Results of Lake Kachess Pumping Alternatives

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Introduction

The Lake Kachess CE-QUAL-W2 water quality model was developed to explore the impacts of the proposed implementation of the Kachess Drought Relief Pumping Plant (KDRPP) project (Berger and Wells, 2017). CE-QUAL-W2 version 4 is a public domain model developed by the US Army Corps of Engineers and Portland State University (Cole and Wells, 2016). It is a 2-dimensional (longitudinal-vertical) hydrodynamic and water quality model capable of predicting water surface, velocity, temperature, nutrients, multiple algae, zooplankton, periphyton, and macrophyte species, fish bioenergetics, sediment diagenesis, dissolved oxygen, pH, alkalinity, multiple CBOD groups, multiple suspended solids groups, multiple generic constituents (such as tracer, bacteria, toxics), and multiple organic matter groups, both dissolved and particulate. The model is set up to predict these state variables at longitudinal segments and vertical layers. The user manual and documentation can be found at the model website: http://www.cee.pdx.edu/w2.

This project utilized the Lake Kachess CE-QUAL-W2 model previously developed under Ecology Contract C1600073. Model simulations explored the water quality impacts of the proposed Kachess Drought Relief Pumping Plant project. Alternatives were designed to help determine the optimum pump intake depth for water quality and fish populations. The CE-QUAL-W2 model used Riverware output (dam outflows and pumping plant pump rates) for the 2014-2015 timeframe to simulate the following alternatives:

- No-action,
- East-shore pumping plant,
- South shore pumping plant, and
- The floating pumping plant (at multiple pipe intake lengths). This alternative included iterations on the pump intake elevation in 5 ft intervals to determine the optimum depth for maintaining thermal stratification for the floating pumping plant alternative.

Model Grid and Dam

Model grid for Lake Kachess is shown in Figure 1. The grid was developed using bathymetric data provided by the US Bureau of Reclamation (Young, 2016). Lake Kachess grid characteristics are shown in Table 1.

Table 1. Lake Kachess grid characteristics.

Parameter	**Value**
Grid length	10.6 miles, 17 km
Number of segments	74
Longitudinal grid spacing	754.7 ft, 230 m
Number of branches/waterbodies	1/1
Upstream active segment/downstream active segment	2/75
Vertical layer thickness	1 m

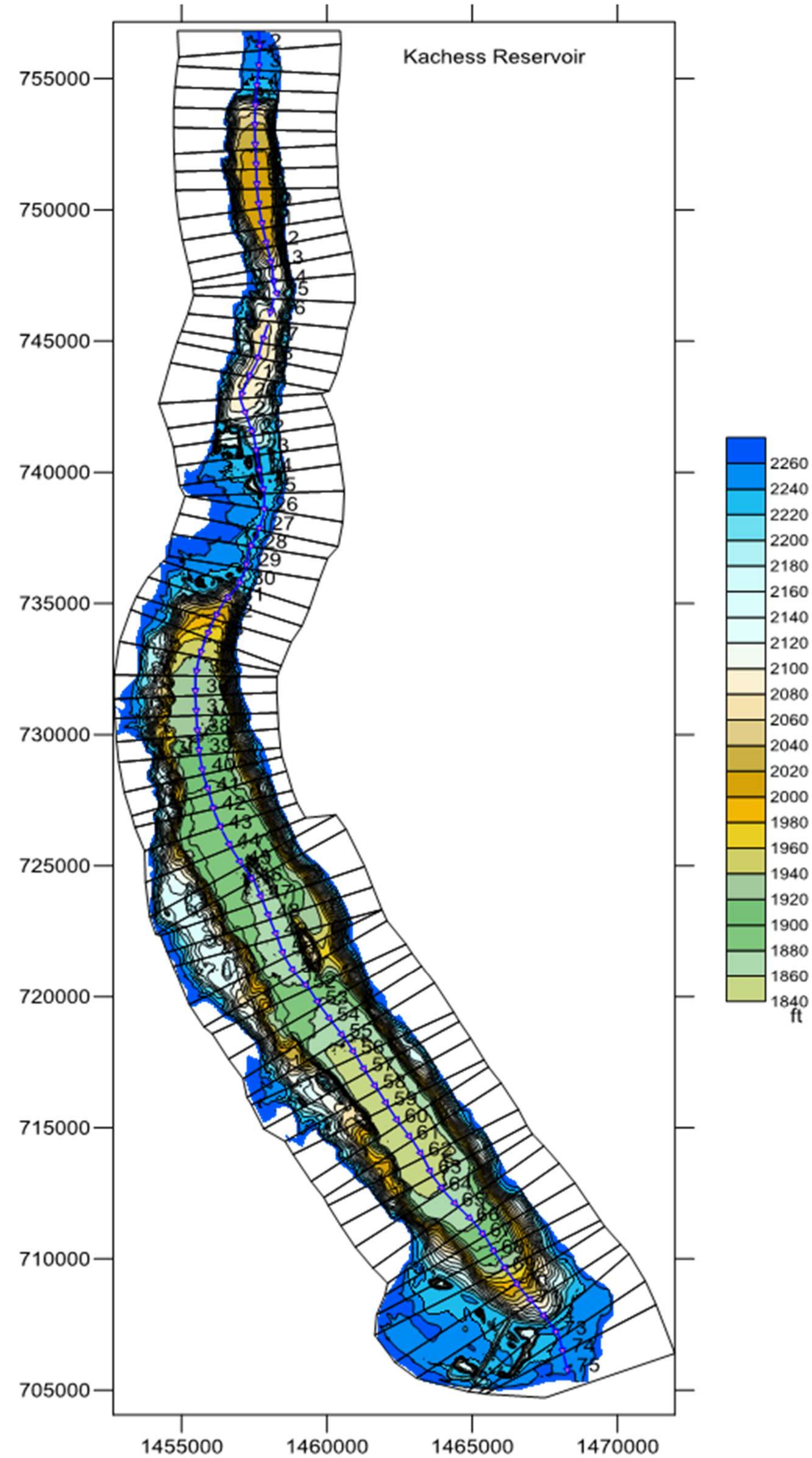

Figure 1. Kachess Reservoir grid showing model segment numbers.

Lake Kachess is a natural lake where storage has been increased by building a dam at the outlet. The dam was built by the U. S. Bureau of Reclamation to provide irrigation water for the Yakima Project. Dam specifications for Lake Kachess are listed in Table 2. Top of the dead storage pool is equal to the outlet gate sill bottom.

Table 2. Specifications for Kachess Dam (USBR).

Parameter	Value
Spillway crest elevation	2264.0 ft (690.067 m)
Top of active conservation pol	2262.0 ft. (689.459 m)
Top of dead storage pool	2192.75 ft. (668.350 m)
Total water storage	239,000 acre-feet
Spillway capacity	4000 cfs
Outlet works capacity	3700 cfs
Outlet gate sill bottom	2192.75 ft.

