Study 7 – Operation Efficiency and Water Quality Plan

FERC: Additional Study Requests
Study Plans for Studies #4 and 7

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<u>Introduction</u>
In response to the request for comments by the Federal Energy Regulatory Commission (FERC) concerning the license application of Nevada Hydro for the Lake Elsinore Advanced Pumped Storage (LEAPS) Project, numerous studies were requested by regional, state and federal resource agencies, municipalities and others. Following review, FERC issued a Response to Additional Study Requests on June 15, 2018 that directed Nevado Hydro to develop two study plans related to water quality. These studies - Studies #4 and 7 - address the need, identified by the Santa Ana Regional Water Quality Control Board (RWQCB), for additional information on the impacts of the LEAPS Project on water quality in Lake Elsinore. Study #4 specifically addresses the impact of pumping, transient storage in the Upper Reservoir, and generation on total nitrogen (N), total phosphorus (P) and cyanotoxin concentrations in return flows to Lake Elsinore. Study #7 addresses the effect of LEAPS operation at different lake surface elevations on water quality in Lake Elsinore and identification of lake elevations when significant negative impacts would occur. This Study Plan outlines the approach, expected results and timeline for Studies #4 and 7; an integrated approach is proposed that will address both the consequences of pumping, transient storage in the Upper Reservoir and generation on water quality of return flows to Lake Elsinore, and the broader issue of impacts of LEAPS operation on water quality at different lake surface elevations. Additional work is also proposed that evaluates strategies to enhance water quality in Lake Elsinore relative to current conditions through design and operation of LEAPS.

Background
The LEAPS Project consists of 3 primary components: (i) Lake Elsinore that serves as the Lower Reservoir and pumped-water supply; (ii) an Upper Reservoir that provides transient storage of water used for generation; and (iii) the turbines/penstocks and related hydroelectric power infrastructure.

Lake Elsinore is a shallow, eutrophic lake in southwestern Riverside County that has varied dramatically in lake surface elevation over time, from episodes of extreme flooding to being dry in the late 1950's to early 1960's. Water quality has also varied profoundly, from salinity levels exceeding sea water with very high nutrient concentrations at extremely low lake levels, to low total dissolved solids (TDS) and nutrient concentrations. Lake Elsinore was placed on the State of California's Clean Water Act Section 303(d) list in 1994 due to hypereutrophication and listed in 1998 as impaired due to excess nutrients, organic enrichment/low dissolved oxygen (DO) and sedimentation/siltation. A total maximum daily load (TMDL) was developed by the RWQCB and incorporated into the Basin Plan in 2004. Since that time, several lake restoration projects have been undertaken, including fishery management through removal of carp (*Cyprinus carpio*) and stocking of hybrid striped bass (*Morone saxatilis*); delivery of up to about 5,000 acre-feet per year of recycled water to supplement natural rainfall and runoff during periods of low lake level and drought; installation in 2004 of 20 axial flow pumps to enhance natural wind-forced and convective mixing processes; and installation in 2007 of a dual diffused aeration system with >20 km of diffuser lines driven by four 200 horsepower compressors. The TMDLs for Lake Elsinore are currently undergoing revision.

The Upper Reservoir, proposed for siting in Decker Canyon at an elevation of over 2600 ft above mean sea level (MSL), will have a maximum capacity of 7175 acre-feet, useable storage volume of approximately 6300 acre-feet, maximum surface area of 76 acres and maximum depth over 150 ft.

The final component of LEAPS involves the turbines, penstocks and related hydraulic and hydroelectric elements that hydraulically link the Upper Reservoir to Lake Elsinore. Water will be pumped from and returned to Lake Elsinore through an inlet-outlet (I/O) structure, with a working I/O design that is approximately 500 ft wide x 40 ft high, sited on the western shore of the lake at a base elevation of 1220 ft and gate elevation of 1223 ft (as noted in objective iii described below, an evaluation with a goal of optimizing the I/O to enhance water quality in Lake Elsinore will be conducted, so alternative design details may be developed).

