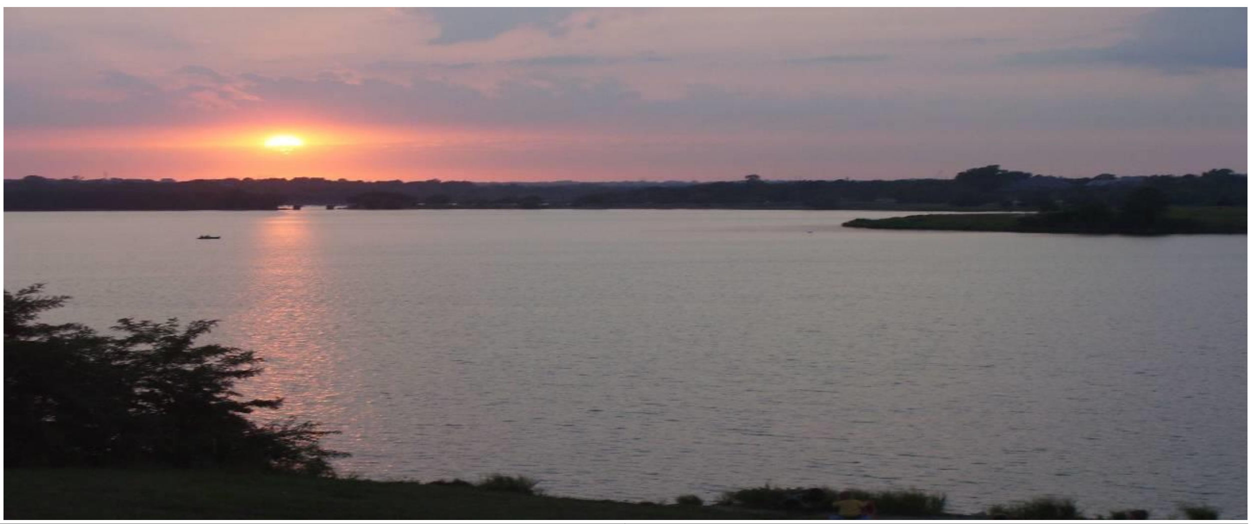
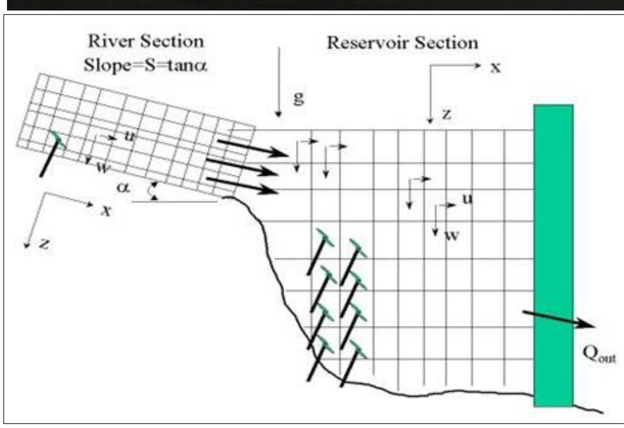
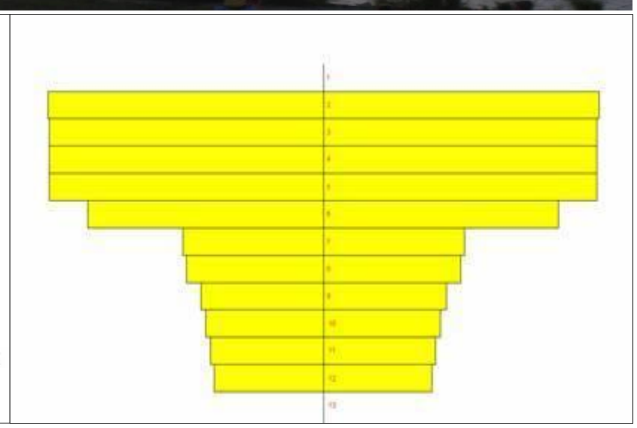
Water Quality Modeling Report

U.S. Army Corps of Engineers
Omaha District

Application and Calibration of the CE-QUAL-W2 Version 3.71 Hydrodynamic and Water Quality Model for Zorinsky Reservoir.







Report Number: CENWO-ED-HA/WQMR/Zorinsky2015

December 2015

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(Report Number: CENWO-ED-HA/WQMR/ Zorinsky2015)

Water Control and Water Quality Section
Hydrologic Engineering Branch
Engineering Division
Omaha District
U.S. Army Corps of Engineers

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For Information Regarding This Document Please Contact:

John Hargrave
U.S. Army Corps of Engineers, Omaha District
1602 Capitol Avenue
Omaha, Nebraska 68102-9000
(402) 995-2347

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EXECUTIVE SUMMARY

A priority water quality management need identified by the Omaha District is the capability to quantifiably assess, with acceptable uncertainty, the affects that operation of District projects have on water quality conditions of impounded reservoirs. To meet this need, the Omaha District is applying the CE-QUAL-W2 Hydrodynamic and Water Quality Model to District reservoirs whenever possible. The goal is to have fully-functioning CE-QUAL-W2 models at District projects that meet the uncertainty requirements of decision-makers. This report documents the application of the CE-QUAL-W2 model to Lake Zorinsky in Omaha, Nebraska.

Lake Zorinsky is an impoundment of Boxelder Creek. The reservoir operates on a “fill and spill” basis using a high level outlet structure to manage pool elevation. This keeps the reservoir pool elevation near 1110 ft-NGVD29. Lake Zorinsky also features a water quality flow augmentation gate at elevation 1104 ft-NGVD29 and a low-level gate at 1090 ft-NGVD29. Years of urbanization and development within watershed have impacted water quality and led to the reservoir exceeding the State of Nebraska’s water quality criteria for total phosphorus, total nitrogen, and chlorophyll *a*. The reservoir is dimictic and stratifies during the summer and winter. During these periods of stratification the hypolimnion or bottom zone of colder, quiescent water becomes hypoxic to anoxic. The reduced chemical conditions liberate sediment bound phosphorus which becomes available for algal uptake during the fall turnover. Algae utilize phosphorus for growth in the photic zone and, upon death, settle to the bottom of the reservoir. The decomposition of this dead algal organic matter further reduces oxygen in the hypolimnion. The reduction of oxygen degrades suitable habitat for warm water aquatic life and results in further degraded water quality conditions.

This application of the CE-QUAL-W2 model to Zorinsky Lake assesses the potential for improved water quality conditions and warm water fishery habitat volume via releases through the low-level gate during summer thermal stratification. It is believed that discharge of poor quality water and its replacement with higher quality inflow water will promote mixing within the reservoir and improve dissolved oxygen conditions in the hypolimnion during thermal stratification. The model for Lake Zorinsky was developed using ambient water quality monitoring data collected during the 2008-2014 growing seasons (May-September). . Monitoring data collected at Lake Zorinsky during the period 1993 through 2105 were used as necessary to facilitate application of the model where data gaps existed. The developed reservoir model was configured to compute temperature, dissolved oxygen, and nutrients using semi-deterministic algorithms and was calibrated to 2008 through 2014 conditions for water temperature, dissolved oxygen, and nutrient measurements.

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1 INTRODUCTION

1.1 APPLICATION OF THE CE-QUAL-W2 HYDRODYNAMIC AND WATER QUALITY MODEL TO LAKE ZORINSKY

1.1.1 WATER QUALITY MODELING NEED

A priority water quality management need identified by the Omaha District (District) is the capability to quantifiably assess, with acceptable uncertainty, the affects that operation of District projects have on water quality of the impounded Corps reservoirs (USACE, 2015). To meet this need, the District is applying the CE-QUAL-W2 Hydrodynamic and Water Quality Model (W2) to Lake Zorinsky. Lake Zorinsky is the largest of four District tributary reservoirs located in the Papillion Creek watershed in the vicinity of Omaha, Nebraska. It was selected for model application based on trophic status, Section 303(d) listing, and the potential to show the impact of using a seasonal hypolimnetic withdrawal through the low-level gate to improve water quality in the Papillion Creek Tributary Reservoirs.

W2 is a "state-of-the-art" model that can greatly facilitate addressing water quality management issues at the District projects. W2 mechanistically models basic physical, chemical, and biological processes such as temperature, nutrient, algae, dissolved oxygen, organic matter, and sediment relationships. Once applied and calibrated, the model can reliably predict reservoir water quality conditions based on changes in environmental conditions or project operations and regulation. The ability to reliably predict reservoir water quality conditions under different environmental, operational, and regulation situations allows the District to determine if water quality at a specific project may be impacted by project operation. As such, the model allows the District to proactively assess how proposed project operations and regulation may affect water quality and allow appropriate water quality management measures to be identified and implemented.

1.1.1.1 Lake Zorinsky Trophic Status

Reservoirs are commonly classified or grouped by trophic or nutrient status. Lake Zorinsky maintains a eutrophic (i.e., high nutrient/high productivity) to hypereutrophic (i.e., very high nutrient/very high productivity) condition. Eutrophication, or the process of a reservoir progressing from a low nutrient/low productivity status to a high nutrient/high productivity status is often accelerated by nutrient addition to the reservoir from cultural activities such as the development which has taken place in the Lake Zorinsky watershed.

1.1.1.2 Section 303(d) Listing

Pursuant to the Federal CWA, the State of Nebraska has listed Lake Zorinsky as a category 5 impaired water (NDEQ, 2016). The beneficial use of aquatic life is identified as impaired due to nutrients and the presence of a fish consumption advisory. The identified parameters of concern include: Hazard Index compounds, mercury, total phosphorus, total nitrogen, and chlorophyll *a*. The State of Nebraska has issued a fish consumption advisory for Lake Zorinsky due to mercury concentrations. Total maximum daily loads (TMDL) were completed for Lake Zorinsky in 2002 for sedimentation and nutrients.

1.1.1.3 Seasonal Hypolimnetic Withdrawal to Improve Water Quality

In Lake Zorinsky the decomposition of organic matter significantly reduces dissolved oxygen in the reservoir hypolimnion. The hypolimnion is the colder, quiescent, bottom zone of the reservoir which develops during seasonal thermal stratification. Anoxic conditions develop and result in the release of sediment-bound substances (phosphorus, metals, sulfides, etc.). As it relates to reservoir eutrophication the release of sediment bound phosphorus is of concern due to its role in fueling algal productivity and subsequent oxygen demand from algal decay. Most fish and other intolerant aquatic life cannot inhabit water with less than 4 to 5 mg/l dissolved oxygen for extended periods, so the conditions in this "stagnant zone" do have an impact on aquatic life in the reservoir.

Lake Zorinsky and the other Papillion Creek Tributary Projects are equipped with a low-level outlet which could potentially be used to make seasonal hypolimnetic withdrawals to "pull" higher quality inflow water towards the dam and improve dissolved oxygen conditions. These releases could also potentially evacuate water with higher concentrations of orthophosphate; which would have been liberated from the sediments under anoxic conditions. This has the potential to reduce the amount orthophosphate readily available for algal growth and improve water quality in the long term by removing phosphorus mass from the reservoir.

1.2 PAPILLION CREEK TRIBUTARY PROJECTS

1.2.1 PAPILLION CREEK WATERSHED HYDROLOGY

Streamflow in the Papillion Creek watershed follows a characteristic pattern. Flows are generally low except for brief periods of rise caused by runoff from rainfall events. A snowpack over the basin in early spring can produce a significant rise in flow as a result of snowmelt runoff. During the winter months streams in the basin are generally frozen over.

1.2.2 TRIBUTARY RESERVOIRS

Four District tributary reservoirs (i.e., Ed Zorinsky, Glenn Cunningham, Standing Bear, and Wehrspann) are located in the Papillion Creek watershed in the vicinity of Omaha, Nebraska (Figure 1.1). The authorized purposes for the four reservoirs are flood control, recreation, fish and wildlife, and water quality. A low-level outlet is installed at each dam to permit draining of the multipurpose pools or to hasten the evacuation of flood storage to avoid damage to shoreline grasses and recreational facilities. The low-level outlet may also be used for water quality management purposes by providing: 1) downstream flow augmentation releases during low-flow periods, and 2) targeted withdrawal from the bottom of the reservoir.

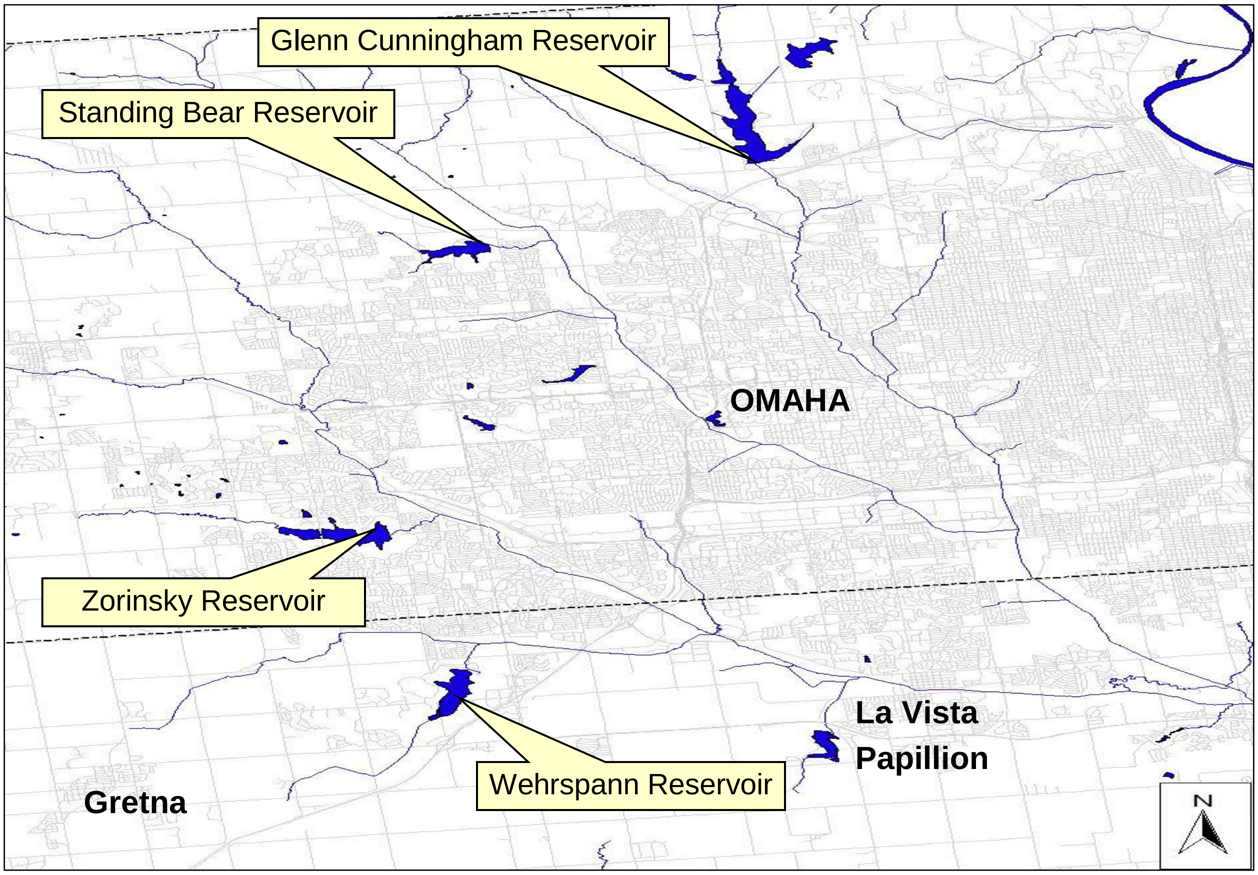

Figure 1.1. Locations of the Corps tributary project reservoirs in the Omaha, Nebraska area.

1.2.3 RESERVOIR REGULATION FOR WATER QUALITY MANAGEMENT

1.2.3.1 Downstream Water Quality Management

When the Papillion Creek Tributary projects were authorized, water quality management was identified as a concern within the Papillion Creek basin. At that time, studies by the Federal Water Pollution Control Administration (FWPCA) indicated that a need existed for water quality storage within the basin. The FWPCA identified the need for 3 cfs water quality flow in the Big Papillion Creek, Little Papillion Creek, and West Branch Papillion Creek. The FWPCA's studies indicated 8 of the proposed 21 reservoirs would collectively have sufficient storage to provide the identified 3 cfs water quality flows. Based on the costs of an alternative groundwater pumping project at that time, the storage was estimated to have an annual value of $10,700. Dam sites 11 (i.e., Glenn Cunningham), 18 (i.e., Ed Zorinsky), and 20 (i.e., Wehrspann) were included in the eight reservoirs potentially identified for having a water quality component in the multipurpose pool. Originally, Dam site 11 was to have a multipurpose pool of 4,600 ac-ft, of which 820 ac-ft was indicated as the water quality storage component. The 1976 survey of Glenn Cunningham Reservoir determined the multipurpose storage of the reservoir at that time was 3,705 ac-ft. Originally, Dam site 18 was to have a multipurpose pool of 4,700 ac-ft with a water quality component of 620 ac-ft. The 1984 survey of Lake Zorinsky established the "as-built" multipurpose storage of the reservoir at 3,037 ac-ft. Originally, Dam site 20 was to have a multipurpose storage of 3,700 ac-ft with a water quality storage component 490 ac-ft. The 1984 survey of Wehrspann Reservoir determined the multipurpose storage of the reservoir at that time was 2,640 ac-ft. The multipurpose pools at the four Papillion Creek reservoirs were projected to fill with sediment in 100 years. To date, releases for downstream water quality management have not been necessary because seepage, releases, and/or tributary inflows at Dam sites 11, 18, and 20 have provided adequate flow for water quality purposes.

1.2.3.2 Reservoir Water Quality Management

Since authorized water quality storage has not been required for downstream water quality management, it is available for reservoir water quality management. The Papillion Creek tributary reservoirs are dimictic and near-bottom areas of the reservoirs become anoxic during the summer and winter. Releases could be made from the reservoirs through the low-level gate to discharge poor quality water during these times and replace it with higher quality influent water. Such releases could also promote mixing within the reservoirs and possibly improve dissolved oxygen conditions in lower depths when the reservoirs are thermally stratified. This report documents application of the W2 model to Lake Zorinsky and investigates the effects of a low-level gate release on reservoir dissolved oxygen conditions and hypolimnetic orthophosphate concentrations.

2 EXISTING CONDITIONS AT LAKE ZORINSKY

2.1 PROJECT OVERVIEW

The dam forming Lake Zorinsky is located on Boxelder Creek, a tributary of the South Papillion Creek in the West Branch Papillion Creek basin. The Lake Zorinsky watershed is 16.4 square miles. The watershed was largely agricultural when the dam was built in 1984; however since then, the watershed has undergone extensive urbanization with the growth of Omaha.

The dam was completed on July 20, 1984; however, potential water quality problems delayed closure. Two wastewater treatment facilities occasionally discharged to upstream tributaries of the reservoir and it was decided to delay final closure until the situation was addressed. The situation was corrected by constructing a diversion pipeline to the Elkhorn River in the fall of 1989. The low-level gate at the dam was closed on December 7, 1989 and the reservoir reached its initial fill in April 1992.

2.2 ZEBRA MUSSELS AT LAKE ZORINSKY

The European freshwater zebra mussel (*Dreissena polymorpha*) and a congener species, quagga mussel (*Dreissena bugensis)* are invasive species that were introduced to North America in the mid-1980s. These mussels produce a planktonic veliger larval stage that eventually settles to the bottom and then uses byssal threads for attachment to firm substrates. They are the only calcareous-shelled invertebrates that attach to firm substratum in freshwater. Their ability to occupy a unique niche makes them an environmental threat and especially problematic as attached biofoulers.

As part of the District's routine maintenance at Lake Zorinsky, the reservoir was lowered 3 feet in the fall of 2010 to pool elevation 1107 ft-NGVD29. This was done to facilitate the placement of additional riprap along the reservoir shoreline for erosion control. On November 18, 2010 a Boy Scout was picking up litter along the reservoir shoreline and picked up an aluminum can with a suspected zebra mussel attached. The can and attached suspected zebra mussel were provided to Nebraska Game and Parks Commission (NGPC) officials who confirmed it as a zebra mussel.

2.2.1 MEASURES IMPLEMENTED TO CONTROL ZEBRA MUSSELS

The District's Missouri River Project Office held an interagency meeting on December 2, 2010 which was followed by a public meeting led by the Nebraska Invasive Species Project on December 7, 2010. Both meetings discussed the potential impacts to Lake Zorinsky and addressed possible zebra mussel transmission to other area lakes. With input from the public and participating agencies it was concluded that this was likely an initial infestation of zebra mussels and measures should be implemented to control their potential spread and protect public infrastructure. An initial measure identified for controlling the zebra mussel population at Lake Zorinsky was drawing the reservoir down over the winter. It is generally believed that a rapid drop in water level (i.e., reservoir drawdown) during the winter months and the subsequent exposure of zebra mussels to sub-freezing temperatures can result in the mortality of emerged zebra mussels due to freezing and desiccation (McMahon, Ussery, & Clarke, 1993). It was also recommended that Lake Zorinsky remain drawn down until zebra mussel veliger sampling could be completed in the summer of 2011 and chemical treatment pursued if warranted.

An additional seven-foot drawdown of Lake Zorinsky began on December 10, 2010 with the reservoir reaching a pool elevation of 1100 ft-NVGD29 on December 18, 2010. The drawdown to pool elevation 1100 ft-NGVD29 was deemed within the District's normal operation and regulation of the reservoir. All participating agencies recommended a complete drawdown of Zorinsky Lake should be pursued and an Environmental Assessment (EA) was completed by the District to evaluate this recommendation. On December 23, 2010 the low-level outlet gates were opened to draw down Lake Zorinsky to the maximum extent possible. On January 4, 2011 Lake Zorinsky reached an elevation of 1092.4 ft-NGVD29 which was the maximum drawdown possible without the removal of accreted sediment in front of the low-level outlet and active pumping of retained water in the reservoir below the elevation of the low-level outlet..

2.2.2 SURVEY OF EMERGED ZEBRA MUSSEL SHELLS AFTER THE LAKE ZORINSKY DRAWDOWN

Preliminary inspections before and after the reservoir drawdown indicated a very low abundance of zebra mussels relative to levels reported in the literature for infested waters. To gain a better understanding of the zebra mussel population at the time of the drawdown it was decided to survey the exposed bottom of the reservoir for the occurrence of emerged adult zebra mussel shells. The survey methodology and results are documented in the report "Assessment of the Water Quality Conditions at Ed Zorinsky Reservoir and the Zebra Mussel (Dreissena polymorpha) Population Emerged after the Drawdown of the Reservoir and Management Implications for the District's Papillion and Salt Creek Reservoirs" (USACE, 2012).

2.3 RESERVOIR STORAGE ZONES

Figure 2.1 depicts the current storage zones of Lake Zorinsky based on the 2007 Corps survey data and estimated sedimentation. It is estimated that 10 to 11 percent of the "as-built" Multipurpose Pool has been lost to sedimentation as of 2015 with the annual volume loss estimated to be 0.38 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Lake Zorinsky's water quality dependent uses are not impaired due to sedimentation.

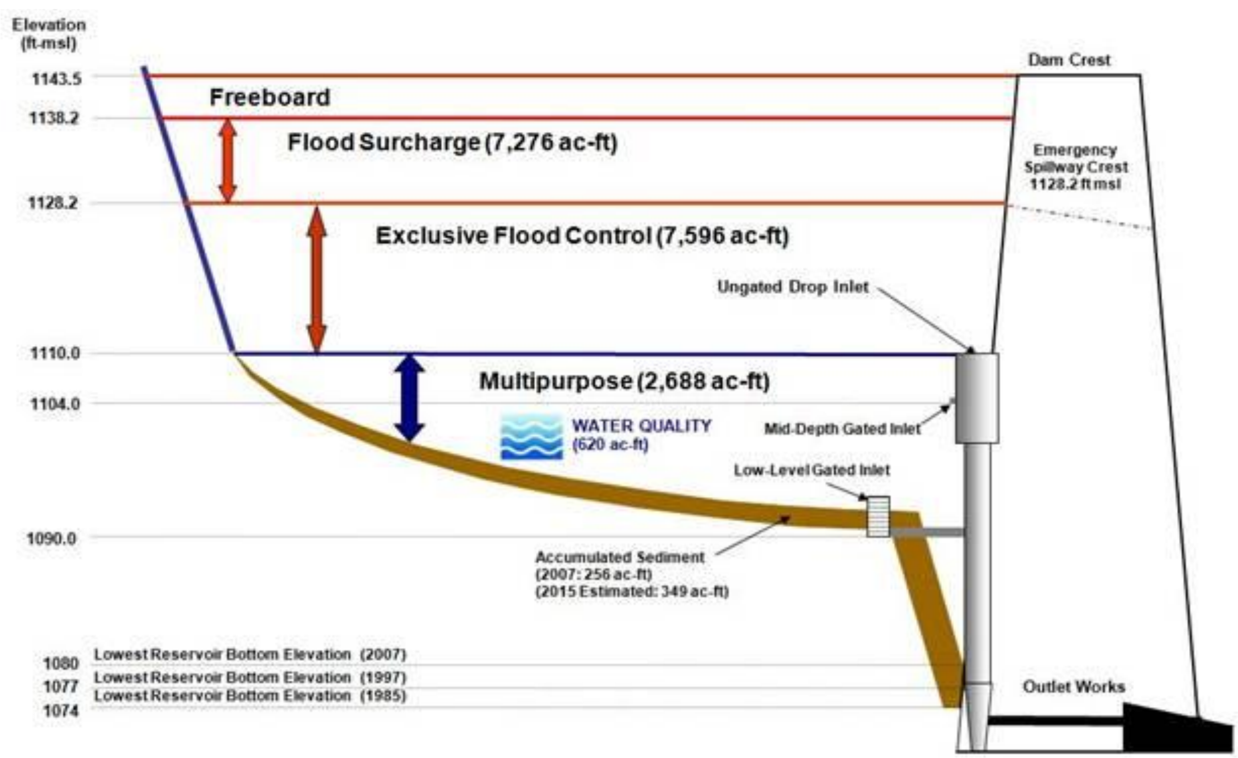

Figure 2.1. Current storage zones of Lake Zorinsky based on a 2007 Corps sediment survey and estimated annual sedimentation.

2.4 AMBIENT WATER QUALITY MONITORING

The District has monitored water quality conditions since the reservoir was initially filled in the early 1990's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 2.2 shows the location of sites that have been monitored for water quality during 2008 through 2015. The near-dam location (i.e., EZRLKND1) was been continuously monitored since 1993.

2.4.1 WATER QUALITY IN LAKE ZORINSKY

2.4.1.1 <u>Existing Water Quality Conditions</u>

2.4.1.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Lake Zorinsky at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 from May through September during the 5-year period 2011 through 2015 are summarized in Plate 1 through 5. A review of these results indicated possible water quality concerns regarding dissolved oxygen, nutrients, and chlorophyll a.

A significant number of dissolved oxygen measurements throughout Lake Zorinsky were below the 5 mg/l criterion for the protection of warm water aquatic life (Plate 1-5). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir and were associated with thermal stratification (Plate 8). The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen levels measured in Lake Zorinsky. Therefore, the measured dissolved oxygen levels below 5 mg/l are not considered exceedences of the water quality standards criteria.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September). The near-surface total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 35, 30, and 70 percent of the samples collected at site EZRLKND1 (i.e., near-dam) (Plate 1). At site EZRLKUP1 (i.e., upper reaches), the near surface total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 70, 55, and 80 percent of the collected samples (Plate 4). All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 1-5) represent the growing season average for the 5-year period 2011 through 2015. The near-surface chlorophyll *a* mean values were 20.1 ug/l and 33.1 ug/l respectively at sites EZRLKND1 and EZRLKUP1. The near-surface total nitrogen mean values were 0.94 mg/l and 1.14 mg/l respectively and near-surface total phosphorus values were 0.05 mg/l and 0.09 mg/l respectively (Plate 1-4). Based on the State of Nebraska's impairment assessment methodology, these mean values indicate impairment of the Aquatic Life beneficial use of Lake Zorinsky due to nutrients.

Figure 2.2. Location of sites where water quality monitoring was conducted by the District at Lake Zorinsky during the period 2008 through 2014.

2.4.1.2 <u>Thermal Stratification</u>

2.4.1.2.1.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal stratification of Lake Zorinsky measured during 2015 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6 provides longitudinal temperature contour plots based on depth profile temperature measurements taken from May through September at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015. Significant thermal stratification occurred in Lake Zorinsky from late-spring through most of the summer during 2015.

2.4.1.2.1.2 Near-Dam Temperature Depth Profile Plots

The depth profile temperature measurements collected during the summer over the past five years at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Lake Zorinsky (Plate 7). These measurements indicate that the reservoir exhibits significant thermal stratification during the summer. The deeper areas of the reservoir, in the area of the old creek channel, do not appear to mix with the upper column of water during the summer. Since Lake Zorinsky ices over in the winter, it appears to be a dimictic lake based on the measured thermal stratification in the summer (Wetzel, 2001). Wetzel (2001) identifies lakes as dimictic if they circulate freely twice a year in the spring and fall and are directly stratified in the summer and inversely stratified under ice cover in winter.

2.4.1.2.2 Dissolved Oxygen Conditions

2.4.1.2.2.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Lake Zorinsky based on depth profile measurements taken during 2015. Plate 8 provides longitudinal dissolved oxygen contour plots based on depth profile measurements taken from May through September in 2015. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored near the reservoir bottom throughout the summer with the exception of May 2015 (Plate 8).

2.4.1.2.2.2 Near-Dam Dissolved Oxygen Depth Profile Plots

The depth profile dissolved oxygen measurements collected during the summer over the past five years at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Lake Zorinsky (Plate 9). Most of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels with most tending towards a clinograde distribution. A few of the plotted profiles indicate dissolved oxygen concentrations above 5 mg/l from the reservoir surface to the bottom. These profiles were measured in early spring or fall and are believed to be a result of thermal stratification breaking down to the depth the profile was measured as “spring turnover” ended or “fall turnover” of the reservoir approached.

2.4.1.2.2.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Lake Zorinsky with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2015 and the District’s current Area-Capacity Tables for the reservoir. The constructed contour plots were reviewed to identify the “worst-case” dissolved oxygen condition. The “worst-case” condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The July 30, 2015 contour plot indicates a pool elevation of 1110.4 ft-MSL, a 5 mg/l dissolved oxygen isopleth elevation of about 1100 ft MSL, and a 2.5

mg/l dissolved oxygen isopleth elevation of about 1098 ft-MSL (Plate 8). The current District Area-Capacity Tables (2007 Survey) give storage capacities of 2,883 ac-ft for elevation 1110.4 ft-MSL, 939 ac-ft for elevation 1100 ft-MSL, and 703 ac-ft for elevation 1098 ft-MSL. On July 30, 2015 it is estimated that 33 percent of the volume of Lake Zorinsky was less than the 5 mg/l dissolved oxygen criterion for the protection of warm water aquatic life, and 24 percent of the reservoir volume was hypoxic.

2.4.1.2.3 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Lake Zorinsky indicated hypoxic conditions during the months of June through September 2015. As a result, longitudinal contour plots were constructed for Oxidation Reduction Potential (ORP) and pH during these months. Depth profiles and near-surface/near-bottom sample comparisons were constructed for periods between 2011 through 2015 when hypoxic conditions were present.

2.4.1.2.3.1 Oxidation-Reduction Potential

Plate 10 provides longitudinal ORP contour plots based on measurements taken in 2015. ORP values present during June and July 2015 indicated somewhat reduced conditions present near the reservoir bottom. Plate 11 plots depth profiles for ORP measured during the summer over the past five years in the deep water area of Lake Zorinsky near the dam, when hypoxic conditions were present. A significant vertical gradient in ORP regularly occurred in the reservoir during the summer.

2.4.1.2.3.2 pH

Longitudinal contour plots for pH conditions measured in 2015 are provided in Plate 12. The reduced conditions in the deeper water of Lake Zorinsky seemingly lead to lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warm water aquatic life. Plate 13 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Lake Zorinsky near the dam when hypoxic conditions were present. An observable vertical gradient in pH regularly occurred in the reservoir during the summer.

2.4.1.2.3.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Lake Zorinsky during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site, EZRLKND1, during the 5-year period 2011 through 2015. During this period a total of 20 paired samples were collected monthly from May through September. Of the 20 paired samples collected, 15 (75%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 14). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for all the assessed parameters except nitrate-nitrite nitrogen. Parameters that were significantly lower in the near-bottom water of Lake Zorinsky when hypoxia was present included: water temperature ($p < 0.0001$), dissolved oxygen ($p < 0.0001$), ORP ($p < 0.0001$), and pH ($p < 0.0001$). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen ($p < 0.0003$), total alkalinity ($p < 0.0001$), total phosphorus ($p < 0.0003$), and ortho-phosphorus ($p < 0.0004$).

2.4.1.2.3.4 Reservoir Trophic Status

Trophic State Index (TSI) values for Lake Zorinsky were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., EZRLKND1). Table 2.1 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Lake Zorinsky is in a eutrophic condition.

Table 2.1. Summary of Trophic State Index (TSI) values calculated for Lake Zorinsky for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	20	63	63	49	76
TSI(TP)	20	53	55	34	71
TSI(Chl)	20	67	67	57	79
TSI(Avg)	20	61	62	51	74

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values for the individual parameters.

2.4.1.1 Water Quality Trends (1993-2015)

Lake Zorinsky reached initial fill in 1992 and water quality monitoring of the reservoir began in 1993. Water quality trends from 1993 to 2015 were determined for Lake Zorinsky for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI. The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., EZRLKND1). Plate 15 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Lake Zorinsky exhibited decreasing levels of total phosphorus ($p<0.05$) (Plate 15). Trends in transparency and chlorophyll *a* are observable; however, they fall slightly short of being statistically significant with p-values of $p=0.06$ and $p=0.052$ respectively (Plate 15). Over the 22-year period since 1993, Lake Zorinsky has generally remained in a eutrophic condition. However, if the current trend continues, the reservoir appears to be moving towards a hypereutrophic condition ($p<0.05$).

2.4.1.2 Existing Water Quality Conditions of Runoff Inflows to Lake Zorinsky

Existing water quality in Boxelder Creek, above Lake Zorinsky, was monitored under runoff conditions during the period of April through September at site EZRNF1. The site is approximately 1½ miles upstream from the reservoir (Figure 2.2). Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 16 summarizes water quality conditions that were monitored at site EZRNF1 under runoff conditions during the 5-year period 2011 through 2015.

3 APPLICATION OF THE CE-QUAL-W2 MODEL

CE-QUAL-W2 (W2) is a two-dimensional (longitudinal and vertical) water quality and hydrodynamic model for rivers, estuaries, lakes, reservoirs, and river basin systems. W2 simulates basic physical, chemical, and biological processes such as temperature, nutrient, algae, dissolved oxygen, organic matter, and sediment relationships. The model is supported by the Environmental Lab at the USACE Engineering Research and Development Center (ERDC) in Vicksburg, MS, and by the Civil Engineering Department at Portland State University in Portland, OR.

Version 3.71 of the W2 model was used to simulate temperature, dissolved oxygen, and nutrients in Lake Zorinsky. Predicted temperatures, dissolved oxygen, and nutrients in the reservoir are influenced by reservoir inflow volumes, temperatures, and nutrient concentrations; environmental factors such as wind, air temperature, and solar radiation; and management factors such as reservoir releases and outflow configurations.

The years 2008 through 2014 were chosen for model calibration based on the data available and previous model applications that were done on an annual basis using W2 model version 3.2. All model calculations and outputs are performed in the International System (SI) of Units; therefore, all subsequent data and figures presented in this report are expressed in SI units.

3.1 HYDRODYNAMICS

The governing equations for hydrodynamics and transport are derived from the conservation of fluid mass and momentum equation. The model uses a hydrostatic approximation for vertical fluid movement rather than rely on the true conservation of momentum equation. Hydrodynamics and transport are laterally and layer averaged, meaning lateral and layer variations in velocities, temperatures and constituents are negligible. The hydrodynamic behavior of the model is dependent largely on initial conditions, boundary conditions, and hydraulic conditions which are described with specific regard to the Lake Zorinsky model in the following paragraphs and later sections of this report.

3.1.1 INITIAL CONDITIONS

Annual simulations were performed from January 1, 2008 (Julian day = 1) to December 31, 2014 (Julian day = 2557) with a minimum model timestep of 1 second. The initial water column temperature was set to 4 °C. An initial ice thickness of 0.1 meters covering the entire reservoir was assumed to begin the simulation.

3.1.2 HYDRAULIC COEFFICIENTS

W2 uses default values for a number of hydraulic parameters that influence the movement of momentum and heat exchange within a water body (**Error! Reference source not found.**). The horizontal dispersion of momentum and heat are determined by the horizontal eddy viscosity and diffusivity, while vertical diffusion of momentum is influenced by the method for computing the vertical eddy viscosity. The W2 Pre-processor program noted maximum values of 0.432 for dispersion of horizontal and vertical momentum in Lake Zorinsky; values shown in Table 3-1 were used. A very important factor influencing momentum transfer and mixing near the bottom of a water body is the bottom friction expressed either as Manning's roughness or Chezy coefficients. In the Lake Zorinsky model, Chezy coefficients were set to 70 throughout the water body.

Table 3-1. W2 model hydraulic, ice cover, and heat exchange default coefficients and coefficients used in the current application of the W2 model.

Parameter*	W2 Default Value	Current Model Application Value
Hydraulic Coefficients		
Horizontal Eddy Viscosity [m^2/s]	1.0	.0432
Horizontal Eddy Diffusivity [m^2/s]	1.0	.0432
Sediment Heat Exchange [W/ m^2/s]	0.3	0.3
Sediment Temperature [°C]	10.0	10.0
Interfacial Friction [-]	0.015	0.01
Fraction Solar at Sediment to Water	1.0	1
Vertical Eddy Viscosity	W2	W2
Maximum Vertical Eddy Viscosity [m^2/s]	1.0	0.001
Vertical Transport Horizontal Momentum	IMP	IMP
For TKE1: BC Choice = 1[Celik88], 2[Rodi83], 3[W2]	3	3
For TKE1: Roughness Coefficient [-]	9.535	9.535
For TKE1: Coefficient used if FBC = 1[0.431] or 2[0.07]	0.431	0.431
For TKE1: Surface Roughness and Manning's Coefficient	24.0	24.0
For TKE1: Boundary Production Coefficient	10.0	10.0
For YKE1: Calculation Procedure for Vertical Transport	IMP	IMP
Friction Type	MANN	CHEZY
Wind Roughness Height	0.001	0.001
Ice Cover and Heat Exchange Coefficients		
Ice Cover Algorithm	OFF	ON
Simple or Detailed Computation Method	DETAIL	DETAIL
Albedo (Reflection/Incident)	0.25	0.25
Coefficient of Water-Ice Heat Exchange	10.0	10.0
Fraction Radiation Absorbed by Ice	0.6	0.6
Solar Radiation Extinction Coefficient [m^{-1}]	0.07	0.07
Minimum Ice Thickness before Ice Formation [m]	0.03	0.05
Temperature above which Ice does not Form [C]	3	3
Term-by-Term or Equilibrium Temperature Method	TERM	TERM
Read Solar Radiation Data	-----	OFF
Evaporation Coefficient A	9.2	9.2
Evaporation Coefficient B	0.46	0.46
Evaporation Coefficient C	2	2
Wind Speed Measuring Height [m]	2	2
Ryan-Harleman Evaporation Formula	OFF	OFF
Fetch Correction to Wind 10m Fang&Stefan	OFF	OFF
Meteorological Data Interpolation	ON	ON

*As defined in the W2 Tool Application provided with the W2 model download from Portland State University.

3.1.3 Heat Exchange

Water surface heat exchange is defined as the sum of incident short and long wave solar radiation, reflected short and long wave solar radiation, back radiation, evaporative heat loss, and heat conduction. The Lake Zorinsky model uses a term-by-term temperature computation in which values are determined using adjacent cell values and data from the previous model time step. This method was selected because it provided a better thermal calibration than the equilibrium temperature computational method during model application. A number of heat exchange coefficients that affect ice formation and transfer of heat through ice are specified in **Error! Reference source not found.**.

Heat is transferred between the bottom sediment-water interface, and a heat exchange rate along with average sediment temperature must be specified. The fraction of solar radiation re-radiating from the lake bottom to the water column is specified as a fraction of radiation reaching the bottom. In Lake Zorinsky very limited shortwave solar radiation reaches the bottom.

The wind measurement height is particularly important because the model adjusts wind speed to the height of the wind speed formulation which drives surface mixing and evaporative heat losses. In addition, the fraction of solar radiation absorbed by the water surface is specified.

3.2 WATER QUALITY

W2 computes numerous water quality constituents in their basic and derived forms based on a constituent mass balance. As part of the mass balance constituents may undergo kinetic reactions that convert nutrients to other organic or inorganic forms via algae utilization or other biological processes. Dissolved oxygen is the primary water quality parameter of concern in Lake Zorinsky; however, to characterize dissolved oxygen within the reservoir the inclusion of nutrients and algal activity was necessary.

3.2.1 Nutrients

Lake nutrients undergo transport and kinetic reactions through biological or chemical transformation to nutrient sources or sinks. Water quality state variables used in the Lake Zorinsky simulations included total dissolved solids (TDS), total suspended solids (TSS), bio-available phosphorus/phosphate/orthophosphate (PO_4), ammonium (NH_4), nitrate-nitrite (NO_x), labile and refractory forms of dissolved and particulate organic matter, algae, and dissolved oxygen (DO). Further discussion on how W2 Version 3.71 handles nutrient kinetics may be found in Appendix B of the User Manual (Cole and Wells, 2011).

3.2.2 Dissolved Oxygen

The purpose of water quality constituent modeling at Lake Zorinsky is to compute dissolved oxygen concentrations throughout the reservoir. The most important components that serve as sources of dissolved oxygen in these simulations are aeration from the atmosphere and algal production from photosynthesis (Figure 3.1). Dissolved oxygen sinks include algal respiration and decay, decomposition of organic sediments and organic matter, and nitrification. Nitrification is the oxidative process which coverts ammonia/ammonium to nitrite then to nitrate. Reaeration, organic matter oxygen demand, algal dynamics, and sediment oxygen demand are discussed in more detail.

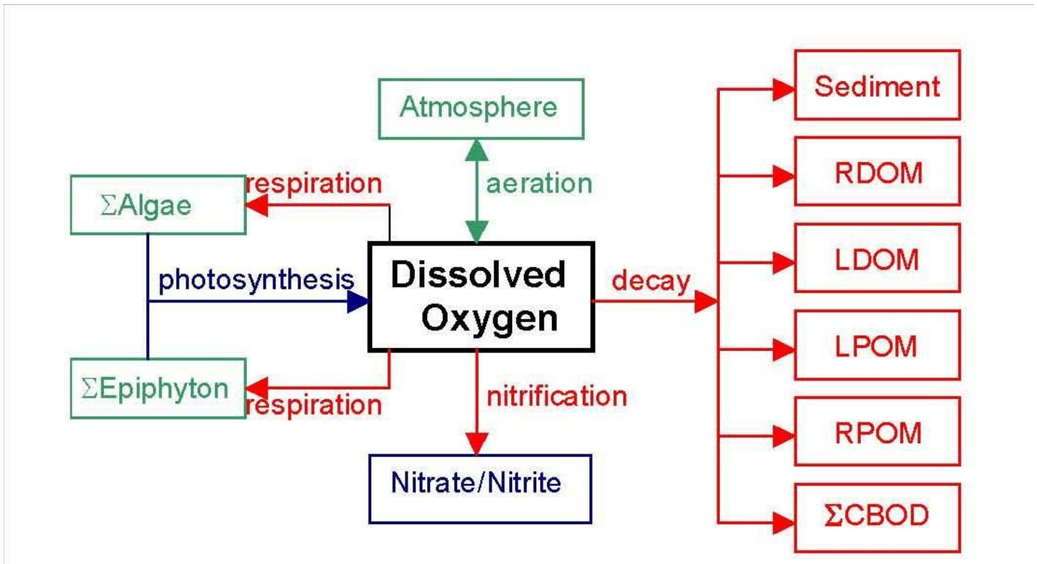

Figure 3.1. Dissolved oxygen dynamics in CE-QUAL-W2 (Cole and Wells, 2011).

3.2.2.1 Reaeration

The reaeration of water with dissolved oxygen occurs in lakes as a function of turbulent mixing caused by surface winds. Reaeration by wind primarily effects dissolved oxygen concentrations in the mixed volume of the water column (e.g., epilimnion during summer thermal stratification, etc.).

3.2.2.2 Organic Matter

The total oxygen demand exerted on a lake is often measured as biological oxygen demand (BOD); however, both decomposition and production of these materials occurs so organic matter represented as BOD must be separated into its major components. In the Lake Zorinsky model these are labile dissolved organic matter (LDOM), refractory dissolved organic matter (RDOM), labile particulate organic matter (LPOM), and refractory particulate organic matter (RPOM). Dissolved organic matter (DOM) and particulate organic matter (POM) are important because they utilize dissolved oxygen (DO) during their decay process. Labile DOM and labile POM decay at a faster rate than refractory OM, which is product of labile OM decay. Settling POM contributes to the lake sediment oxygen demand. DOM and POM are produced by algal mortality and excretion. DO concentrations in the reservoir are influenced by organic matter (OM) dynamics. Initial and observed OM concentrations in the lake and inflows were estimated based on measured concentrations of total organic carbon (TOC).

3.2.2.3 Algal Dynamics

Three different algal groups are included in the model to represent different types of algae: diatoms, green algae, and blue-green algae. Algae are important in nutrient and DO dynamics by utilizing nutrients and producing DO during photosynthesis and then utilizing DO during respiration. Algal mortality and excretion produces DOM and POM which eventually decay and further utilize DO. Chlorophyll *a* (Chl *a*) concentrations are derived within the model using the biomass of the three different algal groups. The Chl *a* concentrations derived by the model were then compared to field measurements as a surrogate for directly measured algal biomass.

3.2.2.4 Sediment Oxygen Demand

In the W2 model organic sediments resulting from algal and OM decay can contribute to nutrients and DO demand in the reservoir using a constant (zero-order) release and demand method or an organic sediment accumulative (first-order) method. The zero-order method specifies a sediment oxygen demand (SOD) and nutrient release rates that are temperature dependent. The first-order method accumulates organic sediment from settling of algae and POM and is more predictive in nature because it attempts to accurately account for the actual SOD. The first-order SOD method was used in the final Lake Zorinsky water quality model.

3.2.3 INITIAL CONDITIONS

Initial constituent concentrations were derived from minimum constituent concentrations detected in the ambient water quality samples from the reservoir with the exception of DO. DO concentrations in the reservoir were set to be 90% saturated at the first day of the simulation based on observed data.

3.3 MODEL SETUP

3.3.1 LAKE BATHYMETRY

The Lake Zorinsky bathymetry was created from a bathymetric map produced by the U.S. Geological Survey (USGS) based on a survey conducted in 2002 (USGS, 2002). The reservoir bathymetry consists of one branch divided into 30 active segments and 19 active layers; layer 4 is shown in Figure 3.2. All bathymetry segments are from 50 to 105 meters in length and have 0.3 to 0.9 meter vertical layer thicknesses based on bathymetric map contour elevations and survey elevations from the Army Corps of Engineers 1985 survey. The length of the lake bathymetry from inlet to outlet is approximately 2600 meters. The model depth from the top of the flood control and multipurpose pool elevation of 338.33 m (1110.0 ft-NGVD29) to the low-level gate is 6.1 meters, the depth to reservoir bottom is 10.03 meters (Figure 3.5). The deeper reservoir area "upstream" of the low-level gate is a possible "stagnant zone" that contains water that might not be drawn into the low-level outlet if the outlet is used during thermal stratification. This potential "stagnant zone" is the reservoir area shown below the red low-level gate elevation line in Figure 3.5. At the top of the flood control and multipurpose pool segment widths range from 10 to 770 meters. Chezy's bottom friction coefficients were all set at 70.

Figure 3.2. Plan view of the Lake Zorinsky model bathymetry segments and orientation in space.

Volume-area-elevation curves constructed from the USGS 2002 survey, the Army Corps of Engineers 1985 survey, and the W2 model bathymetry file are compared in Figure 3.3 and Figure 3.4. Adjustments were made to the initial bathymetry file to reflect the observed reservoir bottom area instead of the total volume. This was done to simulate the internal nutrient flux as accurately as possible. The model and USGS surveyed lake volumes deviate some; yet the areas match closely. The Army Corps of Engineers 1985 survey was used to create the model bathymetry above the conservation pool and compare the model bathymetry to "as built" observations. Figure 3.3 and Figure 3.4 show the model bathymetry reflects the sedimentation and area seen in the 2002 survey and the volume of the "as built" survey at higher elevations.

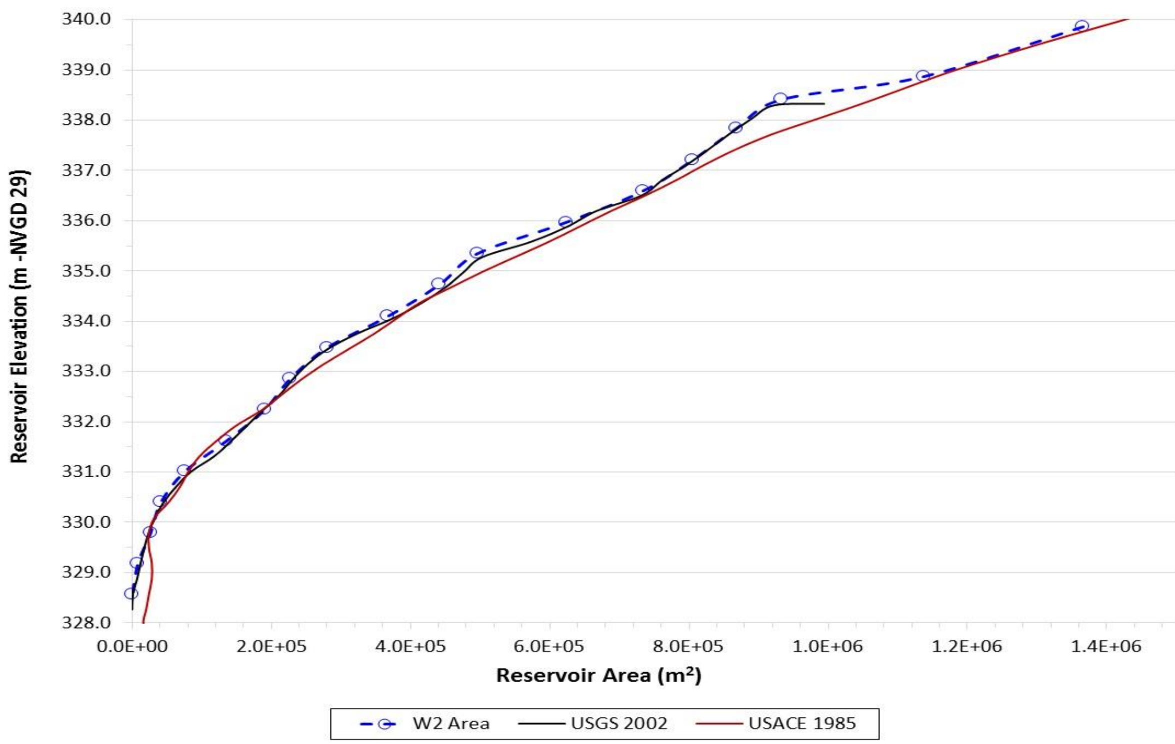

Figure 3.3. Area-elevation curves from the W2 model bathymetry, the 2002 USGS survey, and the 1985 USACE survey.

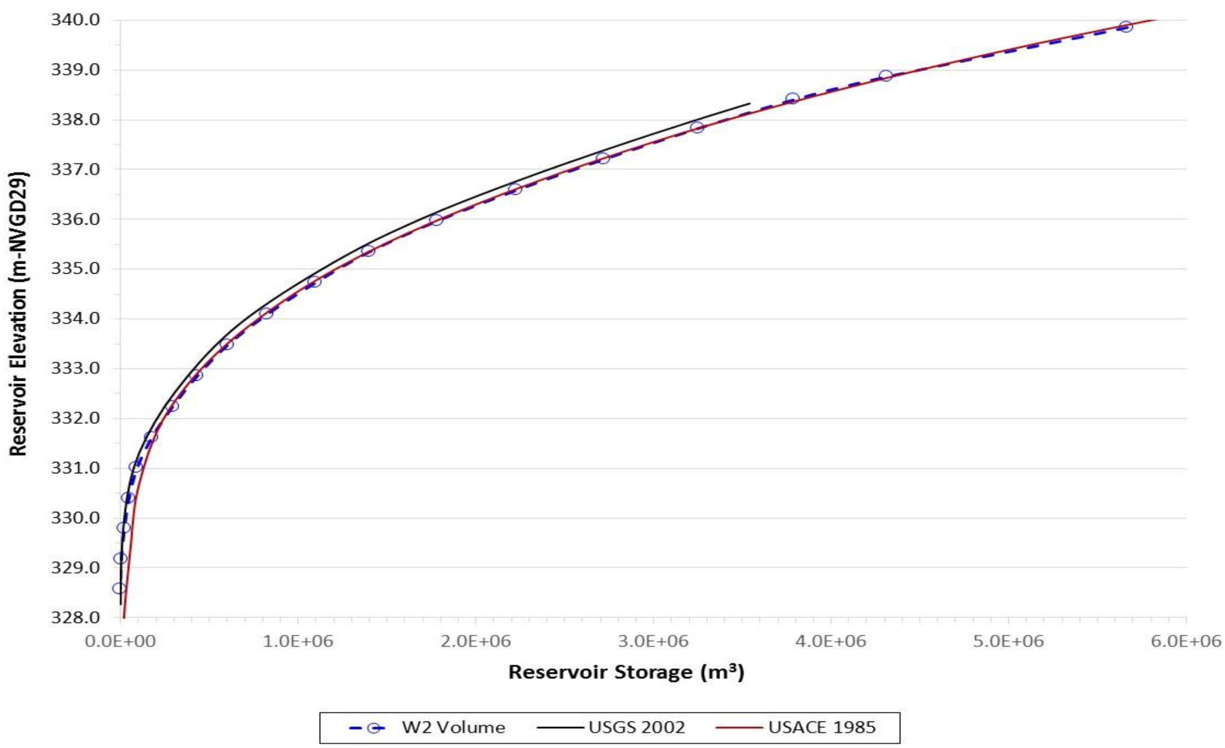

Figure 3.4. Volume-elevation curves from the W2 model bathymetry, the 2002 USGS survey, and the 1985 USACE survey.

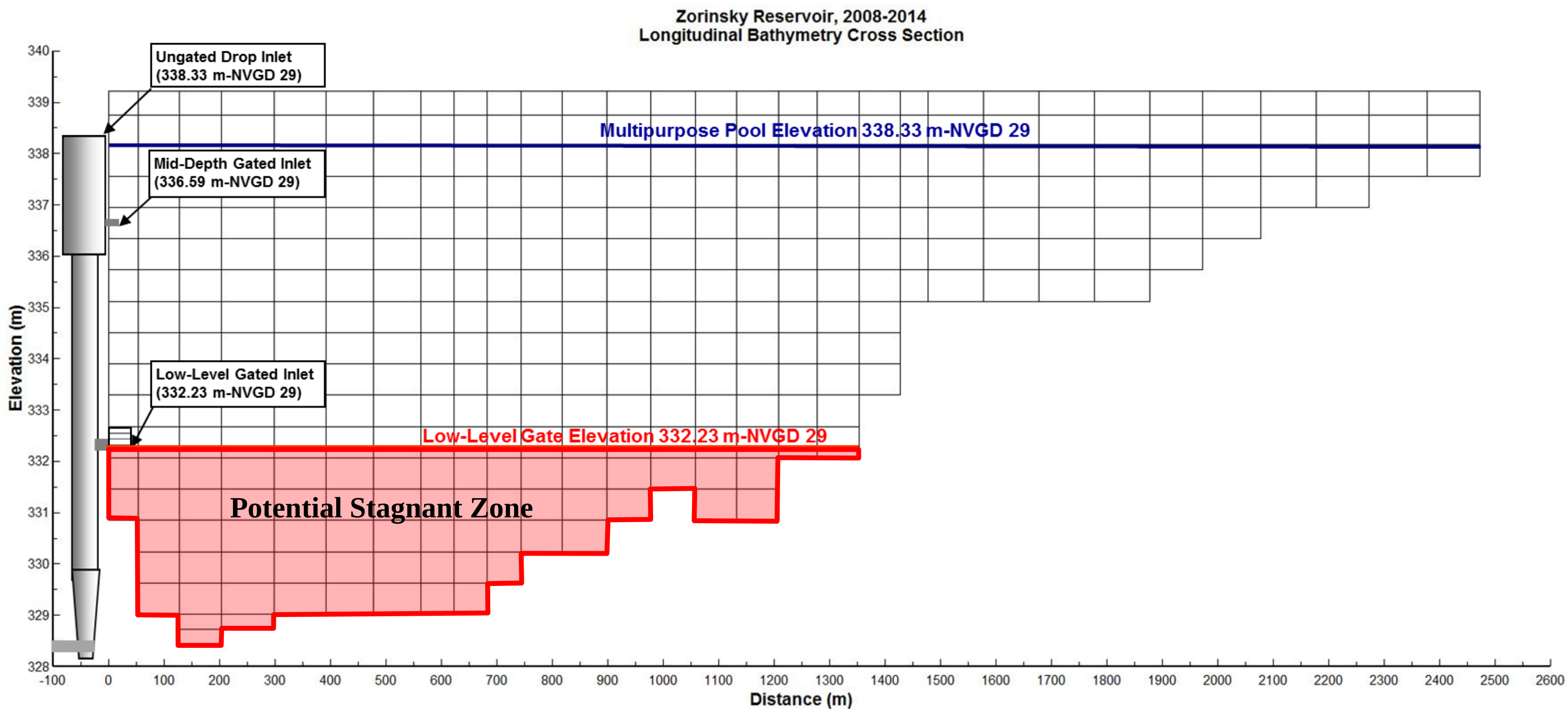

Figure 3.5. Longitudinal cross section view of the Lake Zorinsky model bathymetry.

3.3.2 INTAKE STRUCTURES

The reinforced concrete intake structure at Zorinsky Reservoir has four upper-level intakes, an intermediate-level intake, and a low-level intake. Two upper level intakes have an invert elevation of 338.33 m (1110.0 ft-NGVD29) and the other two have an invert elevation of 340.64 m (1117.6 ft-NGVD29). The intermediate-level intake has an invert elevation of 336.59 m (1104.25 ft-NGVD29), and the low-level intake has an invert elevation of 332.23 m (1090.0 ft-NGVD29). The upper-level intakes are uncontrolled. The intermediate-level intake has a 15.2 cm diameter slide gate for flow augmentation releases for water quality management. The low-level intake is has a slide gate to permit draining of the reservoir to elevation 332.23 m in the event drawdown is desirable. The low-level inlet is constructed 73 meters upstream of the intake tower. The inlet is provided with a trash rack and emergency bulkhead to allow closure with the gate open. A 76 cm reinforced concrete pipe connects the low-level inlet to the intake structure.

3.3.3 OUTLET CONFIGURATION

The outlet works of Lake Zorinsky consist of a tunnel and an outlet structure into the stilling basin. The tunnel is composed of 121.9 cm diameter reinforced concrete piping which extends 203.6 m from elevations 332.23 m (1090.0 ft-NGVD29) to 324.61 m (1065.0 ft-NGVD29). The tunnel empties into a concrete spillway structure which is 20.4 m in length and slopes from elevations 324.61 m (1065.0 ft-NGVD29) to 320.26 m (1050.8 ft-NGVD29). Once water enters the stilling basin it reconstitutes Boxelder Creek.

The model outlets are configured as a point sink at centerline elevations 338.33 m (1110.0 ft-NGVD29) and 332.23 m (1090.0 ft-NGVD29). The intermediate level intake was not included in this model because it was not used during the modeled time frame, but it can be easily added in the future. The bottom withdrawal limitation is 331.62 m (1088.0 ft-NGVD29) and the top limitation is 339.75 m (1114.7 ft-NGVD29); however, the model's internal selective withdrawal algorithm determines what layers water is withdrawn from within the withdrawal limits and near the centerline elevation.

3.4 MODEL INPUTS

3.4.1 METEOROLOGICAL DATA

W2 requires meteorological inputs including air temperature, dew point temperature, wind speed, wind direction, and cloud cover or shortwave solar radiation. Cloud cover was used in the Lake Zorinsky model to determine the amount of shortwave solar radiation reaching the water surface. Sub-hourly weather data that included all necessary parameters were obtained from the Eppley Airfield Weather Station near Omaha, NE. The Eppley Airfield Weather Station is located roughly 16 miles away from Lake Zorinsky. Upon review, wind speeds in excess of 20 m/s were reported on 14 occasions during the months of May through June. Observed water temperature depth profile data do not reflect that these conditions occurred at Zorinsky. In order to accurately characterize actual wind conditions at Lake Zorinsky instantaneous data points were extracted from the sub-hourly meteorological data at 1.5 hour intervals. This eliminated all but 1 measurement in excess of 20 m/s.

3.4.1.1 Temperature

Ambient air and dew point temperatures from 2008 through 2014 are plotted in Figure 3.6 and Figure 3.7.

3.4.1.2 Wind Data

Wind data was a major driving factor of temperature calibration. The 1.5 hour interval data points extracted from the Eppley Airfield weather station wind speeds from 2008 through 2014 are plotted in Figure 3.8.

3.4.1.3 Cloud Cover

Cloud cover data was provided as an abbreviation of sky coverage and then converted to a value on a 0 to 10 scale for use in the W2 model (Table 3-2). The accuracy of cloud cover data is questionable due to the local nature of the cloud cover readings. It is an important component of model application used to limit incoming solar radiation and inhibit the escape of outgoing long-wave radiation. Cloud cover values scaled from abbreviated coverage codes are plotted in Figure 3.9.

Table 3-2. Cloud Cover Conversion Values.

Cloud Cover Abbreviation	Value (0-10)
OVC	8
BKN	6
SCT	4
FEW	2
CLR	0

3.4.1.4 <u>Wind Sheltering Coefficients</u>

Wind sheltering coefficients are the ratio of transferred wind energy to actual wind energy present in the meteorological data. Wind sheltering coefficients are one of the most important calibration parameters because they directly influence the amount of mixing that occurs in the surface layer of the reservoir and therefore the transfer of heat energy from the water surface to deeper layers in the reservoir. Wind sheltering coefficients of 0.8 were used for all segments in the Lake Zorinsky model.

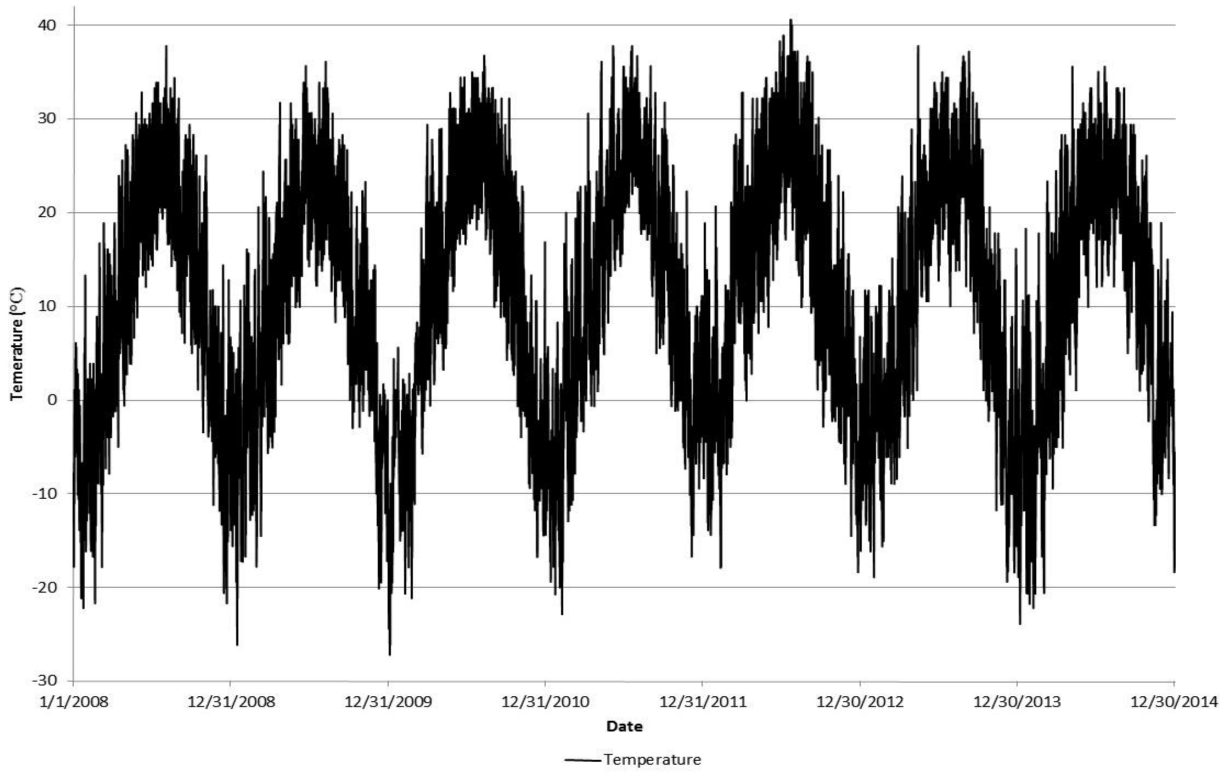

Figure 3.6. Air temperatures used in the model from Eppley Airfield Weather Station near Omaha, NE.

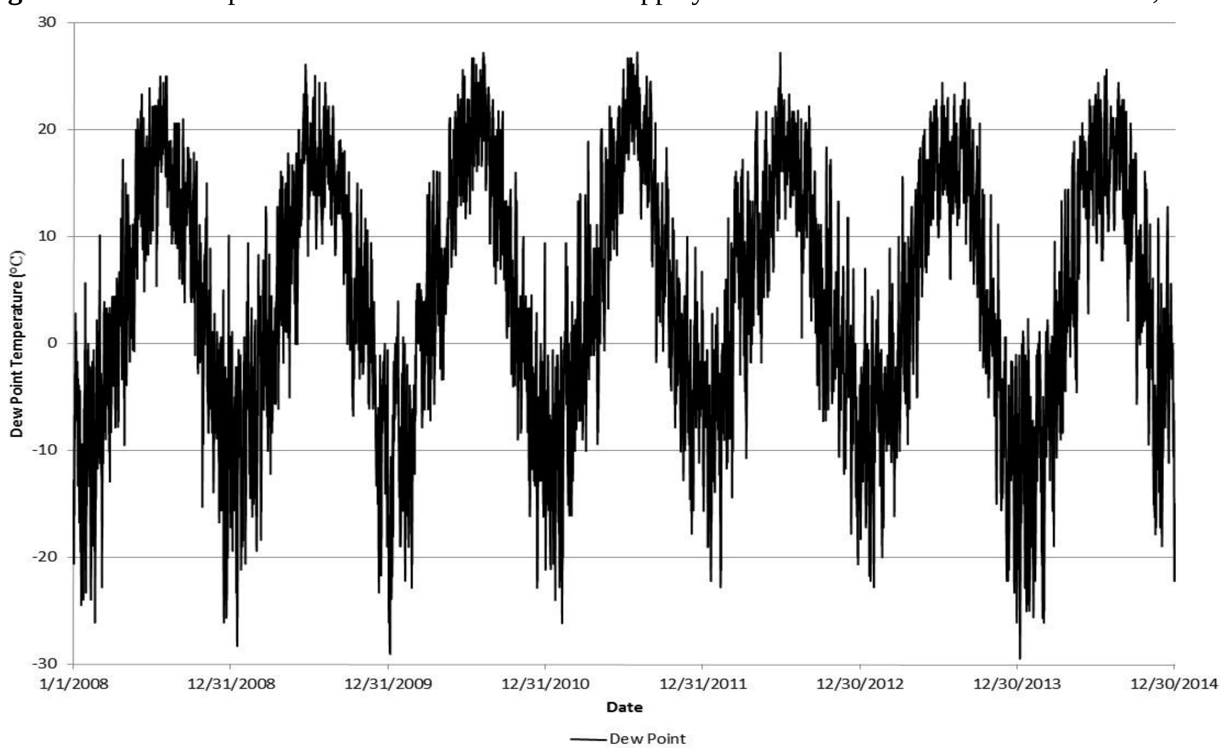

Figure 3.7. Dew point temperatures used in the model from Eppley Airfield Weather Station near Omaha, NE.

