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December 21, 2017

Kimberly D. Bose, Secretary
**Federal Energy Regulatory Commission**
888 First Street, NE
Washington, D.C., 20426

RE: Project No. P–14227
Lake Elsinore Advanced Pumped Storage Project
18 C.F.R. § 4.32(b)(7) Response to Study Requests

Dear Secretary Bose,

In its "Notice of Application Tendered for Filing with the Commission and Soliciting Additional Study Requests" ("Tendering Notice"), issued on October 11, 2017, the Commission solicited additional study requests pursuant to 18 C.F.R. § 4.32(b)(7) of its regulations. Specifically, the Commission announced that if any resource agency, Indian Tribe, or person believes that an additional scientific study should be conducted to form an adequate factual basis for a complete analysis of the application on its merit, they must file a request for a study with the Commission not later than 60 days from the date of filing of the application, and serve a copy of the request on the applicant. Because Nevada Hydro filed its Final License Application on October 2, 2017, the deadline for filing additional study requests was December 1, 2017.

Pursuant to 18 C.F.R. § 4.32(b)(8), the Company is herein filing with the Commission its response to study requests that satisfies the criteria of 18 C.F.R. § 4.32(b)(7) and serving the study request response on the applicable requester.

## 1.0. Introduction to this Letter

The Company received study requests from the U.S. Department of Agriculture, Forest Service, Cleveland National Forest ("Forest Service"), the U.S. Fish and Wildlife Service ("USFWS"), the State Water Resources Control Board ("State Board"), the Santa Ana Regional Water Quality Control Board ("RWQCB"), the State of California Department of Fish and Wildlife ("CDFW") and the Temecula Band of the Luiseño Mission Indians ("Pechanga Tribe" or the "Tribe"). Because of its intimate relationship to the scope of the project, the Company also is addressing here the request of the City of Lake Elsinore ("City").

Table 1: Study Requests Accepted, summarizes those requests to which the Company generally agrees (with modifications) with the requesting agency. Due to the quantity of

information already made available in the FLA, the Company believes that all studies can be completed prior to construction, and that none are required for the application to be deemed complete now by the Commission.

**Table 1: Study Requests Accepted**

| Study Number | Requesting Agency | Section of this Filing | Request | Agree with modifications |
|---|---|---|---|---|
| 1 | RWQCB | 2.2.2.2 | Study of Total Nitrogen, Phosphorus and Cyanotoxins the Project Will Contribute to Lake Elsinore | ✓ |
| 2 | RWQCB | 2.2.2.3 | Study of How the Project Will be Incorporated into Lake Elsinore's "TMDLs" | ✓ |
| 3 | USFWS | 2.3.1.2 | Request for Updated Biological Surveys | ✓ |
| 4 | CDFW | 2.3.2.1 | Request for Updated Biological Surveys | ✓ |
| 5 | CDFW | 2.3.2.2 | Bald Eagle and Peregrine Falcon Studies | ✓ |
| 6 | CDFW | 2.3.2.3 | Golden Eagle and General Raptor Studies | ✓ |
| 7 | CDFW | 2.3.2.4 | Special Status Riparian Bird and Nest Monitoring Study | ✓ |
| 8 | CDFW | 2.3.2.6 | Special Status Plant Study | ✓ |
| 9 | CDFW | 2.3.2.7 | Vegetation Mapping Study | ✓ |
| 10 | CDFW | 2.3.2.9 | Special Status Fish, Amphibian and Aquatic Reptile Study | ✓ |
| 11 | CDFW | 2.3.2.12 | Special Status Butterfly Study | ✓ |
| 12 | Pechanga | 2.4.1 | Update Inventory Report | ✓ |
| 13 | City | 3.3 | Updated Biological Resource Study | ✓ |
| 14 | City | 3.7 | Development of Additional Visual Simulations | ✓ |
| 15 | City | 3.8 | Updated Cultural Resources Assessment Study | ✓ |
| 16 | City | 3.9 | Construction Traffic Analysis Study | ✓ |

## 2.0. Introduction to Agency and Tribe Requests

Although not all study requests satisfied the Commission’s rules at 18 CFR 4.32 (b)(7), the Company is herein treating all agency letters as valid study requests.

To best respond to the range of these requests, the Company retained the services of the following recognized experts:

- GENTERRA Consultants, Inc. (“Genterra”) for geotechnical and hydrological issues.
- TRC Solutions, Inc., (“TRC”) for issues related to biological resource issues.
- Chambers Group, Inc. (“Chambers”) for issues pertaining to cultural resources.
- Dr. Michael Anderson, Professor of Environmental Chemistry, University of California, Riverside (“Dr. Anderson”) for issues pertaining to Lake Elsinore water, its quality and chemistry and recreation resources. Dr. Anderson frequently advises local water agencies.
- ZGlobal Inc. (“ZGlobal”) for electric grid economic issues.
- Fred Depenbrock for transmission and substation electrical engineering.

The Company anticipates that these experts (and others as may be required) will work closely with the resource agencies and Tribes to address their requests and concerns, where necessary to develop appropriate study plans, and perform agreed-to studies.

As the FLA includes a library of reports focusing on the major issues raised: water in Lake Elsinore, geotechnical issues, and biological resources, the Company presents a listing of these reports in the following tables. For ease of access, the tables are organized according to the report’s location in the FLA.

**Table 2: Lake Elsinore Water Report Library**

| FLA Volume | Tab | Content |
|---|---|---|
| 4 | 2. | Lake Elsinore Restoration and San Jacinto River Watershed Protection Program Proposal |
| 4 | 3. | Restoration of Canyon Lake and Benefits to Lake Elsinore |
| 4 | 4 | Alum Application of Lake Elsinore Report and Questionnaire Responses |
| 4 | 5. | Review of Water Quality Data on Lake Elsinore |
| 4 | 6. | Proposed Lake Elsinore Aeration and Bio-manipulation Study |
| 4 | 7. | Lake Elsinore Replenishment Level Study Alternatives Analysis |
| 4 | 8. | Lake Elsinore Technical Memoranda – Nutrient Removal |

| FLA Volume | Tab | Content |
|---|---|---|
| 4 | 9. | Lake Elsinore Draft Fisheries Management Plan |
| 4 | 10. | Lake Elsinore Stabilization and Enhancement Project |
| 5 | E-1 | Conceptual-Level Hydrology Study |
| 5 | E-2 | Lake Elsinore Recycling Water Project Draft Fifth Quarter Monitoring Report |
| 5 | E-3 | Preliminary Guidelines for a Monitoring and Surveillance Program |
| 5 | E-4 | Hydrology Study for FERC Project No. 11504 |
| 5 | E-5 | Biological Resource Assessment |
| 7 | 1. | San Jacinto Nutrient Management Plan – Draft Report |
| 7 | 2. | Lake Elsinore/Canyon Lake Nutrient TMDL Monitoring Program Report for Year 2000/2001 |
| 7 | 3. | Lake Elsinore Nutrient TMDL Monitoring Program Report for Year 2001/2002 |
| 7 | 4. | Internal Loading and Nutrient Cycle in Lake Elsinore |
| 7 | 5. | Lake Elsinore Nutrient Removal Study – Draft Report |
| 7 | 6. | Lake Elsinore Toxins TMDL Monitoring Program Report |
| 7 | 6a. | Representative Sampling Data |
| 7 | 7. | Engineering Feasibility Study for NPDES Permit for Discharge to Lake Elsinore – Final Report |
| 7 | 8. | Lake Elsinore User Survey Results |
| 7 | 9. | Elsinore Basin Groundwater Monitoring Plan |
| 7 | 10. | Elsinore Basin Groundwater Management Plan |
| 7 | 11. | Grant Proposal No. 564 “Canyon Lake and Lake Elsinore Lake Monitoring and Modeling” rejection letter from SWRCB |
| 6 | 7.8 | Water Quality Control Plan, Santa Ana River Basin (8) (SARWQCB) |
| 6 | 7.9 | Water Quality Control Plan, San Diego Basin (9) (SDRWQCB, September 8, 1994) |
| 8 | 1–11 | Augmenting Lake Elsinore Flows |
| 8 | 1–12 | Wastewater Discharge Monitoring |
| 8 | 1–13 | Oxygenation |
| 9 | (3) | Status of Water Rights, Purchase Agreements and Water Reuse |
| 9 | (6) | Level of Effect of Cycling |
| 9 | E. | Final Aeration Monitoring Report (Additional Project Information) |

| FLA Volume | Tab | Content |
|---|---|---|
| 11 | 1. | Elsinore Valley Municipal Water District Urban Water Management Plan, July 2011 |
| 11 | 2. | Methodologies for Calculating Baseline and Compliance Urban Per Capita Water Use, February 2011 |
| 11 | 3. | Elsinore Valley Municipal Water District, Elsinore Basin Groundwater Management Plan, Final Report, March 2005 |
| 11 | 4. | Developing a Baseline of Natural Lake-Level/Hydrologic Variability and Understanding Past Versus Present Lake Productivity over the Late-Holocene: A Paleo-Perspective for Management of Modern Lake Elsinore, March 2005 |
| 11 | 5. | Technical Analysis of the Potential Water Quality Impacts of the LEAPS Project on Lake Elsinore, Michael Anderson, January 31, 2006 |
| 11 | 6. | Technical Memorandum, June 12, 2015 |
| 11 | 7. | Effects of LEAPS Operation on Lake Elsinore: Predictions from 3-D Hydrodynamic Modeling, DRAFT FINAL REPORT, April 23, 2007 |
| 11 | 8. | Report on Water Quality Sampling Events 2004-05 |
| 11 | 9. | Lake Elsinore/Canyon Lake TMDL Compliance Program San Jacinto River Watershed Storm Water Sampling and Analysis Plan (SAP), December, 2008 |
| 11 | 10. | In-Lake Sediment Nutrient Reduction Plan for Lake Elsinore, October 31, 2007 |
| 11 | 11. | Three Species Studies on Nitrogen Offsets in Semi-Desert Lake Elsinore in 2006-08 as part of the Nutrient TMDL for Reclaimed Water Added to Stabilize Lake Levels, June 30, 2009 |
| 11 | 12. | San Jacinto Watershed Model Update (2010) – Final, October 7, 2010 |
| 11 | 13. | Lake Elsinore & Canyon Lake TMDL Comprehensive Phase 2 Compliance Monitoring Program Framework Lake Elsinore & San Jacinto Watersheds Authority Riverside, California, July 6, 2014 |
| 11 | 14. | Lake Elsinore Phase 2 Water Quality Monitoring Plan to Evaluate the Efficacy of the In-Lake Nutrient Reduction Facilities (Aeration and Mixing) for Lake Elsinore, December, 2010 |
| 11 | 15. | Lake Elsinore/Canyon Lake TMDL Compliance Program San Jacinto River Watershed Storm Water Sampling and Analysis Plan (SAP), December, 2008 |
| 11 | 16. | In-Lake Sediment Nutrient Reduction Plan for Lake Elsinore, October 31, 2007 |
| 11 | 17. | Three Species Studies on Nitrogen Offsets in Semi-Desert Lake Elsinore in 2006-08 as part of the Nutrient TMDL for Reclaimed Water Added to Stabilize Lake Levels, June 30, 2009 |
| 11 | 18. | San Jacinto Watershed Model Update (2010) – Final, October 7, 2010 |
| 12 | H1. | Elsinore Valley Municipal Water District Urban Water Management Plan, Final, June, 2016 |
| 12 | H2. | Lake Elsinore and Canyon Lake Nutrient TMDL Annual Water Quality Report, Final Report, August, 2015 |

| FLA Volume | Tab | Content |
|---|---|---|
| 12 | H3. | Lake Heating, Cooling and Stratification During LEAPS Operation, August, 2006 |
| 12 | H4. | Lake Elsinore and Canyon Lake Preliminary Aeration System Report, June, 2004 |
| 12 | H5. | Memorandum, March, 2015 |
| 12 | H6. | Effects of LEAPS Operation on Lake Elsinore: 3-D Hydrodynamic Modeling |
| 12 | H7. | Lake Elsinore Water Supply |
| 12 | H8. | Lake Elsinore Recycled Water Project – Draft 4th Quarterly Report, September, 2017 |
| 12 | H9. | Lake Elsinore Recycled Water Project – Draft Final Report, November,2004 |
| 12 | H10. | Results from the Lake Elsinore Recycled Water Monitoring Project |
| 12 | H11. | Draft Technical Memorandum, Michael Anderson, April, 2015 |
| 12 | H12. | Draft Technical Memorandum, Michael Anderson, June, 2015 |
| 12 | H13. | Lake Elsinore Water Level Sustainability |

