Impacts of the Lake Elsinore Advanced Pumped-Storage (LEAPS) Project on Water Quality in Lake Elsinore

Some Preliminary Results

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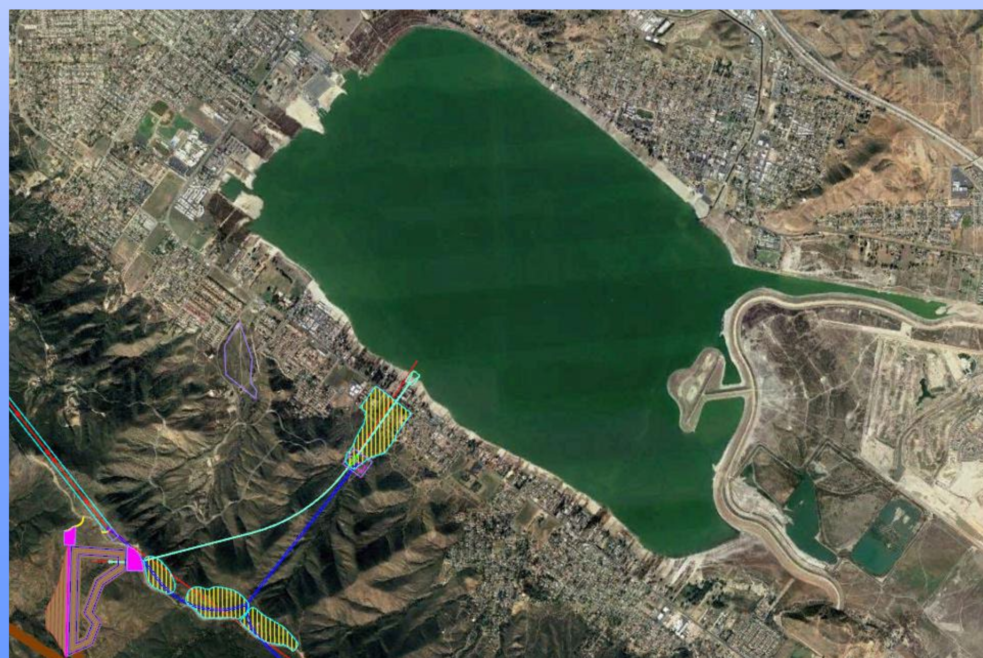
I. Introduction

- Pumped-storage hydroelectric plants play important roles in load balancing of electrical supply grids by
  - providing electricity during periods of peak demand
  - storing renewable energy
  - controlling supply frequency
- The Lake Elsinore Advanced Pumped Storage (LEAPS) project takes advantage of:
  - strong elevation gradient between Santa Ana mountains and Lake Elsinore
  - proximity to both renewable energy sources and the electrical grid for Southern California
- Nonetheless, questions remain about the potential impacts and benefits of LEAPS to Lake Elsinore

LEAPS

- LEAPS consists of 3 primary components:
  i. Lake Elsinore - serves as the Lower Reservoir and pumped water supply
  ii. Upper Reservoir - provides transient storage of water used for generation
  iii. Turbines/penstocks and related hydroelectric power infrastructure – produces electricity and ties to supply grid



i. Lake Elsinore

- Lake Elsinore is a shallow eutrophic lake that has varied dramatically over time in surface elevation, salinity and water quality
- It was placed on state's 303(d) list in 1994 and a TMDL was incorporated in Basin Plan in 2004
- Several lake restoration projects undertaken:
  - Installation of 20 axial flow pumps in 2004 to enhance natural wind-forced and convective mixing
  - Installation of a dual diffused aeration system in 2007 with >20 km of diffuser lines driven by four 200 HP compressors
  - Delivery of about 5000 acre-feet per year of recycled water to supplement natural rainfall/runoff
  - Fishery management through carp removal & stocking of hybrid striped bass

ii. Upper Reservoir

- The Upper Reservoir is proposed for siting in Decker Canyon at an elevation >2600 ft above MSL
  - Maximum capacity of 7175 acre-feet
  - Useable storage volume of about 6300 acre-feet
  - Maximum surface area of approximately 76 acres
  - Maximum depth of over 150 ft

iii. Turbines/penstocks and related infrastructure

- Hydraulically link Lake Elsinore with Upper Reservoir
- Water pumped from and returned to Lake Elsinore through inlet-outlet structure on western shore of lake
  - Base elevation of 1220 ft
  - I/O design being evaluated
    - 40 - 150 m width
    - 3 - 10 m gate height

II. Objectives

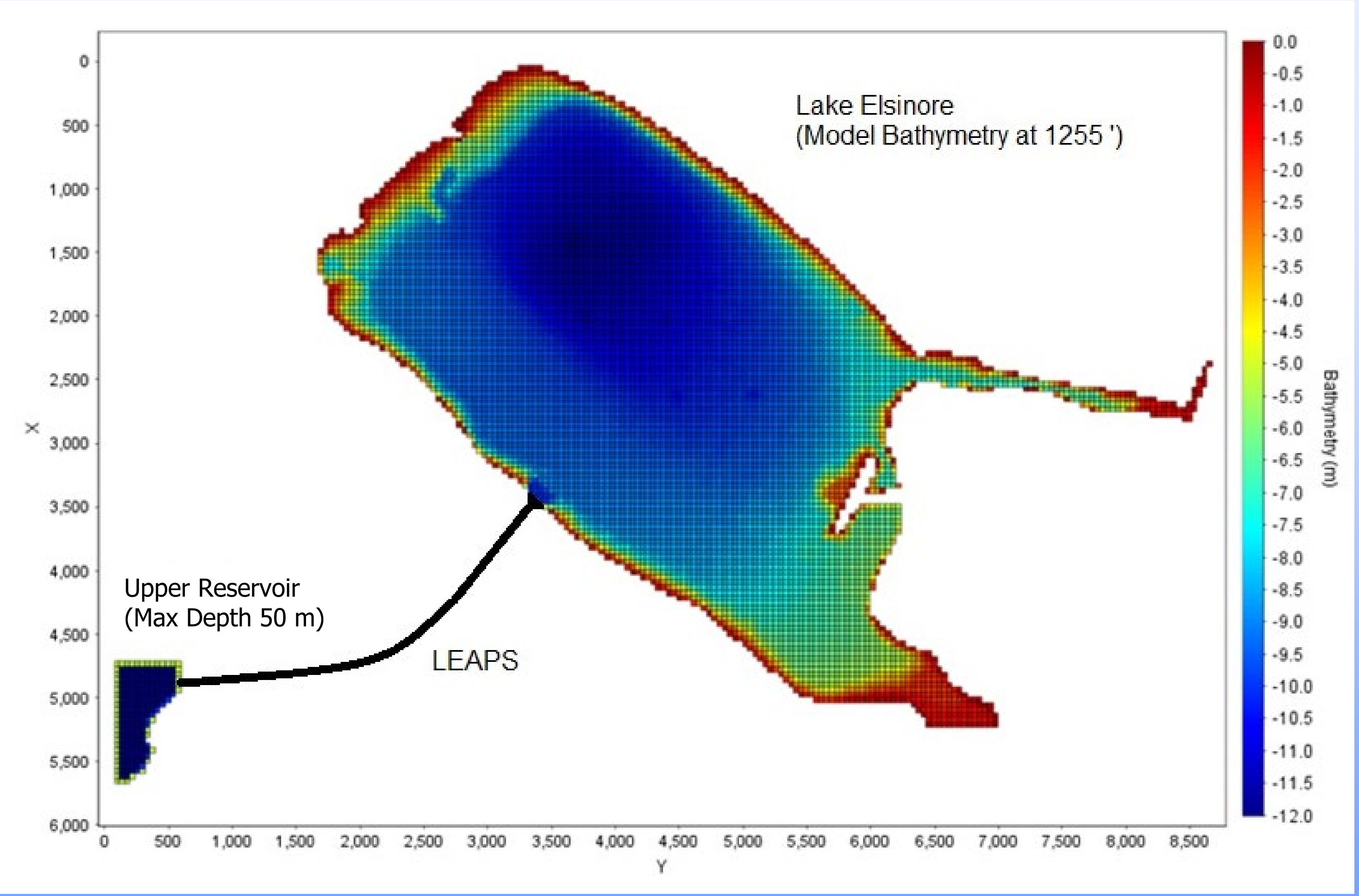
i) assess impact of pumping, transient storage in the Upper Reservoir, and generation on water quality in return flows to Lake Elsinore during operation of LEAPS

ii) quantify effects of LEAPS operation at different lake surface elevations on water quality

iii) evaluate LEAPS design and operational strategies to *enhance* water quality in Lake Elsinore when compared with current conditions.

III. Approach

- Development and use of 3-D hydrodynamic-water quality model (AEM3D) for Lake Elsinore-Upper Reservoir
- AEM3D is based upon and includes enhancements to ELCOM-CAEDYM (Hodges & Dallimore, 2016)
- Lake Elsinore model grid developed from 2010 hydroacoustic survey and revised to 1255 ft based upon satellite imagery at known surface elevations
- Upper Reservoir model grid developed from design
- 40 m x 40 m x 0.3 m used for discretization of Lake Elsinore for solution to Navier-Stokes, advection-dispersion and related equations
- 240,004 cells in computational domain at full pool



- Timestep of 24 sec (needed to meet Courant-Friedrich-Lewy and Lipschitz constant conditions)

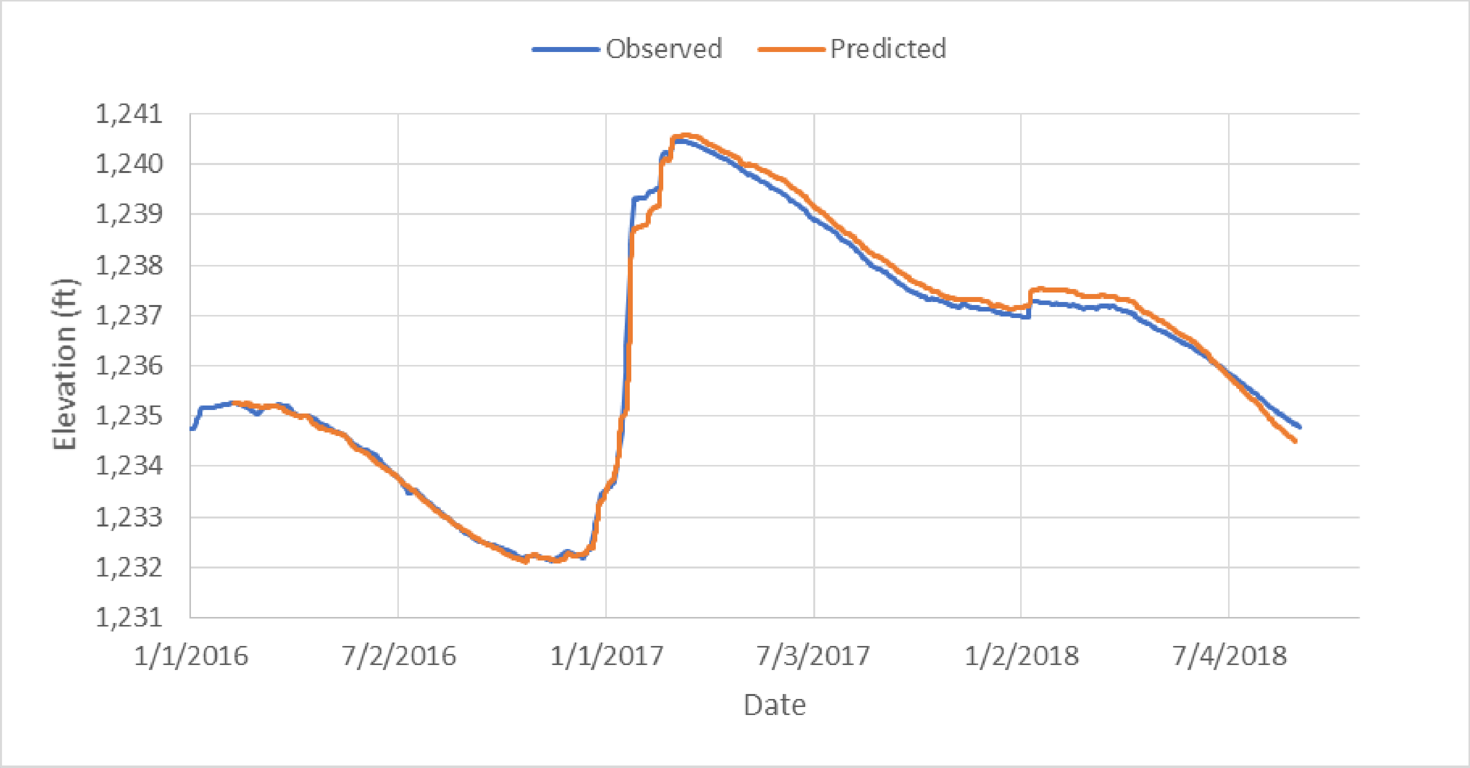
- Diffused aeration simulated using AEM3D bubbler subroutine per design and operational data
  - Twelve 760 m (2500 ft) diffuser lines, 325 holes/line (1-mm)
  - 50 psi line pressure yielding about 0.17 m^3/s air flow/line
- Axial flow pumps simulated using AEM3D pump/jet subroutine
  - 20 units with 0.8 m radius impeller at 1.8 m depth
  - 872 N thrust/unit assumed to operate continuously
- Inflow data
  - San Jacinto River inflows from USGS gage #11070500
  - Recycled water data from EVMWD
  - Local runoff estimated from rainfall onto 13,340 acre ungaged local watershed
  - 15,000 acre-feet supplemental water for LEAPS from State Water Project