Scenarios and Results

The alternatives are listed in Table 3. The simulation period of the alternatives was from January 1, 2014 to September 30, 2015.

Table 3. Lake Kachess KDRPP Alternatives

Alternative #	Name	Comments
1	No-Action	Flows and initial water level generated by Riverware
2	East-shore Pumping Plant	Flows and initial water level generated by Riverware
3	South-Shore Pumping Plant	Flows and initial water level generated by Riverware
4	Floating Pumping Plant	Flows and initial water level generated by Riverware

Alternatives included an east-shore pumping plant (alternative #2), a south-shore pumping plant (alternative #3), and a floating pumping plant (alternative #4). The floating-pumping plant alternative consisted of multiple model simulations at varying withdrawal depths. The location of the pumping plants within the model grid and the withdrawal elevations are listed in Table 4.

Table 4. Model segment locations and withdrawal elevations of pumping alternatives.

Alternative #	Name	Model Segment	Withdrawal Elevation
2	East-shore Pumping Plant	70	1989 ft. (606.25 m)
3	South-Shore Pumping Plant	71	2088 ft. (636.43 m)
4	Floating Pumping Plant	71	Variable, including 10 ft. (3.048 m), 18 ft. (5.49 m), 20 ft. (6.096 m), 25 ft. (7.62 m), 30 ft. (9.144 m), 35 ft. (10.668 m), 40 ft. (12.192 m) and 50 ft. (15.24 m)

Water level predictions of the alternatives are compared in Figure 2. The initial water level for the alternatives on 1/1/2014 was 680.735 m (2233.4 ft). The Lake Kachess dam outflow rates are plotted in Figure 3. For alternatives 2, 3, and 4, dam outflows were zero when pumping began on 8/17/2015 (Figure 4).

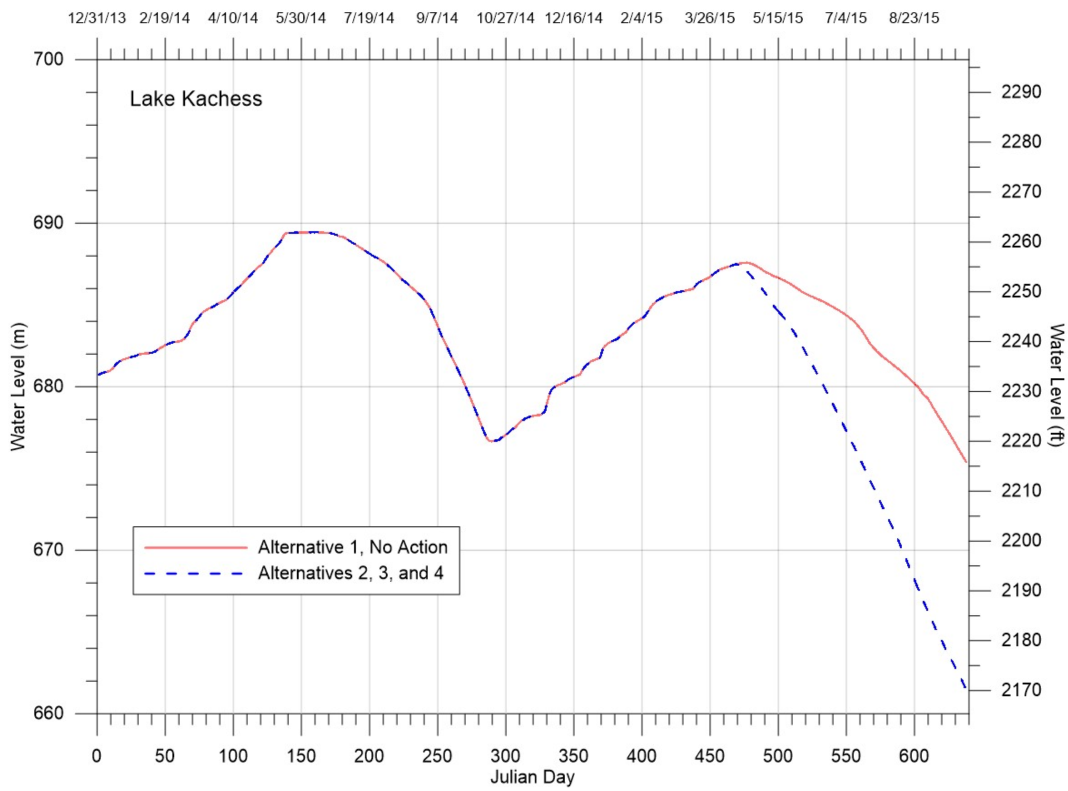

Figure 2. Predicted water levels for the alternatives.