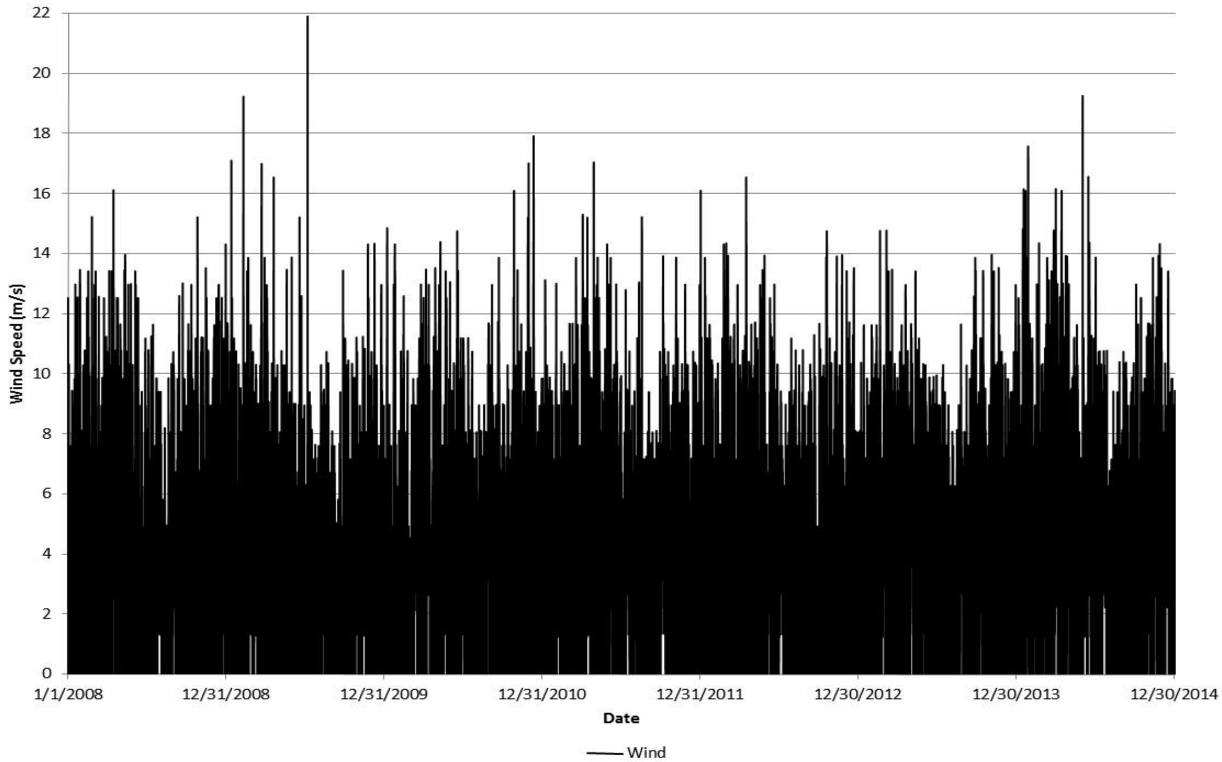

Figure 3.8. Wind speed used in the model from Eppley Airfield Weather Station near Omaha, NE.

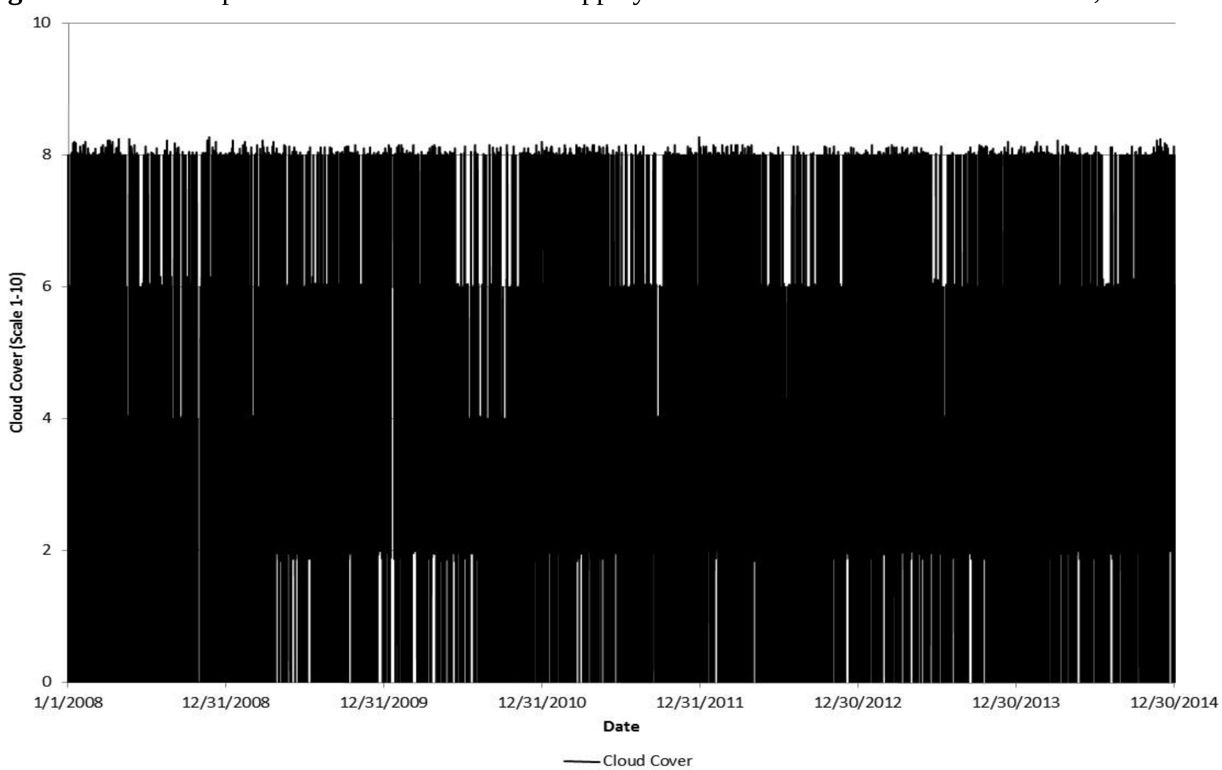

Figure 3.9. Scaled cloud cover used in the model from Eppley Airfield Weather Station near Omaha, NE.

3.4.2 Reservoir Inflow and Outflow

Inflow from Boxelder Creek was input as the reservoir Branch 1 inflow. Daily Boxelder Creek inflows were obtained using the Corps Water Management System (CWMS) managed by the Omaha District. The system is provided data via a satellite link from an elevation monitor at the reservoir. Elevation data are used in conjunction with capacity curves, outlet structure engineering data, and modeled evaporation rates to determine reservoir inflows and outflows. This method of calculating inflow assumes zero seepage and confounds other potential avenues of reservoir flow such as ungaged overland flow, direct precipitation, and groundwater exchange (Figure 3.10); however, the inflow and outflow values obtained from CWMS required only minor modifications. Modifications were based on visual observation of modeled versus observed water surface elevations in order to produce a satisfactory reservoir water balance.

Because the CWMS and the W2 model calculate evaporation in a similar manner, the CWMS values for evaporation were added to the Boxelder Creek inflow and the W2 model was used to calculate evaporation and its effects on the reservoir. During model thermal calibration, hypolimnetic temperatures were over-predicted during the late summer of 2012 and 2013. Examination of the CWMS's reservoir inflows and outflows indicated zero flow during these periods. Groundwater intrusion observed during the winter draw down of 2010 was then included in the model with an estimated flow of 1 cfs and an estimated loss of 1 cfs as seepage at the base of the dam. Groundwater inflow was included seasonally based on the pattern of observed groundwater levels in the area. Inflow values used in the model are plotted in Figure 3.11. Outflow from Zorinsky Reservoir, which is used for the downstream boundary, are plotted in Figure 3.12.

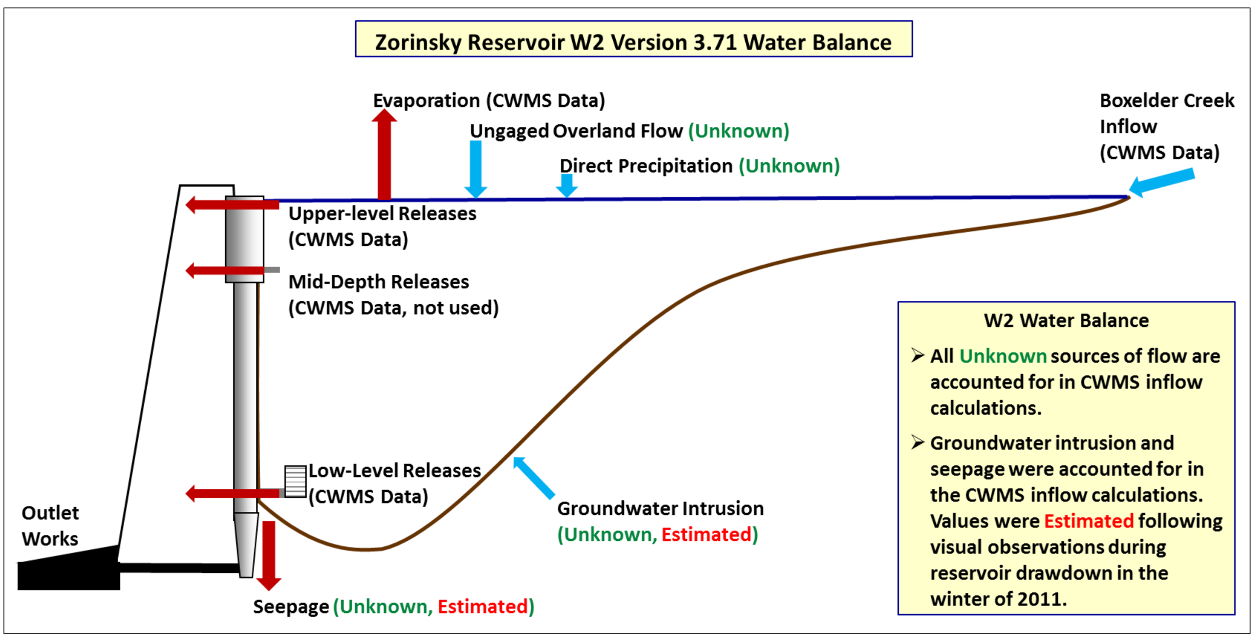

Figure 3.10. Zorinsky Reservoir W2 Version 3.71 Water Balance

3.4.3 Inflow Temperature

Inflow temperatures for Zorinsky Reservoir were not routinely monitored during the simulated time period. Instead, these values were estimated using a program called Response temperature: a simple model of water temperature (rTemp) from the Washington State Department of Ecology (WSDE) (WSDE, 2011). Response temperature can be defined as the temperature a completely mixed water column would have if it were only responding to heat fluxes across the waters surface. The rTemp program expands the response temperature concept to include stream bed, groundwater, and hyphorheic zone heat fluxes; however, due to a lack of observed supporting data these options were not used to estimate inflow temperatures for Zorinsky Reservoir. The rTemp program calculates surface heat exchange from the same meteorological input as the W2 model but does not require wind direction input. An extensive review of these parameters and equilibrium temperature can be found in Edinger et al. (1974). Growing season inflow temperatures were verified on 21 occasions during 2010 through 2014 and had an absolute mean error of 1.1 °C. Simulated and observed inflow temperatures are plotted in Figure 3.13.

3.4.4 INFLOW DISSOLVED OXYGEN

Dissolved oxygen (DO) measurements were made with inflow samples collected during the growing seasons of 2010 through 2014; however, a continuous record of DO concentrations at the reservoir inlet was desired for model application. The continuous DO concentrations were assumed to be 90% of the saturated DO concentration using an empirical equation. The 90% saturated assumption was based on observed data. The equation provided by the Environmental Laboratory of ERDC (shown below) approximates DO concentrations in milligrams per liter of water (mg/l) as a function of water temperature (*T*) in Kelvin (K) and elevation (*z*) in kilometers (km). Simulated water temperatures from the rTemp program were used in the approximation. Growing season inflow DO concentrations were verified on 21 occasions and had an absolute mean error of 0.7 mg/l. Observed and simulated DO concentrations are shown in Figure 3.14.

$$DO = (1 - 0.1148z)\exp\left(-139.3441 + \frac{1.58x10^5}{T} - \frac{6.64x10^7}{T^2} + \frac{1.24x10^{10}}{T^3} - \frac{8.62x10^{11}}{T^4}\right)$$

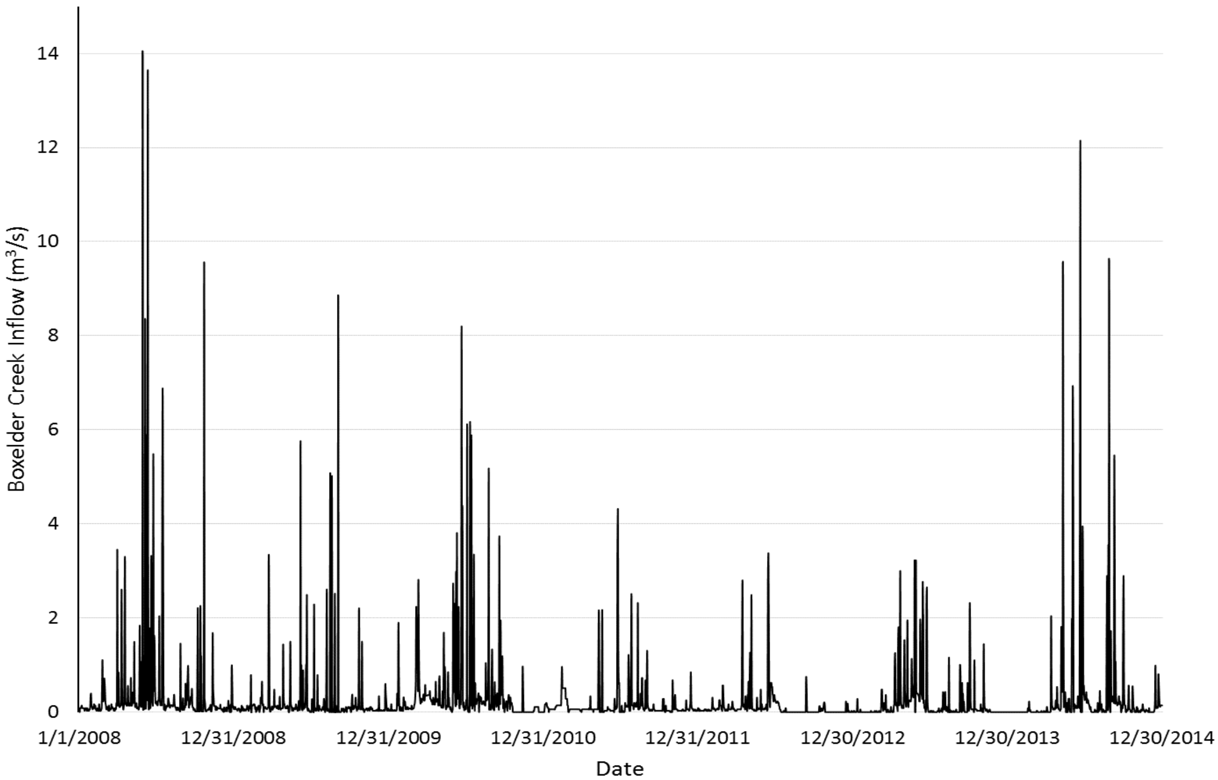

Figure 3.11. Boxelder Creek inflows to Lake Zorinsky.

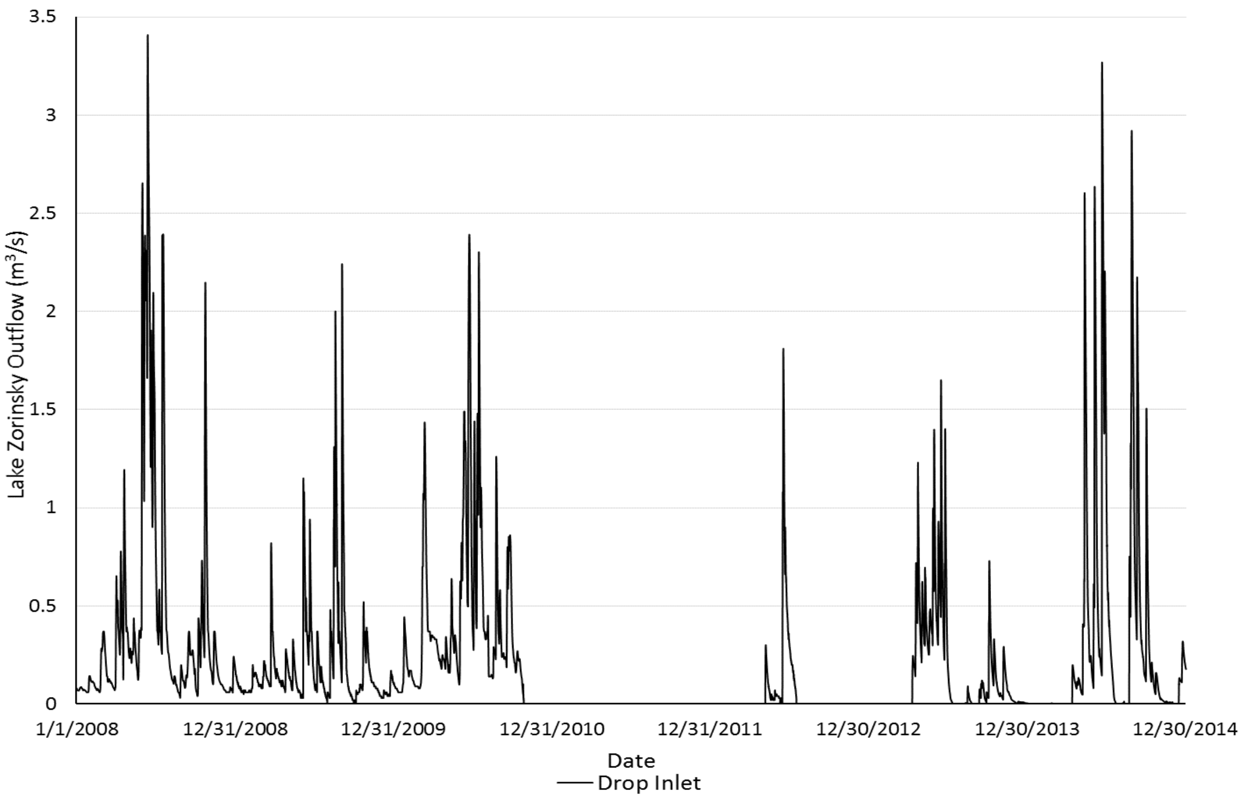

Figure 3.12. Outflows from Lake Zorinsky.

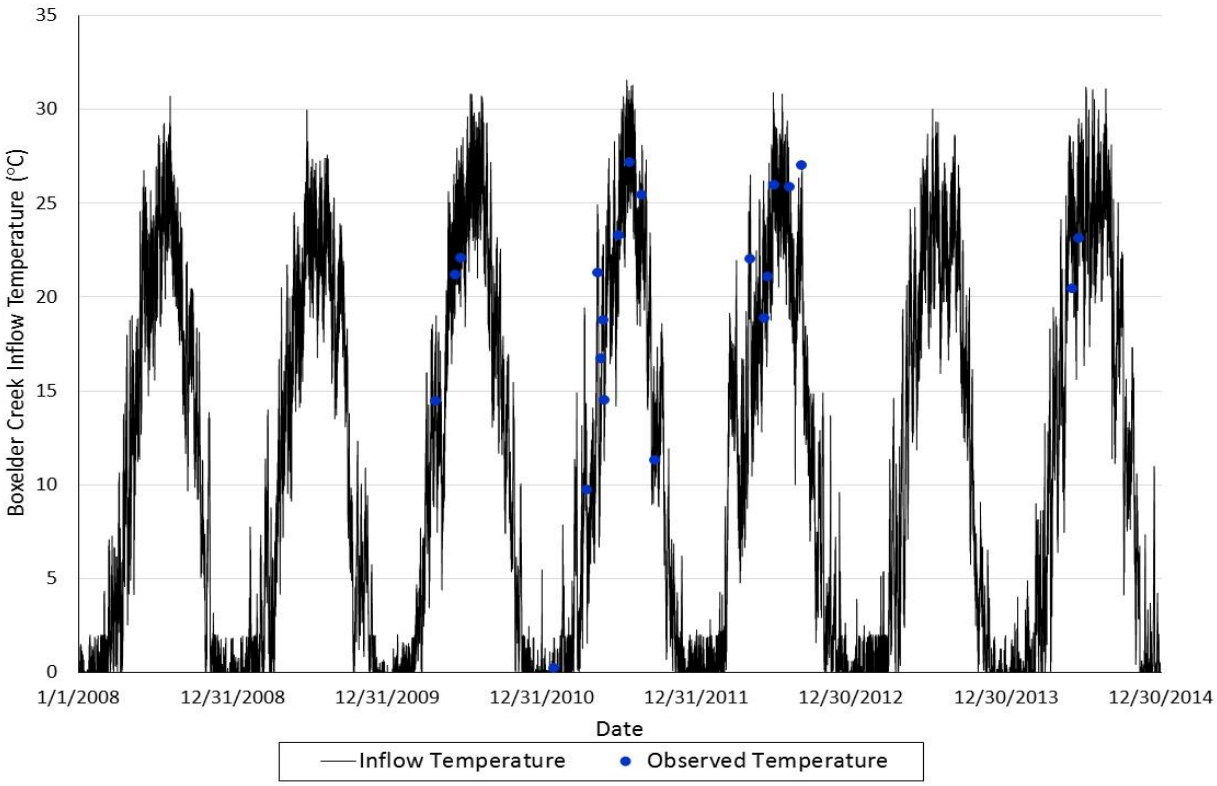

Figure 3.13. Simulated (rTemp) and Observed Boxelder Creek inflow temperature.

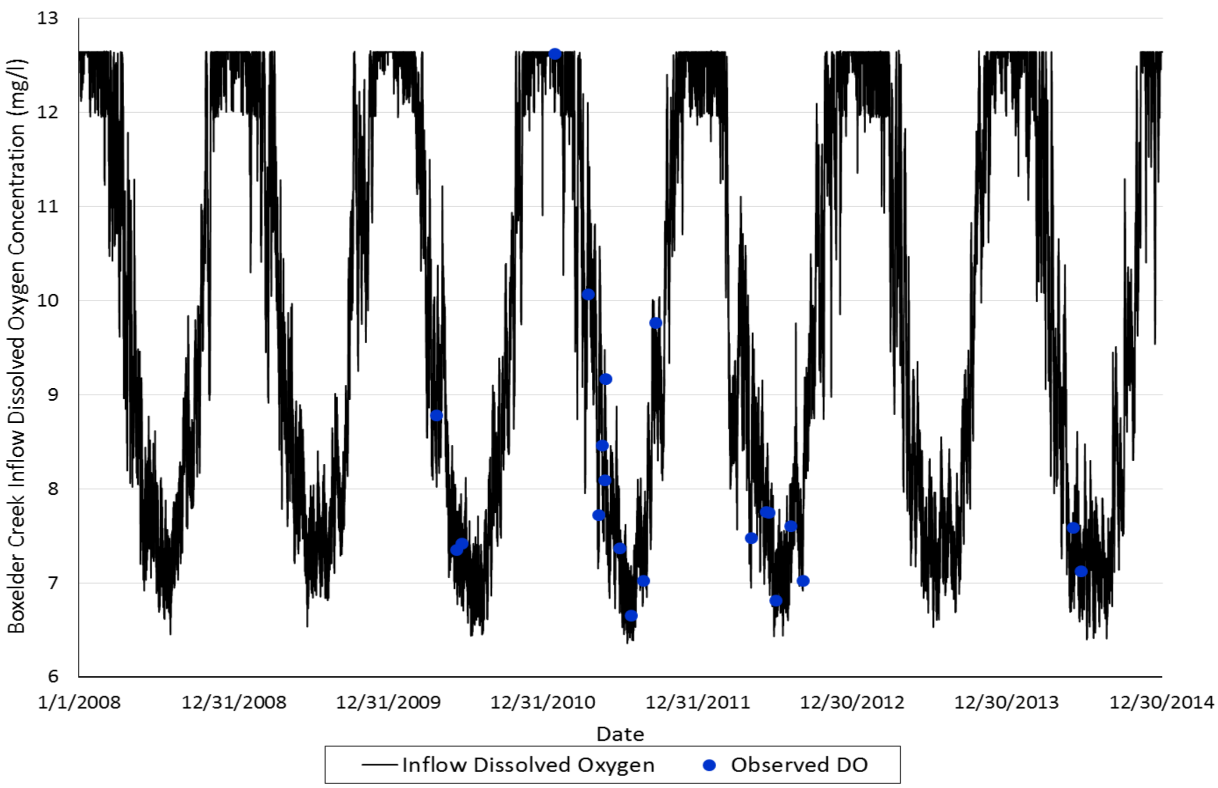

Figure 3.14. Simulated (90% saturated) and Observed dissolved oxygen concentrations in Boxelder Creek.

3.4.5 INFLOW CONSTITUENT CONCENTRATIONS

Water quality samples were taken during the modeled period at the inflow location EZRNF1. The site is approximately 1½ miles upstream from the reservoir (Figure 2.2). Samples were taken under runoff conditions during April through September and analyzed for a number of water quality constituents including: total suspended solids (TSS), total ammonia (NH_4), nitrate/nitrate (NO_x), total phosphorus (TP), and total Kjeldahl nitrogen (TKN). Orthophosphate (PO_4) and total and dissolved organic carbon (TOC, DOC) were measured in 2011 through 2014. Water temperature, DO, pH, specific conductance, and turbidity were measured in the field in 2010 through 2014. From the measured constituent concentrations the following constituents' concentrations were utilized in the model: total dissolved solids (TDS), suspended solids (SS), PO_4, NH_4, NO_x, and DO. Labile and refractory dissolved organic matter, labile and refractory particulate organic matter, and algae, were estimated when using data collected in years prior to model application by the Omaha District. The modeled constituent inputs are shown in FiguresFigure 3.15 through Figure 3.20.

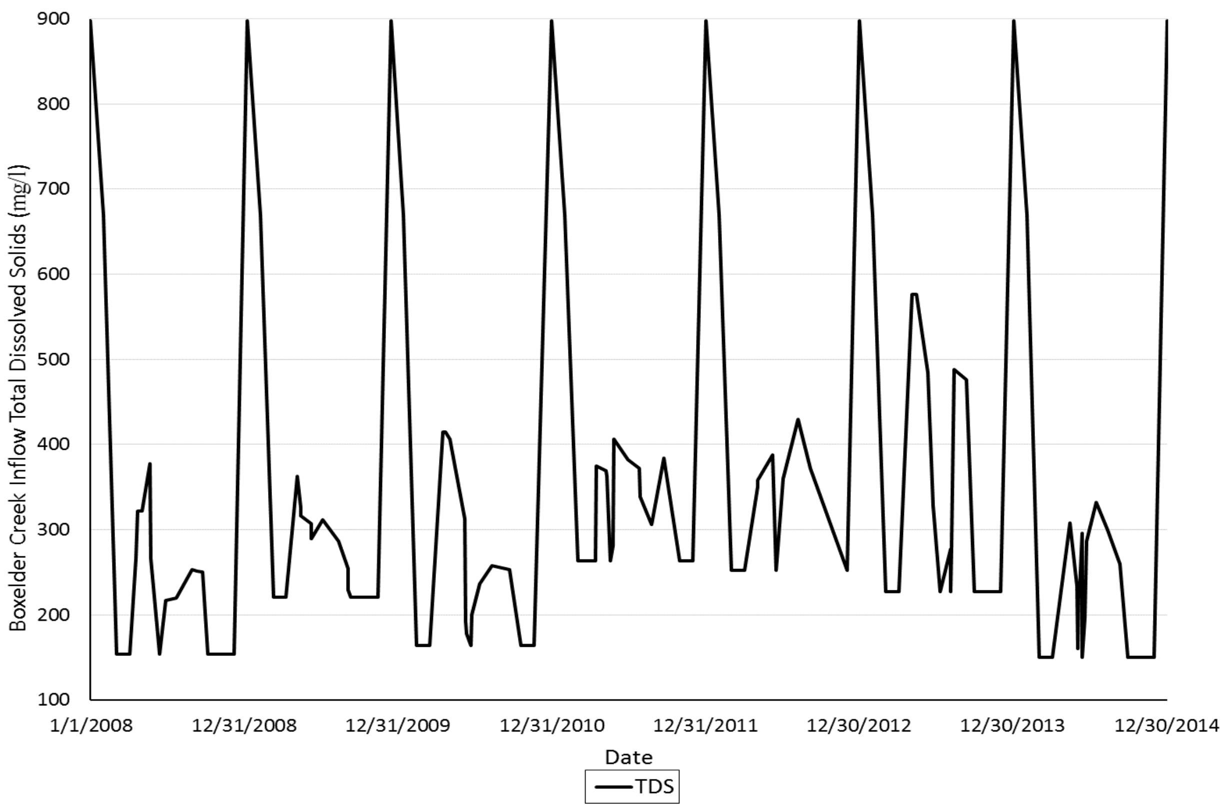

Figure 3.15. TDS inflow concentrations used in the Lake Zorinsky W2 model.

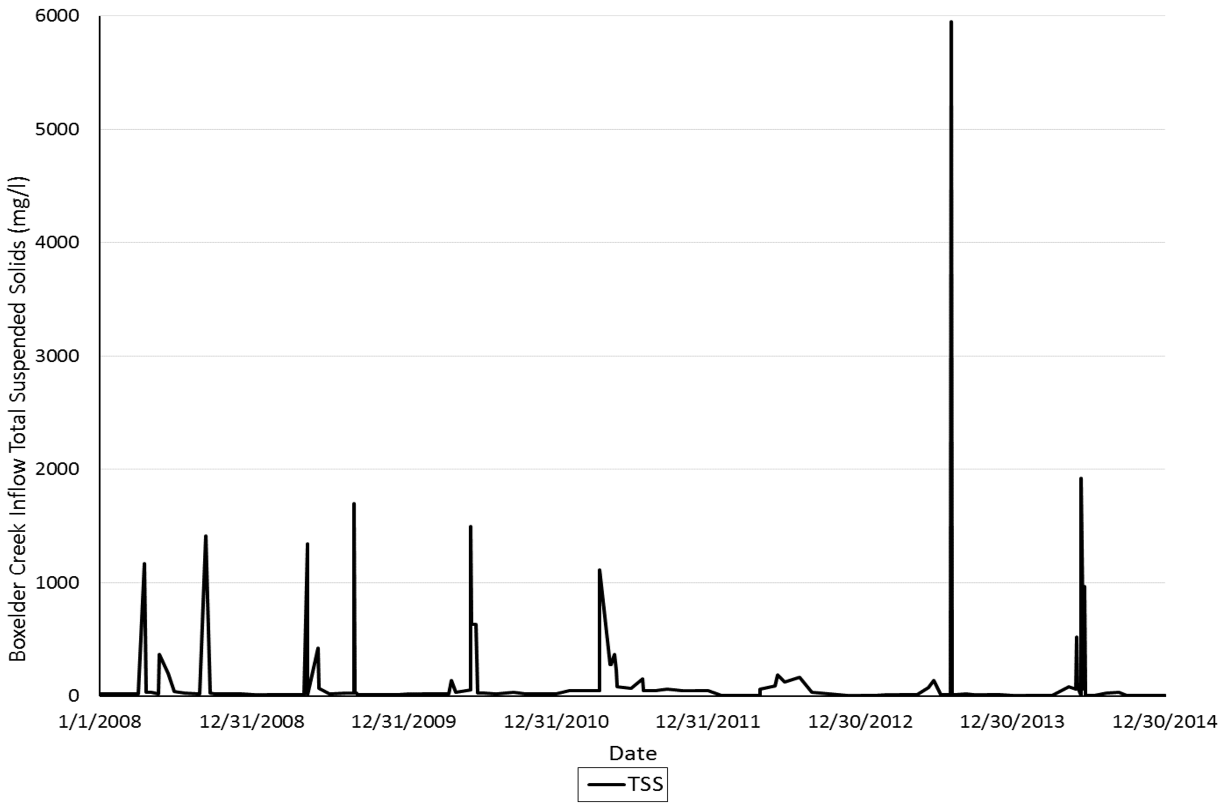

Figure 3.16. TSS inflow concentrations used in the Lake Zorinsky W2 model.

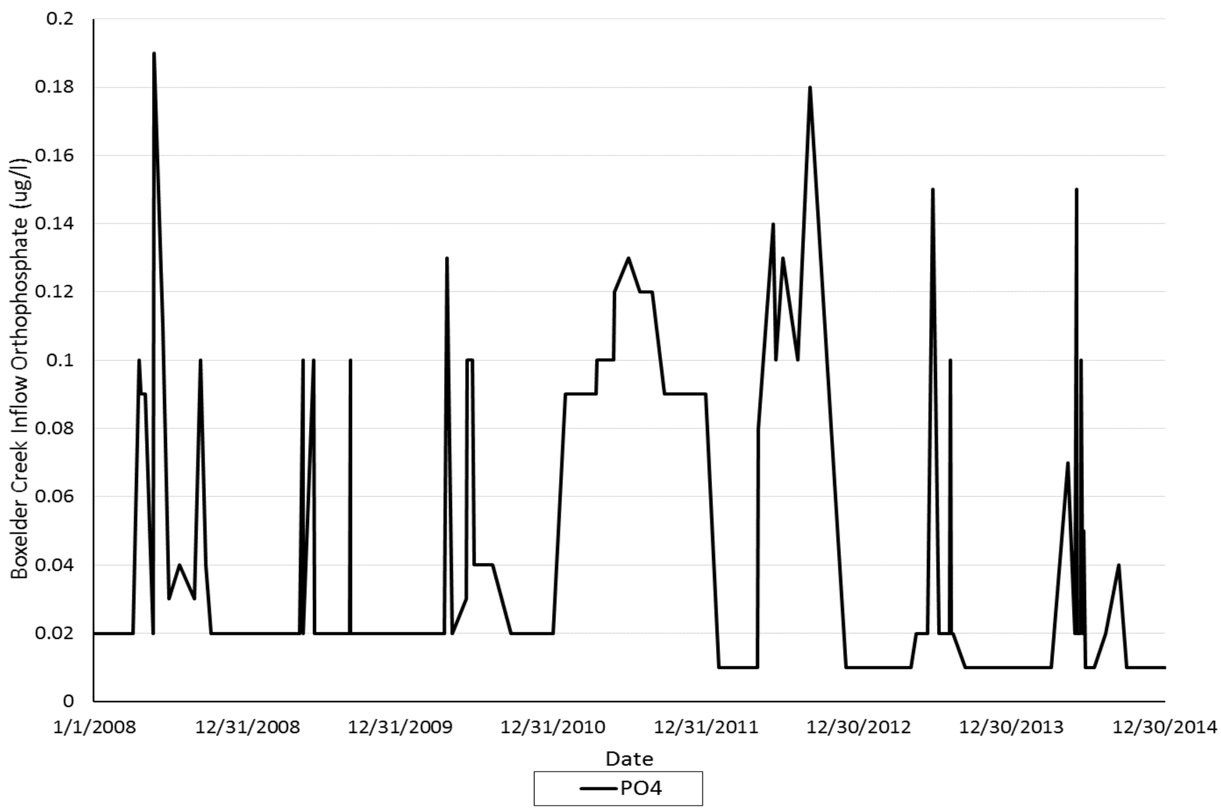

Figure 3.17. Orthophosphate inflow concentrations used in the Lake Zorinsky W2 model.

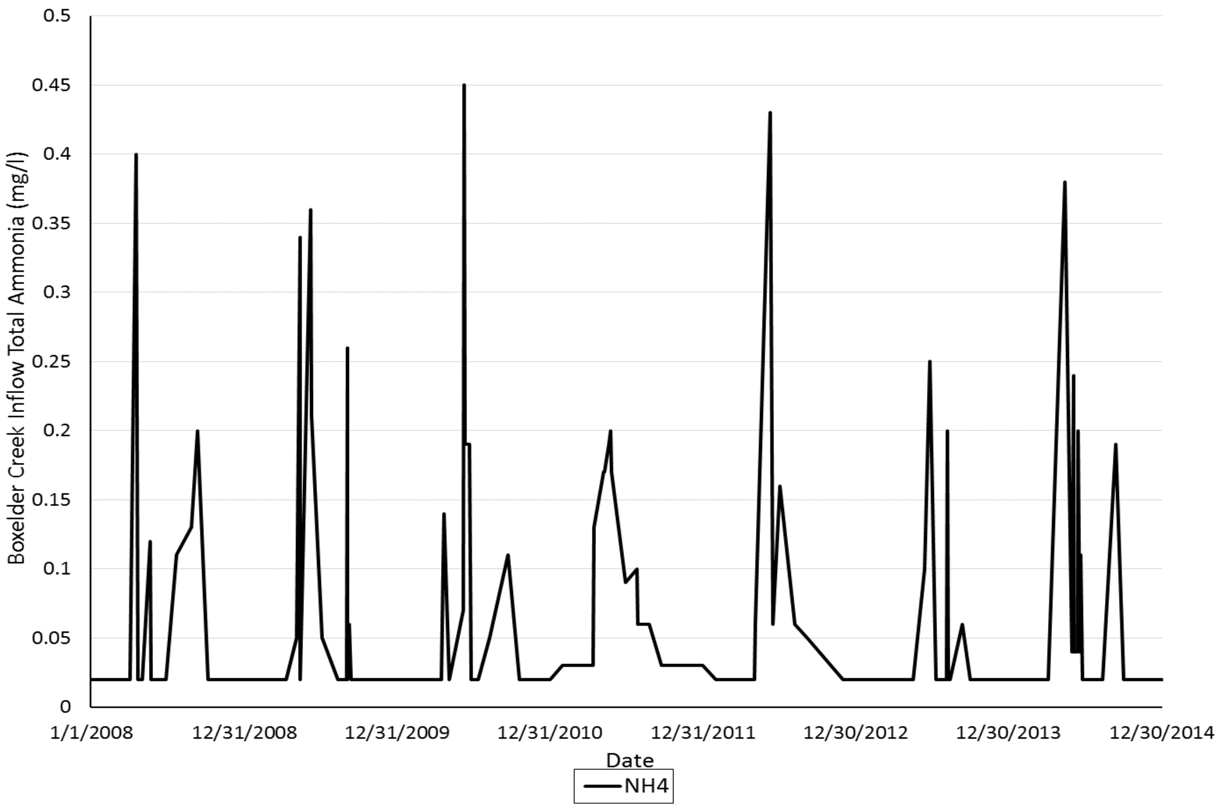

Figure 3.18. Total Ammonia inflow concentrations used in the Lake Zorinsky W2 model.

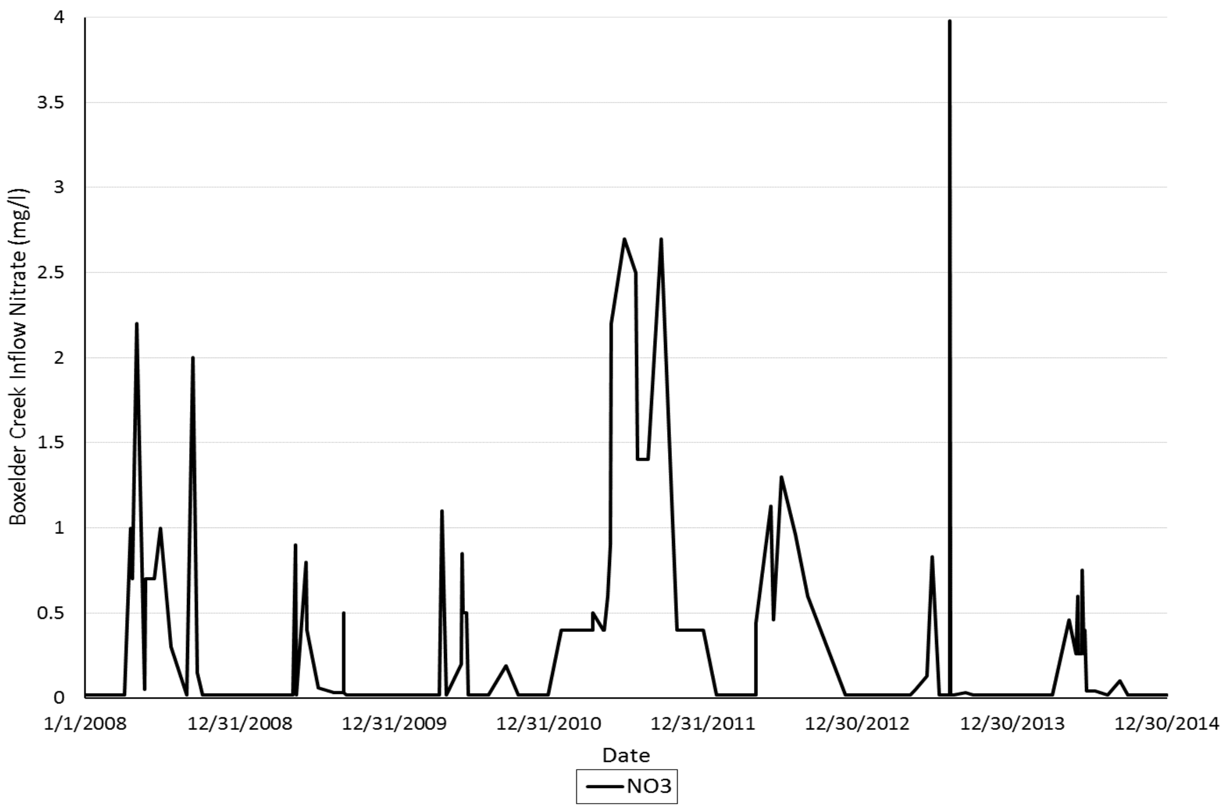

Figure 3.19. Nitrate inflow concentrations used in the Lake Zorinsky W2 model.

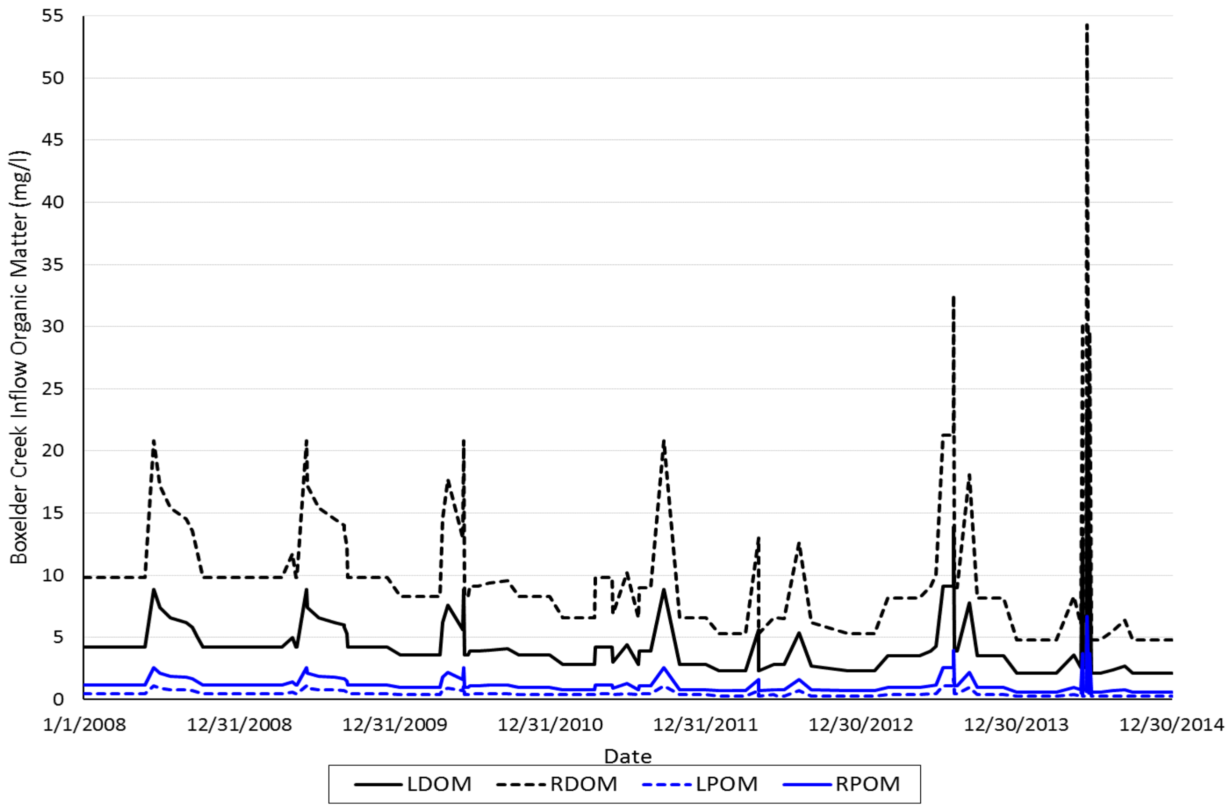

Figure 3.20. Organic Matter inflow concentrations used in the Lake Zorinsky W2 model.

Dissolved and particulate organic matter was estimated from TOC and DOC concentrations. When data gaps were encountered TOC was assumed to be 6 mg/l based on collected data and literature review (Wetzel, 2001). Estimation assumed an organic carbon to organic matter ratio of 0.45. Based on the observed TOC to DOC ratio, 90 percent of organic matter was assumed dissolved and 10 percent particulate. Based on other U.S. Army Corps of Engineers' applied water quality models, 30 percent of organic matter was assumed labile and 70 percent was assumed refractory (USACE, 1999).

Since a continuous daily inflow constituent record was not possible, constituent concentrations were assumed each month during the growing season using data collected at sites EZRLKUP1 and EZRNF1(Figure 2.2). Because the upper basin was designed for sediment retention it is assumed that inflows contained higher sediment concentrations than observed in the near surface samples from site EZRLKUP1.

4 WATER TEMPERATURE & CONSTITUENT CALIBRATION

Reservoir hydrodynamics were calibrated by making minor adjustments to the CWMS's reservoir inflow values to match the simulated reservoir inflow-outflow-storage to the observed water surface elevations. Reservoir temperatures and dissolved oxygen were calibrated at the six locations where profiles were measured.

4.1 OBSERVED WATER QUALITY DATA

Locations where temperature measurements were taken are shown in Table 4-1. Temperature profiles and water quality samples for laboratory analysis were taken monthly from May to September. Depth-profiles (temperature, dissolved oxygen, conductivity, pH, ORP, turbidity, and chlorophyll-a) were measured at all six sites. Water samples for laboratory analyses were collected at sites EZRLKND1 and EZRLKUP1.

Table 4-1. Sample Locations, Site Alias, W2 segment numbers, and approximate lake kilometer.

Site Name	Site Alias	Model Segment Number	Distance from Dam (km)
EZRLKND1	Z1	29	0.15
EZRLKML1A	Z2	25	0.50
EZRLKML1B	Z3	20	0.85
EZRLKML2	Z4	14	1.35
EZRLKUP1	Z5	11	1.50
EZRLKUP2	Z6	6	2.00

4.1.1 TEMPERATURE

Depth-discrete lake temperatures were measured in the field at 0.5-meter depth increments with "Hydrolab" instruments at six different locations along the old creek channel (sites Z1 to Z6). Temperature profiles were constructed from the measurements for comparison to simulated temperatures.

4.1.2 WATER QUALITY

Water quality samples were collected from two in-pool locations. Near-surface samples were collected at sites Z1 and Z5, and near-bottom samples were only collected at site Z1. Near-surface samples were collected at half the Secchi disk depth with a Kemmerer or Van Dorn sampler, or by dipping a plastic churn bucket if the Secchi depth was less than 1 meter. Near bottom samples were collected with a Kemmerer or Van Dorn sampler. Phytoplankton samples were processed directly from near-surface samples and preserved with Lugols solution. A listing of the water quality constituents analyzed and analytical methods is provided in the Quality Control Plan (QCP) "2014 Monitoring of the Omaha District USACE Reservoirs in Nebraska" (USACE, 2014).

Dissolved oxygen and temperature were measured directly using a Hydrolab series 4 or 5 datasonde. Temperature was the initial constituent applied in model calibration and was followed by nutrients, algae, and DO. The algal community in the Lake Zorinsky model had a significant impact on modeled nutrient and DO concentrations. Nutrients and DO were calibrated by making adjustments to the default rates and constants defined in the W2 model (Table 4-2).

Table 4-2. W2 model water quality default coefficients, rates, and constants and those used in the current application of the W2 model to Lake Sakakawea.

Parameter*	W2 Default Value	Current Model Application Value		
Extinction Coefficients				
Water	0.25	0.45		
Inorganic Suspended Solids	0.1	0.01		
Organic Suspended Solids	0.1	0.1		
Fraction of Solar Radiation absorbed at Water Surface	0.45	0.45		
Algae (All Groups)	0.2	0.2		
Suspended Solids Rates				
Suspended Solids Settling Rate [m/day]	1.0	0.8		
Sediment Resuspension Control	OFF	ON		
Critical Shear Stress for Sediment Resuspension [dynes/cm^2]	1.0	-----		
Critical Shear Velocity for Resuspension [m/s]	-----	0.00001		
Algal Rates and Constants				
Number of Algae Groups	-----	3		
Algal Group		**#1**	**#2**	**#3**
Algal Growth Rate [1/day]	2.0	3	2.5	0.8
Algal Dark Respiration Rate [1/day]	0.04	0.04		
Algal Excretion Rate [1/day]	0.04	0.04		
Algal Mortality Rate [1/day]	0.1	0.2	0.25	0.1
Algal Settling Rate [1/day]	0.1	0.2	0.1	0.02
Algal Light Saturation [W/m^2]	100	50	75	25
Lower Temperature for Algal Growth (AT1) [°C]	5.0	5	10	10
Lower Temperature for Maximum Algal Growth (AT2) [°C]	25.0	18	30	35
Upper Temperature for Maximum Algal Growth (AT3) [°C]	35.0	24	35	40
Upper Temperature for Algal Growth (AT4) [°C]	40.0	28	40	50
Fraction of Algal Growth Rate at AT1	0.1	0.1		
Fraction of Maximum Algal Growth Rate at AT2	0.99	0.99		
Fraction of Maximum Algal Growth Rate at AT3	0.99	0.99		
Fraction of Algal Growth Rate at AT4	0.1	0.1		
Algae Stoichiometry – Fraction P	0.005	0.005		
Algae Stoichiometry – Fraction N	0.08	0.08		
Algae Stoichiometry – Fraction C	0.45	0.45		
Algae Stoichiometry – Fraction Si	0.18	0		
Chlorophyll-algae ratio	-----	0.065		
Fraction of Algae Lost by Mortality to POM	0.8	0.8		
Ammonia Preference Factor Equation 1 or 2	2	1		
Ammonia Half Saturation Coefficient for Ammonia-Nitrate	0.001	0.001		
Oxygen Equivalent for Organic Matter for Algae Growth	1.1	1.1		
Oxygen Equivalent for Organic Matter for Algae Respiration	1.4	1.4		

Table 4.2. (Continued).

Parameter*	W2 Default Value	Current Model Application Value
Organic Rates and Constants		
Labile DOM decay rate [1/day]	0.1	0.12
Labile DOM to Refractory Decay Rate [1/day]	0.001	0.001
Maximum Refractory Decay Rate [1/day]	0.01	0.01
Labile POM Decay Rate [1/day]	0.08	0.08
Labile POM to Refractory Decay Rate [1/day]	0.001	0.001
Maximum Refractory Decay Rate [1/day]	0.01	0.01
POM Settling Rate, [m/day]	0.1	1
Organic Matter Stoichiometry – Fraction P	0.005	0.005
Organic Matter Stoichiometry – Fraction N	0.08	0.08
Organic Matter Stoichiometry – Fraction C	0.45	0.45
Organic Matter Stoichiometry – Fraction Si	0.18	0.18
Lower Temperature for Organic Matter Decay (OMT1) [°C]	4.0	4
Upper Temperature for Organic Matter Decay (OMT2) [°C]	25.0	25
Fraction of Organic Matter Decay Rate at OMT1	0.1	0.1
Fraction of Organic Matter Decay Rate at OMT2	0.99	0.99
BOD Rate Constants		
Number of CBOD Groups	-----	0
Nutrient Rates and Constants		
Phosphorus – Sediment Release Rate	0.001	0.004
Phosphorus – Partitioning Coefficient for Suspended Solids	0.0	0
Ammonium – Sediment Release Rate	0.001	0.03
Ammonium – Decay Rate [1/day]	0.12	0.12
Lower Temperature for Ammonium Decay (NH4T1) [°C]	5.0	5
Upper Temperature for Ammonium Decay (NH4T2) [°C]	25.0	25
Fraction of Nitrification Rate at NH4T1	0.1	0.1
Fraction of Nitrification Rate at NH4T2	0.99	0.99
Nitrate – Decay Rate [1/day]	0.03	0.03
Nitrate – Sediment Diffusion Rate	0.001	0.5
Nitrate – Fraction Diffused Converted to Sediment Organic N	0.0	0
Lower Temperature for Nitrate Decay (NO3T1) [°C]	5.0	5
Upper Temperature for Nitrate Decay (NO3T2) [°C]	25.0	25
Fraction of Denitrification Rate at NO3T1	0.1	0.1
Fraction of Denitrification Rate at NO3T2	0.99	0.99
Silica – Dissolved Silica Release Rate (Fraction of SOD)	0.1	0.1
Silica – Particulate Silica Settling Velocity [m/day]	1.0	1.0
Silica – Particulate Silica Decay [1/day]	0.3	0.3
Silica – Silica Partitioning Coefficient	0.0	0.0

Table 4.2. (Continued).

Parameter*	W2 Default Value	Current Model Application Value
Sediment Oxygen Demand Rates and Constants		
First Order Sediment Decay	OFF	ON
Initial Sediment Concentration (g/m^3)	0.0	0.0
Sediment Settling or Focusing Velocity [m/day]	0.1	0.1
Sediment Decay Rate [1/day]	0.1	0.1
Fraction of Zero-Order SOD Rate Used	1.0	1
Fraction of Initial 1st-Order Rate Used	1.0	1
Sediment Burial Rate [1/day]	0.01	0
Turn ON/OFF Dynamic Sediment K	OFF	OFF
Lower Temperature for Sediment Decay (SODT1) [°C]	4.0	1
Upper Temperature for Sediment Decay (SODT2) [°C]	25.0	25
Fraction of Sediment Rate at SODT1	0.1	0.1
Fraction of Sediment Rate at SODT2	0.99	0.99
Other Rates and Constants		
O_2 Limits	0.7	0.1
Iron Sediment Release Rate	0.5	0.5
Iron Settling Velocity [m/day]	2.0	2
Sediment CO_2 Release Rate	1.2	0.1
O_2 Stoichiometry Equivalent for Ammonium Decay	4.57	4.57
O_2 Stoichiometry Equivalent for Organic Matter Decay	1.4	1.4
Reaeration Type	LAKE	LAKE
Reaeration Equation Number	6	6

*As defined in the W2 Tool Application provided with the W2 model download from Portland State University.

4.2 HYDRODYNAMICS

A water balance program is included as part of the W2 model. It is used to compute the difference in observed reservoir storage and simulated reservoir storage by inputting observed and simulated pool elevations, then computing the reservoir inflow or outflow needed to balance the storage. The flows needed to balance the storage in the Lake Zorinsky model were minor and the water balance program was not utilized. Flows were modified by adjusting the reservoir branch 1 inflow when necessary. See Section 3.4.2 for a detailed description of the flows utilized in the model. The hydrodynamic calibration is completed when all reservoir flows reflect a match with observed storage (water surface elevations). The observed and simulated pool elevations are shown in Figure 4.1. The significant drop in pool elevations in December 2010 is attributed to drawing down the reservoir to manage the zebra mussel infestation.

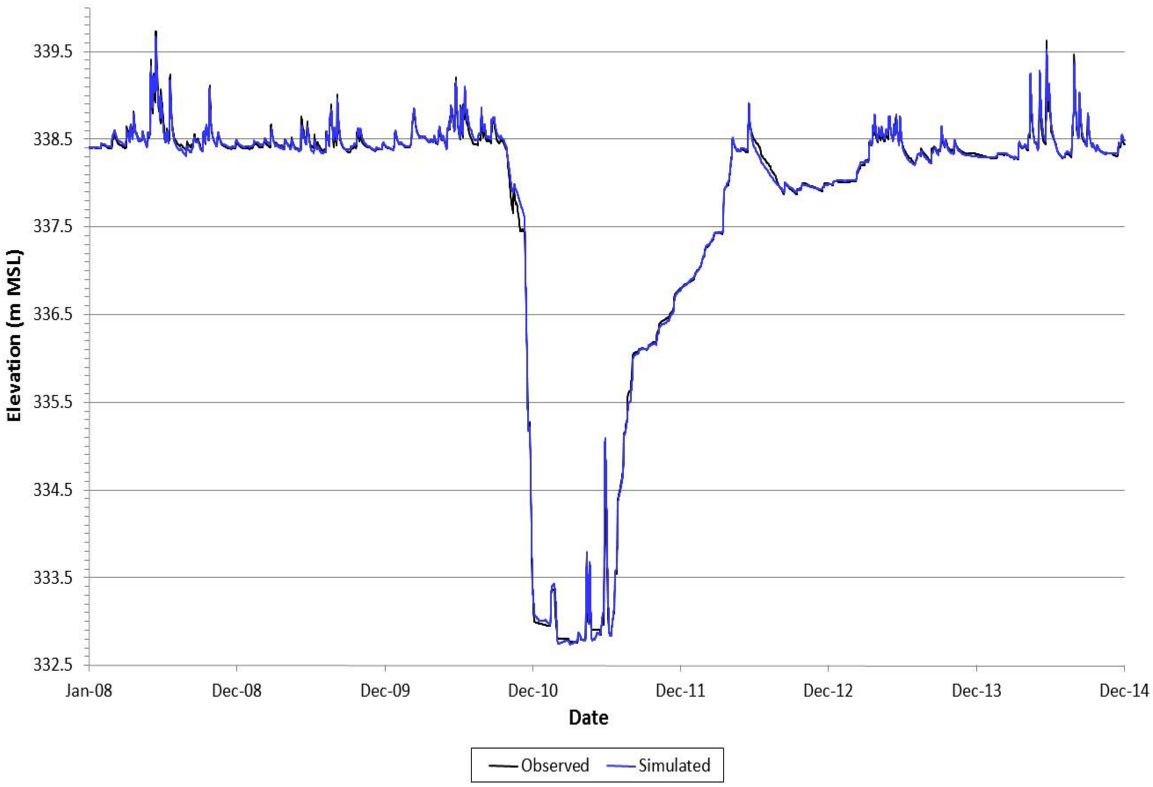

Figure 4.1. Observed and simulated Lake Zorinsky pool elevations 2008 through 2014.

4.3 TEMPERATURE

Simulated reservoir temperatures were compared to temperature profiles measured at locations Z1 through Z6. Comparisons using all six locations are presented in Plate 17 to Plate 40.

The factors that affected temperature calibration the most were wind sheltering coefficient (WSC) and inflow volume. Final WSC's were set at 0.8 for each model segment. This is due to local differences in wind velocity and direction between the weather station at Eppley Airfield and Lake Zorinsky. During the late summers of 2012 and 2013 there were periods of little to no CWMS estimated inflow to the reservoir. During these periods the W2 model would warm the entire water column; this is likely due to a lack of circulation and algal production capable of shading the water column. To reduce hypolimnetic temperatures, tributary flow was added to the reservoir via groundwater intrusion which was observed when the reservoir was drained to extirpate zebra mussels during the winter of 2010. Even with additional tributary flow hypolimnetic temperatures remained somewhat warmer than observed.

The simulation was run continuously from 2008 to 2014. Thermal calibration was examined on a year by year basis to better understand annual variation in the model. Statistically the best temperature calibration was achieved in 2009 while 2013 was the least accurate (Table 4-3). Absolute errors for all years ranged from 0.6 to 1.1°C with an average of 0.9°C. Plots showing simulated versus observed temperature profiles at all reservoir locations are provided in Plate 17 through Plate 40 at the end of the report.

Table 4-3. Average annual absolute error between measured and simulated reservoir temperatures and dissolved oxygen concentrations over all reservoir locations (Z1-Z6).

Year	Absolute Error		
	Temperature (ºC)	Observed Dissolved Oxygen (mg/L)	Saturated* Dissolved Oxygen (mg/L)
2008	0.8	1.1	1.0
2009	0.6	2.7	1.3
2010	0.9	1.5	1.2
2011	0.8	1.3	1.3
2012	0.9	2.3	1.3
2013	1.1	2.1	1.2
2014	1.1	1.5	1.2
Average	0.9	1.8	1.2

* DO was set equal to the 100% saturated value for paired temperature observation to assess the impact of algal production on DO calibration.

4.4 DISSOLVED OXYGEN

The most important factor affecting DO calibration was algal oxygen production. The W2 model did not replicate the supersaturated DO conditions monitored in the reservoir. DO super saturation is the result of photosynthesis by dense colonies of algae. The model did not replicate these conditions due to the frequency of monitored inflow constituent concentrations and the inherent difficulty of modeling algal growth and interactions in a hypereutrophic reservoir. To assess the extent which supersaturated DO conditions affected model calibration the observed dataset was modified for comparison. All observed DO concentrations greater than 100% saturated were set to the 100% saturated value for their corresponding temperature and compared to model output (DO and temperature observations were paired). Algal DO production accounted for a third of all DO error in the model and is presented in Table 4-3.

Statistically the best DO calibration was achieved in 2008 while 2009 was the least accurate (Table 4-3). This discrepancy in model calibration in 2009 and other years is largely due to epilimnetic DO super saturation. The average absolute errors ranged from 1.1 to 2.7 mg/L with an average of 1.8 mg/L. For added perspective, the maximum observed DO concentration during the modeled time period was 16.7 mg/L. Plots showing simulated versus observed DO profiles are provided in Plate 41 through Plate 64 at the end of the report.

4.5 NUTRIENTS

The SOD and nutrient release rates were the most commonly adjusted factors during the nutrient calibration process. The model was initially prepared using the zero-order sediment compartment with user defined release and decay rates for nutrients. Nutrient release rates in the model are then multiplied by the SOD that is input for each model segment by the user. The SOD is temperature dependent based on a user specified curve. Once the model reached a satisfactory calibration using the zero-order sediment compartment, the first-order sediment compartment was used. This first-order sediment compartment improved the previous model calibration. During 2011 the reservoir was drained to eradicate zebra mussels. Nutrient samples were taken in the reservoir on two occasions during the winter; however, influent concentrations were not monitored. Due to the lack of observed data 2011 was omitted from the nutrient analysis presented in Table 4-4.

Based on PO_4 and NH_4 the best nutrient calibration was achieved in 2010 while 2012 and 2013 were the least accurate (Table 4-3). Most of the discrepancy in nutrient calibration for 2012 and 2013 is due to the model underestimating the internal load. This may be the result of trophic instability that resulted from draining the reservoir in late 2010 and the decay of plants which colonized the exposed sediment. The average annual absolute errors for PO_4 ranged from 0.03 to 0.09 mg/L with an average of 0.05 mg/L. The average annual absolute errors for NH_4 ranged from 0.12 to 0.43 mg/L with an average of 0.26 mg/L. The maximum observed PO_4 and NH_4 concentrations during the modeled time period were 0.98 and 5.05 mg/L, respectively. Plots showing simulated versus observed PO_4, NH_4, NO_X, and TDS profiles are provided in Plate 65 through Plate 96 at the end of the report. The TSS, TP, and TKN concentrations were calculated within the W2 model and model output was compared to observed data.

Table 4-4. Average annual absolute error between measured and simulated reservoir nutrient concentrations at reservoir locations Z1 and Z3.

Year	Absolute Error						
	Total Dissolved Solids (mg/L)	**Total Suspended Solids (mg/L)**	**Ortho Phosphorus (mg/L)**	**Total Phosphorus (mg/L)**	**Total Kjeldahl Nitrogen (mg/L)**	**Total Ammonia (mg/L)**	**Nitrate and Nitrite (mg/L)**
2008	23	12	0.05	0.05	0.50	0.16	0.16
2009	53	10	0.04	0.09	0.52	0.20	0.07
2010	64	18	0.03	0.04	0.42	0.12	0.06
2012	42	7	0.09	0.14	0.57	0.32	0.01
2013	64	7	0.08	0.13	0.77	0.43	0.06
2014	42	23	0.03	0.10	0.53	0.32	0.11
Average	48	13	0.05	0.09	0.55	0.26	0.08

4.6 ALGAE

Algal groups representing diatoms, green algae, and blue-green algae are included in the Lake Zorinsky model. The W2 model simulates algal groups and their interaction using user defined parameters to control growth or limitation. The final algal parameter values were close to the example values found in the user manual with the following exceptions. Temperature and growth rate coefficients for diatoms were raised to reflect the epilimnetic temperatures when they were observed and allow them to be a surrogate group for Pyrrophyta. Common blue-green algae observed at Lake Zorinsky (*Aphanizomenon spp., Anabeana spp.*) are known to fix atmospheric nitrogen and were set to do so in the model; the growth rate for blue-green algae was also increased from the example values found in the manual. Green algae were included in the model despite their scarcity in the observed data.

Algal data collected in May, July, and September from 2010 through 2014 showed a seasonal shift in dominance from Diatoms to blue-green algae or Pyrrophyta (*Ceratium spp.*). Chlorophyll *a* was used as an indicator of algal biomass and algal succession was examined to assess if the model represented the seasonal shift in the algal community. The best chlorophyll *a* calibration was achieved in 2008 and 2009 was the least accurate (Table 4-5). The model correctly represented the seasonal shift in the algal assemblage in all years except 2010 (Table 4-6).

Table 4-5. Average annual absolute error between measured and simulated reservoir chlorophyll *a* concentrations at reservoir locations Z1 and Z3.

Year	Absolute Error Chlorophyll *a* (ug/L)
2008	13
2009	34
2010	24
2012	18
2013	18
2014	18
Average	21

Table 4-6. Observed versus modeled algal succession at station Z1.

Date	Observed Dominant Algal Group	Model Dominant Algal Group
Jun-10	Blue-green	Blue-green
Jul-10	Diatom	Blue-green
Aug-10	Blue-green	Blue-green
Sep-10	Diatom	Green
May-12	Pyrrophyta	Diatom
Jul-12	Blue-green	Blue-green
Sep-12	Blue-green	Blue-green
May-13	Diatom	Diatom
Jul-13	Blue-green	Blue-green
Sep-13	Blue-green	Blue-green
May-14	Diatom	Diatom
Jul-14	Cryptophyta	Diatom
Sep-14	Pyrrophyta	Diatom

5 WATER QUALITY ASSESSMENT OF EXISTING CONDITIONS

Water quality was assessed based on reservoir DO concentrations with respect to a warm water fishery habitat criterion (i.e., ≥ 5 mg/l). Because DO conditions in the reservoir are heavily impacted by the algal community, internal PO_4 loading was also examined. Existing condition simulations were performed from 2008 to 2014 using the calibrated W2 model.

5.1 DISSOLVED OXYGEN CONDITIONS

Nebraska water quality standards require a DO minimum concentration of 5 mg/l be met to support warm water aquatic life use. In thermally stratified lakes the 5 mg/l standard does not apply to the hypolimnion; however, water above the thermocline must meet the minimum 5 mg/l criterion. The DO concentration time series at the low-level gate elevation of 332.23 m (1090.0 ft-NGVD29) is plotted for 2008 through 2014 in Figure 5.1. These time series represent the DO concentration of water that persists near the low-level gate elevation and are an indication of the water that would be released through the low-level gate if it were open.

All simulation years maintain DO concentrations above 5 mg/l at elevation 332.23 m until thermal stratification sets up. They remain below or near 5 mg/l before increasing as fall turnover begins. It is evident from Figure 5.1 that the hypolimnion in Zorinsky Reservoir receives little mixing from late June until early August.

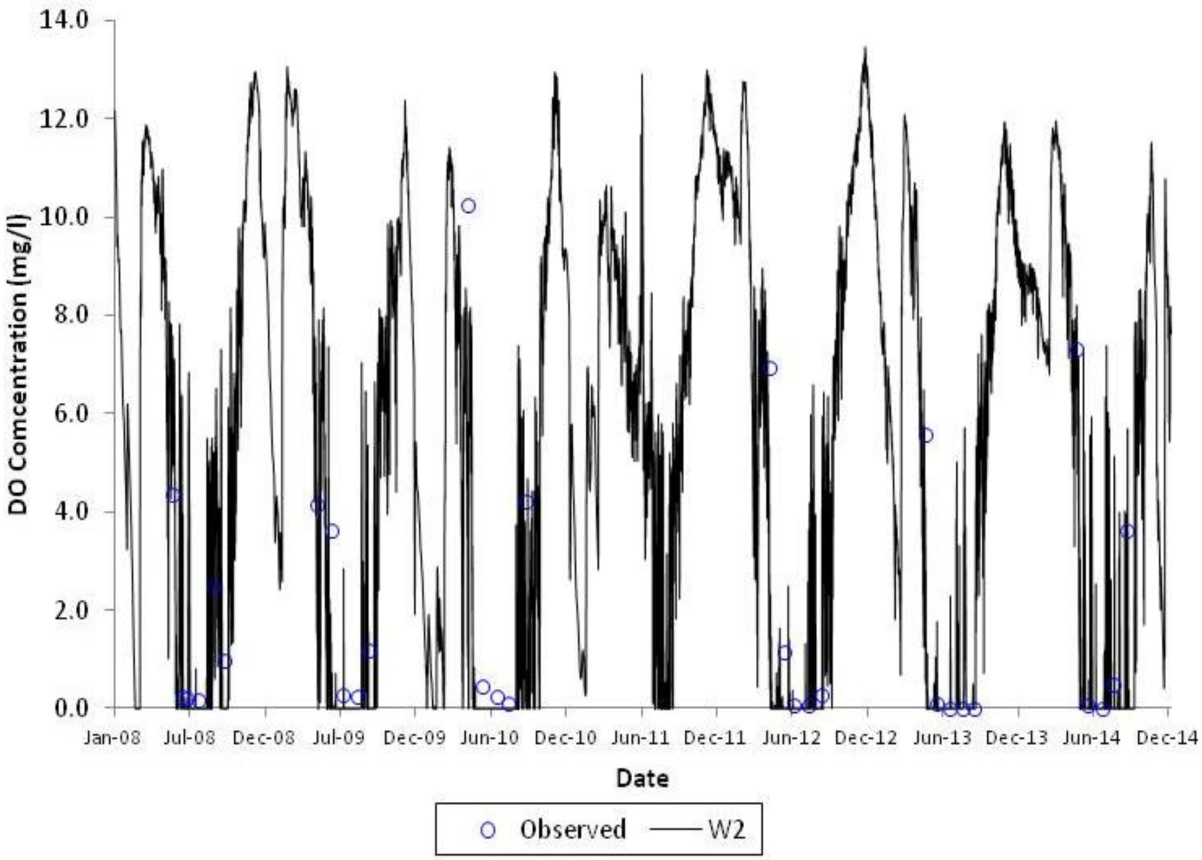

Figure 5.1. Simulated and observed dissolved oxygen concentrations near the low-level outlet centerline elevation 332.23 m at site Z1 – Near the Dam, from 2008 through 2014.