- Meterological data from nearby stations (NOAA #1275, KAJO, ECSC1, CNAC1, CIMIS #44)
- Initial conditions and calibration data taken from AMEC Foster-Wheeler monitoring data
- Period from February 2016 – August 2018 selected for study due to
  - availability of high quality monitoring data, including cyanotoxin data
  - 2016 was lowest lake level and poorest water quality in several decades, representing a ~worst-case condition
  - 2017 included high runoff inputs in winter that resulted in large increase in lake level and decrease in salinity
  - 2018 representative of typical drought conditions

Calibration Results

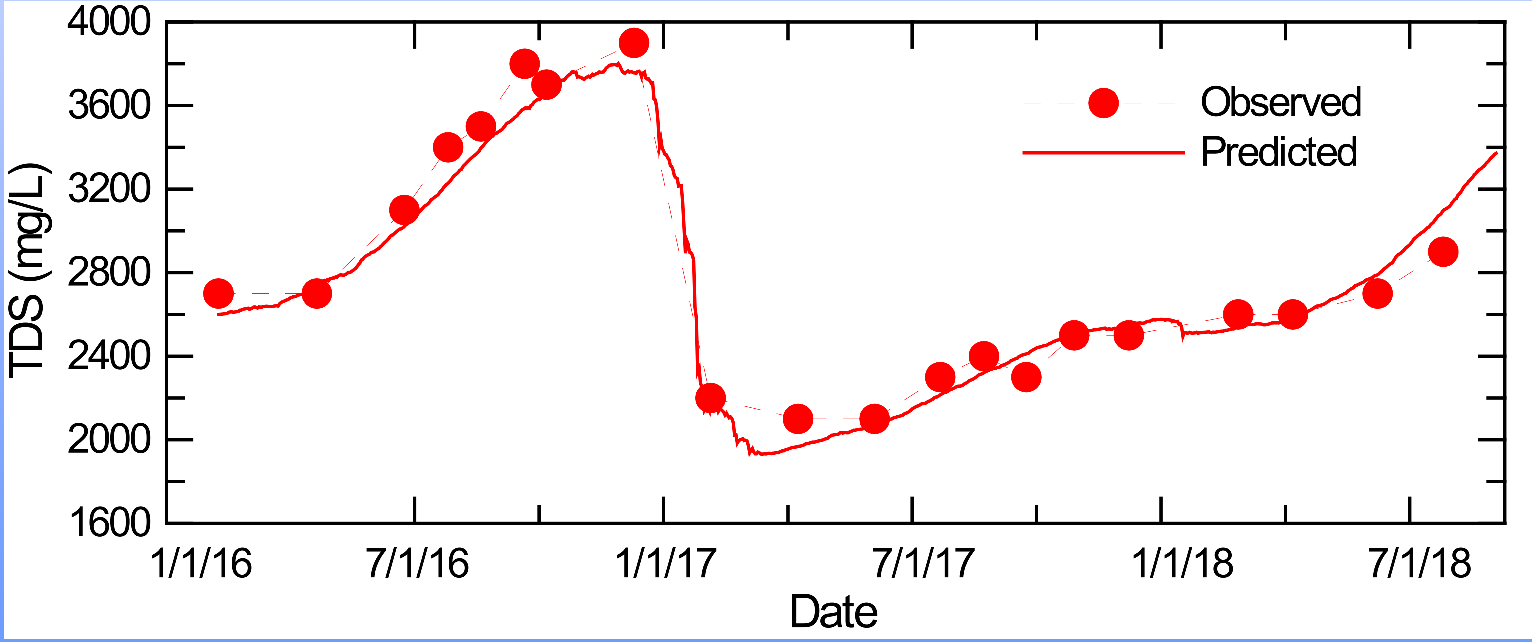
(i) Lake level

- Model accurately predicted lake level over February 2016 – August 2018 period



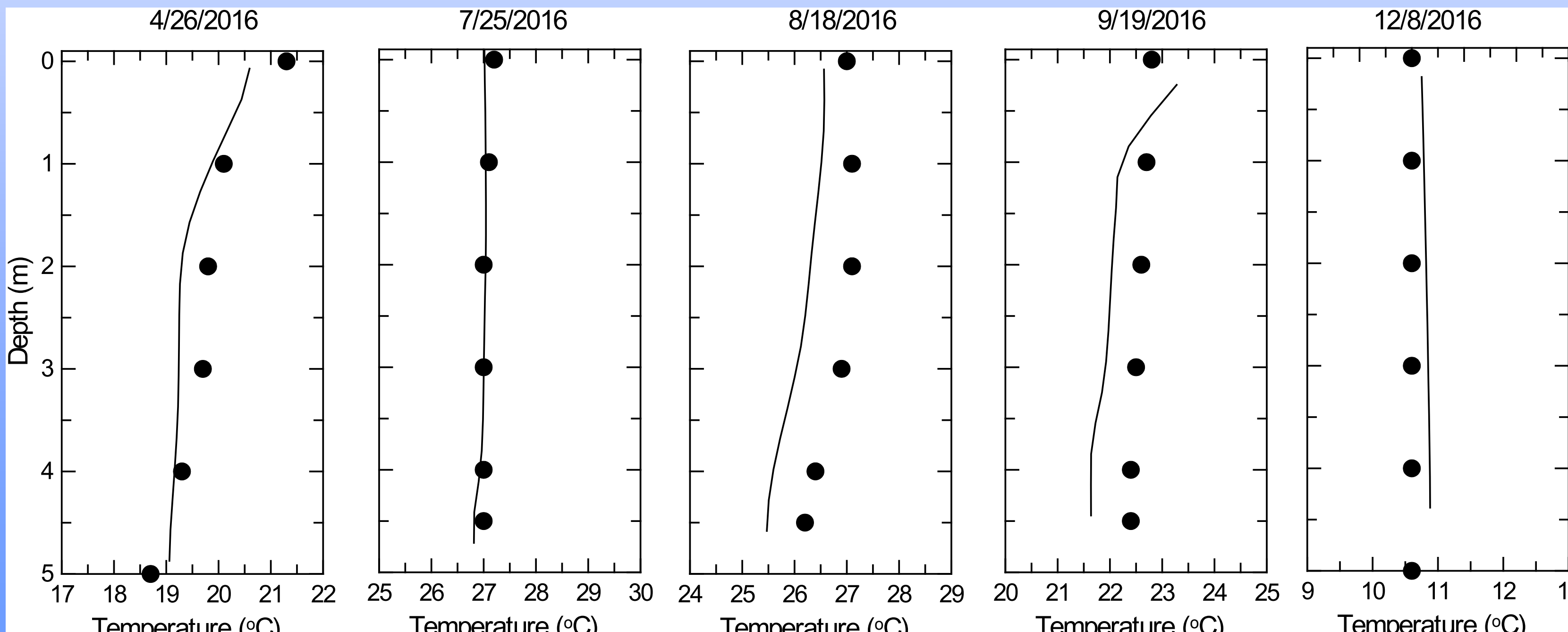
(ii) Total Dissolved Solids

- Model reproduced TDS concentrations in lake over the 2016 –2018 period
  - rapid increase in TDS in 2016 due to evapoconcentration
  - pronounced decrease in TDS due to runoff-dilution in winter 2017



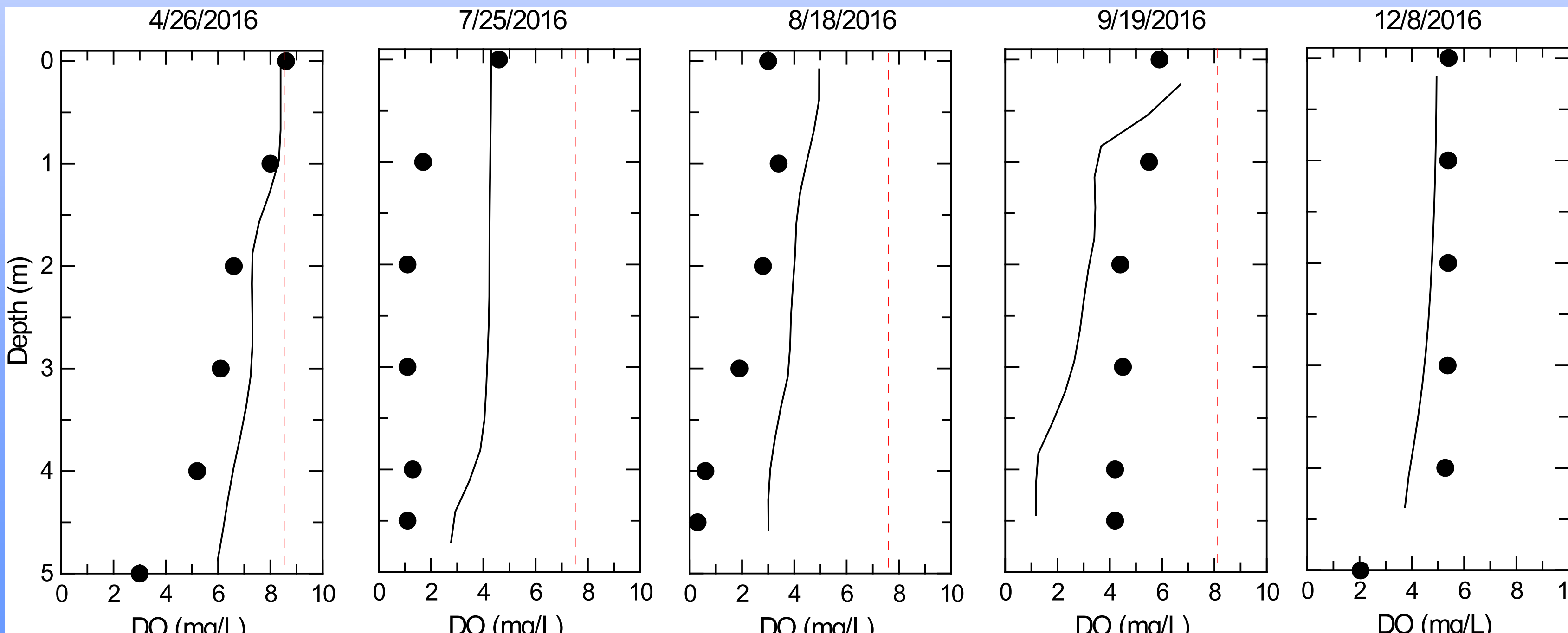
(iii) Temperature

- Temperatures profiles were also adequately reproduced with errors typically <0.6 ^oC:
  - warming through summer
  - rapid cooling in fall
  - modest temperature gradients with depth



