2/15/2010
7:04 PM

Figure 7-11
In-Lake Water Quality Model Calibration of Holiday Lake
Average Climatic Conditions



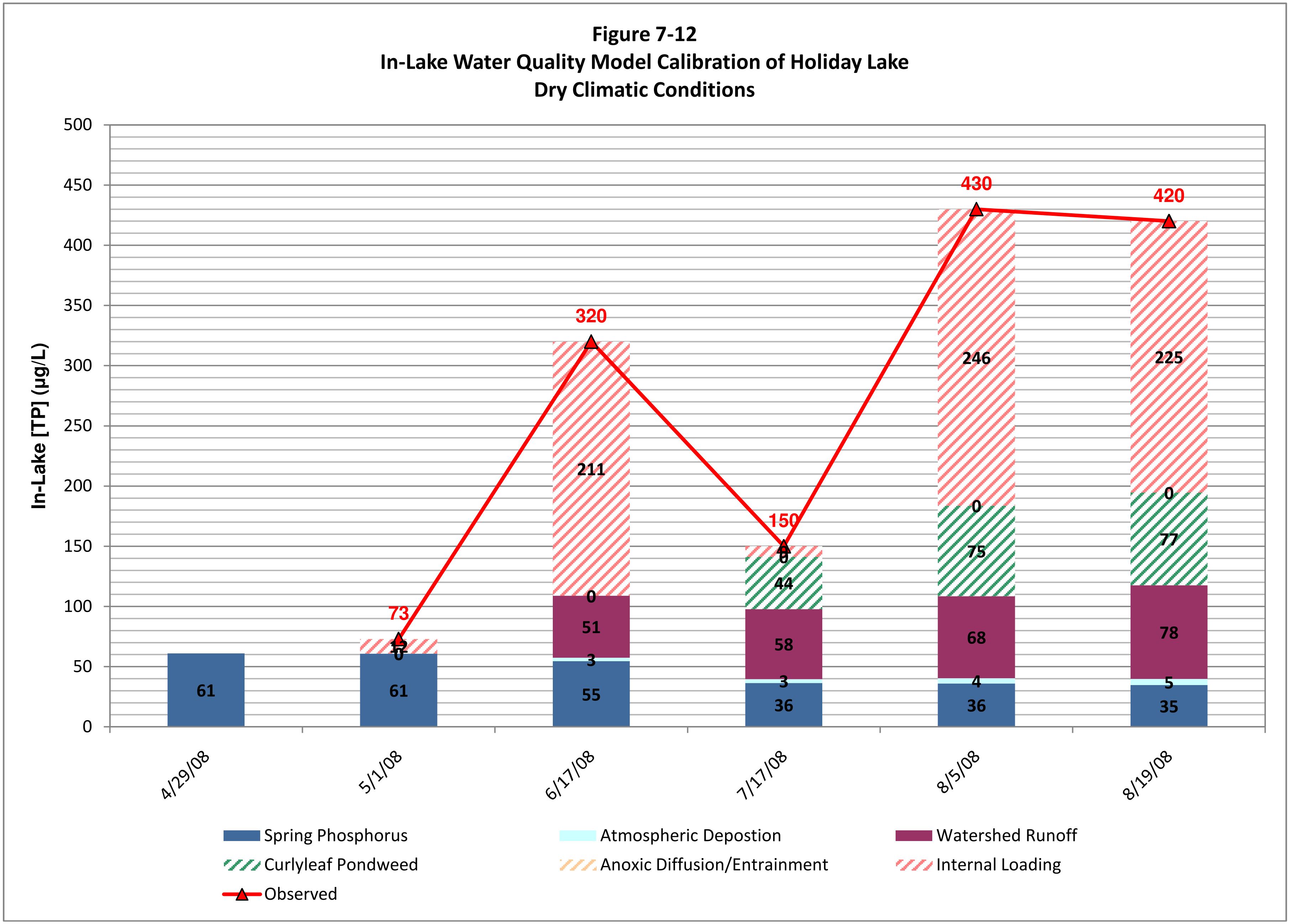
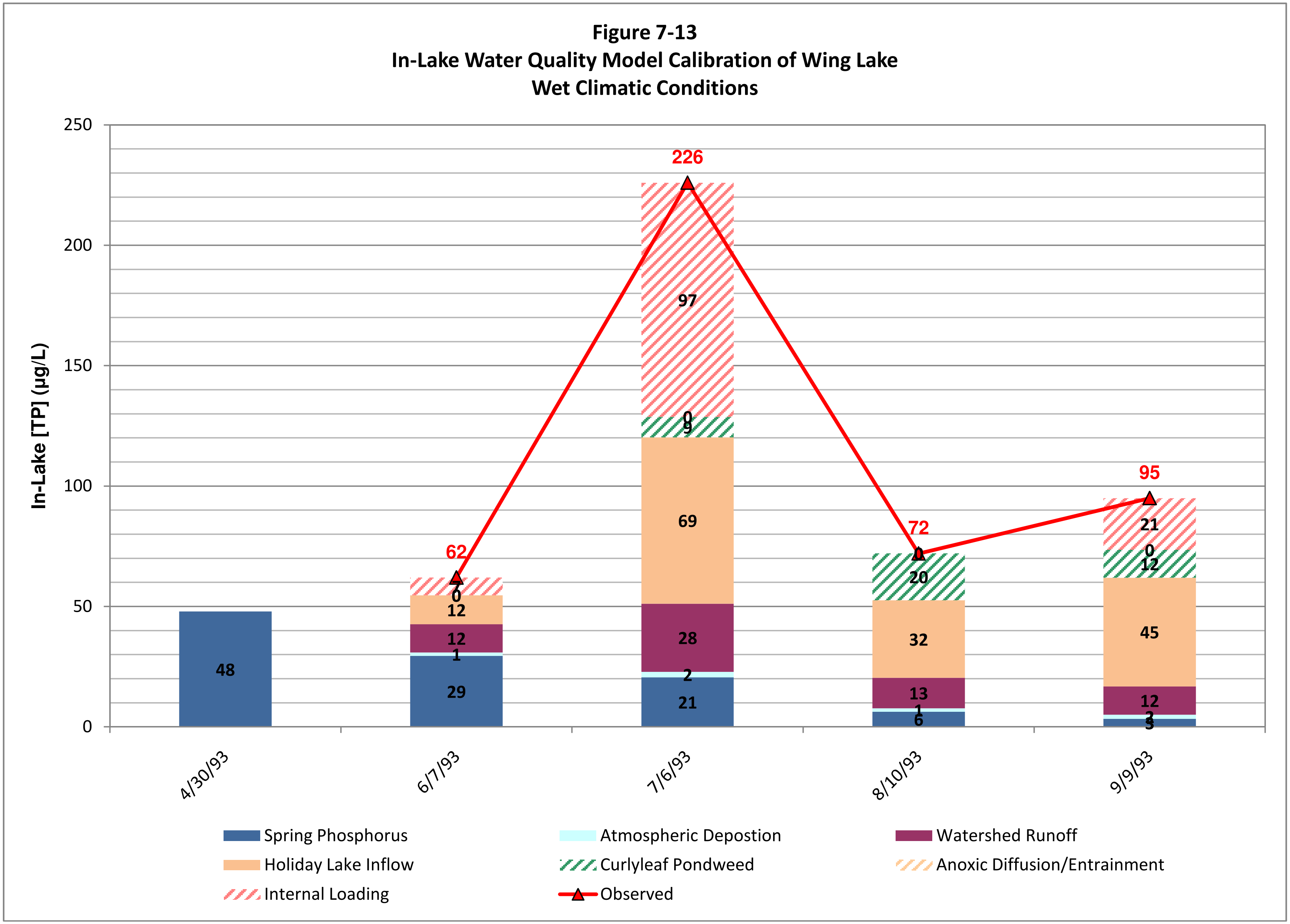