5.2 PHOSPHATE CONDITIONS

Nebraska nutrient criteria for lakes and impounded waters require that the seasonal concentration (April 1st through September 30th) of total phosphorus in the epilimnion be less than 50 ug/l to achieve chlorophyll *a* concentrations of less than 10 ug/l. In thermally stratified lakes the nutrient criteria do not apply to the hypolimnion. Total phosphorus refers to all phosphorus within a collected water sample; much of which is bound and not readily utilized by the algal community. Dissolved orthophosphate or PO_4 is the form of phosphorus which is readily available for algal uptake and is liberated from the sediments under anoxic conditions. The phosphate which is released from the sediments is referred to as the reservoir's internal phosphorus load. During fall turnover elevated hypolimnetic PO_4 concentrations mix with the water column and may fuel late season algal blooms. Observed chlorophyll *a* and PO_4 concentrations confirm that this likely occurs at Lake Zorinsky.

The PO_4 concentration time series from the W2 model are plotted with corresponding observed PO_4 concentrations for 2008 through 2014 in Figure 5.2. These time series are plotted from layers 14 through 19 of the reservoir bathymetry to reflect the depths of the observed data and correspond to the model layer of the low-level gate (layer 14). They show the increased PO_4 concentrations which result from internal loading and could potentially be mitigated (i.e. withdrawn from the reservoir) by utilizing a low-level gated release during summer stratification.

All simulation years in Figure 5.3 show PO_4 concentrations which increase with time as the reservoir remains stratified and then dissipate with fall turnover. The difference in spatial concentrations is also shown as PO_4 concentrations in the model are lower at higher elevations due to dilution. The internal PO_4 releases measured during 2012 and 2013 are not well represented in the model and may be the result of trophic instability from draining the reservoir in late 2010 or the subsequent decay of plants which colonized the exposed sediment. After underestimating PO_4 concentrations in 2012 and 2013 the model does appear to accurately characterize conditions in 2014.

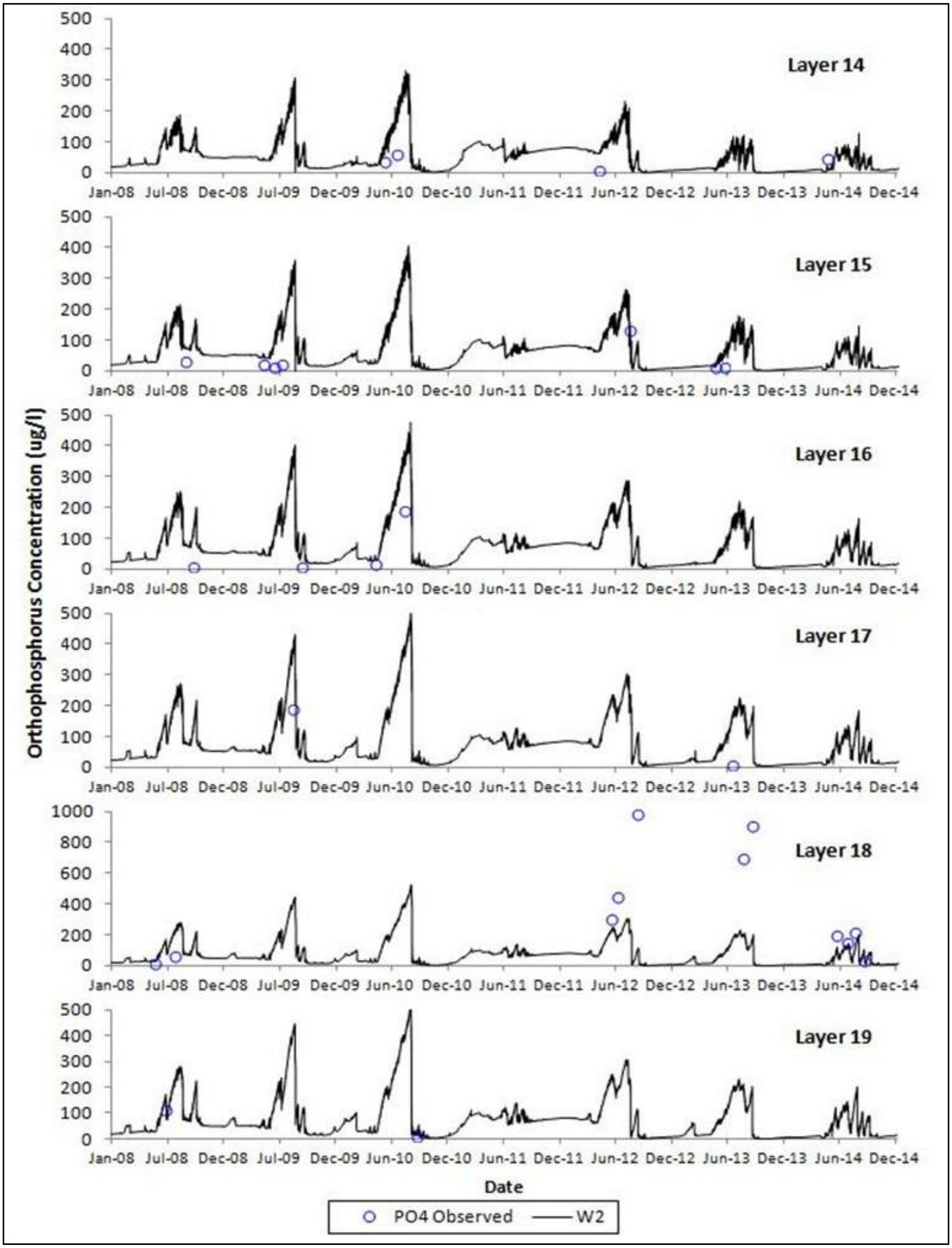

Figure 5.2. Simulated and observed phosphate concentrations in reservoir near-bottom samples from 2008 through 2014.

5.3 WARM WATER FISHERY HABITAT

For the purposes of this report warm water fishery habitat (WWFH) is defined as water ≥ 5 mg/l DO and ≤ 32°C. During the 2008 to 2014 time period temperatures measured in Zorinsky reservoir did not exceed 31.1°C. Because temperature was not a concern WWFH was estimated based on measured DO depth profiles and the reservoir capacity curve.

The calibrated W2 model was used to estimate WWFH by summing the volume of water that met the WWFH DO criteria. WWFH is expressed in units of acre-feet (AF) in this report because acre-feet are the conventional units for reporting reservoir storage volume. WWFH volumes were simulated for 2008 through 2014. Simulated WWFH volumes from the onset of thermal stratification are plotted against measured WWFH volumes by year in Figure 5.3 through Figure 5.8.

In most years thermal stratification begins to set up in late April or early May and fall turnover occurs in late September or early October. In 2008 and 2010 stratification sets up later in May and fall turnover occurs later in October. The fit of modeled WWFH versus WWFH estimated from depth profile measurements at the reservoir near-dam (location Z1) and the reservoir elevation-capacity table appears close in all years with only one observed data point that raises concern. In May of 2008 the observed data indicate the onset of seasonal DO degradation has occurred earlier within the reservoir than what the model indicates. Examination of other years indicates the model is appropriately characterizing the onset of seasonal DO degradation. With the exception of this measurement, the modeled WWFH agrees well with the measured WWFH. The W2 model can provide an estimate of WWFH during times when temperature and DO measurements are not available and be used for scenario testing of water quality management measures.

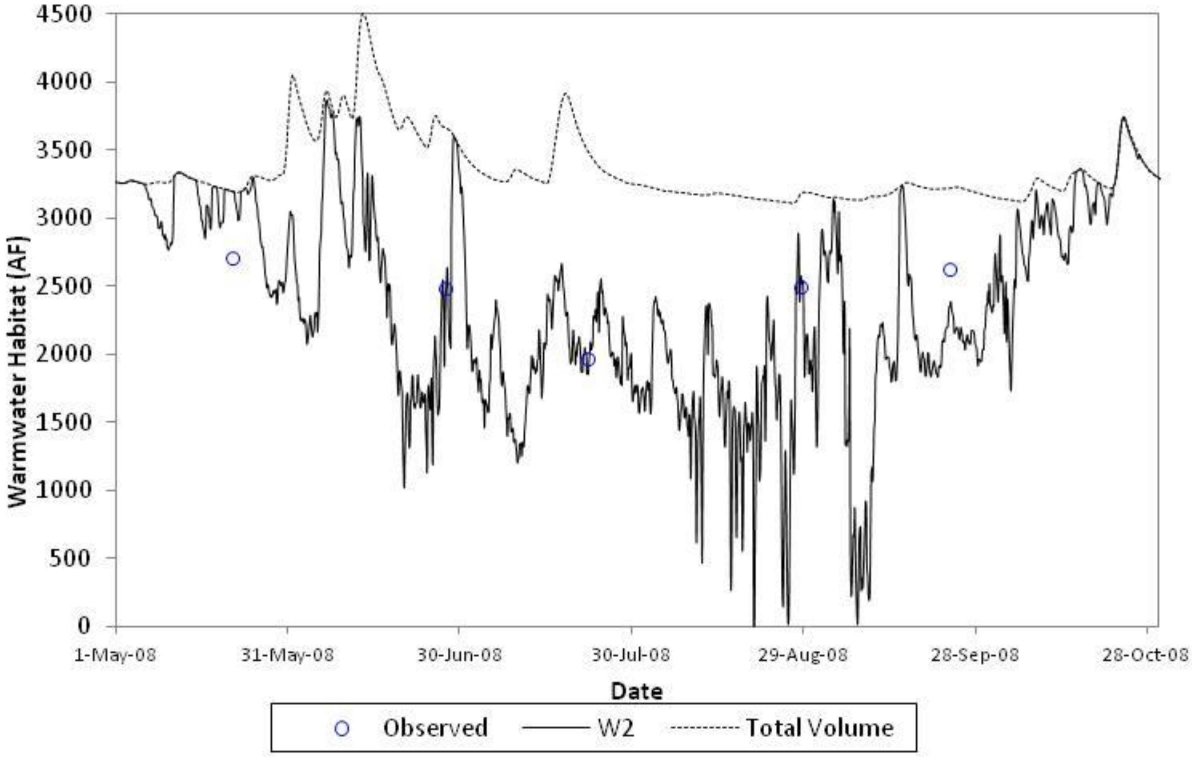

Figure 5.3. Modeled and measured warm water fishery habitat (acre-feet) in Lake Zorinsky during 2008.

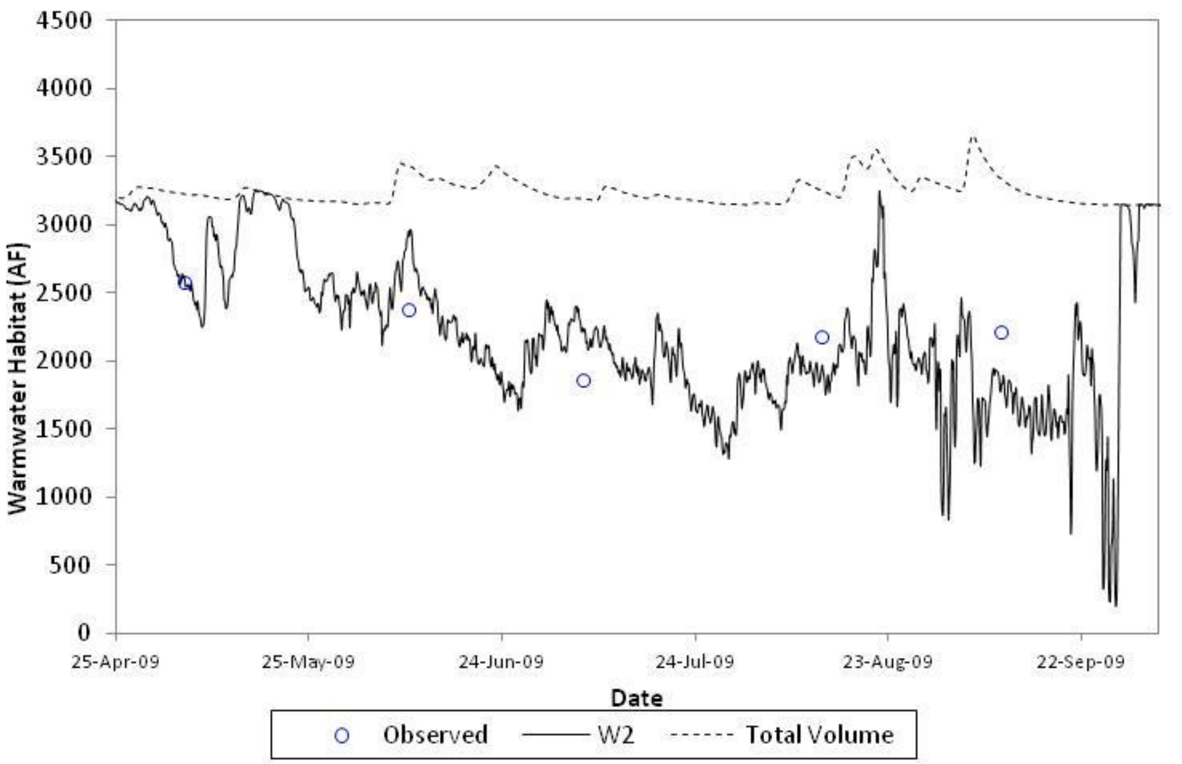

Figure 5.4. Modeled and measured warm water fishery habitat (acre-feet) in Lake Zorinsky during 2009.

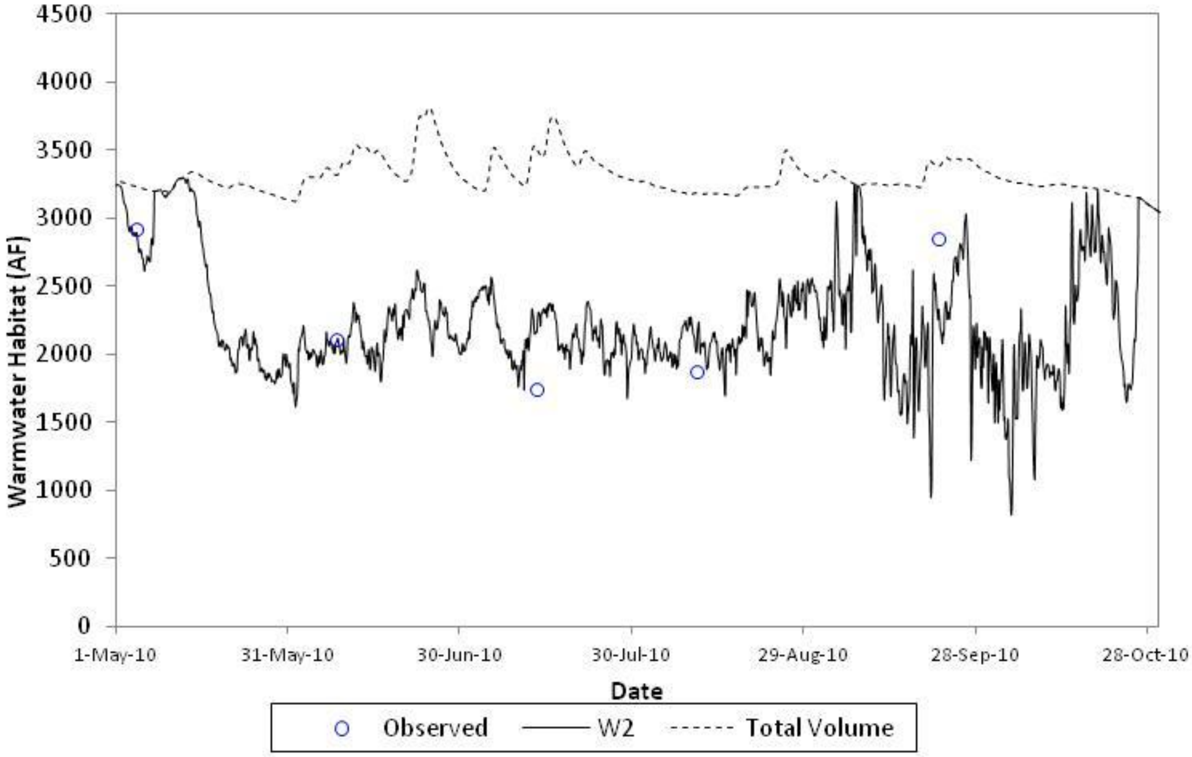

Figure 5.5. Modeled and measured warm water fishery habitat (acre-feet) in Lake Zorinsky during 2010.

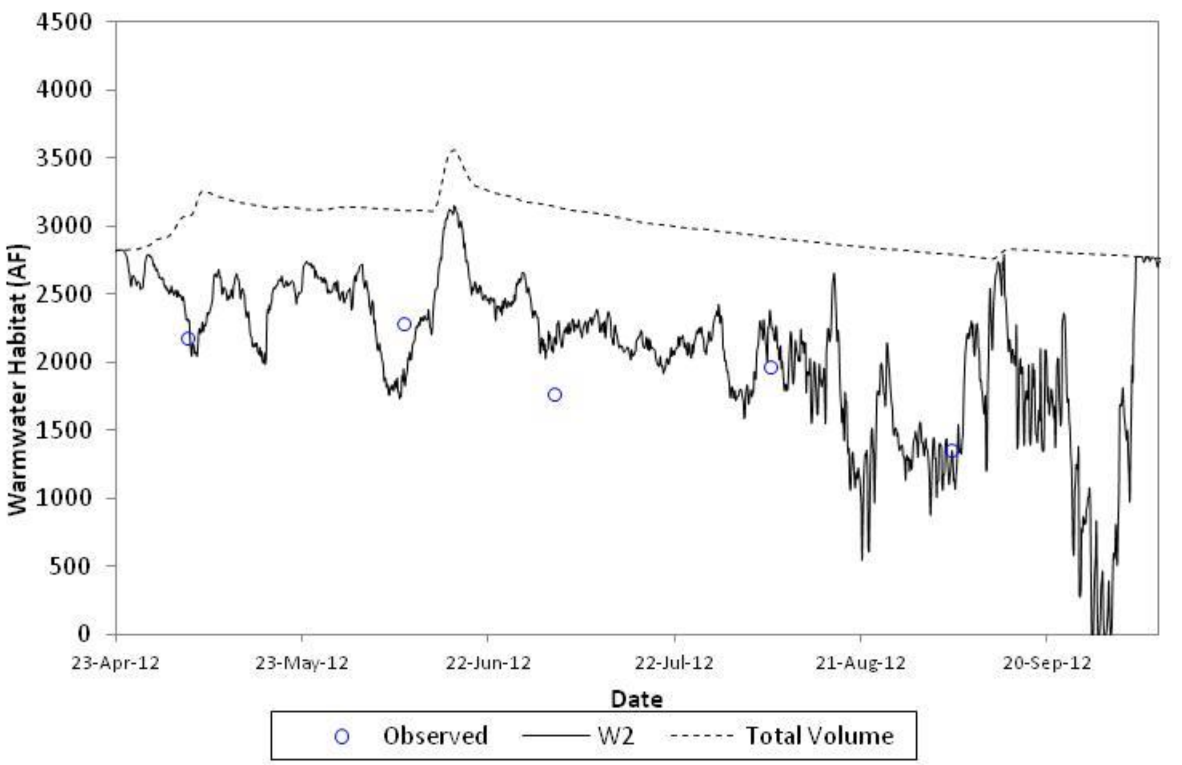

Figure 5.6. Modeled and measured warm water fishery habitat (acre-feet) in Lake Zorinsky during 2012.

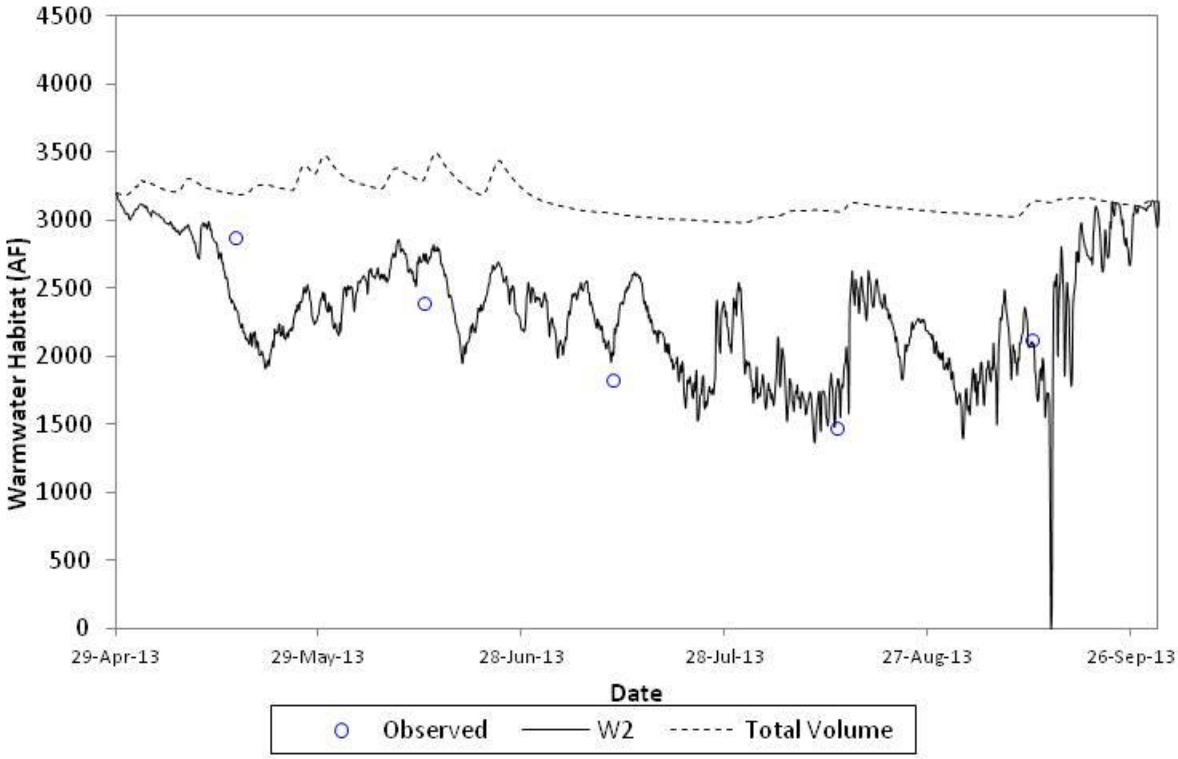

Figure 5.7. Modeled and measured warm water fishery habitat (acre-feet) in Lake Zorinsky during 2013.

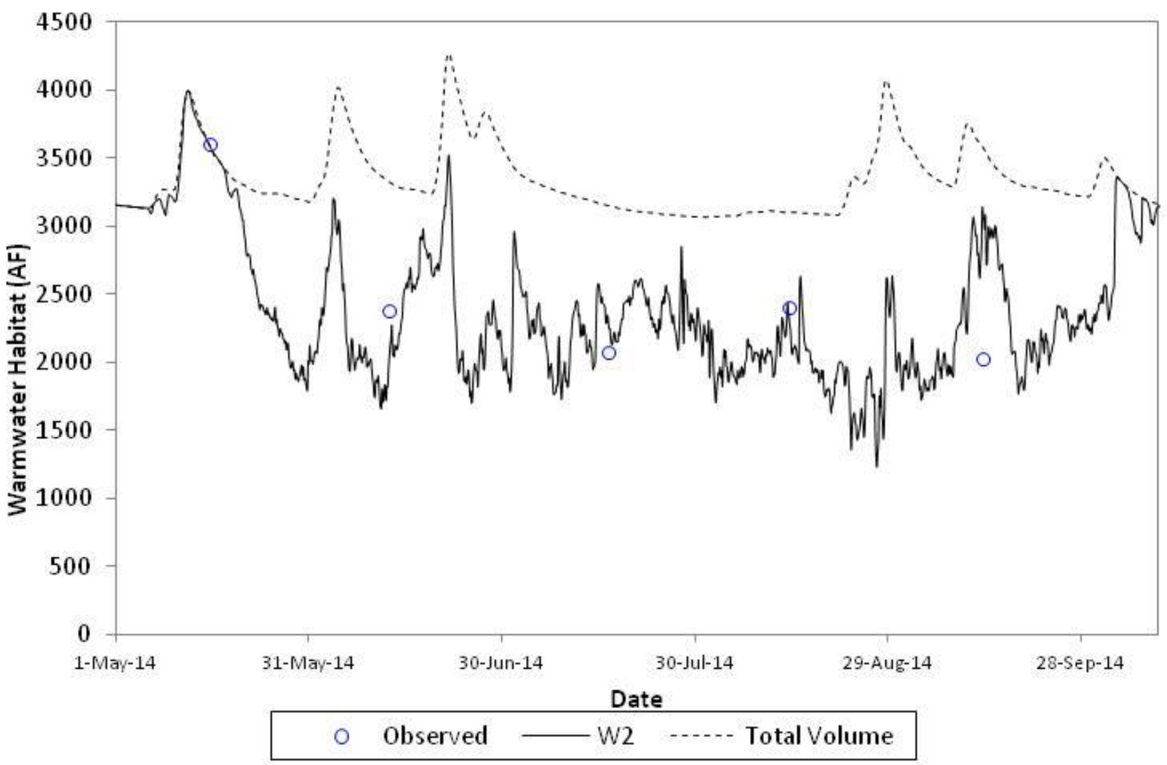

Figure 5.8. Modeled and measured warm water fishery habitat (acre-feet) in Lake Zorinsky during 2014.

6 ASSESSMENT OF A LOW-LEVEL RESERVOIR WITHDRAWAL TO ENHANCE WATER QUALITY

6.1 WATER QUALITY MANAGEMENT MEASURES TO ENHANCE WATER QUALITY AT ZORINSKY RESERVOIR

Releases are possible through the low-level outlet at Lake Zorinsky during periods of seasonal stratification to discharge poor quality water. It is hypothesized that such releases would enhance water quality and WWFH volume in the reservoir by replacing the released poor quality water with better quality influent water, and reducing the internal phosphorus loading to the reservoir by sending it downstream. It could also promote mixing within the reservoir to improve dissolved oxygen conditions at lower depths during periods of thermal stratification. A possible concern regarding low-level releases is that hypoxic water could be passed through the dam and impact Boxelder Creek downstream of the dam. It is unknown whether the stilling basin provides enough agitation to aerate the discharged water to a DO concentration adequate to meet State water quality standards (i.e. 5 mg/L). Anecdotal data collected during the winter 2010-2011 drawdown indicates adequate aeration may be present. This situation could be mitigated by opening the low-level outlet only during periods when the reservoir is spilling or the water surface elevation is above 338.33 m. In such situations the poor quality water discharged through the low-level outlet could be “mixed” with better quality water spilling over the ungated drop inlet.

A hypothetical low-level reservoir withdrawal scenario was evaluated using the Lake Zorinsky W2 model discussed in the previous section. The low-level gate was used in conjunction with the ungated drop inlet at reservoir elevations above 338.33 m. This scenario was intended to model the impact of opening the low-level gate 19 mm in May during the first routine annual water quality sampling event and then closing the gate during the last seasonal sampling event in September. To protect downstream water quality in Box Elder Creek, the gate was closed in the simulation when the reservoir water surface elevation went below 338.33 m. Opening the gate only 19 mm was chosen to ensure the thermal structure of the reservoir remained intact and only hypolimnetic water would be released.

To accurately assess low-level reservoir withdrawal scenarios, the W2 calibrated reservoir outflow volumes were allocated between the unregulated surface outlet and the low-level outlet. This was accomplished by subtracting the low-level gate outflow of .065 cms from the calibrated W2 model drop inlet outflow.

6.2 IMPACTS OF LOW-LEVEL WITHDRAWAL

Reservoir DO conditions were modeled to simulate a hypothetical low-level outlet release. The results are summarized in Figure 6.1 toFigure 6.7. Figure 6.1 toFigure 6.6 plot annual growing season comparisons of reservoir WWFH volumes utilizing the low-level withdrawal scenario versus existing conditions. Figure 6.7 shows time series hypolimnetic PO_4 concentrations in model layers 14 to 19 utilizing the low-level withdrawal scenario versus existing conditions to assess internal PO_4 load mitigation. Layers 14 to 19 represent the hypolimnetic reservoir volume at or below the elevation of the low-level gate (layer 14).

6.2.1 WARM WATER FISHERY HABITAT VOLUME

The impact of a hypothetical low-level outlet release versus the surface structure withdrawal is quantified in terms of seasonal average (May 1st through September 30th) warm water fishery habitat volume in Table 6-1. The simulations indicate that the low-level releases do not result in a significant gain of WWFH volume.

Table 6-1. Comparison of simulated warm water fishery habitat (dissolved oxygen ≥ 5 mg/L) seasonal average volumes for simulated existing conditions and a low-level release.

Warm water Fishery Habitat (WWFH) in Lake Zorinsky			
Year	**Low-level Release Scenario (AF)**	**No Release Modifications (AF)**	**Change in Average WWFH (AF)**
2008	2,293	2,254	39
2009	2,076	2,160	-84
2010	2,277	2,256	21
2012	2,218	2,057	161
2013	2,416	2,325	91
2014	2,347	2,363	-16
Average	2,271	2,236	35

Figure 6.1 throughFigure 6.6 are time series plots of simulated WWFH volumes comparing the existing condition drop inlet surface release with the low-level release scenario for 2008 through 2014. Dates when the low-level gate was opened or closed are indicated in the figures. The low-level gate was not used in 2012 due to low water surface elevations. All years except 2013 and 2014 show slight but insignificant gains in WWFH during the late August to late September period of the growing season.

During 2009, 2012, and 2013 there is a significant difference in WWFH volume during May and June. Comparisons of the two simulations indicated differences in the date ice cover was off the reservoir, this likely resulted in thermal differences which impacted DO concentrations. Total reservoir volumes are also shown in Figure 6.1 throughFigure 6.6 and volumes are closer than the difference seen in WWFH volume. Both the scenario and existing conditions models were run multiple times with the exact same conditions and the WWFH volume output does not change. This indicates that the model is functioning correctly; however, differences in the thermal regime due to changes in reservoir volume were not expected to have a significant impact.

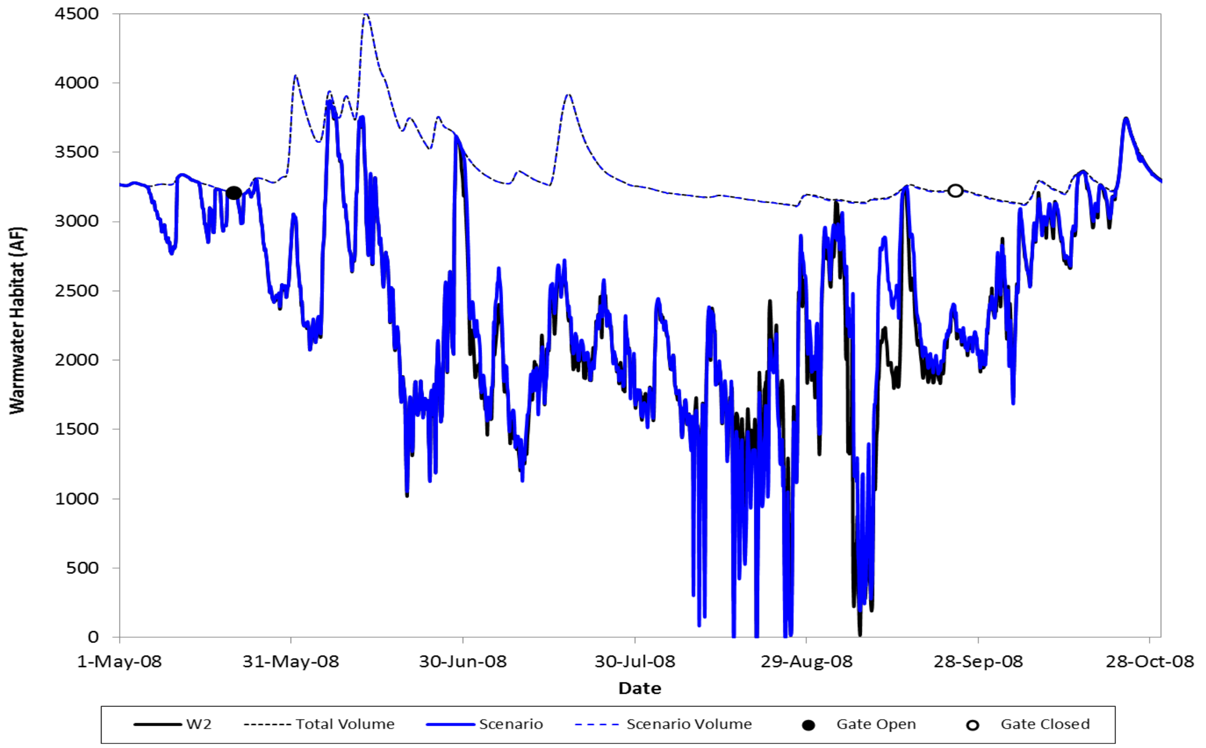

Figure 6.1. Simulated volume of warm water fishery habitat in Zorinsky Reservoir during 2008, without (black) and with (blue) a low-level gate withdrawal.

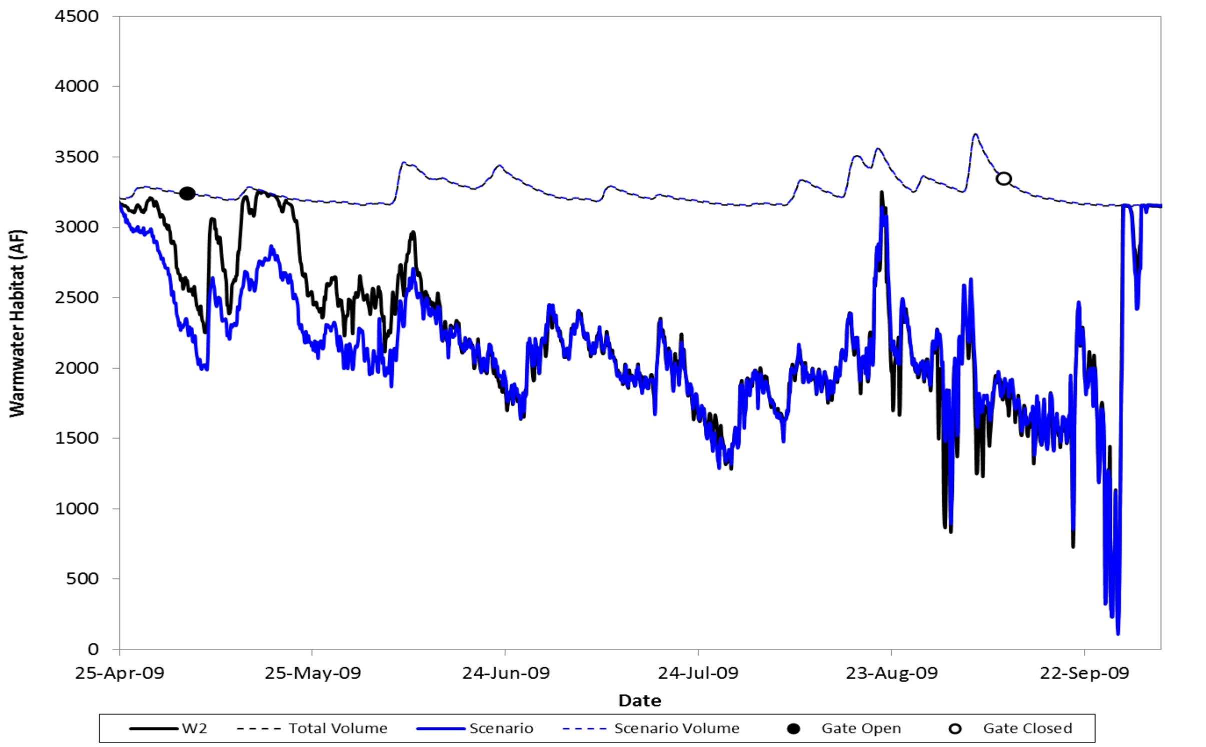

Figure 6.2. Simulated volume of warm water fishery habitat in Zorinsky Reservoir during 2009, without (black) and with (blue) a low-level gate withdrawal.

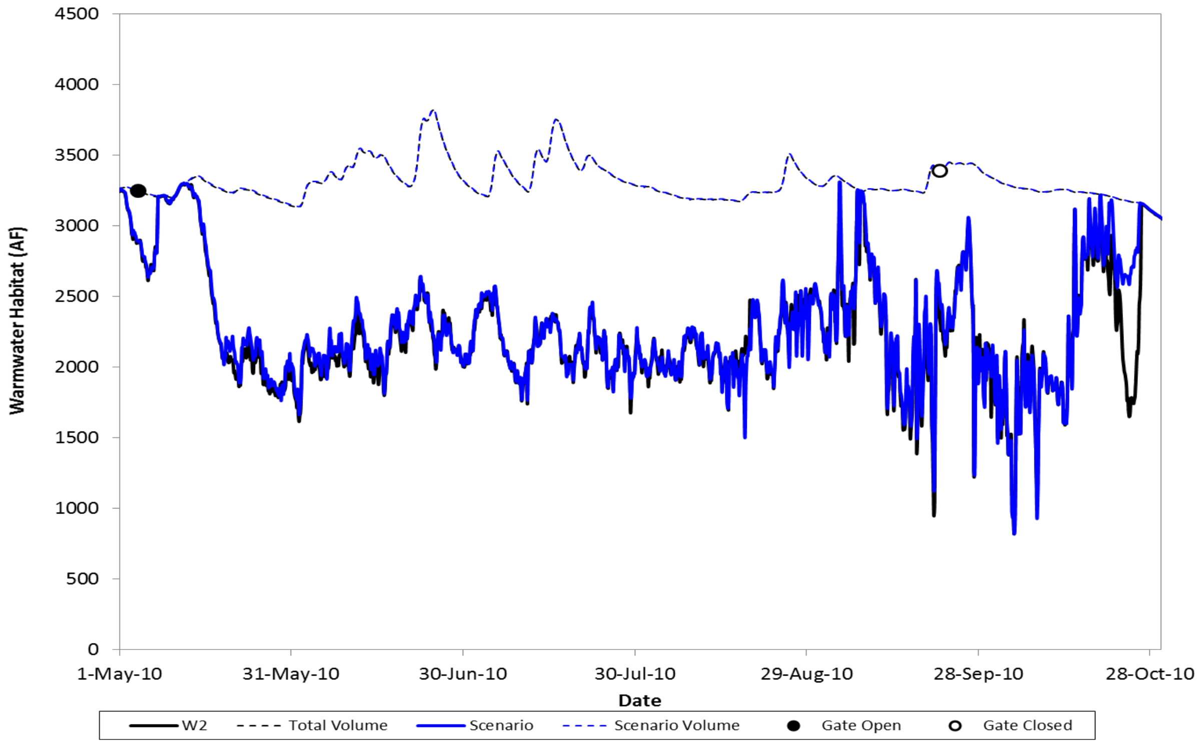

Figure 6.3. Simulated volume of warm water fishery habitat in Zorinsky Reservoir during 2010, without (black) and with (blue) a low-level gate withdrawal.

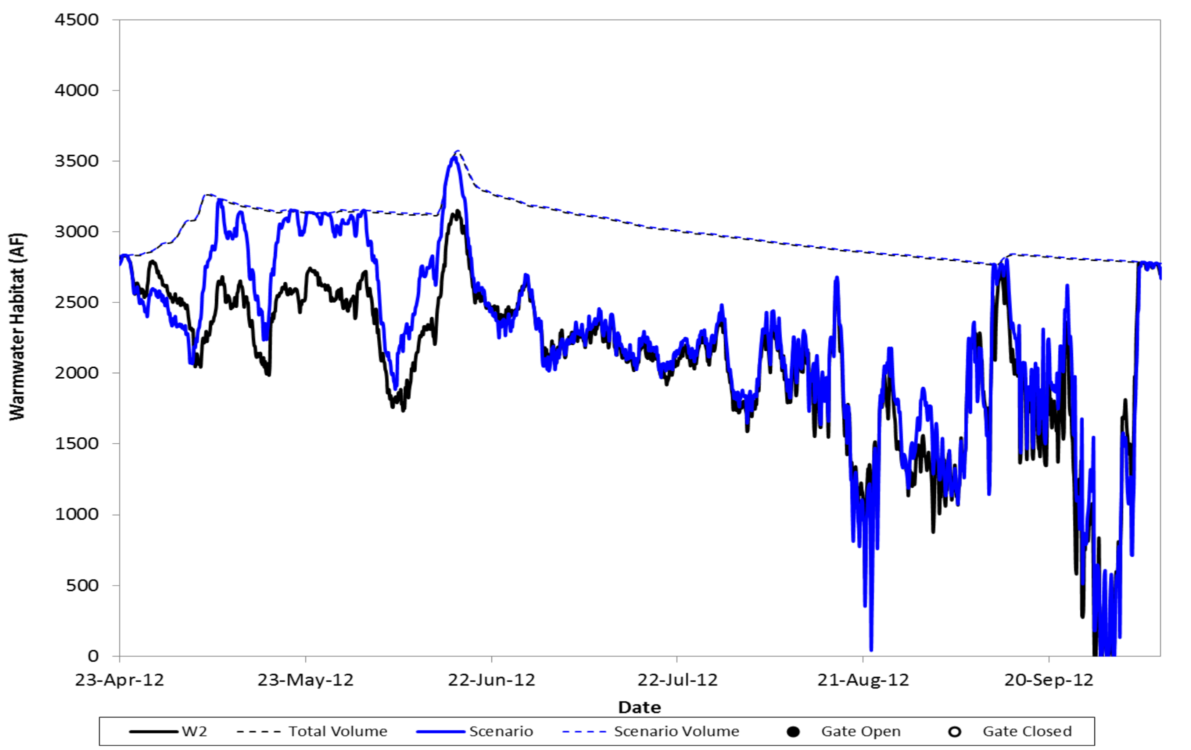

Figure 6.4. Simulated volume of warm water fishery habitat in Zorinsky Reservoir during 2012, without (black) and with (blue) a low-level gate withdrawal.

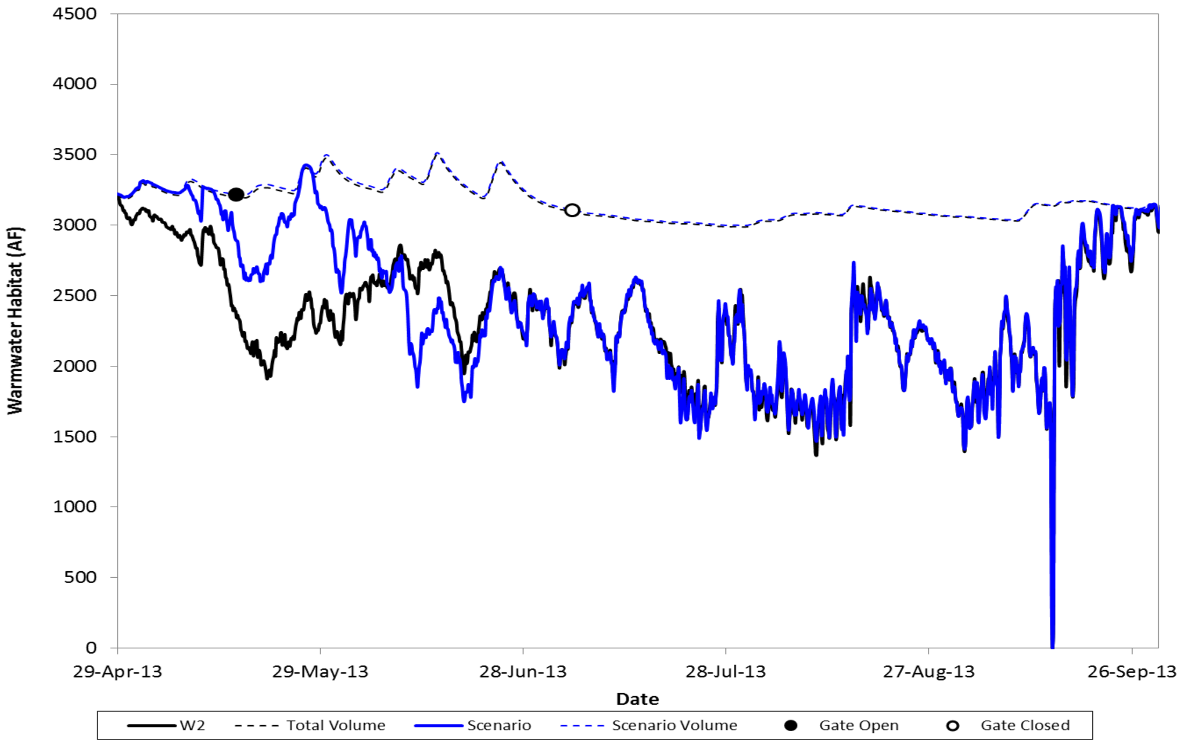

Figure 6.5. Simulated volume of warm water fishery habitat in Zorinsky Reservoir during 2013, without (black) and with (blue) a low-level gate withdrawal.

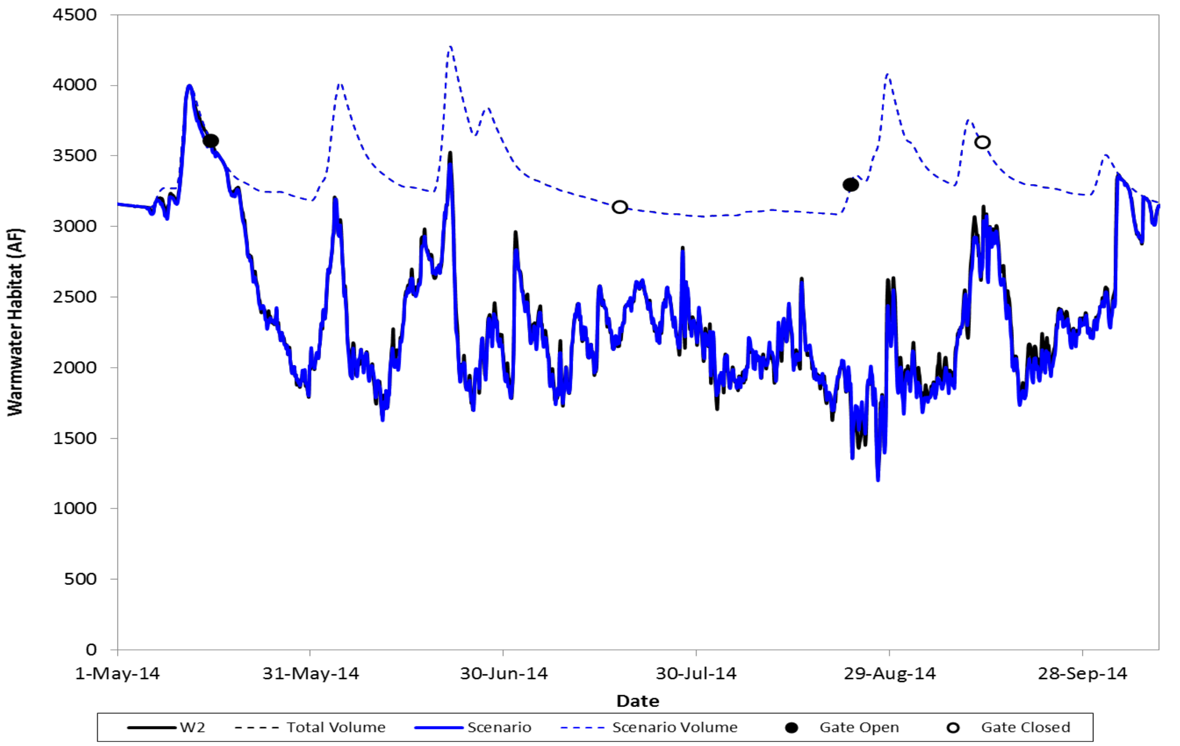

Figure 6.6. Simulated volume of warm water fishery habitat in Zorinsky Reservoir during 2014, without (black) and with (blue) a low-level gate withdrawal.

6.2.2 HYPOLIMNETIC PHOSPHORUS CONCENTRATION

The impact of a low-level outlet release versus the surface structure withdrawal is quantified in terms of seasonal average (May 1st through September 30th) PO_4 concentration at the near dam site (Z1, model segment 29) in Table 6-2. The simulations indicate that the low-level releases may mitigate PO_4 concentrations; however, this only occurs in four out of six years. This represents a potential reduction in PO_4 that may be readily utilized for algal growth during the growing season.

Table 6-2. Comparison of simulated average seasonal PO_4 concentrations for simulated existing conditions and a low-level outlet release scenario.

Seasonal Average PO_4 Concentrations at the Lake Zorinsky Near-Dam Location			
Year	**No Release Modification (ug/l)**	**Release Modification (ug/l)**	**Change in PO_4 Concentration (ug/l)**
2008	0.070	0.067	-0.003
2009	0.047	0.055	0.008
2010	0.050	0.046	-0.004
2012	0.052	0.046	-0.007
2013	0.020	0.015	-0.005
2014	0.025	0.025	0.000
Average	0.044	0.044	-0.002

The impact of a hypothetical low-level outlet release versus the surface structure withdrawal is quantified in terms of hypolimnetic PO_4 concentrations in Figure 6.7. To examine if a low-level release can pass hypolimnetic PO_4 laden water downstream and mitigate the mass of PO_4 available for algal production the existing conditions and low-level release scenario hypolimnetic PO_4 concentrations were compared.

Figure 6.7 shows time series plots comparing the existing condition drop inlet surface release with the low-level release scenario hypolimnetic PO_4 concentrations for 2008 through 2014. During 2009 and 2012 a temporal shift in the onset of internal PO_4 loading can be observed, this is due to thermal differences between the scenario and existing conditions models. All years except 2009 and 2014 show slight but noticeable decreases in PO_4 concentrations in model layer 14. Model layers 14 to 19 represent the hypolimnetic reservoir volume or “stagnant zone” at or below the elevation of the low-level gate (layer 14). This indicates that low-level releases could capture internally released PO_4 and discharge it from the reservoir. The mitigation of internally sourced PO_4 could be further evaluated by development of a "phosphorus budget" of Lake Zorinsky which would account for all sources of phosphorus and PO4 both to and from the reservoir as well as in reservoir phosphorus retention.

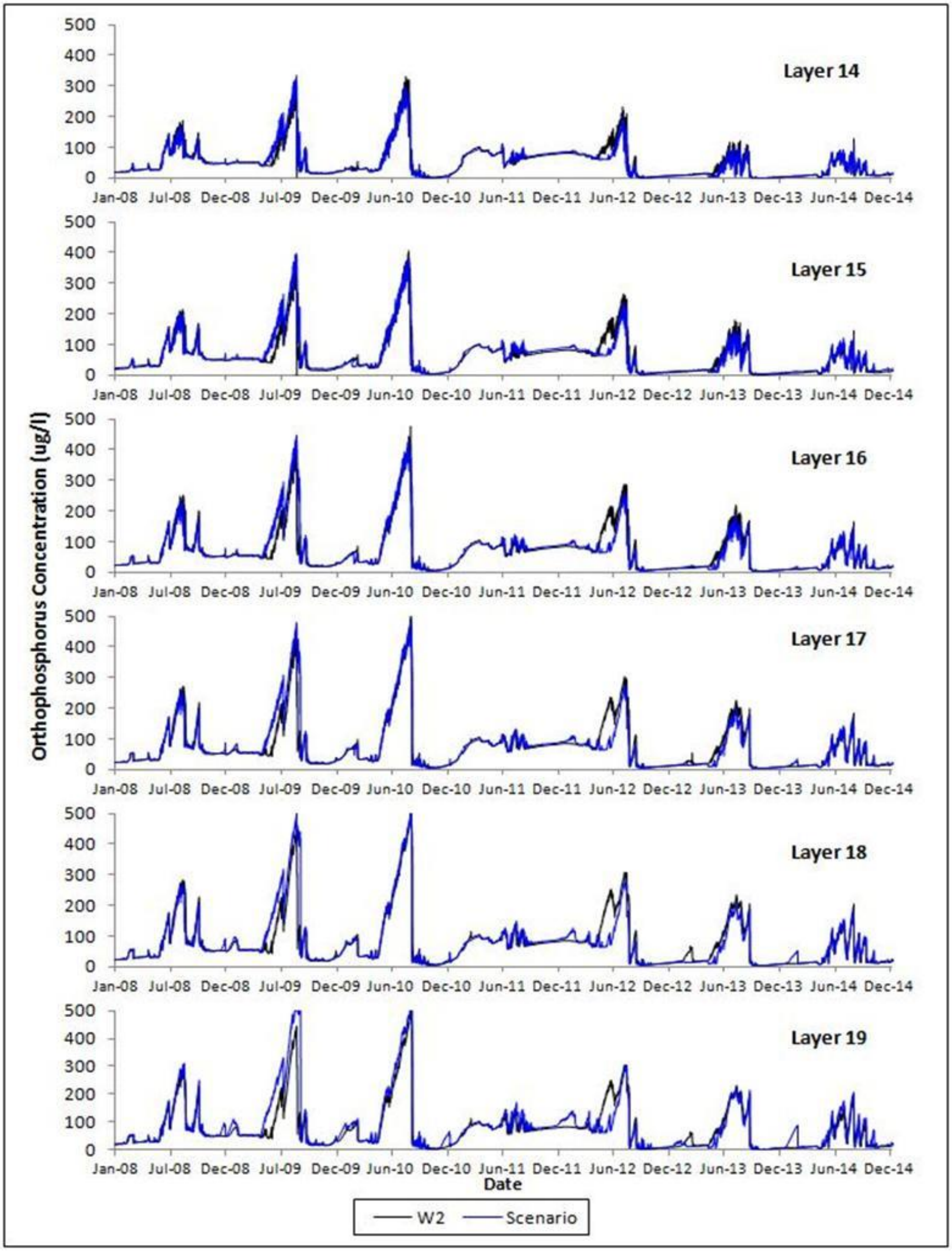

Figure 6.7. Simulated existing condition and low-level release scenario phosphate concentrations in the reservoir hypolimnion at or below the low-level gate (layer 14) from 2008 through 2014.

7 CONCLUSIONS

The W2 version 3.71 model of Lake Zorinsky successfully reproduced many of the observed physical and chemical characteristics of the reservoir, however; further model improvement is needed in some areas. Model thermal calibration for the six year period was less than 1 °C, which is widely accepted as the benchmark for thermal calibration of the W2 model. WWFH volume was successfully reproduced and was a close to match to the volumes estimated from observed depth profile data and the reservoir capacity curve. Model PO_4 concentrations and the onset of hypolimnetic oxygen depletion also closely matched the observed data. Areas the model needs improvement include a more detailed water balance to clarify all water sources and sinks to the reservoir and the ability to accurately reproduce the supersaturated DO concentrations caused by algal production.

Scenario testing utilized the calibrated W2 version 3.71 model to assess a low-level reservoir withdrawal during summer thermal stratification to improve reservoir water quality by increasing WWFH volume and reducing hypolimnetic PO_4 concentrations. The scenario test showed that there was no significant gain in WWFH volume utilizing a low-level release. The scenario test did indicate that a low-level release could potentially reduce hypolimnetic PO_4 concentrations by sending internally sourced PO_4 downstream.

8 RECOMMENDATIONS

The following recommendations address the indicated shortcomings of the W2 version 3.71 model of Lake Zorinsky or improve the evaluation of a low-level release to improve water quality. A more detailed water balance should be pursued in order to clarify all water sources and sinks to the reservoir that may be confounded in the CWMS total reservoir inflow estimate. More frequent inflow samples should be collected to better characterize the in-reservoir conditions which lead to intense algal production and DO supersaturation. A detailed phosphorus budget for Lake Zorinsky should be constructed. This budget would track phosphorus mass influent to the reservoir (externally and internally), reservoir phosphorus retention, and how much phosphorus is being discharged from the reservoir. The application of W2 version 3.8 should be implemented in order to better quantify internal phosphorus flux utilizing a complete sediment diagenesis model. Once applied, W2 version 3.8 should be used to conduct a scenario test evaluating low-level release of phosphorus as a potential way to improve water quality in Lake Zorinsky and evaluate its potential impacts to Box Elder Creek. W2 version 3.8 should also be used to assess how the sediment retention basin upstream of 168th Street potentially enhanced water quality, and how its in-filling will impact Zorinsky Lake water quality.

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10 PLATES

Plate 1. Summary of water quality conditions monitored in Lake Zorinsky at site EZRLKND1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	**No. of Obs.**	**Mean(A)**	**Median**	**Min.**	**Max.**	**State WQS Criteria(B)**	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Pool Elevation (ft-MSL)	0.1	20	1110.43	1110.40	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	347	20.47	20.37	10.18	29.16	32(1)	0	0%
Secchi Depth (in.)	1	20	37.00	33.00	13.00	85.00	-----	-----	-----
Turbidity (NTUs)	1	328	10.07	7.75	n.d.	28.70	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	347	225.84	229.00	-59.00	411.00	-----	-----	-----
Specific Conductance (umho/cm)	1	347	517.70	528.00	303.50	740.00	2,000(3)	0	0%
Dissolved Oxygen (mg/l)	0.1	347	4.39	5.04	n.d.	11.98	≥5(2)	173	50%
Dissolved Oxygen (% Sat.)	0.1	347	52.23	56.80	n.d.	151.50	-----	-----	-----
pH (S.U.)	0.1	347	7.83	7.85	6.51	8.76	≥6.5 & ≤9.0 (1)	0	0%
Alkalinity, Total (mg/l)	1	38	153.50	150.50	97.00	238.00	>20(1)	0	0%
Suspended Solids, Total (mg/l)	4	40	9.48	8.00	n.d.	28.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	40	-----	0.27	n.d.	6.50	>11.01(4,5), >2.1(4,6)	0,7	0%,18%
Kjeldahl N, Total (mg/l)	0.08	40	1.73	1.12	0.47	7.15	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	40	-----	n.d.	n.d.	0.36	100(3)	0	0%
Nitrogen, Total (mg/l)	0.08	40	1.79	1.19	0.50	7.18	1(7)	26	65%
Nitrogen, Total, Near-Surface (mg/l)(C)	0.08	20	0.94	0.95	0.50	1.36	>1	7	35%
Phosphorus, Total (mg/l)	0.005	40	0.25	0.07	n.d.	1.47	0.05(7)	24	60%
Phosphorus, Total, Near-Surface (mg/l) (C)	0.005	20	0.05	0.04	0.01	0.20	0.05(7)	6	30%
Phosphorus-Ortho, Dissolved (mg/l)	0.005	40	-----	0.02	n.d.	0.98	-----	-----	-----
Hardness, Total (mg/l)	0.4	4	134.28	137.70	113.70	148.00	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	4	6.50	6.00	5.00	9.00	340(5), 16.7(6)	0	0%
Beryllium, Dissolved (ug/l)	1	4	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.007	4	-----	0.05	n.d.	0.08	8.1(5), 0.3(6)	0	0%
Chromium, Dissolved (ug/l)	4	4	-----	n.d.	n.d.	n.d.	769.4(5), 100.2(6)	0	0%
Copper, Dissolved (ug/l)	6	4	-----	n.d.	n.d.	n.d.	18.2(5), 11.8(6)	0	0%
Iron, Dissolved (ug/l)	10	23	-----	20.00	n.d.	410.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.09	4	-----	0.15	n.d.	0.80	91.3(5), 3.6(6)	0	0%
Manganese, Dissolved (ug/l)	3	23	-----	20.00	n.d.	6440.00	1000(6)	5	22%
Nickel, Dissolved (ug/l)	8	4	-----	n.d.	n.d.	n.d.	613.8(5), 68.2(6)	0	0%
Silver, Dissolved (ug/l)	0.005	4	-----	0.02	n.d.	0.03	5.98(5)	0	0%
Zinc, Dissolved (ug/l)	6	4	-----	9.00	n.d.	30.00	153.7(5), 154.9(6)	0	0%
Antimony, Dissolved (ug/l)	0.03	4	0.73	0.75	0.60	0.80	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	4	-----	n.d.	n.d.	50.00	750(5), 87(6)	0	0%
Mercury, Dissolved (ug/l)	0.008	4	-----	n.d.	n.d.	0.01	1.4(5)	0	0%
Chlorophyll a (ug/l) – Lab Determined(C)	6	20	20.10	16.00	n.d.	56.00	10(7)	14	70%
Chlorophyll a (ug/l) – Field Probe	6	347	19.40	12.37	n.d.	342.56	10(7)	202	58%
Atrazine, Total (ug/l) (D)	0.1	20	0.82	0.80	n.d.	2.20	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l) (D)	0.1	20	-----	0.20	n.d.	0.40	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(D)	0.1	20	0.45	0.40	n.d.	1.30	-----	-----	-----
Microcystin, Total (ug/l)	0.1	20	-----	n.d.	n.d.	0.20	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Acetochlor, Tot	0.08	5	0.09	n.d.	n.d.	0.19	-----	-----	-----
Atrazine, Tot	0.13	5	0.51	0.45	0.21	0.99	330(5), 12(6)	0	0%
Metolachlor, Tot	0.05	5	-----	0.14	n.d.	0.20	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to value to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of nutrient criteria for aquatic life establishes that samples must represent epiliminetic conditions (i.e. near surface)

(D) Immunoassay analysis.

(E) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean, number of excedences, or percent exceedence indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 2. Summary of water quality conditions monitored in Lake Zorinsky at site EZRLKML1A from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-MSL)	0.1	15	1110.31	1110.10	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	325	20.50	20.39	10.28	29.43	32(1)	0	0%
Dissolved Oxygen (% Sat.)	0.1	325	53.15	55.40	0.00	157.00	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	325	4.48	4.79	0.00	11.57	≥5(2)	169	52%
Specific Conductance (umho/cm)	1	325	520.36	530.20	287.40	741.00	2,000(3)	0	0%
pH (S.U.)	0.1	325	7.83	7.78	6.61	8.80	≥6.5 & ≤9.0 (1)	0	0%
Turbidity (NTUs)	1	308	12.03	7.80	0.00	249.20	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	325	255.19	258.00	-45.00	435.00	-----	-----	-----
Secchi Depth (in.)	1	20	38.00	33.00	11.00	96.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	325	19.44	12.69	0.52	203.86	10(4)	194	60%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedences, or percent exceedence indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 3. Summary of water quality conditions monitored in Lake Zorinsky at site EZRLKML2 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-MSL)	0.1	15	1110.31	1110.10	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	224	22.39	22.42	11.81	29.93	32(1)	0	0%
Dissolved Oxygen (% Sat.)	0.1	224	71.59	77.05	0.00	155.40	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	224	5.89	6.72	0.00	13.18	≥5(2)	73	33%
Specific Conductance (umho/cm)	1	224	489.96	514.00	269.30	721.00	2,000(3)	0	0%
pH (S.U.)	0.1	224	8.03	8.08	6.92	8.93	≥6.5 & ≤9.0 (1)	0	0%
Turbidity (NTUs)	1	214	19.66	12.05	0.00	119.90	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	224	316.42	333.00	6.00	509.00	-----	-----	-----
Secchi Depth (in.)	1	20	33.80	30.50	9.00	113.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	224	27.66	18.26	1.39	439.98	10(7)	160	71%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedences, or percent exceedence indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 4. Summary of water quality conditions monitored in Lake Zorinsky at site EZRLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-MSL)	0.1	15	1110.31	1110.10	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	120	23.55	24.15	15.84	30.71	32[1]	0	0%
Secchi Depth (in.)	1	20	18.90	20.00	4.00	37.00	-----	-----	-----
Turbidity (NTUs)	1	113	46.05	24.30	n.d.	243.50	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	120	355.59	348.00	179.00	499.00	-----	-----	-----
Specific Conductance (umho/cm)	1	120	466.49	481.15	248.00	661.40	2,000[3]	0	0%
Dissolved Oxygen (mg/l)	0.1	120	7.09	7.04	0.13	13.00	≥5[2]	24	20%
Dissolved Oxygen (% Sat.)	0.1	120	87.06	84.15	1.70	169.80	-----	-----	-----
pH (S.U.)	0.1	120	8.12	8.22	7.22	8.80	≥6.5 & ≤9.0 [1]	0	0%
Alkalinity, Total (mg/l)	1	19	130.21	134.00	19.00	197.00	>20(1)	1	5%
Suspended Solids, Total (mg/l)	4	19	22.58	17.00	n.d.	80.00	-----		
Ammonia, Total (mg/l)	0.02	20	-----	n.d.	n.d.	0.38	5.5[4,5], 0.93[4,6]	0	0%
Kjeldahl N, Total (mg/l)	0.08	20	1.04	1.02	0.60	1.66	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	20	0.10	n.d.	n.d.	0.54	100[3]	0	0%
Nitrogen, Total, Near-Surface (mg/l)[C]	0.08	20	1.14	1.07	0.64	1.72	1[7]	11	55%
Phosphorus, Total, Near-Surface (mg/l) [C]	0.005	20	0.09	0.07	0.03	0.24	0.05[7]	14	70%
Phosphorus-Ortho, Dissolved (mg/l)	0.005	20	-----	0.01	n.d.	0.07	-----	-----	-----
Hardness, Total (mg/l)	0.4	3	128.47	128.60	118.30	138.50	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	3	5.67	6.00	4.00	7.00	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	1	3	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.01	3	-----	n.d.	n.d.	0.05	7.5[5], 0.29[6]	0	0%
Chromium, Dissolved (ug/l)	4	3	-----	n.d.	n.d.	n.d.	727.5[5], 94.71[6]	0	0%
Copper, Dissolved (ug/l)	6	3	-----	n.d.	n.d.	8.00	17.0[5], 11.1[6]	0	0%
Iron, Dissolved (ug/l)	10	18	104.83	25.00	n.d.	530.00	1000[6]	0	0%
Lead, Dissolved (ug/l)	0.09	3	-----	n.d.	n.d.	0.30	84.8[5], 3.3[6]	0	0%
Manganese, Dissolved (ug/l)	3	18	66.50	40.00	n.d.	250.00	1000[6]	0	0%
Thallium (ug/l)	0.005	3	-----	n.d.	n.d.	n.d.	1400[5],0.47[8]	0	0%
Nickel, Dissolved (ug/l)	8	3	-----	n.d.	n.d.	n.d.	579.3[5], 64.3[6]	0	0%
Silver, Dissolved (ug/l)	0.005	3	-----	n.d.	n.d.	0.01	5.3[5]	0	0%
Zinc, Dissolved (ug/l)	6	3	-----	8.00	n.d.	10.00	145.0[5], 146.2[6]	0	0%
Antimony, Dissolved (ug/l)	0.03	3	0.83	0.80	0.80	0.90	88[5], 30[6]	0	0%
Aluminum, Dissolved (ug/l)	40	3	-----	n.d.	n.d.	50.00	750[5], 87[6]	0	0%
Selenium, Total (ug/l)	0.4	4	-----	0.95	n.d.	11.00	20[3,5], 5[6]	0, 1	0%,25%
Chlorophyll a (ug/l) – Lab Determined [C]	6	20	33.10	28.50	n.d.	109.00	10[7]	16	80%
Chlorophyll a (ug/l) – Field Probe	6	120	42.14	27.20	n.d.	477.90	10[7]	96	80%
Atrazine, Total (ug/l)[D]	0.1	20	1.28	1.00	n.d.	6.50	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[D]	0.1	20	-----	0.20	n.d.	1.50	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l)[D]	0.1	20	0.55	0.40	n.d.	3.30	-----	-----	-----
Mercury, Dissolved (ug/l)	0.008	3	-----	0.01	n.d.	0.02	1.4[5]	0	0%
Mercury, Total (ug/l)	0.008	4	-----	n.d.	n.d.	0.01	0.77[6]	0	0%
Microcystin, Total (ug/l)	0.1	19	-----	n.d.	n.d.	0.20	20[9]	0	0%
Pesticide Scan (ug/l)[E]									
Acetochlor, Tot	0.08	4	-----	0.12	n.d.	1.41	-----	-----	-----
Atrazine, Tot	0.13	4	0.77	0.41	0.21	2.05	330(5), 12[6]	0	0%
Metolachlor, Tot	0.05	4	-----	0.11	n.d.	0.66	390(5), 100[6]	0	0%

n.d. = Not detected.

[A] Nondetect values set to value to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[B] [1] General criteria for aquatic life.
[2] Use-specific criteria for aquatic life.
[3] Agricultural criteria for surface waters.
[4] Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
[5] Acute criteria for aquatic life.
[6] Chronic criteria for aquatic life.
[7] Nutrient criteria for aquatic life.
[8] Human health criteria.
[9] Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

[C] Nebraska's Impairment assessment of nutrient criteria for aquatic life establishes that samples must represent epiliminetic conditions (i.e. near-surface)

[D] Immunoassay analysis.