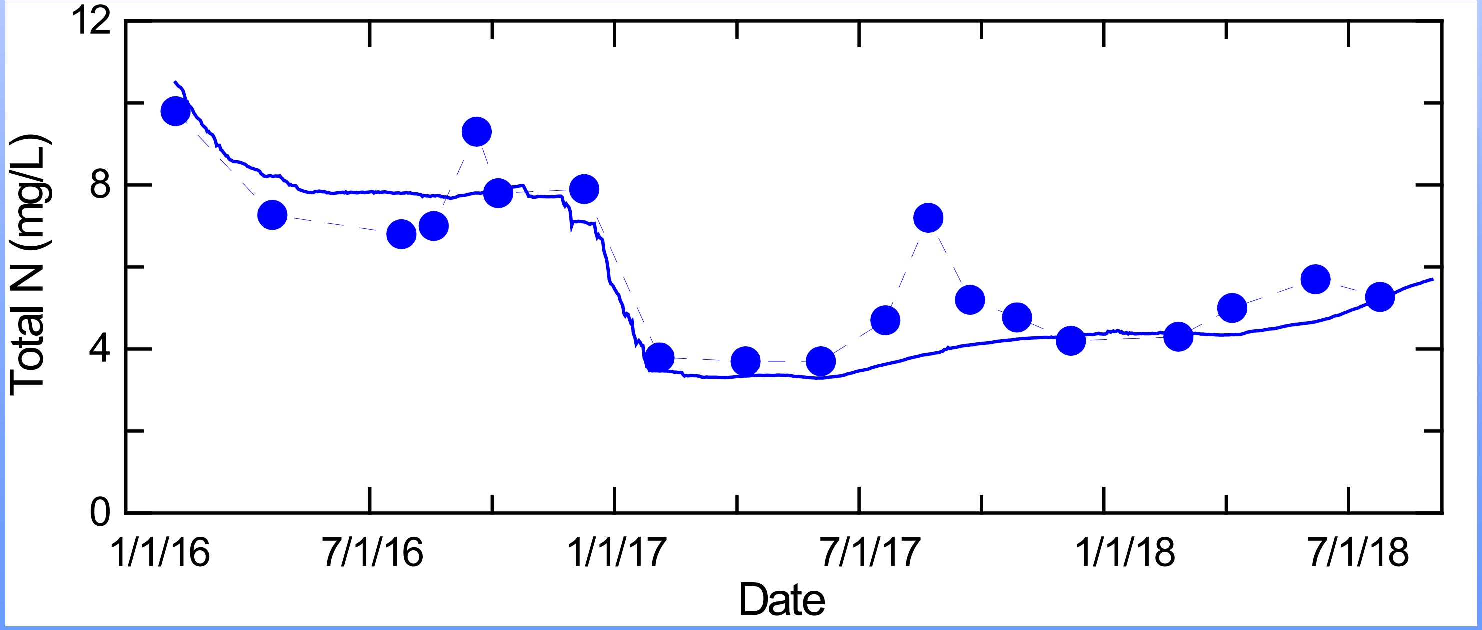
(iv) Dissolved Oxygen

- DO levels were routinely well-below saturation values (red lines) indicating very high water and sediment oxygen demand in lake
- Model reproduced trends adequately on most dates, but over-predicted DO on July 25th when strongly anoxic conditions present throughout water column



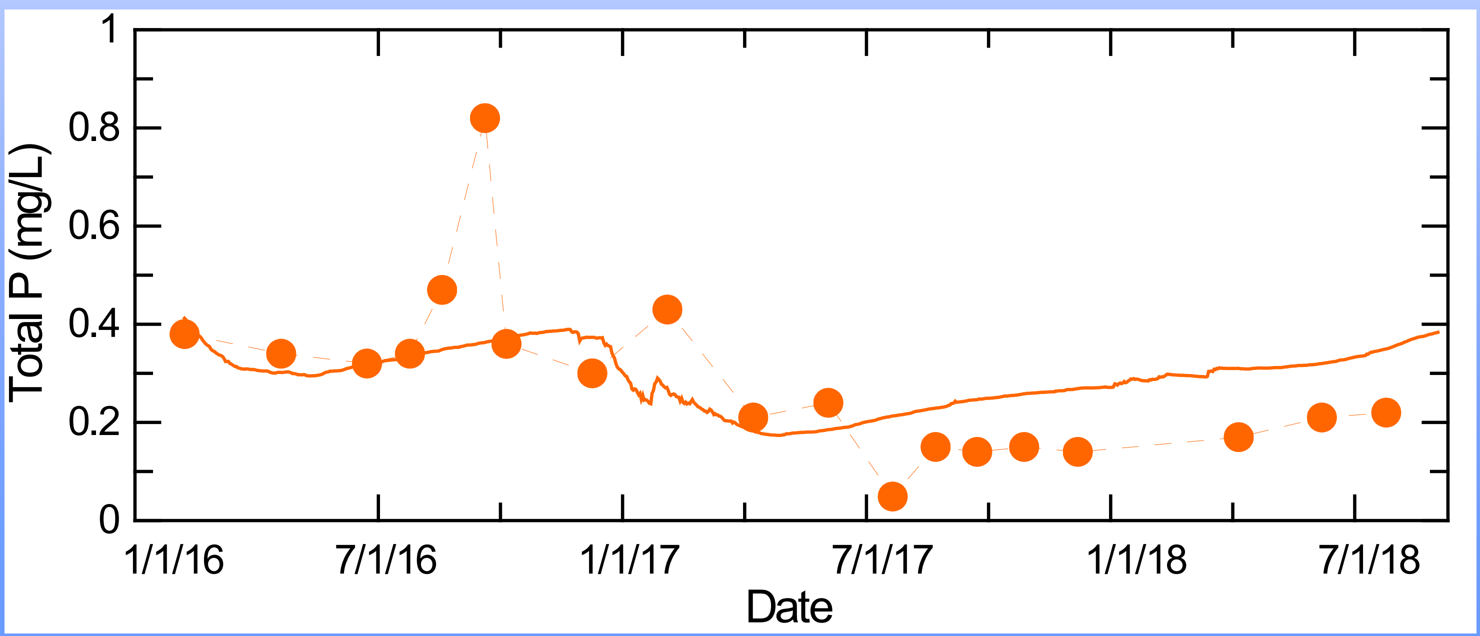
(v) Total Nitrogen

- Model reasonably reproduced observed TN levels over 2016-218 period
  - very high total N concentrations in 2016
  - marked concentration decline with winter runoff in 2017
  - gradual increase in 2018
- Model did not capture short near-doubling of TN concentration in late summer 2017 however



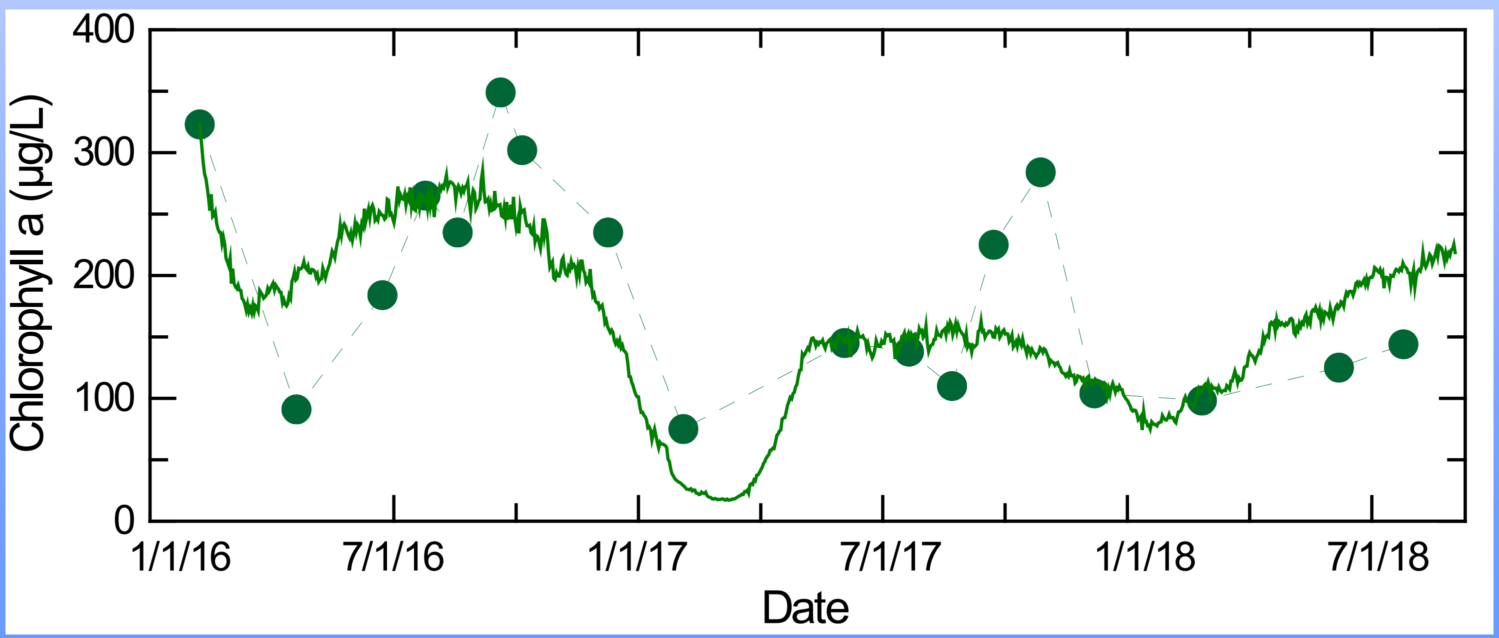
(vi) Total Phosphorus

- Model reproduced many features of total P levels over time but also exhibited some discrepancies
- It failed to capture the short-lived apparent doubling of TP in later summer 2016
- The model also over-predicted the total P concentrations in the latter part of simulation period



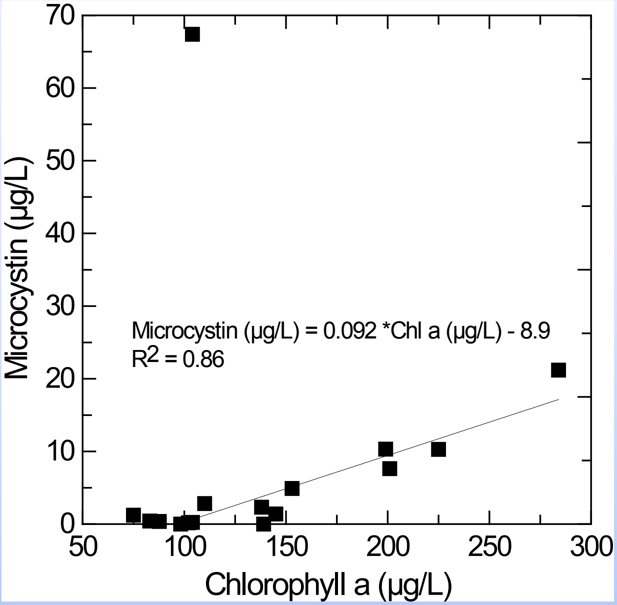
(vii) Chlorophyll a

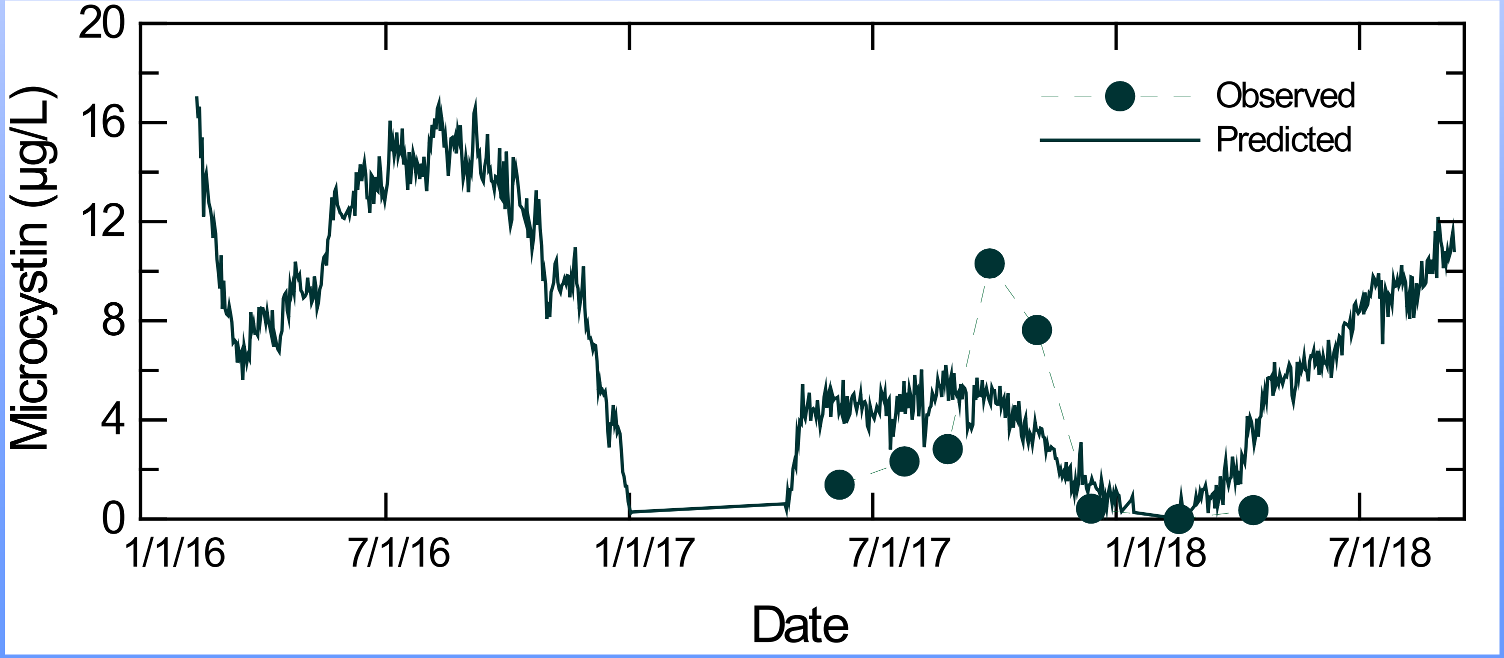
- Chlorophyll a levels varied strongly since 2016
  - very high concentrations in 2016
  - Sharp reduction in late 2016 and with winter runoff
  - Levels moderated somewhat in 2017-18 but were routinely >100 µg/L and exceeded 200 µg/L in late fall 2017
- Model reproduced these trends adequately on most dates, but did not predict the late fall 2017 bloom