A series of studies were conducted in 2006-2007 to determine the potential water quality impacts of the LEAPS project at the request of the Santa Ana Regional Water Quality Control Board as part of the earlier FERC application process. The studies included review of published studies of pumped-storage hydroelectric plant operations, analytical model calculations of turbulent kinetic energy inputs, water column stability, and organism entrainment (Anderson, 2006a), heat budgets for Lake Elsinore and the upper reservoir (Anderson, 2006b), 3-D numerical simulations of pumped-storage operation and effects on thermal stratification, sediment resuspension and organism entrainment using the Environmental Fluid Dynamics Code (EFDC) (Anderson, 2007a), and modeling of ecological impacts and trophic cascades using a simplified linear food chain model (Anderson, 2007b).

In addition to modeling studies conducted using EFDC (Anderson, 2006a,b; Anderson, 2007a,b), Lake Elsinore has been evaluated using the 1-D Dynamic Reservoir Simulation Model (DYRESM)-Computational Aquatic Ecosystem Dynamics Model (CAEDYM) model (e.g., Anderson, 2015a,b,c), including simulations in support of the TMDL revision for the lake (CDM-Smith, 2018). These simulations focused on long-term representations of lake level, TDS and water quality in Lake Elsinore over the period 1916-2016 that highlighted the tremendous variability present (from periods of widespread flooding to complete desiccation in the late-1950's to early-1960's). The 1-D approximation allowed simulations over the decadal to century time-scales, although it does not capture the spatially and temporally complex hydrodynamic and water quality impacts resulting from operation of LEAPS.

As noted above, prior analyses of the LEAPS project included analytical model calculations and numerical 3-D hydrodynamic simulations. Since these studies were conducted, sophisticated water quality and aquatic ecology models have been developed and linked to 3-D hydrodynamic models that allow comprehensive representation of the physics, chemistry and biology of lakes and reservoirs (e.g., Hodges and Dallimore, 2014; Hipsey, 2014). In addition, substantial improvements have been achieved in computational power over the past decade, allowing solutions for systems at fine temporal and spatial scales over seasonal and multi-year timescales (e.g., Preston et al., 2014a). Moreover, 3-D hydrodynamic models are increasingly used to optimize design and operation of hydraulic systems (Preston et al., 2014b), including reservoir water quality management (Anderson et al., 2014) and compliance with regulatory requirements (SBDDW-16-02). A coupled 3-D hydrodynamic-water quality model dynamically solving heat, water and nutrient budget equations, transport equations, water quality and aquatic ecology is proposed for use to address existing gaps in understanding about LEAPS and its impacts on Lake Elsinore.

Objectives

The objectives for this study are to:

i) assess impact of pumping, transient storage in the Upper Reservoir, and generation on total N, total P and cyanotoxin concentrations in return flows to Lake Elsinore during operation of LEAPS (Study #4);

ii) quantify effect of LEAPS operation at different lake surface elevations on water quality in Lake Elsinore and identification of lake elevations when significant negative impacts would occur (Study #7); and

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

Approach

A 3-D hydrodynamic-water quality model using the Aquatic Ecosystem Model (AEM3D) will be developed for Lake Elsinore and the Upper Reservoir to numerically simulate initial filling of the Upper Reservoir and the daily, seasonal and multi-year operation of LEAPS in conjunction with rainfall, runoff, and water supplementation and effects on water level, as well as the relevant physical, chemical and biological processes affecting water quality. The AEM3D model is based upon, and includes enhancements to, the Estuary Lake and Coastal Ocean Model (ELCOM)-Computational Aquatic Ecosystem Dynamics Model (CAEDYM) (Hodges and Dallimore, 2016). Dynamic Dirichlet boundary conditions linking water withdrawal from Lake Elsinore and delivery to the Upper Reservoir (and vice versa) will be implemented so that water and the associated water quality (e.g., temperature, DO, nutrient concentrations, algae and algal toxin levels) can be transferred between the two water bodies during operation of LEAPS.