[E] The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean, number of exceedences, or percent exceedence indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5. Summary of water quality conditions monitored in Lake Zorinsky at site EZRLKUP2 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-MSL)	0.1	15	1110.31	1110.10	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	28	24.22	25.46	15.80	30.92	32(1)	0	0%
Dissolved Oxygen (% Sat.)	0.1	28	104.68	97.55	59.50	163.10	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	28	8.43	7.56	5.36	13.36	≥5(2)	0	0%
Specific Conductance (umho/cm)	1	28	443.05	443.75	246.00	660.00	2,000(3)	0	0%
pH (S.U.)	0.1	28	8.31	8.33	7.48	8.94	≥6.5 & ≤9.0 (1)	0	0%
Turbidity (NTUs)	1	27	49.32	30.00	3.90	211.30	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	28	373.82	380.50	262.00	498.00	-----	-----	-----
Secchi Depth (in.)	1	20	13.85	11.50	4.00	31.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	28	30.34	23.32	3.83	173.64	10(4)	20	71%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedences, or percent exceedence indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

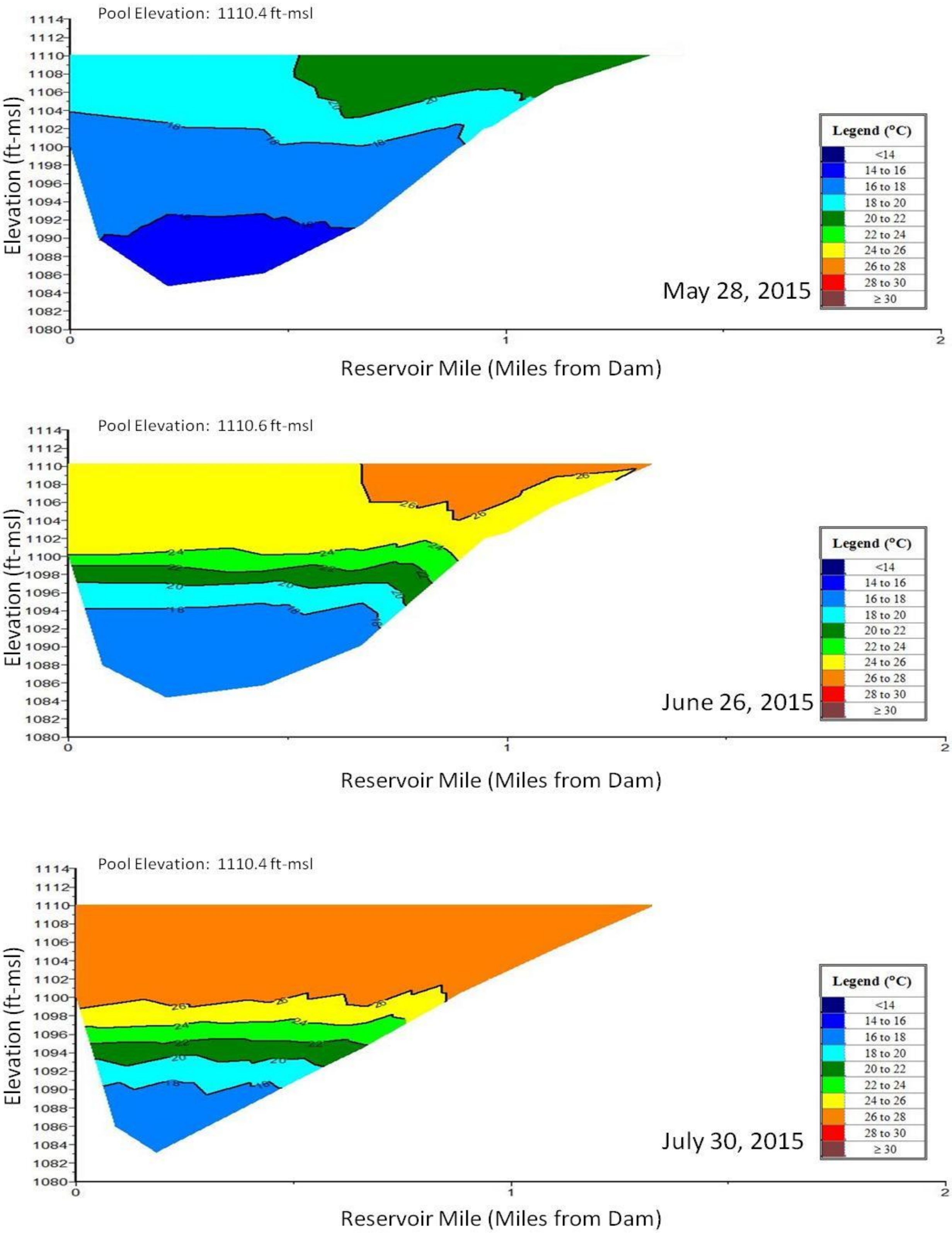
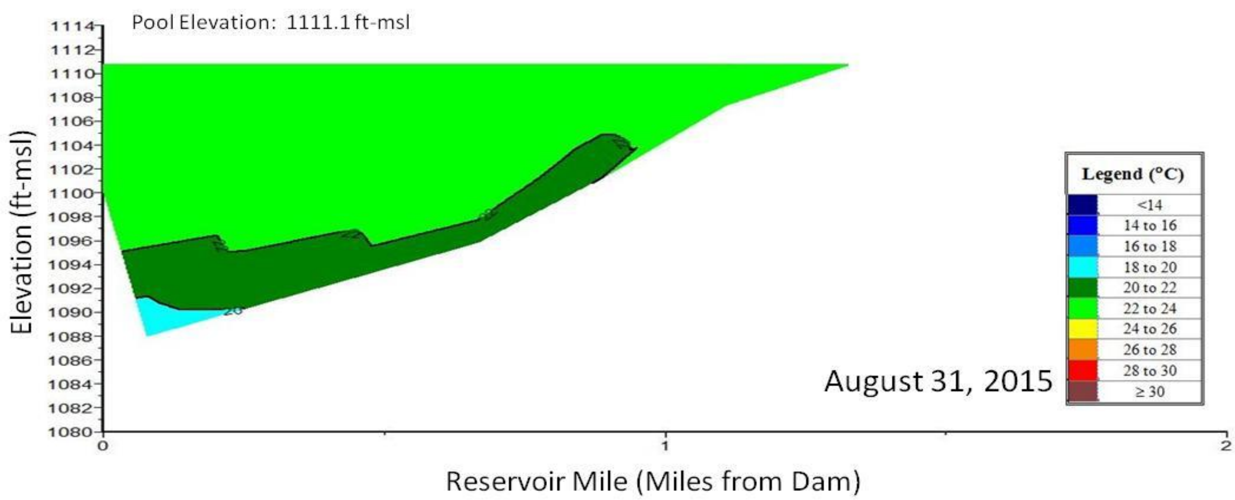


Plate 6. Longitudinal water temperature contour plots of Lake Zorinsky based on depth profile water temperatures (°C) measured from May to September 2015.



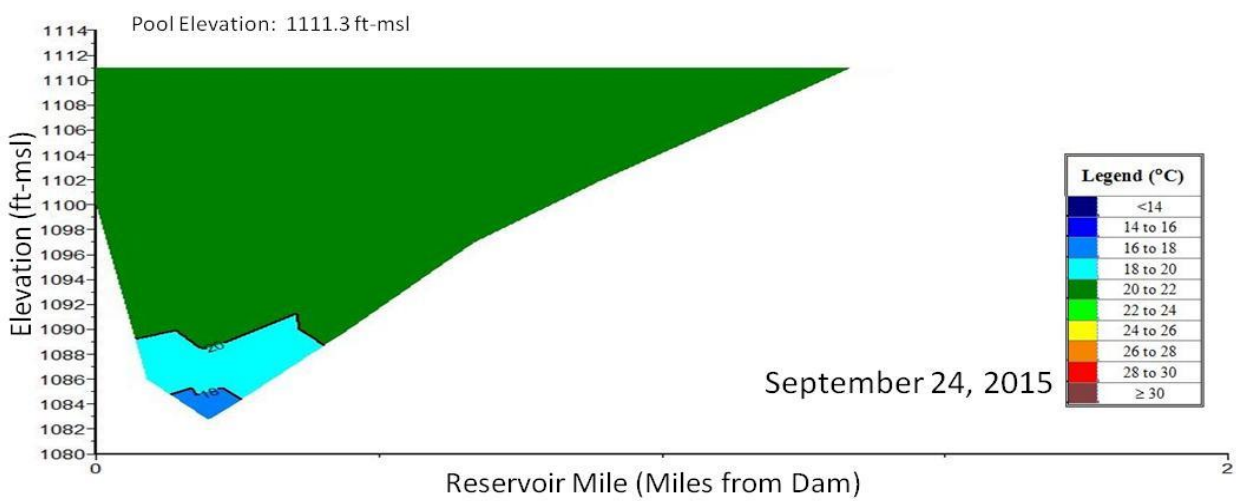


Plate 6. Longitudinal water temperature contour plots of Lake Zorinsky based on depth profile water temperatures (°C) measured from May to September 2015.

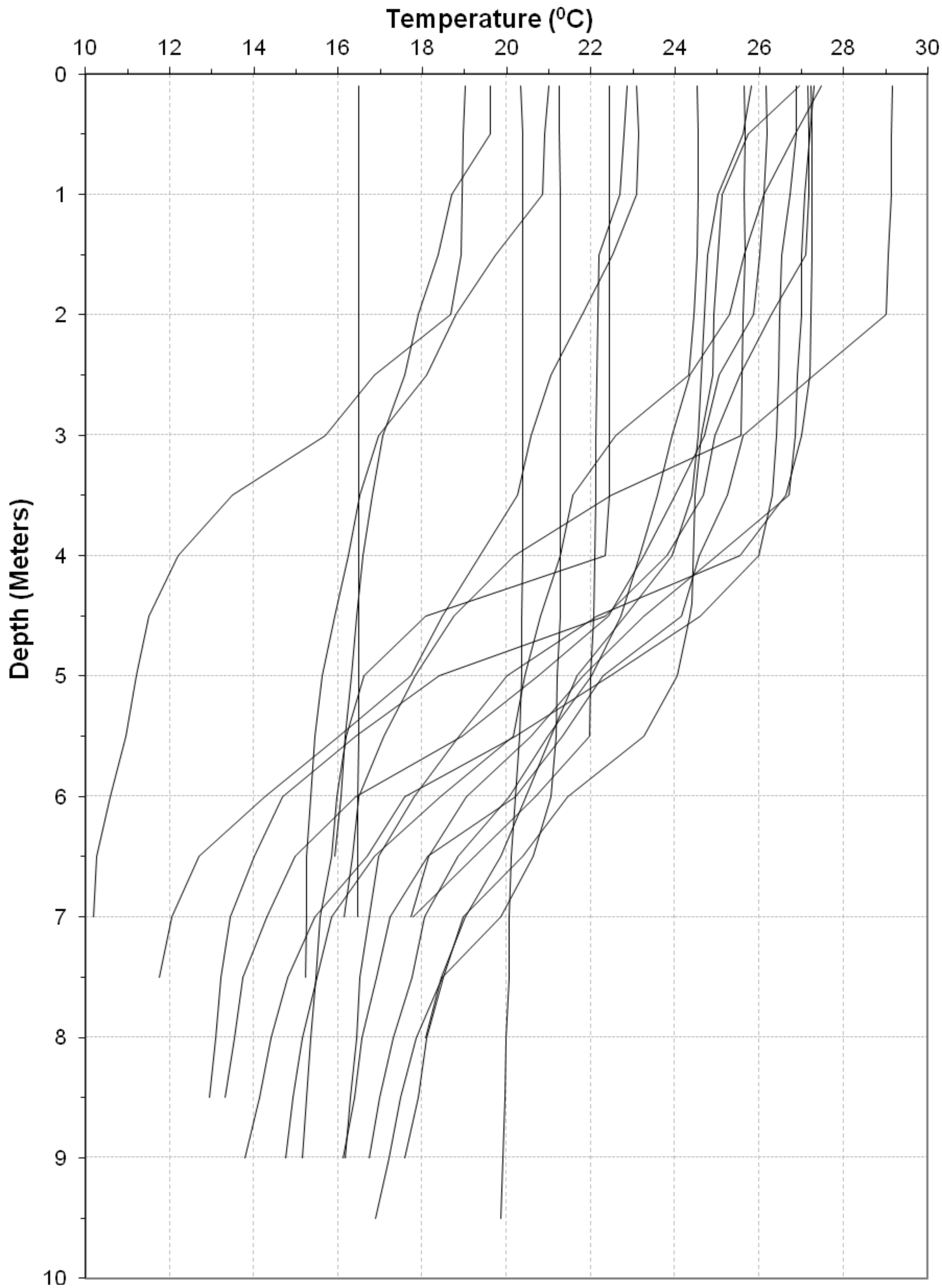


Plate 7. Temperature depth profiles for Lake Zorinsky compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015.

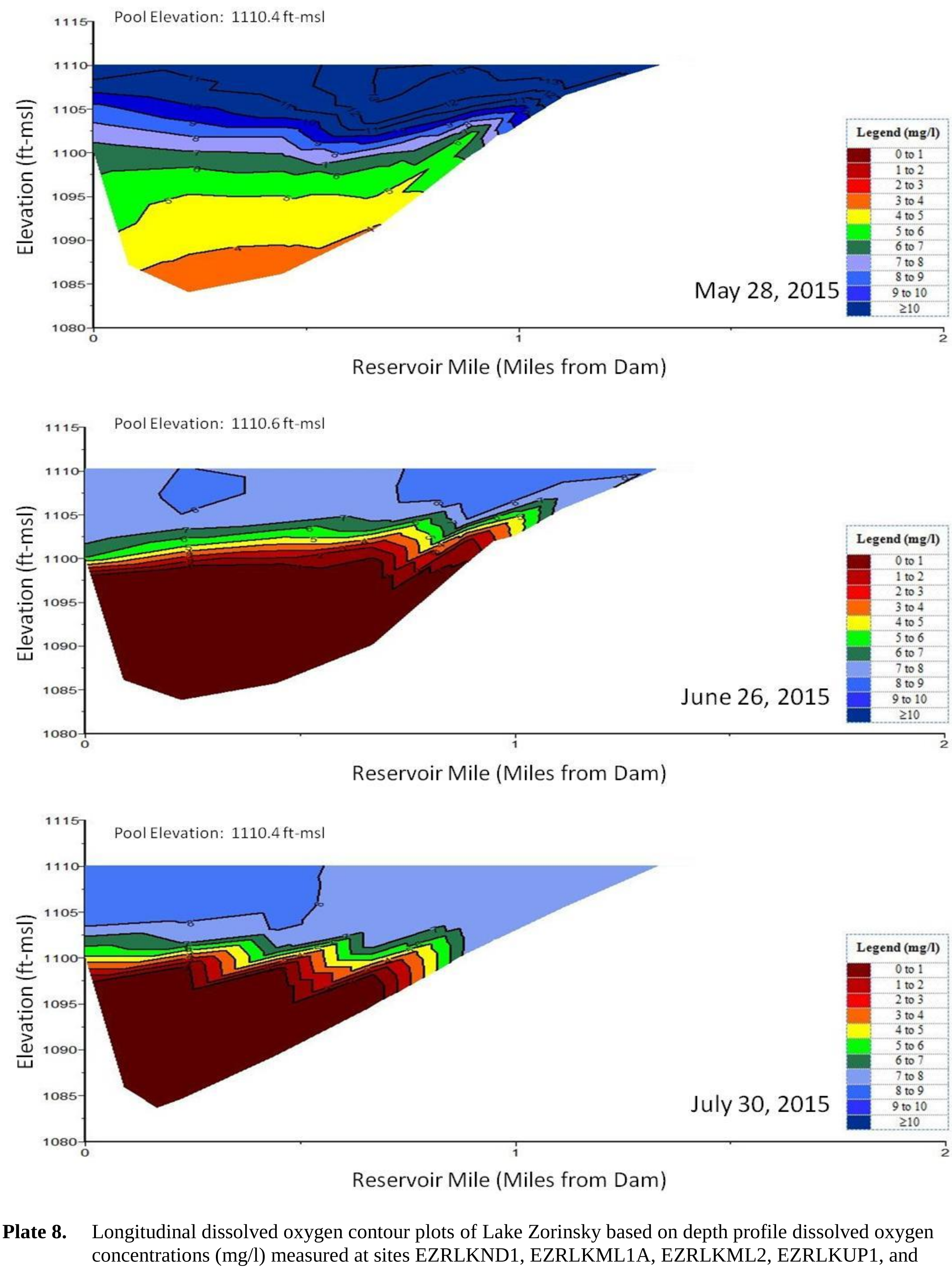


Plate 8. Longitudinal dissolved oxygen contour plots of Lake Zorinsky based on depth profile dissolved oxygen concentrations (mg/l) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.

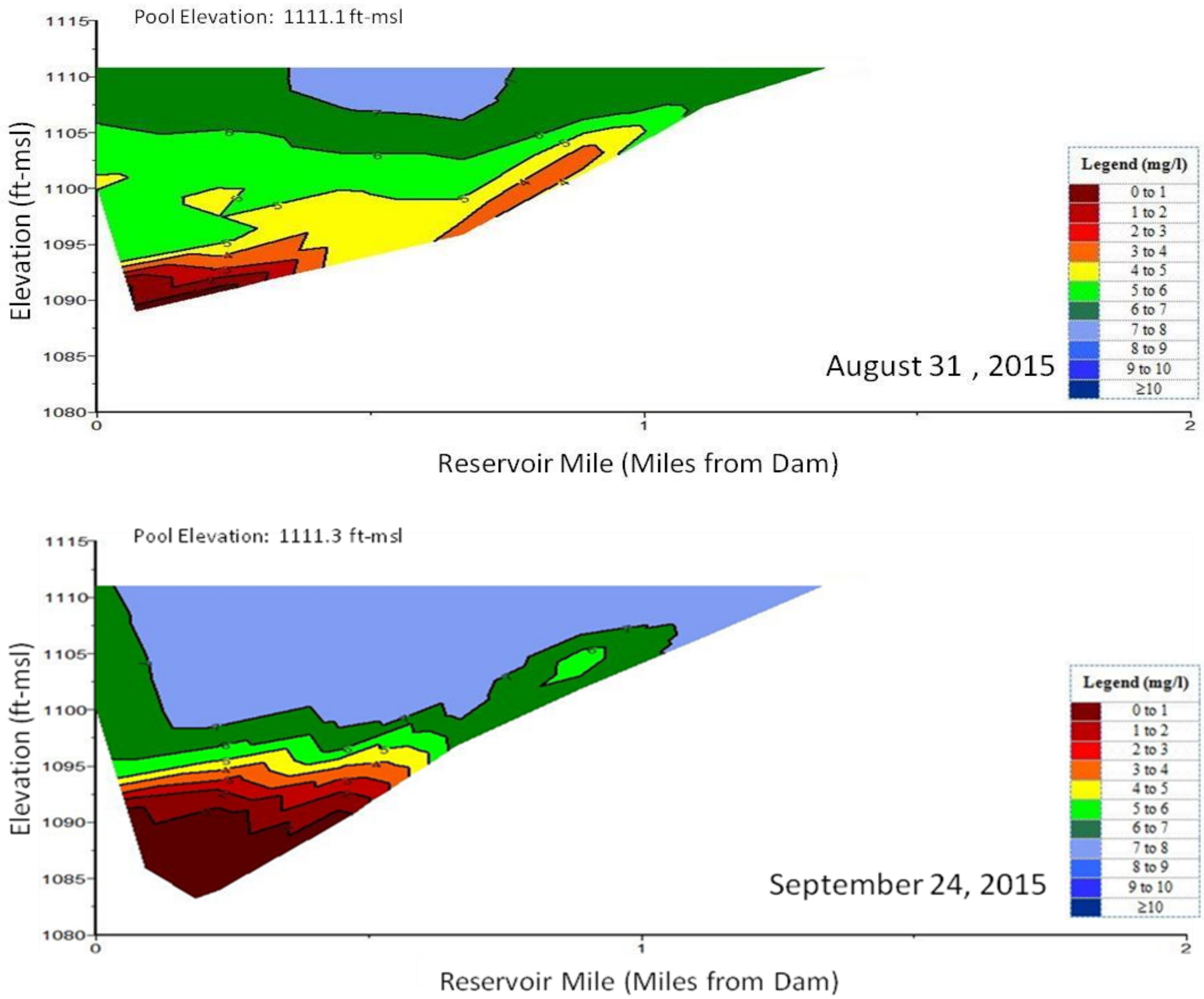


Plate 8. Longitudinal dissolved oxygen contour plots of Lake Zorinsky based on depth profile dissolved oxygen concentrations (mg/l) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.

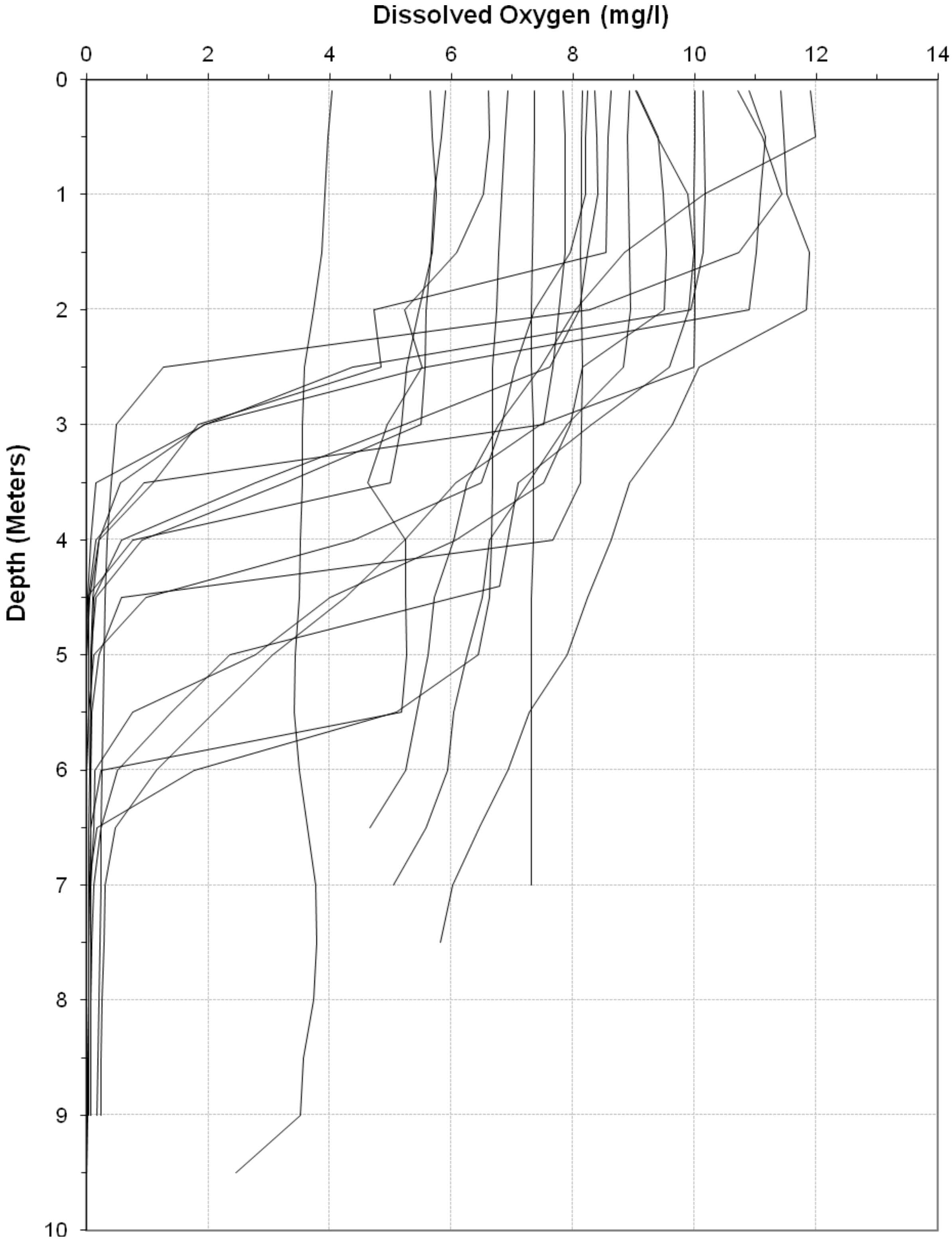


Plate 9. Dissolved oxygen depth profiles for Lake Zorinsky compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015.

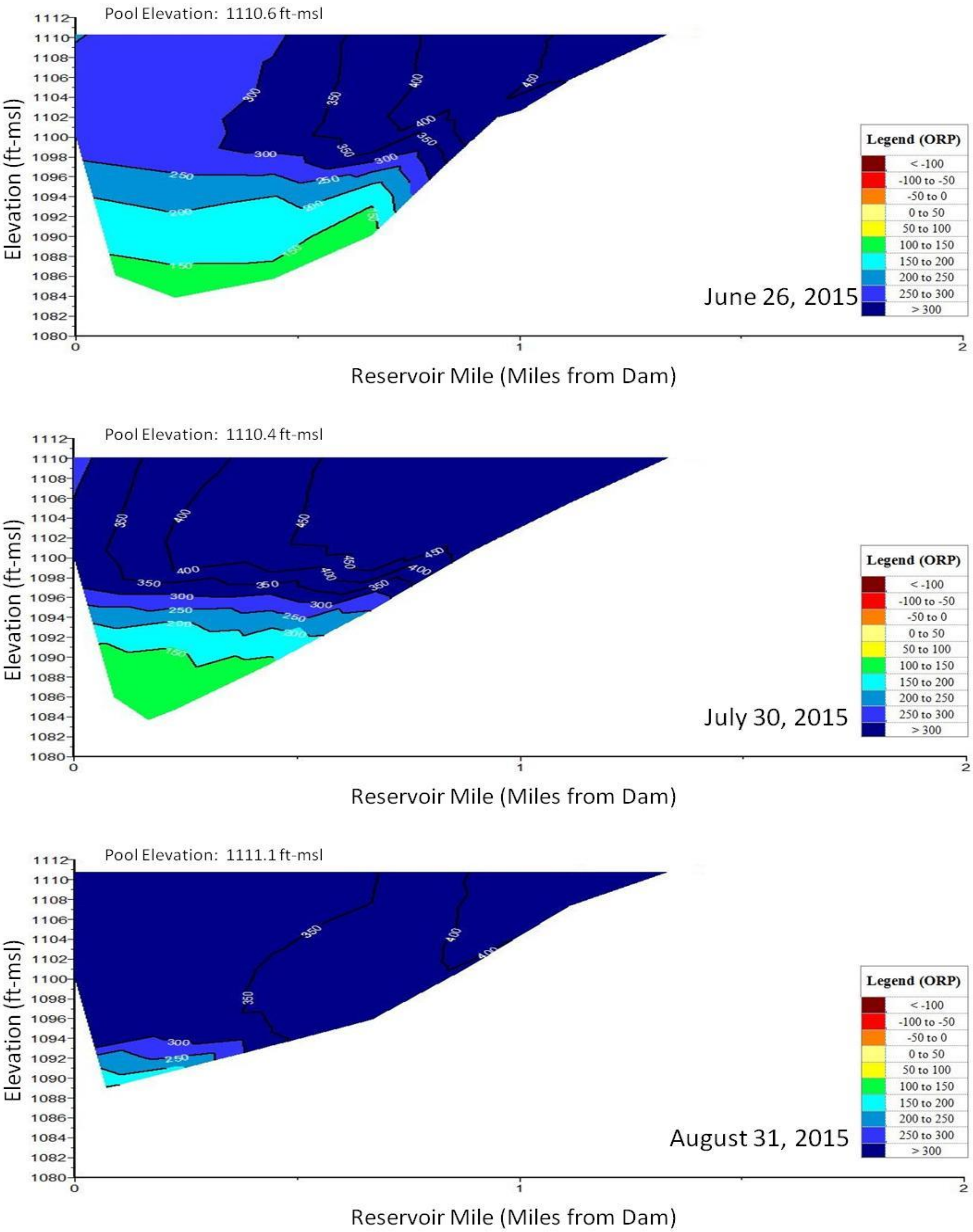


Plate 10. Longitudinal oxidation-reduction potential (ORP) contour plots of Lake Zorinsky based on depth profile ORP levels (mV) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.

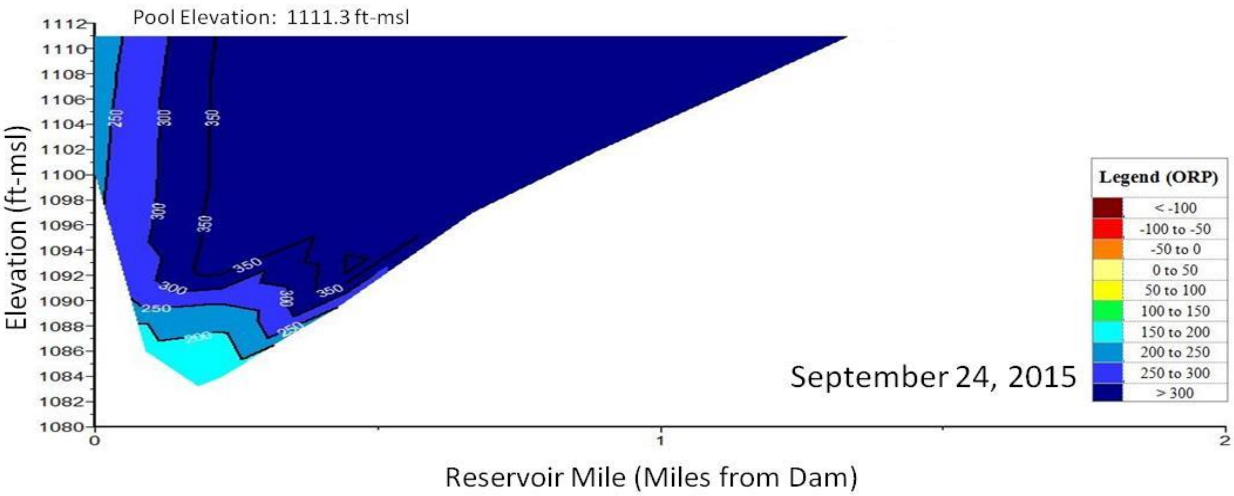


Plate 10. Longitudinal oxidation-reduction potential (ORP) contour plots of Lake Zorinsky based on depth profile ORP levels (mV) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.

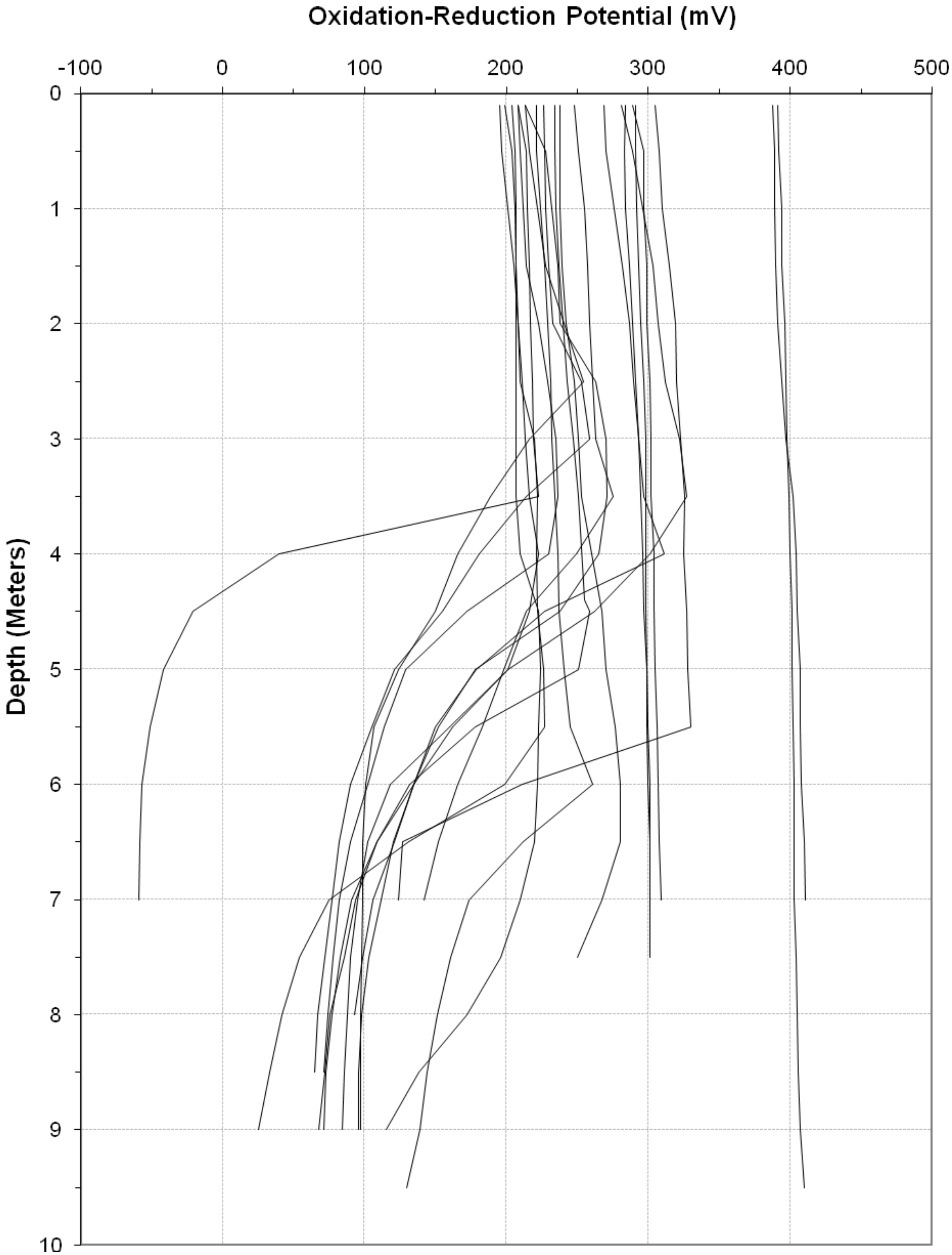


Plate 11. Oxidation-reduction potential depth profiles for Lake Zorinsky compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015

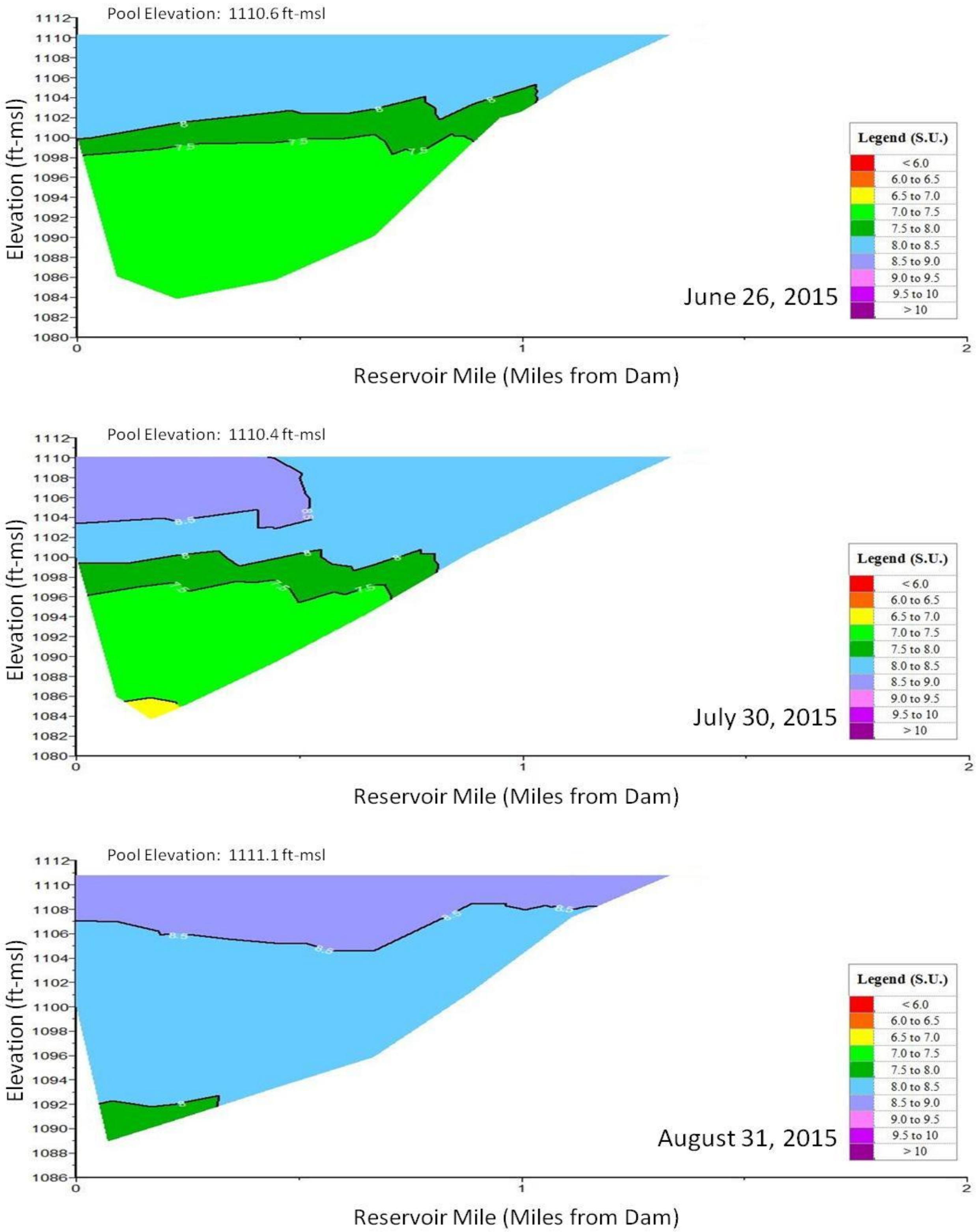


Plate 12. Longitudinal pH contour plots of Lake Zorinsky based on depth profile pH levels (S.U.) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.

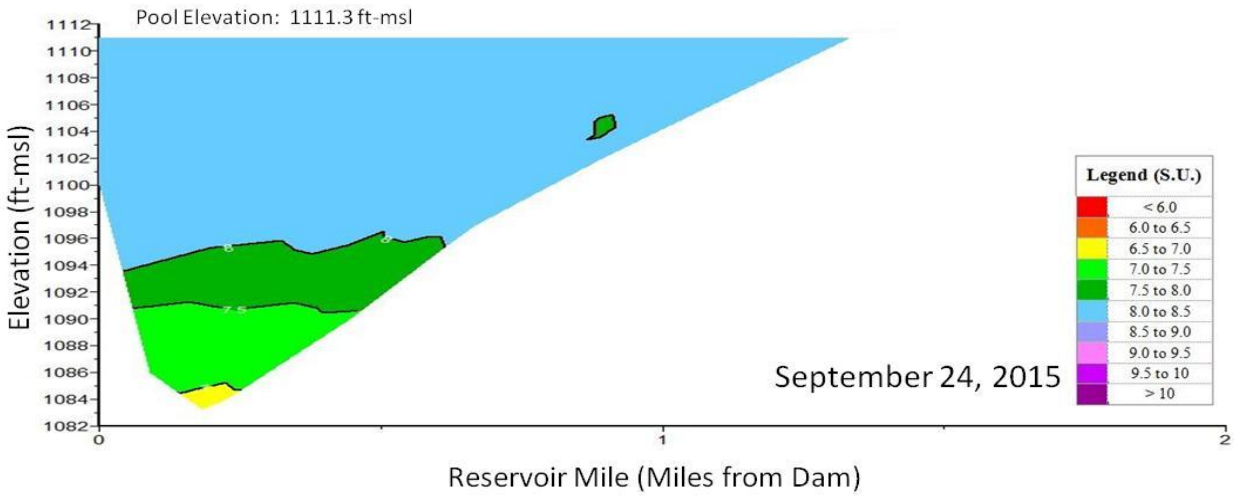


Plate 12. Longitudinal pH contour plots of Lake Zorinsky based on depth profile pH levels (S.U.) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.

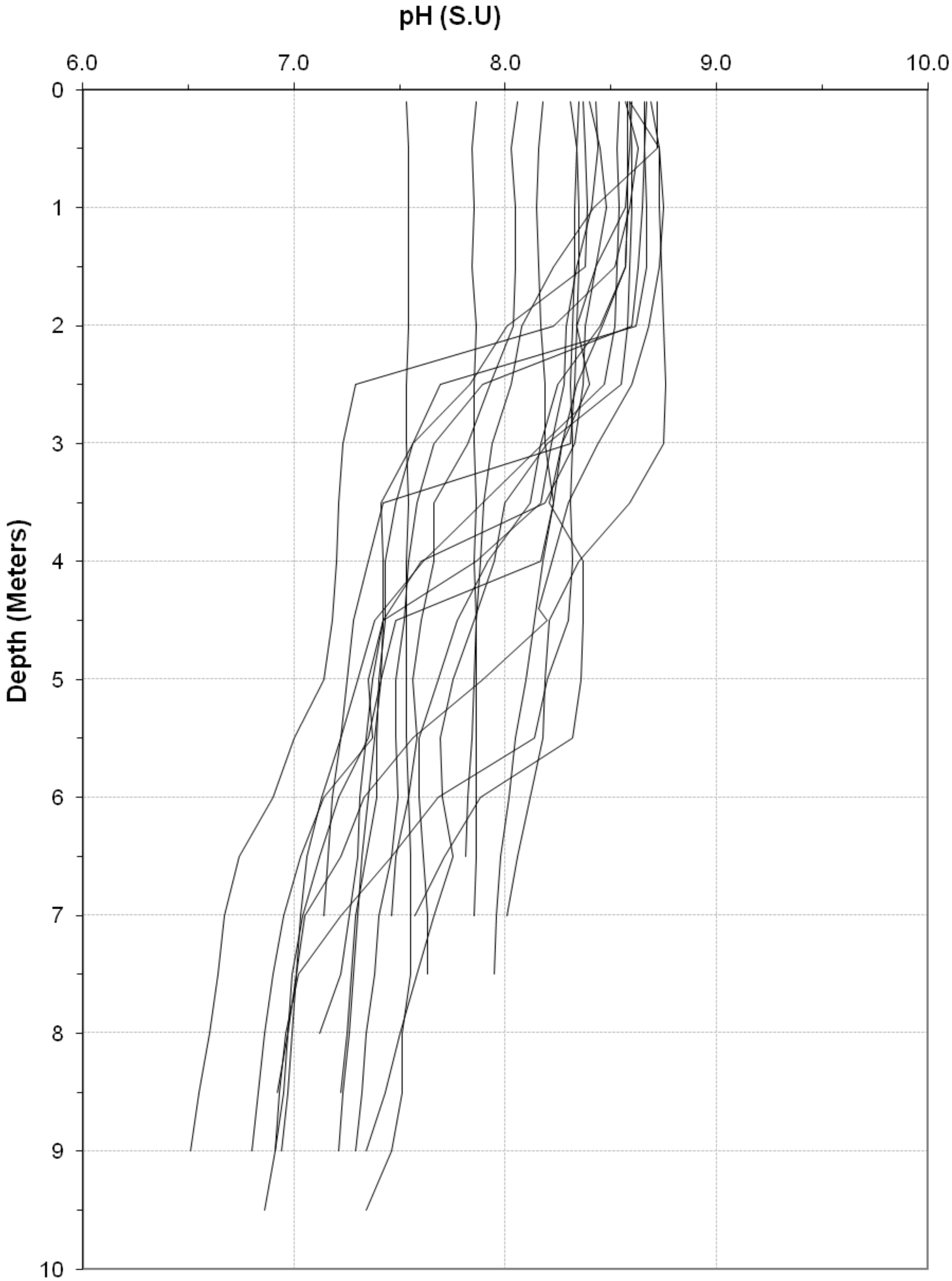


Plate 13. pH depth profiles for Lake Zorinsky compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015.

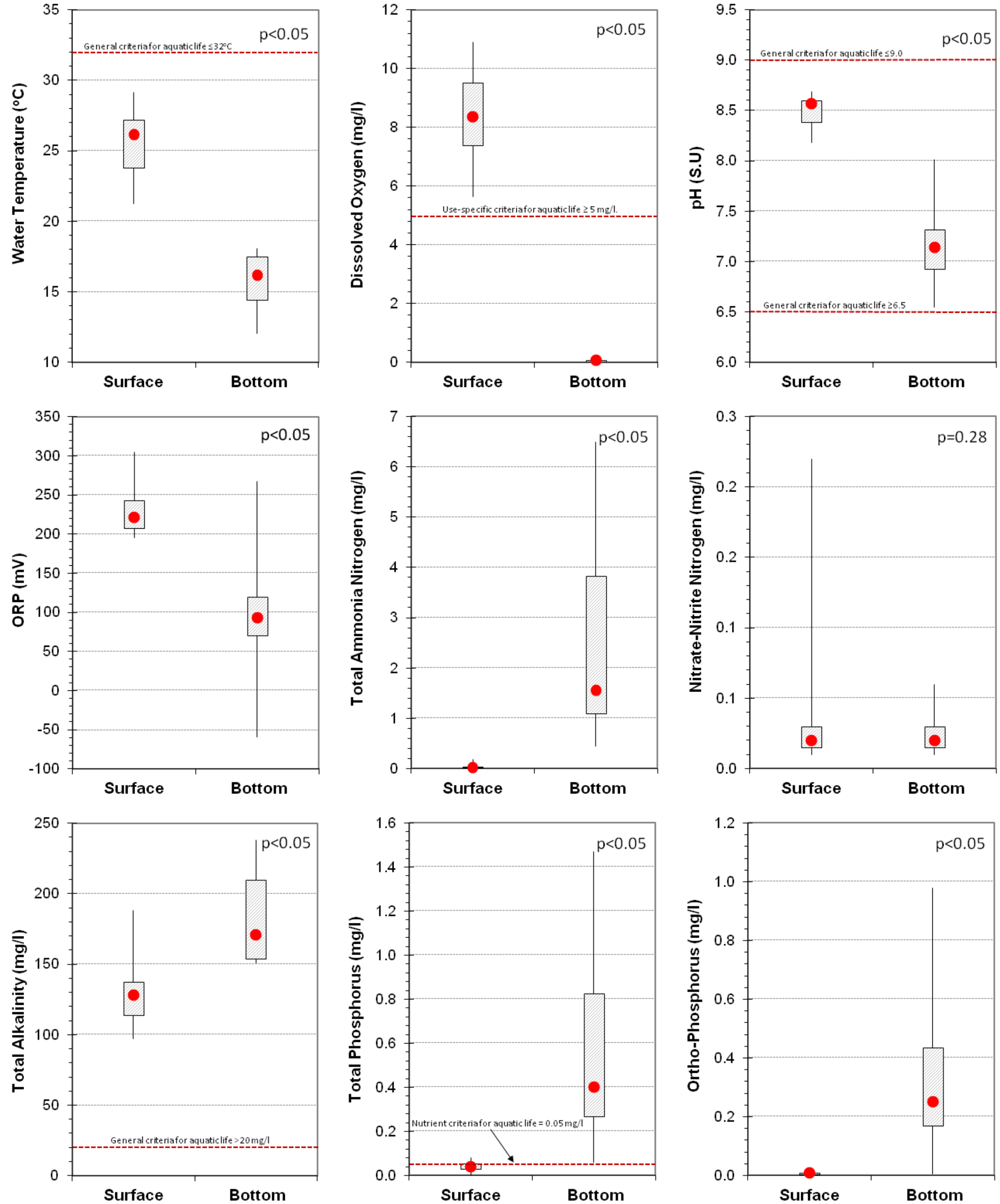


Plate 14. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Lake Zorinsky (site EZRLKND1) when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=15). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test ($\alpha = 0.05$). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

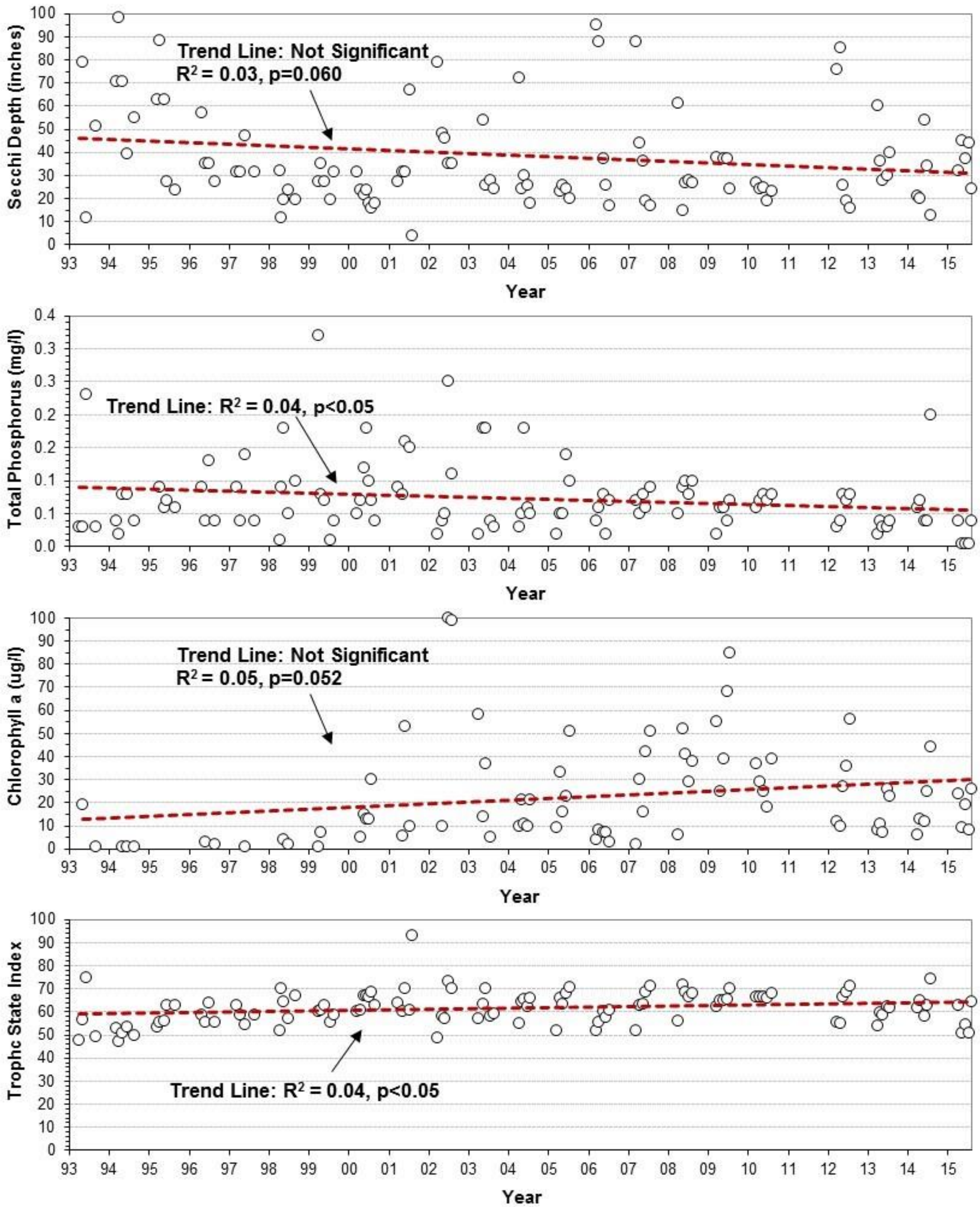


Plate 15. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Lake Zorinsky at the near-dam, ambient site (i.e., site EZRLKND1) over the 22-year period of 1993 through 2015.

Plate 16. Summary of runoff water quality conditions monitored in the Boxelder Creek inflow to Ed Zorinsky Reservoir at monitoring site EZRNF1 during the 5-year period 2011 through 2015**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	**No. of Obs.**	**Mean(A)**	**Median**	**Min.**	**Max.**	**State WQS Criteria(B)**	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Turbidity (NTUs)	1	23	224.19	92.60	12.40	1092.00	-----	-----	-----
pH (S.U.)	0.1	23	8.20	8.17	7.53	9.70	$\geq$6.5 & $\leq$9.0 (1)	0,1	0%,4%
Suspended Solids, Total (mg/l)	10	25	548.04	140.00	18.00	5950.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	26	0.13	0.10	n.d.	0.43	6.07(2,3), 1.22(2,4)	0	0%
Kjeldahl N, Total (mg/l)	0.8	26	1.89	1.58	n.d.	5.58	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	26	1.43	0.98	0.37	3.98	100(5)	0	0%
Nitrogen, Total (mg/l)	0.8	26	3.32	2.99	2.01	9.56	-----	-----	-----
Phosphorus, Total (mg/l)	0.008	26	0.66	0.31	0.10	6.11	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.005	21	0.12	0.12	0.02	0.18	-----	-----	-----
Iron, Dissolved (ug/l)	10	11	729.09	40.00	n.d.	4940.00	1000(4)	2	18%
Manganese, Dissolved (ug/l)	3	11	110.36	100.00	4.00	230.00	1000(4)	0	0%
Atrazine, Total (ug/l)(C)	0.05	16	1.36	0.90	n.d.	3.50	330(3), 12(4)	0	0%
Metolachlor, Total (ug/l)(C)	0.1	16	-----	0.40	n.d.	1.70	390(3), 100(4)	0	0%
Acetochlor, Total (ug/l)(C)	0.1	16	1.33	0.90	n.d.	3.80	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to value to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(3) Acute criteria for aquatic life.
(4) Chronic criteria for aquatic life.
(5) Agricultural criteria for surface waters.
(6) Nutrient criteria for aquatic life.

(C) Immunoassay analysis.

* A highlighted mean, number of excedences, or percent exceedence indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

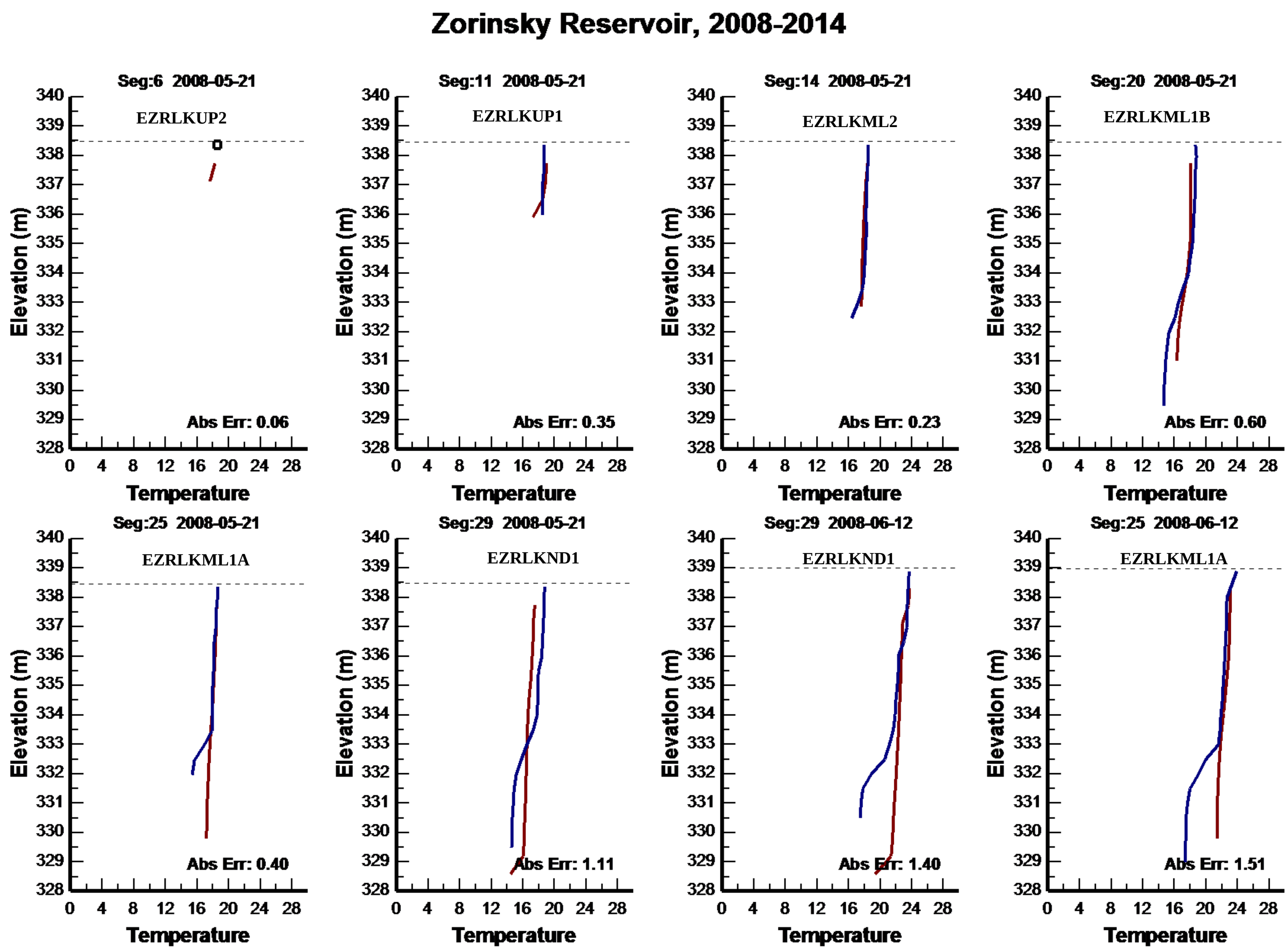


Plate 17. Observed (blue) versus model (red) temperature calibration profiles for May to June 2008.

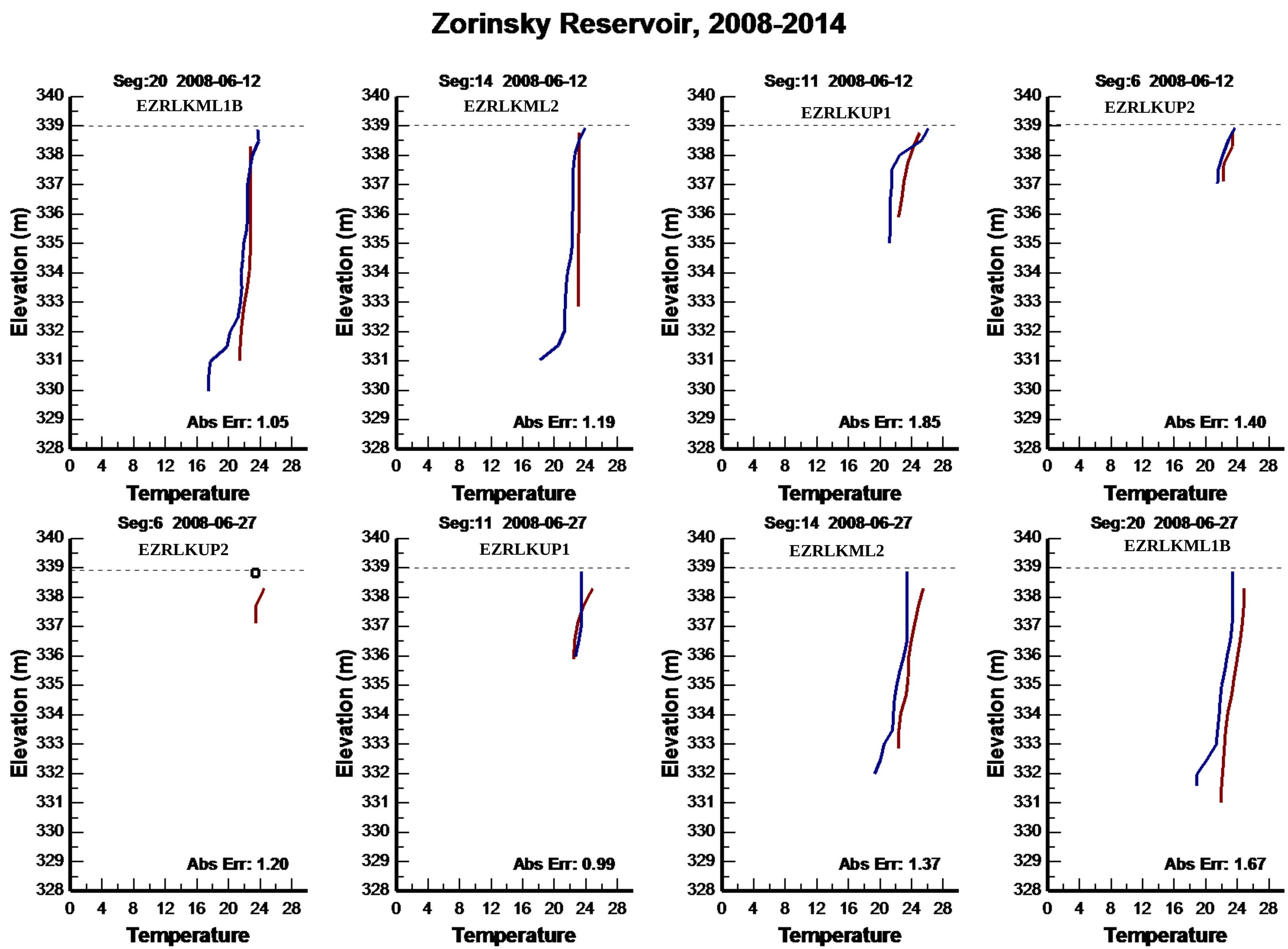


Plate 18. Observed (blue) versus model (red) temperature calibration profiles for June 2008.

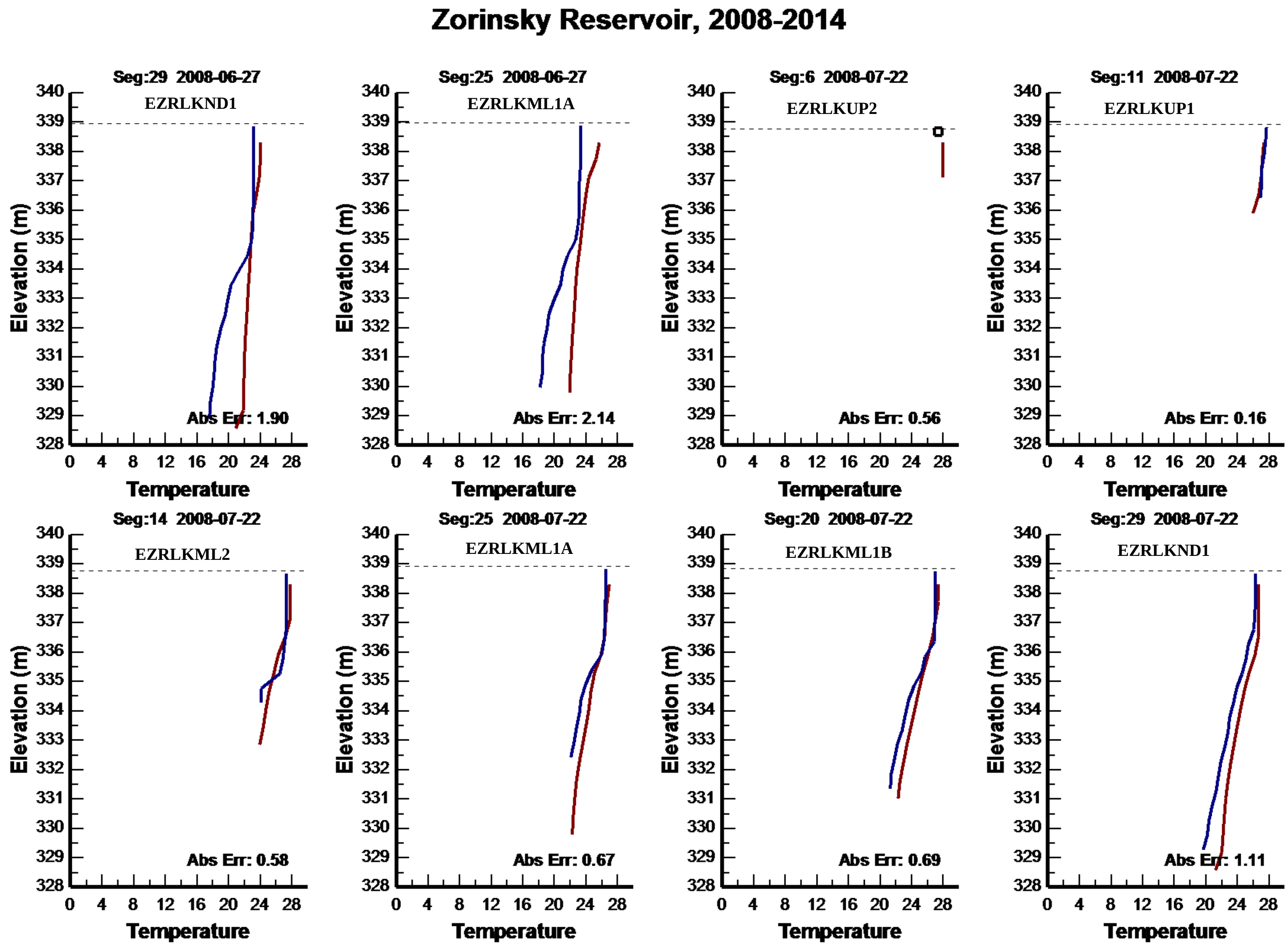


Plate 19. Observed (blue) versus model (red) temperature calibration profiles for June to July 2008.

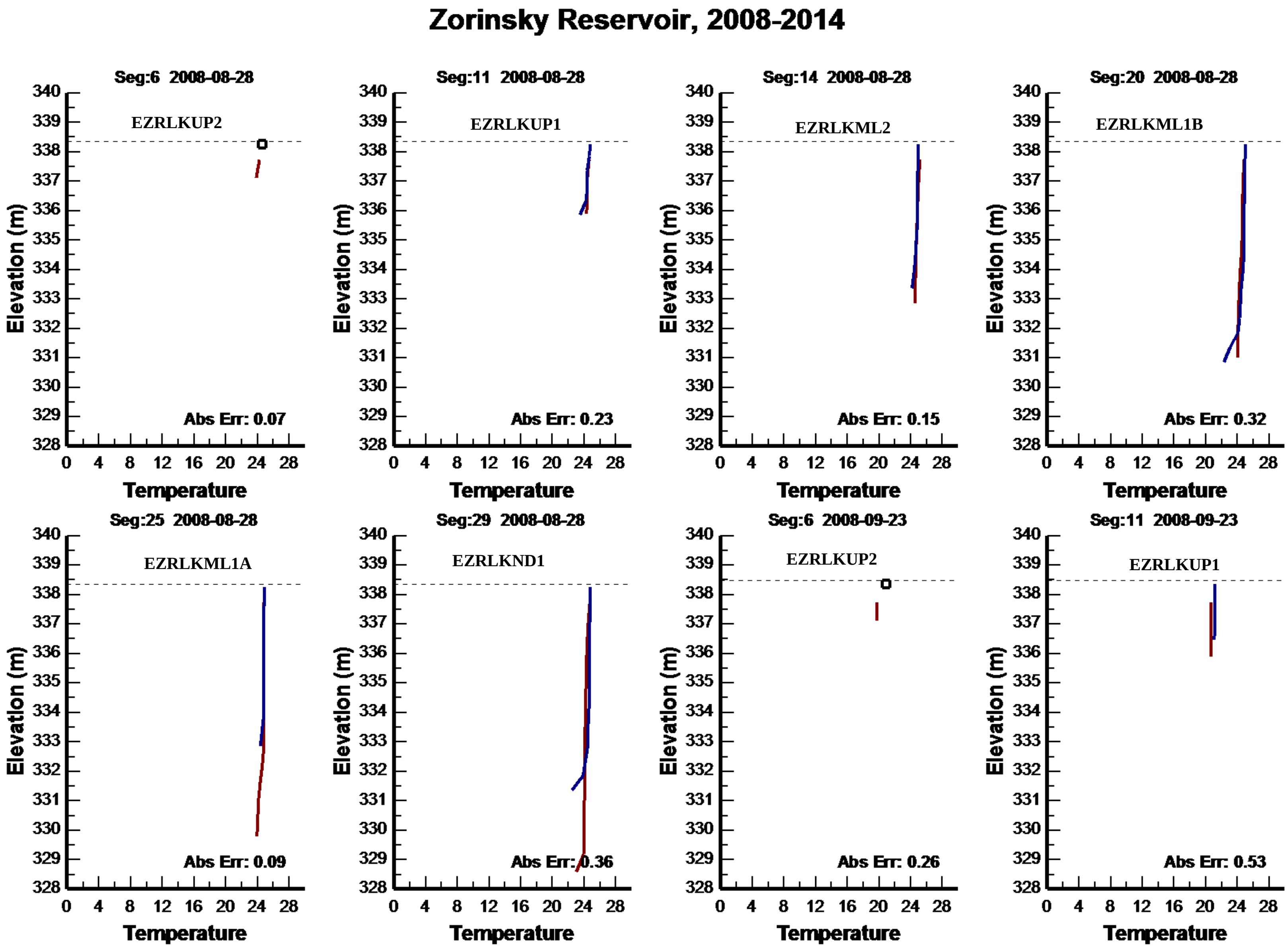


Plate 20. Observed (blue) versus model (red) temperature calibration profiles for August to September 2008.

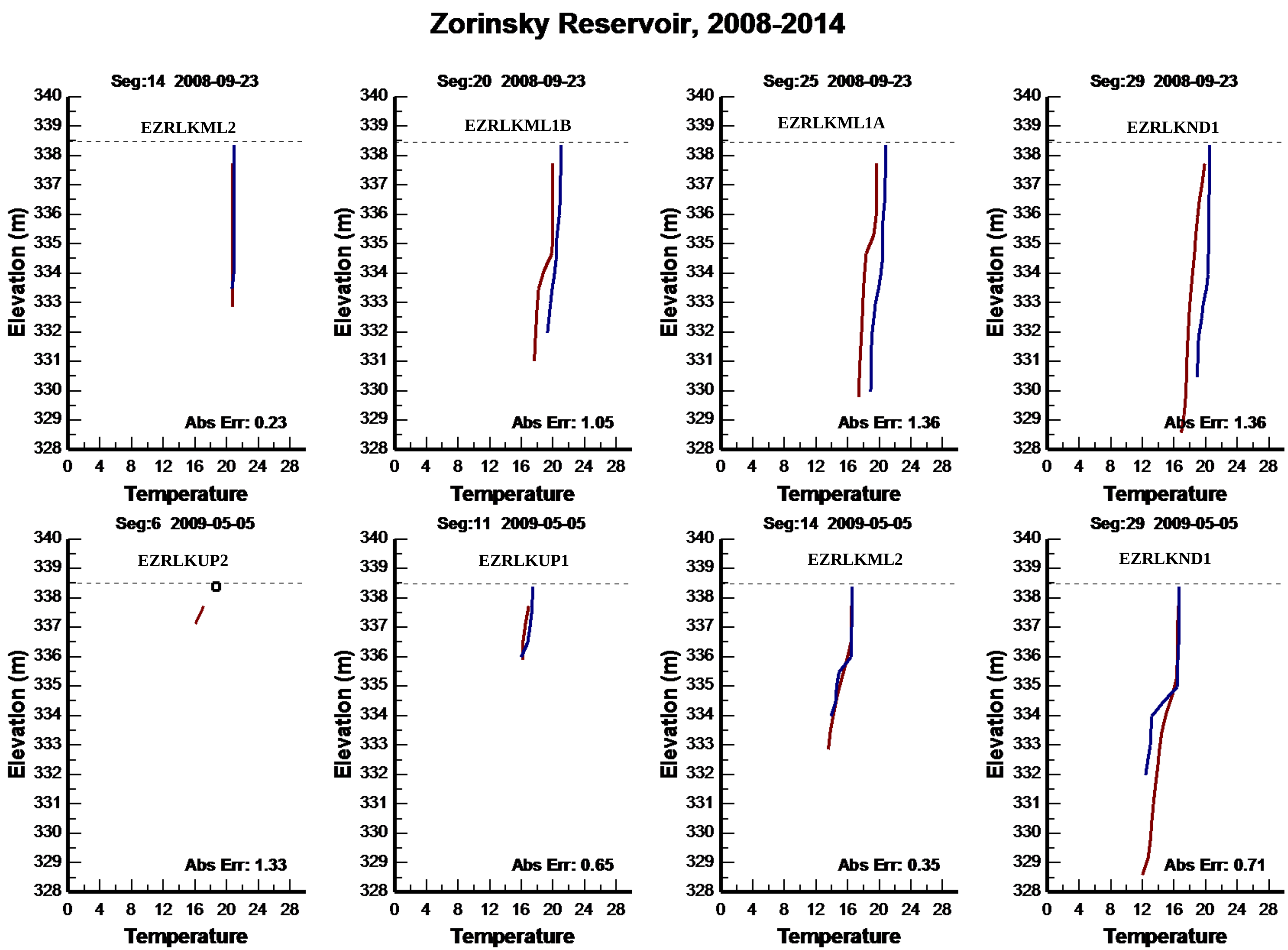


Plate 21. Observed (blue) versus model (red) temperature calibration profiles for September 2008 to May 2009.