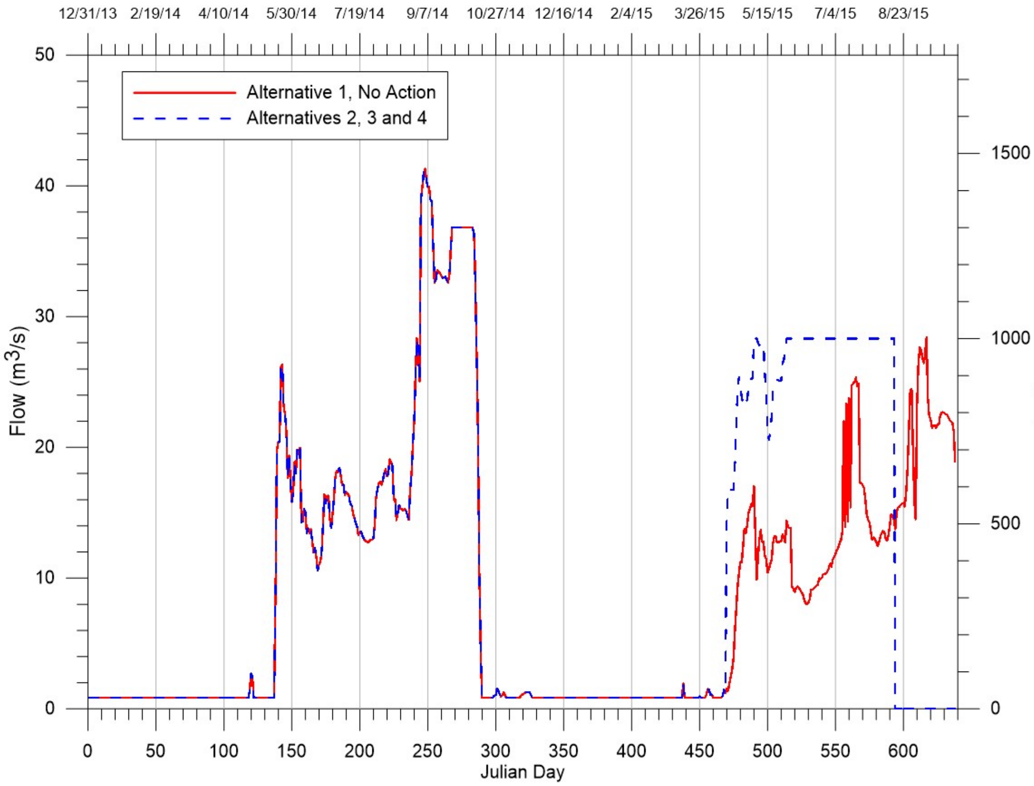

Figure 3. Lake Kachess dam outflow rates

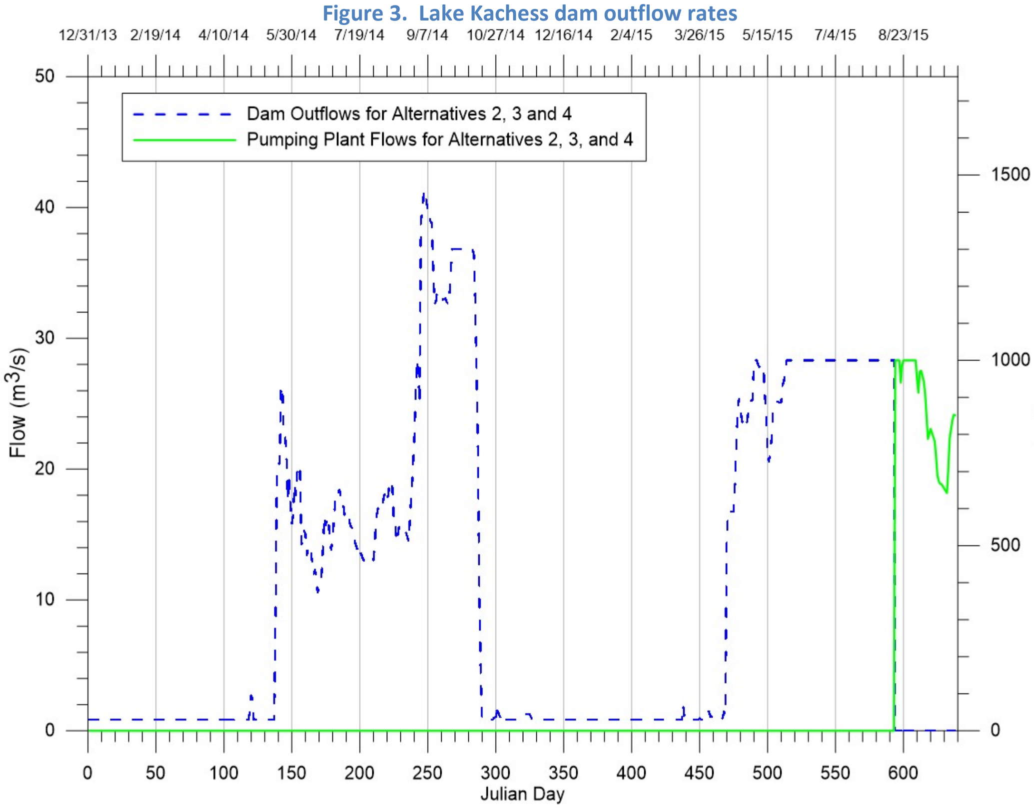

Figure 4. Lake Kachess pumping flows and dam outflows for alternatives 2, 3, and 4.

To illustrate the depth of the thermocline for the alternatives, vertical temperature profiles of model segment 70 near the dam were compared (Figure 5). Pumping plant withdrawals began 8/17/2015 (Julian

Day 594) and continued through the end of the simulations on 9/30/2015 (Julian Day 638). Vertical temperature profiles at the start of pumping plant withdrawals on 8/17/2015 are plotted for alternatives 1, 2 and 3 in Figure 6 and for alternative 4 in Figure 7. Vertical temperature profiles are also compared for 9/7/2015 (Figure 8 and Figure 9) and 9/29/15 (Figure 10 and Figure 11). The alternatives did not significantly change the depth of the thermocline or water temperatures deep in the hypolimnion. Temperatures in the epilimnion varied by up to 1.5° Celsius. Because the elevations of the withdrawals were relatively deep, no warm epilimnetic water was being withdrawn near the surface for the east-shore and south-shore pumping plant alternatives. Temperatures in the epilimnion for these alternatives were 1° C warmer relative to the no-action alternative by 9/29/15 (Figure 10). Epilimnetic temperatures for the alternative 4 simulations were dependent upon the depth of the withdrawal. By 9/29/15, epilimnion temperatures approximately 1.5° cooler for the 10' pumping depth simulation relative to the simulations with the greatest pumping depths (Figure 11).