The grid for the Lake Elsinore model will be developed from the hydroacoustic bathymetric survey conducted in 2010 (Anderson, 2010) and revised to 1255 ft based upon satellite imagery at known lake surface elevations. Bathymetry for the Upper Reservoir will be taken from design documents. A 20 m x 20 m horizontal grid will be used to represent the lateral dimensions of Lake Elsinore and the Upper Reservoir. This yields a total of 35,558 horizontal cells representing the surfaces of Lake Elsinore and the Upper Reservoir at their maximum surface elevations (Fig. 1). The vertical dimension is represented by 49 layers that are 0.5 m in thickness for the uppermost 12 m (representing the approximate maximum depth of Lake Elsinore) that then smoothly grade to 2 m in thickness at 31.5 m depth and remain at 2 m thickness to a depth of 50 m for the vertical discretization of the Upper Reservoir. Hydrologic inputs for the model will be taken from daily flow records for the San Jacinto River into Lake Elsinore at USGS gage #11070500. Daily rainfall records will be taken from Riverside County Flood Control District rain gauge for Quail Valley to estimate runoff from the local 13,340 acre watershed not captured by gaged San Jacinto River flows. Hourly air temperature, relative humidity/vapor pressure, shortwave radiation, and windspeed will be taken from nearby meteorological stations (e.g., Elsinore Valley Municipal Water District, (EVMWD), California Irrigation Management Information System (CIMIS) station #057, or other local stations).