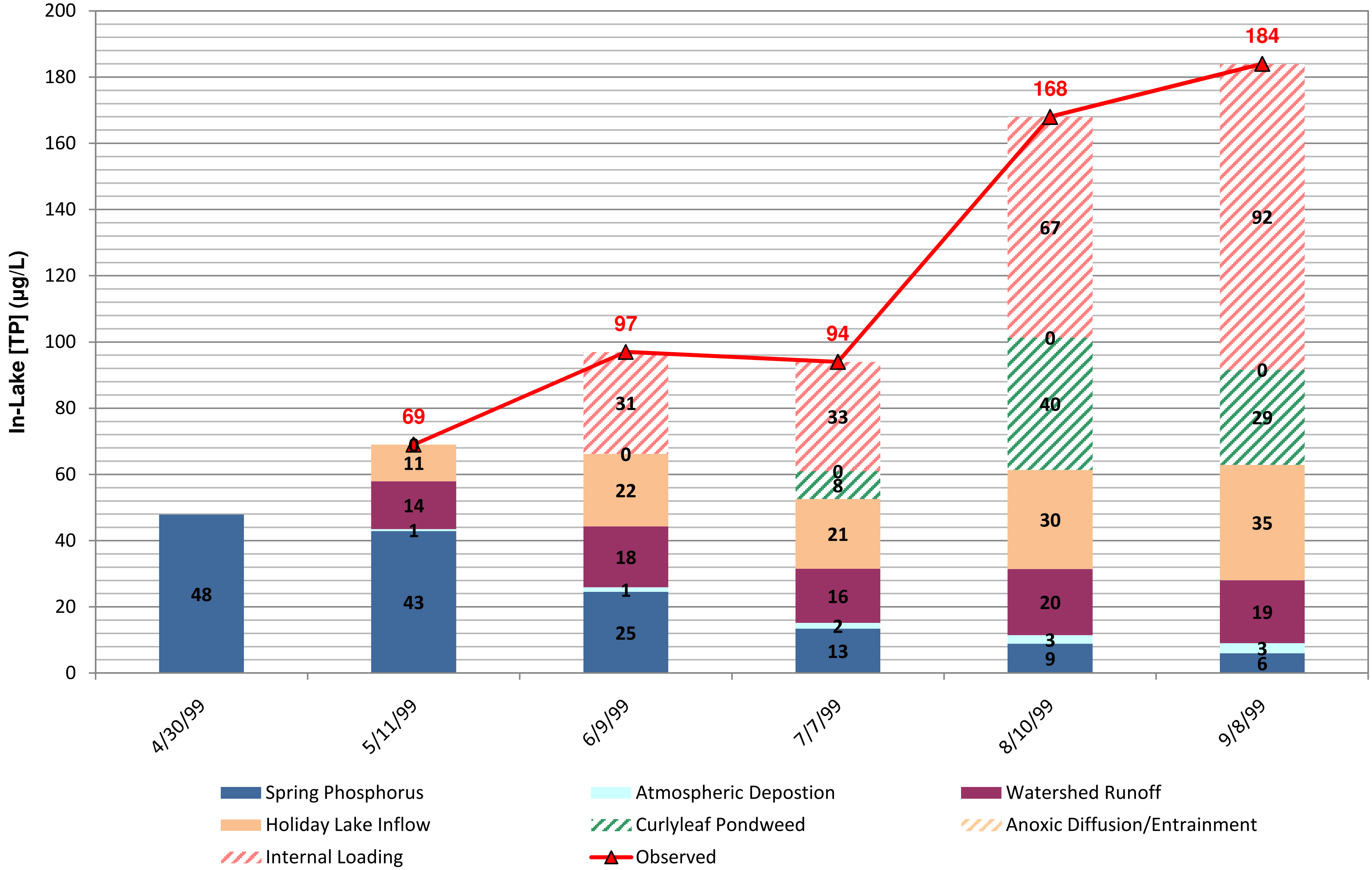
Figure 7-12
In-Lake Water Quality Model Calibration of Holiday Lake
Dry Climatic Conditions
In-Lake [TP] (µg/L)
500
450
400
350
300
250
200
150
100
50
0
73
320
150
430
420
61
61
12
0
55
3
51
0
211
36
3
58
44
0
36
4
68
75
0
246
35
5
78
77
0
225
4/29/08
5/1/08
6/17/08
7/17/08
8/5/08
8/19/08
Spring Phosphorus
Atmospheric Depostion
Watershed Runoff
Curlyleaf Pondweed
Anoxic Diffusion/Entrainment
Internal Loading
Observed