Source: FLA

**Table 3: Biological Resources Report Library**

| FLA Volume | Tab | Content |
|---|---|---|
| 8 | 1–14 | Botanical and Zoological Surveys |
| 8 | II–1 | Terrestrial Biological Resources Study, Lake Elsinore Advanced Pumped Storage, Talega-Escondido/Valley Serrano Interconnect Project |
| 8 | II–2 | Draft Fisheries Management Plan for Lake Elsinore |
| 9 | (7) | Quantitative Information on Impacts to Terrestrial Resources |
| 9 | (8) | Existing Shoreline Vegetation and Proposed Mitigation Measures |
| 9 | (9) | Invasive Plants |
| 9 | a. | Existing Aquatic Vegetation in Lake Elsinore and Potential Project Effects |
| 9 | b. | Upland, Wetland, and Riparian Weeds and Non-Native Invasive Plants and Proposed Control Measures |
| 9 | (10) | Special Status Wildlife Species |
| 9 | a. | USFS Management Indicator Species (MIS) and USFS Sensitive Species |
| 9 | b. | Bald Eagle Surveys and Potential Project Effects |
| 9 | c. | Proposed Measures to Mitigate Impacts to Special Status Species |

| FLA Volume | Tab | Content |
|---|---|---|
| 9 | (11) | Additional Information about Bird use of Lake Elsinore |
| 9 | A. | Proposed Designation of Critical Habitat for Allium Munzil (Munz's Onion) |
| 10 | 1. | Terrestrial Biological Resources Study LEAPS Project and Talega Escondido/Valley Serrano 500-kV Interconnection Project, Riverside County, California, November, 2004 |
| 10 | 2. | Summary of 2005 Focused Survey Results for the LEAPS and Talega/Escondido – Valley Serrano Interconnect Projects Riverside County and San Diego, September 29, 2005 |
| 10 | 3. | Impact Assessment Letter Report for LEAPS and Talega-Escondido/Valley Serrano 500-kV Interconnection Project, June 21, 2007 |
| 10 | 4. | Delineation of Jurisdictional Waters and Wetlands Proposed LEAPS Unincorporated Riverside and San Diego Counties, California, November 14, 2007 |
| 10 | 5. | Fisheries Management Plan for Lake Elsinore, September 20, 2005 |
| 10 | 6. | White and Leatherman Bioservices, Munz's Onion, December, 1992 |

Source: FLA

**Table 4: Geotechnical Report Library**

| b | Tab | Title |
|---|---|---|
| 5 | E-10 | Geotechnical Feasibility Report |
| 5 | E-11 | Second Stage Geotechnical Evaluation |
| 5 | E-12 | Conceptual-Level Inundation Studies |
| 5 | E-13 | Construction Traffic Analysis |
| 12 | G1. | Technical Memorandum No. 3, Preliminary Evaluation of Faulting and Seismicity, LEAPS, July 18, 2008 |
| 12 | G2. | Technical Memorandum No. 2, Geologic Mapping, LEAPS, July 17, 2008 |
| 12 | G3. | Technical Memorandum No. 1, Summary Report of Existing Information, Geology, Seismicity and Geotechnical Issues, LEAPS, January 25, 2008 |
| 12 | G4. | Memorandum to U.S. Army Corps of Engineers, Input for United States Army Corps of Engineers Section 404 Permit, LEAPS, November 22, 2006 |
| 12 | G5. | Technical Memorandum, Comments on Issues Relating to Hydrology as Identified in the DEIS, LEAPS, March 31, 2006 |
| 12 | G6. | Technical Memorandum, Comments on Geotechnical Issues as Identified in the DEIS, LEAPS, March 30, 2006 |

| | | |
|---|---|---|
| 12 | G7. | Technical Memorandum, Comparative Review of Geotechnical Conditions at Three Candidate Powerhouse Sites: Ortega Oaks, Santa Rosa and Evergreen, LEAPS, March 24, 2006 |
| 12 | G8. | Phase I Work Plan, Preliminary Geotechnical Investigation, LEAPS, June 10, 2005 |
| 12 | G9. | Report on Water-Quality Sampling Events 2004-05 Wet Season, LEAPS, May 31, 2005 |
| 12 | G10. | Geotechnical Feasibility Report, LEAPS, August 28, 2003 |
| 12 | G11. | Supplemental Report, Conceptual-Level Dike Breach Inundation Study, LEAPS, December 12, 2003 |
| 12 | G12. | Supplement No. 1 to Geotechnical Feasibility Report, October 16, 2003 |
| 12 | G13. | Conceptual-Level Hydrology Study, LEAPS, August 28, 2003 |
| 12 | G14. | Conceptual-Level Inundation Study, LEAPS, August 28, 2003 |

Source: FLA

A summary of the Company's responses to the specific requests of each agency follows.

### 2.1. Study Requests of the US Forest Service

In its November 30, 2017 letter, the Forest Service made of number of comments that the Company proposes to address in direct discussion with appropriate Forest Service personnel. The Company intends to provide clarification to the Forest Service on the issues it raised.

#### 2.1.1. Project Fire Risk, Impacts to Fire Suppression Efforts & Hazardous Fuels Reduction Assessment

The first study requested is to address "the extent of hazardous fuel loading, fire risk, and potential impacts to firefighters that could be affected by the proposed project."

The Company understands that it cannot take any unilateral action related to fuel loading without express approval from the Forest Service and that the Forest Service is ultimately responsible for fuel management in the CNF. As a result, the Company can only address fuel loading issues to the extent so directed by the CNF. As a result, the Company disagrees with this request.

Regarding fire risk and impacts to firefighters that could be affected by the Project, the Company notes that water in the Decker Canyon reservoir will always be available for firefighting, and that it is a non–recreational water body roughly 1,600 feet above Lake Elsinore. Further, associated with the presence of the Decker Canyon reservoir, at the option of the Forest Service, fire hydrants could be located in the area. This resource had previously been viewed by the Forest Service as a major benefit the Project provides to the CNF and should be included in any overall assessment of fire risks the Project may bring to the CNF.

The Company understands that the Forest Service has conditioning authority and can file Section 4(e) conditions relative to fire. For example, the FEIS noted that one of the Forest Service's standard conditions filed in its June 22, 2006 letter in the Project No. 11858 proceeding and discussed in the FEIS involves "fire prevention measures that would conform to water quality protection practices consistent with the USFS' best management practices for water quality management for National Forest System lands in California." Condition 33, of the previously-filed 4(e) conditions, required the creation of a vegetation and invasive weed management plan. Condition 9 of the previously-filed 4(e) conditions, explicitly addressed "fire prevention, response and investigation". In addition, this issue was addressed in Volume 2, Section 5.16 of the FLA, and also discussed in the FEIS in response to comments 201, 202, and 203 in Appendix E, and as the Company has supplemented this analysis as described in Section 4.2, Fire Risk and Impact on Fire Suppression of this Volume 14. Therefore, the Company disagrees that additional studies on fire risks brought about by the presence of the Project are needed.

The Company notes that the FEIS prepared with the cooperation of the Forest Service in the Project No. 11858 proceeding, noted that the "staff alternative" adopted in full for the Project, "includes an alternative facility location for the upper reservoir as well as a revised transmission alignment developed by the USFS and Commission staff" that in part was developed to minimize fire suppression–related risks.[1] The June 22, 2006 letter from the Forest Service in which it transmitted its preliminary 4(e) conditions concludes:

> *The staff alternative, which avoids impacts to unique riparian habitat, and provides transmission line locations that would not hinder fire suppression actions necessary to protect watershed values, would be consistent with the reservation.*[2]

As the FEIS pointed out in response to a comment, the scope of responsibility is relatively clear:

> *The co-applicants do not propose to clear vegetation under the transmission line, but fuel management in the future may require manipulation to reduce the risk of fire. Methods selected for fuel management would be developed* ***in consultation with the USFS*** *and would depend on site-specific factors (e.g., vegetation type, slope, aspect, access), and could include grazing, prescribed fire, or mechanical means to create and maintain firebreaks. Existing firebreaks that intersect the proposed alignment would also be maintained, as needed* ***and as specified by the USFS****. The increased risk of fire that would be associated*

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[1] / FEIS at page 5–1, 5–18. See also Table 55 of the FEIS.

[2] / FEIS at page C–2.

> *with uncontrolled public access and weed invasion highlights the importance of effective road and weed management. The objective is to eliminate all man caused fires within the project area and to take prompt, aggressive action on all fires in the vicinity. Our recommended hazardous vegetative fuel treatment plan* ***as specified by the USFS*** *would set forth protocols for the treatment of vegetation in the vicinity of the transmission lines.*[3]

The Company's proposed transmission line route in the FLA is substantially similar to the staff alternative alignment described in the FEIS. The Company looks forward to working with the Forest Service to develop any plans required by the Forest Service with respect to the construction and operation of the Project to further protect the CNF and its neighbors from fire risks.

### 2.1.2. Project Site Specific Seismic Hazard and Geotechnical Study

The Forest Service's second study request is that the Company conduct a seismic and geotechnical study to conduct a deterministic and probabilistic seismic hazard evaluations to estimate earthquake ground motion parameters at the Project site, assess the potential loads the proposed Project facilities would be subject to during seismic events, and develop appropriate design and safety criteria for Project facilities and operation.

**The Company addressed this issue in Exhibit E–6 in Volume 1 of its FLA and in Section 4.8 and 5.6 of Volume 2 of the FLA. The Company requested a response to this request from its geotechnical consultant. Their response may be found in Attachments**

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[3] / FEIS response to comment 124 at page E–38. Emphasis added.

Attachment 1: Site-Specific Seismic Hazard and Geotechnical Study Plan IssuesAttachment 1: Site-Specific Seismic Hazard and Geotechnical Study Plan Issues The studies requested by the Forest Service present a level of effort and cost which would be overly burdensome relative to the need for the information at this time. As the FEIS addressed these issues in responding to comments 68 and 69 in Appendix E, Genterra believes that the preliminary reports it prepared remain sufficient to inform the Commission of these geotechnical issues at this stage, particularly as the Commission relied on these same studies in reaching its conclusions described in the FEIS. More invasive investigations are planned to develop design level engineering criteria.

### 2.2. Study Requests from Water Agencies

The Company received a range of requests for studies from the State and regional water agencies, the State Board and the and the RWQCB. As discussed below, the Company has been invited to participate in the Lake Elsinore and Canyon Lake TMDL (Total Maximum Daily Load) Task Force ("Task Force"). The Task Force is comprised of local stakeholders interested in improving water quality and attaining water quality standards at both Lake Elsinore and the neighboring Canyon Lake. The Task Force includes representatives from local cities, Riverside County, agriculture and dairy, environmental groups, and the regulatory community.

In 1994 the Regional Water Quality Control Board (RWQCB) placed Lake Elsinore on the Clean Water Act Section 303(d) list of impaired waterbodies due to the lake's ongoing problem with hypereutrophication, or an excessive amount of nutrients, namely phosphorous and nitrogen, in the water. This in turn caused high algal productivity and fish kills. In 1998 and 2002, Lake Elsinore was listed for unknown toxicity, nutrients, organic enrichment/low dissolved oxygen, and sedimentation/siltation.

The TMDL Task Force works with the RWQCB to monitor lake water quality, provide nutrient source assessment models, and produce studies periodically to further understand the impairment processes affecting Lake Elsinore and publish ongoing reports periodically. All of the topics for studies requested by these two agencies will be addressed by the Task Force through the course of its work. As all of these topics had been addressed in reports described in the FLA (see for example, the reports listed in Table 2: Lake Elsinore Water Report Library) and FEIS, the Task Force will be providing periodic updated information that can be used to fine tune the design and operation of the Project prior to construction. The Company believes that both these agencies currently have sufficient information for the Commission to now accept the FLA as complete and not wait for completion of the ongoing work by the Task Force.

#### 2.2.1. Study Requests of the State Water Resources Control Board[4]

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[4]/ Much of the information relied upon in this section references reports prepared by Dr. Anderson. For ease of reference, the major reports referenced in this section may be found in Attachment 3: Copies of Select Reports from Dr. Anderson. These

The State Water Resources Control Board ("State Board") submitted study requests in its June 30, 2014 letter to the Commission. The Company herein responds to those requests.

### 2.2.1.1. Daily Water-Level Fluctuation at Lake Elsinore

Comment #2 in the State Board's letter requests a study of the extent of the expanding shoreline due to project operations at various foreseeable lake levels including a series of drought years. The Company does not believe an additional study is necessary, as described below.

As noted in this letter and described in the Commission's FEIS, fluctuations in lake surface elevation and lake area will result from operation of the Project. The bathymetry of the lake, lake surface elevation during operation, and pumping (withdrawal) and generation (return flow) volumes will dictate the changes in lake surface elevation and surface area. An assessment was conducted in connection with the license application submitted for Project No. 11858, which can be found in Volume 7 of the pending FLA, and further analysis was part of a study commissioned by the RWQCB.[5] Lake elevation was predicted to change 1.0 foot during weekday operation and 1.7 feet during the weekend when extended pumping could occur. Using bathymetry reported by Black & Veatch, a 1.0-foot elevation change corresponds to 49 acres of exposed (or rewetted) sediment, while 1.7 feet resulted in an 83-acre change. Using bathymetry developed from point sampling across the lake (Anderson, 2004), somewhat larger areas were predicted (79 and 134 acres exposed for 1.0 and 1.7-foot drawdown, respectively). A further analysis of water level fluctuations was conducted for the RWQCB using bathymetric data developed from 270 km of hydroacoustic measurements in 2010 (Anderson, 2010). This analysis is provided in Section 4.5, Dr. Anderson's Analysis of Daily Water Level Fluctuation at Lake Elsinore, and yielded exposed sediment areas of 72 and 122 acres for 1.0 and 1.7-foot elevation change at 1247 feet, which is in good agreement with earlier estimates from Dr. Anderson.