(viii) Algal Toxins

- Algal toxin concentrations correlated with chl a levels
- Strong seasonal and interannual differences predicted *(work-in-progress)*





IV. Simulation Results Evaluating LEAPS

- The model described water movement that is principally driven by wind-forcing on lake surface

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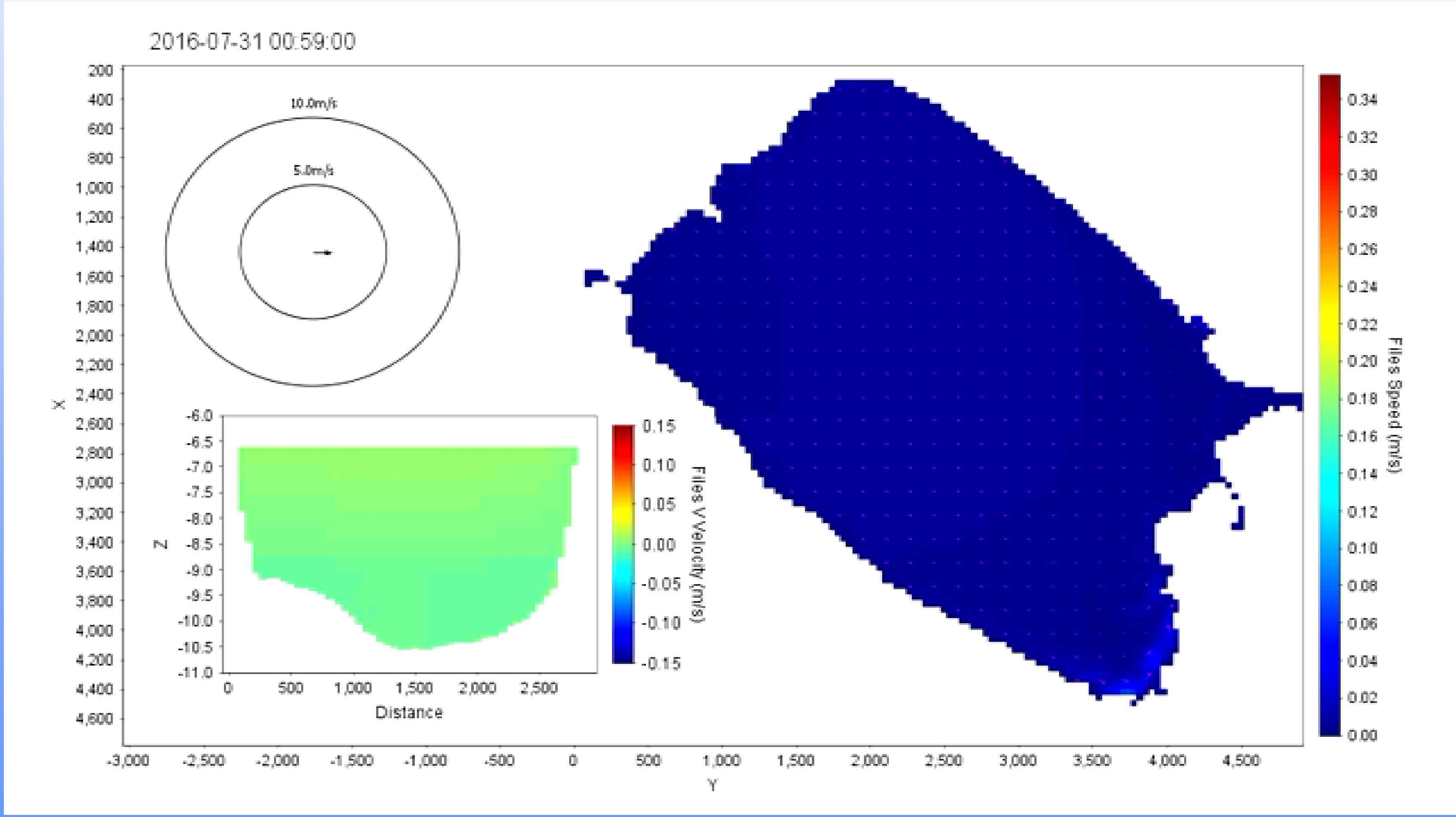
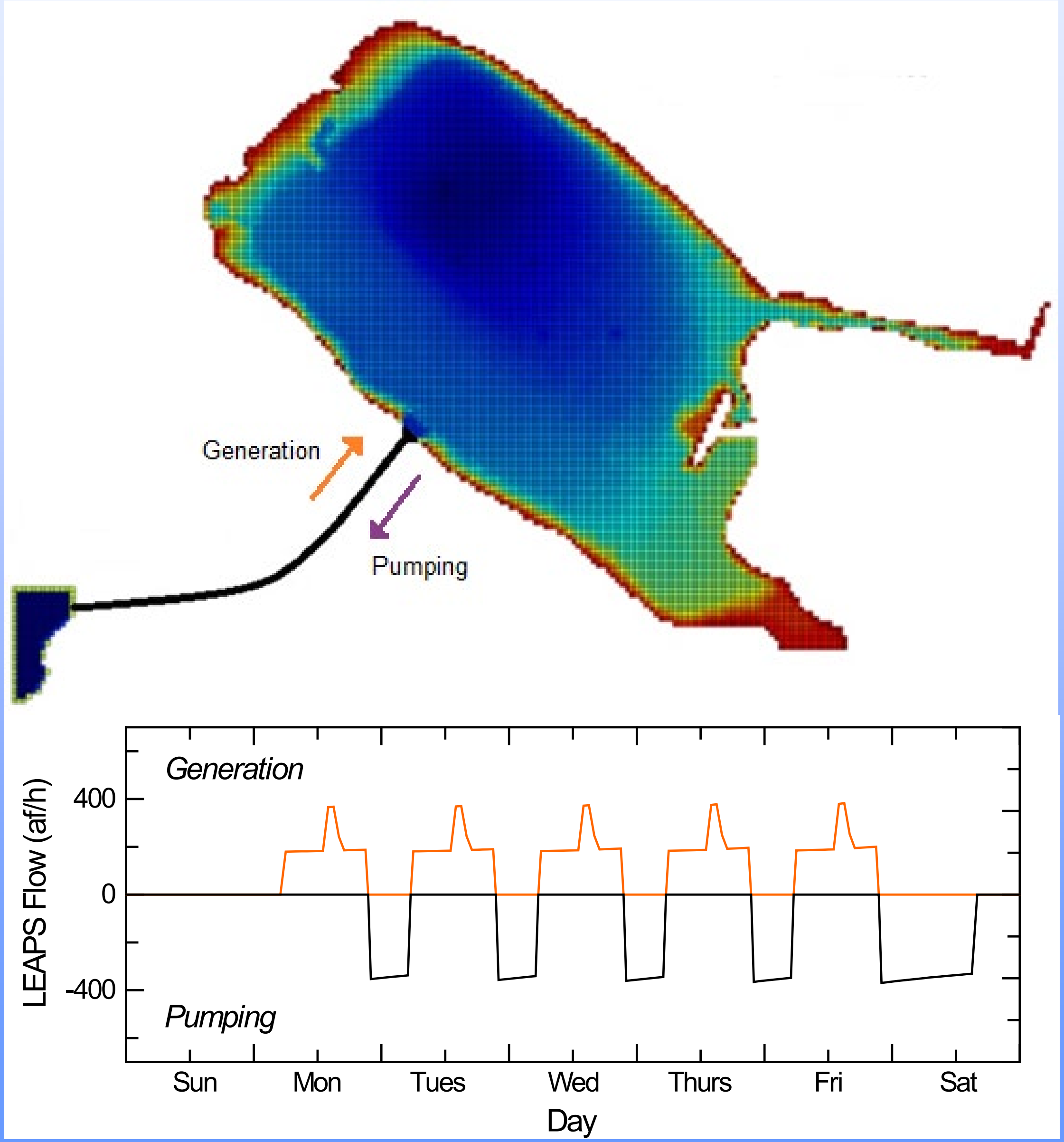
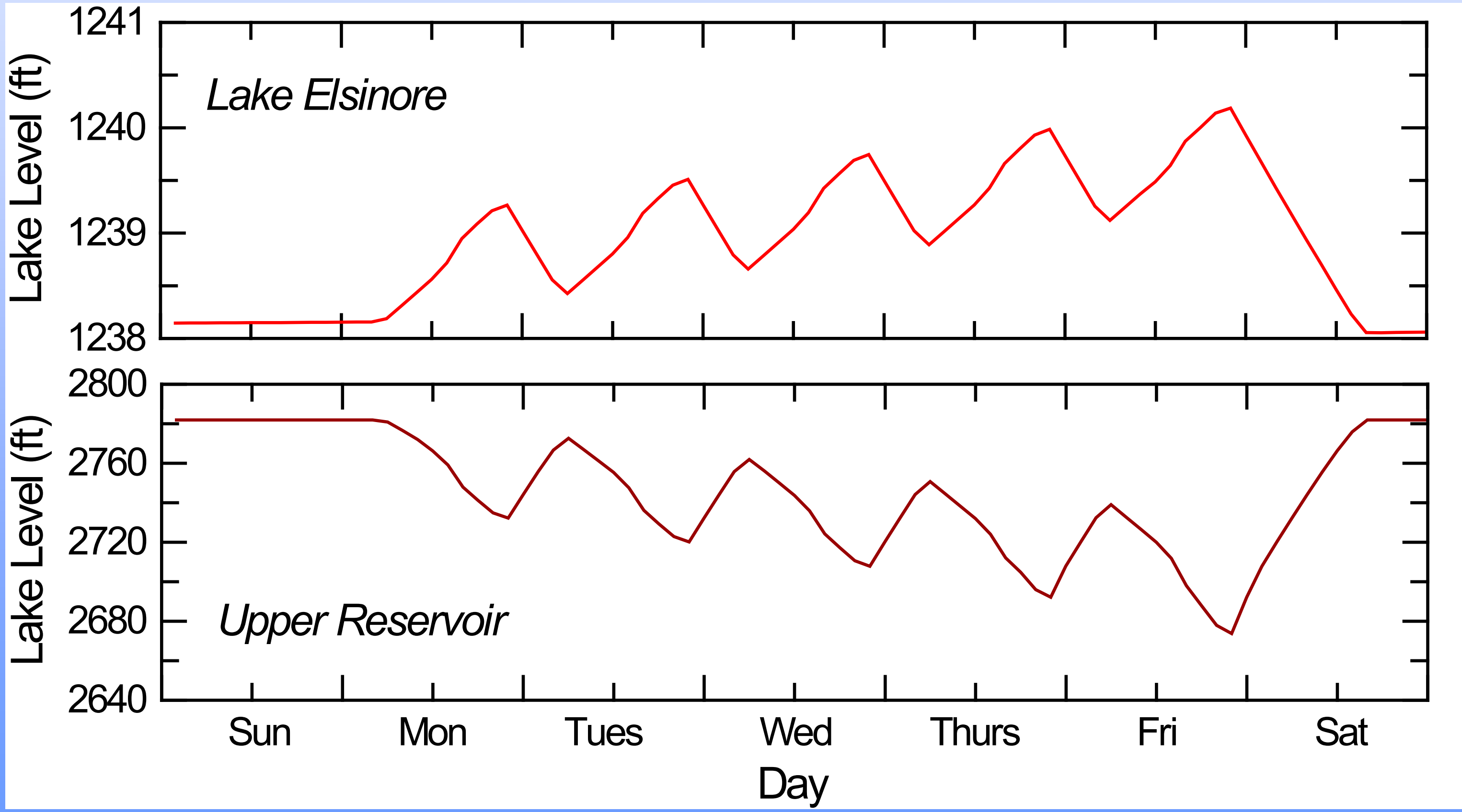