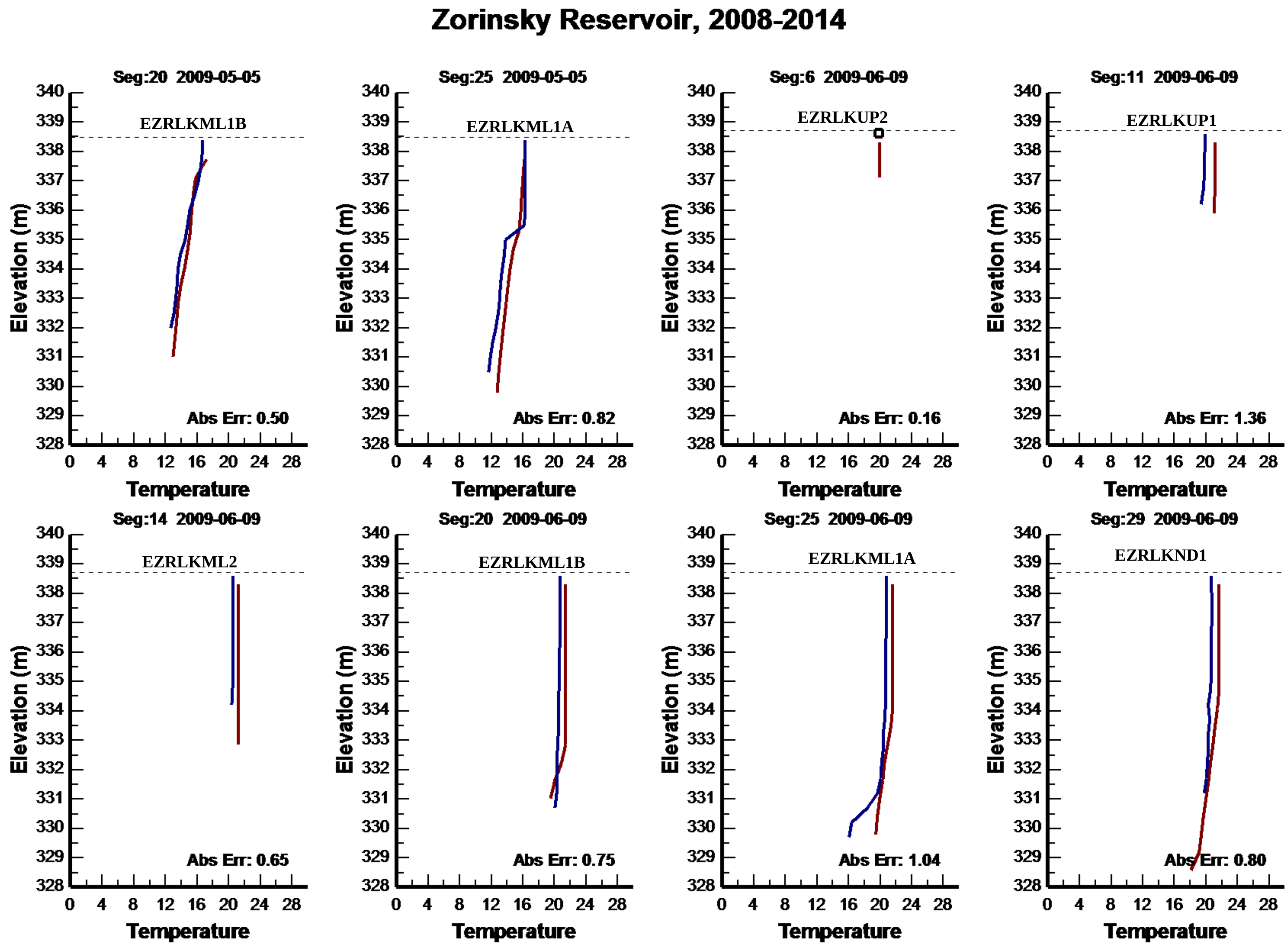


Plate 22. Observed (blue) versus model (red) temperature calibration profiles for May to June 2009.

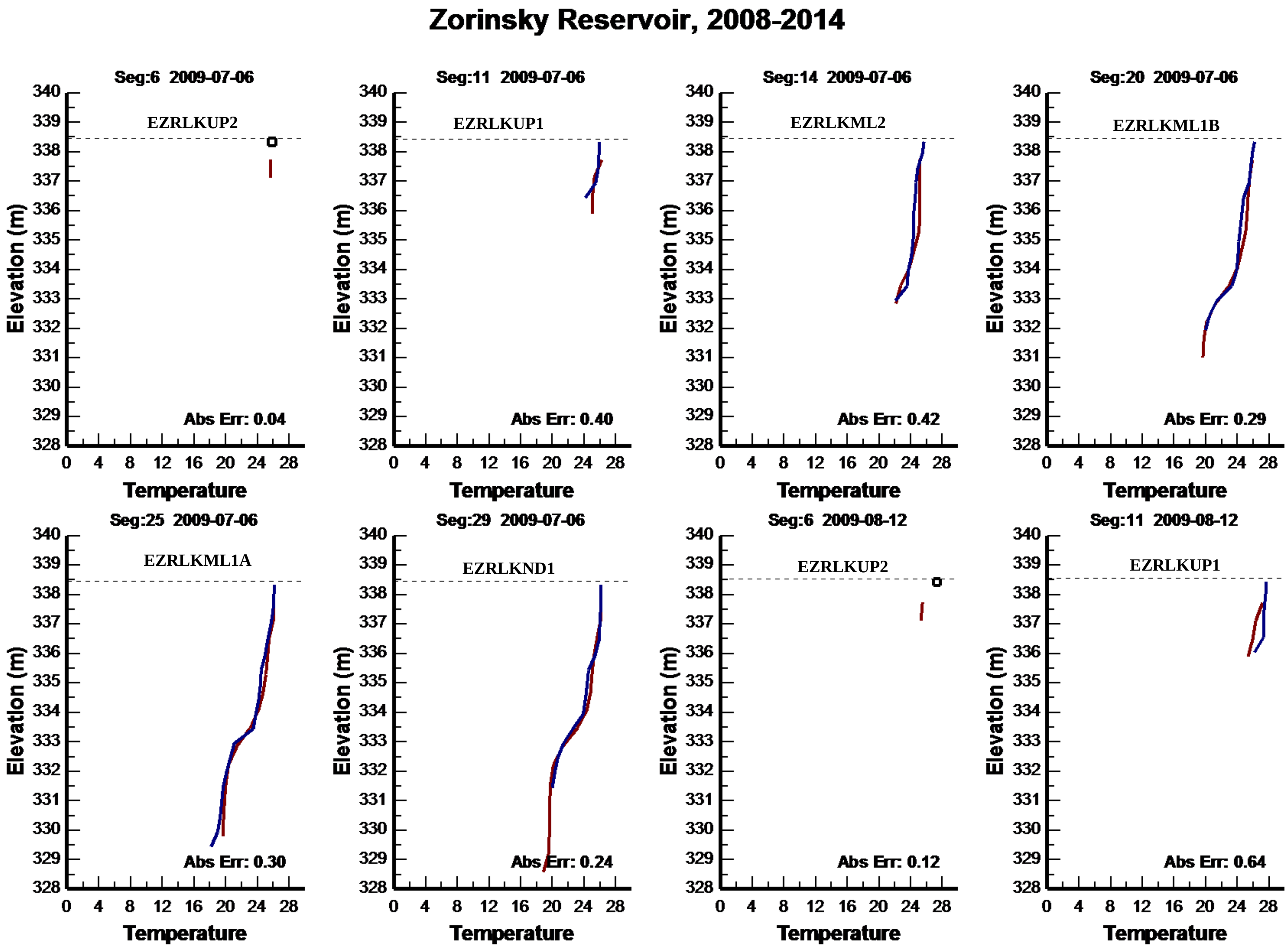


Plate 23. Observed (blue) versus model (red) temperature calibration profiles for July to August 2009.

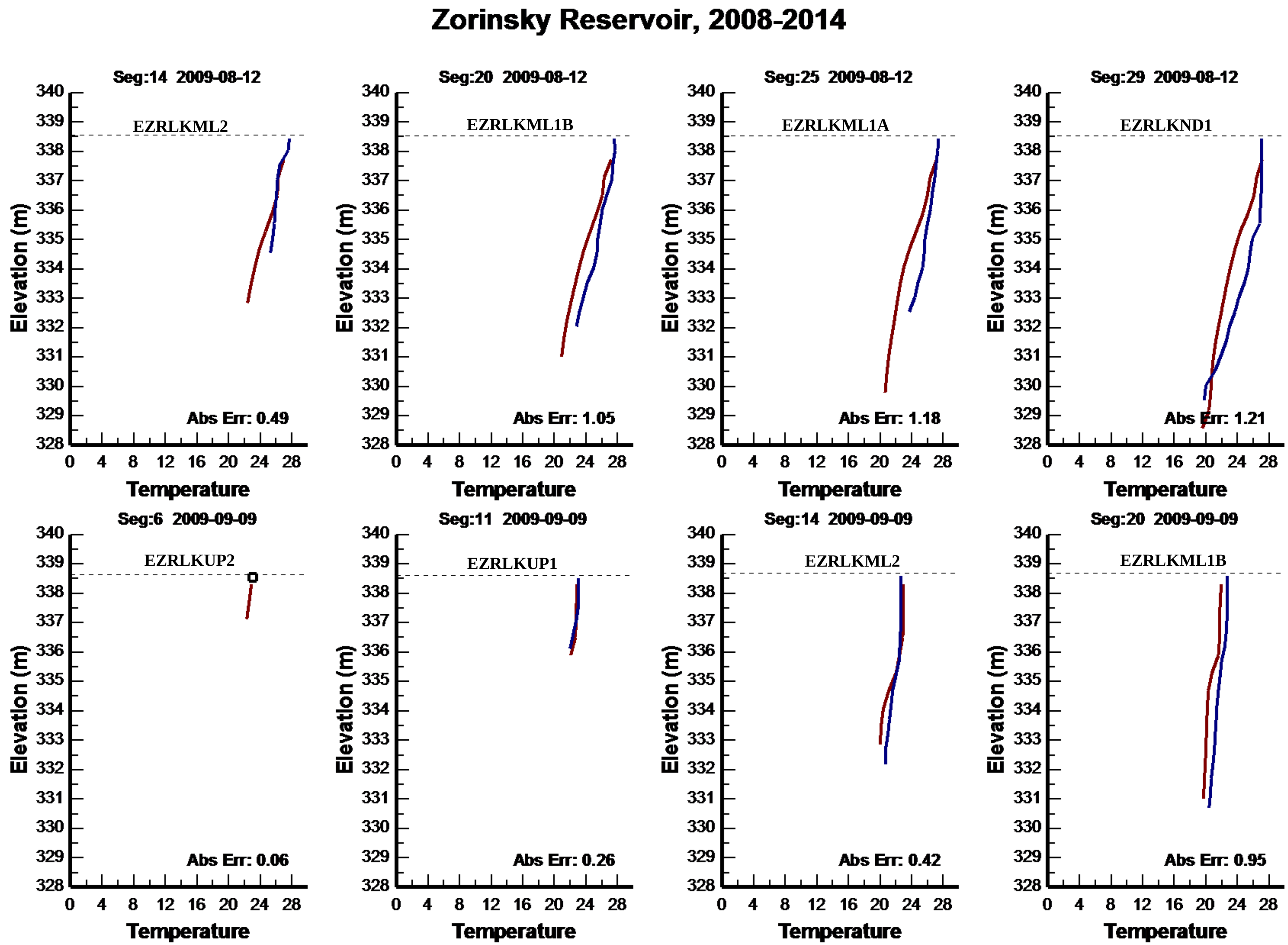


Plate 24. Observed (blue) versus model (red) temperature calibration profiles for August to September 2009.

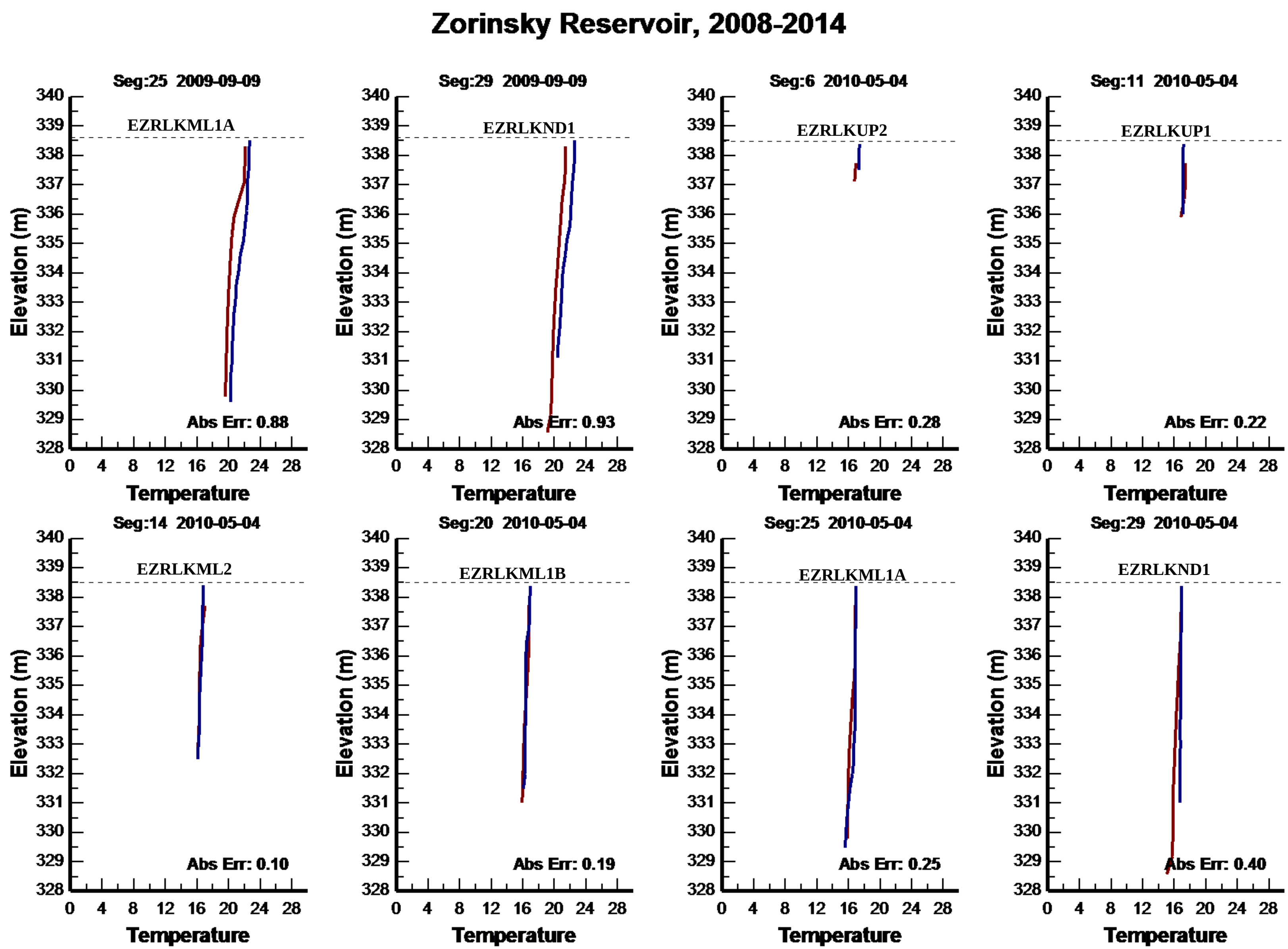


Plate 25. Observed (blue) versus model (red) temperature calibration profiles for September 2009 to May 2010.

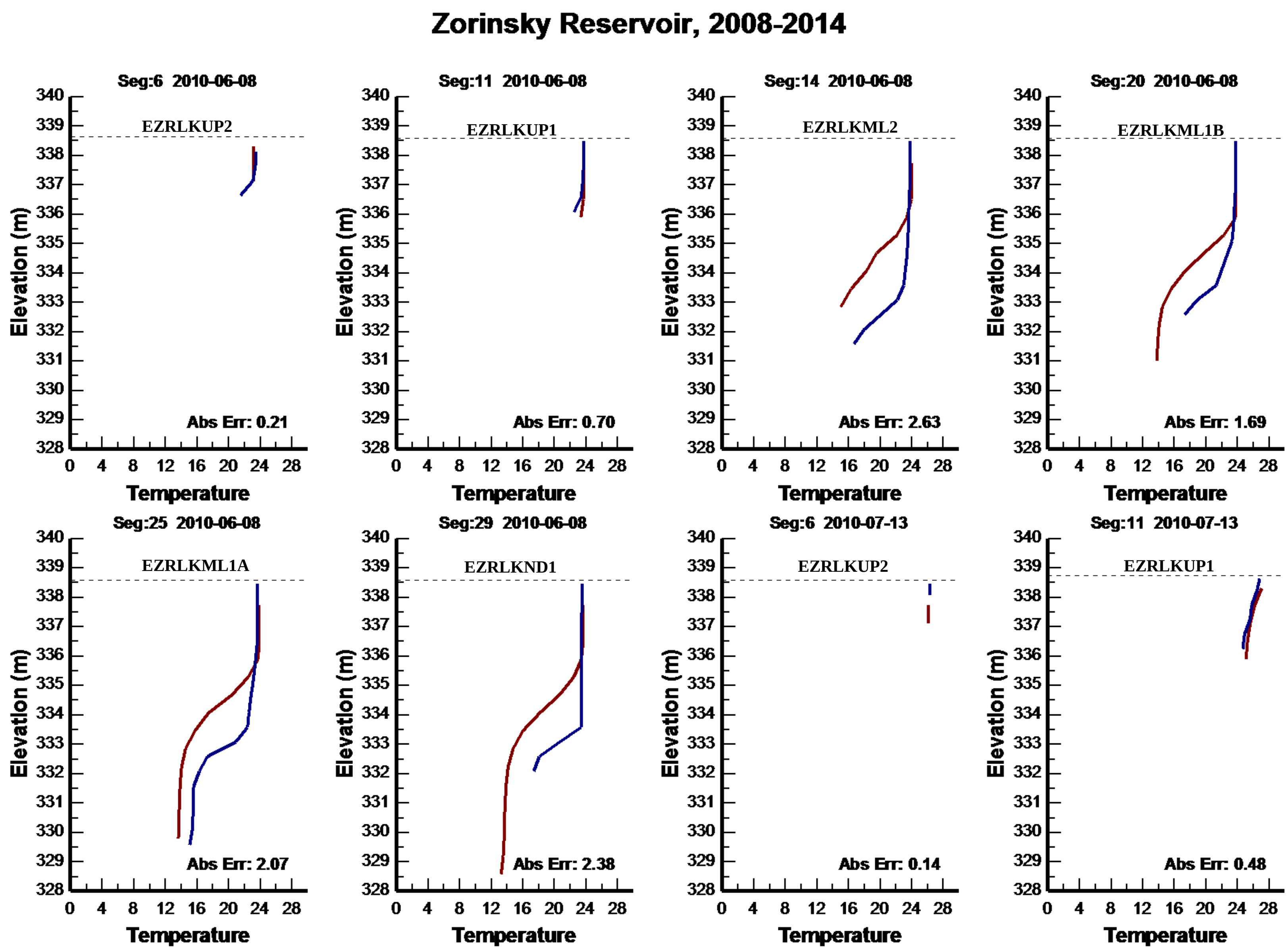


Plate 26. Observed (blue) versus model (red) temperature calibration profiles for June to July 2010.

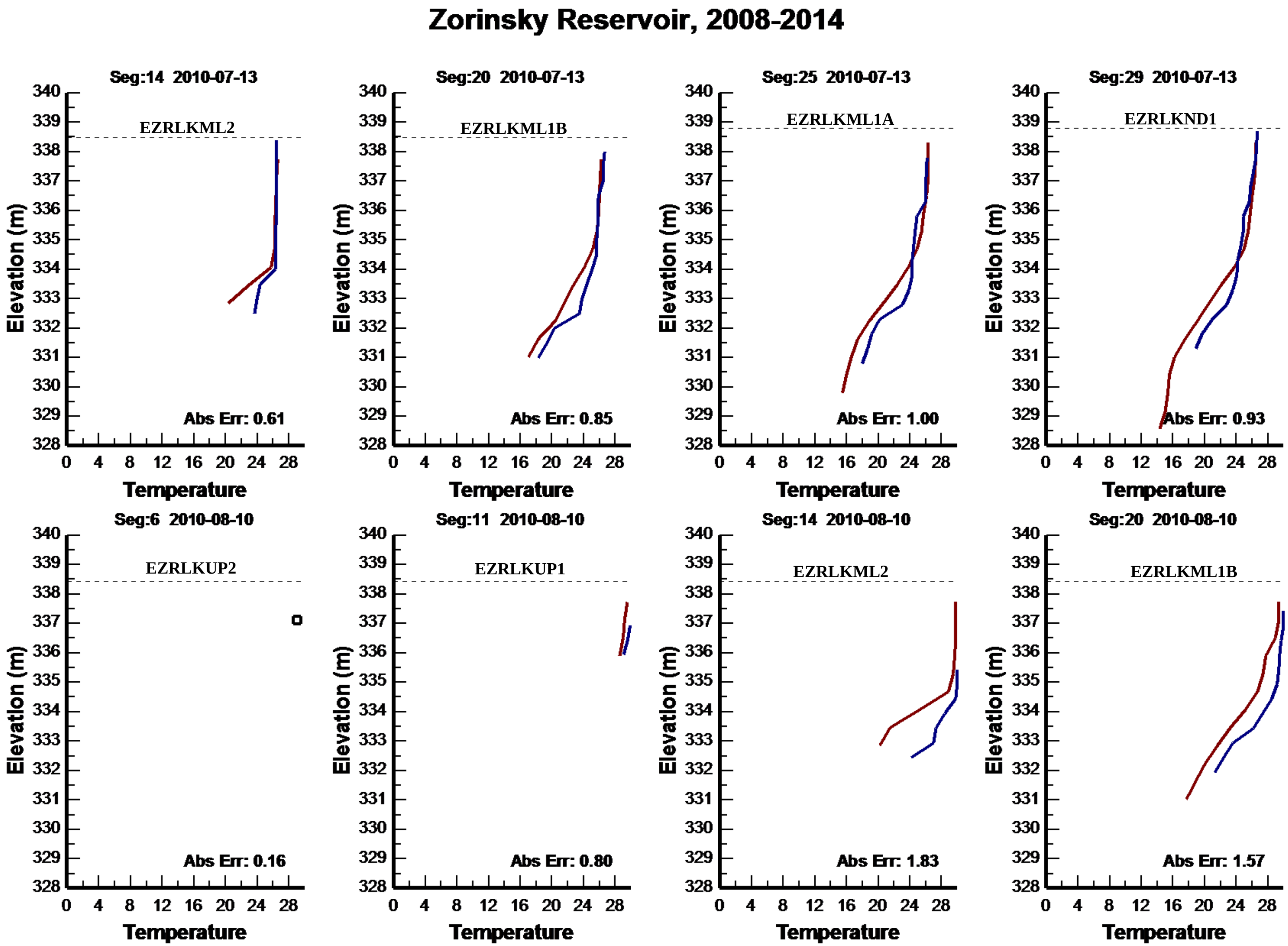


Plate 27. Observed (blue) versus model (red) temperature calibration profiles for July to August 2010.

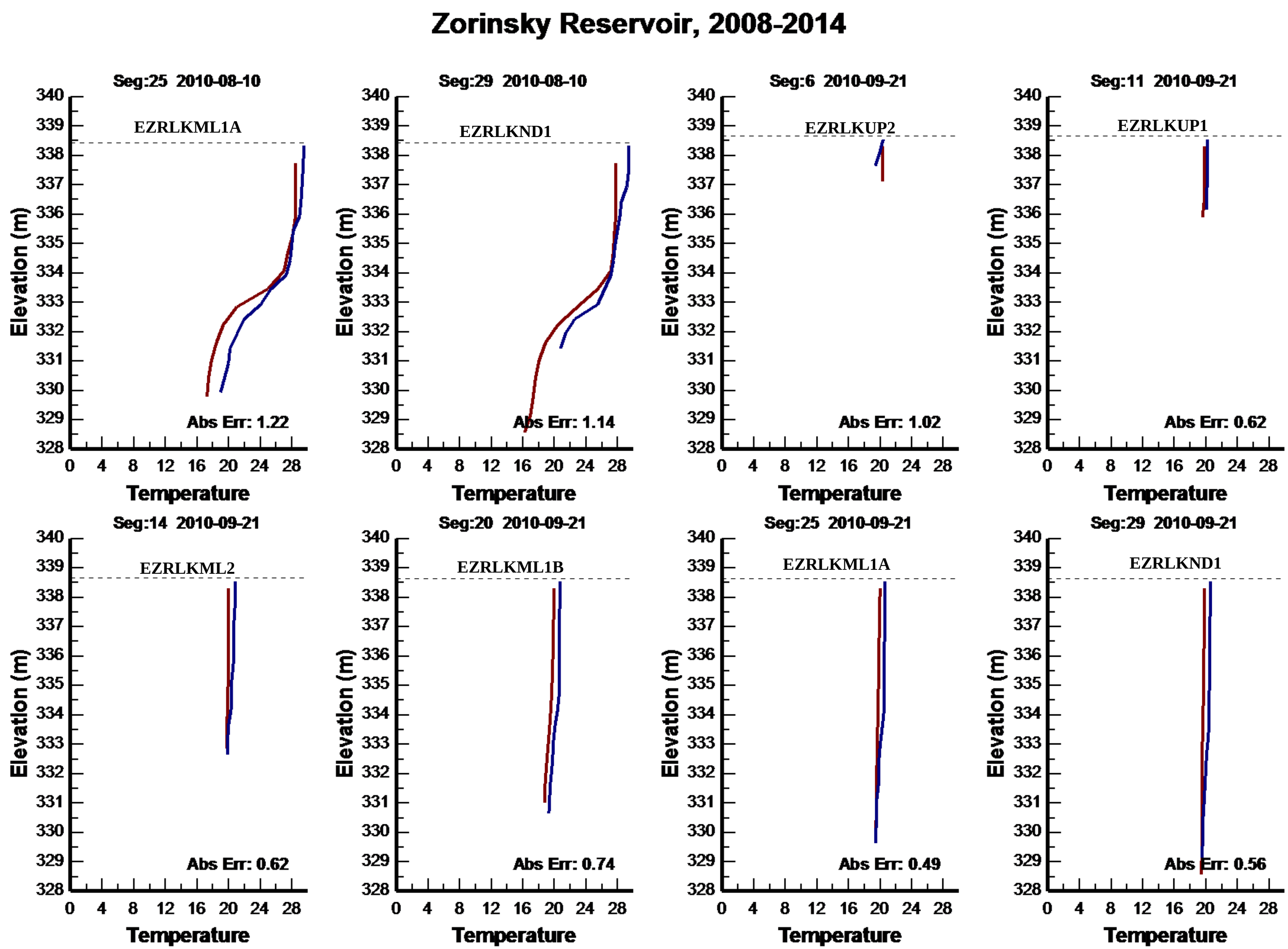


Plate 28. Observed (blue) versus model (red) temperature calibration profiles for August to September 2010.

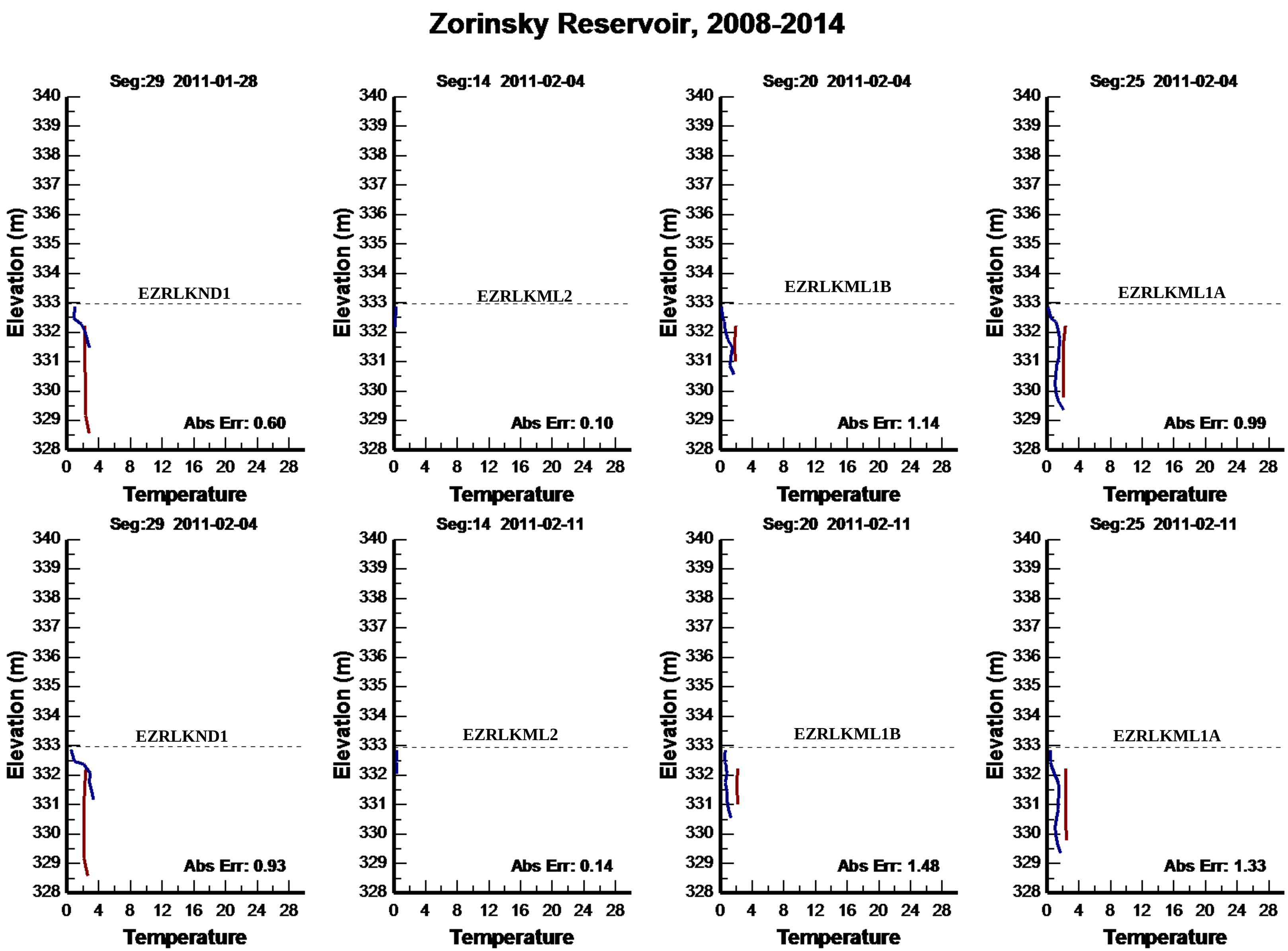


Plate 29. Observed (blue) versus model (red) temperature calibration profiles for January 2011 to February 2012.

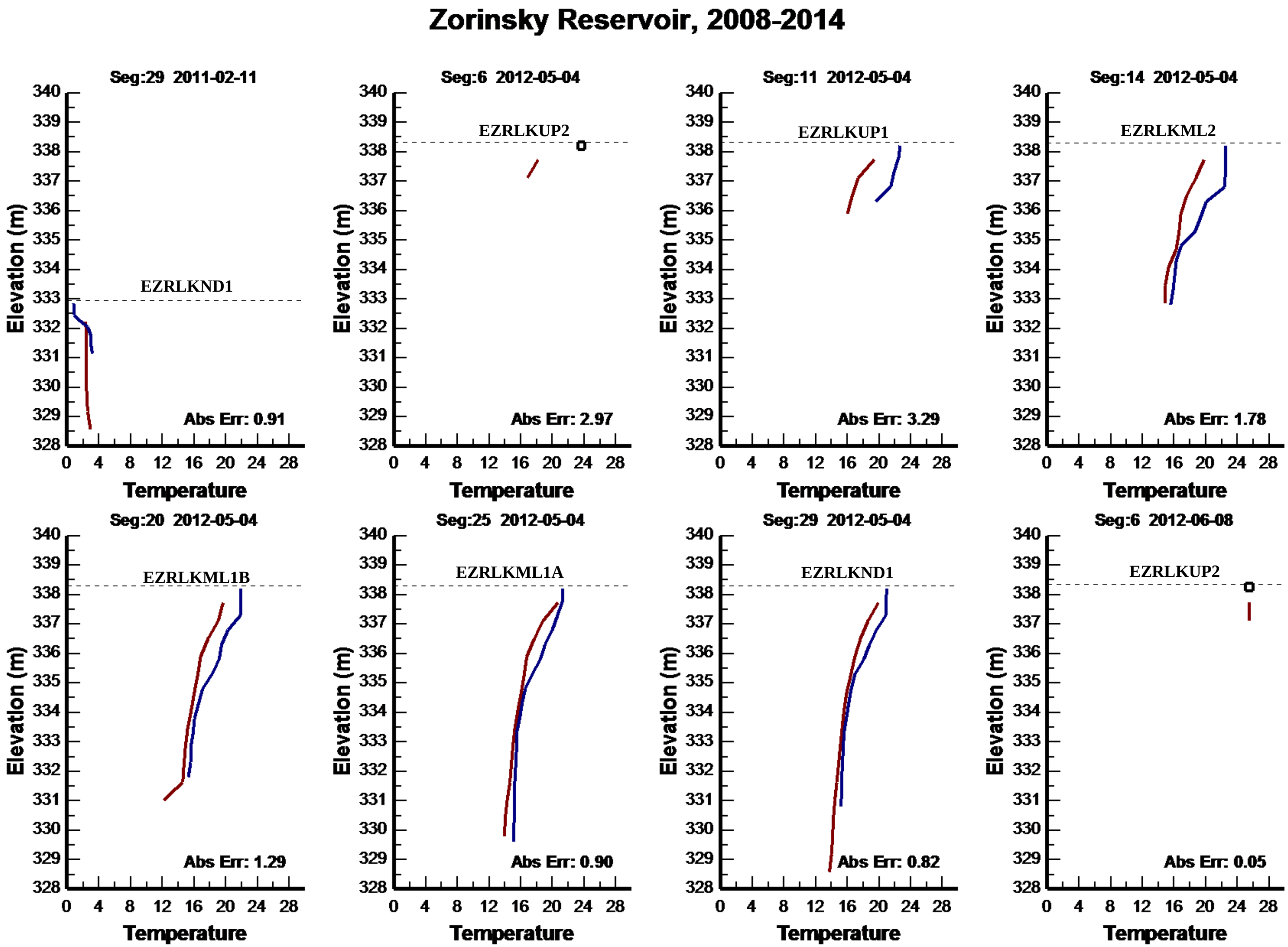


Plate 30. Observed (blue) versus model (red) temperature calibration profiles for February 2011 to June 2012.

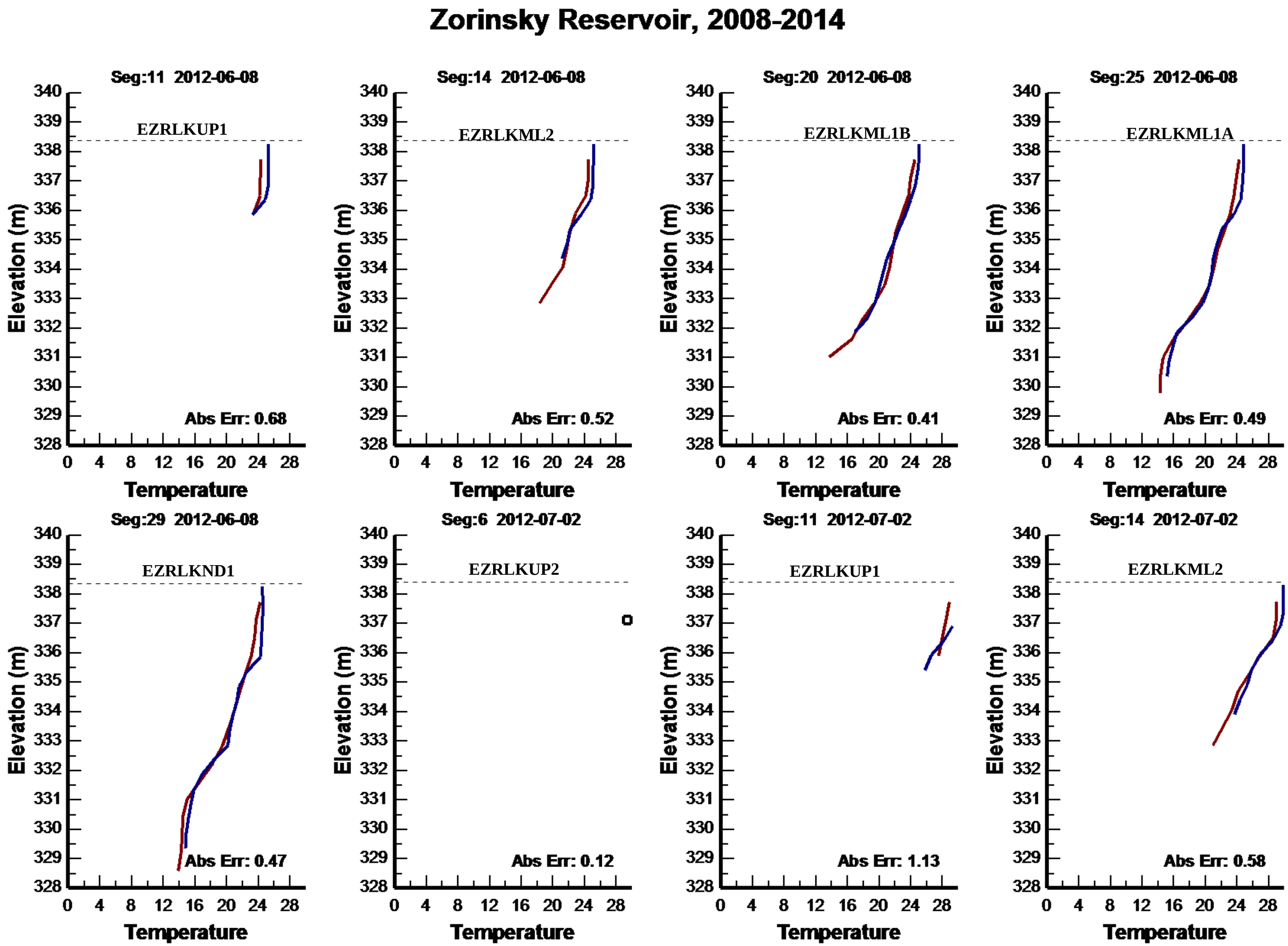


Plate 31. Observed (blue) versus model (red) temperature calibration profiles for June to July 2012.

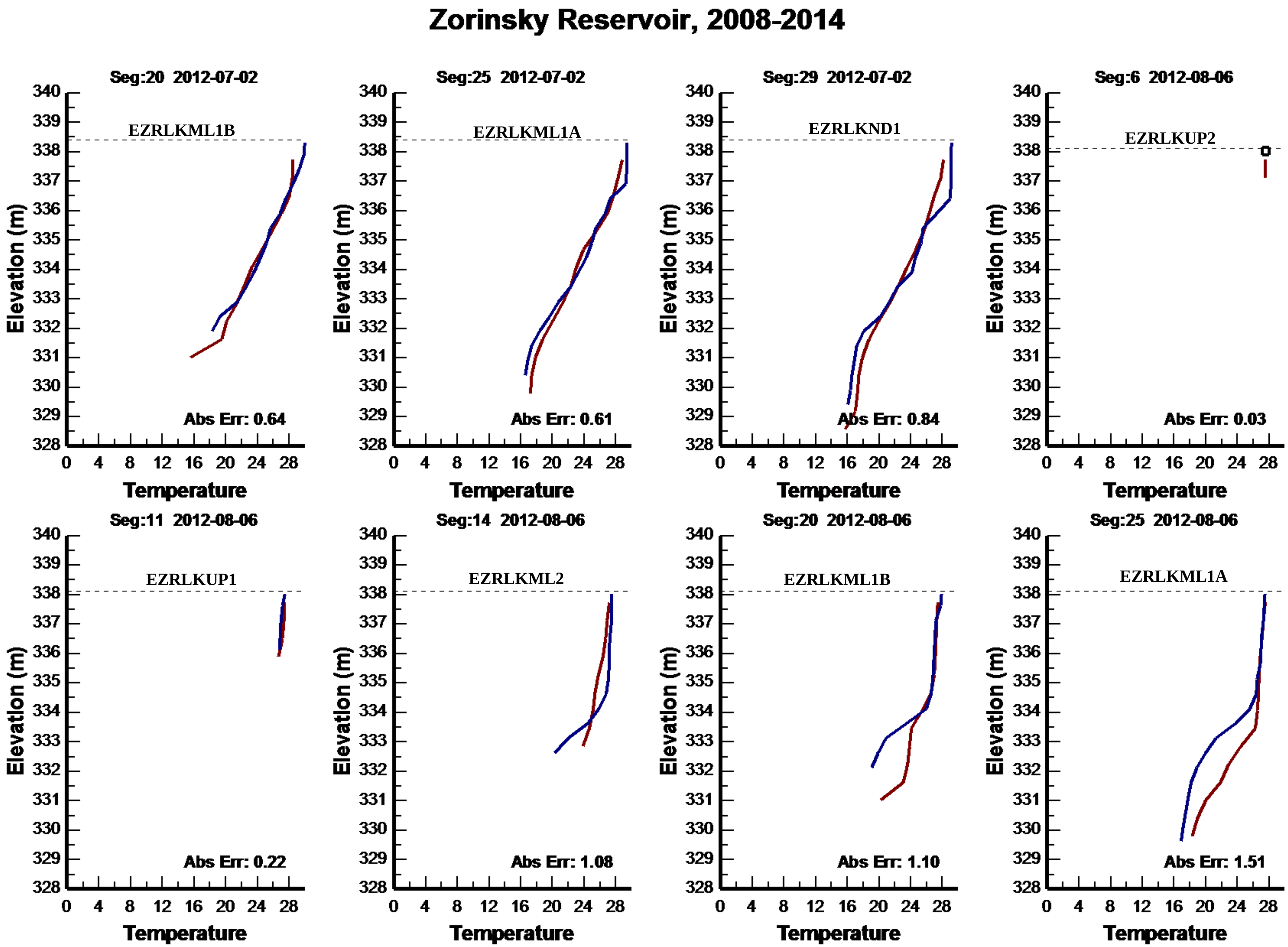


Plate 32. Observed (blue) versus model (red) temperature calibration profiles for July to August 2012.

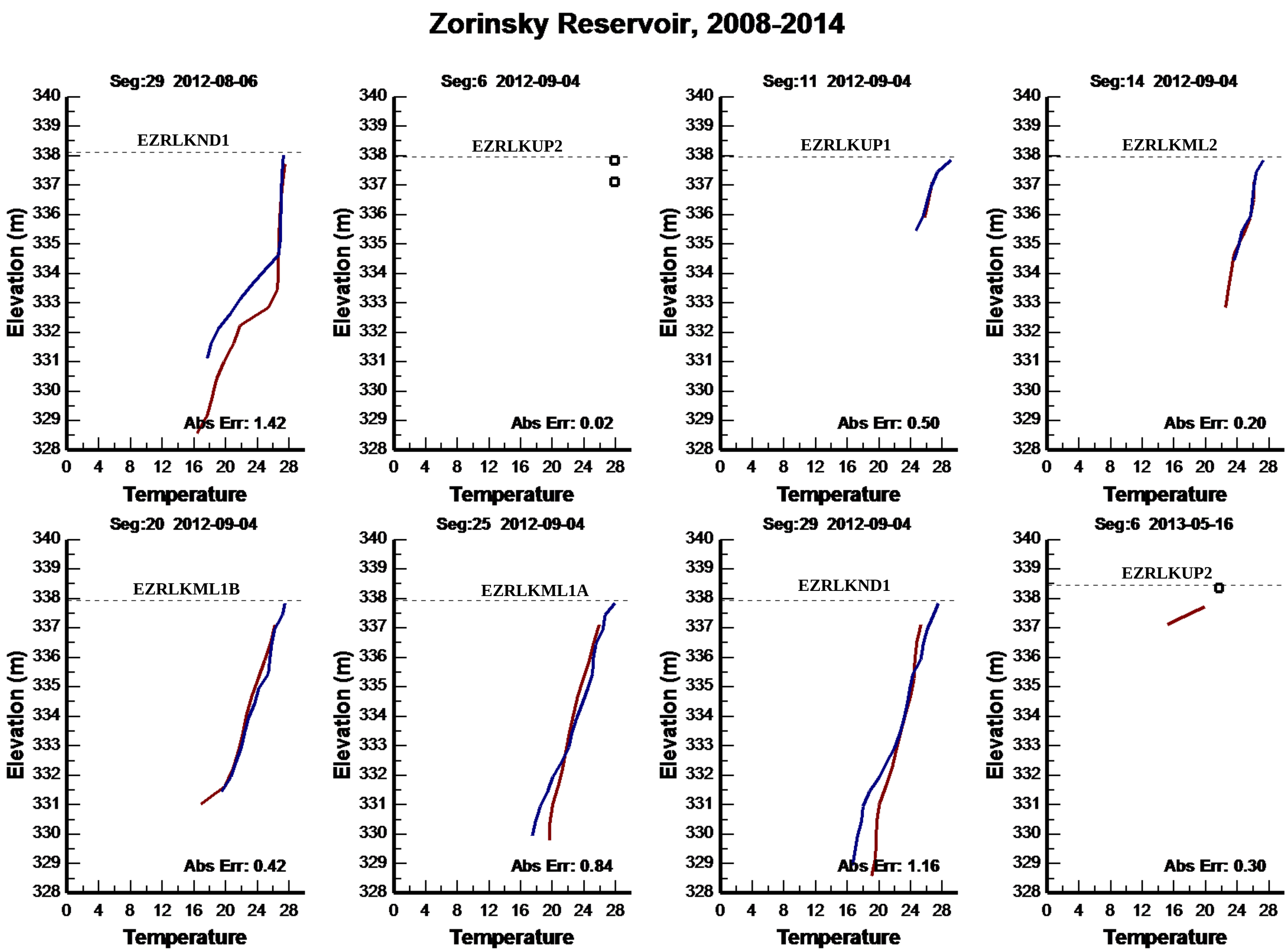


Plate 33. Observed (blue) versus model (red) temperature calibration profiles for August 2012 to June 2013.

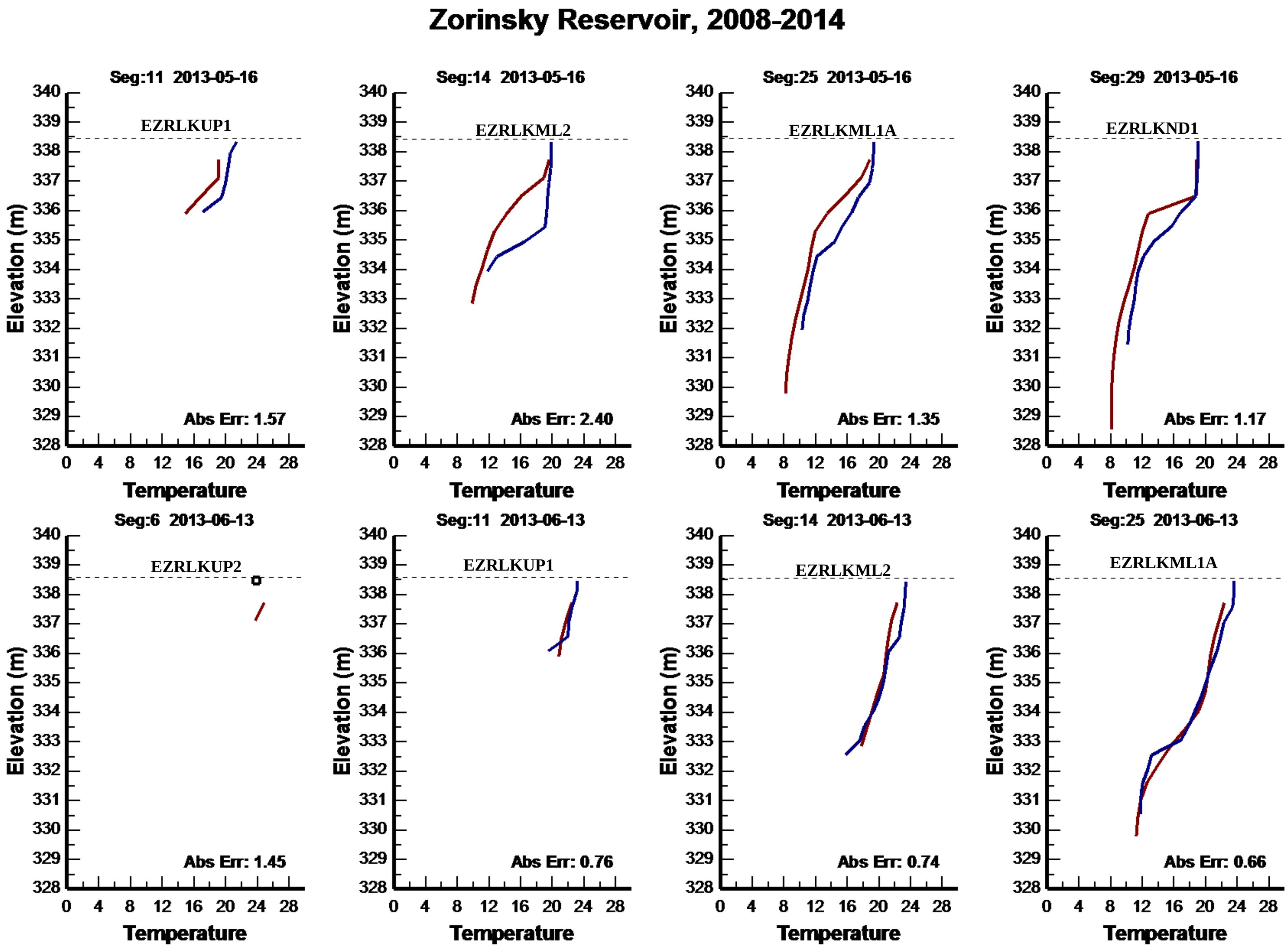


Plate 34. Observed (blue) versus model (red) temperature calibration profiles for May to June 2013.

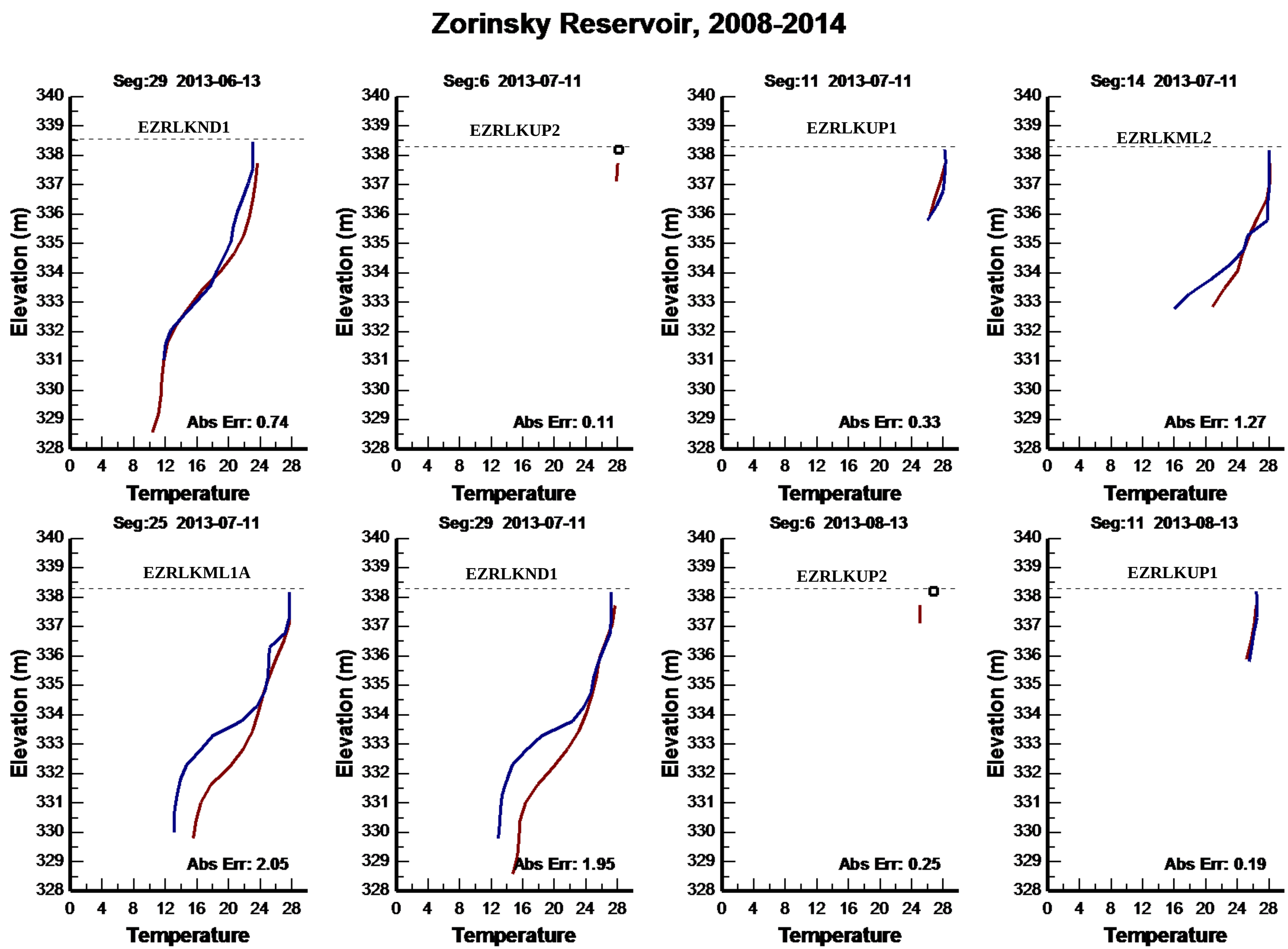


Plate 35. Observed (blue) versus model (red) temperature calibration profiles for June to August 2013.

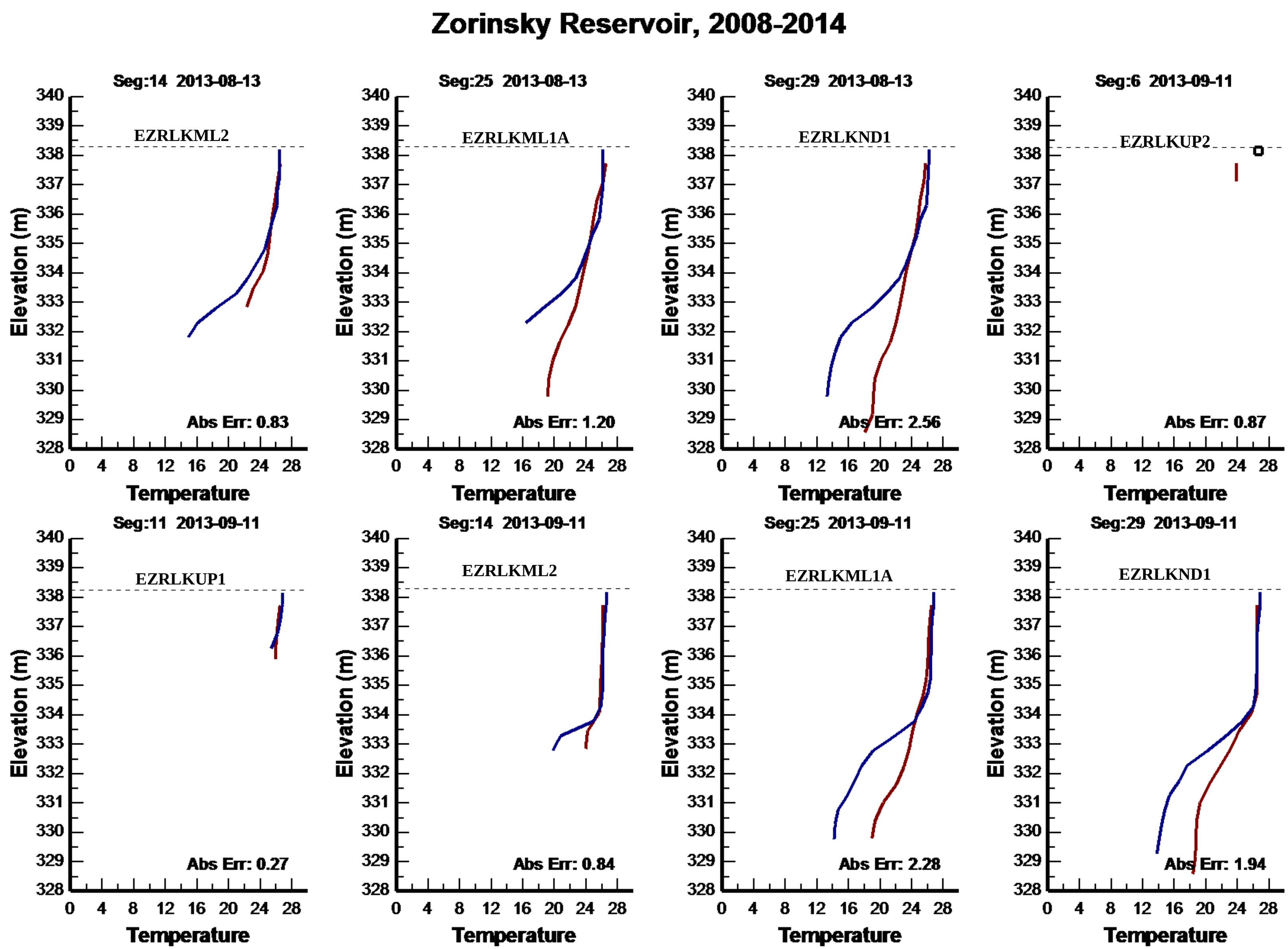


Plate 36. Observed (blue) versus model (red) temperature calibration profiles for August to September 2013.

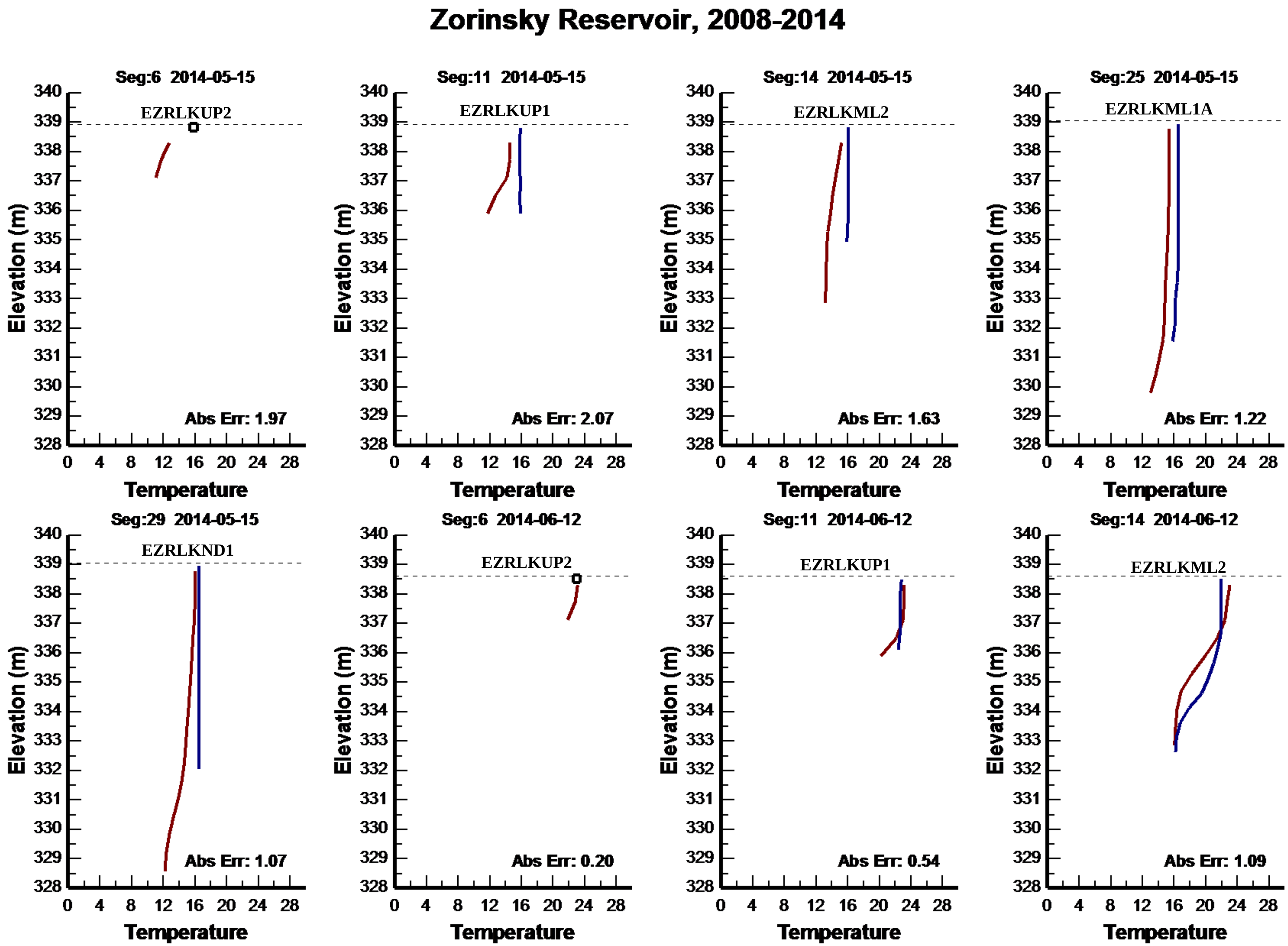


Plate 37. Observed (blue) versus model (red) temperature calibration profiles for May to June 2014.

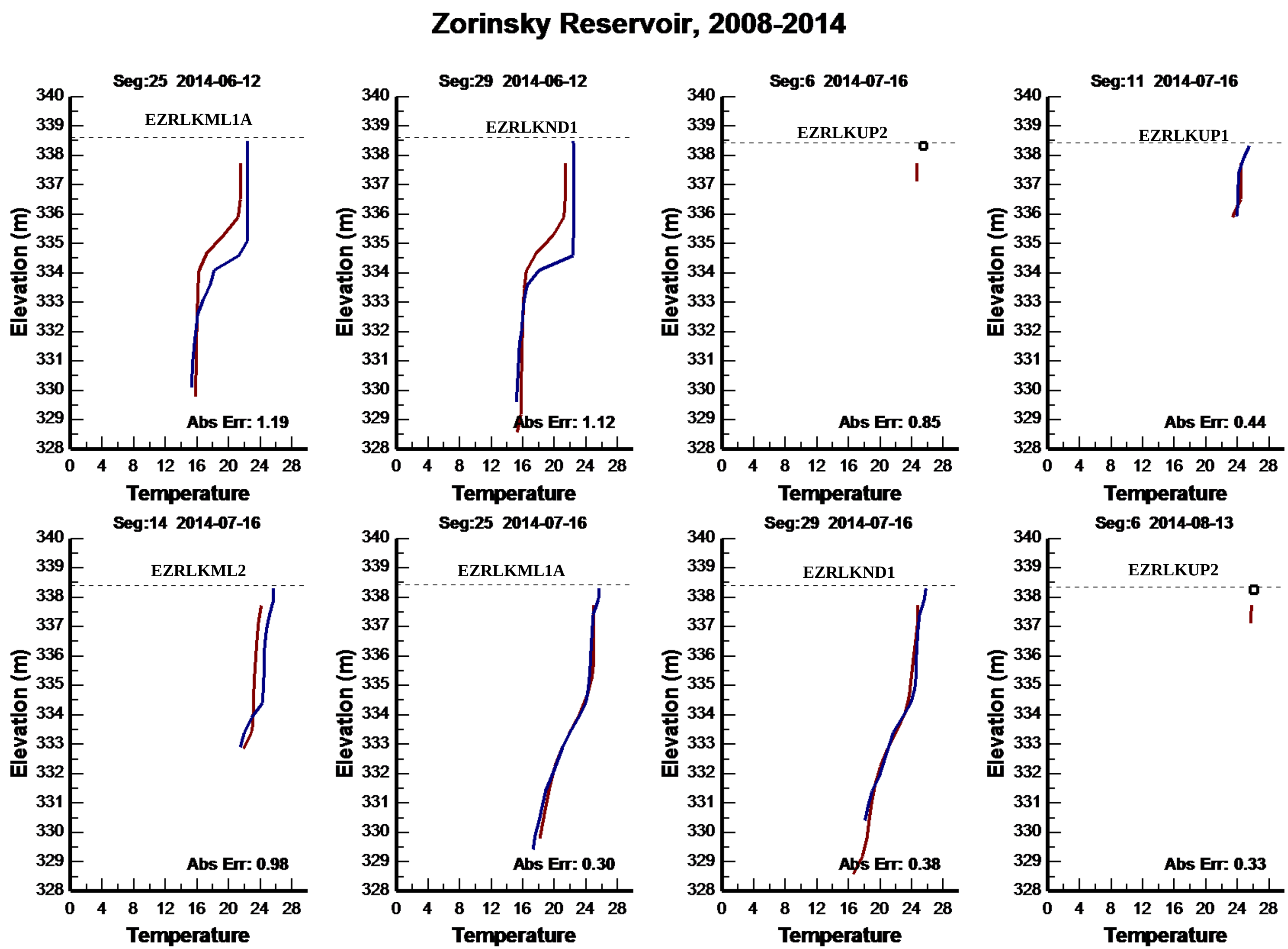


Plate 38. Observed (blue) versus model (red) temperature calibration profiles for June to August 2014.

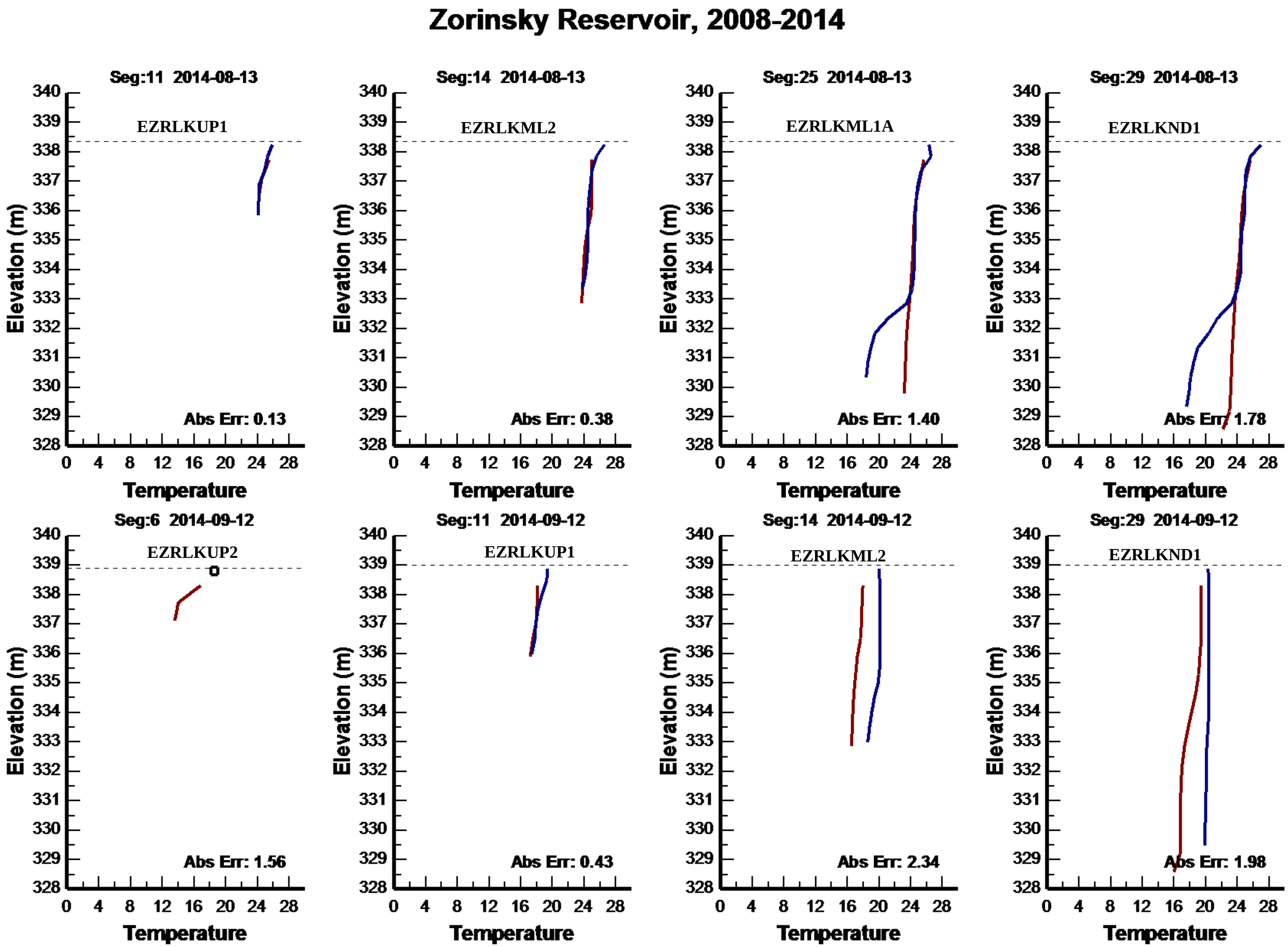


Plate 39. Observed (blue) versus model (red) temperature calibration profiles for August to September 2014.