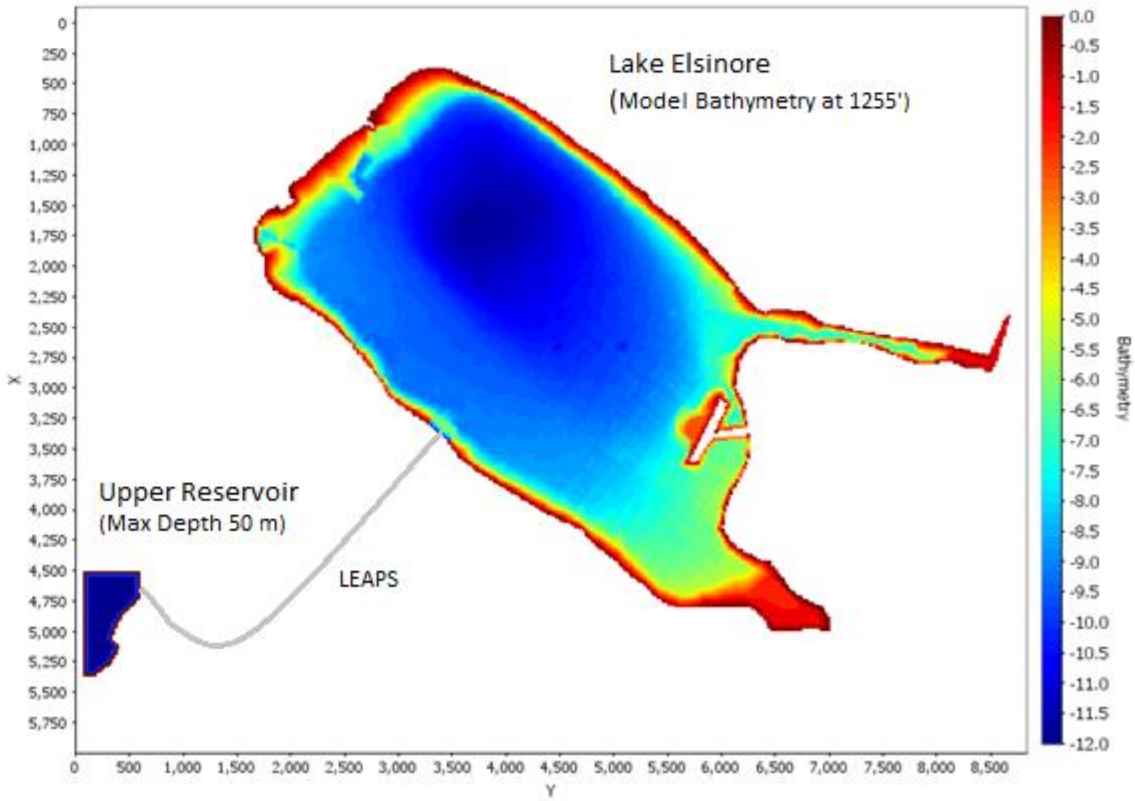

Fig. 1. Model bathymetry (35,558 horizontal "wet" cells at maximum surface elevations, 20 m x 20 m). Grid not shown due to density of grid lines not allowing grid resolution.

Initial testing and calibration of AEM3D will be conducted using the temperature profile and available acoustic Doppler velocimeter data from 2006 previously used to calibrate the EFDC model (Anderson, 2007a). Acoustic Doppler current profiler data collected on August 22, 2001 (unpublished data) will also be evaluated for possible use subject to available meteorological data.

Model parameterizations from recent DYRESM-CAEDYM simulations for Lake Elsinore will be used as a starting point in AEM3D for representation of nutrient cycling, algal production, DO dynamics and other processes in the lake. Simulations will also include calibration to and representation of algal toxin production and persistence. AEM3D allows simulation of algal toxin concentrations through internal toxin concentrations within algae that are considered to be a linear function of their growth rate (Long et al., 2001) and its release to water through cell lysis and excretion modulated by bacterially-mediated decay (Hodges and Dallimore, 2016; Hipsey et al., 2014). Although comprehensive studies evaluating algal toxin levels, nutrient concentrations, water column conditions and algal population dynamics have not been conducted, available algal toxin and chlorophyll a concentration data (Amec Foster Wheeler, 2018), information from earlier phytoplankton speciation and quantitation (Anderson et al., 2011) and available literature (e.g., Walls et al., 2018; Buford and O'Donohue, 2006; PacifiCorp, 017; FERC, 2007) will form the basis for calibration and prediction of algal toxin concentrations.

Objective i) Impacts of Pumping, Transient Storage in Upper Reservoir and Generation on Water Quality in Return Flows (Study #4)

The effects of pumping of water from Lake Elsinore to the Upper Reservoir, transient storage in the Upper reservoir, and return of water to Lake Elsinore during generation are not sufficiently understood. The Upper Reservoir represents an additional surface from which water will evaporate, thus increasing somewhat evaporative losses and altering the water budget for the lake. At the same time, increased elevation at the Upper Reservoir will yield lower local air temperatures related to the environmental lapse rate as well as a potentially different wind field and microclimate due to shading. Weather stations have been identified at approximately 2500 to 3080 ft above MSL near the Upper Reservoir site with sub-hourly meteorological data that will be used to drive the heat budget, evaporation and wind-mixing of the Upper Reservoir in AEM3D; weather stations at EVMWD and/or other sites will be used to provide a separate meteorological forcing for Lake Elsinore. In this way, water temperature, stratification, photosynthesis and other processes can be accurately simulated for both water bodies, in concert with heat and water budget changes (and other constituent mass balances) resulting from operation of LEAPS. Dynamic boundary conditions will transfer water and its associated water quality between Lake Elsinore and the Upper Reservoir through the model-represented inlet/outlet (I/O) structures. As described above, a large shore-mounted I/O is planned for the west side of Lake Elsinore, while an approximately 40 m^2 I/O will be located on the eastern face at the bottom of the Upper Reservoir (Fig. 1). Key processes that will be evaluated include hydrodynamics (and potential for interflow, underflow or overflow conditions depending upon season), nutrient transformations and uptake/sedimentation/loss, photosynthesis, respiration, and algal toxin production/loss.