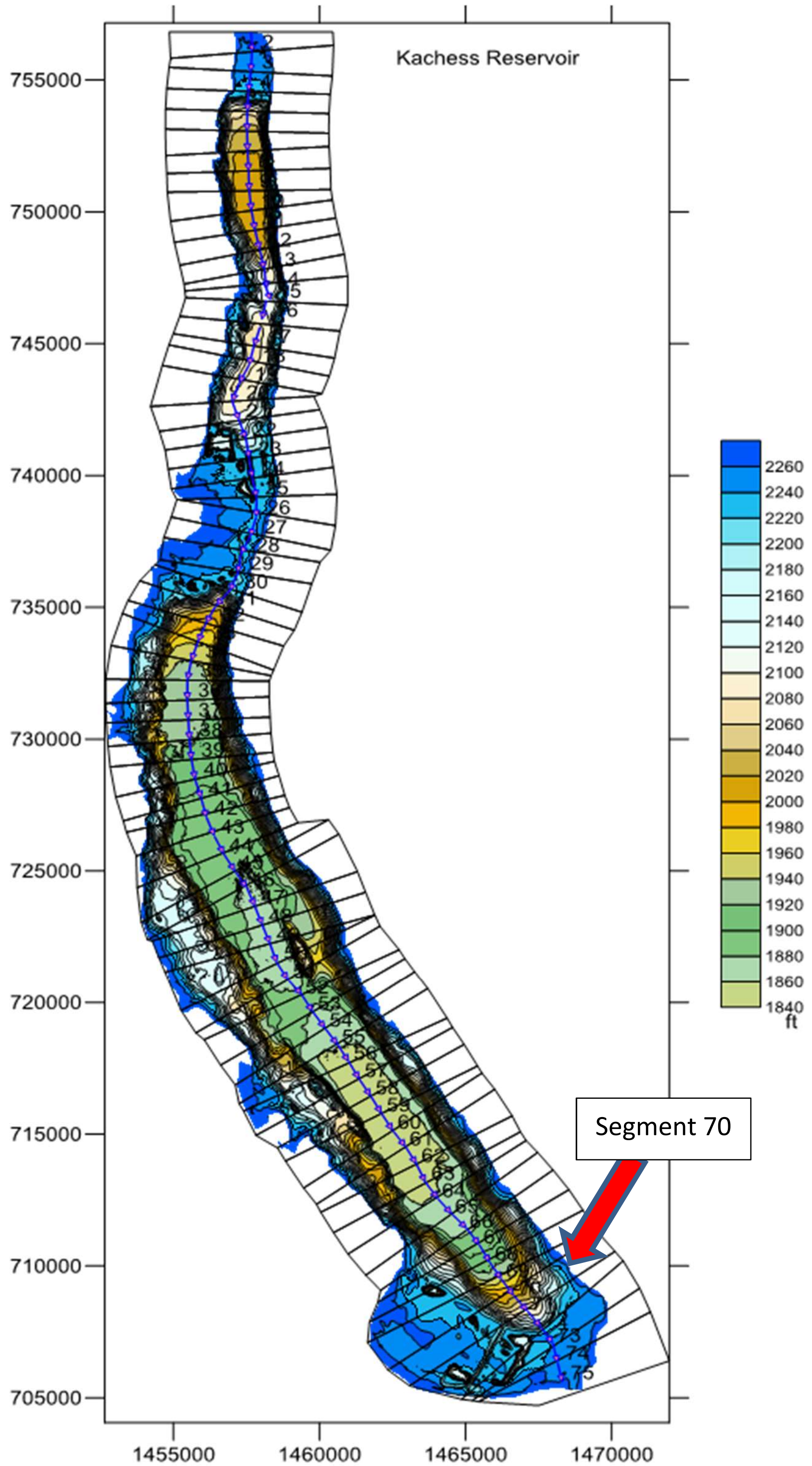

Figure 5. Lake Kachess grid showing model segment numbers. Vertical profiles were plotted for segment 70 near the bottom of the illustration.

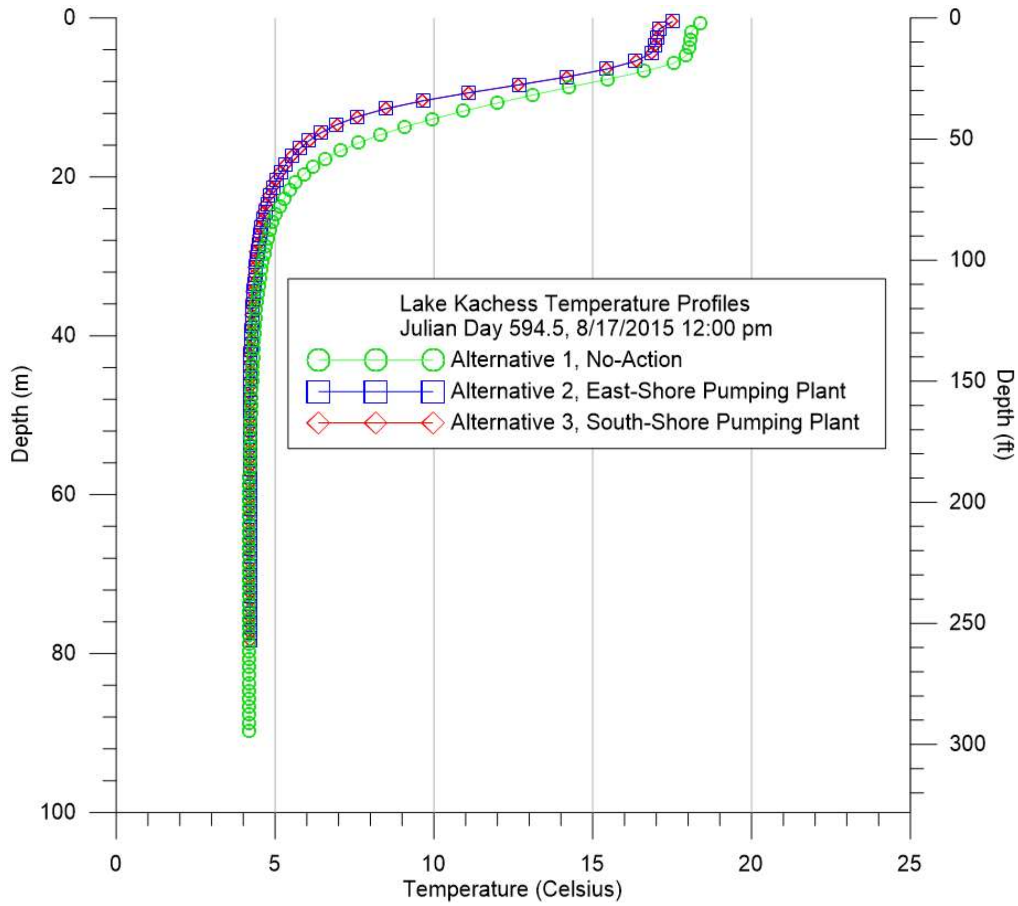

Figure 6. Lake Kachess temperature profiles for alternatives 1, 2, and 3 on 8/17/2015. Pumping plant withdrawals began on this date.