Zorinsky Reservoir, 2008-2014

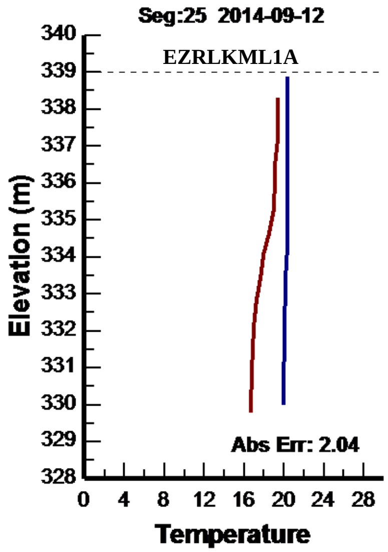


Plate 40. Observed (blue) versus model (red) temperature calibration profiles for September 2014.

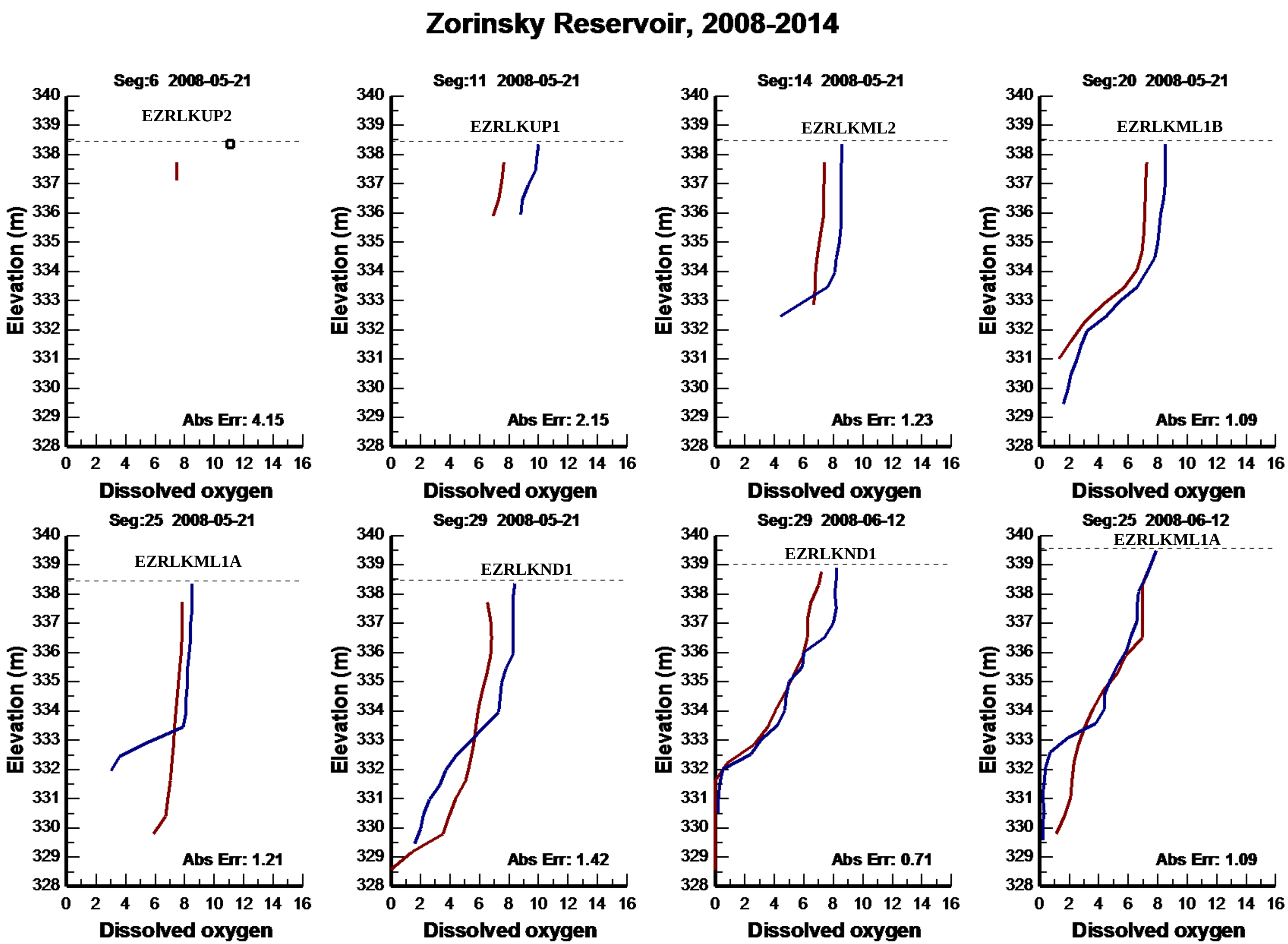


Plate 41. Observed (blue) versus model (red) DO calibration profiles for May to June 2008.

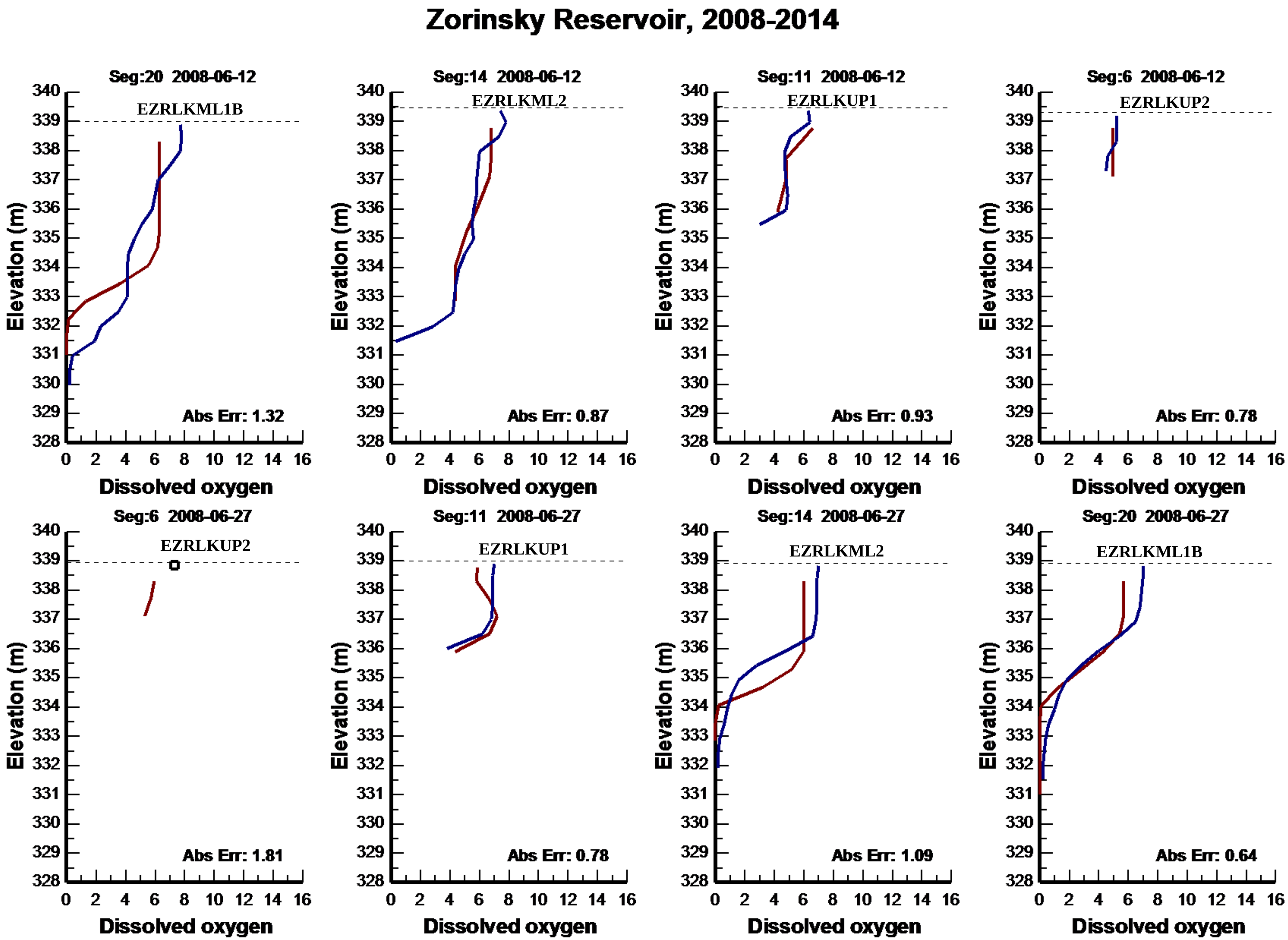


Plate 42. Observed (blue) versus model (red) DO calibration profiles for May to June 2008.

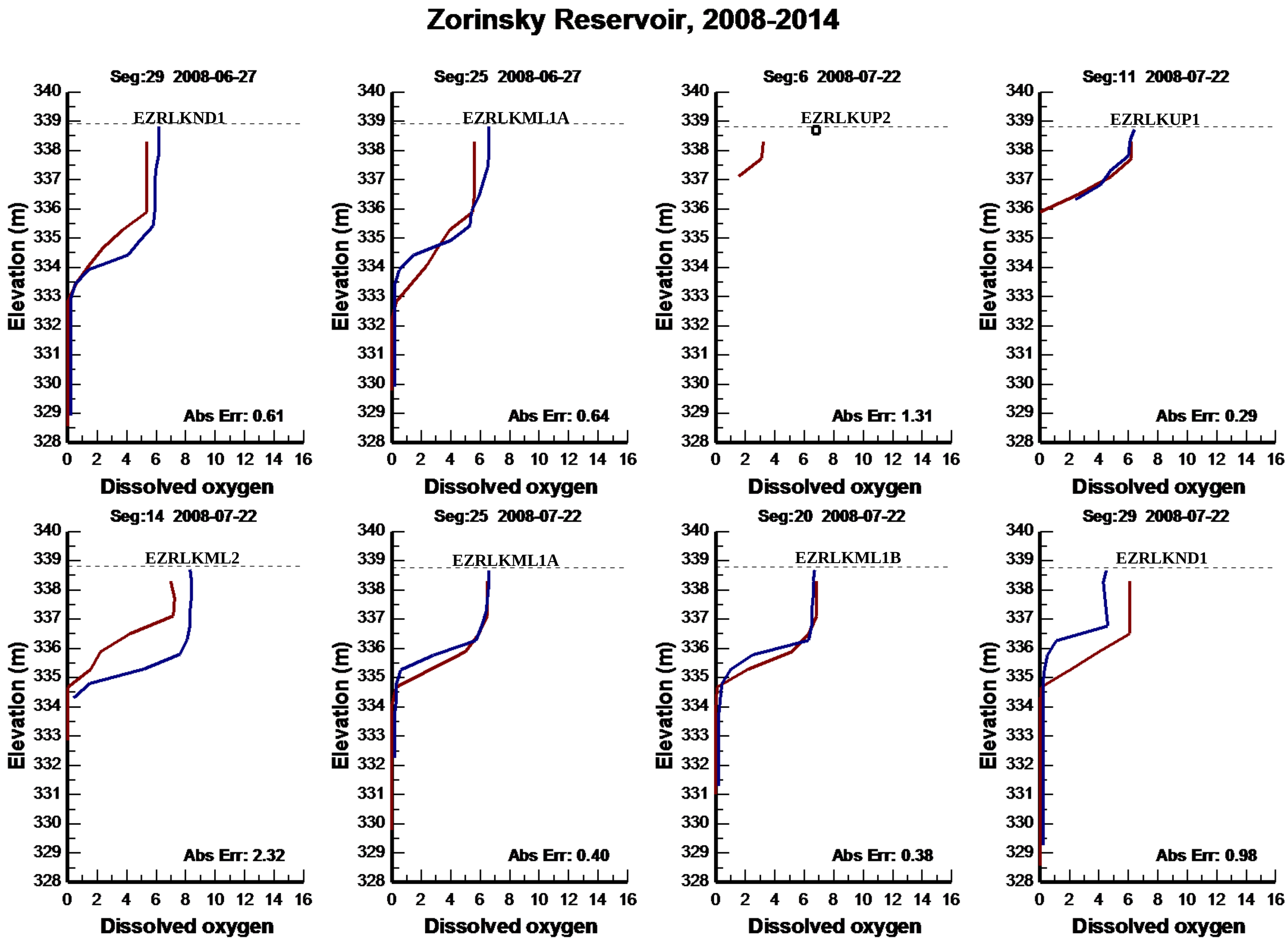


Plate 43. Observed (blue) versus model (red) DO calibration profiles for June to July 2008.

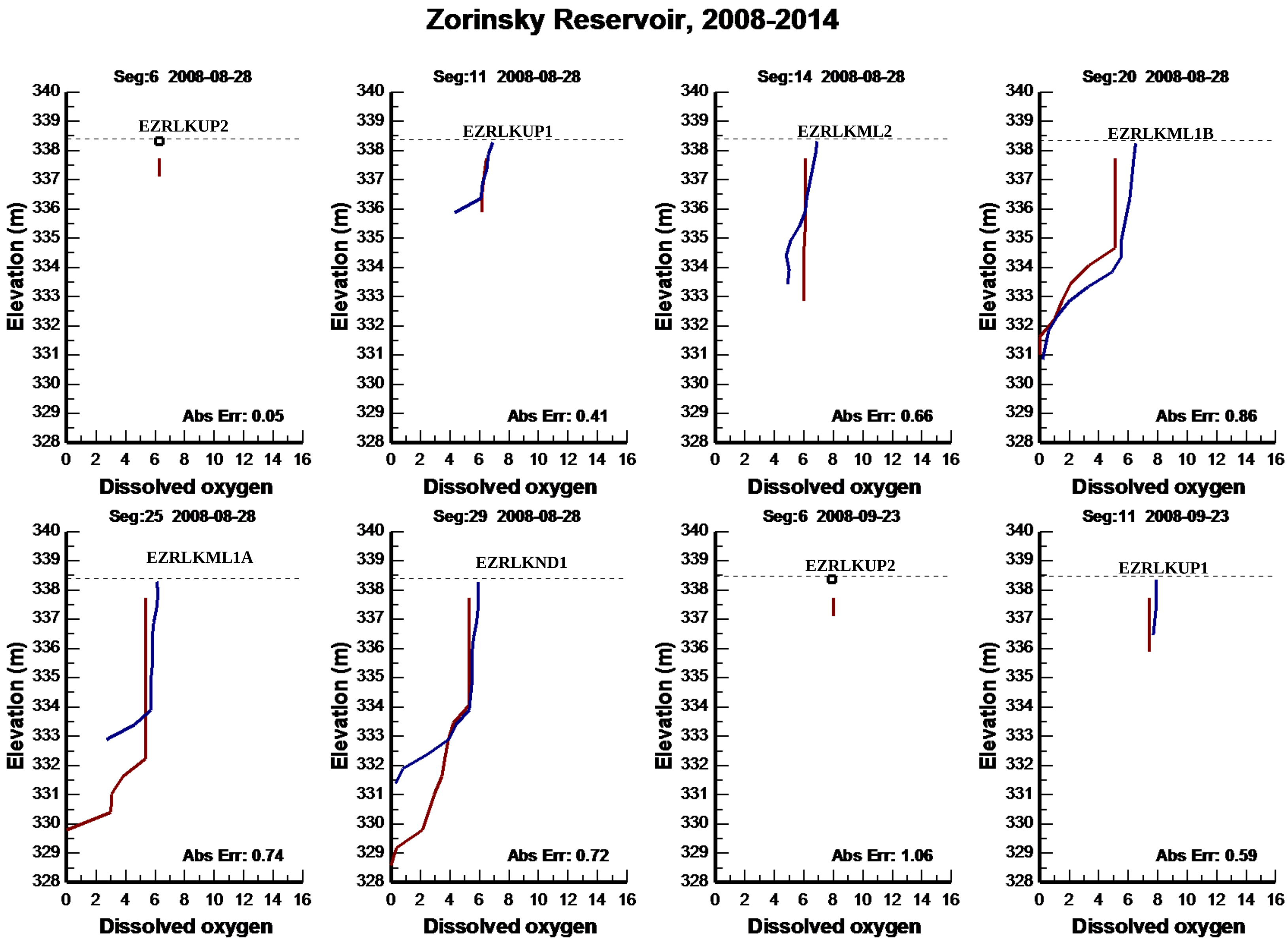


Plate 44. Observed (blue) versus model (red) DO calibration profiles for August to September 2008.

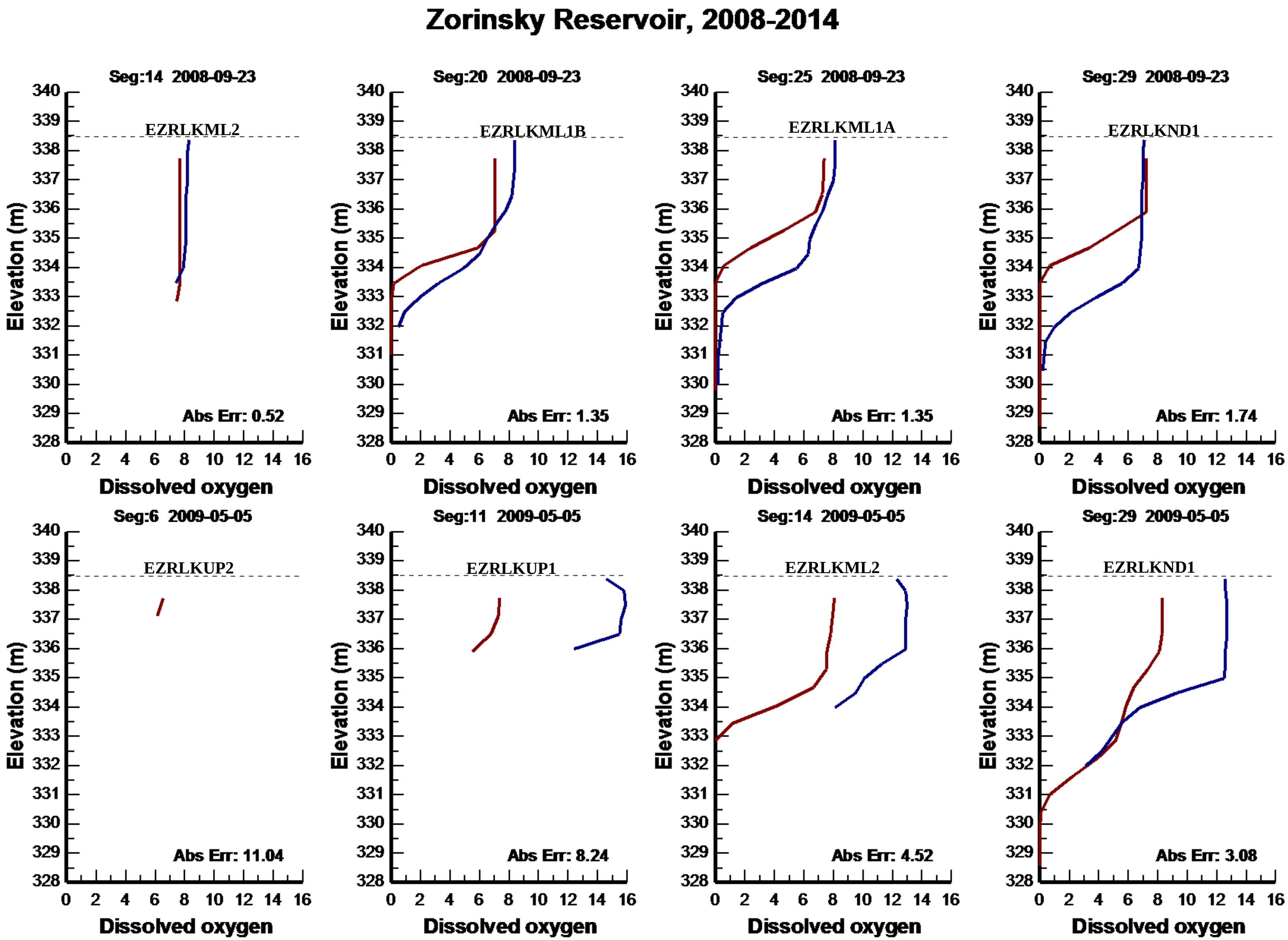


Plate 45. Observed (blue) versus model (red) DO calibration profiles for September 2008 to May 2009.

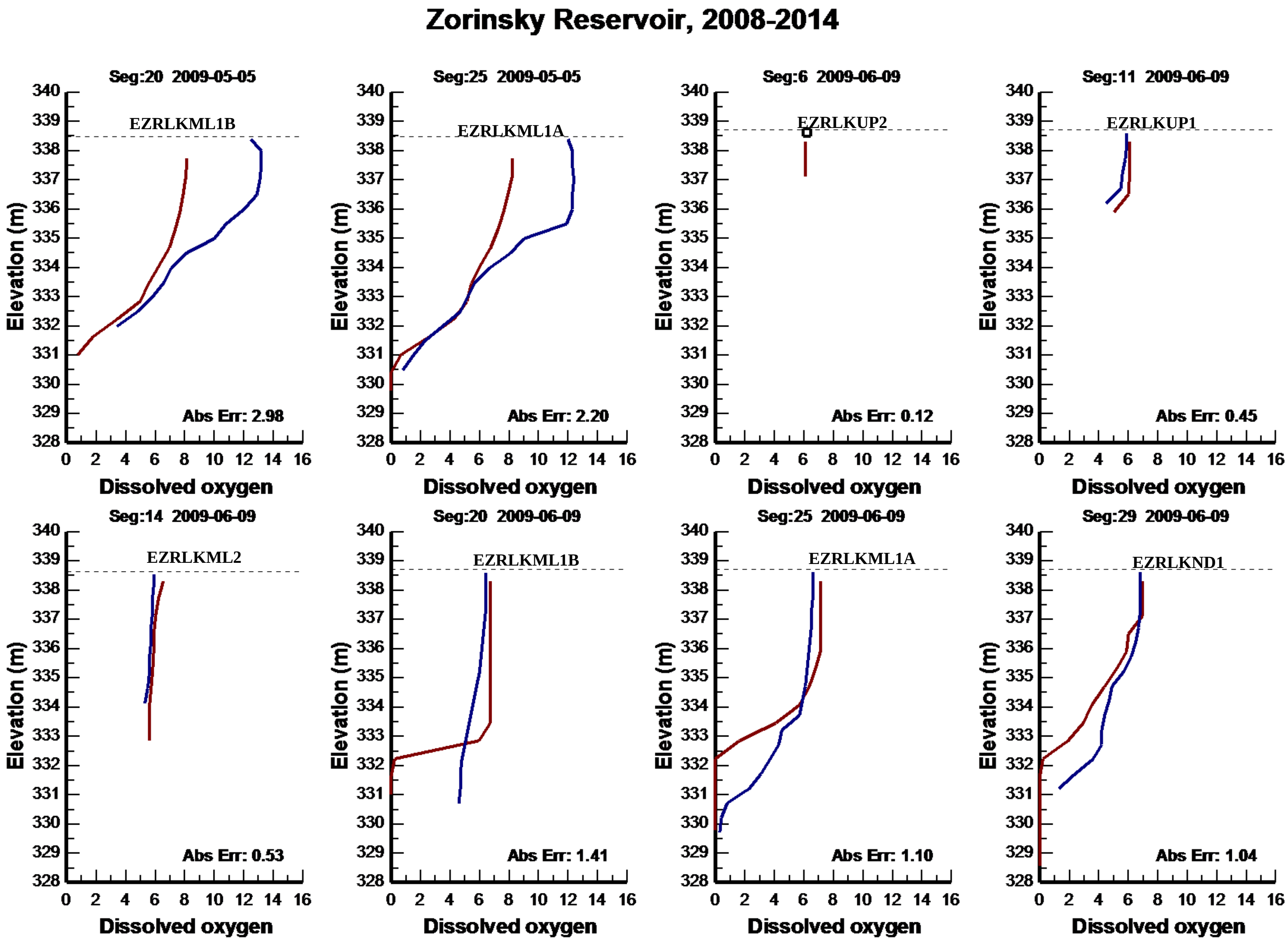


Plate 46. Observed (blue) versus model (red) DO calibration profiles for May to June 2009.

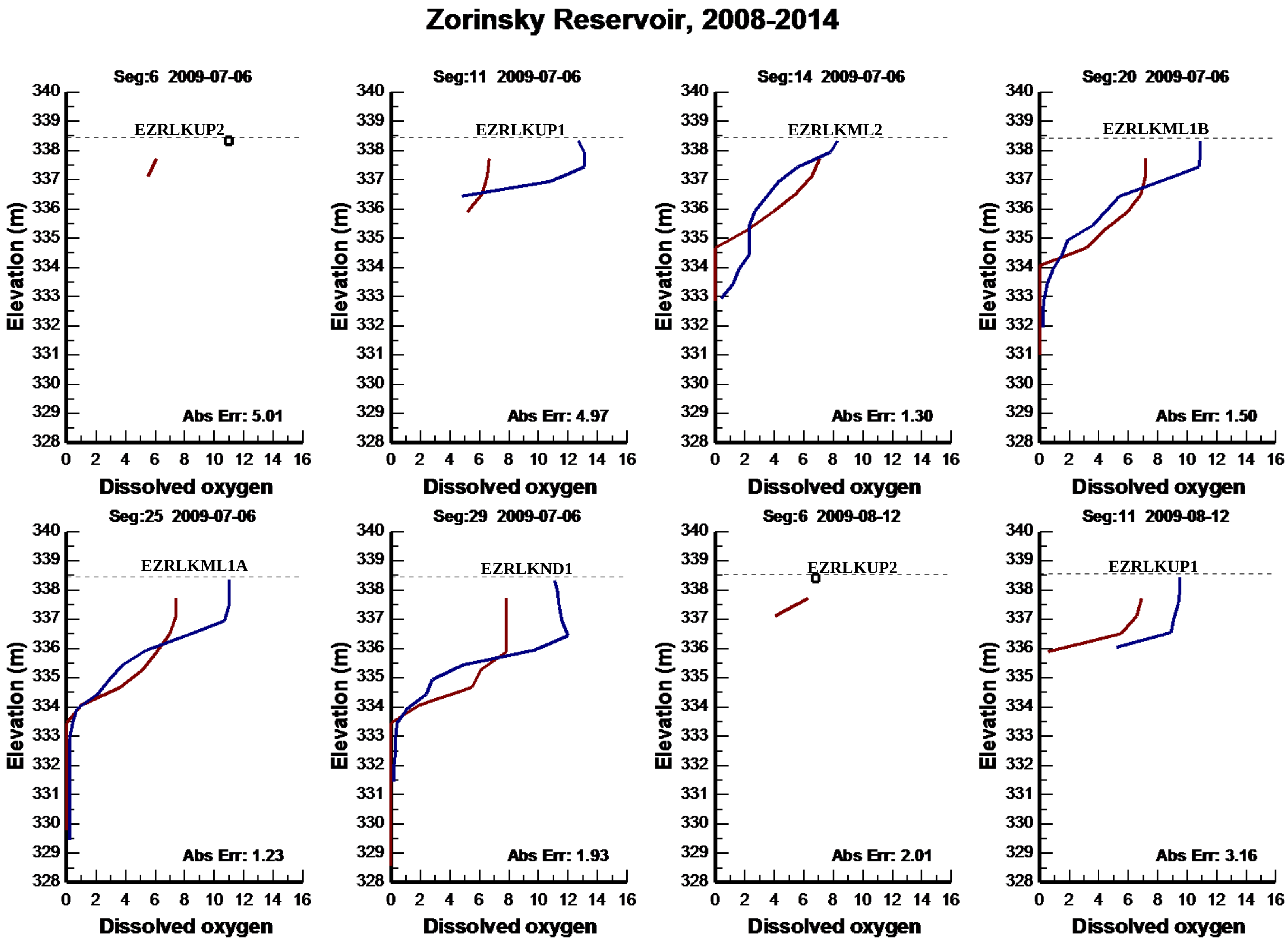


Plate 47. Observed (blue) versus model (red) DO calibration profiles for July to August 2009.

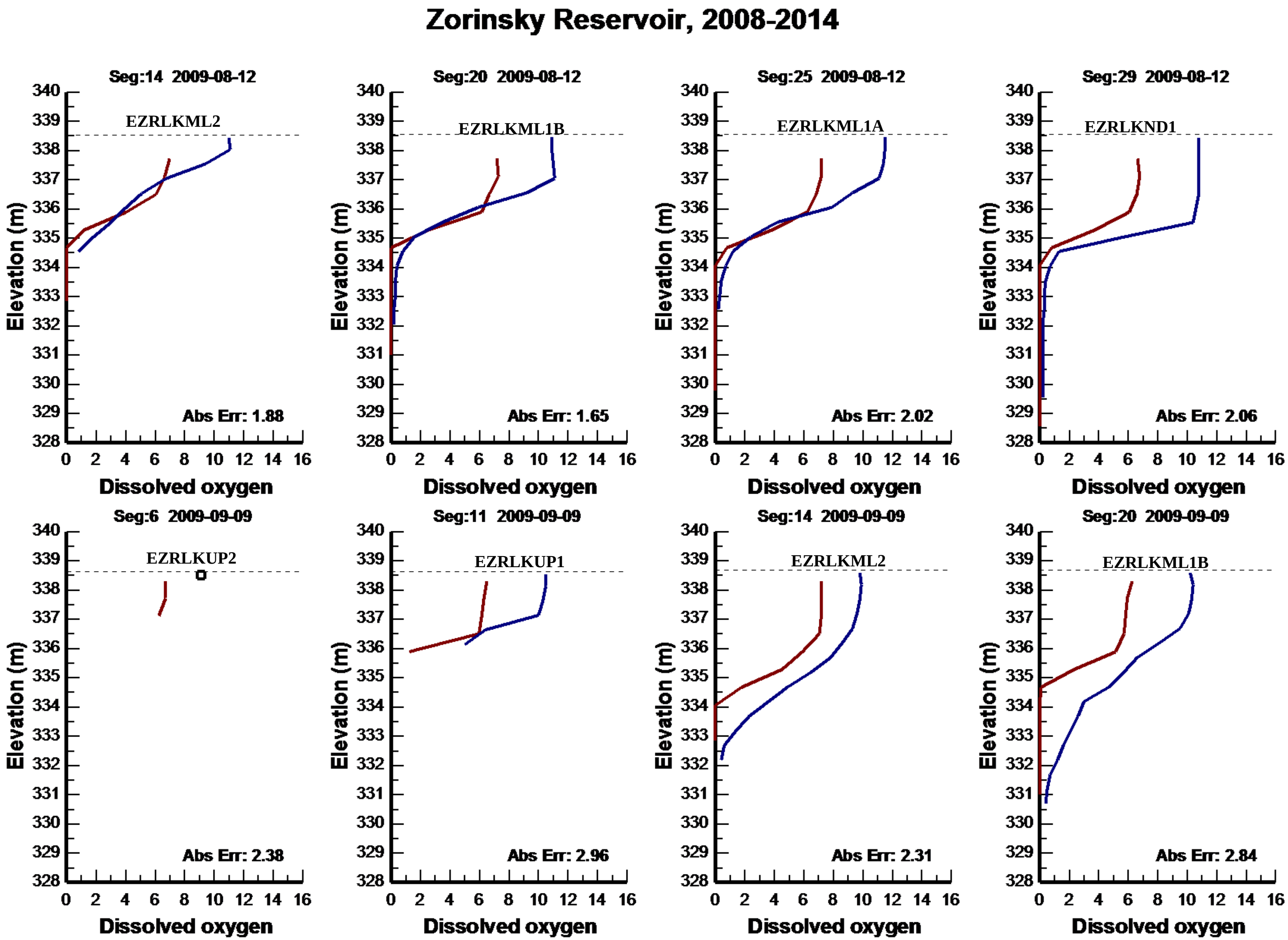


Plate 48. Observed (blue) versus model (red) DO calibration profiles for August to September 2009.

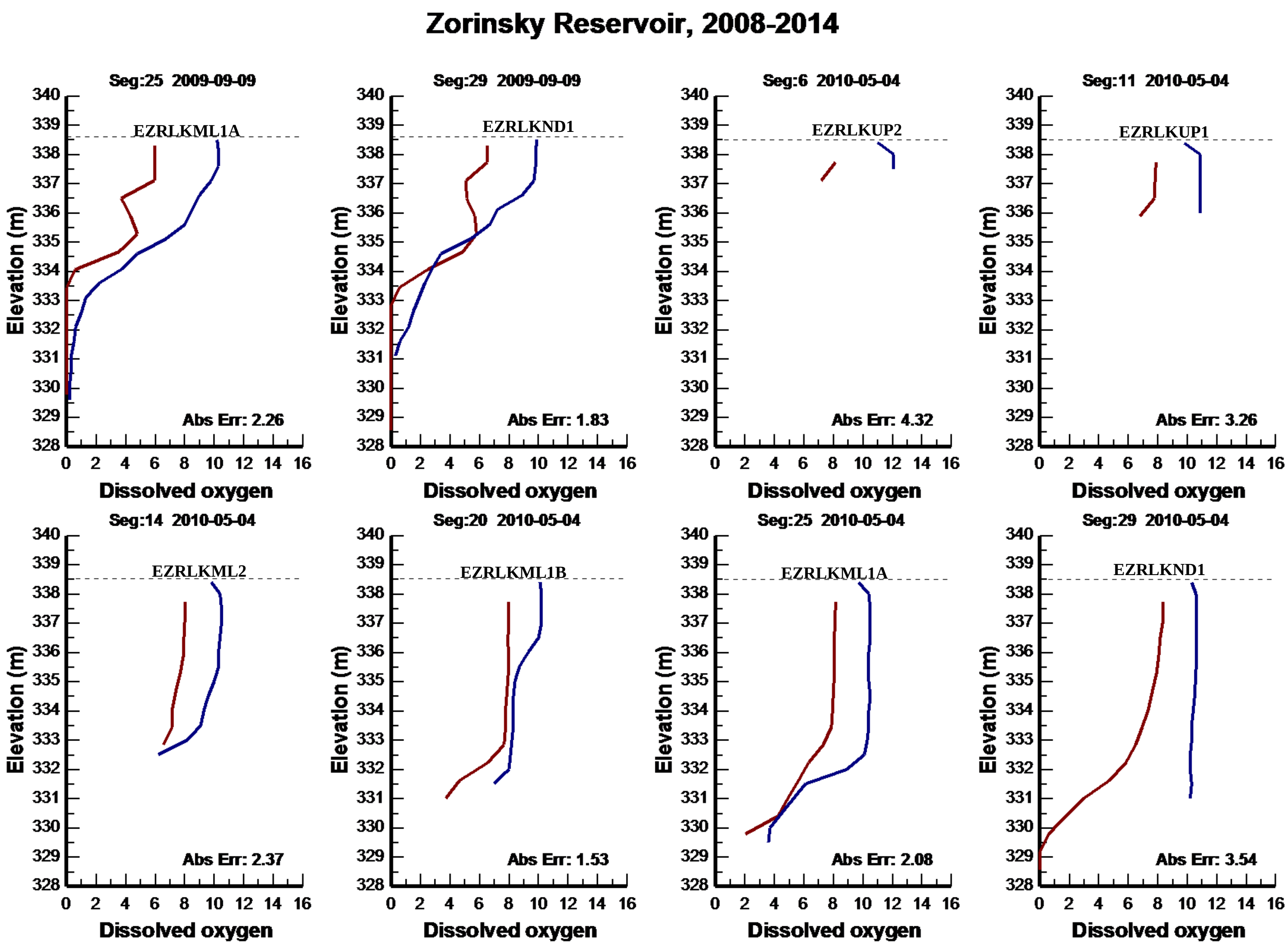


Plate 49. Observed (blue) versus model (red) DO calibration profiles for September 2009 to May 2010

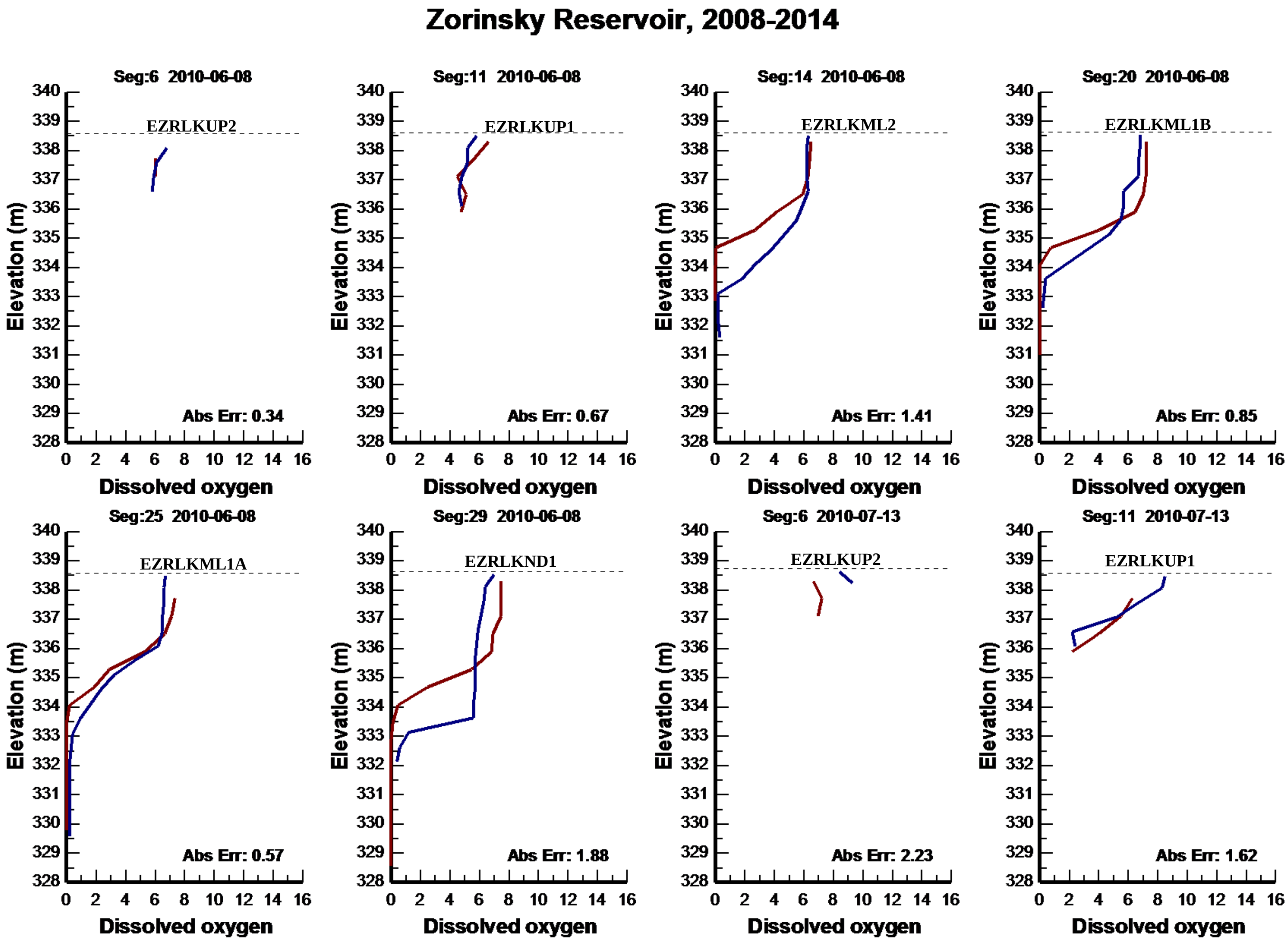


Plate 50. Observed (blue) versus model (red) DO calibration profiles for June to July 2010

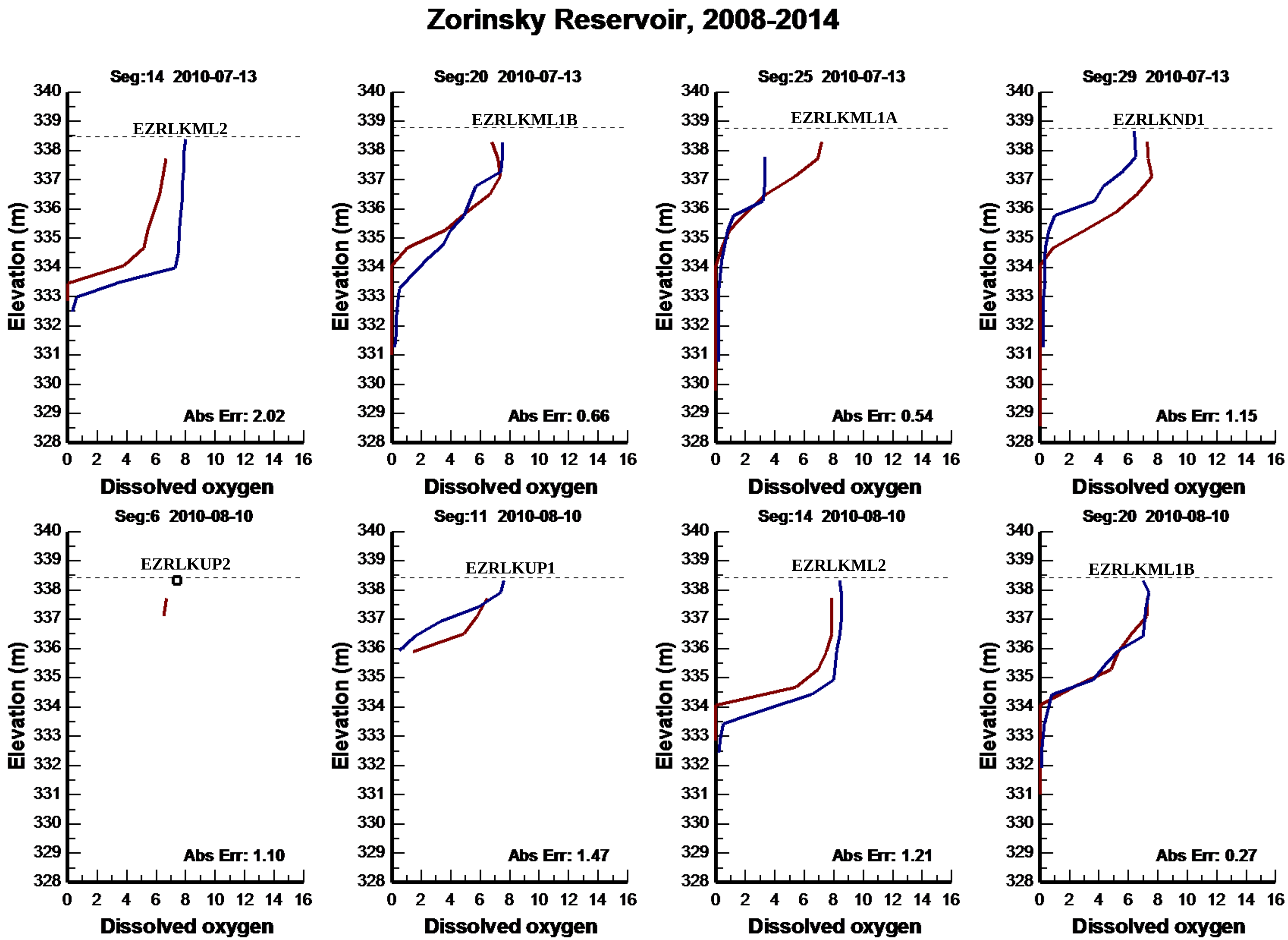


Plate 51. Observed (blue) versus model (red) DO calibration profiles for July to August 2010.

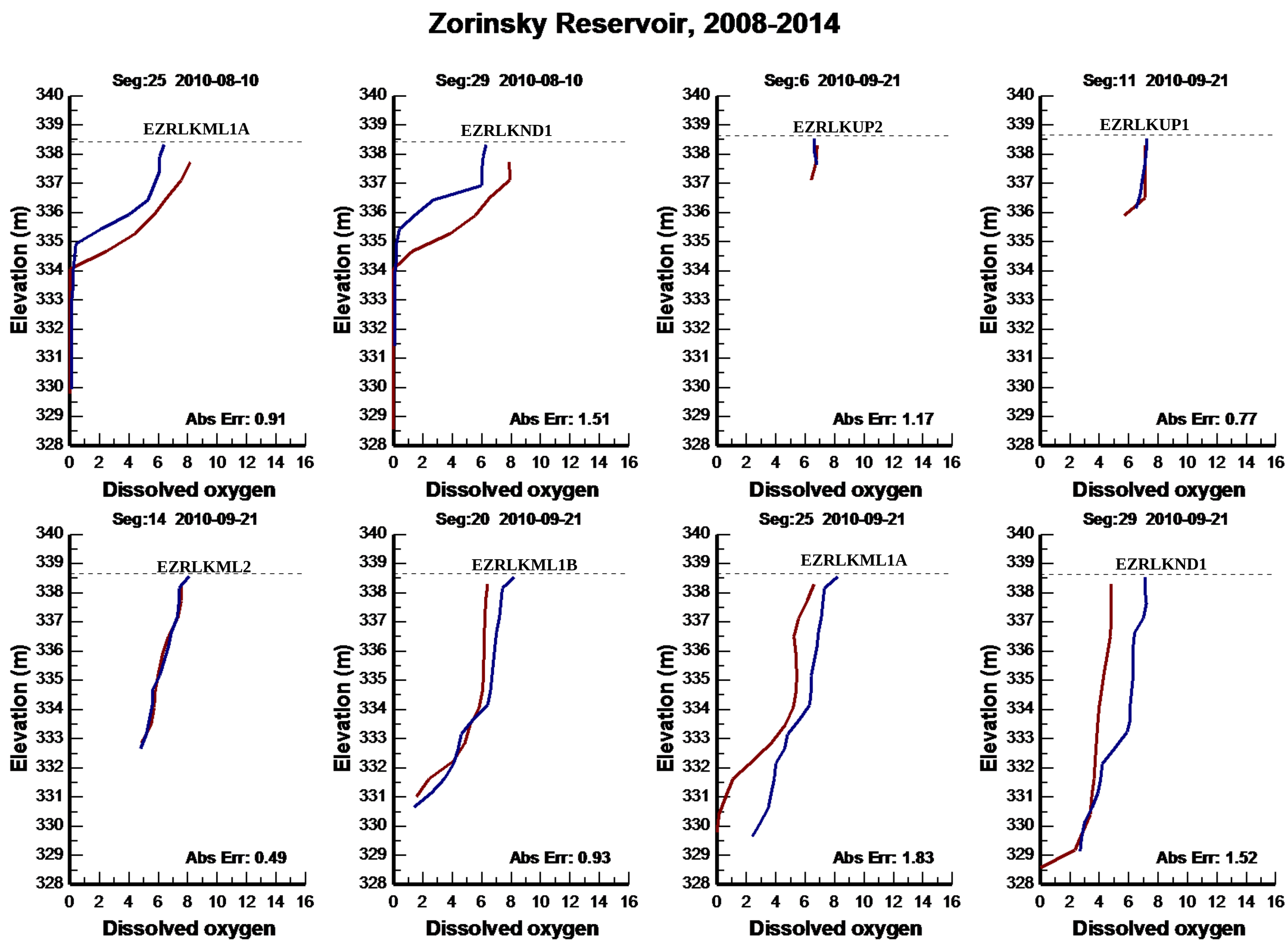


Plate 52. Observed (blue) versus model (red) DO calibration profiles for August to September 2010.

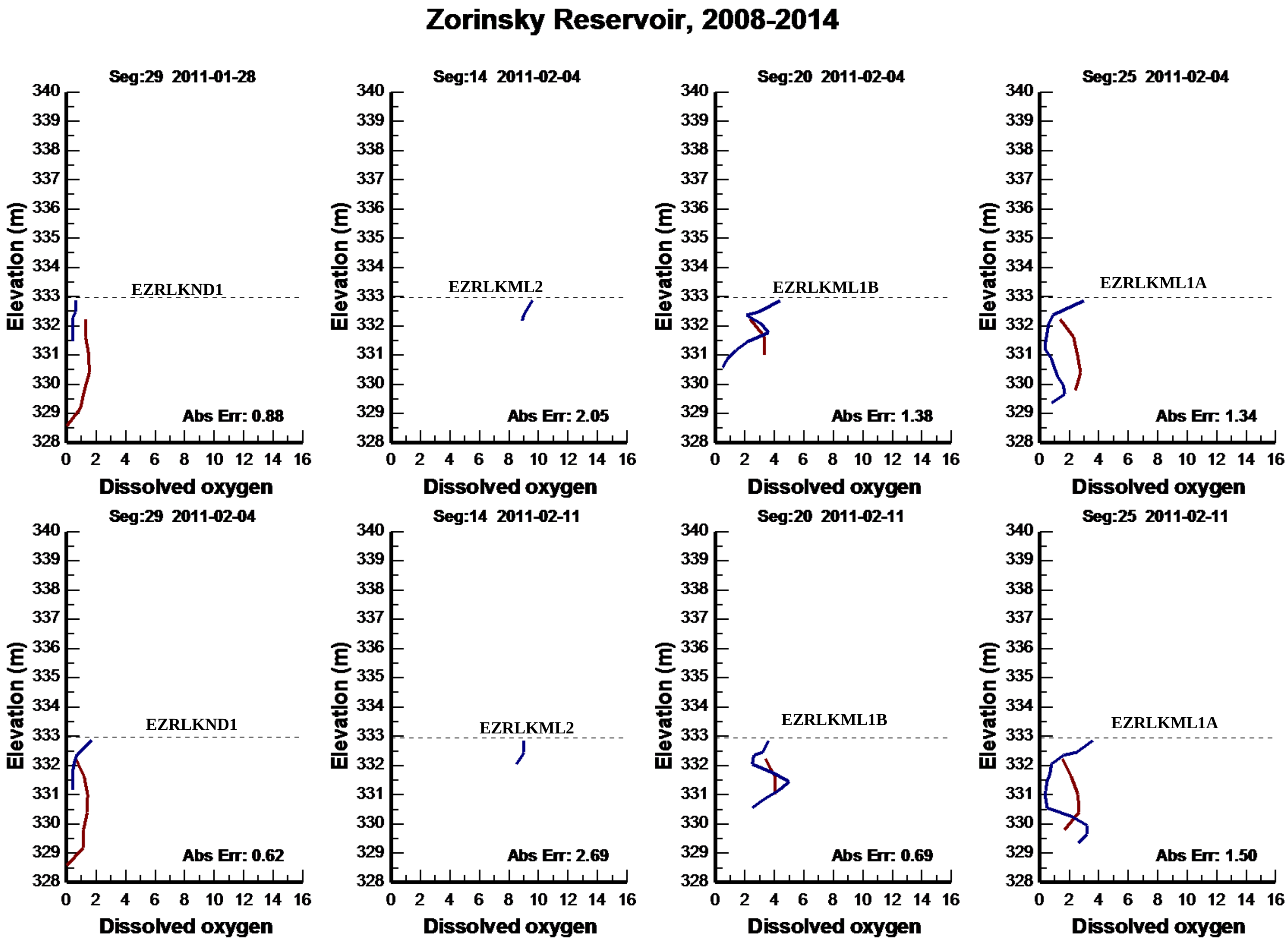


Plate 53. Observed (blue) versus model (red) DO calibration profiles for January to February 2011.

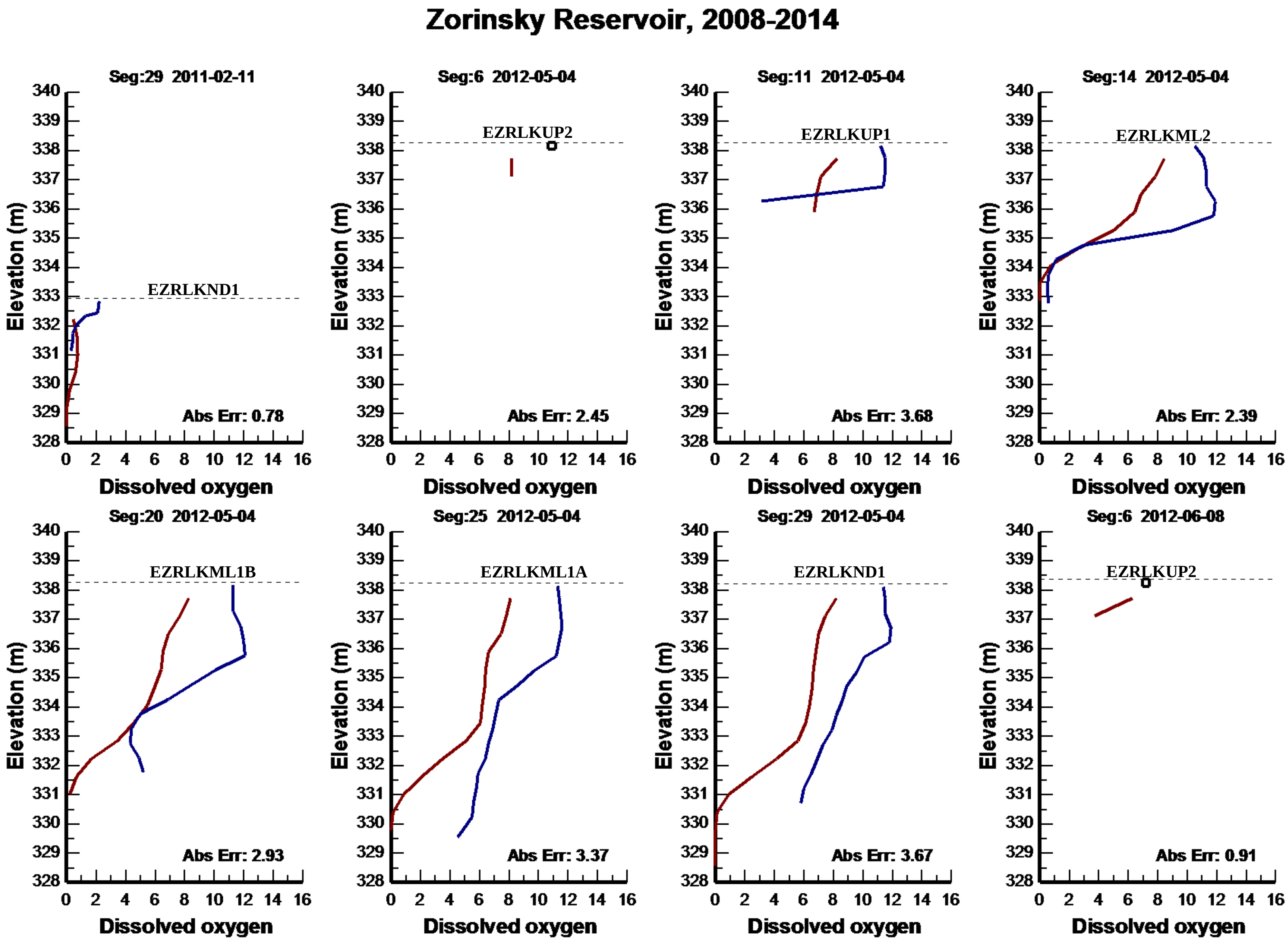


Plate 54. Observed (blue) versus model (red) DO calibration profiles for February 2011 to June 2012.

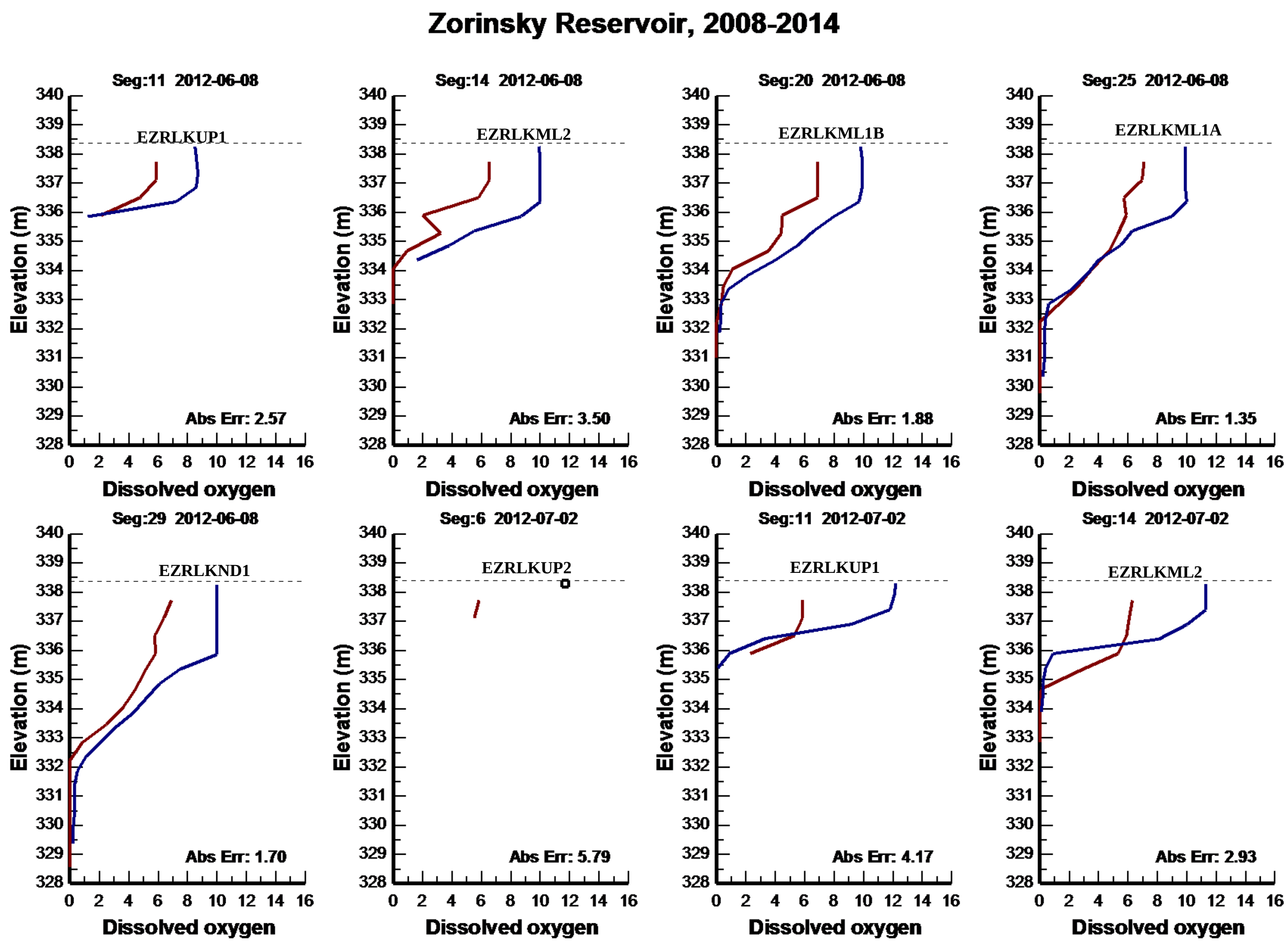


Plate 55. Observed (blue) versus model (red) DO calibration profiles for June to July 2012.

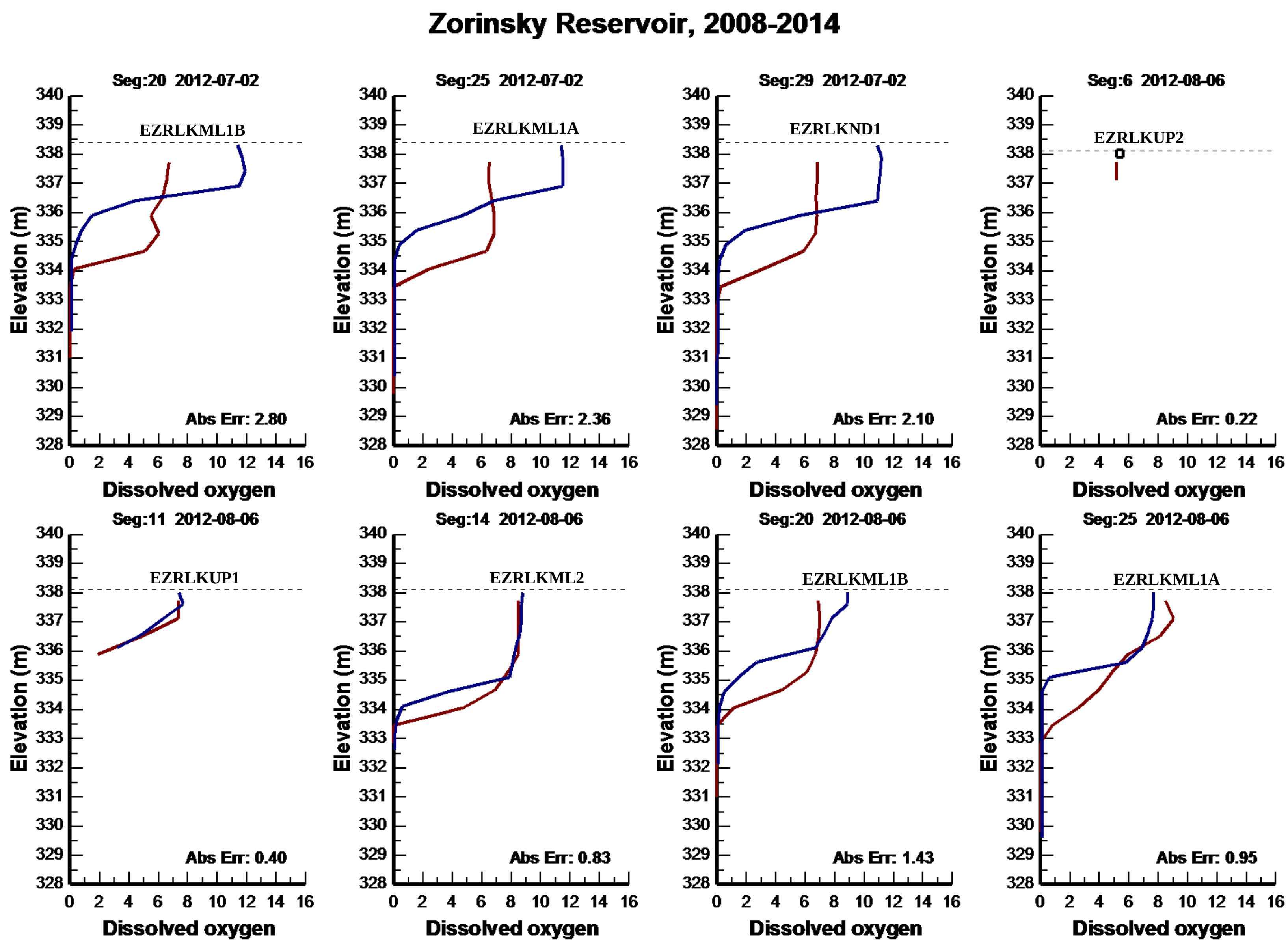


Plate 56. Observed (blue) versus model (red) DO calibration profiles for July to August 2012.

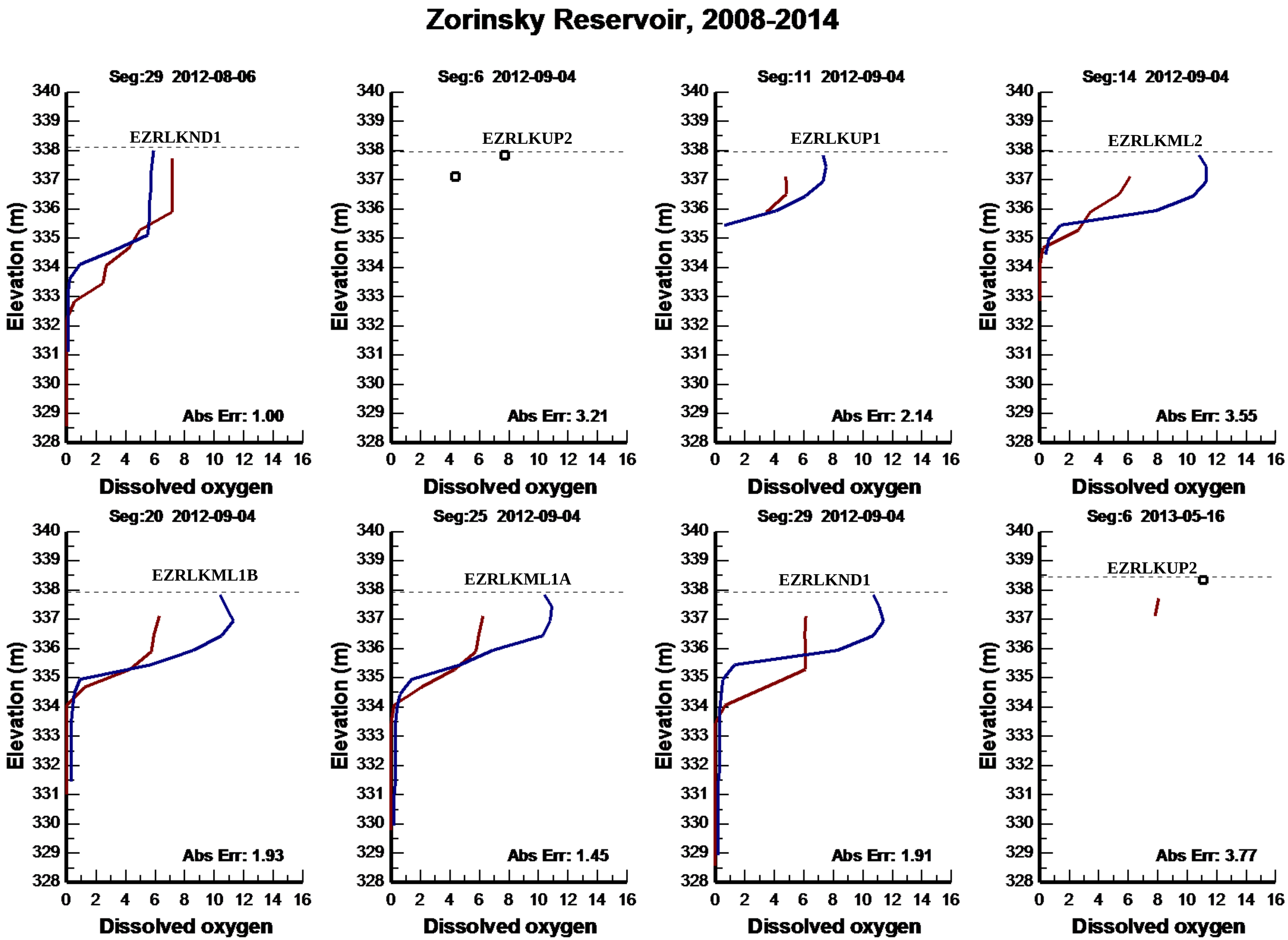


Plate 57. Observed (blue) versus model (red) DO calibration profiles for August 2012 to May 2013.

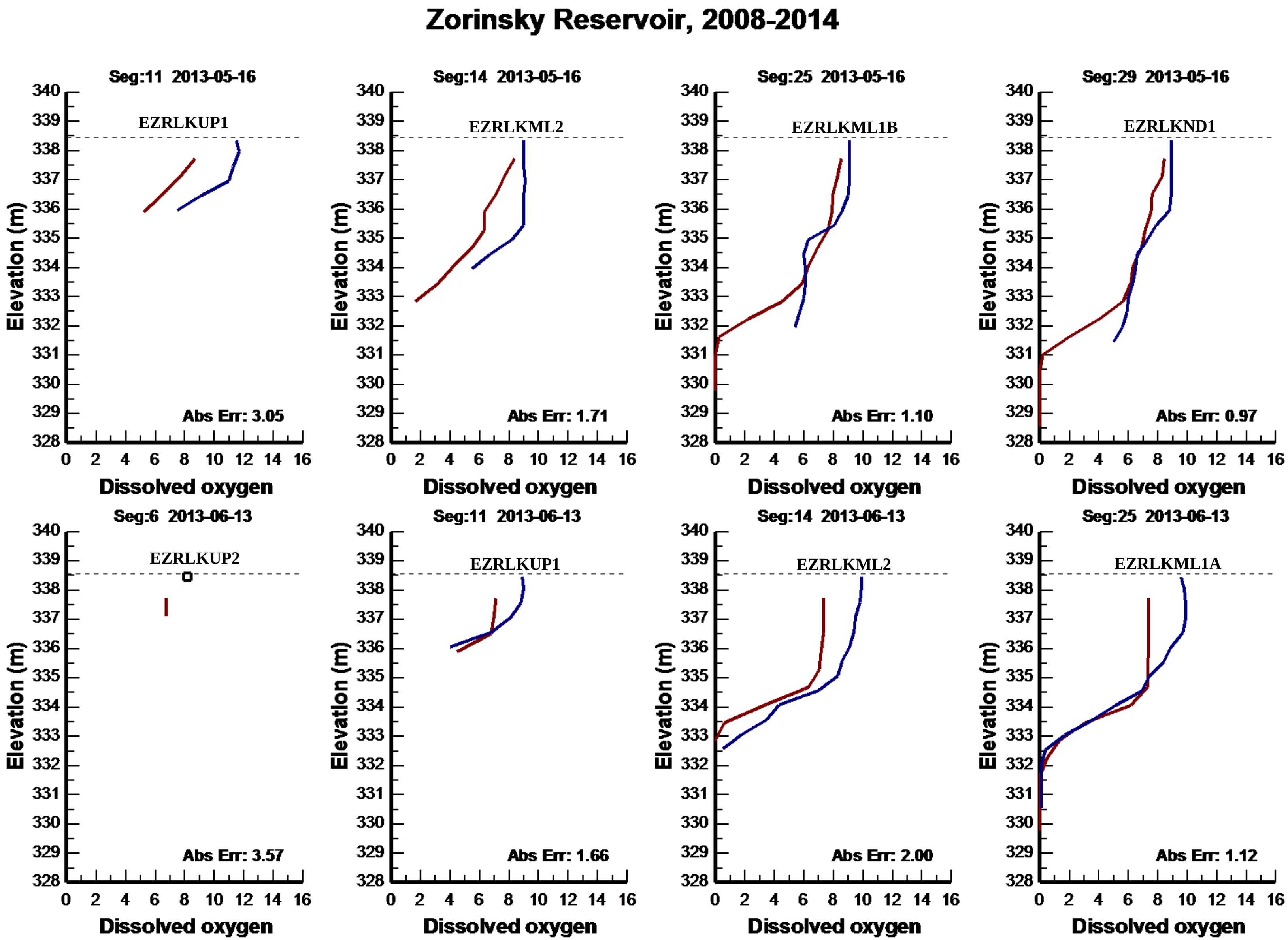


Plate 58. Observed (blue) versus model (red) DO calibration profiles for May to June 2013.