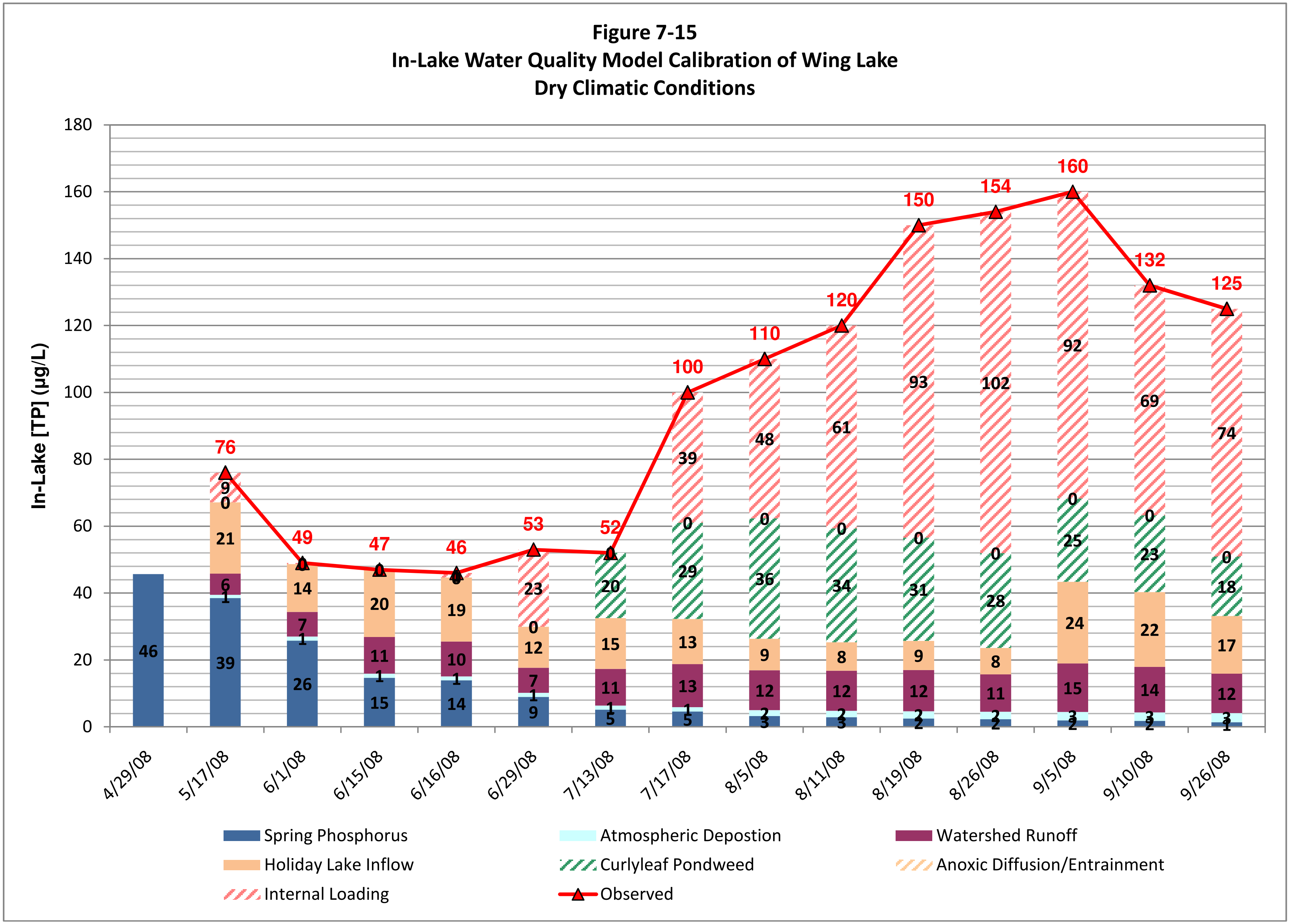


P:\Mpls\23 MN\27\2327634\WorkFiles\Holiday_Wing_Rose UAA\InLake_Modeling\Calibration Figures: Wing Lake Wet

2/4/2010
5:57 PM

Figure 7-14
In-Lake Water Quality Model Calibration of Wing Lake
Average Climatic Conditions





P:\Mpls\23 MN\27\2327634\WorkFiles\Holiday_Wing_Rose UAA\InLake_Modeling\Calibration Figures: Wing Lake Dry

2/4/2010
5:57 PM

Figure 7-16
In-Lake Water Quality Model Calibration of Lake Rose
Wet Climatic Conditions