This compares with the range of surface elevation of Lake Elsinore of >20 feet since 2000 and variation in surface area of >1400 acres (Appendix). The loss of recreational access and use, as well as habitat loss, over the past several years has been dramatic. With annual variations in lake elevation commonly 3-4 feet and surface area reductions of 200-300 acres per year, a key advantage of the Project is the longer-term stabilization of lake level within an operational range of 1240 – 1247 feet and about 2800-3300 surface acres; although daily oscillations will be much larger than present at the lake, the longer-term stabilization will provide greater recreational and habitat value especially during periods of protracted drought.

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reports document the analyses and modeling he conducted on behalf of the RWQCB a decade or so ago to assess possible water quality impacts from operation of the Project. They have been numbered to indicate the order in which they were developed, and are best read in that order.

[5]/ See Professor Anderson's 2006 report, "Technical Analysis of the Potential Water Quality Impacts of the LEAPS Project on Lake Elsinore, Final Report submitted to the Santa Ana Regional Water Quality Control Board" ("Anderson 2006").

Lastly, further discussion of this issue may be found in:

- Comments 76, 77, 78 91, 120 and 191 in Appendix E of the FEIS, in which the Commission addressed these issues in responding to specific questions on this topic.
- Section E-2 in Volume 1 of the FLA.
- Section 4.16 in Volume 2.
- Memoranda in Volume 12 of the FLA.

### 2.2.1.2. Water Quality in Lake Elsinore

Comment #9 in the State Board's letter requests a study of how the cycling of the water used by the Project will affect water quality in the lake. The Company does not believe an additional study is necessary, as described below.

Resuspension of bottom sediments and sediment-associated nutrients and other contaminants resulting from operation of the Project was previously identified as a possible concern. In studies commissioned by the RWCB, an analytical wind-wave model and 3-D hydrodynamic model evaluated resuspension derived from operation of the Project. Hourly wind data were used with the model of Carper and Bachmann[6] to calculate wave period and wind-mixed depth; these calculations demonstrated that natural wind-wave action resuspends fine bottom materials in Lake Elsinore at a depth of 1 foot about 70% of the time, transporting that material into deeper regions of the lake, and thus yielding correspondingly low organic C content present in these shallow sediments.[7] Application of a 3-D hydrodynamic model further evaluated bottom shear and sediment resuspension.[8] Simulations for the proposed 150 m wide intake structure at 1247 feet elevation yielded average bottom shear values near the intake of only about 0.02 N $m^{-2}$; bottom shear increased at 1240 feet but the Santa Rosa site remained below the assumed critical value of 0.1 N $m^{-2.}$[9] As a result, resuspension was not predicted to be a significant concern for the full shoreline-mounted intake structure. Moreover, as previously noted, sediment near the margins of Lake Elsinore are coarse-textured (70-90% sand) with very little organic C that results from wind-wave action and seasonal lake surface elevation changes that focus organic matter and associated nutrients into the deeper regions of the lake.

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[6] / Carper, G.L. & R.W. Bachmann, 1984. Wind resuspension of sediments in a prairie lake. Canadian Journal of Fisheries and Aquatic Sciences 41: 1763-1767.

[7] / Anderson, 2006.

[8] / Please see Dr. Anderson's 2007 report, "Ecological Impacts from LEAPS Operation: Predictions Using a Simple Linear Food Chain Model. Final Report submitted to the Santa Ana Regional Water Quality Control Board". ("Anderson, 2007").

[9] / Id.

Although not proposed for implementation, additional simulations also evaluated 1-m vertical gates with 150, 40 and 10 m intake widths; these scenarios yielded predicted bottom shear values of 0.24, 0.54 and 1.61 N $m^{-2}$ that could resuspend bottom sediment and result in elevated local concentrations of suspended sediment.[10] The resuspension process itself would be relatively short-lived however, as the bottom sediment would quickly equilibrate to the local shear stress.

A useful example of sediment equilibrating to the local shear stress is with the axial flow pumps installed at the lake. Horizontal velocities > 40 cm s-1 have been measured directly above soft organic sediments adjacent to the pumps11 that eroded sediment immediately beneath them. See Figure 4-2: Map Showing Basin Elevation as a Function of Latitude and Longitude with 3–D Representation and note circular depressions in inset. These velocities are an order of magnitude greater than average velocities above sediments near the Project's intake (generally <4 cm s-1).12 Measurements of acoustic backscatter (a measure of turbidity) adjacent to operational axial flow pumps did not indicate any differences with values recorded elsewhere in the lake.13 Moreover, the type-I coarse-textured sediment near the lake margins require high shear stress to mobilize and are low in total N, total P and with low pore-water nutrient concentrations that release very little nutrients (Anderson, 2001).14 Rip-rap placed near the intake will also armor the bottom. As a result, chronic resuspension of bottom sediment and sediment-borne nutrients is not expected from the operation of the Project, with its large shore-mounted intake structure.

Lastly, the Commission addressed these issues in responding to comments 85, 89 and 95 in Appendix E of the FEIS.

### 2.2.1.3. Aquatic Resources.

Comment # 10 in the State Board's letter requests a study of the consequences of lake fluctuation and the exposure of near shore littoral habitats to support the Lake Elsinore Fishery Management Plan. The Company does not believe an additional study is necessary, as described below.

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[10] /Id.

[11] /Lawson, R. and M.A. Anderson. 2007. Stratification and mixing in Lake Elsinore, California: An assessment of axial flow pumps for improving water quality in a shallow eutrophic lake. Water Res. 41:4457-4467.

[12] /Anderson, 2007.

[13] /Anderson's 2006.

[14] /Anderson, M.A. 2001. Internal Loading and Nutrient Cycling in Lake Elsinore. Final Report to the Santa Ana Regional Water Quality Control Board.

The fluctuation in lake level and exposure of near shore littoral habitats is not anticipated to substantially affect spawning of sport fish. Largemouth bass and bluegill typically spawn in water that is 1-3 m (3-10 feet) deep (Stuber et al., 1982); variation on the order of 1 foot due to the Project is below this range, and within the guidelines in the habitat suitability index model of Stuber et al. (1982). Moreover, maintenance of higher lake levels for operation of the Project with additional supplemental water will also avoid extreme salinity concentrations that are present at low lake levels. High salinities have been previously identified as interfering with sport fish and beneficial zooplankton reproduction in Lake Elsinore.[15]

Further discussion of this issue can be found in Sections 3.3.3 and 5.2.5 in the FEIS and Exhibit E–3 of Volume 1 of the FLA.

### 2.2.2. Study Requests of the Santa Ana Regional Water Quality Control Board[16]

In its December 1, 2017 letter, the RWQCB requested the studies described in the following subsections:

#### 2.2.2.1. Water Supply Study

Study request #1 involves identifying an adequate water supply for the Project's use in the lake.

The Company understands this has been an ongoing issue for the lake for decades, and that many agencies that have been involved in resolving this issue, including the RWQCB. The Company anticipates that its involvement in the process, and its willingness to provide funds for any needed supplementary water, will allow this issue to be finally resolved to everyone's satisfaction.

Additional information on this issue can be found at comment 75 in Appendix E of the FEIS, in which the Commission addressed this issue in responding to a specific question on this topic. Also, please see Sections 3.3.2 of the FEIS, Section E–2 of Volume 1 of the FLA, Section 3.6.2.6.1 and 4.18 of Volume 2 of the FLA.

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[15] /Veiga-Nascimento, R.A. 2004. Water Quality and Zooplankton Community in a Southern California Lake Receiving Recycled Water Discharge. M.S. Thesis, University of California, Riverside, CA. 87 pp.

[16] /Much of the information relied upon in this section references reports prepared by Dr. Anderson. For ease of reference, the major reports referenced in this section may be found in Attachment 3: Copies of Select Reports from Dr. Anderson. These reports document the analyses and modeling he conducted on behalf of the RWQCB a decade or so ago to assess possible water quality impacts from operation of the Project. They have been numbered to indicate the order in which they were developed, and are best read in that order.

The Company disagrees that a new study needs to be undertaken by it since the operation of the Project is a non-consumptive use. Rather than embarking on another study of the issue, the Company anticipates working closely with the Lake Elsinore stakeholders to secure adequate, long term water for the lake to serve its water quality and recreation needs.

#### 2.2.2.2. Study of Total Nitrogen, Phosphorus and Cyanotoxins the Project Will Contribute to Lake Elsinore

Study request #2 notes that evaporation and biogeochemical processes occurring in the upper reservoir may increase concentrations of nutrients and cyanotoxins in water during storage there. The Company agrees that additional study of processes occurring in the upper reservoir is warranted, as modified from the request below.

Preliminary consideration suggests that evapoconcentration will not be a dominant factor, but biogeochemical and physical processes may change concentrations and forms of some water quality constituents. Analytical or numerical modeling should help ascertain whether water quality is improved, degraded or unchanged during transient storage in the upper reservoir.

The Company agrees that a supplemental study could be needed on this issue and looks forward to working with the RWQCB on this issue. The Company suggests that this issue be included within the scope of the Task Force undertaking. As discussed above, due to the scope of analysis already completed, primarily by Dr. Anderson, and documented in the FLA, the Company proposes that this study be completed in due course by the Task Force, and implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

#### 2.2.2.3. Study of How the Project Will be Incorporated into Lake Elsinore's "TMDLs"

Study request #3 involves development of relevant information to incorporate the Project in Lake Elsinore's TMDLs. The Company agrees that additional work is needed to address this issue, as described below.

The TMDL revision presently underway by the TMDL Task Force, as described in Section 2.2, Study Requests from Water Agencies, includes a placeholder for the Project, and the Company is now working with the Task Force to develop this element. The Company will suggest to the Task Force that the development of a waste load allocation should be included in their studies, based on the differential load between that in water withdrawn from the lake during pumping and that returned to the lake during generation. While additional work is warranted to understand any changes in water quality within the upper reservoir and assess the need for and implications of a waste load allocation for the upper reservoir, based upon the schedule for the Task Force to complete their work, the Company proposes that this element of their study be completed in due course by the Task Force, and implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

Information on this topic can be found in comments 89 and 95 in Appendix E of the FEIS, in which the Commission addressed this issue in responding to specific questions on this topic.

### 2.2.2.4. Study of any Increase in Nutrients in the Water Column from the Project

Study request #4 notes that bottom sediments represent a primary source of nutrients released to the water column, and that resuspension of sediments and nutrients through operation of the Project needs to be assessed.

The Company agrees that sediment resuspension and enhanced nutrient release is a very important issue, but believes that the issue of sediment resuspension and potential for enhanced nutrient release was adequately addressed in previously commissioned studies by the RWQCB as reported in Anderson (2006), Anderson (2007), and discussed in Sections 2.2.1.1, Daily Water-Level Fluctuation at Lake Elsinore and 2.2.1.2, Water Quality in Lake Elsinore.

Moreover, because further analysis will likely be undertaken by the Task Force, and due to the scope and timing for the proposed completion of the Task Force's work, the Company does not believe any additional information is necessary for the Commission to assess this issue.

### 2.2.2.5. Study on the Impacts to Water Contact Recreation

Study request #5 addresses the impacts of the Project on recreation and safety. The Company agrees that safety measures (likely implemented as best management practices) will be needed to exclude contact with facilities at the lake and prevent injury to recreators and proposes a modified version of the study to develop a safety plan as part of the project. The Company proposes to develop a safety plan to be implemented prior to construction or operation of the Project.

The drawdown of shoreline, and variation of lake elevation with pumping/generation was previously addressed in Anderson (2006), Anderson (2007) and considered further in response to comments in Sections 2.2.1.1, Daily Water-Level Fluctuation at Lake Elsinore and 2.2.1.2, Water Quality in Lake Elsinore. As noted in Section 2.2.1.1, Daily Water-Level Fluctuation at Lake Elsinore, stabilization of the lake at nominal operating levels of 1,240 – 1,247 feet is thought to provide enhanced long-term recreational opportunities compared with recent conditions in which lake levels have dropped as low as 1,233 feet which limited use of boat launches, created navigational hazards, yielded extremely poor water quality, and generated public health concerns and recreational restrictions due to algal toxins. Moreover, as is illustrated in 4.5, Dr. Anderson's Analysis of Daily Water Level Fluctuation at Lake Elsinore, bathymetric data indicates that shallow regions in the southern part of the lake away from beach and boat launch areas are most sensitive to lake level changes.

Information on this topic can be found in Sections 3.3.6, 5.2.8 and comments commencing with number 168 of Appendix E of the FEIS, in which the Commission addressed this issue in responding to a specific question on this topic. Additional information can also be found in Exhibit E–7 of Volume 1 of the FLA and Sections 4.16 and 5.14 of Volume 2 of the FLA.

### 2.2.2.6. Study of the Impacts of Impingement and Entrainment on Aquatic Organisms

Study request #6 concerns how Project operation will potentially impact aquatic organisms in Lake Elsinore. The Company does not believe an additional study is needed based upon the previous studies commissioned by the RWQCB. Impacts were specifically evaluated for phytoplankton, zooplankton, and larval and adult fish in Anderson (2006). The impacts were minimal for phytoplankton due to their rapid rate of reproduction compared with the rate of lake volume exchange, while greater loss was predicted for zooplankton (7-25% reduction due to Project operation) and most significant for larval fish (40-100% loss). A Gunderboom system proposed for the Project reduced entrainment and lowered larval fish mortality to 8-29% and zooplankton loss to approximately 3-12% in these studies.[17] A linear food-web model was subsequently developed to project possible trophic cascades resulting from Project operation.[18]

Information on this issue can be found in Sections 3.3.3 and 5.2.5 of the FEIS.