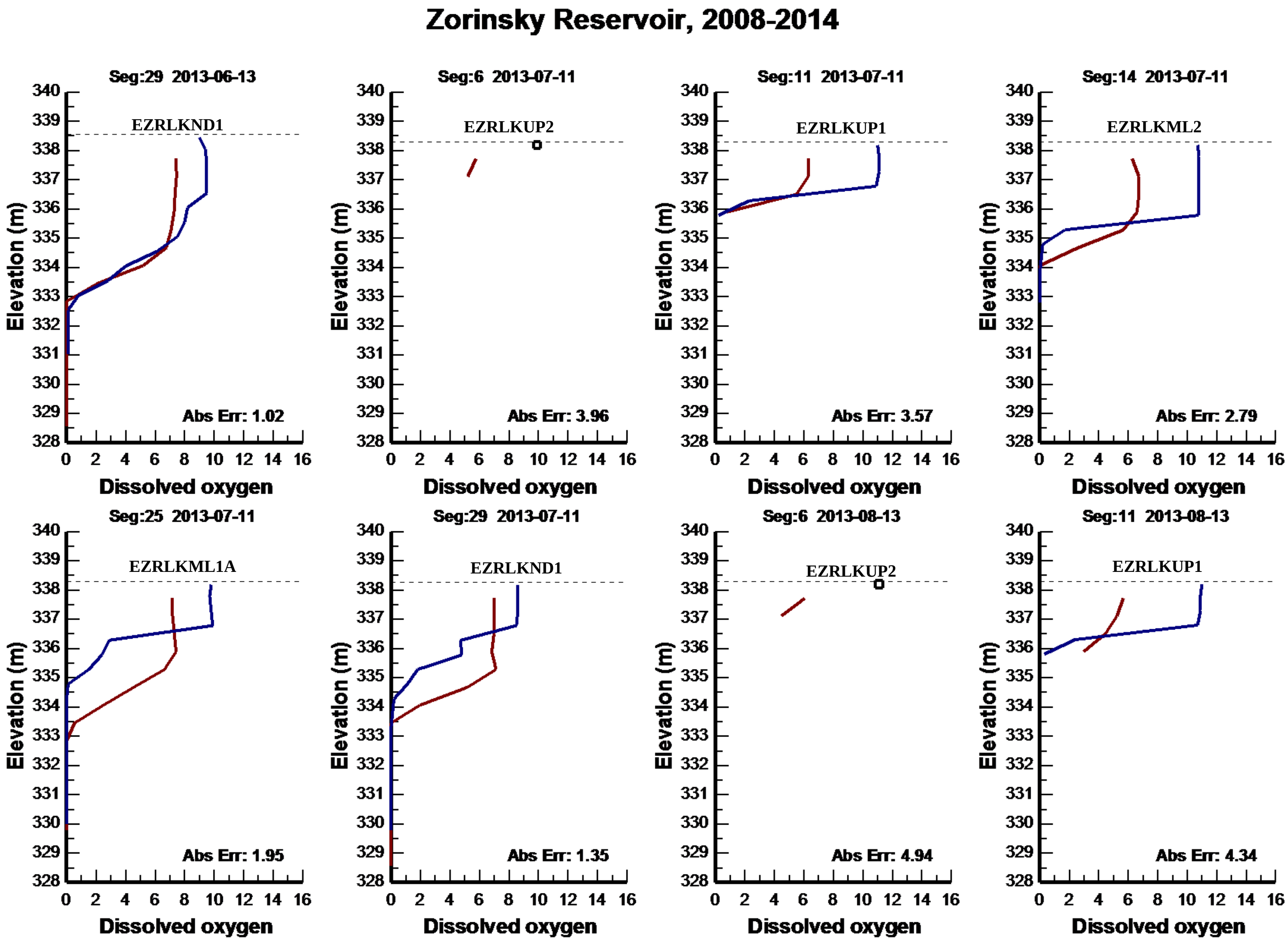


Plate 59. Observed (blue) versus model (red) DO calibration profiles for June to August 2013.

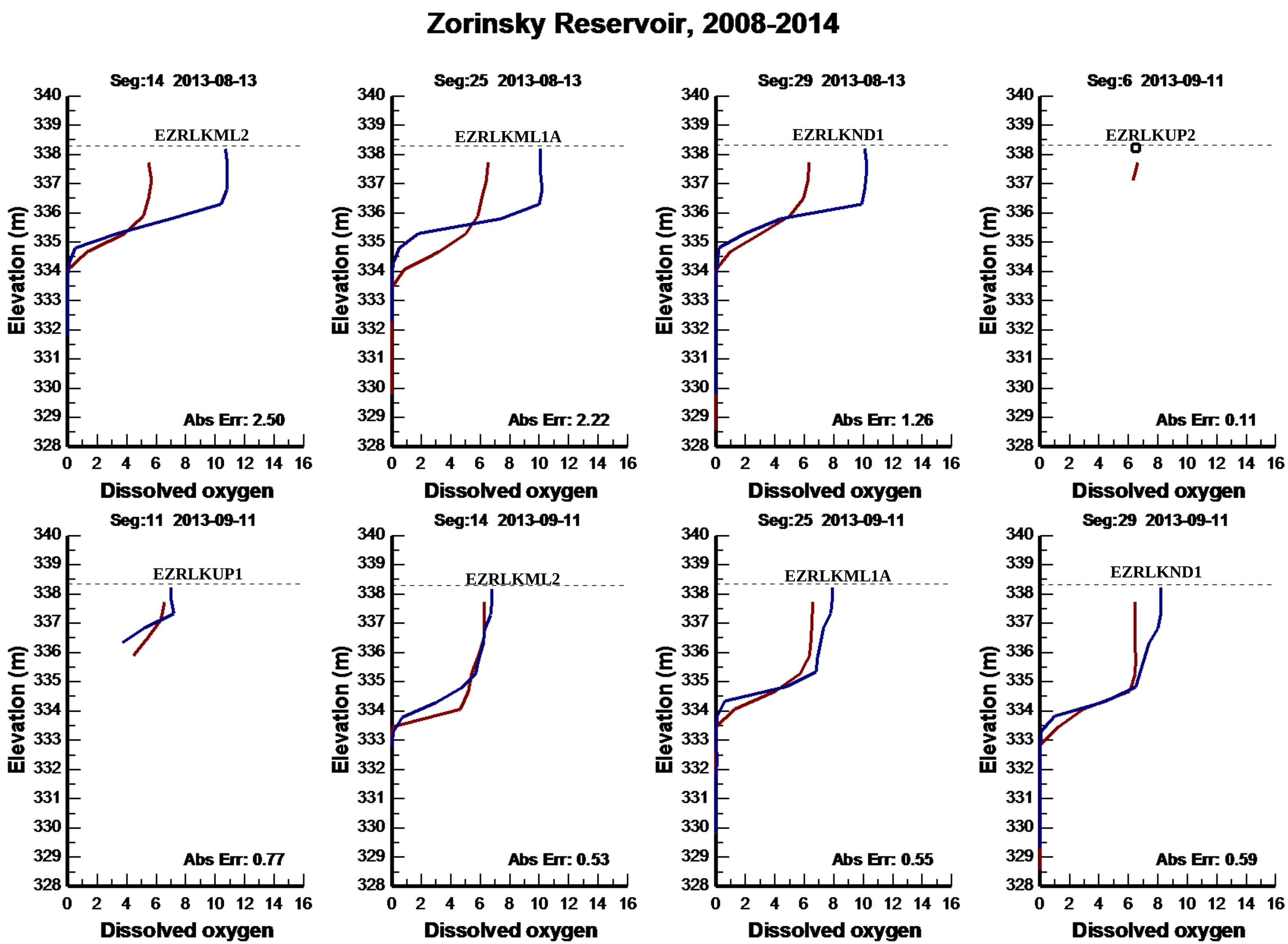


Plate 60. Observed (blue) versus model (red) DO calibration profiles for August to September 2013.

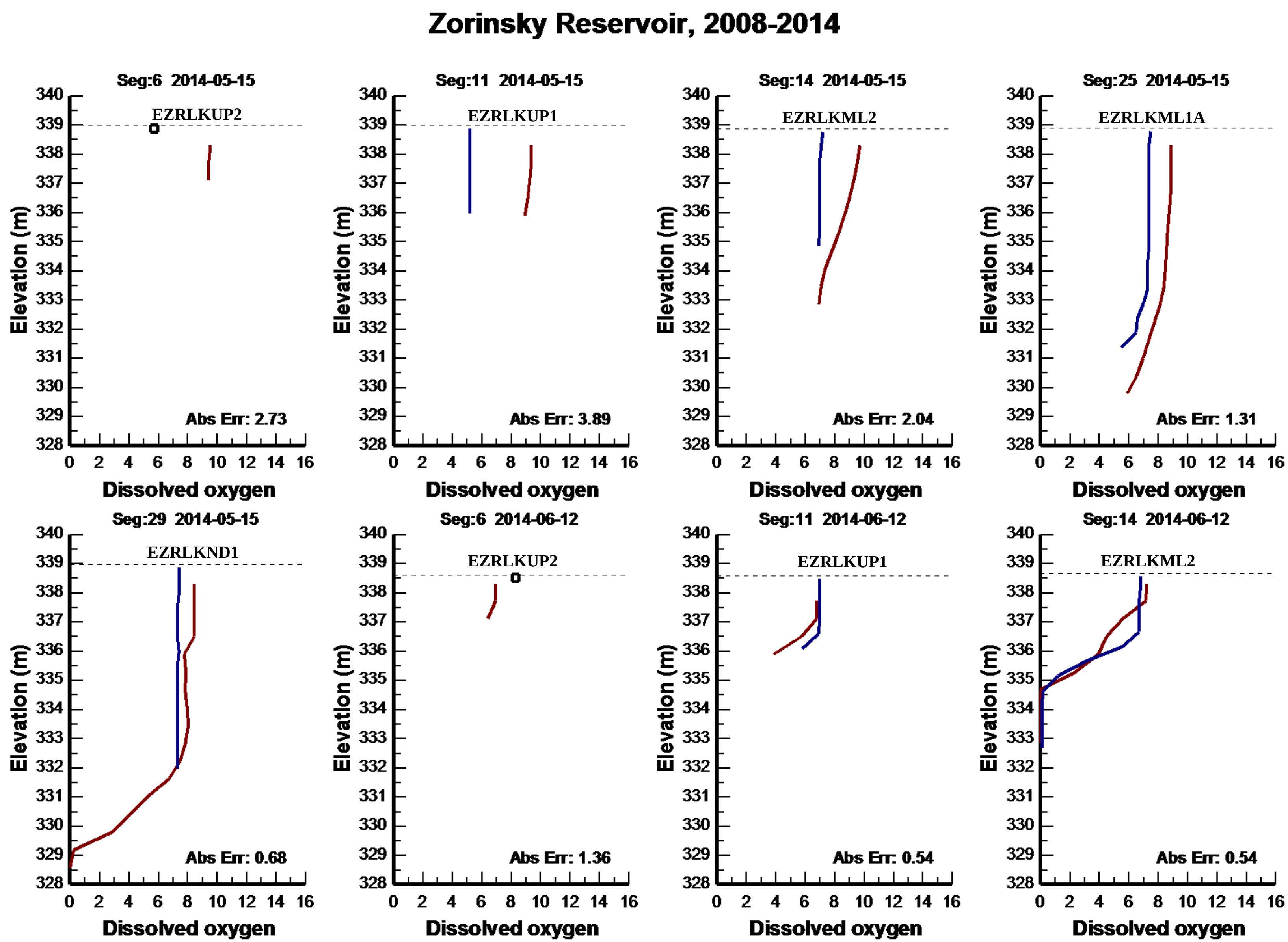


Plate 61. Observed (blue) versus model (red) DO calibration profiles for May to June 2014.

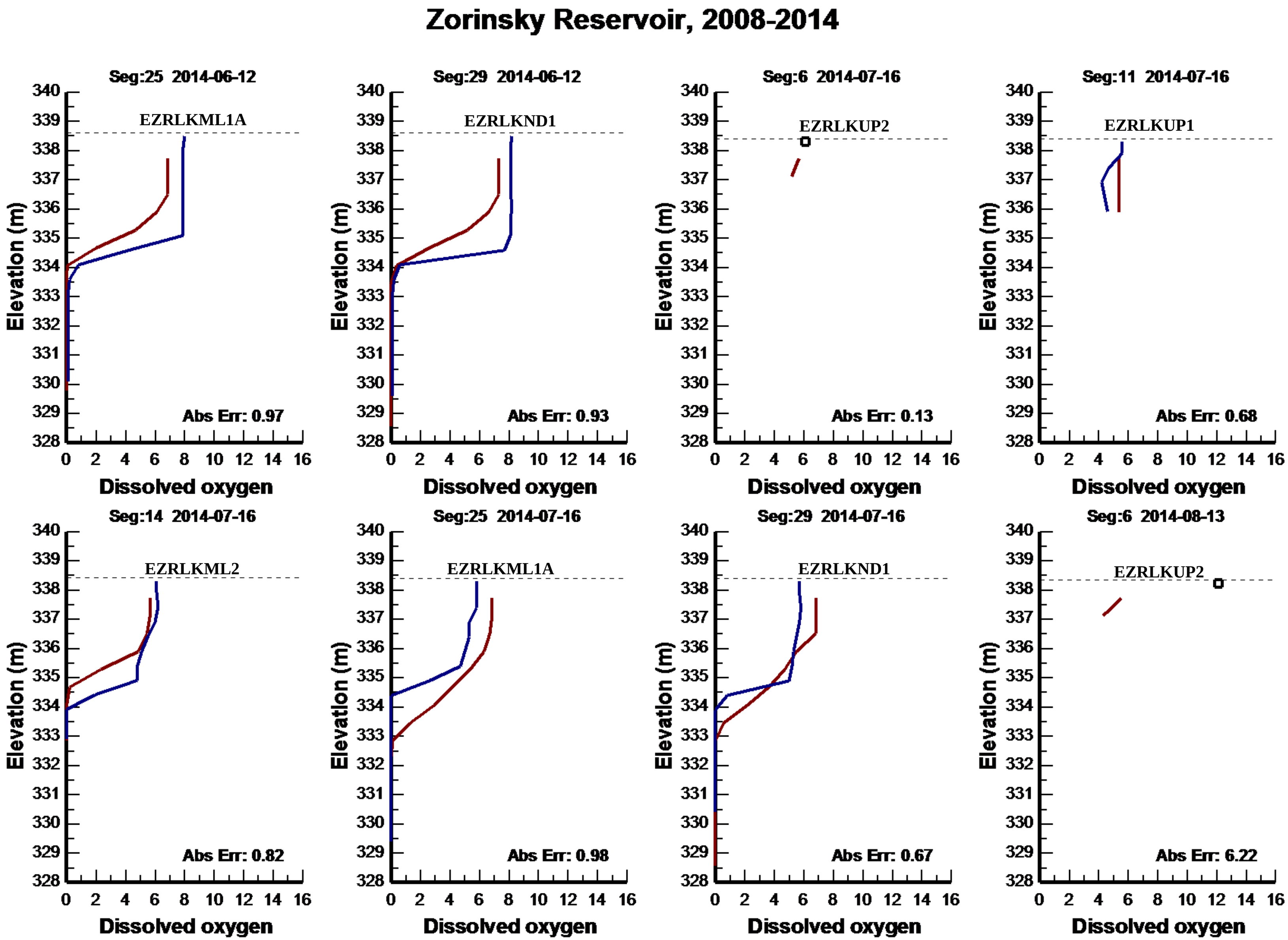


Plate 62. Observed (blue) versus model (red) DO calibration profiles for June to August 2014.

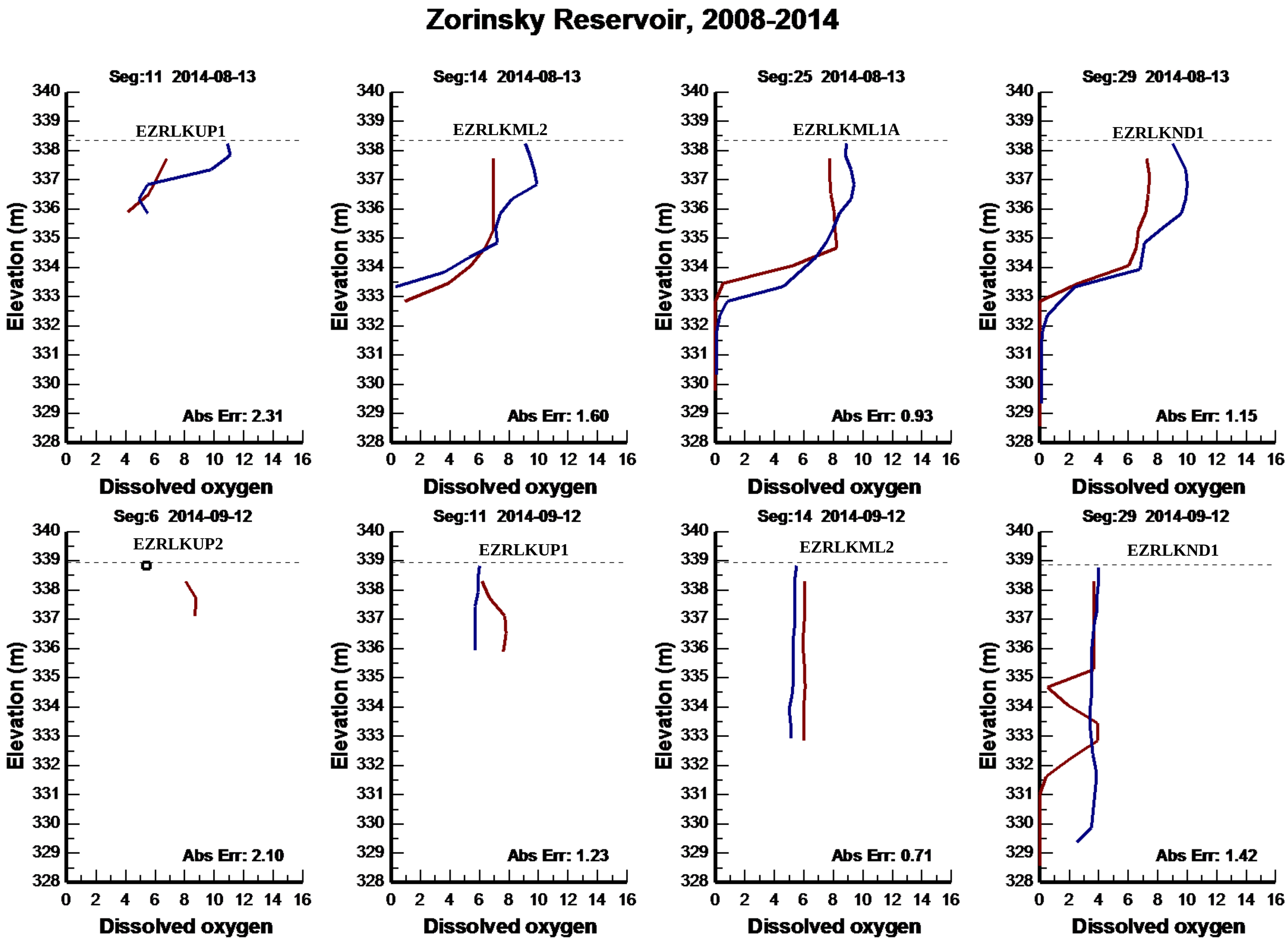


Plate 63. Observed (blue) versus model (red) DO calibration profiles for August to September 2014.

Zorinsky Reservoir, 2008-2014

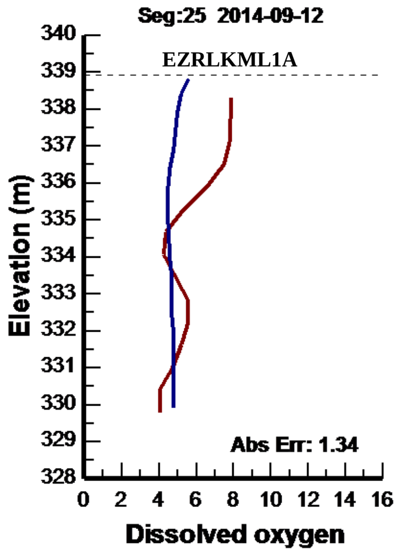


Plate 64. Observed (blue) versus model (red) DO calibration profiles for September 2014.

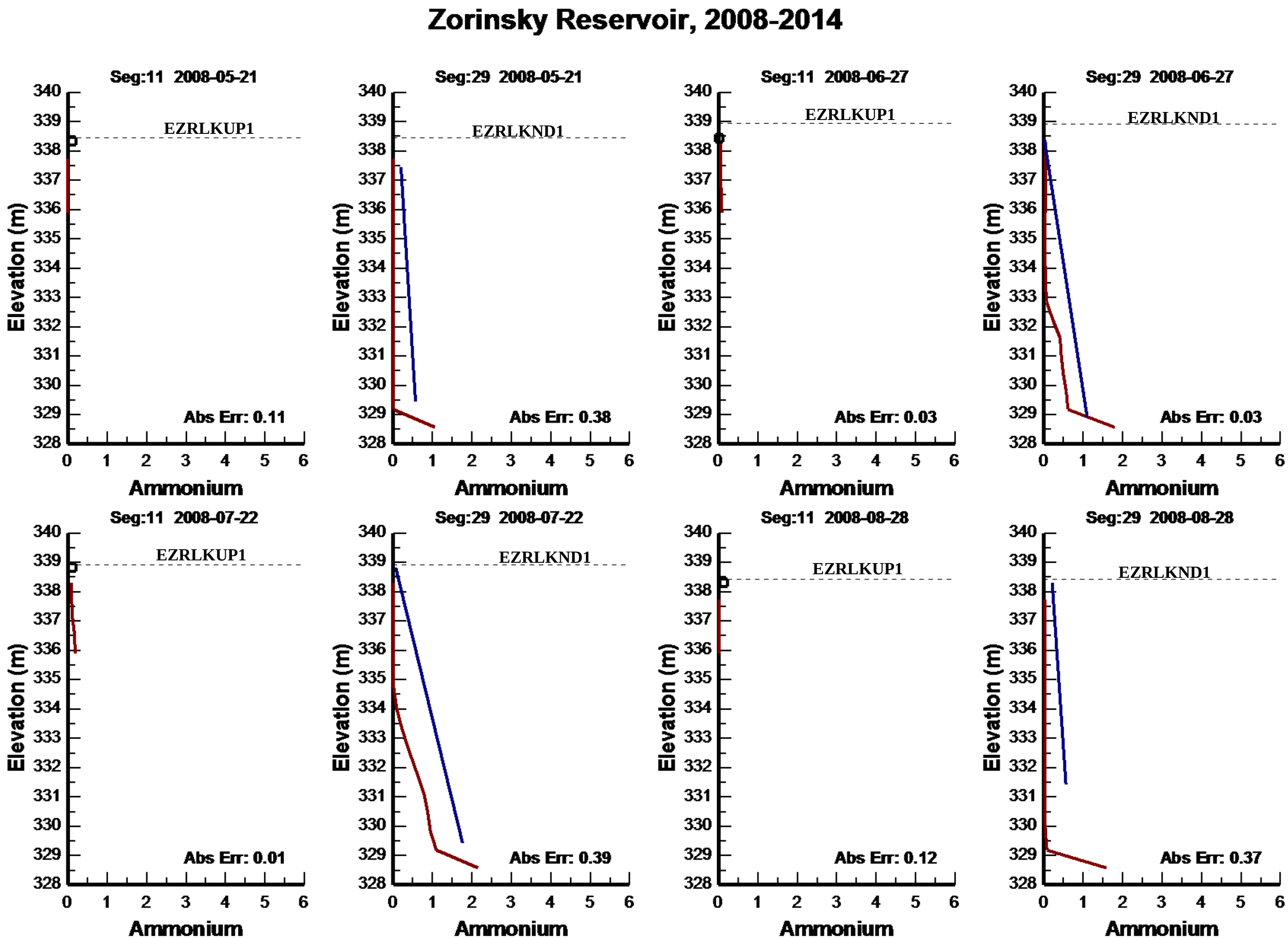


Plate 65. Observed (blue) versus model (red) NH_4 calibration profiles for May 2008 to August 2009.

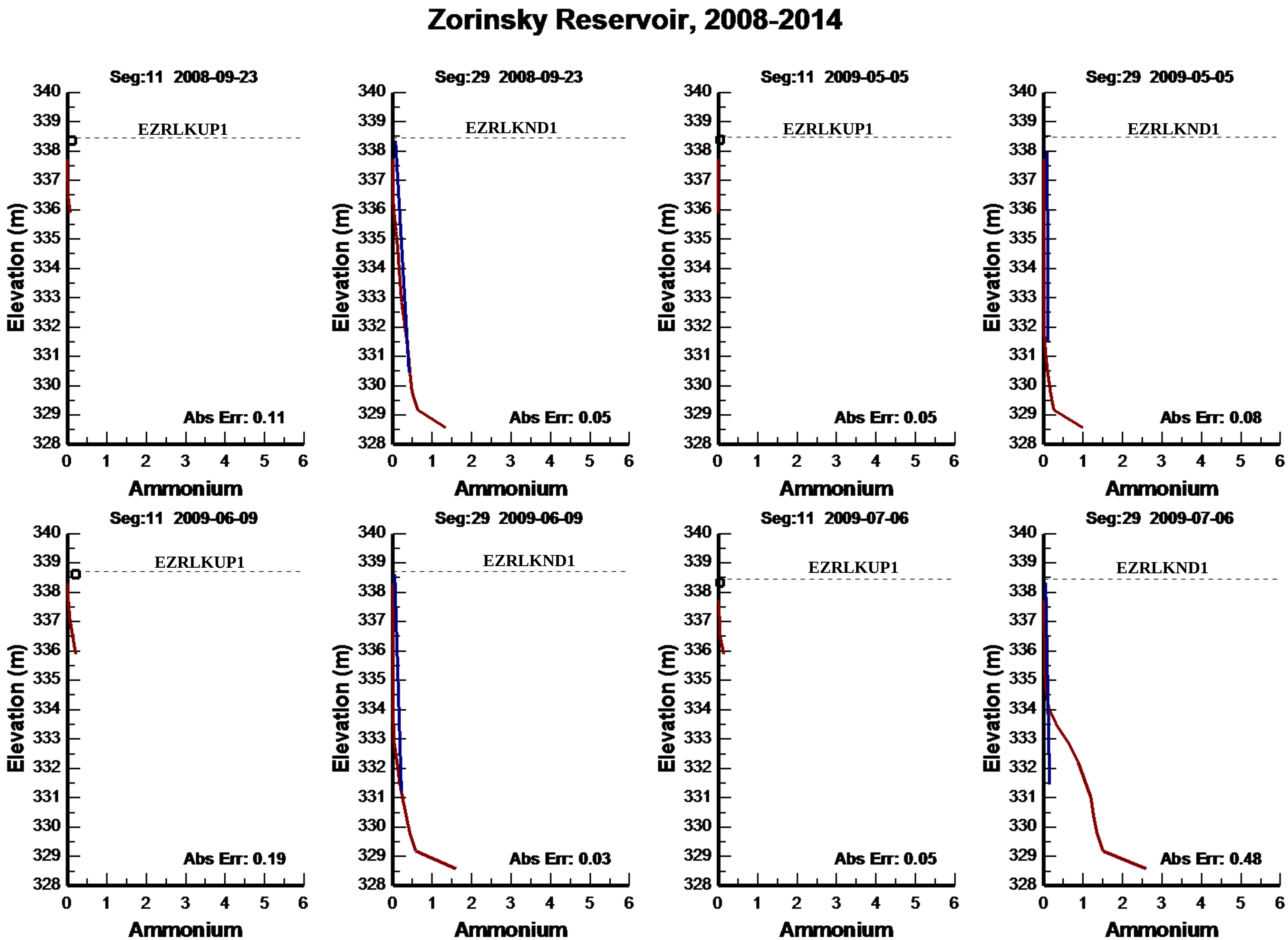


Plate 66. Observed (blue) versus model (red) NH_4 calibration profiles for September 2008 to July 2009.

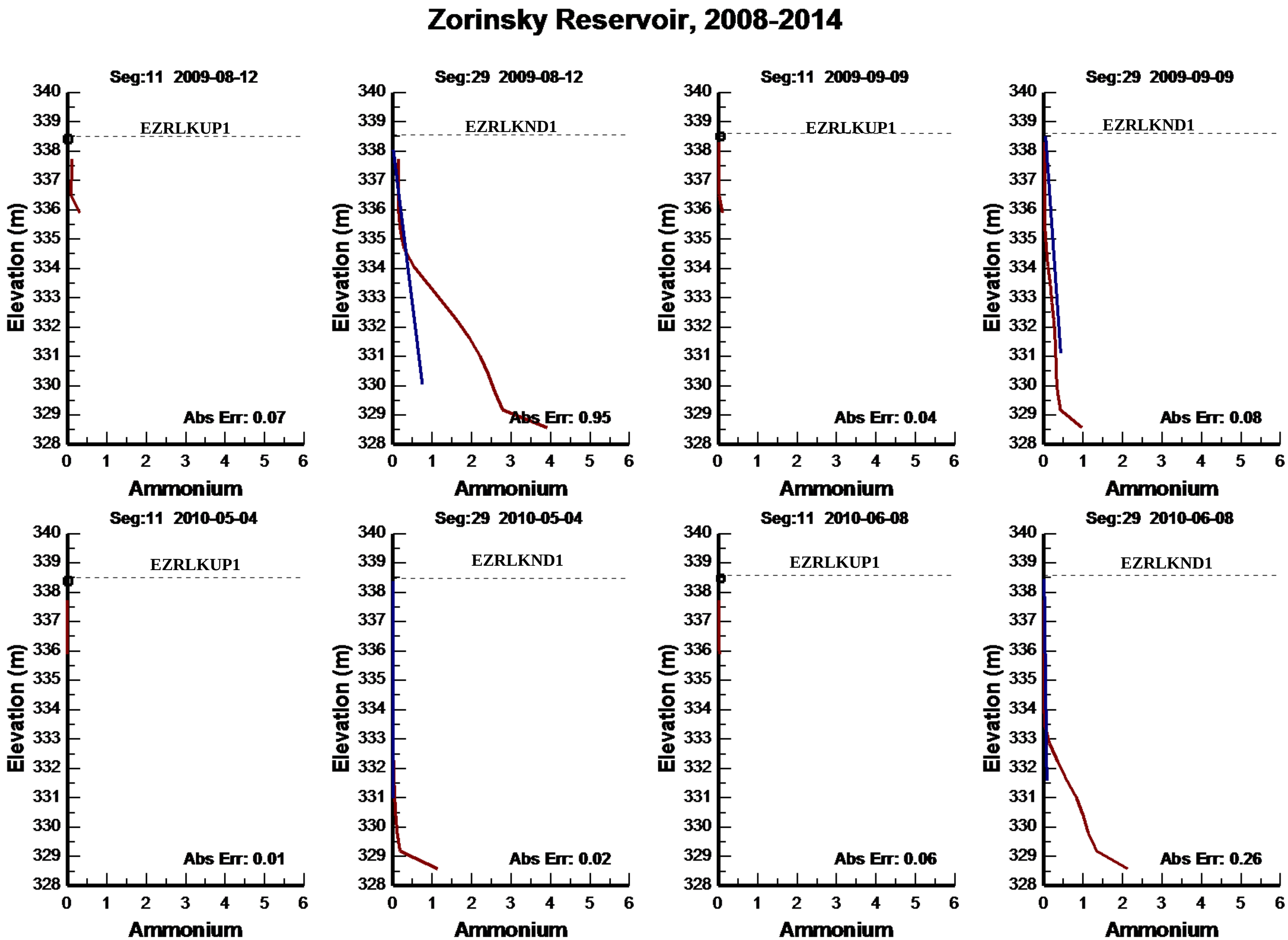


Plate 67. Observed (blue) versus model (red) NH_4 calibration profiles for July 2009 to June 2010.

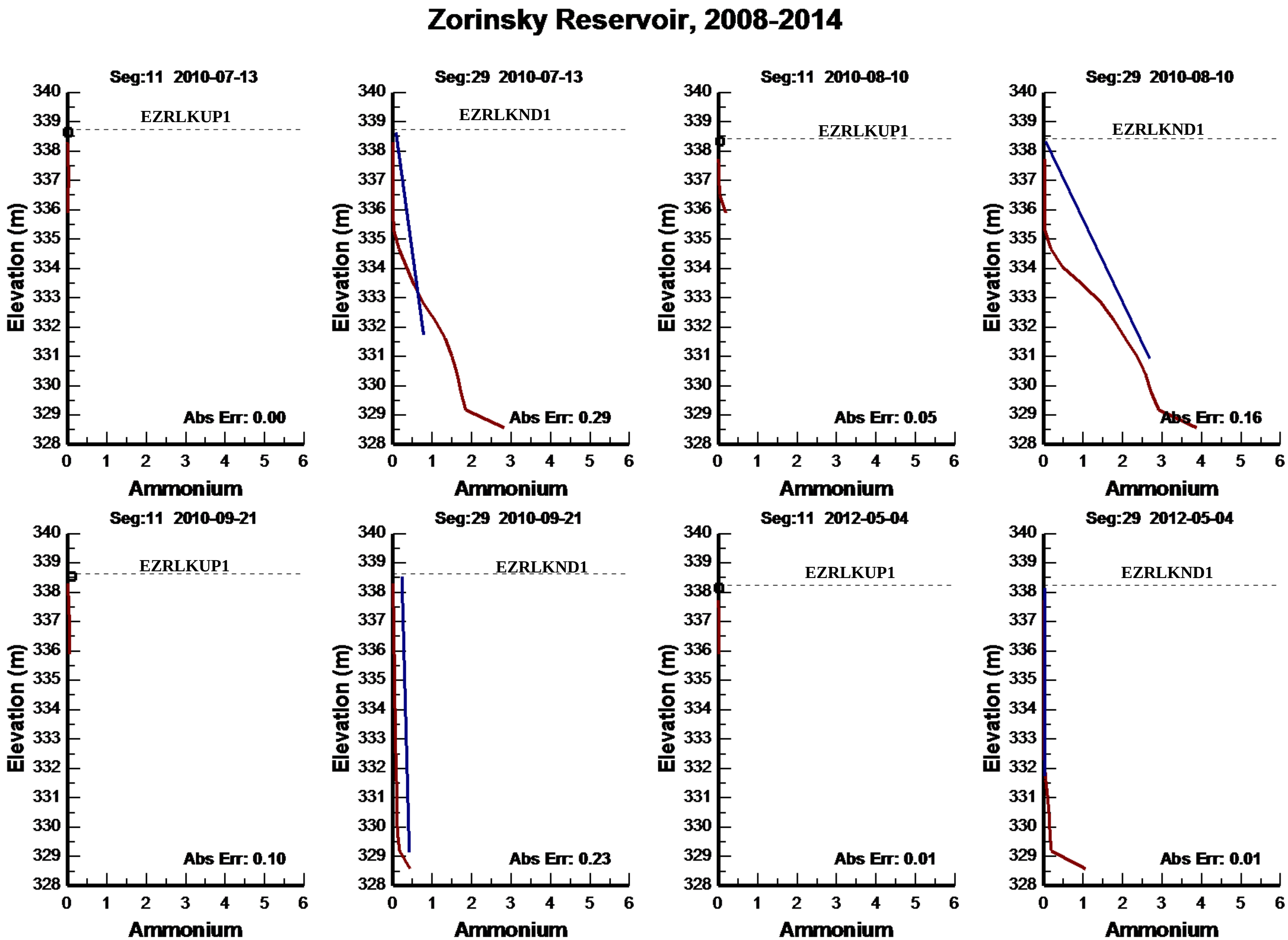


Plate 68. Observed (blue) versus model (red) NH_4 calibration profiles for July 2010 to May 2012.

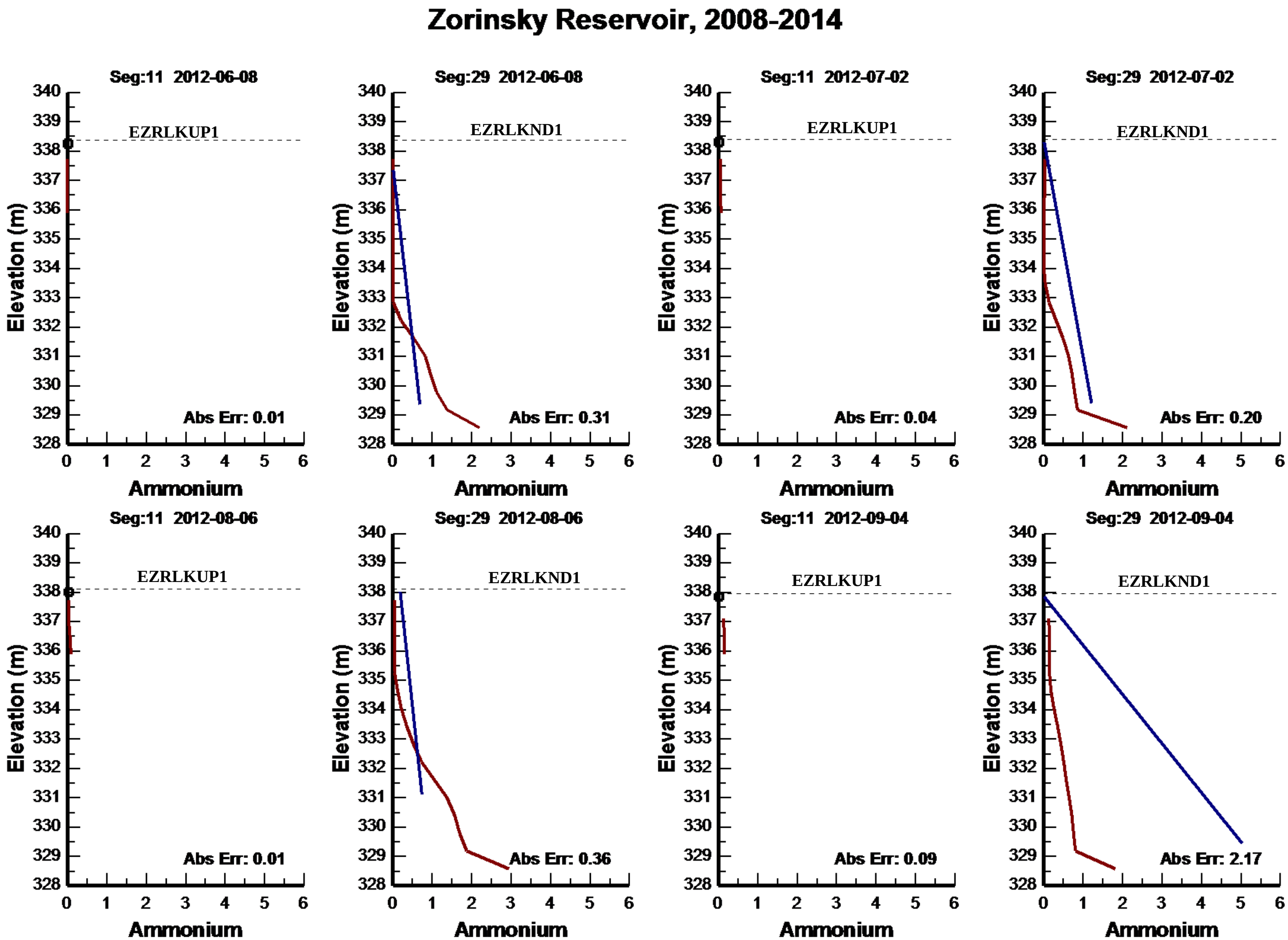


Plate 69. Observed (blue) versus model (red) NH_4 calibration profiles for June 2012 to September 2012.

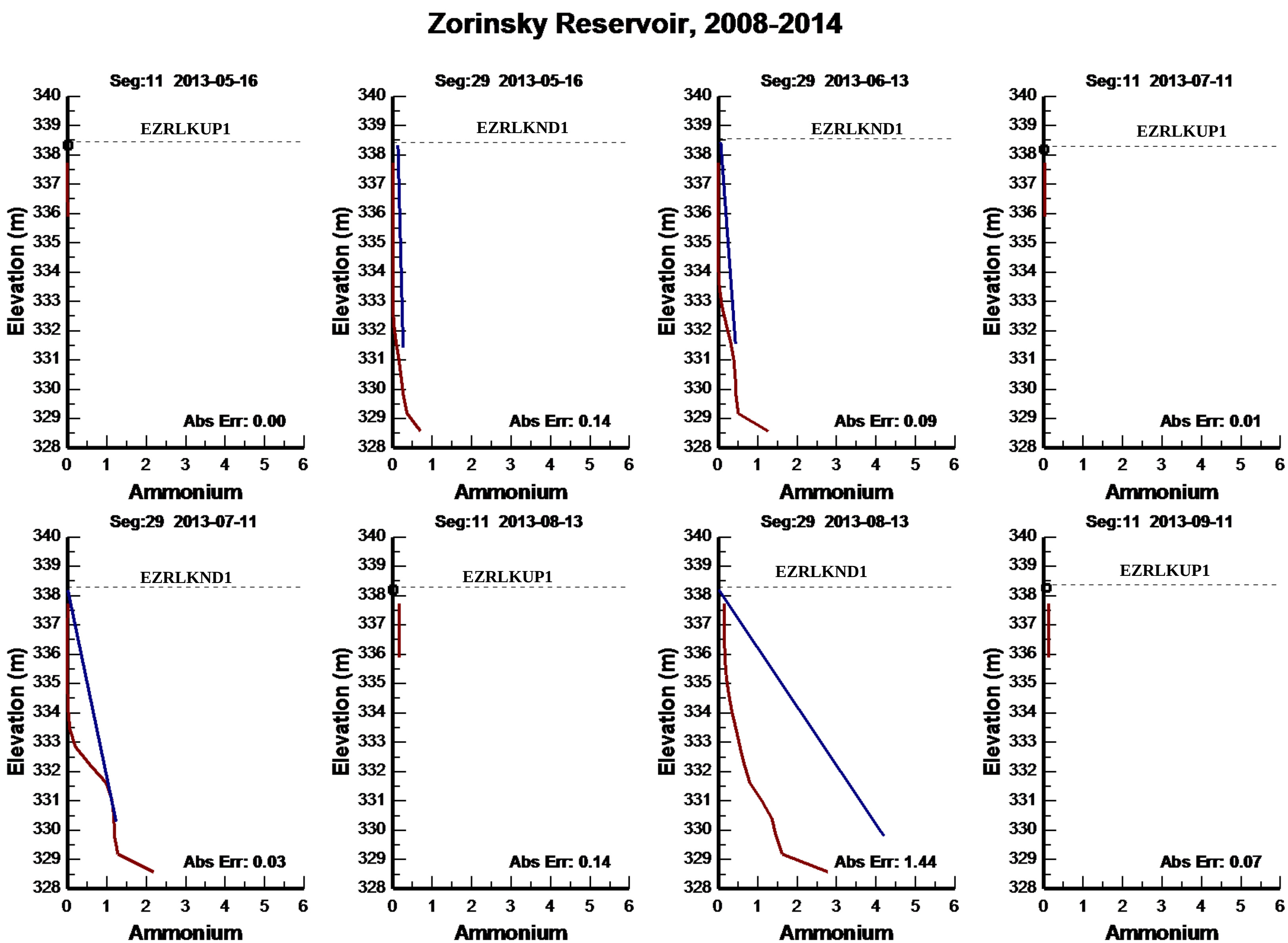


Plate 70. Observed (blue) versus model (red) NH_4 calibration profiles for May to September 2013.

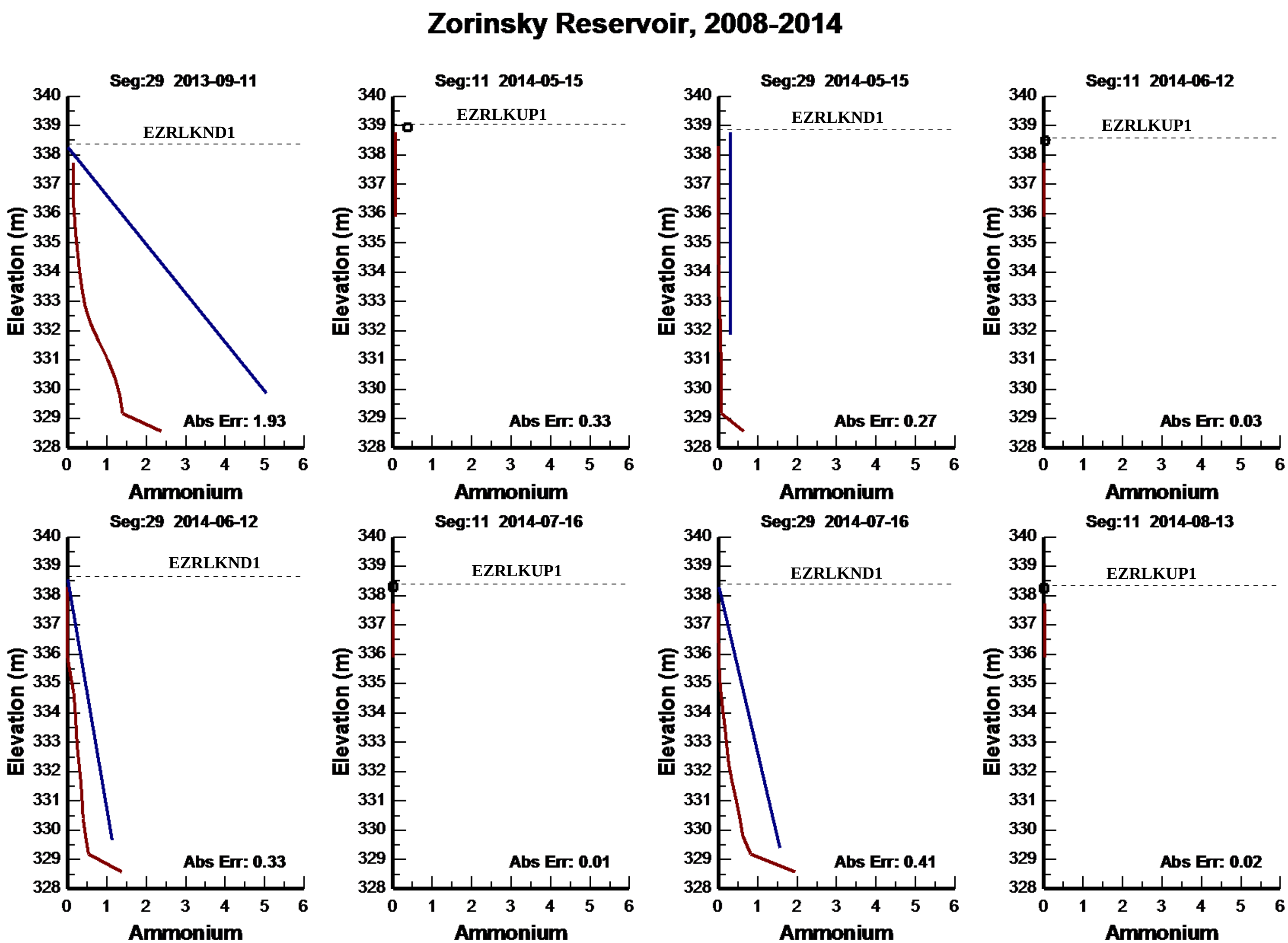


Plate 71. Observed (blue) versus model (red) NH_4 calibration profiles for September 2013 to August 2014.

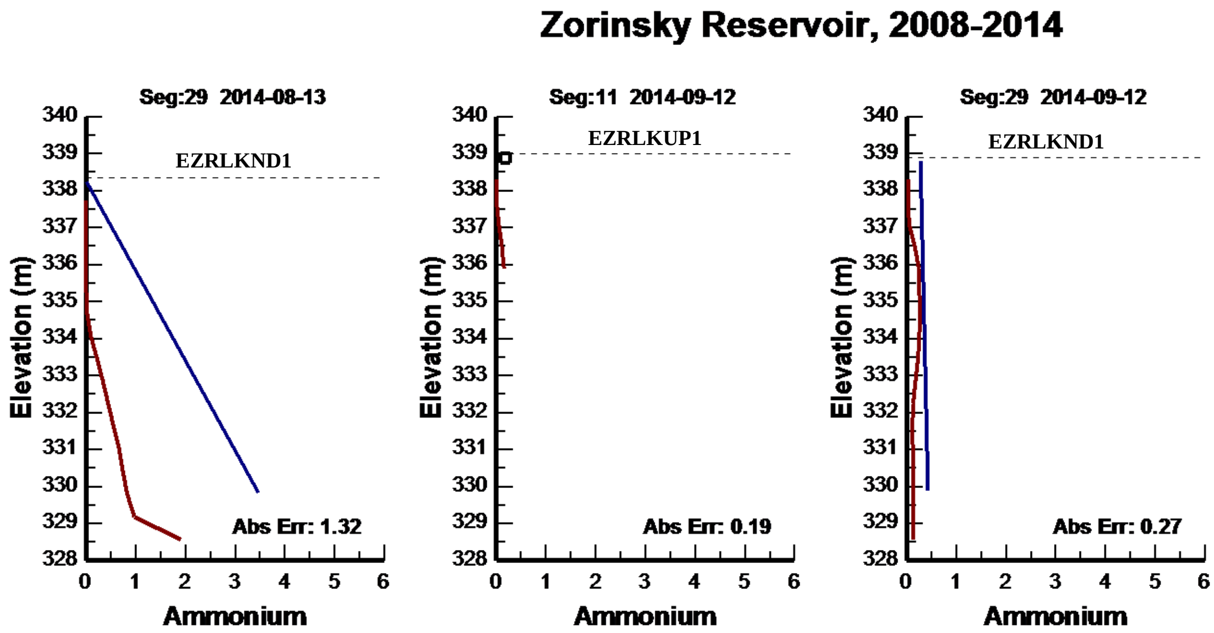


Plate 72. Observed (blue) versus model (red) NH_4 calibration profiles for August to September 2014.

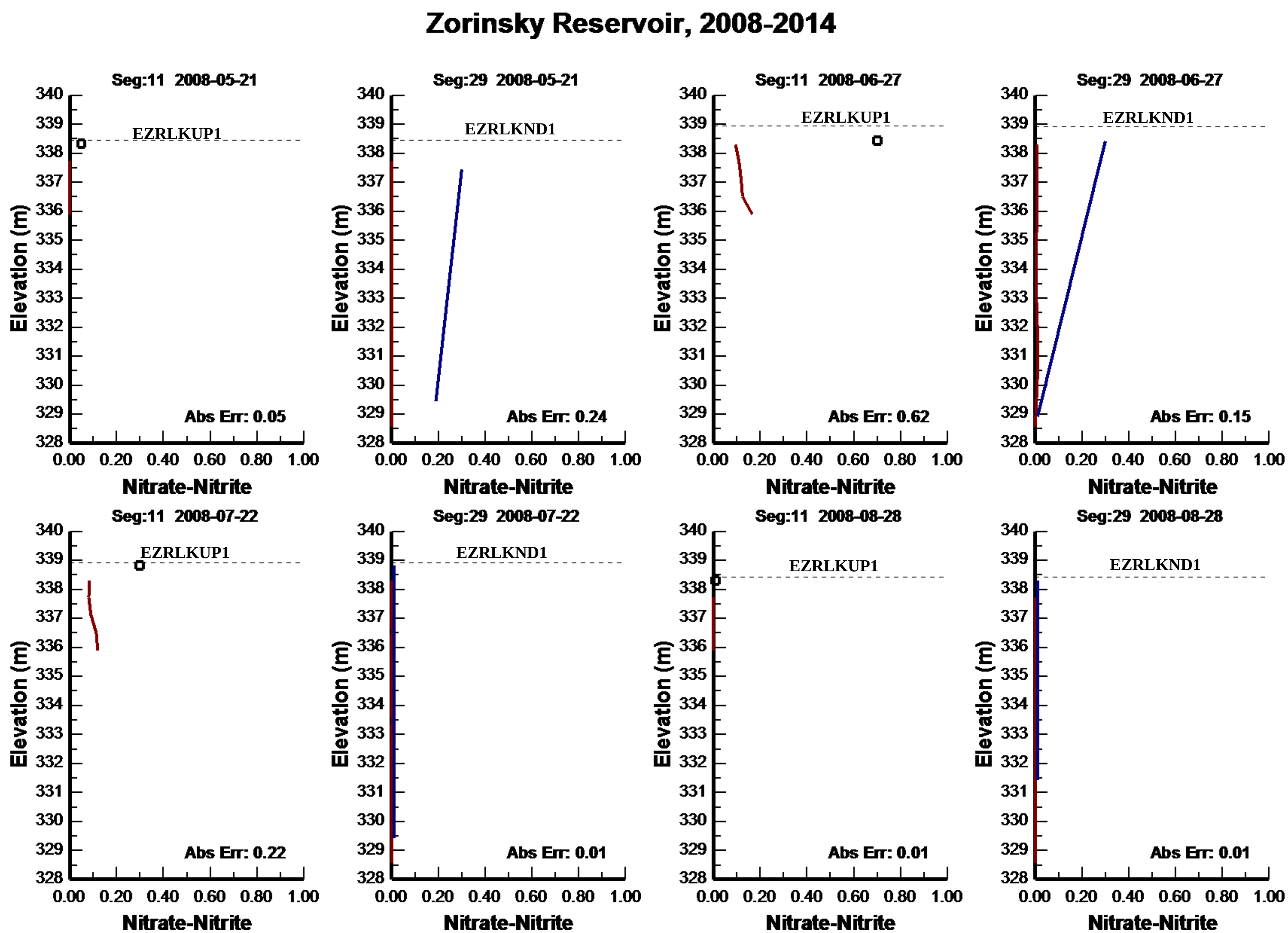


Plate 73. Observed (blue) versus model (red) NO_X calibration profiles for May to August 2008.

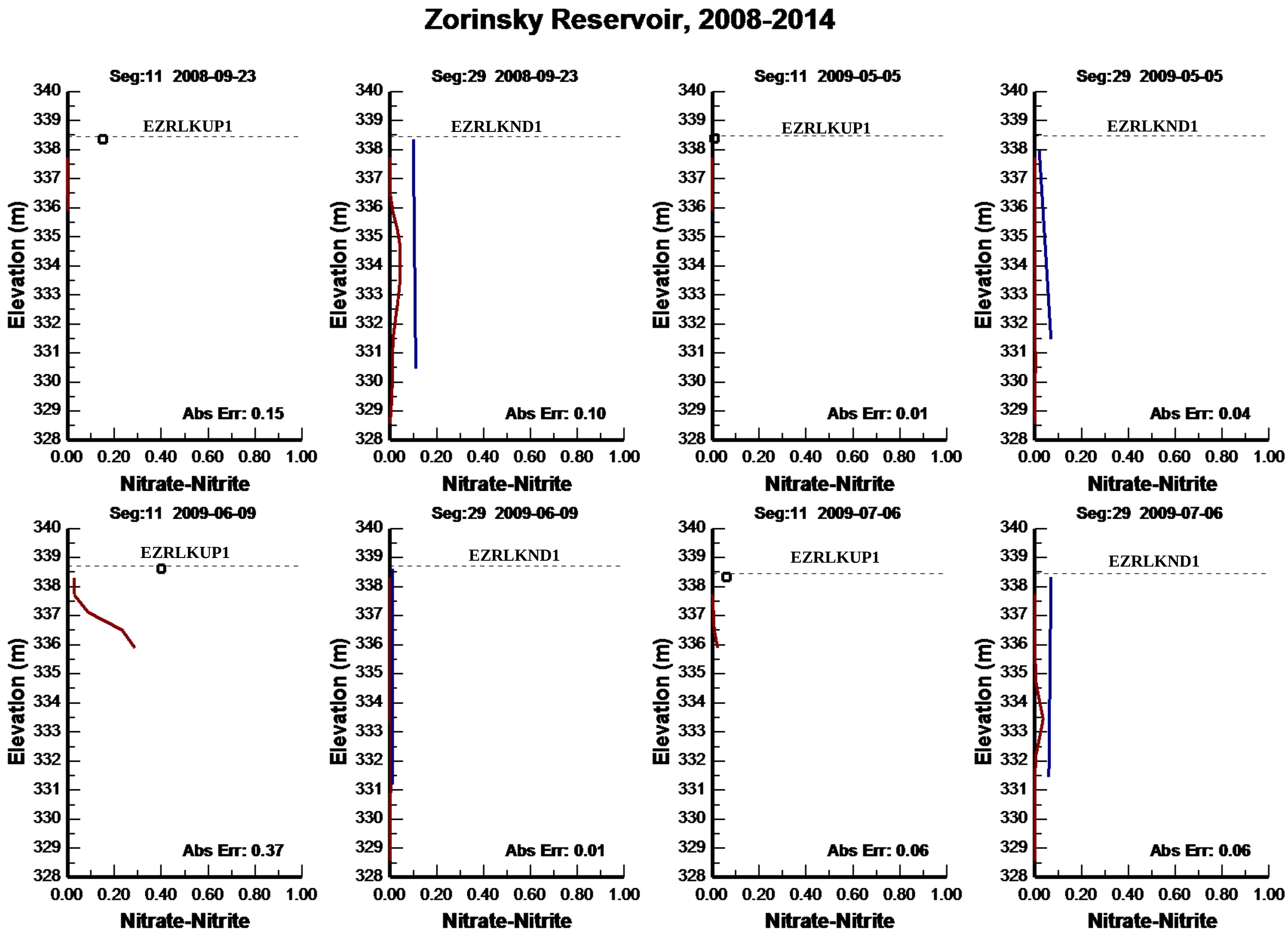


Plate 74. Observed (blue) versus model (red) NO_X calibration profiles for September 2008 to July 2009.

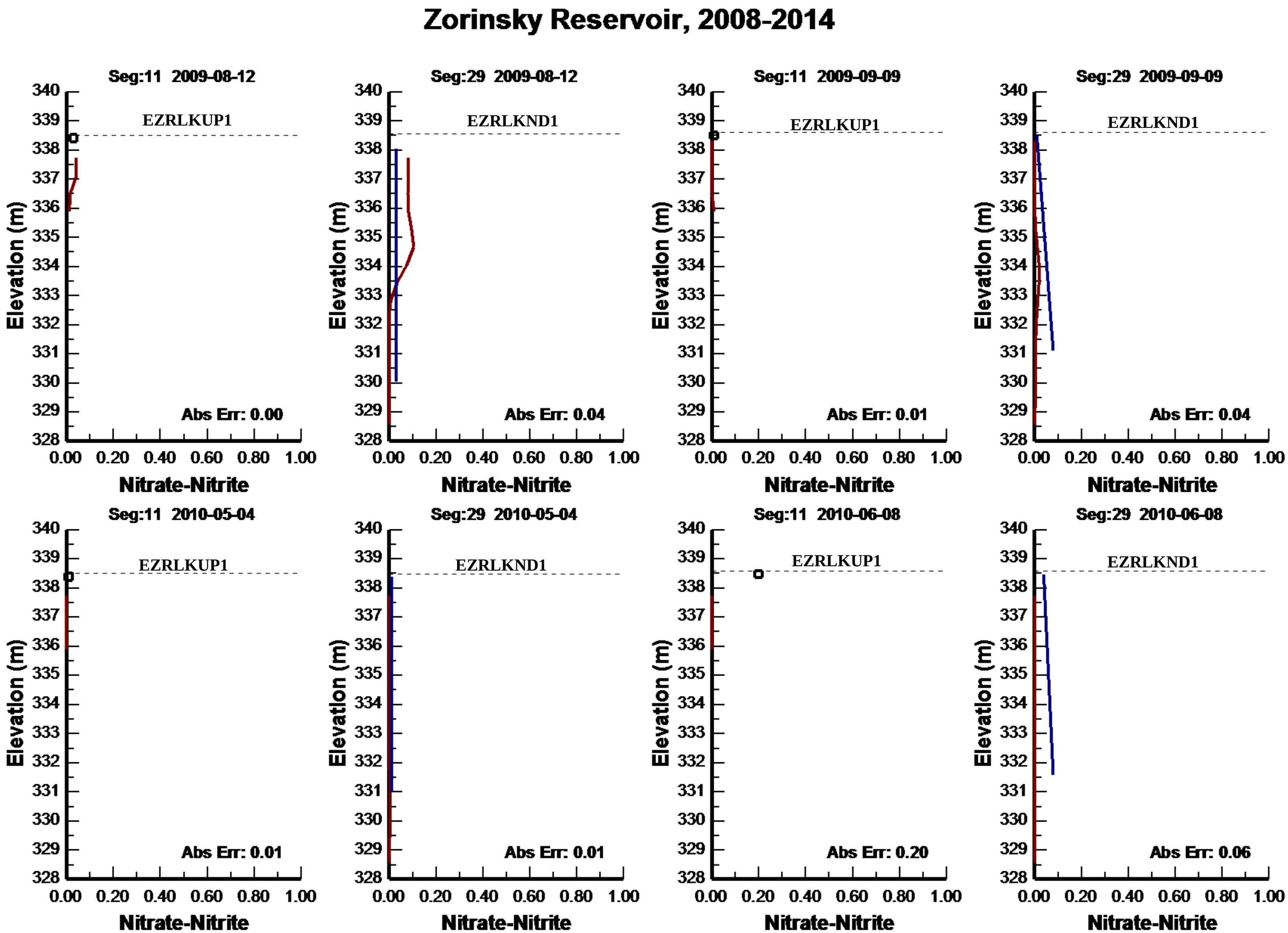


Plate 75. Observed (blue) versus model (red) NO_X calibration profiles for August 2009 to June 2010.

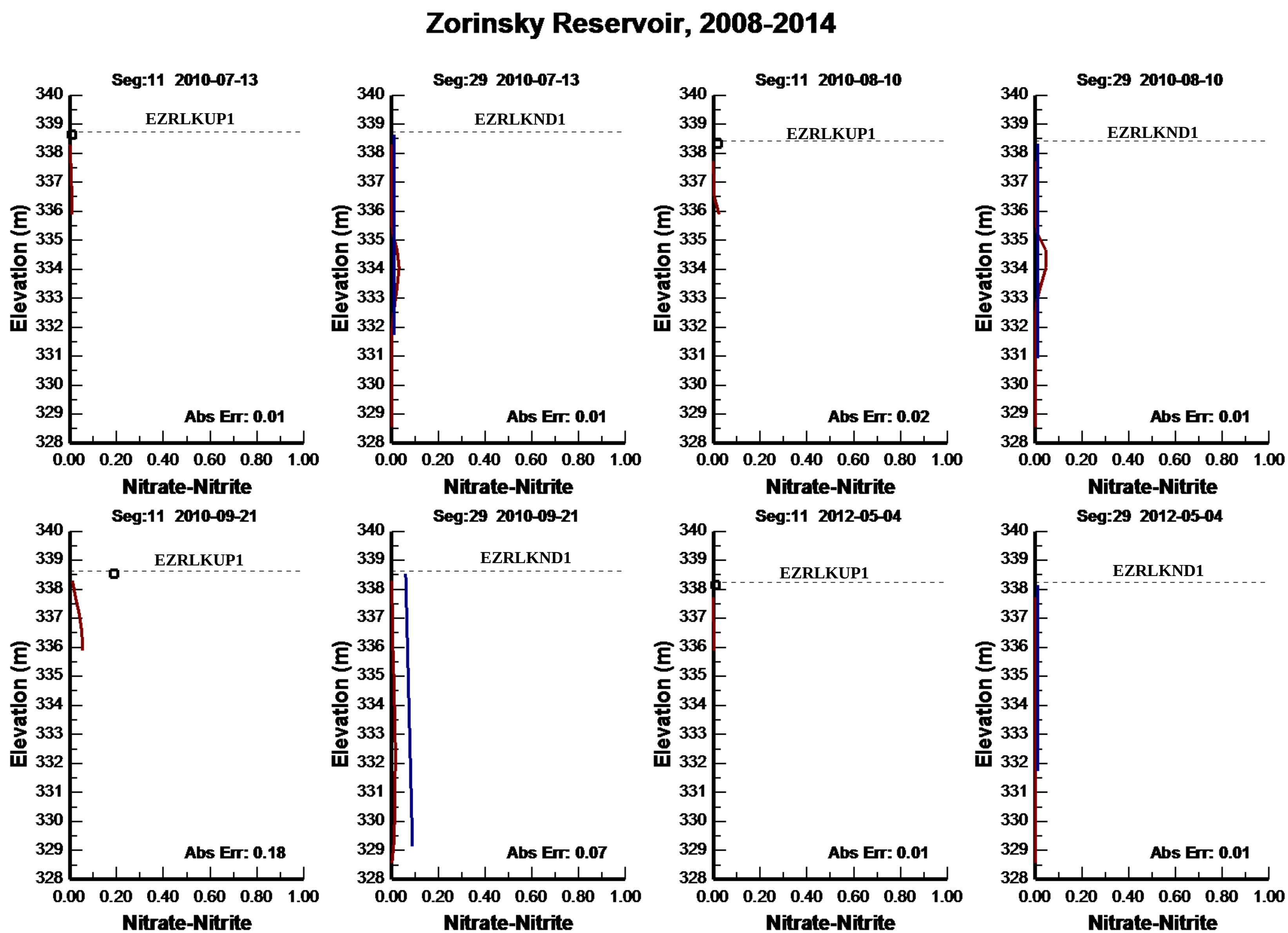


Plate 76. Observed (blue) versus model (red) NO_X calibration profiles for July 2010 to May 2012.

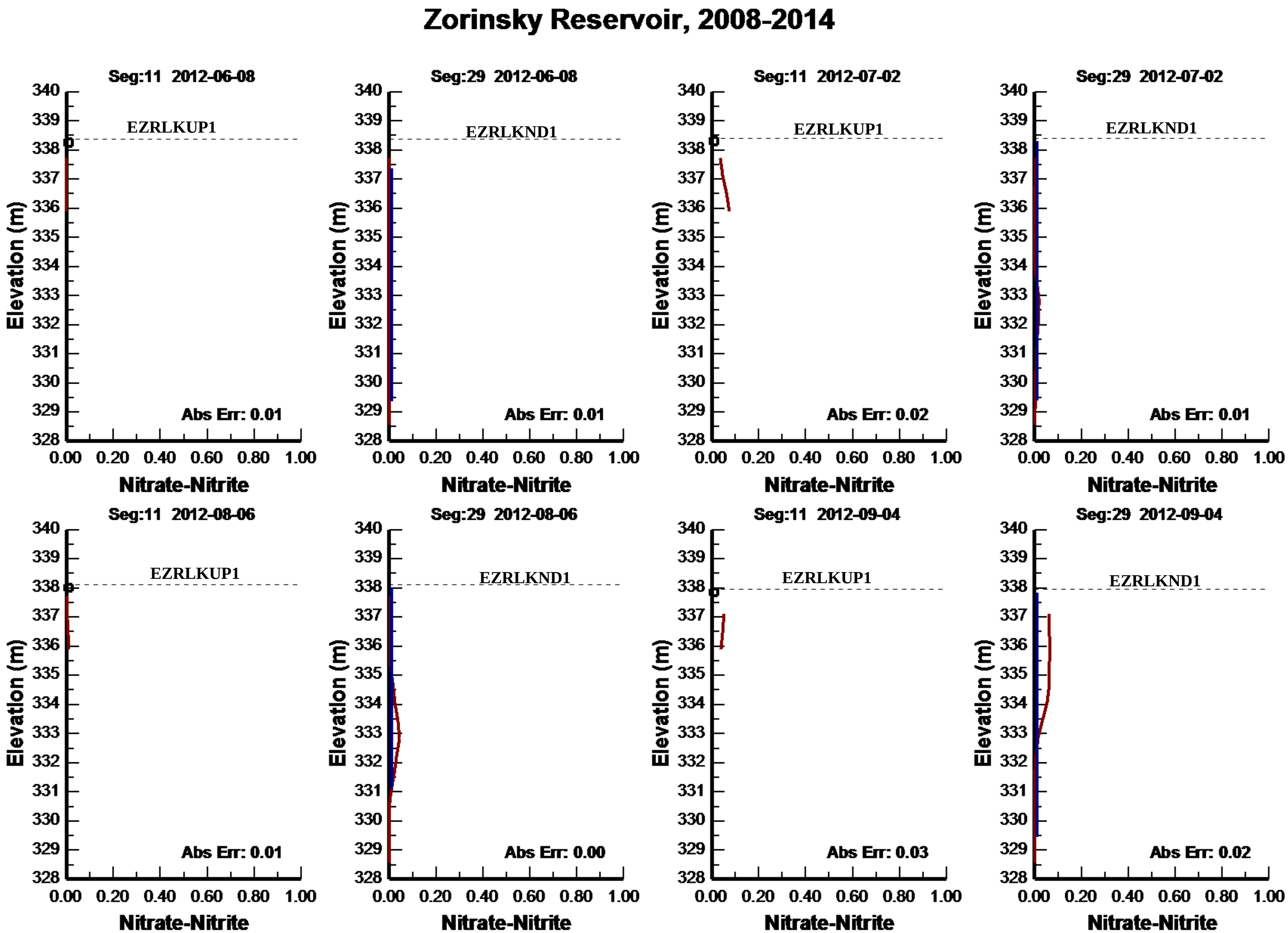


Plate 77. Observed (blue) versus model (red) NO_X calibration profiles for June to September 2012.