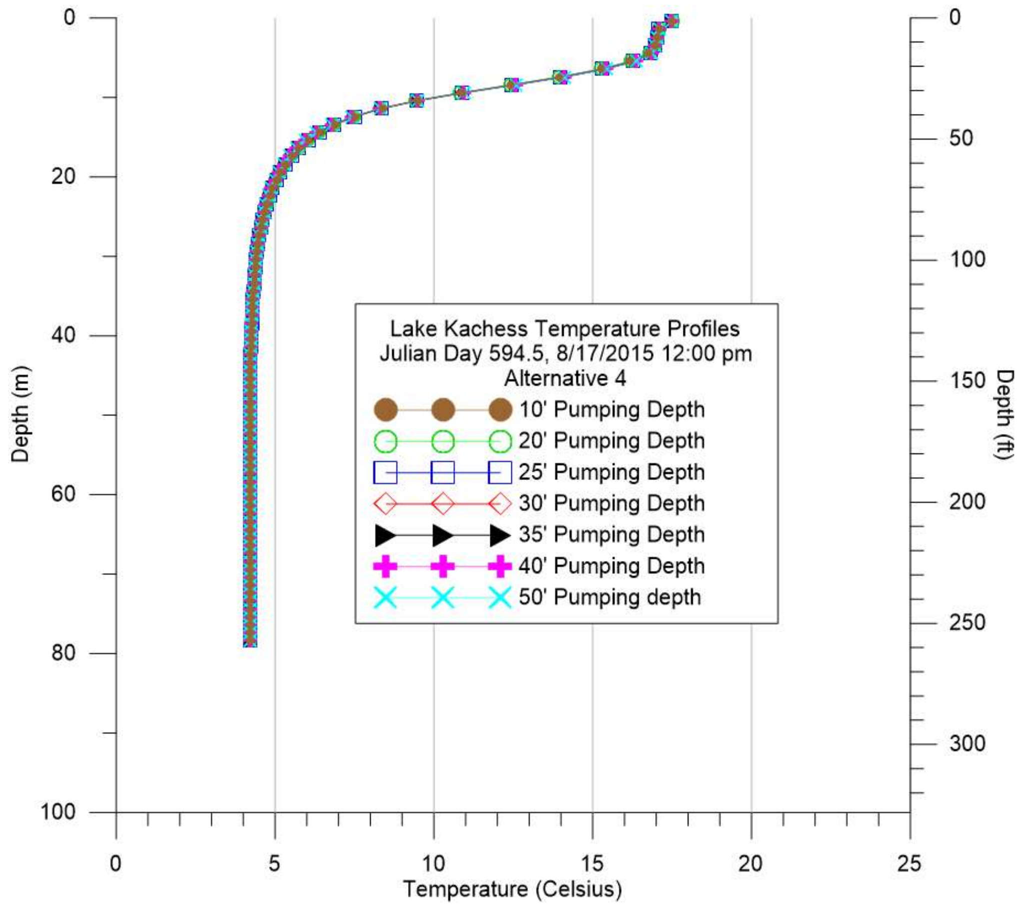

Figure 7. Lake Kachess temperature profiles for alternative 4 simulations on 8/17/2015. Pumping plant withdrawals began on this date.

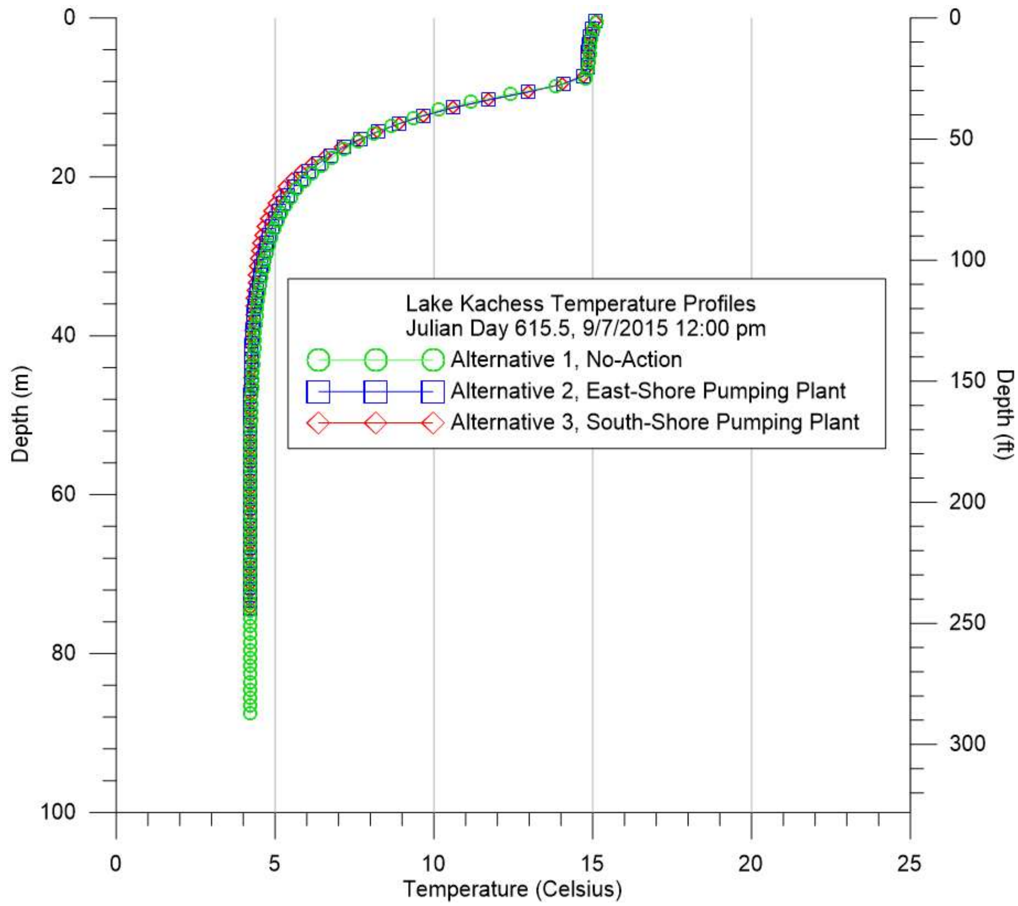

Figure 8. Lake Kachess temperature profiles for alternatives 1, 2, and 3 on 9/7/2015, 3 weeks after pumping began.