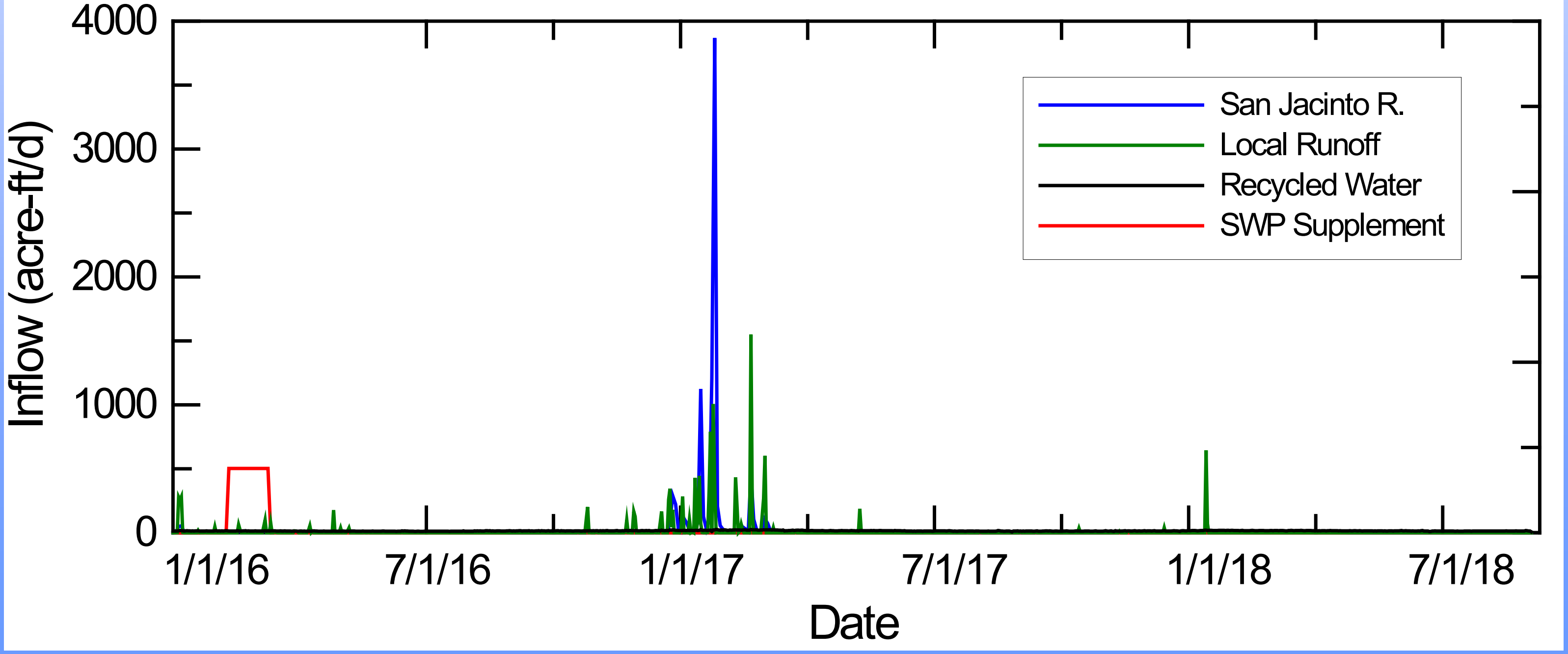
- Operation of LEAPS adds additional source of energy



- LEAPS operation results in:
  - increased inputs of turbulent kinetic energy (TKE)
  - diel oscillations in surface elevation in Lake Elsinore and the Upper Reservoir



- Influence of initial supplementation with 15,000 acre-feet of State Water Project (SWP) water evaluated
- Water was delivered through SJR-Canyon Lake at rate of 250 cfs for 30 days 2/9 - 3/9/2016
- Simulation with 3-D Canyon Lake model indicated that steady-state water quality reached ~3-4 days



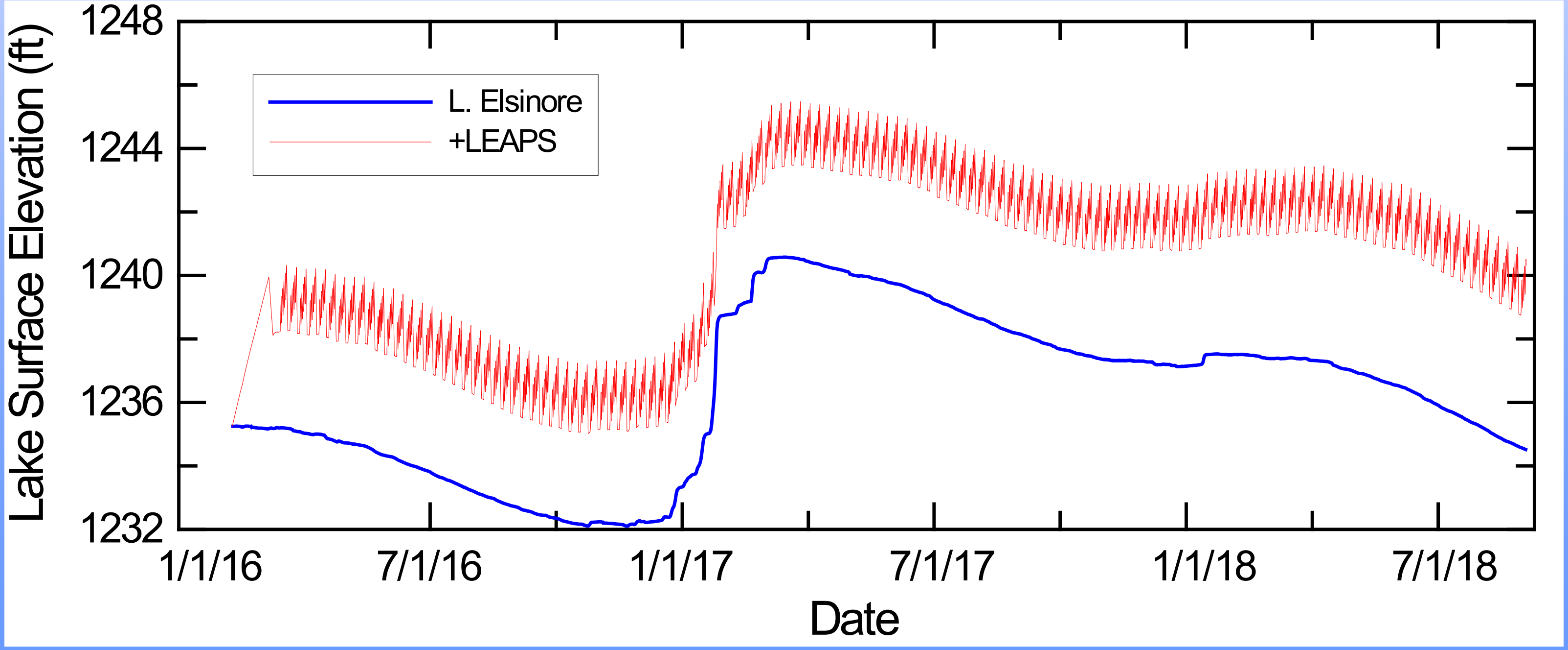
- SWP water is of considerably higher quality than other sources
  - Total N concentration is 20-50% of other sources
  - Total P concentration is 15-20% of other waters

Source	Total Inorganic N (mg/L)	Total N (mg/L)	ortho-PO_4-P (mg/L)	Total P (mg/L)
SJR	0.92	1.89	0.28	0.51
Local Runoff	1.02	1.82	0.20	0.48
Recycled Water[a]	4.11	4.76	0.30	0.37
SWP	0.56	0.93	0.06	0.07

[a]Water quality for 2016-2018 calibration-simulation period

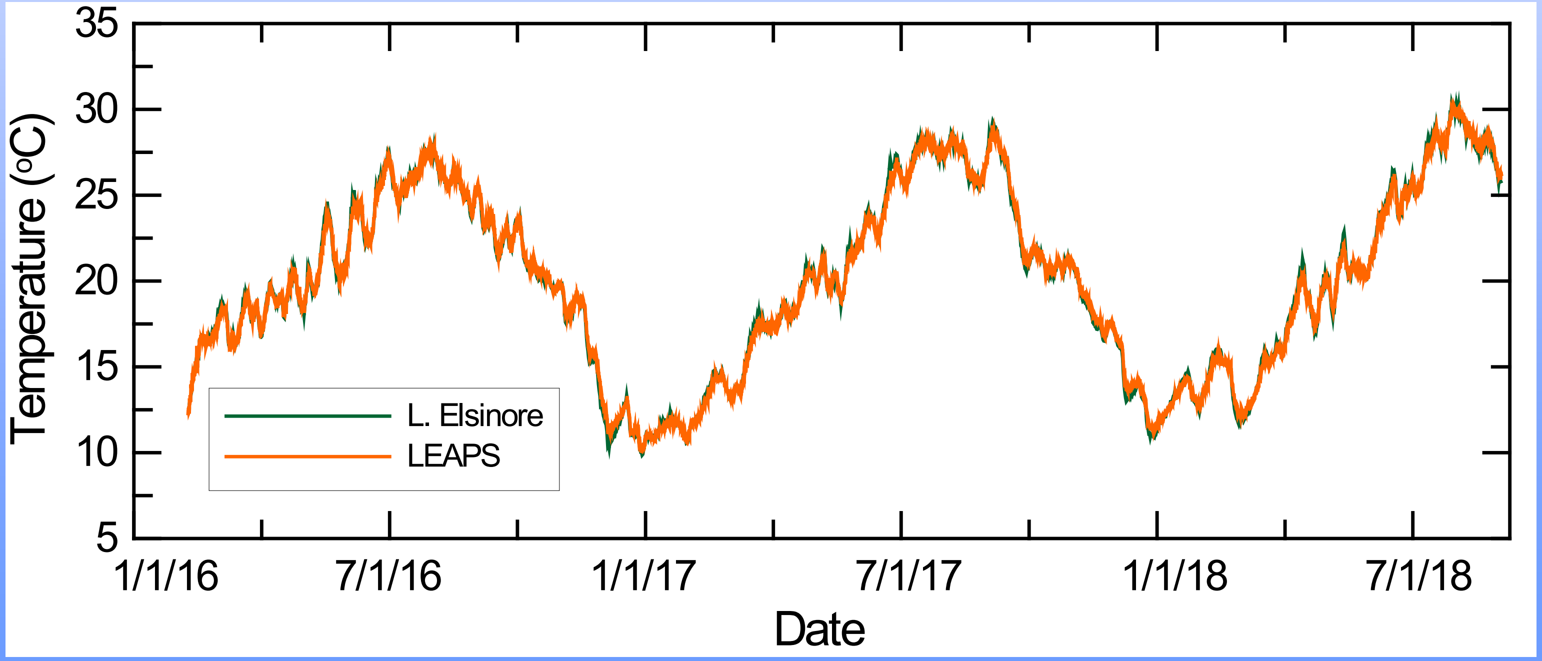
(i) Lake level

- The addition of 15,000 acre-feet (approximately 8,500 acre-feet net to lake and 6,500 acre-feet to fill Upper Reservoir)
  - increased lake level 3 ft, from 1235.2 ft in February 2016 to 1238.2 ft after filling the Upper Reservoir in March 2016
  - Diel pump-generation cycles superimposed regular oscillations on seasonal trends in lake surface elevation