### 2.2.2.7. Study of the Lake Level Impact of Project Operation

Study request #7 notes that lake level governs water quality and ecosystem health. It is agreed that a critical surface elevation exists below which the Project would not be operated. The FLA explicitly assumes a nominal operating elevation of 1240-1247 feet above MSL. Detailed hydrodynamic modeling was conducted to assess water velocities and bottom shear at 1240 and 1247 feet elevations.[19] The intent is that water will be supplied to the lake to maintain the nominal elevation above 1240 feet, a target minimum elevation for the lake that is recognized in the initial TMDL as well as the TMDL revision process as conferring generally favorable water quality conditions for recreational and ecological beneficial uses. The Company will engage with the TMDL Task force as appropriate, but does not believe additional studies apart from those underway by the TMDL Task force are necessary at this time for the Commission to assess the impacts of the proposed Project. Thus, the Company disagrees that this study is required.

Additional information on this topic can be found at comments 76, 77, 78, 91, 130 and 191 in Appendix E of the FEIS, in which the Commission addressed this issue in responding to specific questions on this topic.

### 2.2.2.8. Study of Impacts of Project Chemicals (if any) on the Lake

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[17] /Anderson 2006.

[18] /Anderson 2007.

[19] /Anderson 2007.

Study request #8 concerns impacts of any chemical additions to the water that would represent a discharge to the lake. The Company does not believe a study is necessary since chemical addition for algal or nutrient control is not presently planned as part of the Project.

### 2.3. Studies Requested by Biological Resource Agencies

Both the USFWS and the CDFW submitted comments and study requests in their December 1, 2017 letters.

We agree with some requests, would agree to others with modifications as explained below, and disagree with others for the reasons given below. The Company has prepared a proposed Biological Resources Study Program which sets forth in more detail the study plans we propose and modifications from agency-requested studies. This Study Program will serve as a basis for consultation with agencies on study modifications and final study plans and protocols. A copy may be found in Attachment 2: Proposed Biological Resources Study Program. For all studies in this Section 2.3 that the Company agrees may be needed, each can be implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

Additional information on these topics can be found in:

- Sections 3.3.3, 3.3.4 and 3.3.5 of the FEIS.
- From the FLA, Exhibit E–3 in Volume 1, and in Volume 2, Sections 4.6 and 5.0 as well as Attachments 5 and 11. Also see Tab E–5 in Volume 5 and in Volume 8, Tab 2, part 2–1.

The following subsections provides detailed responses to each request.

#### 2.3.1. Study Requests of the US Fish and Wildlife Service

In its December 1, 2017 letter, the USFWS requested the studies described in the following subsections:

##### 2.3.1.1. Study of Project Effects on Nearby Critical Habitat Designated after 2007

First, the USFWS is requesting an analysis of the project effects to designated critical habitats for the federally endangered Munz's onion (*Allium munzii*), Quino checkerspot butterfly (*Euphydryas editha quino*), arroyo toad (*Anaxyrus californicus*), and southwestern willow flycatcher (*Empidonax traillii extimus*) and the federally threatened thread-leaved brodiaea (*Brodiaea filifolia*), California redlegged frog (*Rana draytonii*), and coastal California gnatcatcher (*Polioptila californica californica*), which have changed since the preparation of the existing 2007 FEIS.

The Company updated changes to designated critical habitat for these species in its October 1, 2017 Final License Application and proposes to address each of these species and their critical habitats in its proposed study program, found in Attachment 2: Proposed Biological Resources Study Program, as described for each individual species described below.

Sections 3.3.5 and 5.2.7 of the FEIS also addresses this issue.

#### 2.3.1.2. Request for Updated Biological Surveys

USFWS request number 2 recommends completing updated protocol surveys and habitat assessments for federally listed species and other sensitive biological resources and updating the description of potential impacts to habitats. USFWS especially recommends updated surveys for Quino checkerspot butterfly and for any areas affected by wildfires since the 2006 surveys. As noted in our response above, the Company intends to address each of these species, including the butterfly, in special-status species surveys as also requested by CDFW (below).

The Company notes, however, that just because an area may have burned would not necessarily indicate a need to conduct new surveys of the burned area if the project will not have significant effects there. The Company is proposing to conduct surveys in areas where significant effects may occur, and if those areas have burned, these surveys will also reflect any changes due to wildfire at those locations.

FEIS Sections 3.3.3 through 3.3.5 and 5.2.5 through 5.2.7 and Appendix G all provide additional information. Please also see Sections 4.6 and 5.4 of Volume 2 of the FLA.

We note that the Forest Service and City also have requested updated biological surveys, and our response to those requests would be the same as that given here for the USFWS and for CDFW, below.

### 2.3.2. Study Requests of the California Department of Fish and Wildlife

As noted above, the USFWS, in its letter dated December 1, 2017, recommends completing updated protocol surveys and habitat assessments for federally listed species and other sensitive biological resources and updating the description of potential impacts to habitats. USFWS especially recommends updated surveys for Quino checkerspot butterfly and for any areas affected by wildfires since the 2006 surveys. As noted in our response above, the Company intends to address each of these species, including the butterfly, in special-status species surveys requested by CDFW (below).

The fact that an area may have burned would not indicate a need to conduct new surveys of the burned area if the project will not have significant effects there. The Company is proposing to conduct surveys in areas where significant effects may occur, and if those areas have burned, these surveys will also reflect any changes due to wildfire at those locations.

We note that the Forest Service and City also request updated biological surveys, and our response to those requests would be the same as that given here for the USFWS.

Because those requests pertain to the area of interest of USFW and CDFW, the Company will work to develop protocols with these agencies and advise the Forest Service and the City of progress.

### 2.3.2.1. Request for Updated Biological Surveys

CDFW requests that the Company complete updated general biological surveys over the entirety of the proposed Project footprint, including the perimeter of Lake Elsinore.

A broad biological field survey of the entire Project is not considered necessary to evaluate probable significant effects. Although CDFW did not define what a "General Biological Survey" would entail, the Company believes that the comprehensive desktop site assessment that it proposes to conduct for biological resources potentially affected by the project (see Attachment 2: Proposed Biological Resources Study Program), in combination with the focused special-status species studies, as described below will be adequate. The desktop assessment will consider a 0.5-mile transmission corridor and the immediate vicinity of the hydro facilities. For other populations that are not likely to be significantly affected by the project, existing information is expected to be adequate.

The Company addresses each of the individual study requests in the following subsections. For those studies the Company agrees to undertake, with modifications noted, the Company believes that all will be developed in consultation with the USFWS and the CDFW, and implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction

The FEIS Sections 3.3.3 through 3.3.5 and 5.2.5 through 5.2.7 and Appendix G all provide additional information. Please also see Sections 4.6 and 5.4 of Volume 2 of the FLA.

### 2.3.2.2. Bald Eagle and Peregrine Falcon Studies

CDFW requests that the Company develop a Bald Eagle and Peregrine Falcon Study Plan in order to obtain information about how bald eagles and peregrine falcons may be affected by Project construction, operation, and maintenance. Section 3.4 of Exhibit E in Volume I of the FLA and Sections 4.6 and 5.4 of Volume 2 of the FLA address the potential occurrences of bald eagles and peregrine falcons in the vicinity of the Project. In addition, the Company submitted information related to bald eagles and peregrine falcons that was analyzed by the Commission in Sections 3.3.5 and 5.2.7, and Appendix G of the 2007 FEIS. The Company agrees that the license should require that a Bald Eagle and Peregrine Falcon Protection Plan be developed in consultation with the USFWS and the CDFW, and implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

### 2.3.2.3. Golden Eagle and General Raptor Studies

CDFW requests #3-4 provide an extensively detailed study request for golden eagles and raptor surveys. We agree with modifications.

The Company believes that alternative studies at a lesser cost or level of effort would be sufficient to meet the stated information needs and that such studies be implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

Because of the heavily wooded terrain, lack of road access, and the required survey buffers (0.5 mi for golden eagles and 500 feet for other raptors), the Company proposes to locate and monitor nests from the air using a drone or helicopter. For efficiency, when possible golden eagle surveys would be paired with general raptor surveys and with bald eagle nesting and roost surveys to complete multiple species surveys during each field mobilization. The Company proposes to consult with CDFW and USFWS to discuss potential modifications to study protocols that could be more time- and cost-effective, and meet or improve data quality (e.g., the ability to determine number of eggs, accurate documentation and ease of locating nests in the terrain adjacent to the Project).

FEIS Sections 3.3.5 and 5.2.7 and Appendix G provide additional information. Exhibit E, Section 3.4 of Volume 1 and Sections 4.6 and 5.4 of Volume 2 of the FLA also discuss this topic.

### 2.3.2.4. Special Status Riparian Bird and Nest Monitoring Study

CDFW study #5 requests special-status riparian bird surveys and nest monitoring, including surveys for Southwestern willow flycatcher, least Bell's vireo, and coastal CA gnatcatcher. The Company believes that alternative studies at a lesser cost or level of effort would be sufficient to meet the stated information needs and that such studies be implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

Since yellow-breasted chat, yellow warblers, and other non-federally listed riparian avian species may have a moderate to high potential to occur within the Project Area and a 500-foot buffer in riparian habitats, the Company proposes to modify this study plan to include point count surveys in suitable habitats to determine their presence during the nesting season, but to exclude nest searches. Nest searches have the potential to disturb nesting pairs, and point count surveys should be sufficient to inform the agencies as to which riparian species may occur (and are likely to breed) within the survey area. Further, if construction or vegetation clearing occurs within the nesting season, nest searches for birds would be conducted at that time to avoid impacting active nesting pairs. As the clear majority of passerine species do not reuse nests in subsequent years, locating nests prior to the proposed construction season is not sufficiently informative to justify costs and potential disturbance to the birds that may occur during non-clearance surveys. Rather, birds recorded during point count surveys would be assumed to be breeding in the area if they are observed during the appropriate season and are known to breed in the vicinity.

Lastly, information on the habitat of coastal gnatcatcher can be found at comment 161 in Appendix E of the FEIS, in which the Commission addressed this issue in responding to a specific question on this topic.

As noted above, the Company agrees to analyze potential project affects to federally designated critical habitats for Southwestern willow flycatcher and California coastal gnatcatcher, and to conduct updated field studies for those two species plus the least Bell's vireo. Surveys would be focused on identified suitable habitats for the species targeted, and final study protocols would be agreed in consultation. Again, the Company believes that such studies can be implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

FEIS Sections 3.3.5 and 5.2.7 and Appendix G provide additional information. Exhibit E, Section 3.4 of Volume 1 and Sections 4.6 and 5.4 of Volume 2 of the FLA also address this issue.

#### 2.3.2.5. Special Status Bat Study

CDFW study #6 requests special status bat surveys. We do not agree with the need for this study. Initial desktop review did not identify bat species of concern likely to be affected.

#### 2.3.2.6. Special Status Plant Study

CDFW study #7 requests special-status plant surveys.

The Company generally agrees to the study plan, excluding federally-listed Munz's onion which has been addressed in the Commission's response to comment 158 in Appendix E of the FEIS. Final study protocols for other species would be developed in consultation with the agencies. As sufficient information is already in the record, the Company believes that such studies can be implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

Additional information may be found in FEIS Sections 3.3.5 and 5.2.7 and Appendix G, as well as Exhibit E, Section 3.4 of Volume 1 and Sections 4.6 and 5.4 of Volume 2 of the FLA.

#### 2.3.2.7. Vegetation Mapping Study

CDFW study #8 requests vegetation mapping. We agree with the need for this study, with modifications.

The Company agrees to conduct vegetation mapping. However, the level of effort and cost to conduct the VegCAMP method as proposed is overly burdensome relative to the need for the information; therefore, the Company proposes to use existing digital vegetation/habitat information, including CalFIRE to update vegetation communities potentially affected within the footprint of the proposed project components. This information will be used to identify the areas of suitable habitat for the species-specific surveys. As so much information on this topic is presently in the record, the Company believes that such studies can be implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction.

Section 5.4 of Volume 2 includes additional information on this issue.

### 2.3.2.8. Terrestrial Wildlife Movement Study

CDFW study #9 requests a study of terrestrial wildlife movements. We do not agree with the need for this study.

The Company believes that the requested Regional Connectivity/Wildlife Movement Corridor Assessment is not necessary to evaluate the probable significant effects of the Project. Existing information is considered adequate to evaluate effects, as wildlife movements are unlikely to be significantly affected by the project.

Section 5.4 of Volume 2 provides additional information.

### 2.3.2.9. Special Status Fish, Amphibian and Aquatic Reptile Study

CDFW requests that the Company develop a Special-Status Fish, Amphibian, and Aquatic Reptile Study Plan in order to obtain information regarding special-status fish, amphibian, and aquatic reptile species in the Project vicinity, to perform an analysis of how the species may be affected by Project construction and long-term operations and maintenance activities, and to develop appropriate buffers and avoidance and minimization measures for Project construction, operations, and maintenance activities. Section 5.4 of Volume 2 of the FLA discusses these species. The Company agrees that a study plan should be developed in consultation with CDFW and USFWS, and implemented prior to the Company engaging in any ground-disturbing activities associated with Project construction. Such plan would identify all aquatic habitats during field wetland delineations conducted prior to Project construction and certain Project components may be located to avoid identified habitats for special-status fish and amphibians. The plan also would include a focused field survey in suitable and critical arroyo toad habitat, as outlined in the study plan found in Attachment 2: Proposed Biological Resources Study Program. Finally, this plan may propose adequate buffer zones and avoidance and protection measures, if necessary.