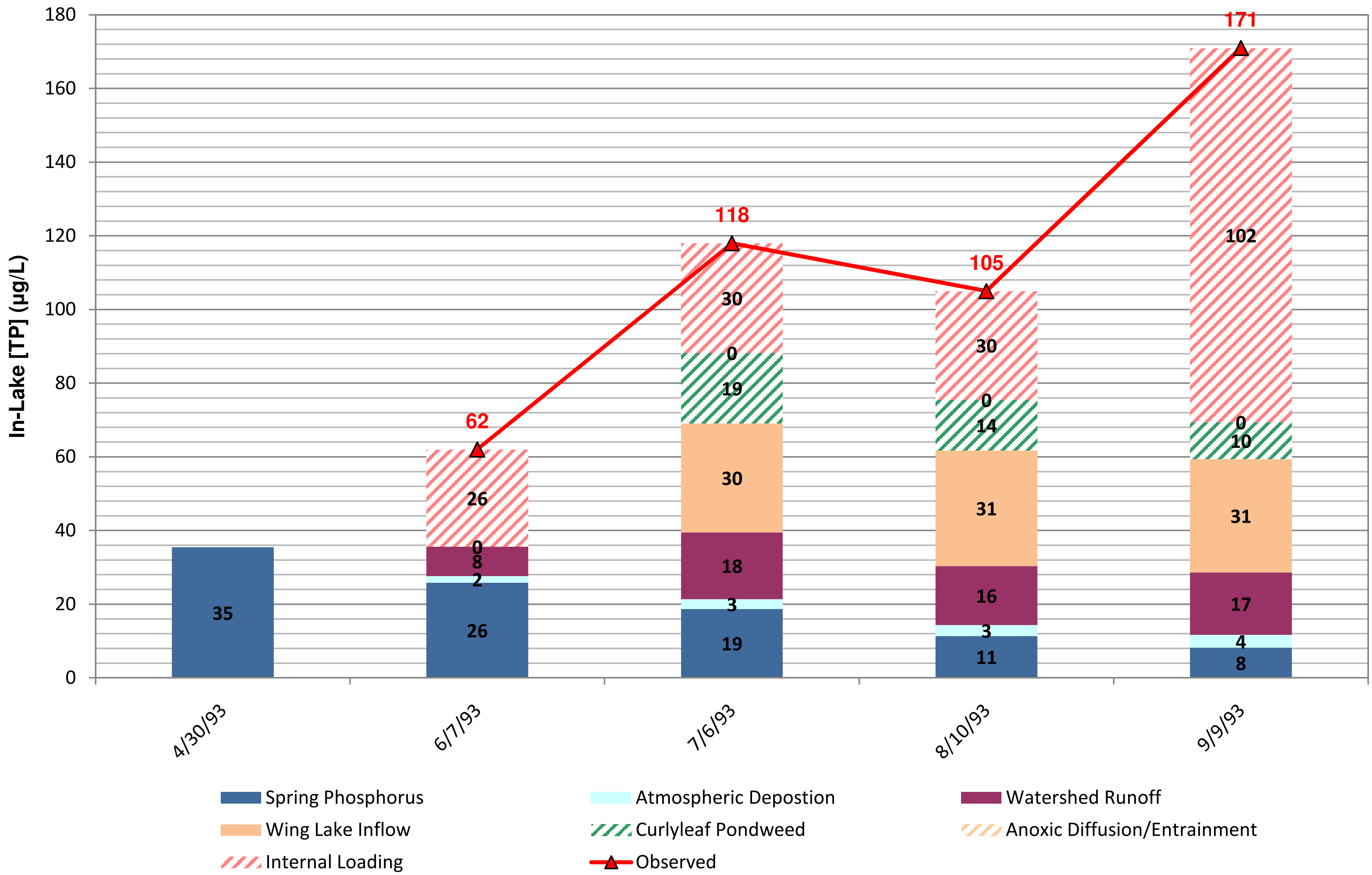
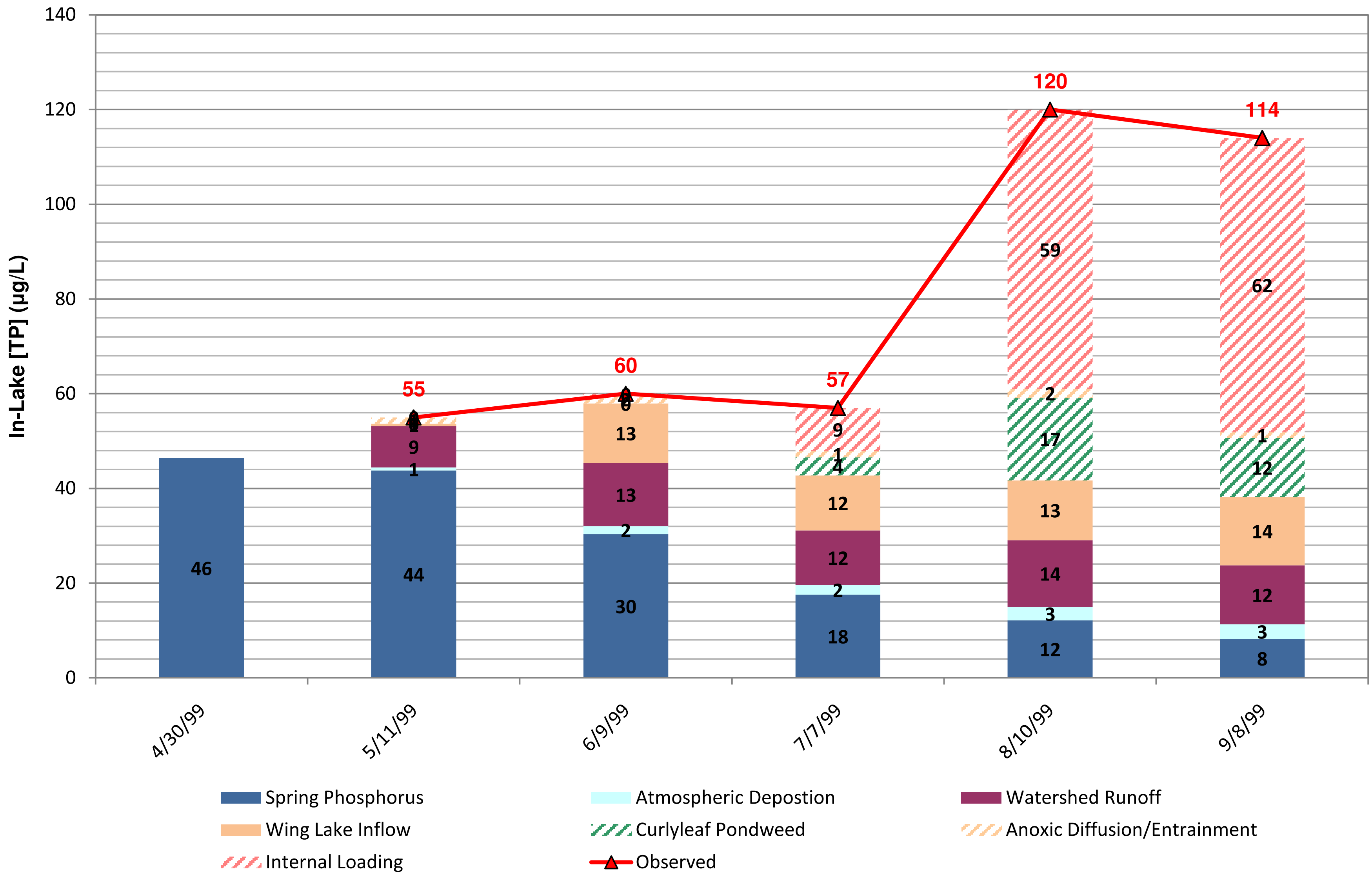
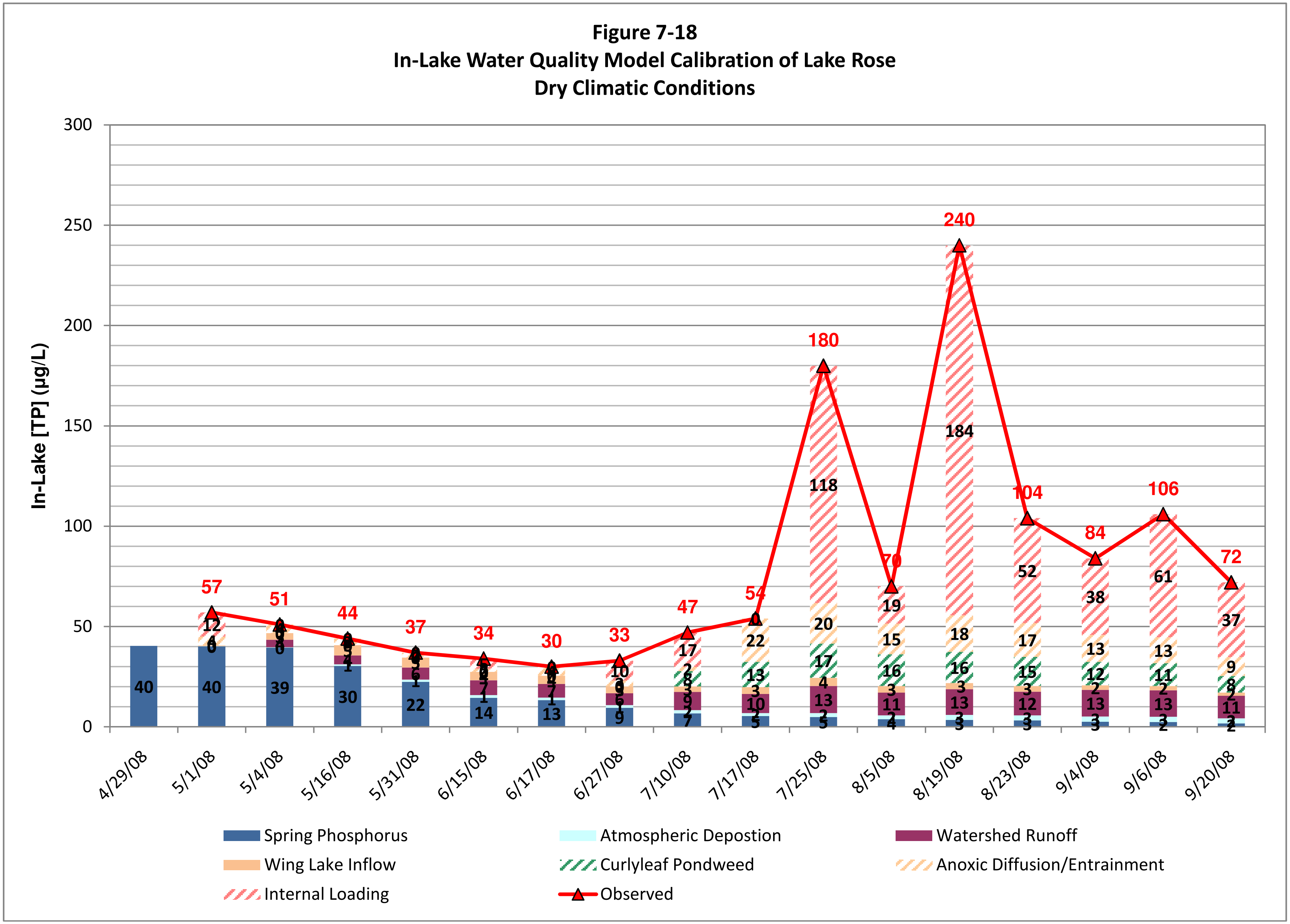