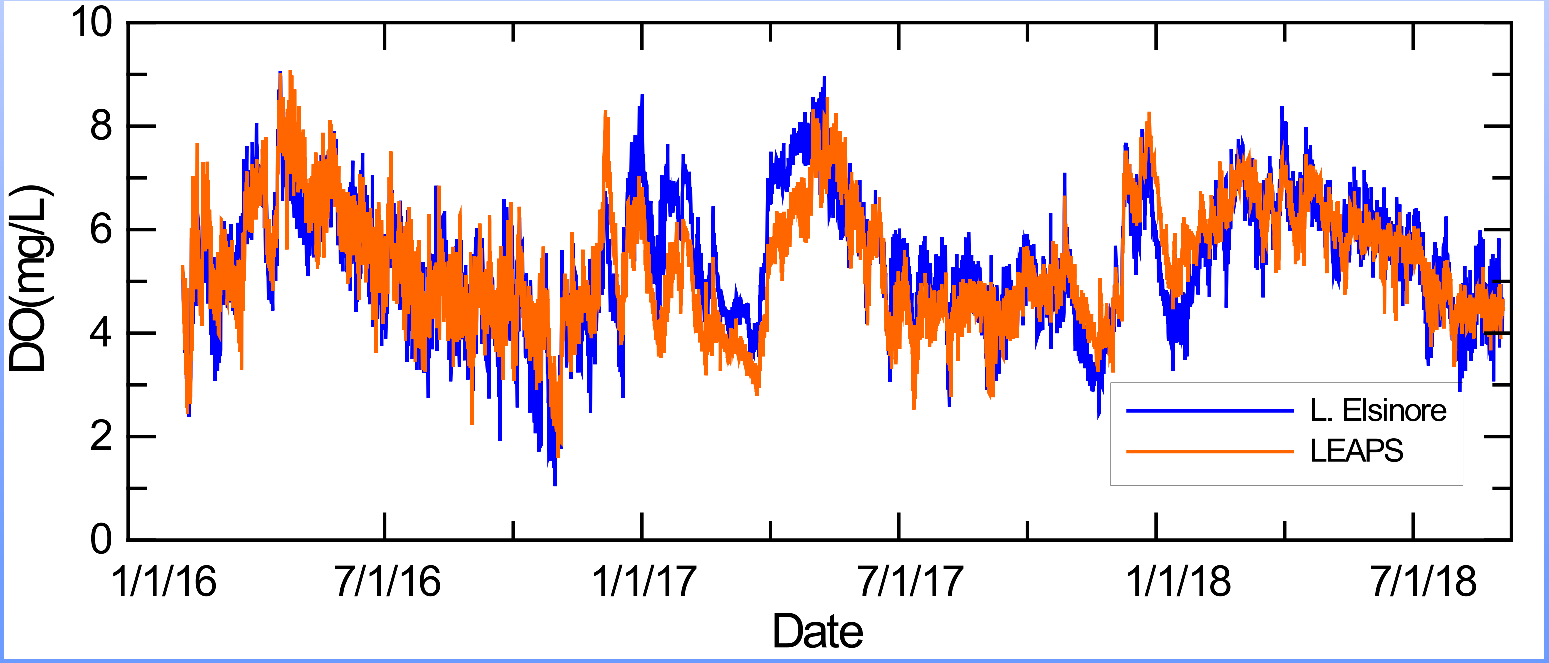
(ii) Temperature

- Operation of LEAPS had no significant effect on the depth-averaged temperature of Lake Elsinore
  - Temperature varied from about 10°C to 28-30°C seasonally
  - Shorter term increases or decreases due to prevailing weather conditions were also present and unaffected by LEAPS



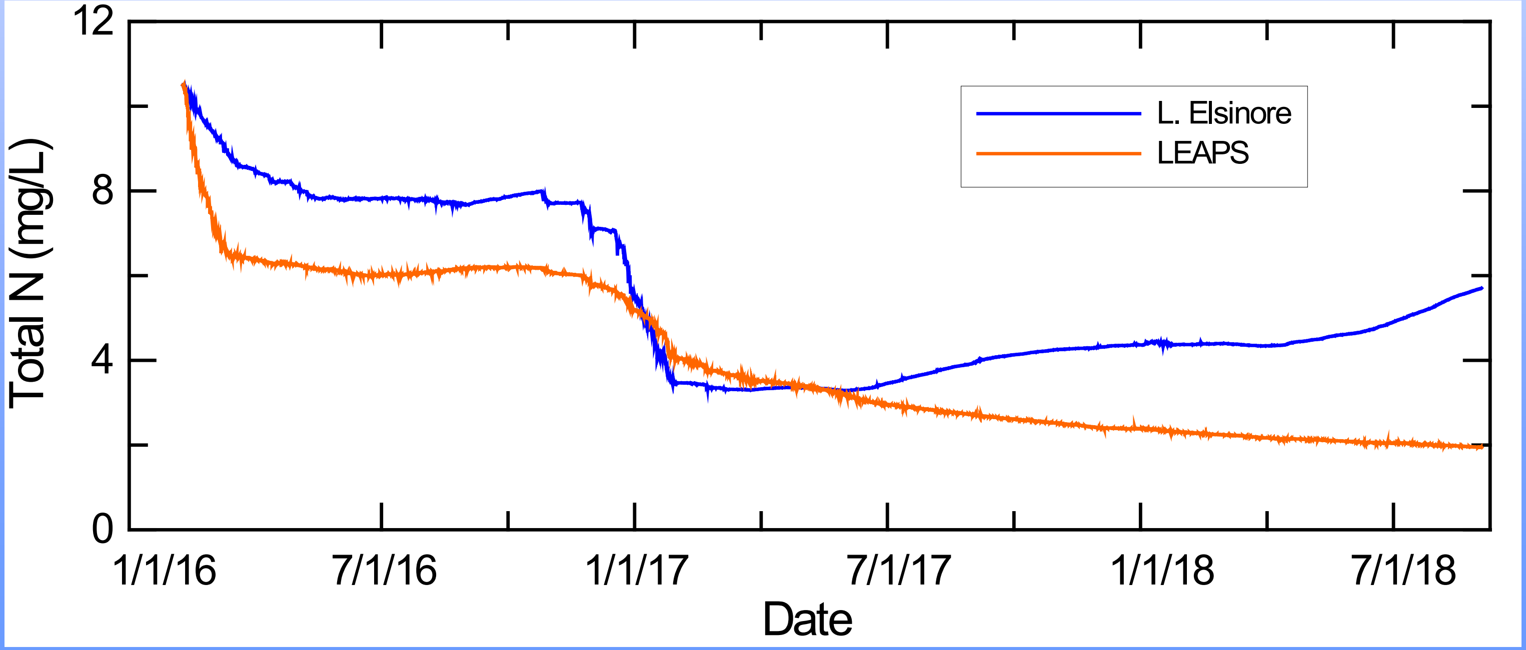
(iii) Dissolved Oxygen

- Modest differences in depth-averaged DO concentrations were periodically predicted
- LEAPS operation yielded
  - slightly higher concentrations in spring 2016
  - somewhat lower DO concentrations in spring 2017
  - ensemble mean of 5.39 mg/L vs 5.34 mg/L with LEAPS



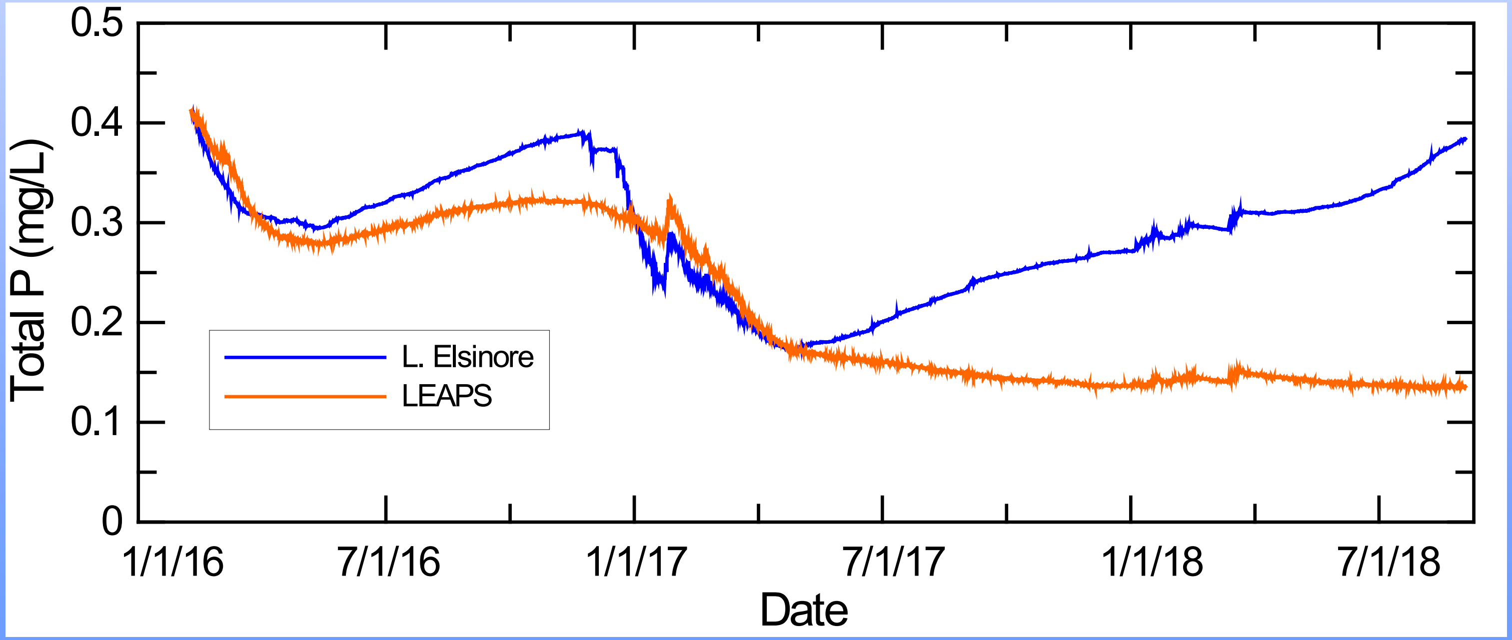
(iv) Total N

- Operation of LEAPS was predicted to have a more dramatic effect on total N concentrations
  - Supplementation with SWP water with low total N concentrations resulted in a rapid dilution from over 10 mg/L to about 6 mg/L
  - Total N levels continued to decline through 2017-18 and were predicted to drop to 2 mg/L by August 2018