### 2.3.2.10. Vernal Pool Study

CDFW study #11 requests surveys of vernal pools. The Company does not agree to conduct this study as it has worked with the Forest Service to ensure that project facilities avoid these areas. Attachment 11 of Volume 2 includes detailed information on facility placement within the CNF.

### 2.3.2.11. Coastal Cactus Wren Study

CDFW #12 requests surveys of coastal California cactus wren. We do not agree that this study is needed.

As San Diego cactus wren has a low potential to occur within the Project Area and a 500-foot buffer, based on geographic range, the Company does not propose to conduct the requested study.

### 2.3.2.12. Special Status Butterfly Study

CDFW study #13 requests studies of special-status butterflies, including the federally-listed Quino checkerspot butterfly. We agree with modifications to the study proposal to conduct a survey in advance of construction of the Project. This approach is consistent with the Commission's response to comment 159 in Appendix E of the FEIS in which the Commission acknowledged that the construction of the project could adversely affect Quino checkerspot butterfly.

Our proposed study approach is provided in the Biological Resources Study Program found in Attachment 2: Proposed Biological Resources Study Program.

#### 2.3.2.13. Pacific Pocket Mouse Study

CDFW study #14 requests surveys of the Pacific Pocket mouse. We do not agree that this study is needed.

CDFW cites several papers regarding the recommended methodology for the requested survey, including live trapping and the use of canine scent-dogs, which would require permitting from the USFWS, an MOU from the CDFW and potentially approval from the CNF. The level of effort and cost for both methods is overly burdensome relative to the need for the information. Live trapping is considered suboptimal for this species as evaluated in the 2010 5-Year Species Review. This species lives in the immediate vicinity of the coast and has not been found further than 2.5 miles inland. CDFW did not state that the species was likely found within the Project area, but only in the general vicinity. There is no nexus between project operations and potential effects (whether direct, indirect, or cumulative). There is a low likelihood of species occurrence, and low probability of significant impact.

#### 2.3.2.14. Water Balance/Operations Model Study

CDFW study #15 requests a water balance/operations model study for Lake Elsinore. The Company understands that CDFW may look to a water operations models to determine effects on resources under its control. However, the Company believes that alternative studies at a lesser cost or level of effort would be sufficient to meet the stated information needs. Specifically, the Company suggests that the scope of this type of study (if required) can best be determined in consultation with the RWCQB. Further, this type of study is likely included in the ongoing work of the TMDL Task Force. Thus, the Company suggests that CDFW may wish to participate in the Task Force to obtain current information on this topic.

### 2.4. Studies Requested by the Temecula Band of Luiseño Mission Indians

In their December 1, 2017 letter, the Pechanga Tribe has requested numerous studies regarding impacts on Traditional Cultural Property and updates to Tribal Cultural Resources to augment traditional scientific archeology from its elders and community members. The letter from the Tribe is greatly appreciated and provides valuable information regarding their knowledge and concerns for the project area. Nevada Hydro is seeking to actively engage with the Pechanga Tribe regarding the issues raised. Please also see the cultural resources assessment in Tab E–6 of Volume 5 and the SHPO and Tribes Correspondence and Distribution List in Section B of "Additional Project Information" of Volume 9 of the FLA.

The Company has retained the services of the Chambers Group to assist with issues relating to historic properties and cultural resources. Chambers had previously been involved in the Project, and authored the Historic Properties Management Plan for the Project. On behalf of the Company, Chambers has reached out to the Pechanga Tribe to coordinate with them, and has requested a meeting.

Nevada Hydro President Rex Wait has written a formal response to the Pechanga Tribe's December 1, 2017 submission, thanking the Tribe for its participation in the Study Request period of the licensing process. Mr. Wait expressed his respect for the Tribe and the issues raised in their submission and requested a meeting to discuss a close collaboration in preparation and updating of studies regarding the Tribe's Traditional Cultural Property. A copy of this letter may be found in Attachment 4: Letter from the Company to the Temecula Band of Luiseño Mission Indians.

Nevada Hydro respects the historical perspective of the Tribe, and looks forward to the senior-level meeting in early 2018, which the Company hopes and expects will lead to engagement and insights from the Tribe, its leadership, and its Elders.

While largely agreeing with the Tribe's recommendations, the Company believes some refinement and clarification to the specifics with regards to the updates and additional studies that may be required. While the Company agrees that while the Historic Properties Management Plan ("HPMP") created for Project No. 11858 is now aged, it still contains quite a bit of useful information that remains largely unchanged today. Below is an overview of the updates the Company believes are necessary to achieve the results the Tribe requested so that all parties are informed. The Company intends to discuss this approach with the Tribe, as soon as a meeting has been scheduled with them.

### 2.4.1. Update Inventory Report

Prior to implementing any ground disturbing activities, and in consultation with the Tribe, the Company proposes that an updated study define the Area of Potential Effect (APE) in the original HPMP including the direct and indirect areas. The Company proposes to update the technical inventory report to include an updated record search, archival research, prehistoric and historic context (as-needed), ethnographic context (with Tribal input), field survey data, summary of findings, and eligibility and management recommendations. The Tribal outreach will include an updated Native American Heritage Commission (NAHC) Sacred Lands File (SLF) search and contacting the Tribes listed on the NAHC response letter. The additional field work will entail revisiting all sites previously inventoried and updating the report as needed, and surveying areas that are publicly accessible but were not surveyed previously within the APE. The revised report will include updated figures, maps, and site forms. As part of the inventory process the following documents will also be prepared to assess potential impacts to previously unknown resources and/or traditional cultural properties (TCP) to avoid and/or resolve adverse impacts to historic properties and TCPs.

### 2.4.2. Geoarchaeological Study

A geoarchaeological study will address the Tribe's concern regarding the potential for buried sites within the APE. The study will use concepts and methods of earth sciences (especially geology, geomorphology, hydrology, sedimentology, and pedology) to understand the changes that have occurred over time in the area that would make certain areas likely to contain cultural resources, including the potential for submerged sites. This study will be conducted by a qualified geoarchaeologist with support from senior cultural resources experts.

### 2.4.3. Landscape Study

The landscape study will include a thorough review and reporting of ethnographic information about the region and will weigh heavily on the Tribal knowledge obtained through interviews and references reviewed and approved by the Tribe. This task will also include documentation of Lake Elsinore as a Traditional Cultural Property. Additionally, a visual assessment will be conducted to include evaluating the overall viewshed changes from Indirect APE vantage points to evaluated potential viewshed-related impacts to eligible cultural resources. This study will be conducted by a qualified ethnographer (where applicable) with support from senior cultural resources experts.

### 2.4.4. Draft Programmatic Agreement ("PA")

Upon the review and approval of the above documents, a Project Programmatic Agreement ("PA") is anticipated. A Project PA would be appropriate because the project involves multiple agencies, and the effects to historic properties may not be fully determined in advance due to private property and/or the potential for submerged (or buried) sites. The PA will serve as the overarching agreement document or guide that sets out the measures that will be implemented to resolve any adverse effects through avoidance, minimization, or mitigation.

The Company anticipates developing an Historic Properties Management Plan ("HPMP") to be based on the updated Inventory Report and the results of additional studies. The HPMP will be updated to include the current findings and approved measures for the Project. The updated HPMP will also follow the *Guidelines of the Development of Historic Property Management Plans for FERC Hydroelectric Projects* (2002). The HPMP will also include a plan for the treatment of human remains (NAGPRA Plan) and unanticipated discoveries (Inadvertent Discovery Plan) in the event such is identified during construction activities.

### 3.0. Studies Requested by the City of Lake Elsinore

Although the City of Lake Elsinore is not a resource agency under Commission rules, because of the important role it holds regarding the status and management of the lake, the Company is herein responding to its requests as if it were a resource agency. The Company was gratified to note that the City appeared to be one of the few commenters to have reviewed the entire FLA.

In its December 1, 2017 letter, the City requested the studies described in the following subsections.

### 3.1. Additional Geotechnical Studies

The City's first study request is that the "preliminary" reports prepared by Genterra be updated. Conceptual-level statements and descriptions presented by the Company and its geotechnical consultant in their reports were prepared as required by Commission rules, and so are considered as provisional and subject to revision by the Commission. Refinements to the conceptual design are to be made during preliminary and final design of the Project facilities, as required by Commission rules. Additional discussion on this issue can and on the geotechnical reporting requirements the Commission imposes on license applicant can be found in Section 4.3, Potential Impacts on Local Groundwater Resources.

Thus, the Company disagrees that additional geotechnical studies are required at this stage of the Commission's licensing process.

### 3.2. Study on Potential for Breach of the Lake's Clay Liner

The City's second request involves a study of whether and how construction of the powerhouse could breach the clay liner of the lake. The Company believes that the discussion in Section 4.3, Potential Impacts on Local Groundwater Resources sufficiently addresses the issue, describing the design and construction techniques to be utilized to protect aquifers from contamination. Consequently, the Company does not agree that additional studies on this issue are required.

### 3.3. Updated Biological Resource Study

The City's third request was that the Company conduct updated biological surveys. Please see the discussions in 2.3, Studies Requested by Biological Resource Agencies, where the Company addresses this issue in detail. Because this request pertains to the area of interest of USFW and CDFW, the Company will work to develop protocols with these agencies and advise the City of progress.

### 3.4. Shoreline Erosion and Turbidity Study.

The fourth request of the City focused upon the potential for sediment erosion and generation of turbidity because of Project operation. This is an issue that has been identified in earlier reviews, as well as part of this current application review. The issue was considered in an initial technical analysis of potential water quality impacts of the Project[20], and evaluated more rigorously in the subsequent 3-D hydrodynamic modeling analysis.[21] While the statement indicating "persistence of turbidity induced by sediment resuspension from regular Project operation is not clear" on p.7 in Anderson (2006) identified in this letter, subsequent empirical evidence in that report supported the notion that chronic resuspension would not be expected. This evidence included acoustic backscatter measurements near the axial flow pumps that, despite continued input of a large amount of bottom shear, did not generate suspended sediments from soft organic sediments there. Additional evidence was provided from 3-D hydrodynamic simulations that yielded average bottom shear values below critical values required to resuspend sediments near the 150-m long shore-mounted intake.[22]

Additional information can be found in the following locations:

- Section 2.2.1.2, Water Quality in Lake Elsinore.
- The Commission's response to comments 19, 76, 77, 78, 85, 91 and 130 in Appendix E of the FEIS in which the Commission addressed and resolved this issue in responding to specific questions on this topic.
- From the FEIS, Sections 3.3.1.2, 3.3.2.1 and 3.3.2.2.
- From Volume 1 of the FLA, Exhibit E–3.
- From Volume 2 of the FLA, Sections 3.1.1, 4.10.1.3 and 5.8.2.

As a result, the Company does not believe additional studies are called for on this topic.

### 3.5. Study on Recreation Needs

The City's fifth request is to evaluate recreational use information to identify current and future needs.

The Company proposes to consult with the City and other interested parties to evaluate the present state of understanding to determine what further studies may be required to update the information already available. As a result, the Company is willing to participate in a recreation study with other interested parties, but the outcome of this study should not cause a delay in Commission acceptance of the FLA. As a result, the Company does not believe an additional study is required at this time. However, the Company expects that the cooperative effort of all

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[20] /Anderson 2006.

[21] /Anderson 2007.

[22] /Anderson 2007 at pages 22–25.

interested parties during the licensing process will form recreation–related mitigation proposals for the Commission.

Recreation is addressed extensively in Sections 3.3.6 and 5.2.8 in the FEIS. Additional information can be found in Exhibit E–7 of Volume 1 of the FLA and Sections 4.16 and 5.14 of Volume 2 of the FLA.

### 3.6. Effect of Daily Lake Elevation Fluctuations on Existing Recreational Activities.

The sixth study request by the City is to study the effect of daily lake elevation fluctuations on existing recreational activities. In consultation with Dr. Anderson, the Company believes that the general issue of lake elevation fluctuations was considered in some detail in earlier studies and has been updated in Section 2.2.1.1, Daily Water-Level Fluctuation at Lake Elsinore. As noted in that section, with annual variations in lake elevation now commonly 3-4 feet and surface area reductions of 200-300 acres per year, a key advantage of the Project's presence is the longer-term stabilization of lake level within an operational range of 1240 – 1247 feet and about 2800-3300 surface acres; although daily oscillations will be larger than present at the lake, the longer-term stabilization will provide greater recreational and habitat value especially during periods of protracted drought.

Additional information on the topic may be found at comment 168 in Appendix E of the FEIS in which the Commission addressed and resolved this issue in responding to specific questions on this topic.

The Company therefore does not believe additional studies on this topic are needed at this time. As noted in the previous section, the Company expects that the cooperative effort of all interested parties during the licensing process will form recreation–related mitigation proposals for the Commission.

### 3.7. Development of Additional Visual Simulations

The City's seventh study request is to update and expand the visual simulations present in the FLA. The Company agrees that many of the simulations presented in the FLA are dated and should be updated during the Commission's licensing process. The Company will consult with the City to determine appropriate images.