Figure 7-17
In-Lake Water Quality Model Calibration of Lake Rose
Average Climatic Conditions



P:\Mpls\23 MN\27\2327634\WorkFiles\Holiday_Wing_Rose UAA\InLake_Modeling\Calibration Figures: Rose Lake Avg

2/4/2010
5:58 PM



P:\Mpls\23 MN\27\2327634\WorkFiles\Holiday_Wing_Rose UAA\InLake_Modeling\Calibration Figures: Rose Lake Dry

2/4/2010
5:58 PM

7.4 Modeling Chlorophyll *a* and Secchi Disc Transparency

The P8 model used for the analysis predicts phosphorus loads to Lake Holiday, Wing Lake, and Lake Rose; the in-lake models are used to determine the resulting phosphorus concentrations in each lake when the P8 runoff load is combined with other sources and sinks. This method estimates only the concentration of phosphorus, and neglects other important water quality parameters. To estimate the likely chlorophyll *a* concentrations and Secchi disc transparencies, it was necessary to develop additional models (i.e., regression relationships) for each lake.

Several authors have published equations giving general relationships between TP and Chl *a*, and between Chl *a* and transparency. These published equations are generally best-fit regression equations developed as general descriptions of the results of water quality analysis for many lakes. The MPCA has published relationships for phosphorus-limited lakes (as well as all lakes) based on data collected for several lakes in Minnesota. The MPCA relationships are:

$$SD = 38.57[TP]^{-0.856}$$

$$\frac{1}{[Chl\ a]} = 15.136[TP]^{-1.45}$$

…where:

[TP]	=	measured or estimated epilimnetic (mixed surface layer) mean summer total phosphorus concentration (µg/L)
[Chl *a*]	=	estimated epilimnetic mean summer chlorophyll *a* concentration (µg/L)
SD	=	estimated mean summer Secchi disc transparency (m)

The published regression equations give reasonable indications of the algal growth and transparency dynamics for lakes of a particular class or region, but they may or may not be well-suited for a specific lake. Analysis of the available data for Lake Holiday and Lake Rose indicate that the MPCA relationship between TP and SD for phosphorus limited lakes is applicable to Lake Holiday and Lake Rose (see Figures 7-19b and 7-21b). The MPCA relationship between TP and Chl *a* for phosphorus limited lakes is also applicable to Lake Rose (see Figure 7-21a).