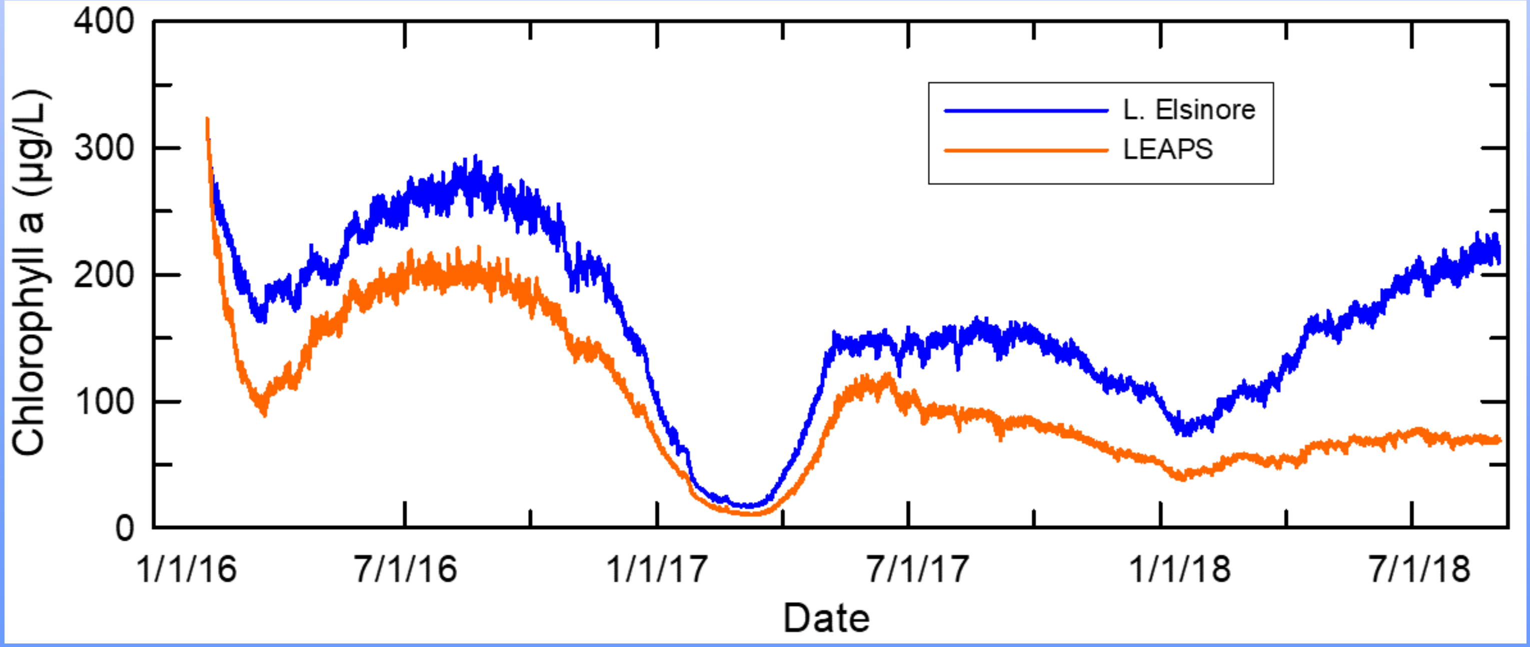
(v) Total P

- Total P levels exhibited broadly similar trends, with concentrations dropping from 0.4 to near 0.3 mg/L in summer of 2016
- Concentrations predicted to drop further in 2017-18 to 0.15 mg/L



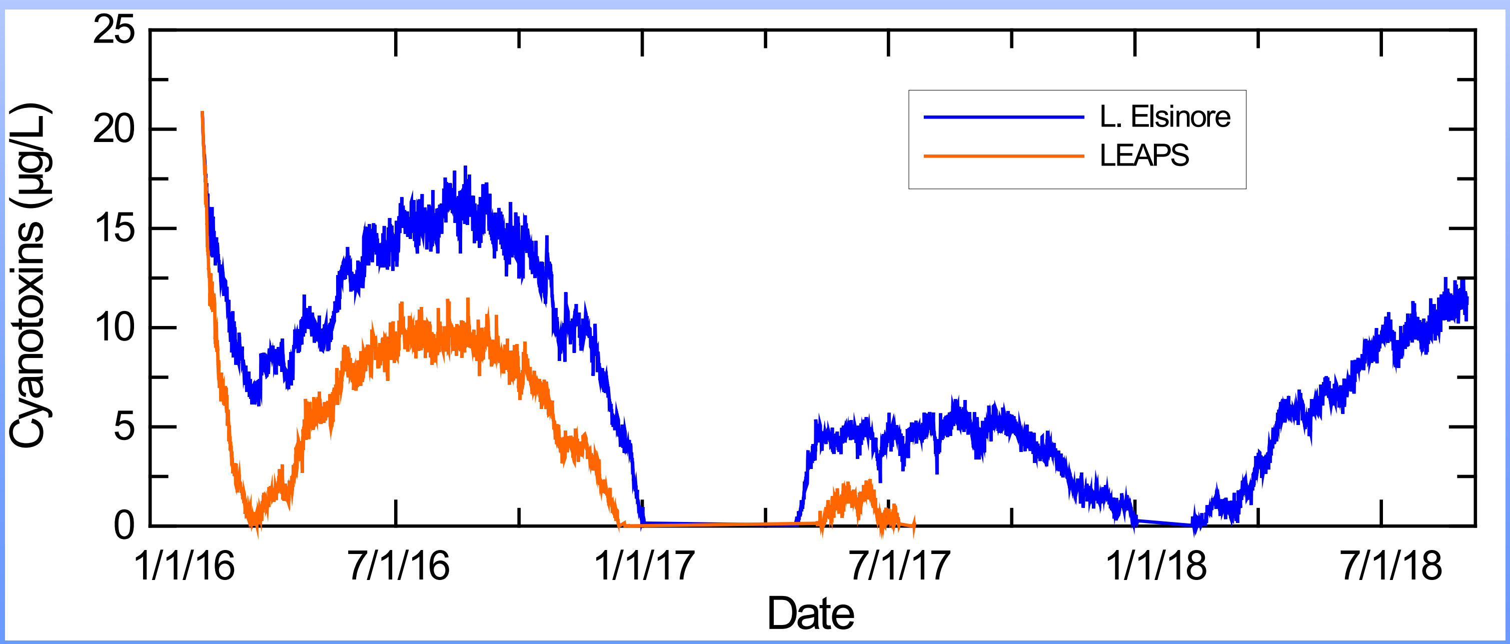
(vi) Chlorophyll a

- Chlorophyll a concentrations were about 50 µg/L lower with water supplementation and operation of LEAPS compared with lake values
- Low nutrient concentrations in 2018 further suppressed chlorophyll a concentrations

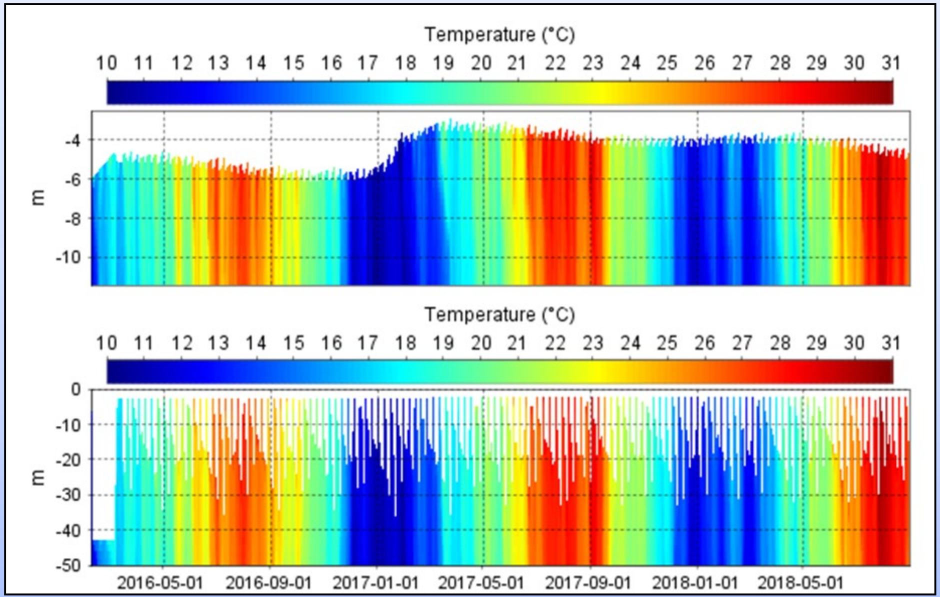


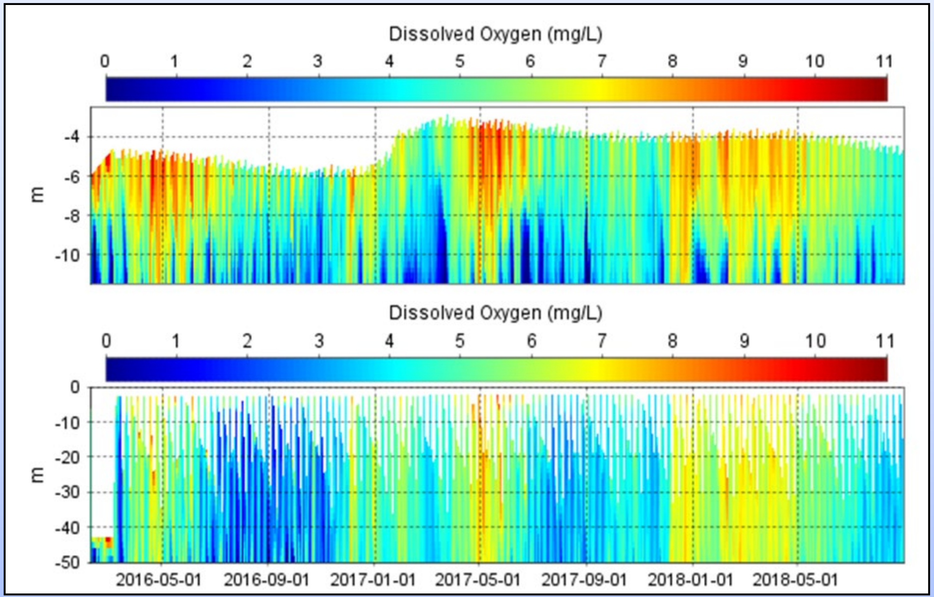
(vi) Microcystins

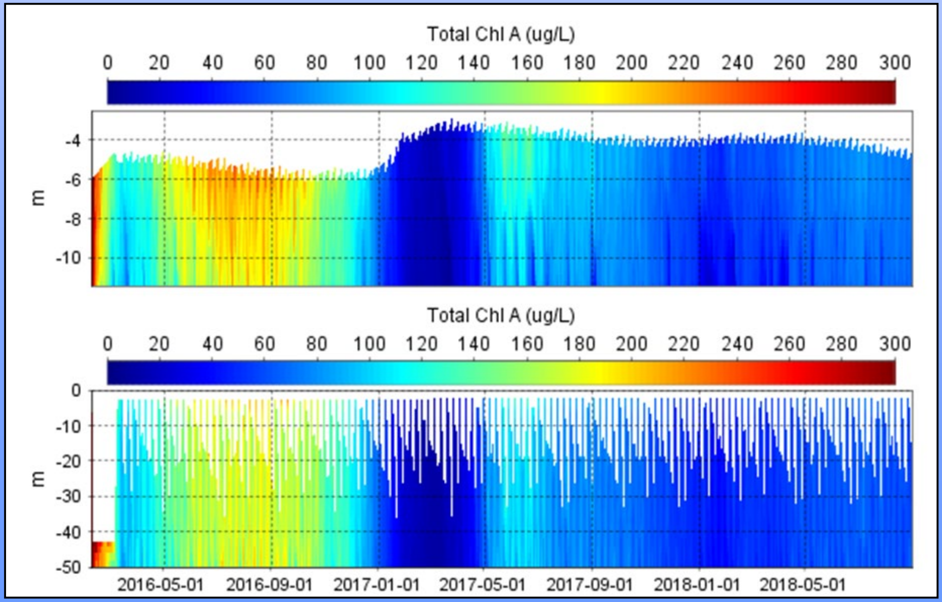
- Based upon linear regression between chlorophyll a and microcystin concentrations, LEAPS predicted to substantially lower levels in lake
- Microcystin concentrations about 5-7 µg/L lower in 2016 with LEAPS and negligible most of 2017-18
- Further analyses are underway to better predict cyantoxin concentrations in lake

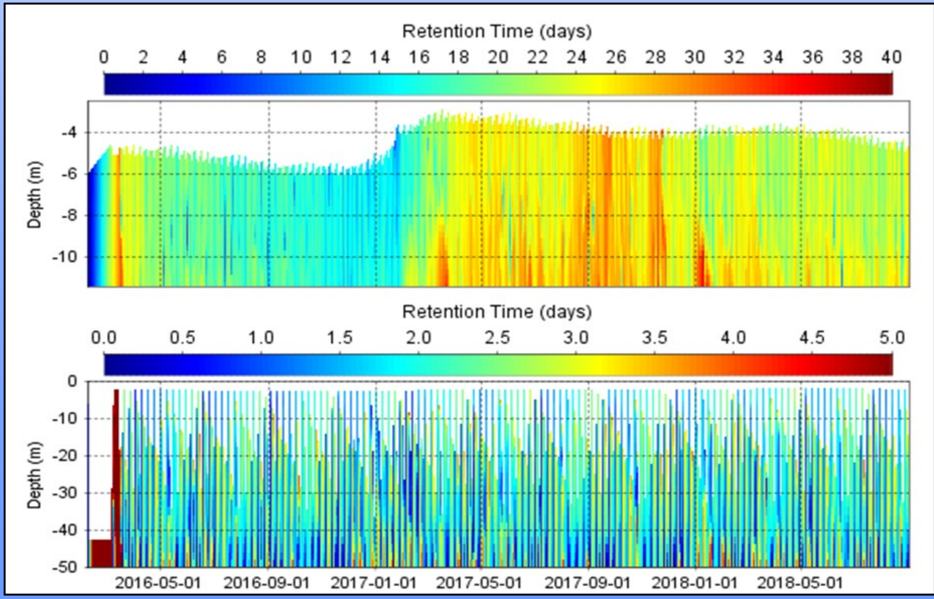


Upper Reservoir vs. Lake Elsinore









LEAPS as Part of Lake Management

- LEAPS evaluated for its ability to deliver high concentrations of DO to lake bottom