### 3.8. Updated Cultural Resources Assessment Study

Regarding the City's eighth request for an updated cultural resources assessment, the Company believes that this issue is best addressed with the Pechanga Tribe as described in Section 2.4, Studies Requested by the Temecula Band of Luiseño Mission Indians, and so does not believe studies on this topic should be undertaken relating to this request.

### 3.9. Construction Traffic Analysis Study

The City's ninth request asks the Company to undertake and updated analysis of construction traffic. The Company presented an extensive traffic analysis in section 5.15 of Volume 2 of its FLA. The Commission addressed this issue extensively in response to comments 67, 159, 221, 222, 223, 224, 225 and 226 in Appendix E of the FEIS. Nonetheless, the Company agrees that an updated traffic analysis is appropriate, and is willing to undertake an updated traffic analysis prior to construction.

### 3.10. Construction Noise and Vibration Assessment Study

In its tenth request, the City asks for a noise and vibration assessment related to construction of the Project. The Commission addressed this issue in response to comment 258 and 259 in Appendix E of the FEIS. As a result, the Company does not believe additional studies are required.

Additional information on noise is scattered throughout the FEIS. Please also see Sections 4.13 and 5.18 of Volume 2 of the FLA.

### 3.11. Property Value Assessment Study

In its final study request, the City asks for a study of the short and long-term effects of the project on residential property values.

Socio–economic impacts were addressed in the FEIS in Section 3.3.8.2 and updated in Section 5.12 of Volume 2 of the FLA. See the Commission's response to comments 195, 198, 218 and 227 in Appendix E of the FEIS in which the Commission addressed this issue in responding to specific questions on this topic. The Company, therefore, disagrees that any update to these conclusions is needed at this stage of the Commission's licensing process.

## 4.0. Detailed Responses to major Issues Raised

### 4.1. Introduction

In the study requests discussed in this letter, the issues of fire risk, groundwater and lake water quality were raised by more than one party. Those issues are addressed in more detail in this section.

### 4.2. Fire Risk and Impact on Fire Suppression

Many stakeholders are concerned that the Project's proposed primary transmission lines could present a fire risk. The Company has addressed this issue herein in Sections 2.1.1, Project Fire Risk, Impacts to Fire Suppression Efforts & Hazardous Fuels Reduction Assessment. As noted there, the Commission addressed this issue extensively in its response to comments 201, 202 and 203 in Appendix E of the FEIS. The Forest Service also addressed the issue in its Sec. 4(e) condition #9 in the FEIS.

As described below, the Company is of the view that these concerns are not well founded. 500 kV lines like the primary transmission lines that are part of the Project have essentially never caused fires. In addition, these lines are operated to not impair firefighting efforts.

On November 8, 2017, the California Public Utilities Commission published a proposed decision in its Docket Rulemaking 15–05–006 titled, "Decision Adopting Regulations to Enhance Fire Safety in the High Fire-Threat District."[23] As both CalFire and the Forest Service participated in the development of this decision, the Company views it as the "state of the art" in California, and will design and operate its facilities according to the parameters set out in the proposed and final decision, when made available.

Finally, the Company has worked with CNF personnel to assure them that water in the Decker Canyon head lake will be available for firefighting use.

### 4.2.1. 500 kV Lines do not Cause Fires

Several letters asked about the transmission lines that ignited the devastating Butte fire in 2015. Nevada Hydro retained Fred Depenbrock as a transmission planning consultant to the Project. Mr. Depenbrock has significant credentials in electric utility planning and operations, engineering analysis, economic and regulatory studies, and human dynamics. He has extensive experience in system load flow, dynamics and short circuit analysis using both Siemens PTI's PSS®E and GE's PSLF software and has used Siemens PTI's PSS®MUST software to analyze outlet capabilities of new generation projects. He represented Siemens PTI to the WECC Modeling and Validation Work Group and the WECC Modeling and Validation Work Group.

Fires such as in Butte in 2015 were caused by smaller, lower voltage lines that generally are designed for local distribution from a substation or tap off a line between two substations to supply homes and businesses. The high voltage 500 kV primary transmission lines that will connect the Project to the grid are different from the lower voltage residential and business connections that have been associated with wildfires. Mr. Depenbrock has researched the available data and found only a single fire caused by 500 kV transmission line anywhere in the country. According to a 2005 report from the National Electric Reliability Council, this fire occurred when a Lombardi Poplar tree fell across the transmission line, and subsequent arcing set fire to a nearby house. The fire was a result of inadequate vegetation management.

The Project includes about 33.2 miles of 500 kV primary transmission lines, including approximately 2.7 miles underground[24]. This is a small fraction of the approximately 15,000 miles

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[23] /The Proposed Decision is available at http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M198/K355/198355203.PDF

[24] /This consists of approximately 31.2-mile length from the San Diego Gas and Electric and Southern California Edison systems, plus two, one-mile lines to connect the powerhouse. These two circuits are run in a single one-mile long tunnel running up the hill from the powerhouse.

of 500 kV lines that make up the arterial system of the US electric system in the Western Electricity Coordinating Council ("WECC"). The WECC system provides fast-acting performance that is overseen by government agencies such as the Commission and local experts in utilities and their regional councils. Reliability and safety are paramount at all levels of the oversight process.

All 500 kV lines have protective relays at both ends of the line that communicate to each other constantly. If this doesn't result in a zero-net flow difference or if there is any loss of communication, the relays initiate a line trip using circuit breakers at both ends of the line. This de-energizes the line in less than one tenth of a second, **so the probability of a fire igniting is very low**.

In addition to the extremely fast de-energization ensured by the differential protection relays and constant communication on the transmission line, there are numerous protections provided for the 500 kV lines in WECC. Wide transmission rights-of-way (ROW) for this voltage level of line ensure that line behavior such as conductor swings in high winds will not impact the nearby area. As well, vegetation management (tree and brush trimming and monitoring) along the ROW keeps debris from hitting the line and reduces potentially flammable patches of grass, bush or trees. California's electricity industry maintains active vegetation management programs to keep existing transmission and distribution powerlines clear of potentially hazardous vegetation.

### 4.2.2. High Voltage Lines are Operated in a Manner that does not Impair Fire Fighting

Transmission lines located in areas with high fire risk and high occurrence of lightning strikes creates a reliability risk to the grid system. Dense smoke from wildfires can "trip" a circuit, causing it to go out of service, or outages can result from emergency line de-rating or shut-downs during a nearby fire to prevent thermal damage to the line, to prevent a smoke-caused trip, or to meet the safety needs of firefighters.

The U.S. Forest Service and municipal fire-fighting organizations have set protocols and rigorous training procedures for line operations and for fire suppression, including the use of helicopters near high voltage power lines and how to fight fires on the ground near such facilities. The transmission array proposed by Nevada Hydro is not new or unique, and in fact a similar line traverses the valley and crosses the I-15 near Temescal Valley.

Nevada Hydro is committed to abiding by industry-leading fire prevention and operation protocols in conjunction with Federal, CNF, State and local officials. To the extent allowed by the CNF, the Company will maintain a rigorous vegetation management program on the ROW, reducing fuel sources and limiting the opportunity for fire near transmission towers and lines. The ROW will be monitored by camera, drones and physical inspection.

### 4.2.3. Water in the Decker Canyon Reservoir will be Available for Fighting Fires.

The creation of a new reservoir in Decker Canyon will provide a new, convenient source of water for fire suppression high on the mountain in the Cleveland National Forest. This will allow for easier access to water and shorter trip times for firefighters.

### 4.3. Potential Impacts on Local Groundwater Resources

In response to concerns raised by a variety of parties relative to potential impacts the Project may have on groundwater resources, the Company called on its Geotechnical Consultant, Genterra Consultants, Inc. ("Genterra") to formulate a response. Genterra has been responsible for the geotechnical analysis for the Project as documented in the FLA. Genterra is a California corporation, headquartered in Irvine, California, specializing in geotechnical engineering, hydrology, and hydraulics for dams, reservoirs, and other water facilities. The firm has provided consulting engineering services on more than 160 dams and reservoirs, most of them located in California.

#### 4.3.1. Introduction

During 2003, in support of the Company's prior proposal to license the Project, Genterra had prepared a feasibility-level report on geotechnical issues, a conceptual-level hydrology report, and a conceptual-level inundation study report. See Volumes 11 and 12 of the FLA for copies of these reports.

The major components of the Project include the dam and reservoir located in Decker Canyon (upper reservoir), near the upstream end of the watershed adjacent to South Main Divide Road, a single approximately 21-foot diameter shaft and pressure tunnel descending from the upper reservoir to an underground powerhouse located near Grand Avenue and Santa Rosa Avenue on the west side of Lake Elsinore, a probable second smaller utility tunnel (non-pressure) from the upper reservoir area to the powerhouse, an access tunnel to the powerhouse, single or double tailrace tunnels leading from the powerhouse to Lake Elsinore (lower reservoir), and an inlet/outlet structure located in Lake Elsinore. Water will cycle between the existing lower reservoir (Lake Elsinore) and the man-made upper reservoir located roughly 2,792 feet above MSL.

The Company recognizes that the construction and subsequent operation of the Project has the potential to impact groundwater resources in the immediate vicinity of the facilities, and in areas located hydraulically down-gradient from the facilities. Conceptual-level statements and descriptions presented by Genterra in its reports were prepared as required by Commission rules, and so are considered as provisional and subject to revision by the Commission. It is understood that refinements to the conceptual design may be made during preliminary and final design of the Project facilities, as required by Commission rules.

#### 4.3.2. Groundwater Issues

The Commission responded to questions on this issue in its response to comments 82, 83, 112 and 117 in Appendix E in the FEIS. As noted in Genterra's Geotechnical Feasibility Report dated August 28, 2003, evidence of groundwater near the surface was not observed in Decker Canyon during site reconnaissance visits. However, it is likely that groundwater does exist in fractures in the bedrock underlying the proposed Decker Canyon reservoir. Invasive groundwater studies were not performed as part of the conceptual-level studies done by Genterra, but are scheduled before commencement of construction can commence. Therefore, as part of anticipated preliminary design activities as required by Commission rules, potential groundwater issues and concerns will be further addressed by the Company. Research and field investigations are planned to address the issues of concern related to potential adverse impacts to groundwater near Project facilities. Three to four deep (approximately 1,000 feet) borings are planned along each selected penstock alignment to obtain cores of the granitic rock that will be tunneled through, as well as to assess existing groundwater conditions.

It is anticipated that the subsurface investigations may include the following activities:

- Assessment of any aquifers, springs, and local groundwater;
- Assessment of information on domestic water wells near the Project;
- Research into potential Project impacts to nearby domestic water wells;
- Exploratory drilling and sampling to assess current groundwater conditions as well as to determine level of fractures in the bedrock materials;
- Installation of piezometers with automated data acquisition system for long-term collection of groundwater monitoring data;
- In-situ permeability testing (Packer testing) in selected borings by measuring water loss within the weathered granite and granitic bedrock (which will be used to determine appropriate grouting to minimize groundwater loss during tunneling); and,
- Additional in-situ testing, such as Downhole P- and S-wave Logging, 3-Arm Caliper Logging, Acoustic and/or Optical Televiewer, Heat Pulse Flowmeter Testing, and Gamma Ray Neutron Logging, will be performed to better understand the characteristics of bedrock materials, and for engineering evaluation.

### 4.3.3. Mitigation of Groundwater Issues

The Decker Canyon reservoir will be impounded by a dam to be constructed on its downstream (west) side. At the Decker Canyon site, the Project design is anticipated to include construction of storm water diversion structures to prevent runoff of rainfall from flowing into the reservoir from upstream areas, diverting it instead to is natural streamflow. Therefore, the only reservoir inflow would be from direct rainfall within the perimeter drainage boundary of the reservoir.

It is recognized that tunneling through the subsurface and other Project construction activities may cause impacts to the local groundwater system. It is anticipated that tunneling conditions across existing fault zones will quickly transition from competent granitic rock to soft, saturated lake sediments. Tunneling through the soft lake sediments will require ground stabilization methods to allow tunneling, and measures to control any significant groundwater inflow that may occur. Ground improvement of the sediments may be necessary to allow for efficient tunneling. The selection of methods to be used for construction of the tunnel will be based on consideration of how to minimize adverse impacts to the groundwater. For example, during the tunneling process groundwater will tend to drain out of any open fractures in the rock that contain free water. Any significantly large amount of drainage into the tunnel could cause some lowering of local groundwater levels. By grouting the fractures before advancing the tunneling process, the potential adverse effects of the construction activities on the groundwater system in the area can be minimized. Therefore, prior to and/or during tunneling activities, it is anticipated that pressure grouting will be used to seal-off the open fractures as needed to minimize the flow of groundwater into the tunnel and to reduce impacts to existing wells in the vicinity of the Project site. All wells and piezometers will be carefully monitored during construction to implement necessary mitigation measures that are needed to reduce the impacts to existing wells.

The mitigation of potential impacts due to construction of Project facilities is anticipated to include the following:

- Implementation of an effective erosion control plan during construction in accordance with local and state requirements. The erosion control plan will include Best Management Practices;
- Provide for watering of the construction sites to minimize the generation of any dust;
- Provide and maintain vegetation for disturbed areas; and,
- Minimization of the size and extent of disturbed areas by designating appropriate construction traffic areas, worker areas, and off-limits areas.