The MPCA equations, however, do not accurately describe water quality relationships in Wing Lake or the TP to Chl *a* relationship in Lake Holiday. The observed summer-averages from these lakes, however, may be used to create lake-specific relationships. For Lake Holiday, a lake-specific relationship between TP and Chl *a* was developed using the MPCA relationship for phosphorus limited lakes as a starting point and minimizing the model error (see Figure 7-19a). Relationships between TP and Chl *a* and between TP and Secchi transparency were developed using a similar approach. Figures 7-19, 7-20, and 7-21 depict the numerical water quality models used to estimate chlorophyll *a* and Secchi depth values for Lake Holiday, Wing Lake, and Lake Rose, respectively.

For Lake Holiday, the lake-specific equation is:

$$\frac{1}{[Chl\ a]} = 4.34[TP]^{-1.16} \qquad R^2 = 0.628$$

…and for Wing Lake, the lake-specific equations are:

$$SD = 27.80[TP]^{-0.757} \qquad R^2 = 0.495$$

$$\frac{1}{[Chl\ a]} = 105.20[TP]^{-1.82} \qquad R^2 = 0.467$$

…where:

[TP]	=	measured or estimated epilimnetic (mixed surface layer) mean summer total phosphorus concentration (µg/L)
[Chl *a*]	=	estimated epilimnetic mean summer chlorophyll *a* concentration (µg/L)
Secchi (SD)	=	estimated mean summer Secchi disc transparency (m)

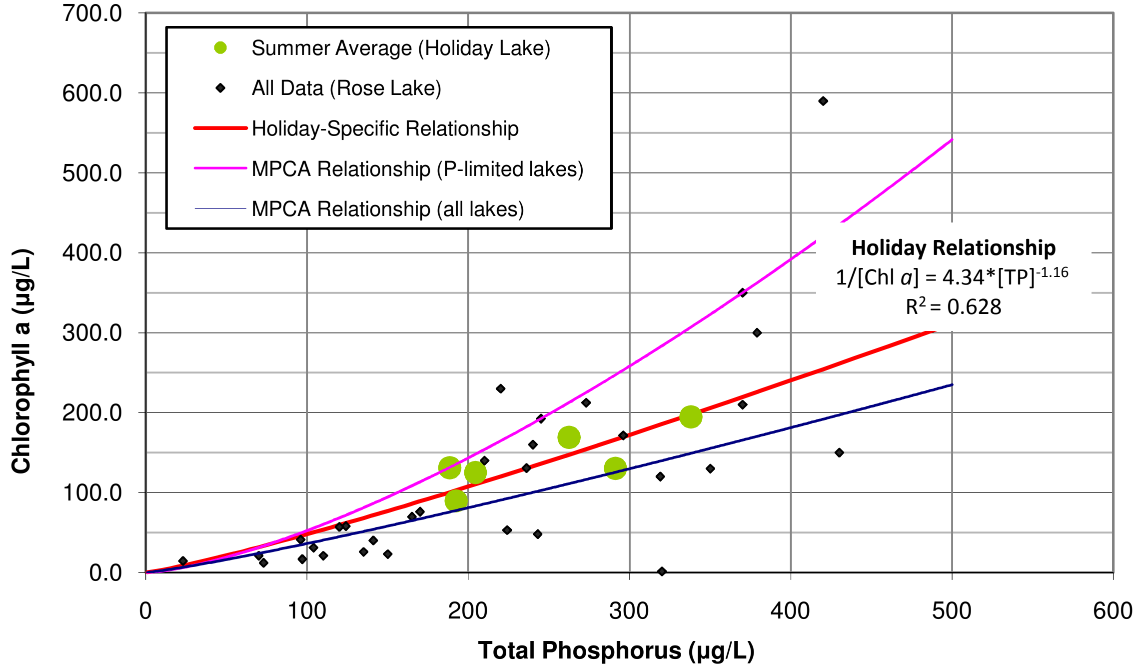
These equations were subsequently used to give indications of what may be expected with respect to summer-average Chl *a* and transparency, given the P8/in-lake model results for summer-average TP. These relationships are based on summer-average data and are not intended to accurately describe the relationship between individual TP and Chl *a* measurements or between individual TP and transparency measurements. It should also be noted that the response of Chl *a* and Secchi depth to TP is highly variable. Due to the high variability, the regression equations can be expected only to allow a general indication of the lake response to changing TP concentrations, and the predicted Chl *a* and Secchi depth values should not be construed as absolute.

7.5 Use of the P8/In-Lake Models

The in-lake models, adjusted to account for internal loading and calibrated to measured in-lake TP concentrations, were subsequently used to estimate the in-lake total phosphorus concentrations under future conditions (i.e. future land use and storm sewer system) with and without the implementation of additional best management practices within the Lake Holiday watershed, Wing Lake watershed, and Lake Rose watershed (see Section 9.0).

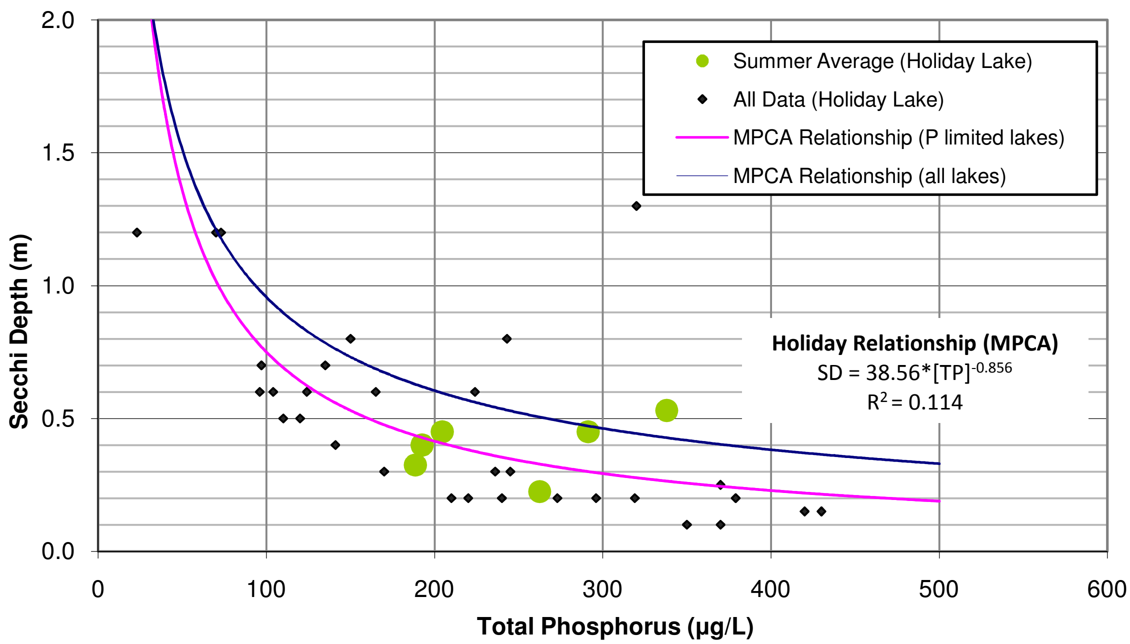
The internal loading for each lake varies during different climatic conditions (see Section 7.3.1.3). Therefore, the calibrated in-lake water quality models for each climatic condition were used to evaluate each lake's response to the P8-predicted loadings resulting from several BMP scenarios. Details of the modeling results and a discussion of management opportunities are presented in Section 8.2 and Section 9.1, respectively.