Objective ii) Effects on Water Quality In Lake Elsinore from LEAPS Operation at Different Lake Elevations (Study #7)

As noted above and illustrated in Fig. 1, water quality in Lake Elsinore and the Upper Reservoir will be dynamically linked, so objectives i) and ii) are also linked, and soluble only by considering the overall system in a unified way. The approach described in i) thus holds here, with particular interest in this part of the study on LEAPS operation at different lake surface elevations. In the earlier assessment (Anderson, 2007), the effect of LEAPS operation was considered at two surface elevations (1240' representing the minimum operating level for LEAPS, and 1247' representing nominal to upper operating level). That 3-D numerical study focused on stratification, sediment resuspension and organism entrainment, so representation of additional physical, chemical and biological processes through the coupled hydrodynamic-water quality model will provide valuable new insights about effects of LEAPS on Lake Elsinore. Moreover, a wider range of operating levels will be evaluated, including levels near those reached in fall 2016 (e.g., <1235'), as well as near 1255', to understand effect of lake surface elevation on impacts of LEAPS and to identify a minimum lake level where LEAPS would not be operated. Key variables include those stipulated in the TMDL (total N and total P, chlorophyll a concentrations and DO levels), as well as algal toxin concentrations, suspended solids, TDS and other properties.

Objective iii) Harnessing LEAPS to Improve Water Quality

The third objective is to assess how LEAPS may be able to improve water quality in Lake Elsinore compared with current conditions. The focus of the initial design and operational plan of LEAPS was to minimize the negative impacts of its operation on conditions, use and water quality at Lake Elsinore. As previously noted, considerable effort has been expended over the past 15 years to enhance mixing and distribute dissolved oxygen throughout the water column to reduce fish kills and improve water quality. Despite these efforts, intervals of low DO and corresponding fish kills have continued to periodically recur. The design, installation and operation of LEAPS presents an opportunity to further enhance mixing, improve DO levels, reduce fish kills, maintain lake level, lower internal recycling of phosphorus from bottom sediments and reduce chlorophyll a concentrations in Lake Elsinore. Temperature, nutrient availability and mixing regime are also known to affect blue-green algae abundance and production of microcystin and other algal toxins (Visser et al., 1996; Buford, 2006, Walls et al., 2018).

Additional work is thus needed to evaluate the capacity of LEAPS to enhance water quality and to develop a flexible I/O design and operational strategy to achieve this goal while maximizing energy storage and production. One feature that will be evaluated is the influence of additional supplementation with high quality water, such as that derived from the State Water Project (beyond the recycled water provided by EVMWD), on water level and water quality. Importation of such water will raise the lake level, lower TDS and is expected to generally improve water quality for some period of time. Opportunities also exist to introduce air or oxygen into the return flows from the Upper Reservoir to enhance DO levels in the lake, and to design the I/O to enhance mixing of the water column and maximize distribution of DO.

Timeline

A working 3-D model for Lake Elsinore-Upper Reservoir has been developed and initial model calibration has been completed. Model verification and application of the model to objectives i-iii is ongoing. Preliminary results are expected by the end of September and completion of the study is expected by December 2018.

Reporting

A draft and final report will be prepared.

References

AMEC Foster Wheeler. 2018. 2017-18 Lake Elsinore and Canyon Lake Nutrient TMDL In-Lake Monitoring Quarter 2 Report. 32 pp.

Anderson, M.A. 2006a. *Technical Analysis of the Potential Water Quality Impacts of the LEAPS Project on Lake Elsinore.* Draft Final Report submitted to the Santa Ana Regional Water Quality Control Board. 30 pp.

Anderson, M.A. 2006b. *Heating, Cooling and Stratification during LEAPS Operation.* Draft Final Report submitted to the Santa Ana Regional Water Quality Control Board. 24 pp.

Anderson, M.A. 2007a. *Effects of LEAPS Operation on Lake Elsinore: Predictions from 3-D Hydrodynamic Modeling.* Draft Final Report submitted to the Santa Ana Regional Water Quality Control Board. 49 pp.

Anderson, M.A. 2007b. *Ecological Impacts from LEAPS Operation: Predictions Using a Simple Linear Food Chain Model.* Draft Final Report submitted to the Santa Ana Regional Water Quality Control Board. 22 pp.