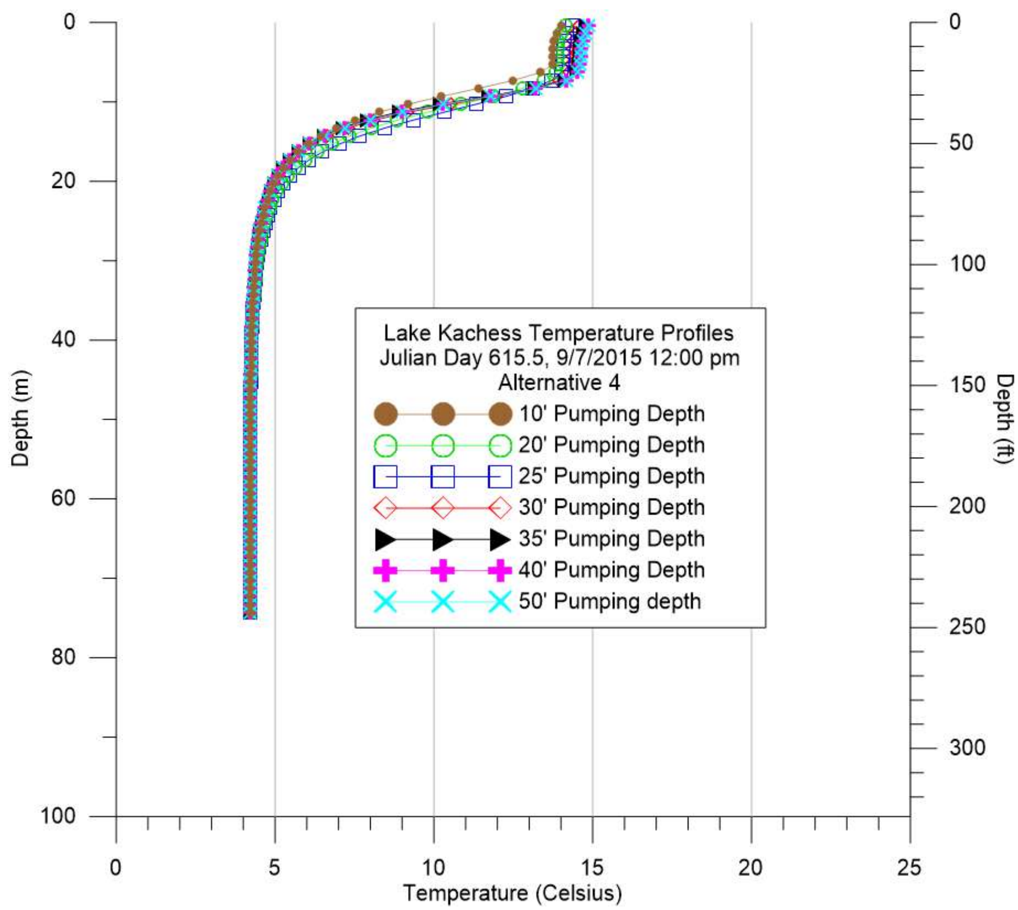

Figure 9. Lake Kachess temperature profiles for alternative 4 simulations on 9/7/2015, 3 weeks after pumping began.

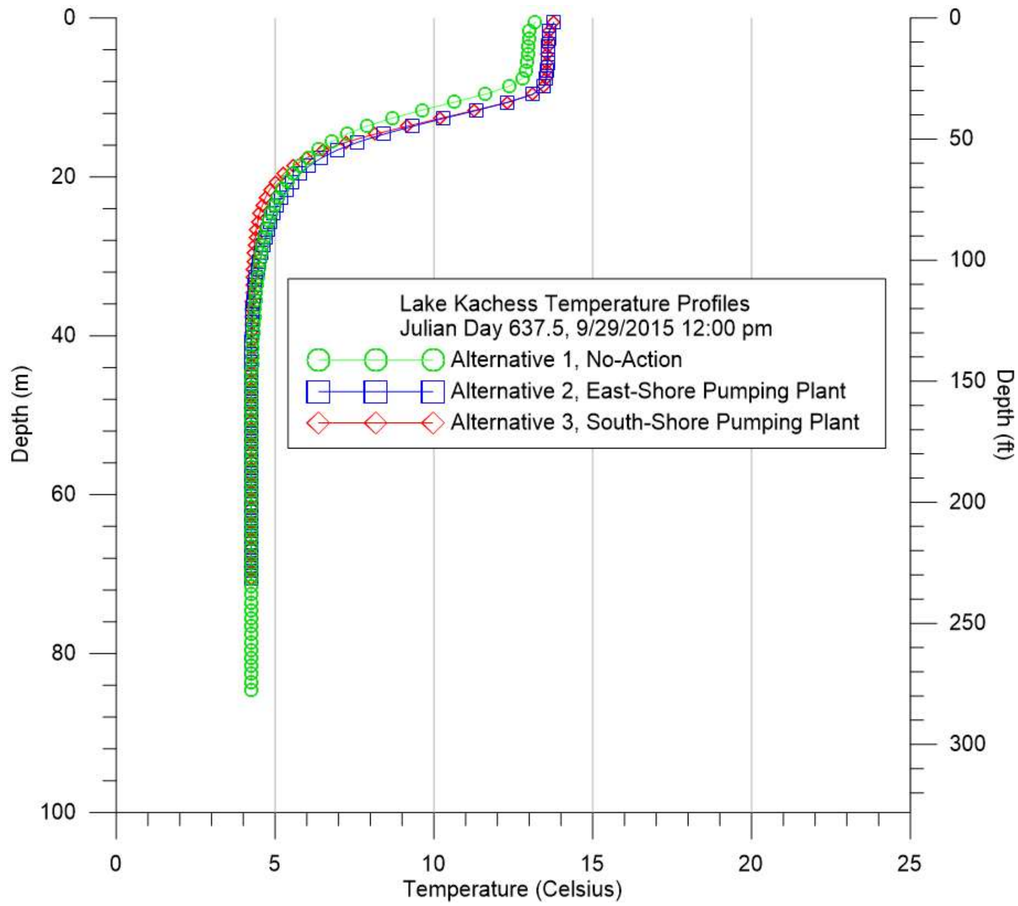

Figure 10. Lake Kachess temperature profiles for alternatives 1, 2, and 3 on 9/29/2015.

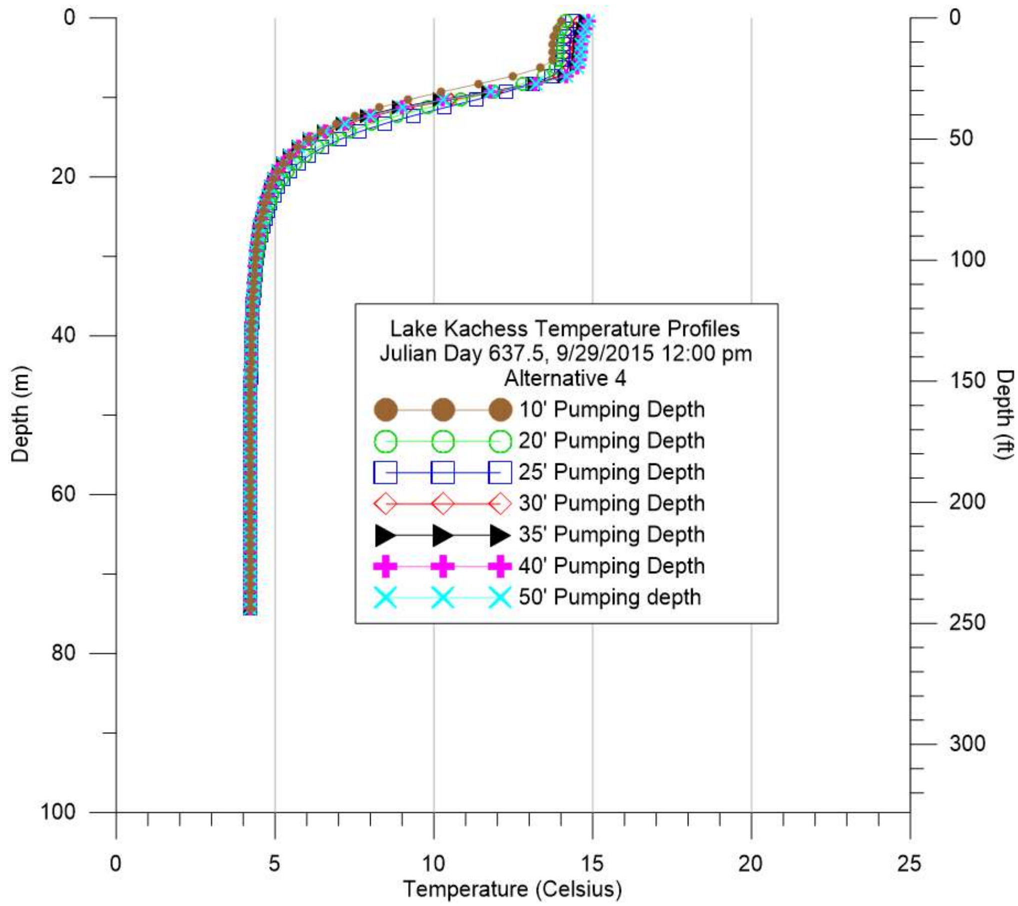

Figure 11. Lake Kachess temperature profiles for alternative 4 simulations on 9/29/2015.