Figure 7-19a
Holiday Lake Total Phosphorus-Chlorophyll *a*
Summer Average Relationship (1993 - 2008)



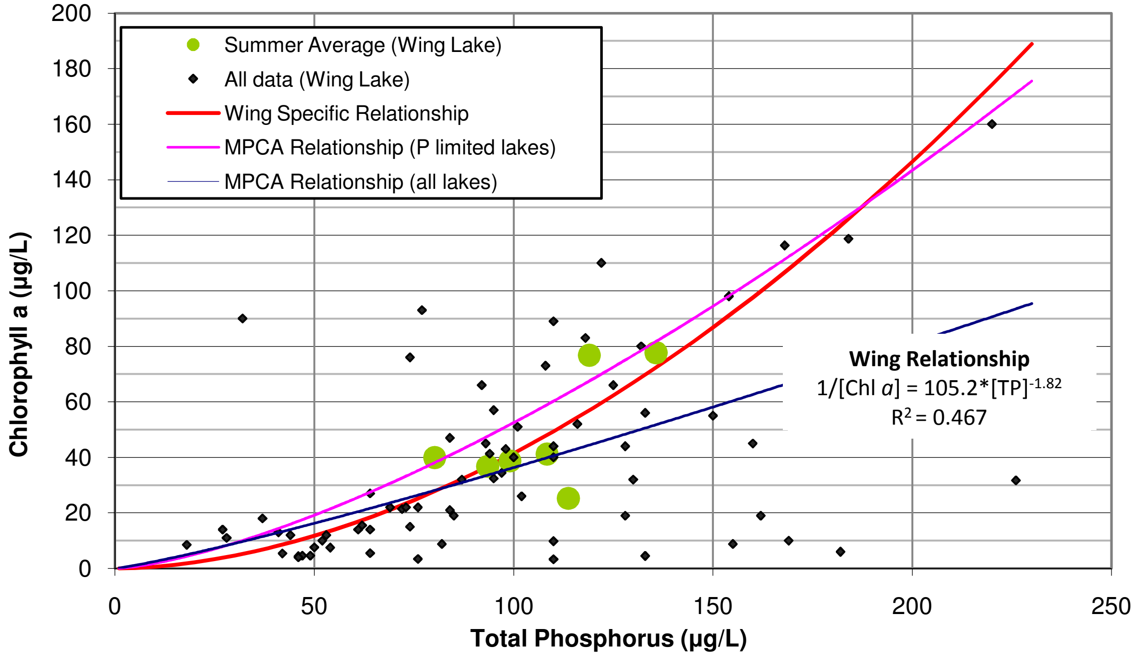
MPCA relationships based on Minnesota Lake Water Quality Assessment Report

Figure 7-19b
Holiday Lake Total Phosphorus-Secchi Disc Transparency
Summer Average Relationship (1993 - 2008)



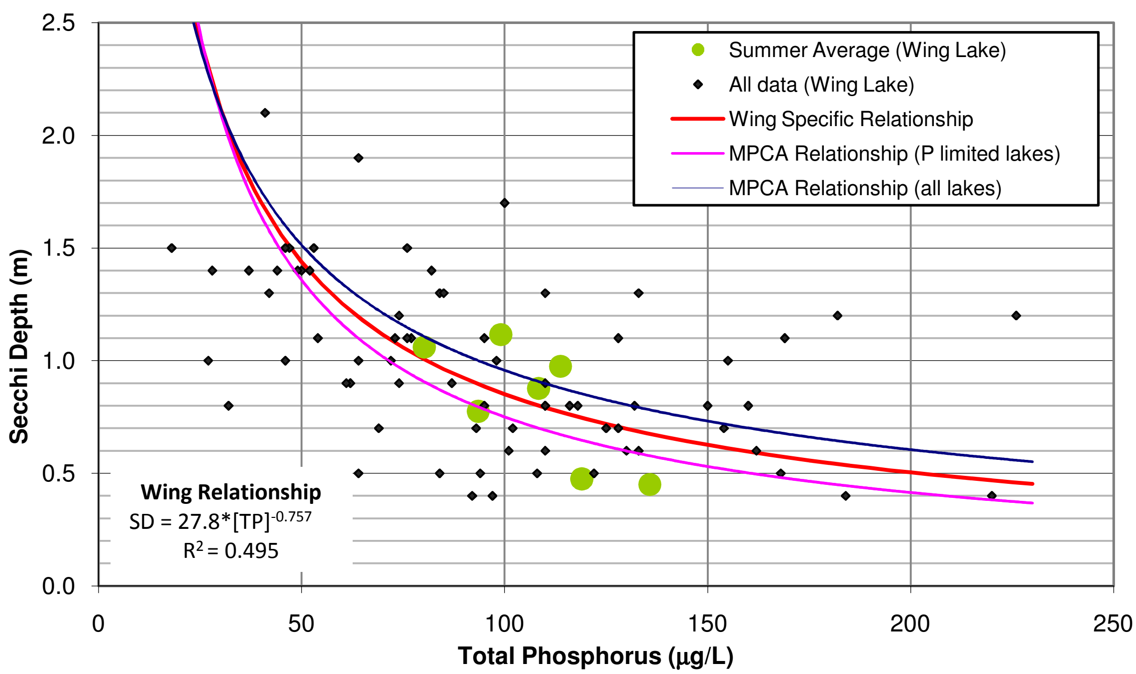
MPCA relationships based on Minnesota Lake Water Quality Assessment Report