Anderson, M.A. 2010. *Bathymetric, Sedimentological and Retrospective Water Quality Analysis to Evaluate Effectiveness of the Lake Elsinore Recycled Water Pipeline Project.* Draft Final Report to the Lake Elsinore & San Jacinto Watersheds Authority. 50 pp.

Anderson, M.A., J. Tobin and M. Tobin. 2011. *Biological Monitoring for Lake Elsinore.* Final Report to the Lake Elsinore & San Jacinto Watershed Authority. 57 pp.

Anderson, M.A., A. Komor and K. Ikehata. 2014. Flow routing with bottom withdrawal to improve water quality in Walnut Canyon Reservoir, California. *Lake Reserv. Manage.* 30:131-142.

Anderson, M.A. 2015. *Technical Memorandum Task 1.0: Surface Elevation and Salinity in Lake Elsinore: 1916-2014.* Draft Technical Memorandum to Lake Elsinore-San Jacinto Watersheds Authority. 13 pp.

Anderson, M.A. 2016. Technical Memorandum Task 1.2: *Water Quality in Lake Elsinore under Selected Scenarios: Model Predictions for 1916-2014 with Current (post-LEMP) Basin.* Draft Technical Memorandum to the Lake Elsinore-San Jacinto Watersheds Authority. 33 pp.

Buford, M.A. and M.J. O'Donohue. 2006. A comparison of phytoplankton community assemblages in artificially and naturally mixed subtropical water reservoirs. *Freshwater Biol.* 51:973-982.

FERC. 2007. *Final Environmental Impact Statement for Hydropower License. Volume II – Appendices. Klamath Hydroelectric Project.* FERC Project No. 2082-027. 250 pp.

FlowScience, Inc. 2016. *Flow-3D v.11.1. User Manual.* FlowScience, Inc. Santa Fe, NM.

Hodges, B. and C. Dallimore. 2016. *Aquatic Ecosystem Model: AEM3D.* v.1.0 User Manual. HydroNumerics, Docklands, Victoria, Australia. 125 pp.

Hipsey, M.R. 2014. *Computational Aquatic Ecosystem Dynamics Model: CAEDYM. V.3.3 User Guide.* Centre for Water Research, Univ. of Western Australia. 88 pp.

Hodges, B. and C. Dallimore. 2014. *Estuary, Lake and Coastal Ocean Model: ELCOM. v.3.0 User Manual.* Centre for Water Research, Univ. of Western Australia. 65 pp.

Long, B.M., G.J. Jones and P.T. Orr. 2001. Cellular microcystin content in N-limited Microcystis aeruginosa can be predicted by growth rate. *Appl. Environ. Micro.* 67:278-283.

PacifiCorp. 2017. 2016 Evaluation of Intake Barrier Curtain in Iron Gate Reservoir to Improve Water Quality in the Klamath River. Final Report. 74 pp. + Appendices.

Preston, A., I.A. Hannoun, E.J. List, I. Rackley and T. Tietjen. 2014. Three-dimensional management model for Lake Mead, Nevada, Part 1: Model calibration and validation. *Lake Reserv. Manage.* 30:285-302

Preston, A., I.A. Hannoun, E.J. List, I. Rackley and T. Tietjen. 2014. Three-dimensional management model for Lake Mead, Nevada, Part 2: Findings and applications. *Lake Reserv. Manage.* 30:303-319.

SBDDW-16-02. Surface Water Augmentation (SWA) Regulations. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/Surface_Water_Augmentation_Regulations.html

Visser, P.M., B.W. Ibelings, B.Van Der Veer, J. Koedood and L.R. Mur. Artificial mixing prevents nuisance blooms of cyanobacterium Microcystis in Lake Nieuwe Meer, the Netherlands. *Freshwater Biol.* 36:435-450.

Walls, J.T., K.H. Wyatt, J.C. Doll, E.M. Rubenstein and A.R. Rober. 2018. Hot and toxic: temperature regulates microcystin release from cyanobacteria. *Sci. Tot. Environ.* 610-611:786-795.