The model predicted 7-day average of daily maximum and minimum outflow temperatures through the dam structure are plotted in Figure 12. Flows through the dam structure ended when pumping began on 8/17/15, so there are no dam structure outflow temperatures for alternatives 2, 3, and 4 plotted after this date. Daily maximum and minimum pumping plant outflow temperatures for alternatives 2 and 3 are shown in Figure 13. Due to the depth of the withdrawals, the east-shore and south-shore pumping plant outflow temperatures were much cooler than that of the no-action alternative. Pumping plant daily maximum and minimum outflow temperatures for alternative 4 scenarios including the 10’ pumping depth simulation, 18’ pumping depth simulations, 30’ pumping depth simulation, and the 50’ pumping depth simulation are plotted in Figure 14. As expected, the 10’ pumping depth simulation had the highest outflow temperatures because water was being withdrawn from the epilimnion. The daily maximums of the 18’ pumping depth simulation were close to that of the 10’ pumping depth scenario, but daily minimums were 0° to 3° C cooler. The 30’ depth pumping depth simulation withdrew water close to the thermocline, and daily maximums and minimum varied considerably depending upon the location of the thermocline which could vary due internal seiching. Outflows of the 50’ deep withdrawal scenario were coolest.

Average reservoir outflow temperatures of the alternatives between 8/17/15 and 9/30/15 are listed in Table 5. These are the average water temperatures passing through the pumping plant or through the dam (for the no-action alternative). The deeper the withdrawal depth, the cooler the water temperatures passing out of the reservoir.

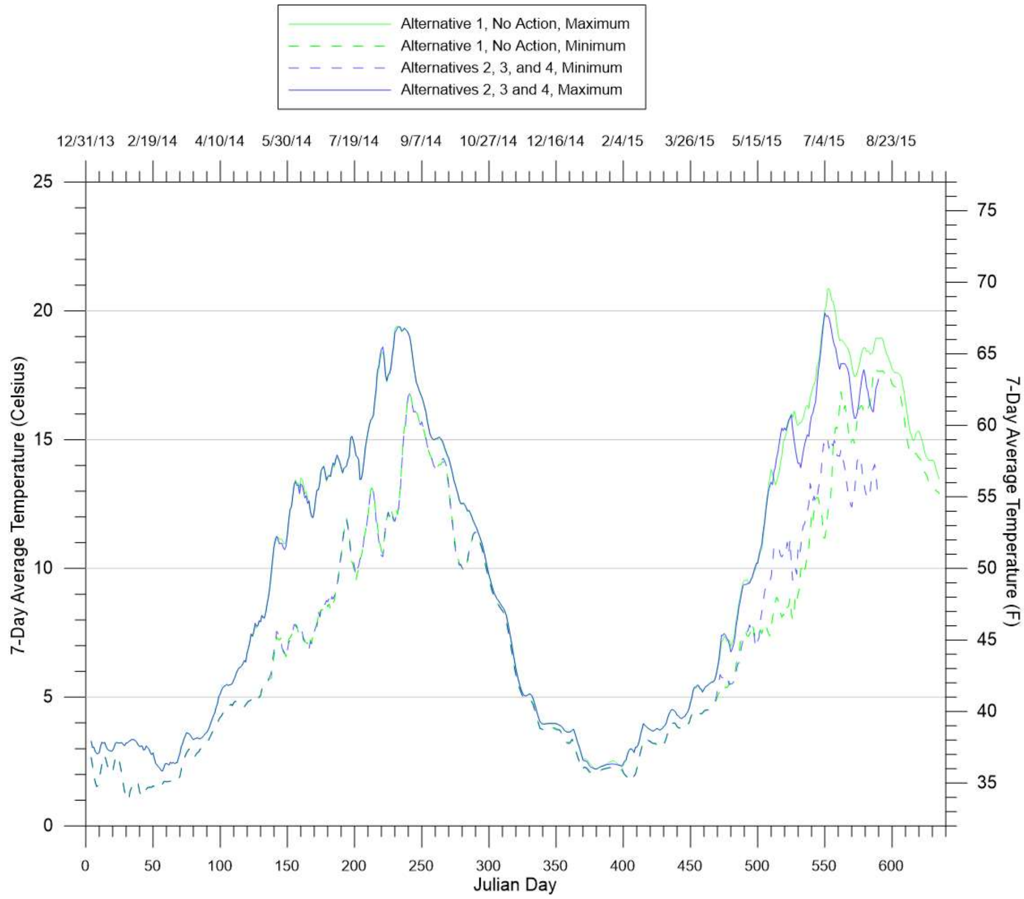

Figure 12. Lake Kachess 7-day average of daily maximum and minimum dam structure outflow temperatures. Flows through the dam structure ended for alternatives 2, 3, and 4 ended on 8/17/15.