These mitigation measures are commonly performed for many projects and will be used successfully for the Project to limit potential impacts to the environment at the site.

The Decker Canyon reservoir design is anticipated to include installation of a double-liner system, which will function to minimize impacts to the groundwater beneath the reservoir. This liner system will include seepage collection facilities to direct seepage flows into the drainage system. Water that accumulates at the drainage system collection points will then be removed by pumping the water back into the reservoir. Water will not be released to the downstream area because the objective is to prevent lake water from getting into the local groundwater system. During the preliminary design phase of the Project, it is anticipated that a double liner system alternative will be selected as the design alternative for the reservoir liner. The liner system would consist of two impermeable layers, and the secondary liner would serve as a barrier for any leakage that might pass through the primary liner. The drainage layer would be sandwiched between the liners. Sensors will be designed and installed at key locations to act as a detection system, and to assist in finding locations where any repairs may be needed to minimize possible leakage. An additional subdrain below the lower liner may be required to collect water from existing seeps, if any, in the subgrade. The reservoir liner will be designed to minimize the potential for any mixing of reservoir water with the local groundwater. All Project features will be waterproofed to prevent existing groundwater from getting into the Project systems, as well as to prevent any lake water from getting into the local groundwater system.

Domestic water wells are currently being used by communities located along South Main Divide Road, and in other nearby areas. Much of the flow of groundwater towards these wells is assumed to occur through fractures in the subsurface bedrock materials. By keeping the groundwater resources largely intact with proper design and construction techniques, the residents of the local communities can continue to rely on the groundwater to supply water to their wells. The Project design is anticipated to include a mitigation plan with strategies to minimize adverse Project impacts so that the wells can continue to provide the same quality of water to the owners.

In addition, Genterra's Technical Memorandum dated December 1, 2017 not only discussed the groundwater issues and concerns about the dam and reservoir to be constructed in the Decker Canyon area, it also addressed potential groundwater impacts and mitigation measures related to the construction of the shaft and tunnel from the upper reservoir to the underground powerhouse, the vertical access to the underground powerhouse, and the single (or double) tailrace from the powerhouse to the Lake Elsinore inlet/outlet structure. During construction of the tailrace and inlet/outlet structure at Lake Elsinore, it is anticipated that soft lake sediments will be encountered. Mitigation measures will need to be implemented to deal appropriately with soft soils encountered in the subsurface.

Also, in the Technical Memorandum of December 1, 2017, Genterra noted that tunnel construction activities could impact the local groundwater resources in the Decker Canyon area because groundwater would tend to flow into the tunnel during construction. The inflow of water from intersected fractures in the rock could potentially lead to a lowering of groundwater levels in the overlying Decker Canyon area. Genterra engineers and scientists have the requisite skills and experience needed to develop features that can be designed to appropriately deal with these issues. Grouting and other cost-effective mitigation measures are important for implementation to reduce the risk of water loss from the groundwater system. The groundwater issues can be handled in an effective manner by development of sound design and construction plans, monitoring during construction, and the implementation of appropriate mitigation measures, all of which are to occur upon issuance of the Commission's license.

## 4.4. Non–Technical Description of Lake Elsinore Water Level Fluctuation

### 4.4.1. Introduction

Throughout the study request process, many respondents requested a variety of water and aquatic habitat studies to update those contained in the FLA. As discussed throughout this document, these requests are being evaluated through further meetings with agencies, municipality administrations and the Pechanga Band of Luiseño Indians. Specifically, Nevada Hydro is working closely with LESJWA, the TMDL Task Force, and such notable experts as Dr. Michael Anderson of University of California – Riverside who is assisting Nevada Hydro's Project team. These agencies, administrations, and subject experts will inform studies on water quality and shoreline impacts as part of a larger water management program. Although the Company believes this review meets any Commission's requirements, it will, of course abide by future Commission orders on the issue.

### 4.4.2. Water Levels

Note that Commission addressed this issue in response to comments 76, 77, 78, 85, 91, 130 and 191 in Appendix E in the FEIS.

Lake Elsinore is a relatively shallow lake with a large surface area that is a naturally occurring sink for the San Jacinto River watershed. The lake has a surface area of 3,412 acres at a maximum water level of 1,247 feet above mean sea level (AMSL) between December and March, and a minimum surface elevation of 1,240 AMSL. The normal operating level is 1,245 feet AMSL with an average depth of about 25 feet. Normal evaporation causes the lake level to drop about 4.5 feet every year. This, combined with excessive nutrient input, causes algae blooms that lead to depressed lake oxygen levels and related fish die-offs.

Over the past eighty years, Lake Elsinore has flooded seven times and gone dry twice. Various State and local agencies have significantly modified the lake for water control and have invested to improve both the quality and quantity of water. Millions of dollars have been invested in projects to reduce the size of the lake, the Lake Management Project, the Wetlands Enhancement Project, and mixing systems to help destratify the lake's water column. Water stratification occurs when water masses with different properties such as salinity, oxygenation, density, and temperature form layers that prevent mixing.

To prevent large fluctuations in water levels, SAWPA undertook a major management project with the U.S. Army Corps of Engineers beginning in 1988. The project included a 17,800-foot rolled-earth levee to separate the main basin from the floodplain, a 1,600-foot overflow weir across the San Jacinto River channel, and an outlet channel with a sill elevation of 1,255 feet AMSL. During normal conditions, water is stored in the main basin, with the 356-acre wetland/flood control facility (the back basin) providing additional storage capacity in the event of major storms.

The proposed Project could be viewed as the final of a series of projects implemented to benefit water management of Lake Elsinore. A recent UC Riverside study suggests that the proposed water transfer will increase water circulation in the lake, increasing aeration and potentially improving fish habitat and reducing algal overgrowth. The Project will be able to support regional watershed agency initiatives by selling electricity and contributing a portion of the revenue to projects that directly benefit the lake, providing a source of non–governmental funds to implement projects and helping to fund experts and needed studies to improve water quality. These funds also could be used to augment water from the Elsinore Valley Municipal Water District to maintain water levels.

### 4.4.3. Shoreline Rise and Run

The Project will essentially create a regular but minor "tide" effect where the water will raise and fall regularly plus or minus six inches throughout the 24-hour cycle. This vertical rise will create a lateral run where portions of the lake with a steeper shoreline may not even notice the change, but other areas could see the water moving up and down the shore. Because of the current 4.5 to 7-foot variance in lake levels, it is difficult to state a definitive shoreline movement even without Project impact. Additional study may be required to determine where mitigation efforts can be undertaken to lessen the impact in those areas where the shoreline is less steep, in conjunction with the agencies and subject experts mentioned above.

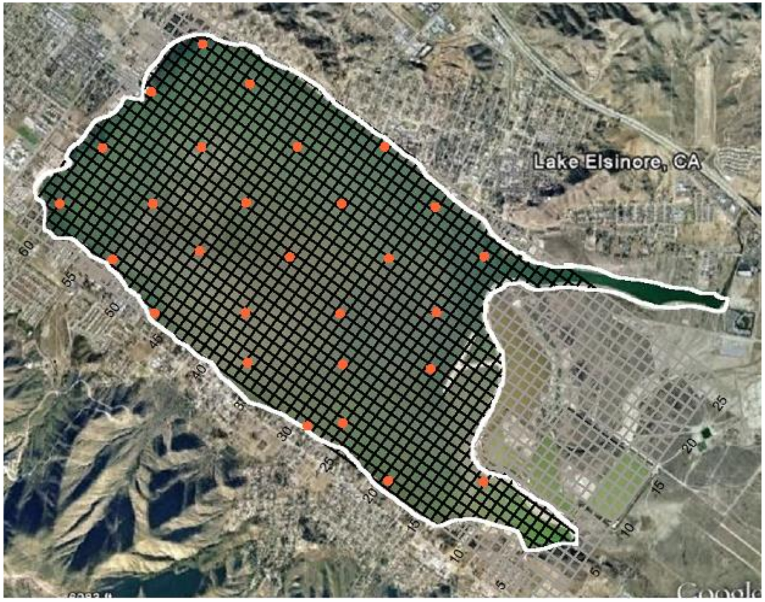
### 4.5. Dr. Anderson's Analysis of Daily Water Level Fluctuation at Lake Elsinore

As noted in this filing and described in the 2007 FEIS, fluctuations in lake surface elevation and lake area will result from operation of the Project. The bathymetry of the lake, lake surface elevation during operation, and pumping (withdrawal) and generation (return flow) volumes will dictate the changes in lake surface elevation and surface area. An assessment was conducted in the original 2005 license application and further analysis was part of a study commissioned by the SARWQCB (Anderson, 2006). Lake elevation was predicted to change 1.0 foot during weekday operation and 1.7 feet during the weekend when extended pumping is planned. Using bathymetry reported by Black & Veatch, a 1.0-foot elevation change corresponds to 49 acres of exposed (or rewetted) sediment, while 1.7 feet resulted in an 83-acre change. Using bathymetry developed from point sampling across the lake (Anderson, 2004), somewhat larger areas were predicted (79 and 134 acres exposed for 1.0 and 1.7-foot drawdown, respectively). Given the limited number of soundings and discrepancy between these two datasets, it is useful to reevaluate using the hydroacoustic survey of the lake conducted on June 27-30 and July 12-14, 2010 that involved hundreds of thousands of points along 270 km of orthogonal transects (Anderson, 2010; Fig. 1). The hydroacoustic survey was conducted with the lake surface elevation at 379.0 m (1243.4 feet) above MSL.

This survey allowed development of a revised bathymetric map shown in Figure 4-2: Map Showing Basin Elevation as a Function of Latitude and Longitude, depicting the elevation of the lake bottom at 2-foot contours. The minimum bottom elevation was 1216 feet beneath the axial flow pump located in the deepest part of the lake that resulted from scouring of the soft organic sediments there. Excluding this small area, the nominal minimum bottom elevation is 1218 feet. This bathymetric map indicates that the variation in lake surface elevation will have most pronounced effect in the southern end of the lake, followed by the northwest shoreline at nominal values near 1240 as shown in the above referenced figure. The tight contour lines on the northeast and southwest parts of the lake shore indicate that shoreline will recede comparatively little with changes in lake level at surface elevations greater than roughly 1232 feet.

The change in lake surface area as a function of lake surface elevation was assessed more quantitatively as shown in Figure 4-3: Hypsographic Data of Lake Elsinore. As shown in the figure, a 4th-order polynomial fit to the data (r2=0.99) displays the lake surface area as a function of lake surface elevation, while the slope of the hypsographic curve represents the change in lake area associated with a 1-foot decline in lake surface elevation (Figure 4–3b).

**Figure 4-1: Hydroacoustic Survey Grid and Sediment Sampling Locations**



Source: Dr. Michael Anderson[25]

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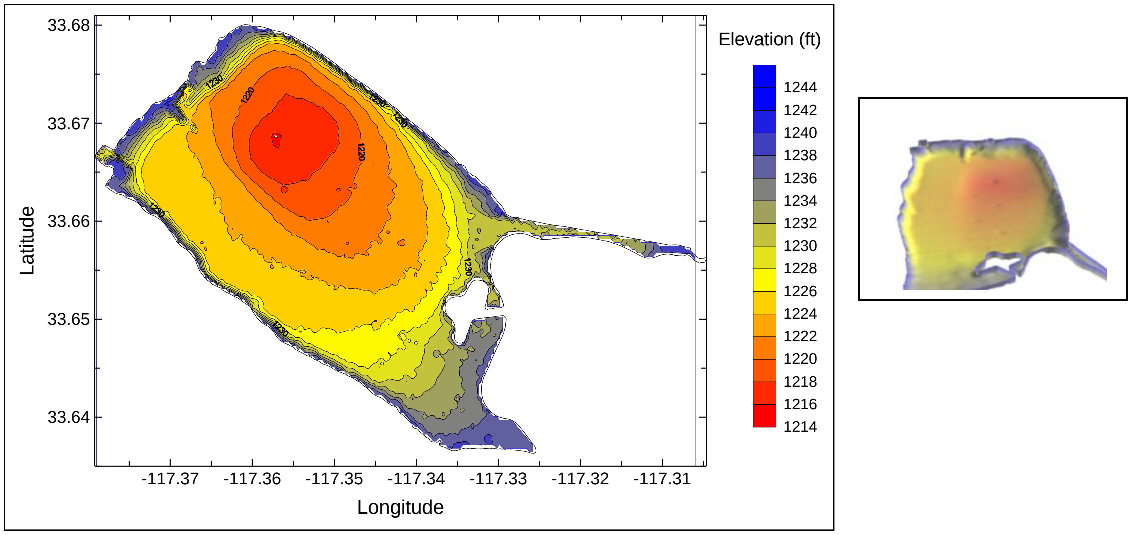
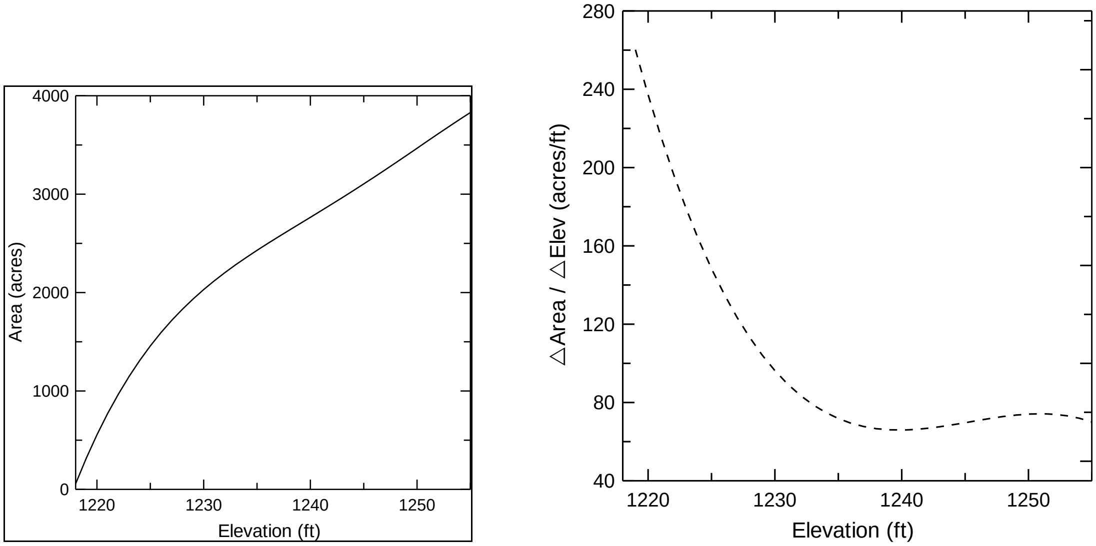
[25] /See Dr. Anderson's 2010 report, Bathymetric, Sedimentological and Retrospective Water Quality Analysis to Evaluate Effectiveness of the Lake Elsinore Recycled Water Pipeline Project. Final Report submitted to Lake Elsinore & San Jacinto Watersheds Authority. This report may be found in Attachment 3: Copies of Select Reports from Dr. Anderson..