Figure 7-20a
Wing Lake Total Phosphorus-Chlorphyll *a* Average Summer Relationship (1993-2008)



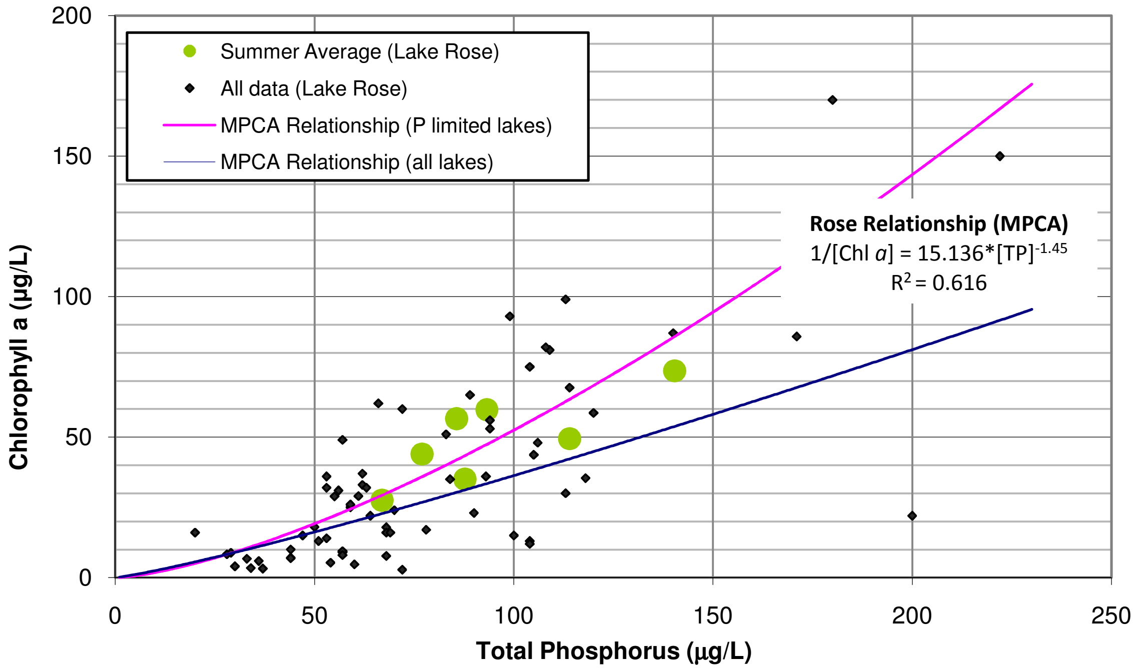
MPCA relationships based on Minnesota Lake Water Quality Assessment Report

Figure 7-20b
Wing Lake Total Phosphorus-Secchi Disc Depth Average Summer Relationship(1993-2008)



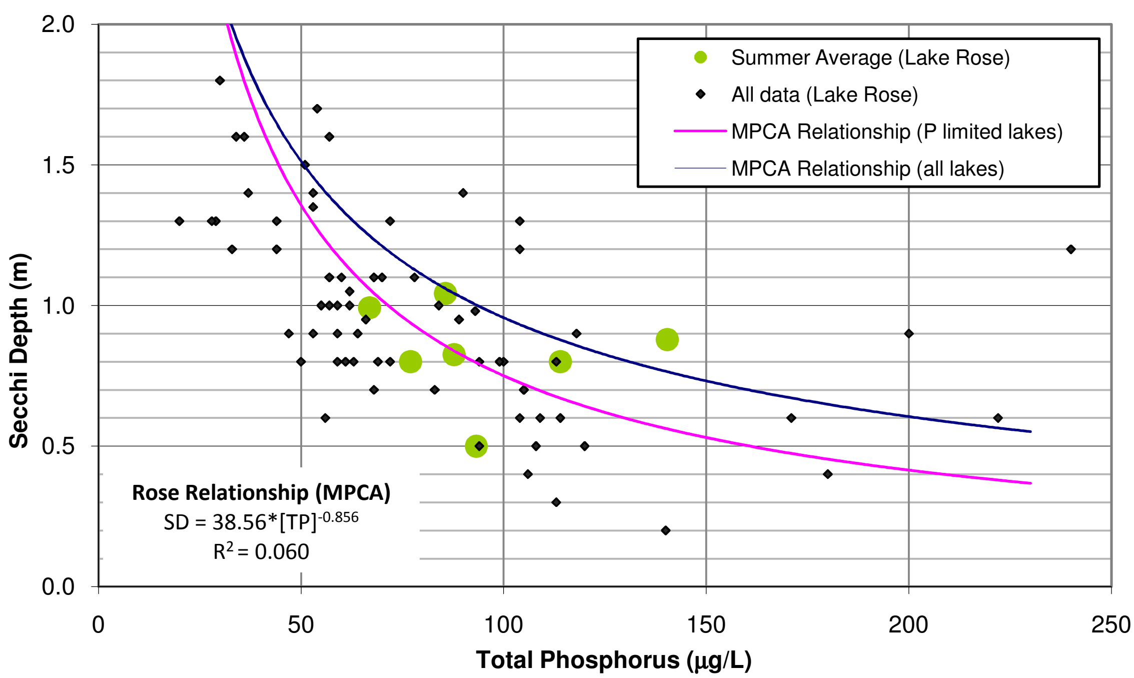
MPCA relationships based on Minnesota Lake Water Quality Assessment Report

Figure 7-21a
Lake Rose Total Phosphorus-Chlorophyll *a*
Average Summer Relationship (1993-2008)



MPCA relationships based on Minnesota Lake Water Quality Assessment Report

Figure 7-21b
Lake Rose Total Phosphorus-Secchi Disc Depth
Average Summer Relationship (1993-2008)



MPCA relationships based on Minnesota Lake Water Quality Assessment Report