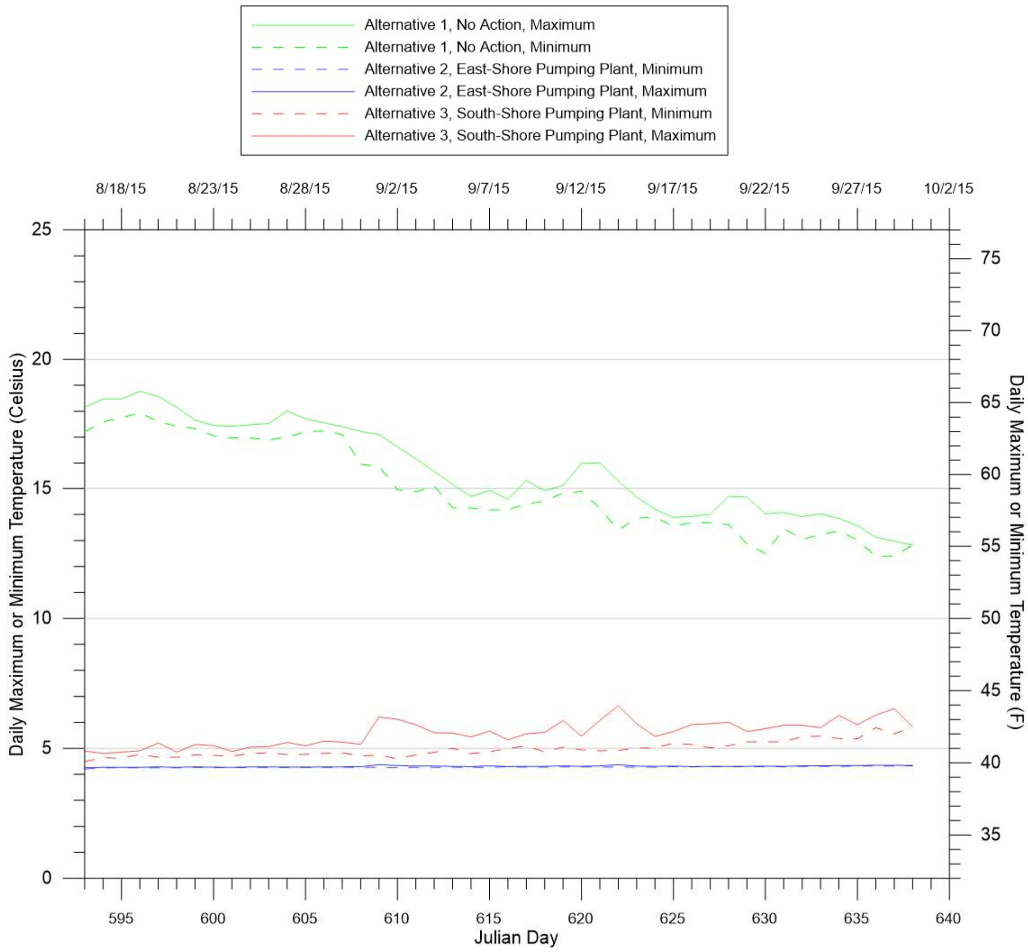

Figure 13. Daily maximum and minimum pumping plant outflow temperatures for alternatives 2 and 3 compared with dam structure outflow temperatures of alternative 1 (no action).

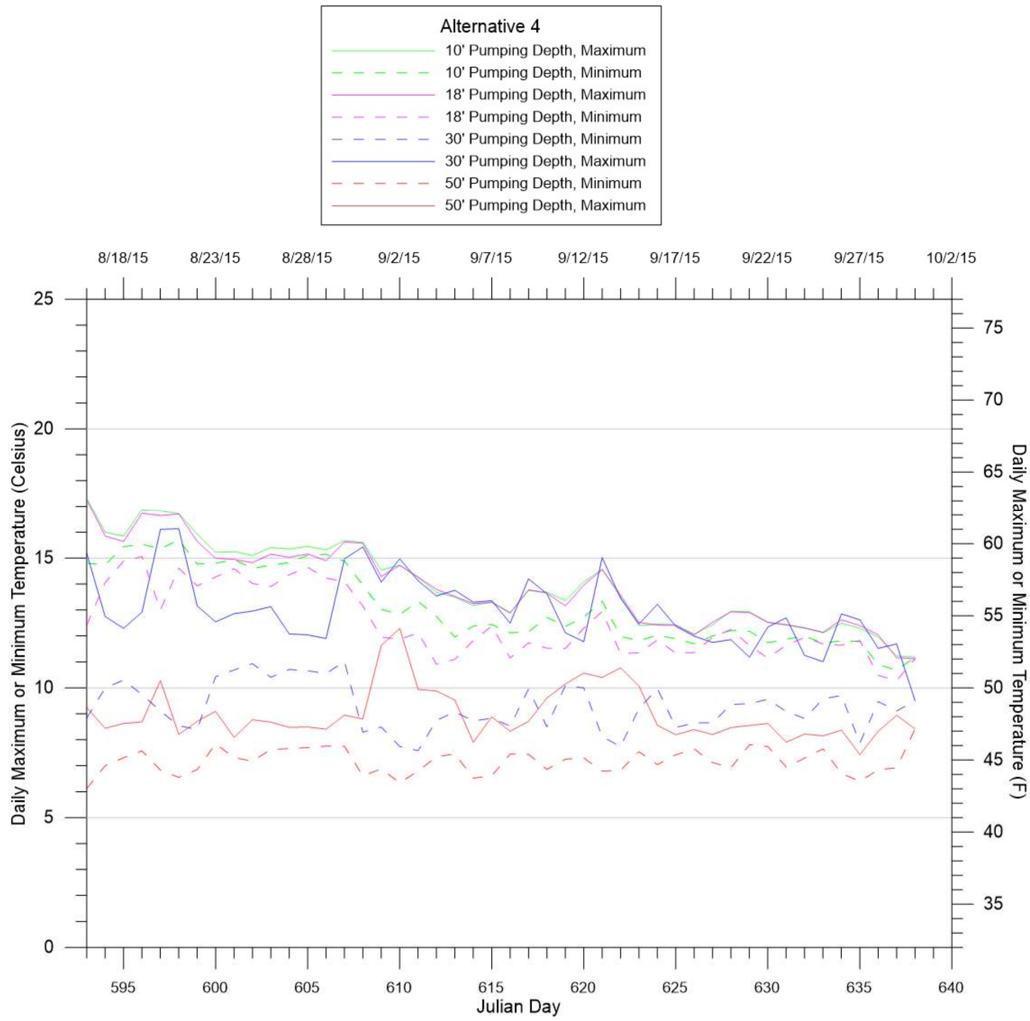

Figure 14. Daily maximum and minimum pumping plant outflow temperatures for alternative 4 simulations.

Table 5. Average reservoir outflow temperatures between 8/17/15 and 9/30/15 for the alternatives.

Alternative #	Description	Reservoir Outflow Temperature (Celsius)
1	No-Action	15.40
2	East-shore Pumping Plant	4.29
3	South-Shore Pumping Plant	5.20
4 (10 ft. pumping depth)	Floating Pumping Plant, 10 foot pumping depth	13.54
4 (18 ft. pumping depth)	Floating Pumping Plant, 18 foot pumping depth	13.27
4 (20 ft. pumping depth)	Floating Pumping Plant, 20 foot pumping depth	13.10
4 (25 ft. pumping depth)	Floating Pumping Plant, 25 foot pumping depth	12.28
4 (30 ft. pumping depth)	Floating Pumping Plant, 30 foot pumping depth	11.01

Alternative #	Description	Reservoir Outflow Temperature (Celsius)
4 (35 ft. pumping depth)	Floating Pumping Plant, 35 foot pumping depth	9.70
4 (40 ft. pumping depth)	Floating Pumping Plant, 40 foot pumping depth	8.96
4 (50 ft. pumping depth)	Floating Pumping Plant, 50 foot pumping depth	7.91

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