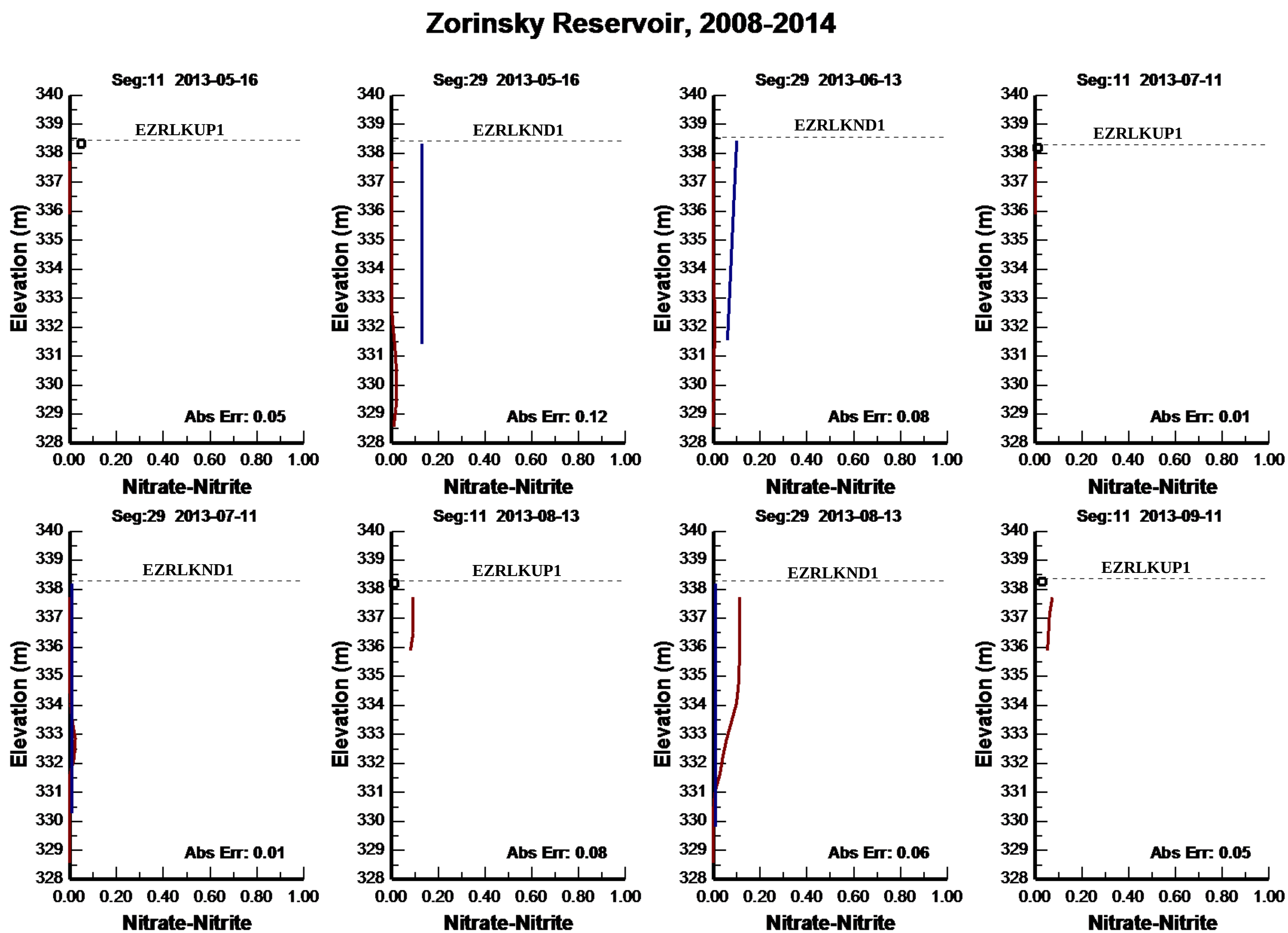


Plate 78. Observed (blue) versus model (red) NO_X calibration profiles for May to September 2013.

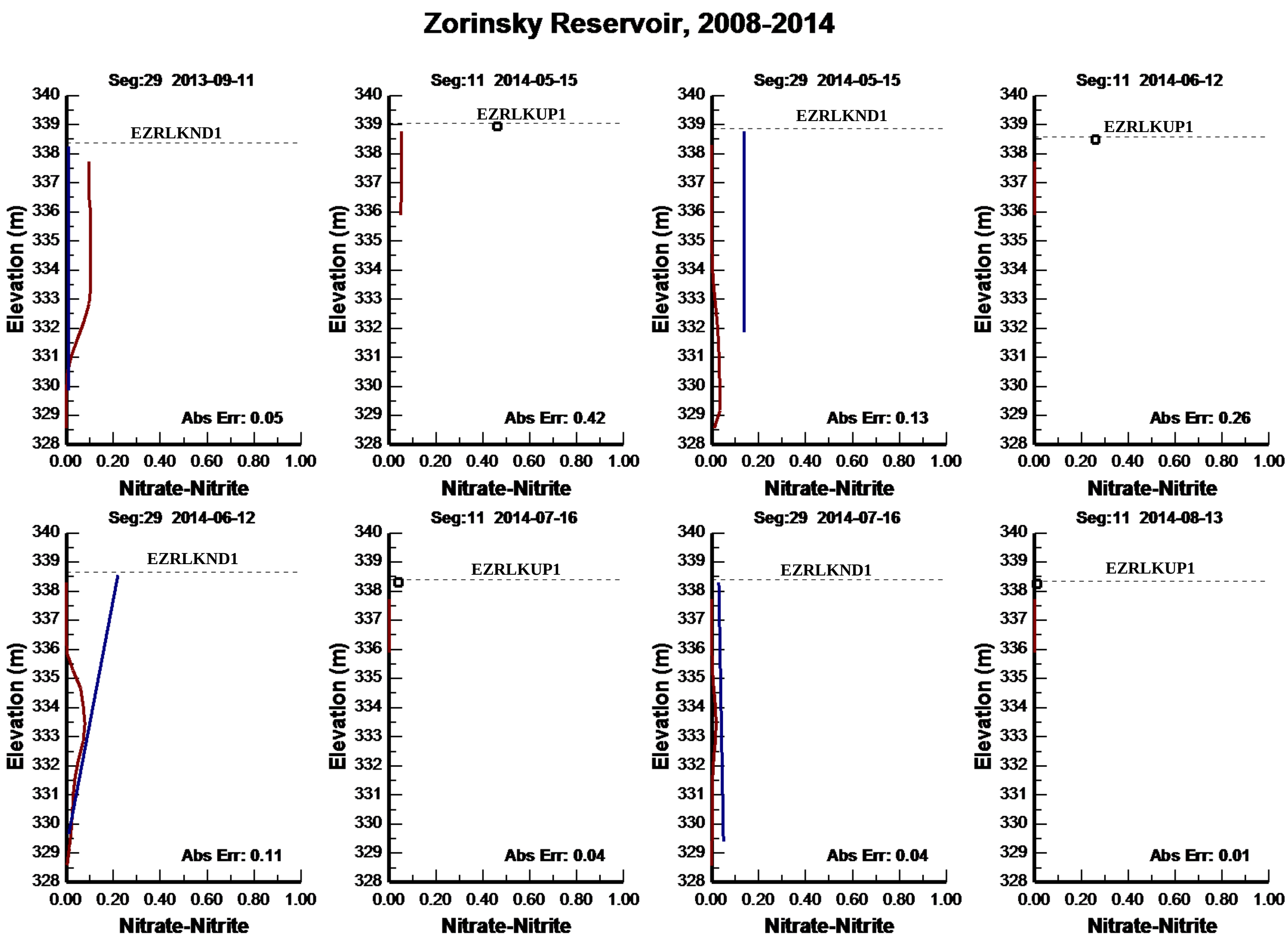


Plate 79. Observed (blue) versus model (red) NO_X calibration profiles for September 2013 to August 2014.

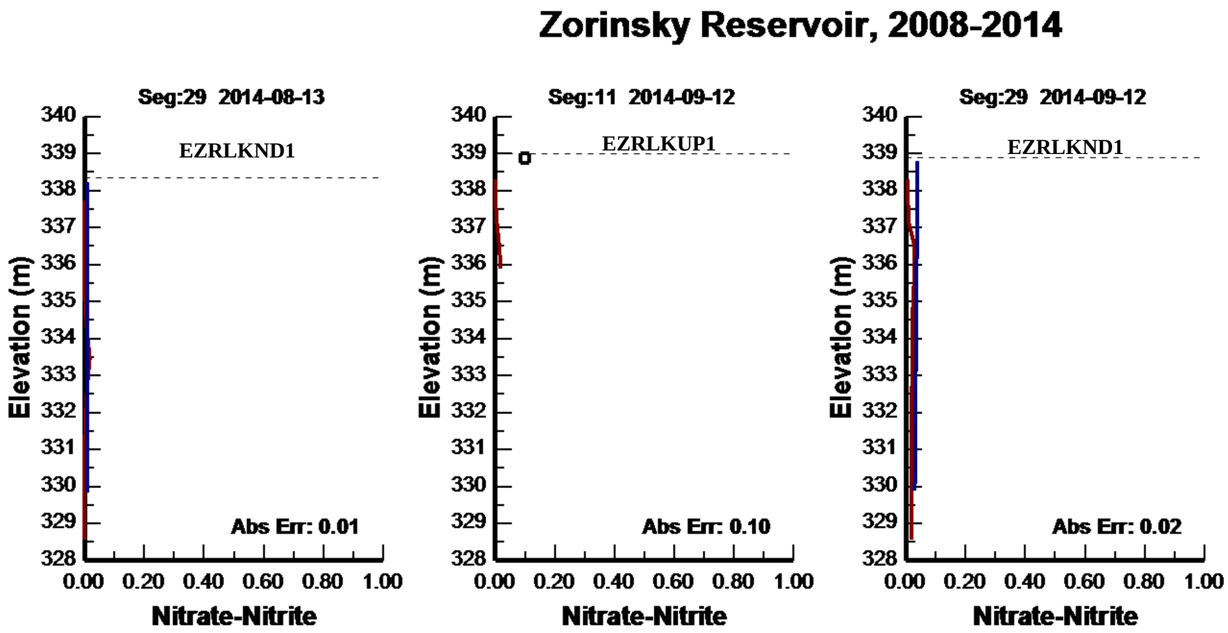


Plate 80. Observed (blue) versus model (red) NO_X calibration profiles for August to September 2014.

Zorinsky Reservoir, 2008-2014

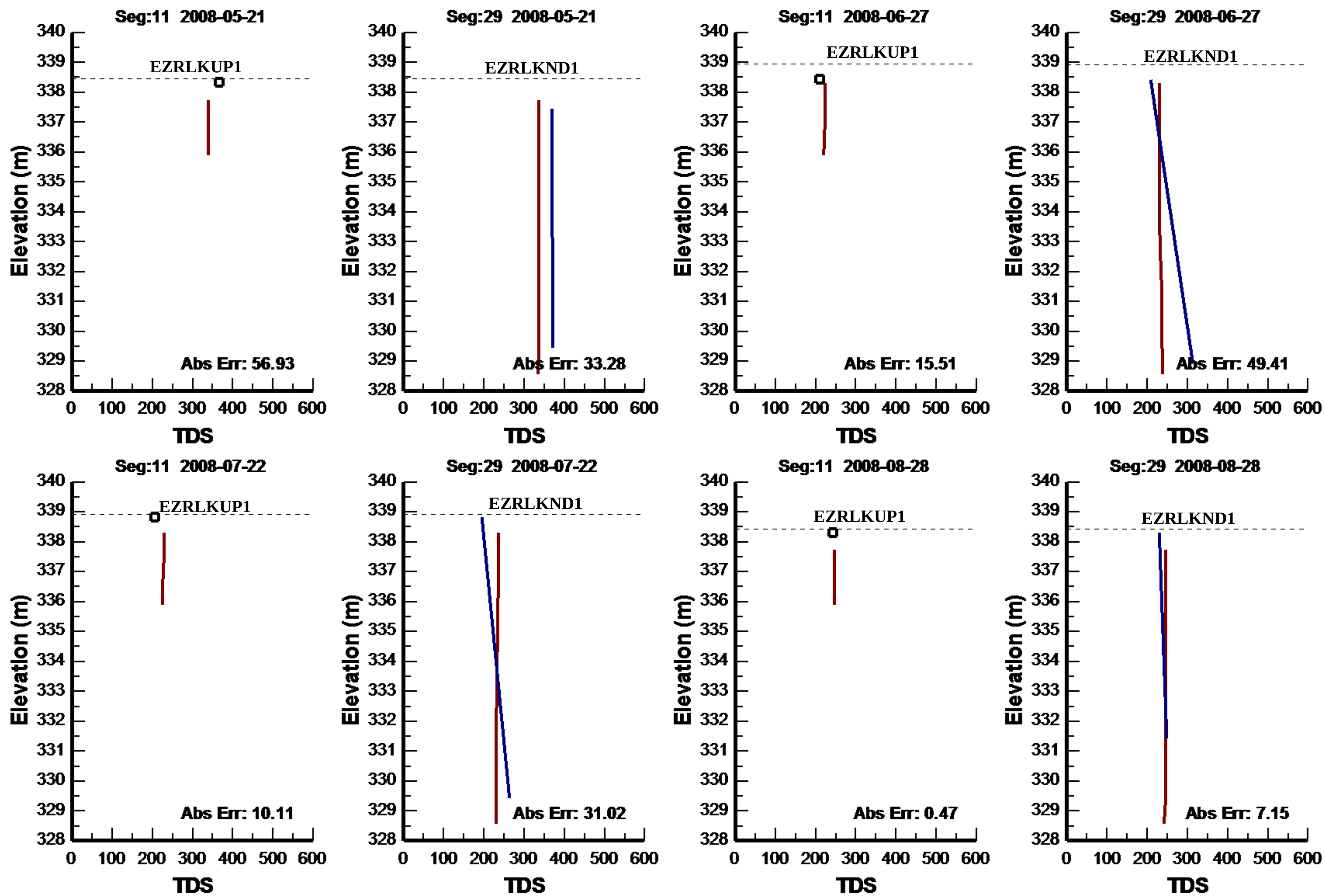


Plate 81. Observed (blue) versus model (red) TDS calibration profiles for May to August 2008.

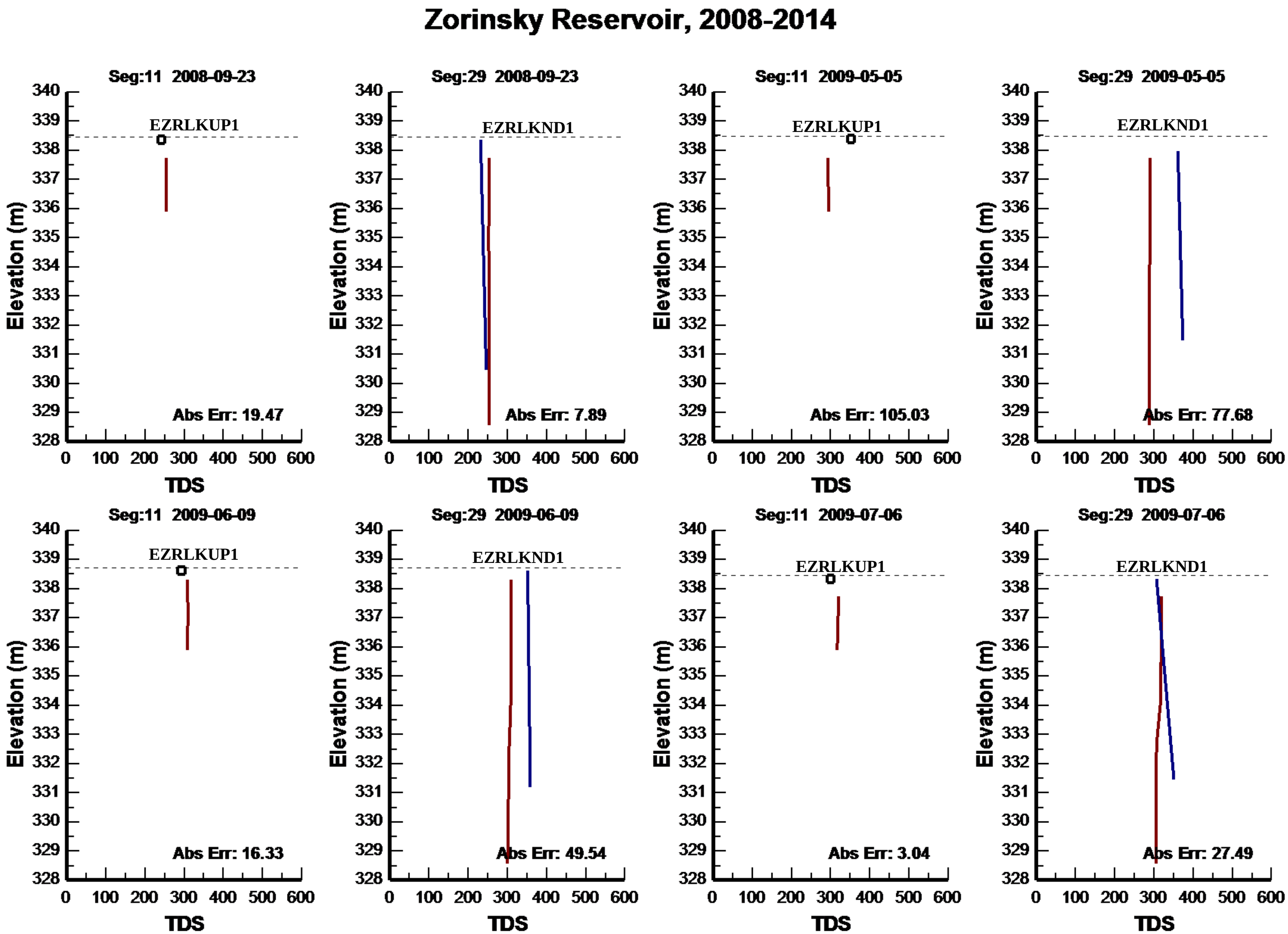


Plate 82. Observed (blue) versus model (red) TDS calibration profiles for September 2008 to July 2009.

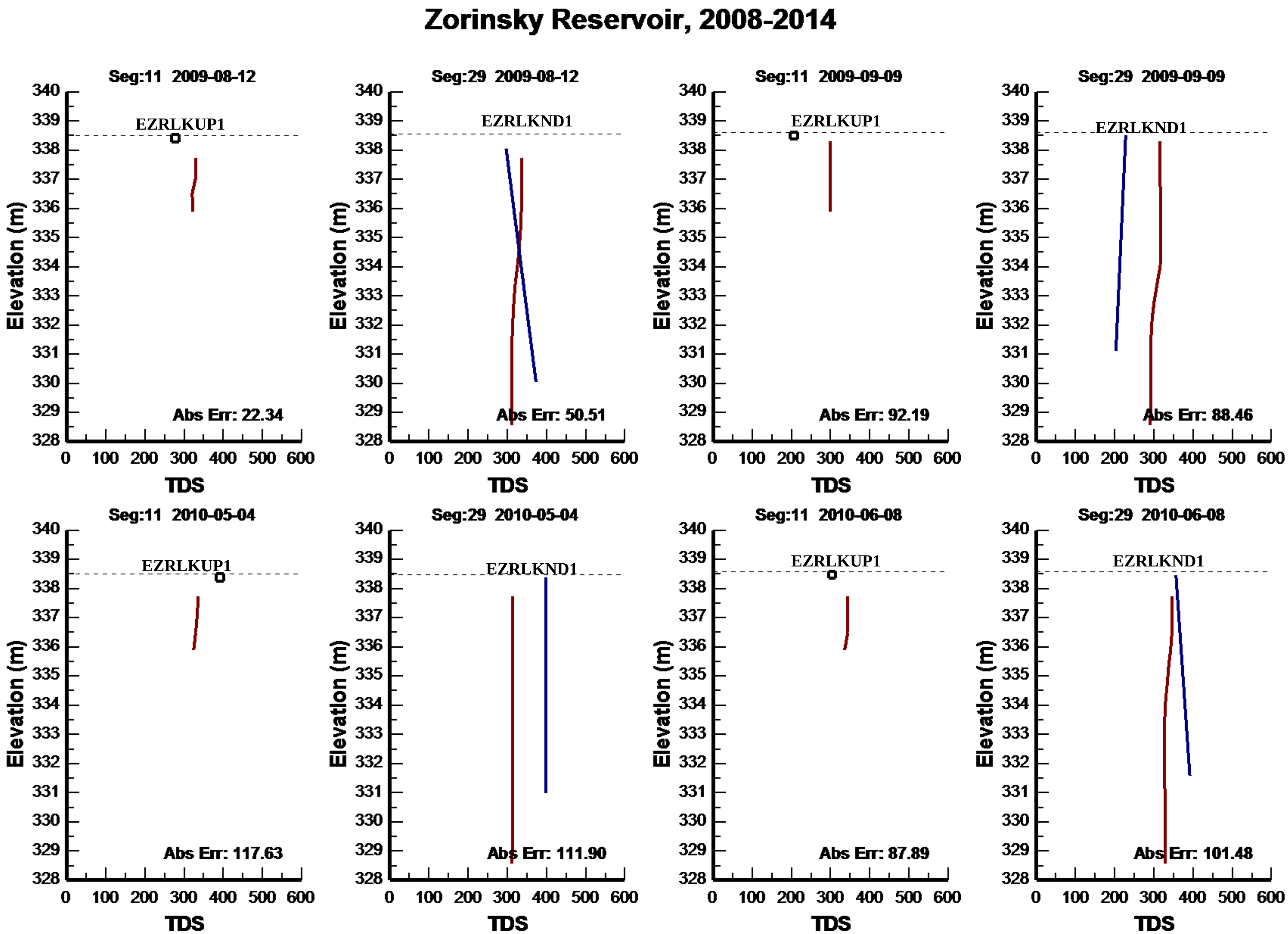


Plate 83. Observed (blue) versus model (red) TDS calibration profiles for August 2009 to June 2010.

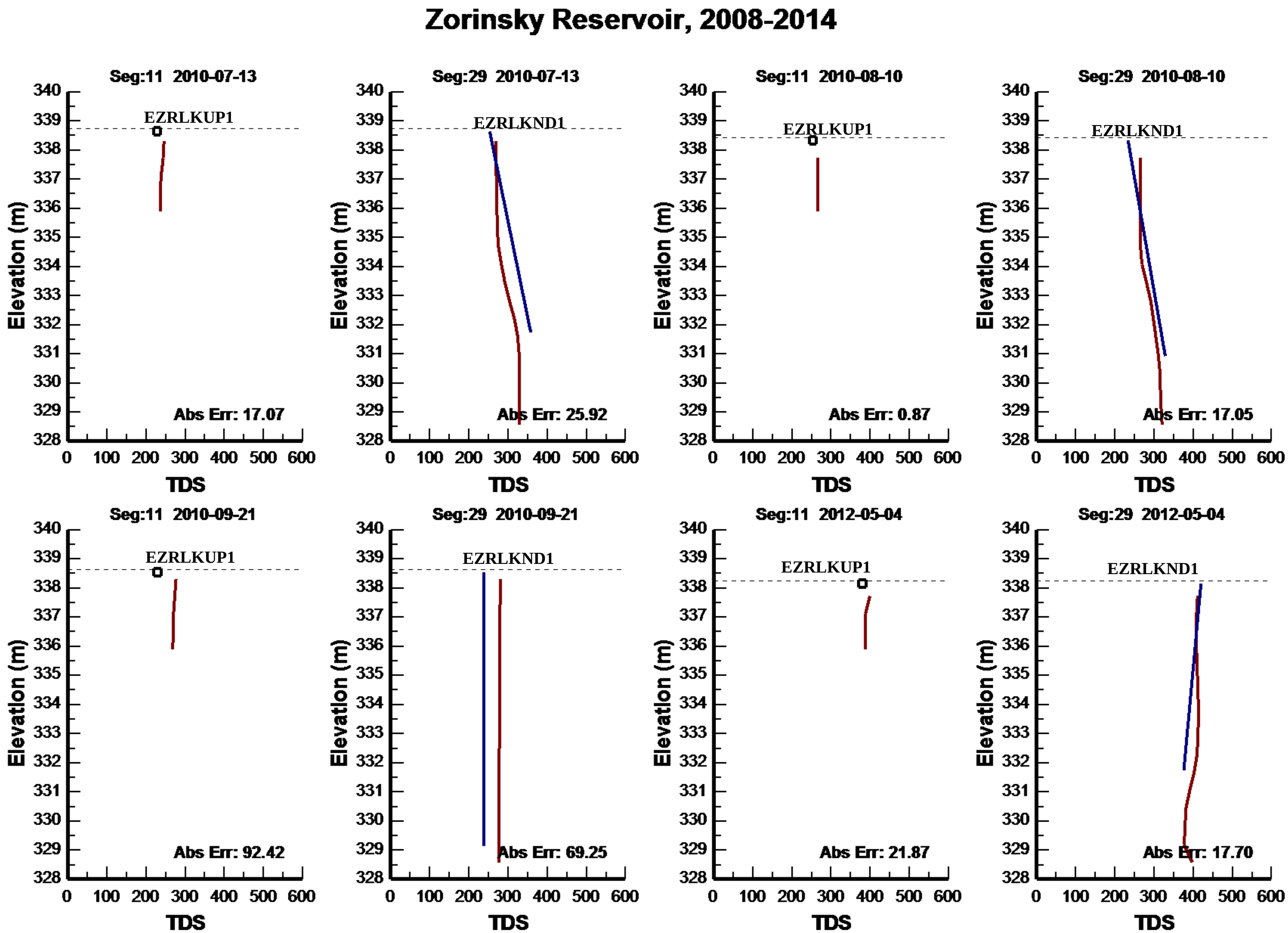


Plate 84. Observed (blue) versus model (red) TDS calibration profiles for July 2010 to May 2012.

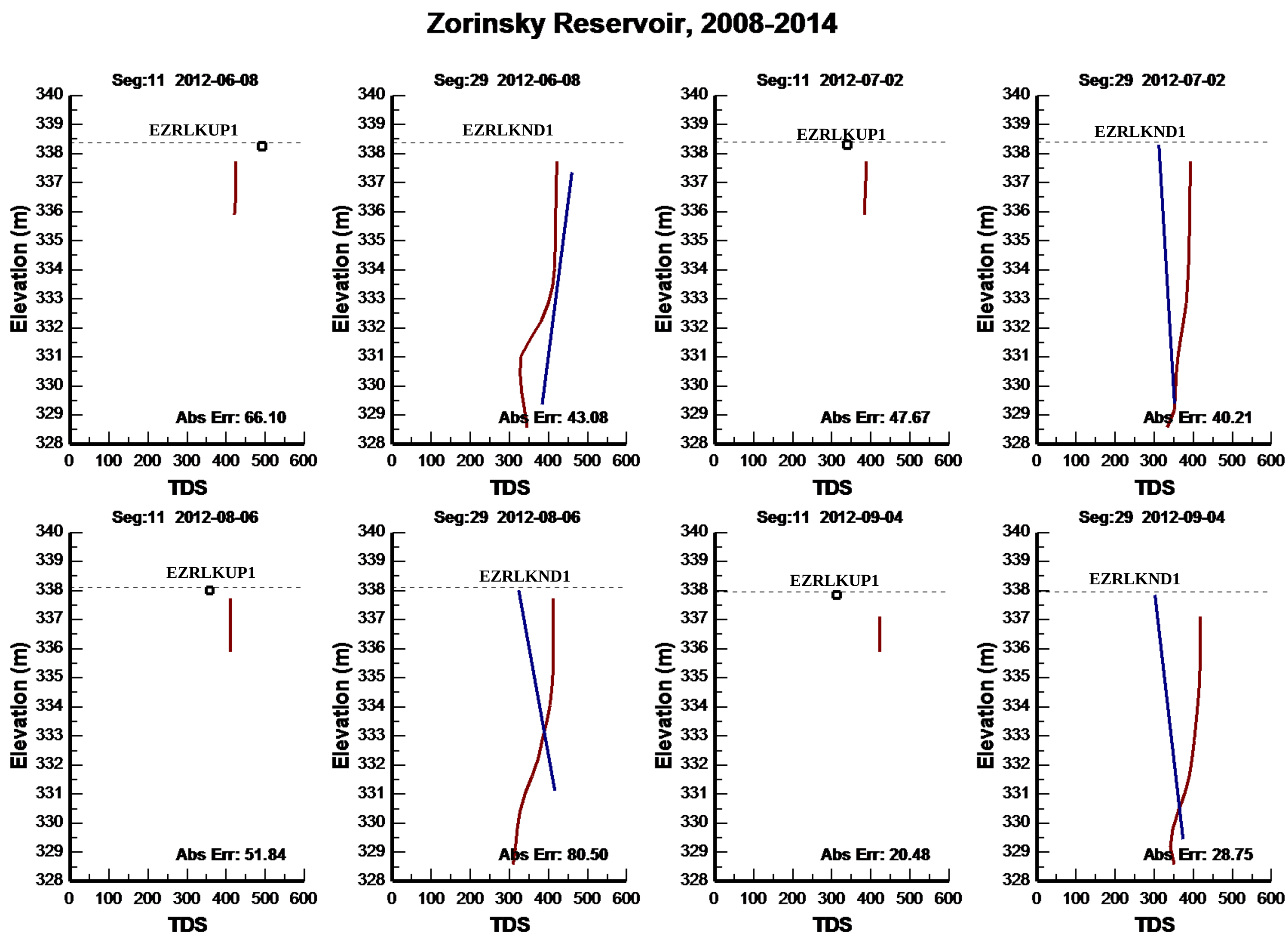


Plate 85. Observed (blue) versus model (red) TDS calibration profiles for June to September 2012.

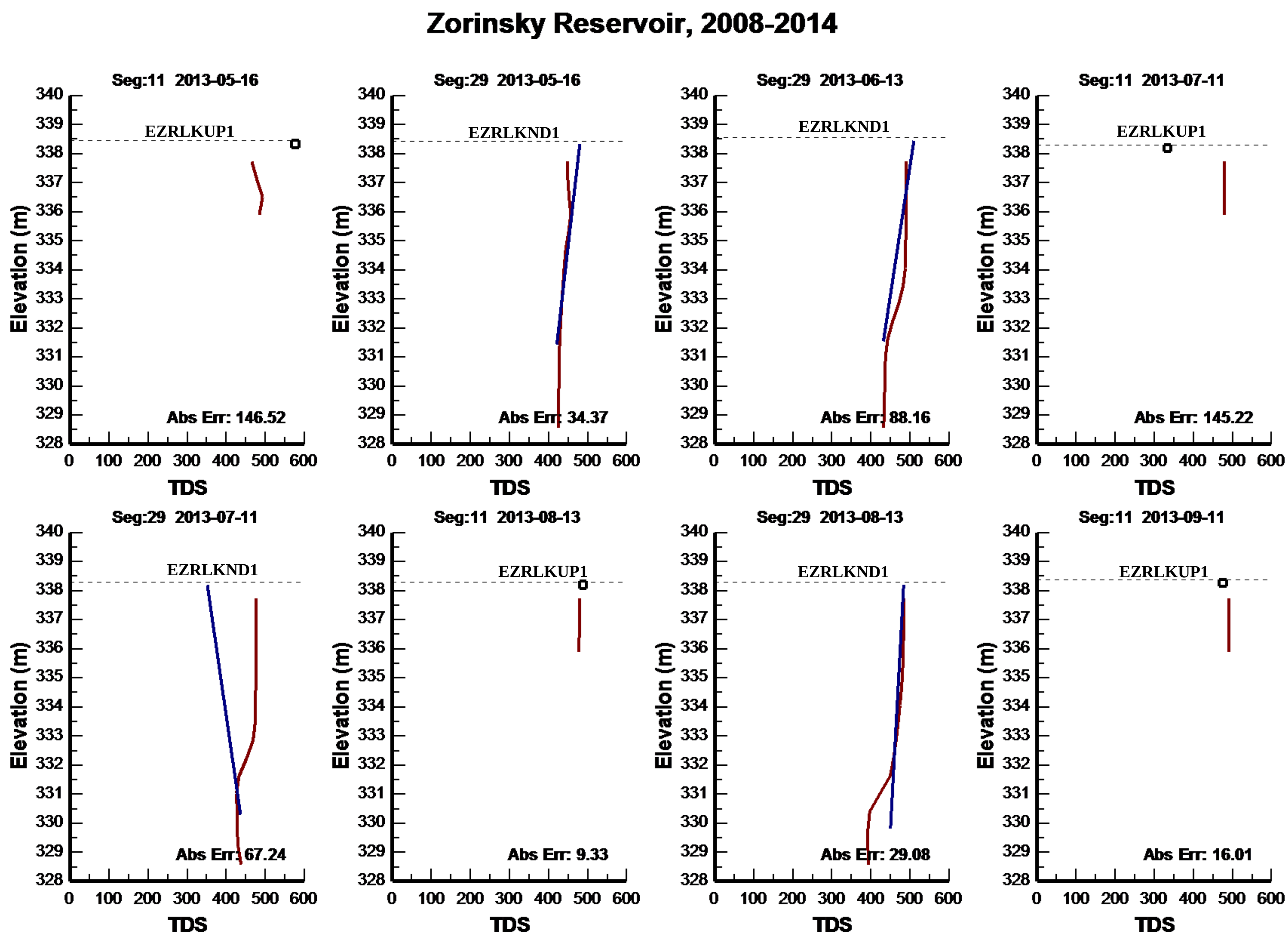


Plate 86. Observed (blue) versus model (red) TDS calibration profiles for May to September 2013.

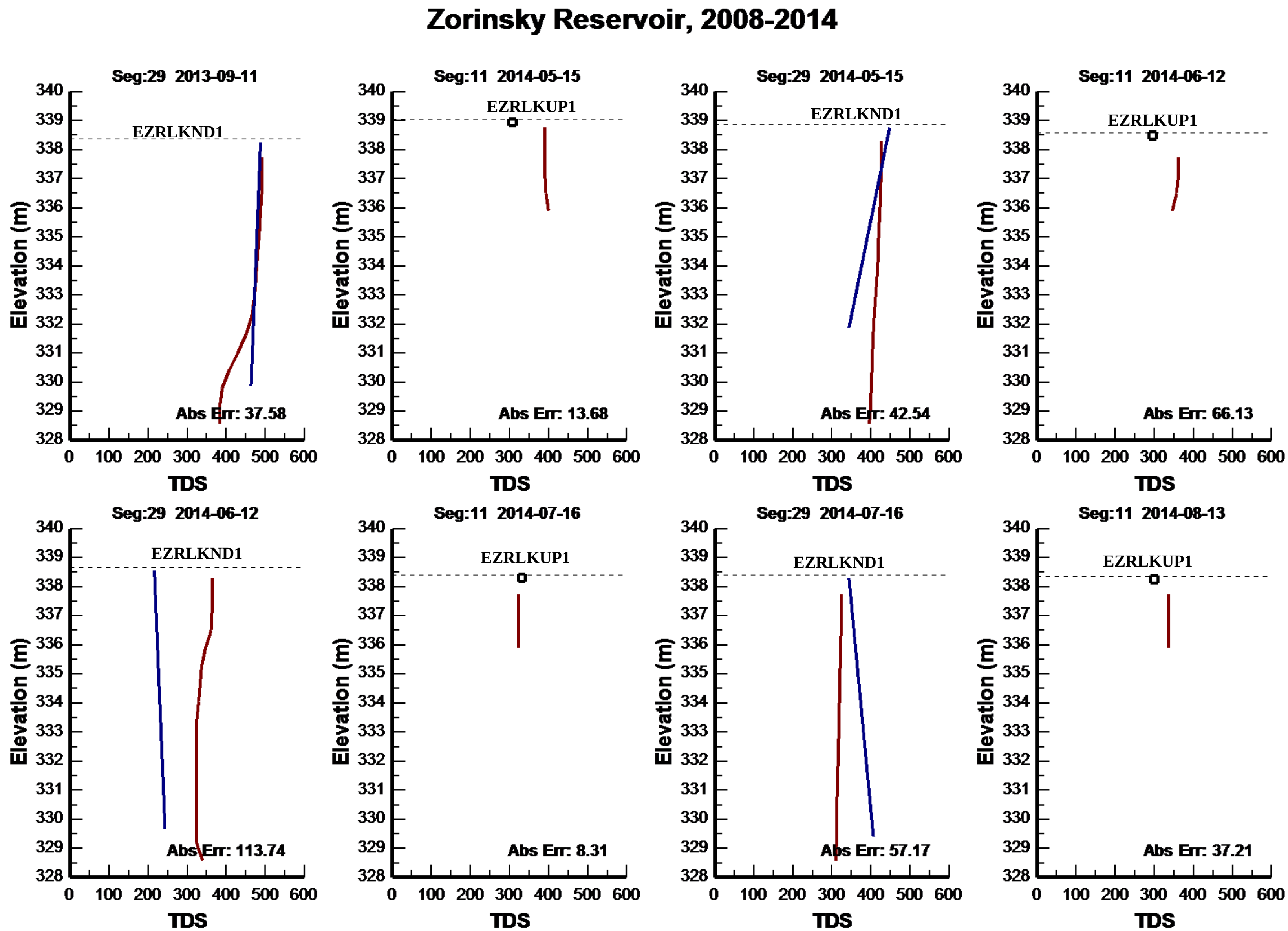


Plate 87. Observed (blue) versus model (red) TDS calibration profiles for September 2013 to August 2014.

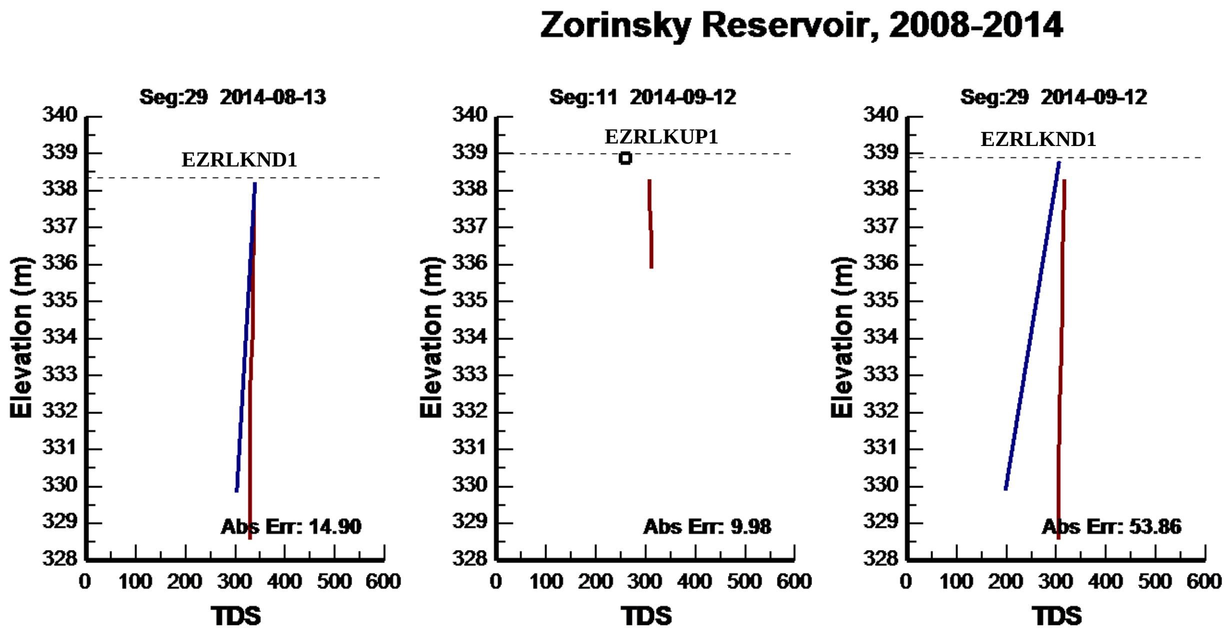


Plate 88. Observed (blue) versus model (red) TDS calibration profiles for August to September 2014.

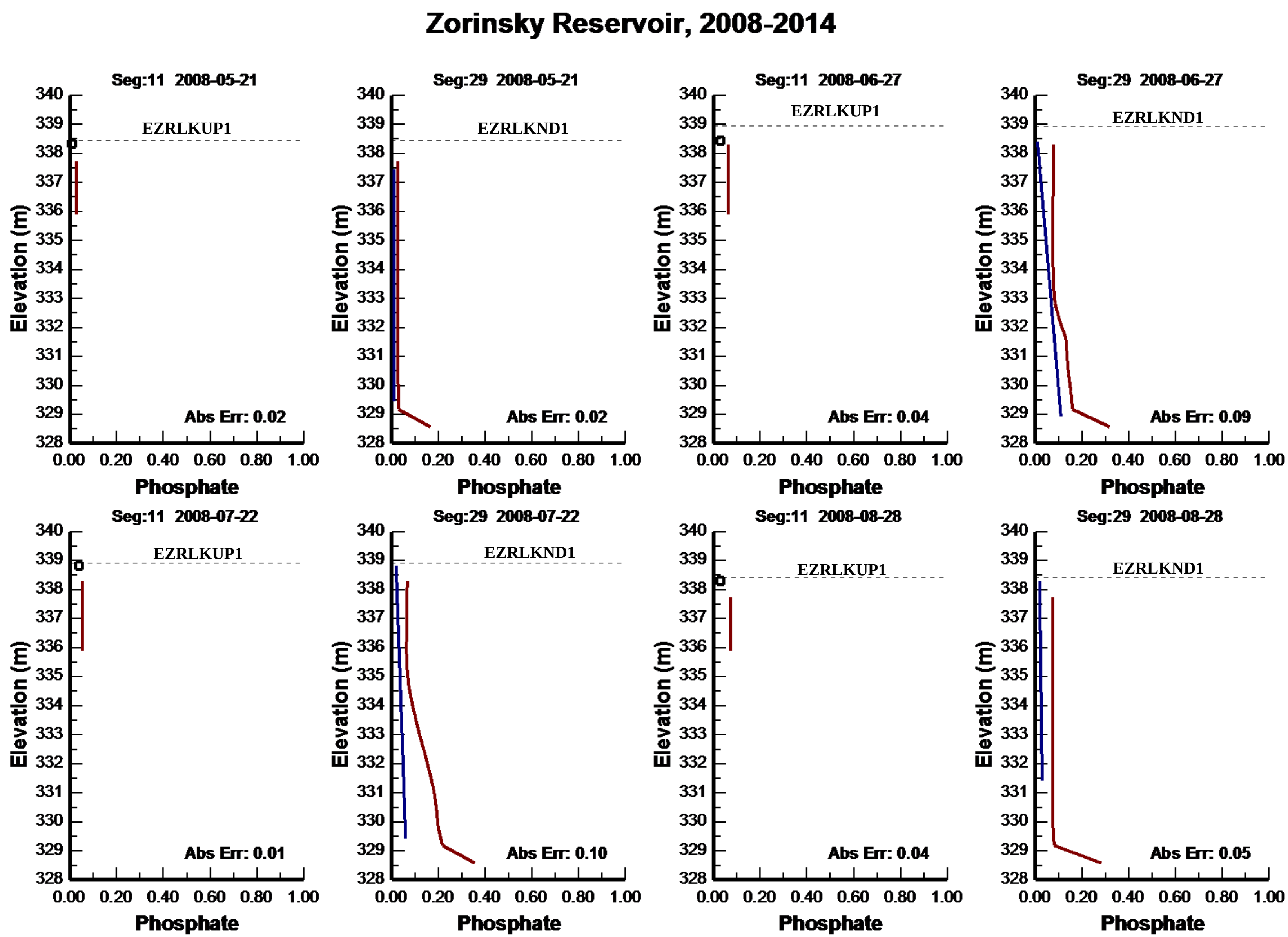


Plate 89. Observed (blue) versus model (red) PO_4 calibration profiles for May to August 2008.

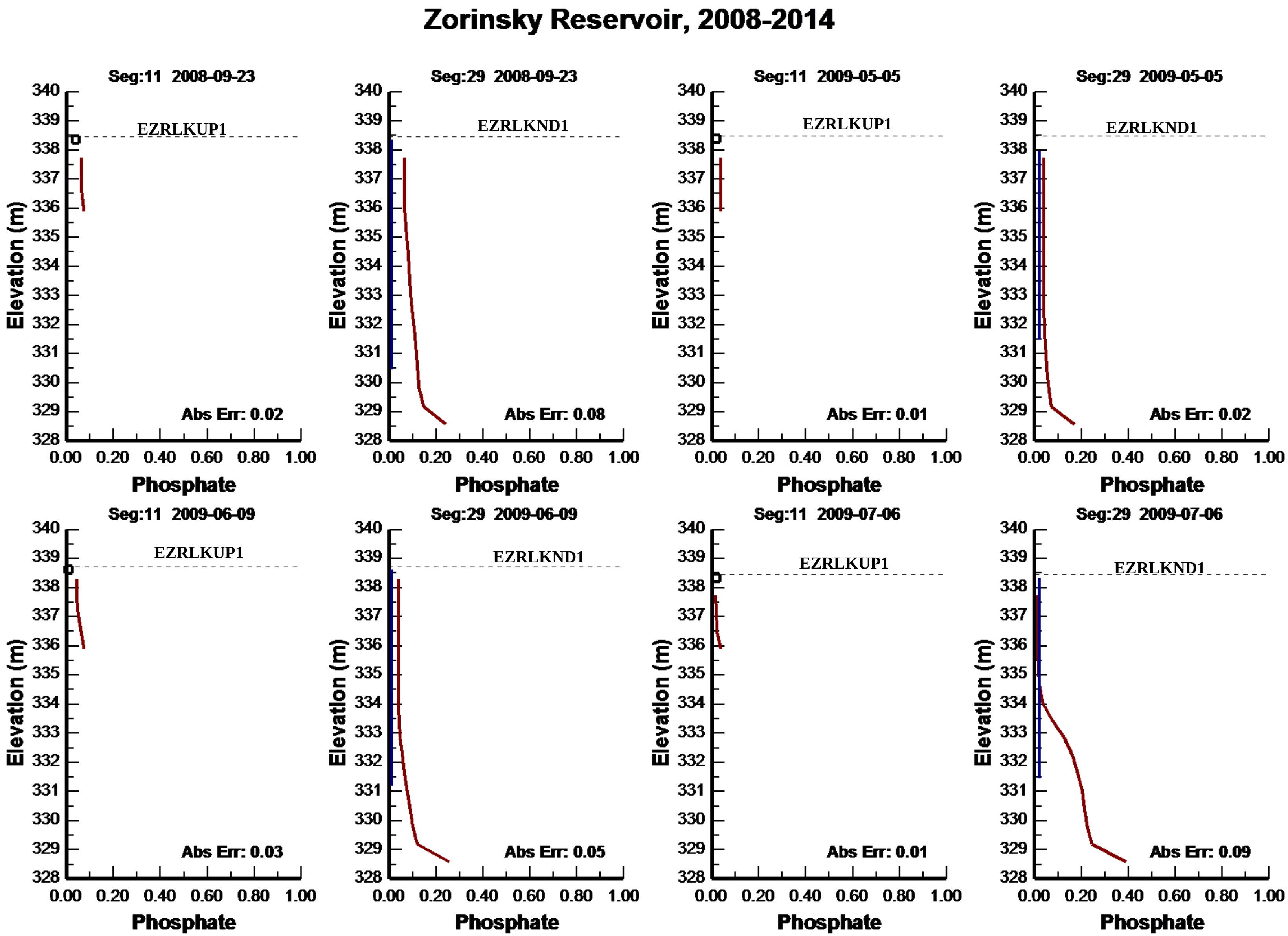


Plate 90. Observed (blue) versus model (red) PO_4 calibration profiles for September 2008 to July 2009.

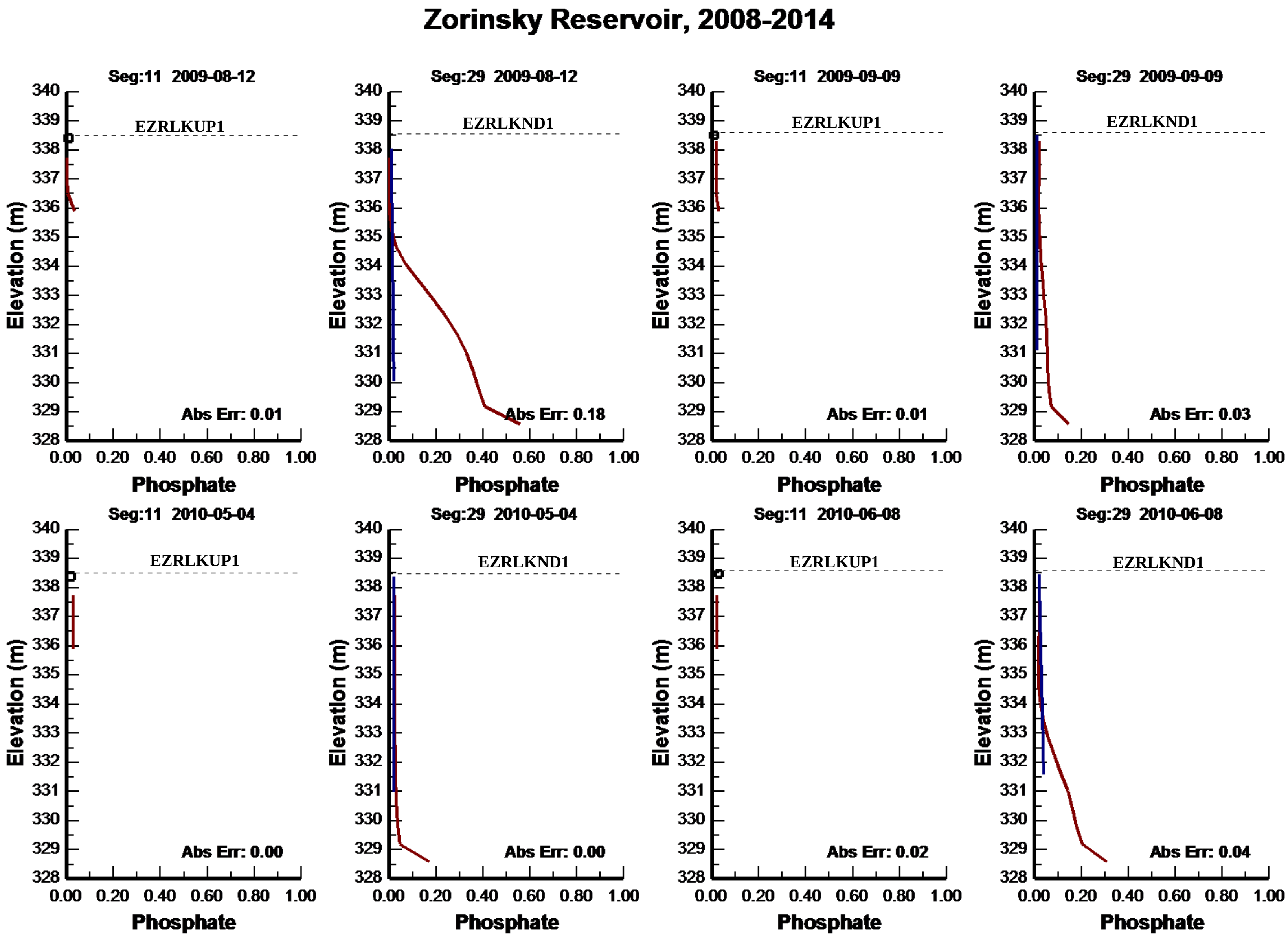


Plate 91. Observed (blue) versus model (red) PO_4 calibration profiles for August 2009 to June 2010.

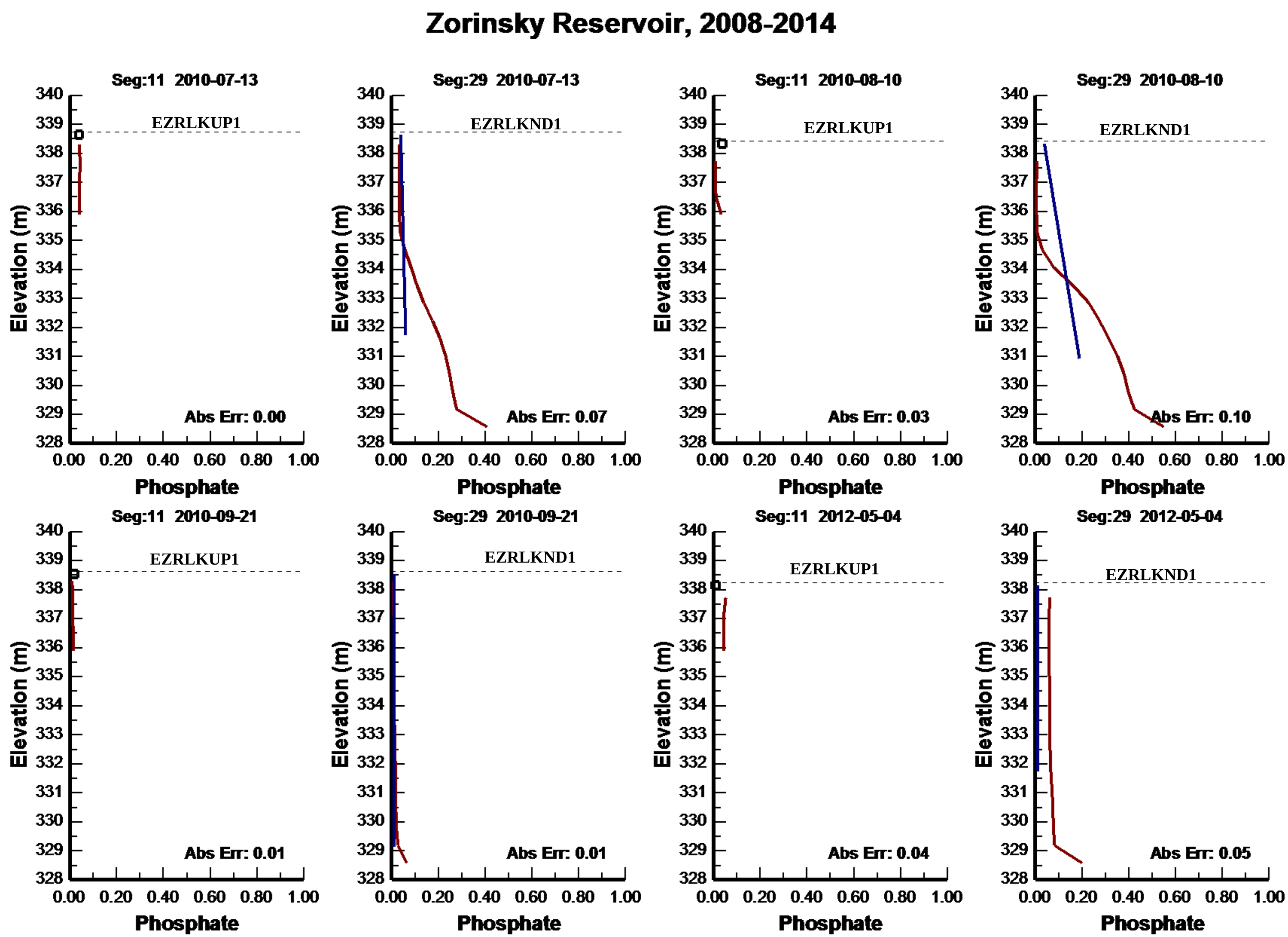


Plate 92. Observed (blue) versus model (red) PO_4 calibration profiles for July 2010 to May 2012.

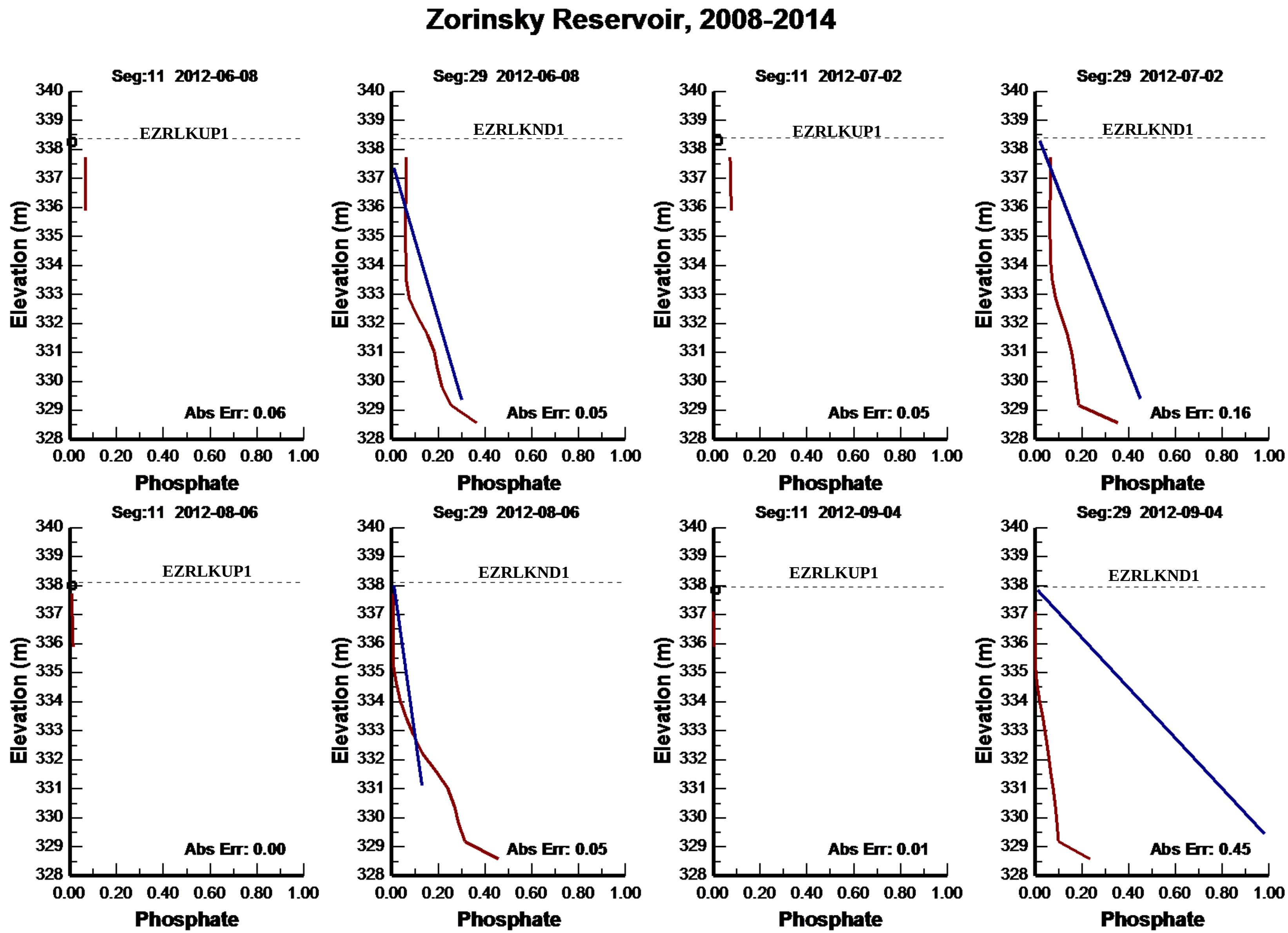


Plate 93. Observed (blue) versus model (red) PO_4 calibration profiles for June to September 2012.

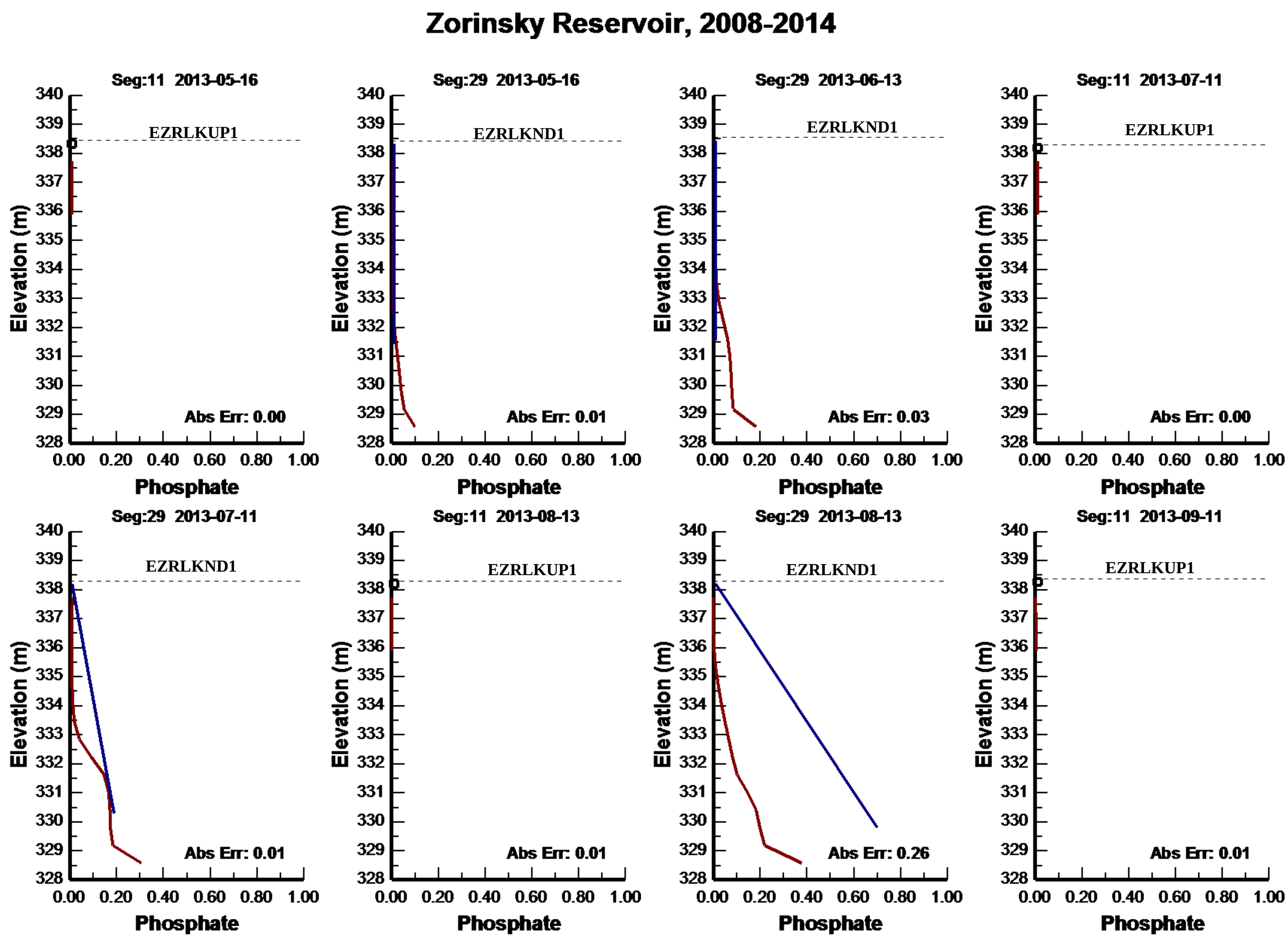


Plate 94. Observed (blue) versus model (red) PO_4 calibration profiles for May to September 2013.

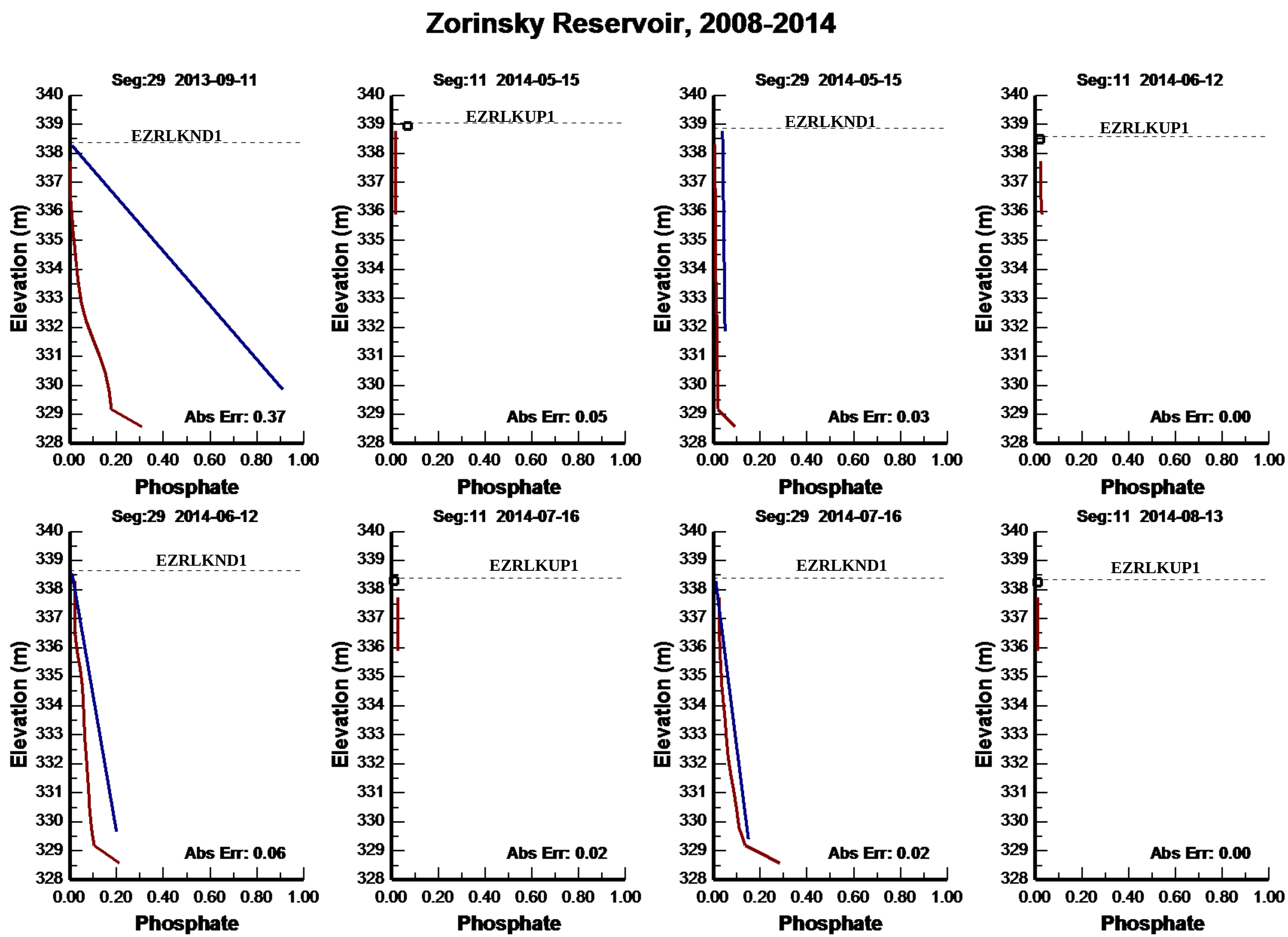


Plate 95. Observed (blue) versus model (red) PO_4 calibration profiles for September 2013 to August 2014.

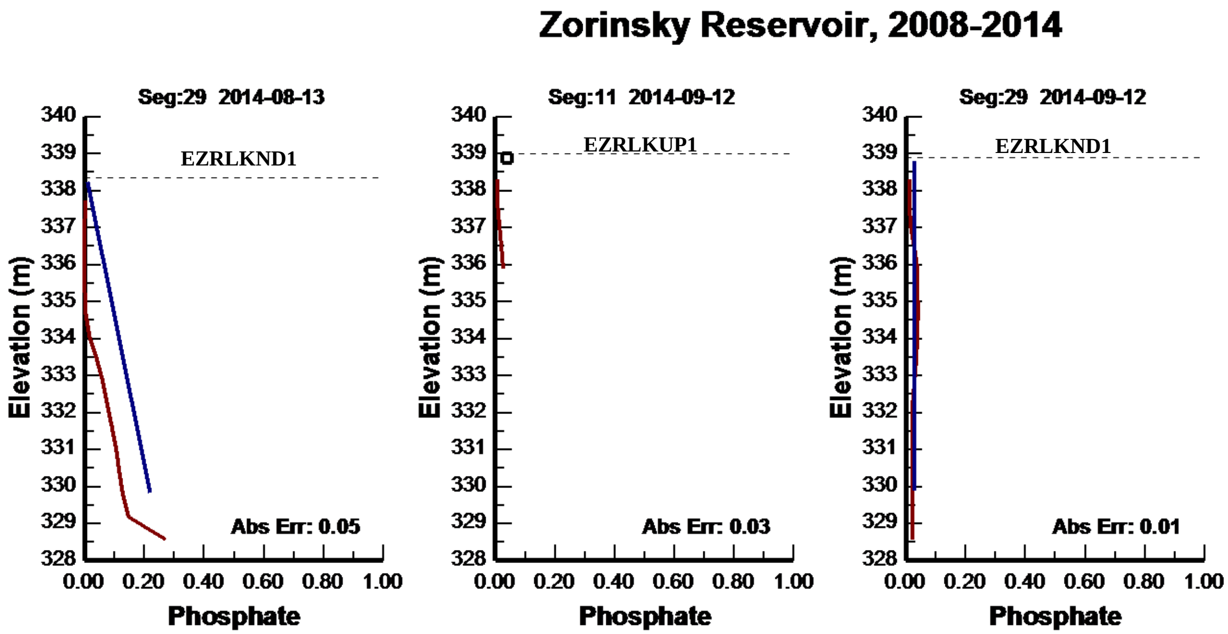


Plate 96. Observed (blue) versus model (red) PO_4 calibration profiles for August to September 2014.