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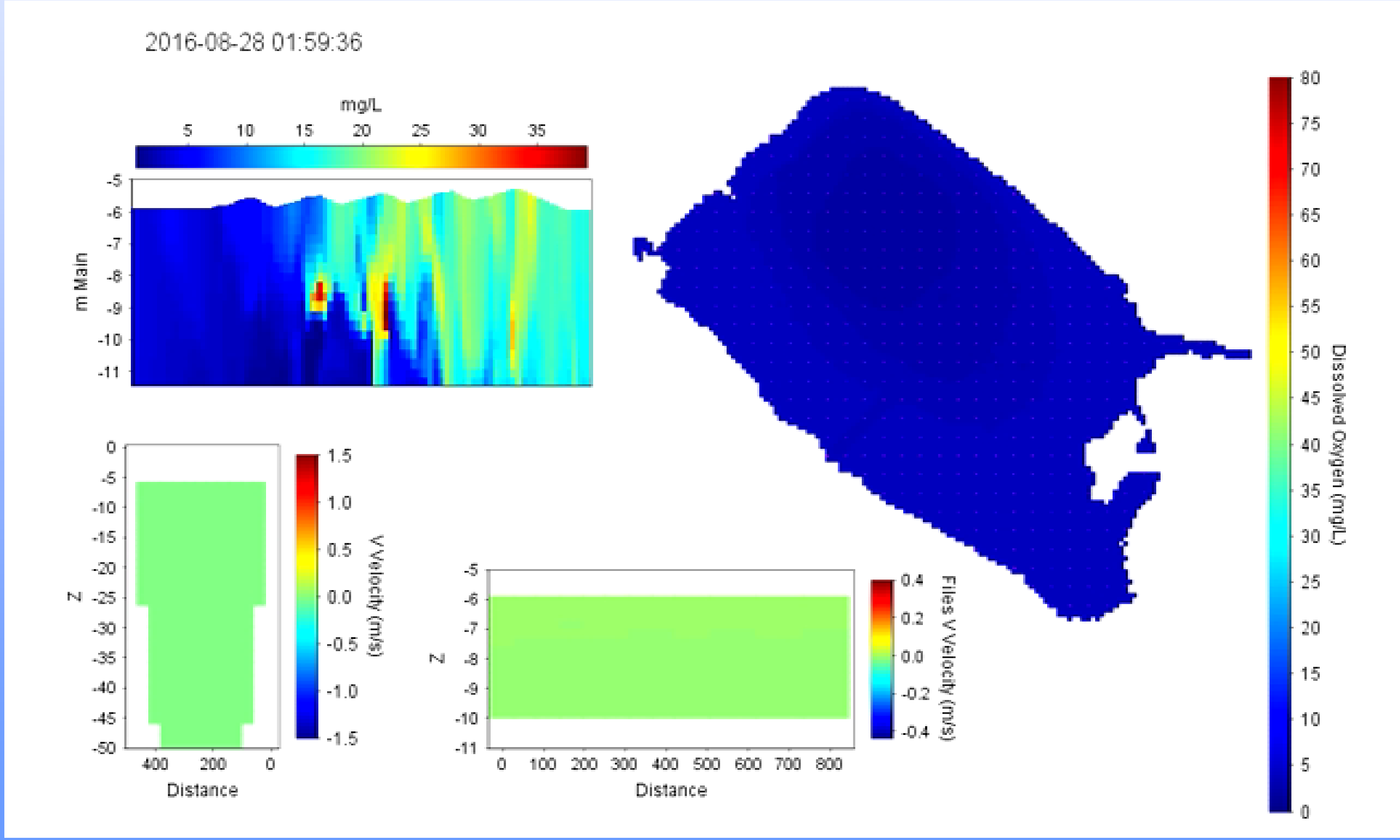
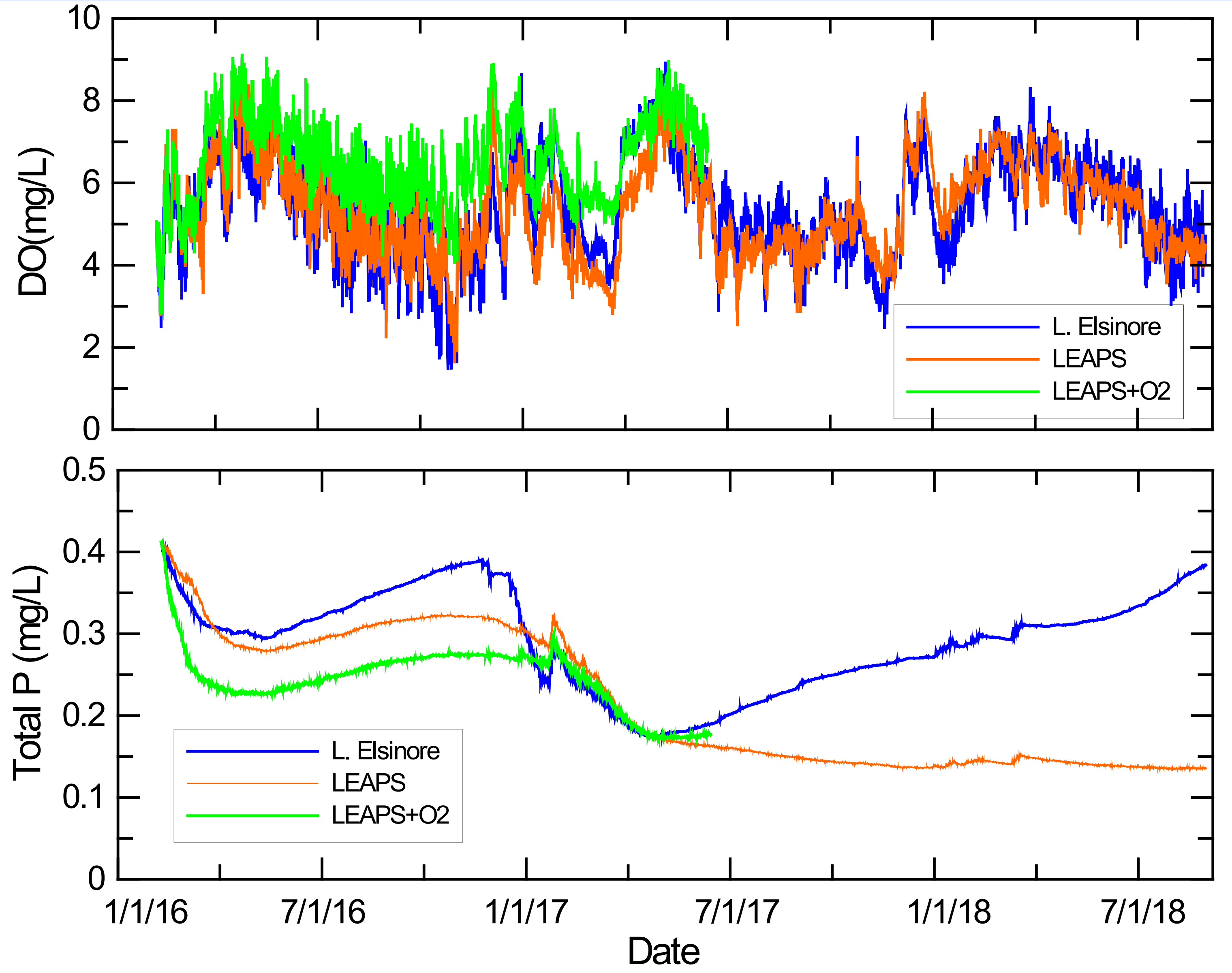


LEAPS+O_2 (up to 10 mg/L)



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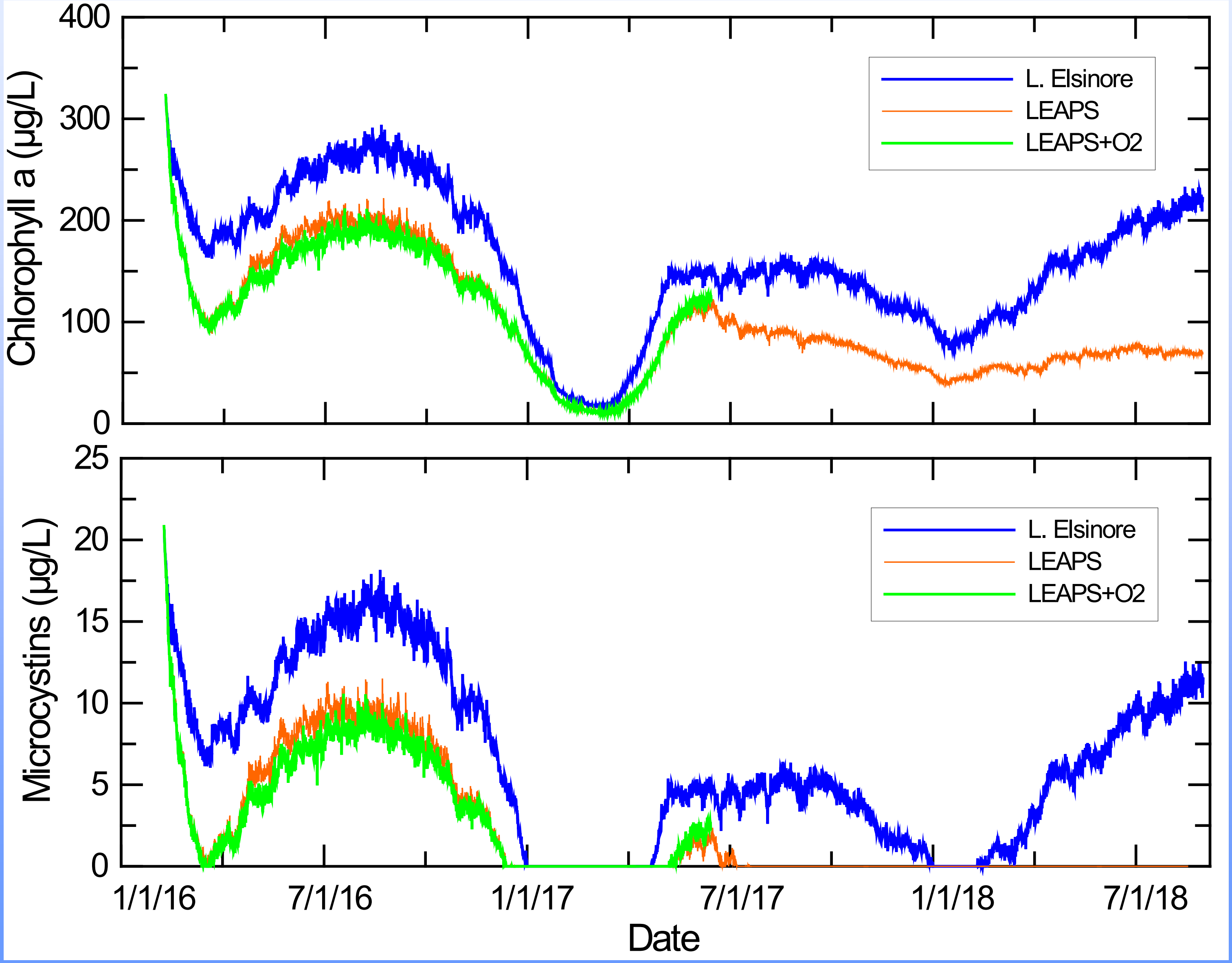

V. Conclusions

- 3-D model adequately reproduced water column properties in Lake Elsinore for 2016-18 period
- Supplementation of lake with high quality SWP water
  - increases lake level and decreases salinity
  - improves overall water quality
- Operation of LEAPS results in diel oscillations in lake surface elevation that are well-below seasonal changes
- LEAPS potentially could deliver high concentrations of DO to bottom waters, reduce fish kills and suppress nutrient release