### Figure 4-2: Map Showing Basin Elevation as a Function of Latitude and Longitude with 3–D Representation



Source: Dr. Michael Anderson[26]
Note: Lake surface elevation of 1243.4 feet above MSL with basin also shown in 3-D.

### Figure 4-3: Hypsographic Data of Lake Elsinore



Source: Dr. Michael Anderson
Hypsographic data: a) lake area vs. lake surface elevation, and b) change of area associated with a 1-foot decline in surface elevation. (Values above 1243.4 feet from earlier engineering reports.)

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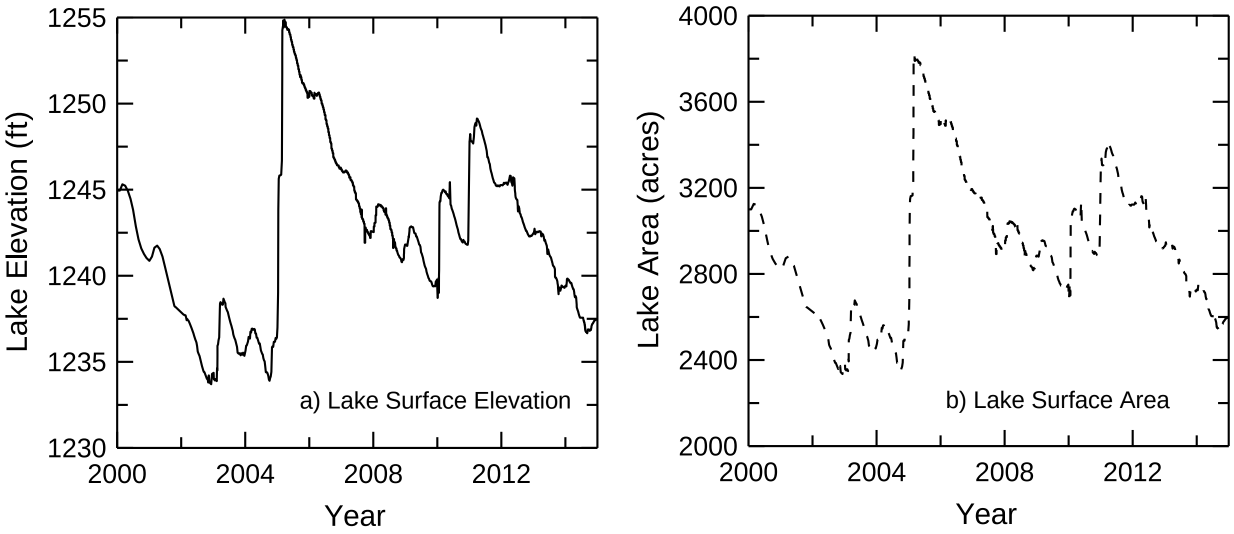
[26] /Id.

Thus, one sees that about 70 acres of lake shore will be exposed with a 1-foot decline in lake surface elevation (or about 6 acres per inch change in elevation), and about 120 acres exposed for a 1.7-foot change depending upon specific elevation within the range of 1233 and 1255 feet, in general agreement with earlier estimated values.[27]

It is helpful to consider these variations resulting from operation of the Project with the natural seasonal and annual variations in lake elevation and surface area. The region has experienced intervals of extreme drought as well as near record rainfall over that has dramatically altered elevation and surface area as shown in Figure 4-4: Reported lake surface elevation and derived lake surface area for Lake Elsinore (2000-2014).

**Figure 4-4: Reported lake surface elevation and derived lake surface area for Lake Elsinore (2000-2014)**



Source: Dr. Michael Anderson[28]

The lake surface elevation and surface area have both varied greatly over this period, with a range in elevation as much as 20 feet and 1400 acres (this does not include 2015-16 in which lake elevation declined to about 1233 feet). The loss of recreational access and use, as well as habitat loss, over the past several years has been dramatic. With annual variations in lake

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[27] /Anderson 2006.

[28] /Please see Dr. Anderson's 2016 Report, 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 LESJWA. This report may be found in Attachment 3: Copies of Select Reports from Dr. Anderson.

elevation commonly 3-4 feet and surface area reductions of 200-300 acres per year, a key advantage of the Project's presence is the longer-term stabilization of lake level within an operational range of 1240 – 1247 feet and about 2800-3300 surface acres; although daily oscillations will be much larger than present at the lake, the longer-term stabilization is thought to provide greater recreational and habitat value especially during periods of protracted drought.

Please let me know if you have any questions on this filing.

Sincerely,

*/s/ David Kates*
David Kates
For The Nevada Hydro Company

Attachments

Cc: Darrell Vance, Cleveland National Forest, w/attach.
Kennon A. Corey, U.S. Fish and Wildlife Service, w/attach.
Gary Dubois, Pechanga Cultural Resources Department, w/attach.
Joanna Gibson, California Department of Fish and Wildlife, w/attach.
Mark Smythe, Santa Ana Regional Water Quality Control Board, w/attach.
Barbara Leibold, City of Lake Elsinore, w/attach.

# Attachments

# Attachment 1: Site-Specific Seismic Hazard and Geotechnical Study Plan Issues

GENTERRA
CONSULTANTS, INC.
ENGINEERING & GEOTECHNICAL SERVICES

# TECHNICAL MEMORANDUM

TO: David Kates and Rex Wait, The Nevada Hydro Company

FROM: Joseph J. Kulikowski, PE, GE, GENTERRA Consultants, Inc.

SUBJECT: LEAPS Project
Site-Specific Seismic Hazard and Geotechnical Study Plan Issues
GENTERRA Project No. 411-NHC

DATE: December 15, 2017

This Technical Memorandum has been prepared by engineers and a senior engineering geologist at GENTERRA Consultants, Inc. (GENTERRA) in response to a request from The Nevada Hydro Company (TNHC) for support in responding to the United States Department of Agriculture (USDA) Forest Service request for new study "LAND 2 – Project Site-Specific Seismic Hazard and Geotechnical Study Plan" presented in a letter from the Forest Service to the Federal Energy Regulatory Commission (FERC) dated November 30, 2017.

## Site-Specific Seismic Hazard and Geotechnical Study Plan

### Background and Summary Response

GENTERRA's prior studies through July 2008 for geotechnical, geological and seismic issues were based on surficial reconnaissance, review of available published data, known fault maps, United States Geologic Society (USGS) fault database, and California Geologic survey (CGS) database, limited geophysical surveys, preliminary evaluation of faulting and seismicity which included probabilistic and deterministic seismic hazard analyses using 1997 attenuation relationships and 2002 CGS fault model for the currently proposed project sites, and limited analyses on which to enable conceptual designs of the dam and other components of the overall project.

A preliminary work plan was developed and submitted for review by the USFS. It is now intended to perform more comprehensive field evaluations with detailed geotechnical investigations and exploration of subsurface soil and rock materials, evaluation of groundwater conditions, fault studies, seismic hazard analyses using the latest attenuation relationships and fault models, development of more detailed preliminary designs, dam-break inundation studies and mapping, and engineering analyses to develop necessary information for potential failure mode analyses (PFMA) for risk-based decision making for the design and construction alternatives. This PFMA process will help to eliminate all known risks associated to this project and deliver a safe project, while meeting or exceeding federal, state and local agencies requirements for type of projects.

A detailed work plan will be developed to address all of the goals and objectives for seismic risk analyses as defined in the ten bullets in Criteria 1 under the Land section of the USFS letter, plus other goals and objectives. The tasks that will be included in the detailed work plan will be intended to provide needed geotechnical, geological and seismic design parameters for preliminary design of the project.

## Introduction

The major components of the LEAPS project include the dam and reservoir located in Decker Canyon (upper reservoir), near the upstream end of the watershed adjacent to South Main Divide Road, a single approximately 32-foot-diameter shaft and pressure tunnel descending from the upper reservoir to an underground powerhouse located near Grand Avenue and Santa Rosa Avenue on the west side of Lake Elsinore, a probable second smaller utility tunnel (non-pressure) from the upper reservoir area to the powerhouse, an access tunnel to the powerhouse, single or double tailrace tunnels leading from the powerhouse to Lake Elsinore (lower reservoir), and an inlet/outlet structure located in Lake Elsinore. Water will cycle between the existing lower reservoir (Lake Elsinore) and the man-made upper reservoir located approximately 1,650 feet above Lake Elsinore within the Cleveland National Forest.

The Nevada Hydro Company (TNHC) recognizes that the construction and subsequent operation of the LEAPS hydroelectric project will occur in a geologic environment within Southern California that is highly seismically active, contains extreme variability of geotechnical conditions as well as groundwater conditions, and therefore poses significant design and construction challenges. TNHC is committed to delivering and operating a project that is first and foremost safe, is constructed in an environmentally sustainable manner, is protective of natural resources, and ultimately provides important economic benefits to the affected community.

Conceptual-level statements and descriptions presented by GENTERRA are considered provisional and subject to revision because they are largely based on review of information that was available at the time of GENTERRA's previous studies that were carried out during the years 2001 to 2008. It is understood that refinements to the conceptual design may be made during preliminary and final design of the project facilities.

GENTERRA is a California corporation, headquartered in Irvine, California, specializing in geotechnical engineering, hydrology, and hydraulics for dams, reservoirs, and other water facilities. The firm has provided consulting engineering services on more than 160 dams and reservoirs, most of them located in California.

## Seismic Hazard

The Forest Service letter requests that the following items relevant to seismic hazard be addressed by additional studies:

- Identify seismic sources along which future earthquakes are likely to occur;
- Characterize the activity, classification of faulting, maximum magnitudes, and recurrence interval for each identified fault;
- Identify whether a fault may be encountered beneath or adjacent to the dam and dike, the penstock and the powerhouse and tailrace facilities. Assess the activity of the feature and, if active, the likelihood of effects from potential fault displacement and ground offset;
- Develop maps and information detailing the locations of faults and seismic sources zones with specific distance parameters to evaluate ground motion from each source;
- Collect historical seismicity data for the region;
- Determine the distance and orientation of each fault with respect to the proposed reservoir, underground project infrastructure, powerhouses, and switchyards;

- Estimate ground motion at the proposed dam, dike, reservoir and penstock sites based on current probabilistic models (Note: GENTERRA will include deterministic models as well to enhance the safety of the project);
- Evaluate the project infrastructure with regard to all seismic hazards including ground rupture and/or displacement, strong ground motion (and site-specific amplification factors), landslide/rockslide/slope instability, seismically-induced settlement and liquefaction;
- Prepare an assessment that evaluates the stability of the proposed designs under seismic loading events. Address the potential for dam break or dike failure at full stage and effects to life, property and resources downstream; and,
- Use an independent engineering technical review group to determine structural analysis and/or develop site-specific design criteria.

GENTERRA concurs that these issues require further investigation including data collection and engineering analysis. GENTERRA's *Technical Memorandum No. 1 – Summary Report of Existing Information – Geology, Seismicity and Geotechnical Issues,* dated January 25, 2008, noted in part:

"The project poses several major geological, seismic and geotechnical challenges. These include:

1. Peak horizontal ground accelerations from earthquakes on nearby active faults that could exceed 1g.
2. Up to several hundred feet of soft saturated liquefiable lake sediments underlie portions of the tailrace tunnels and inlet/outlet structure. Substantial ground improvement will likely be needed to mitigate static and dynamic settlement, including liquefaction of these lake sediments.
3. There is the presence of the potentially active Willard and Wildomar faults, one or both of which cross the tailrace tunnel alignment. Movement on these faults could result in offset of the project conveyance features. There may also be previously unidentified faults within the region which also require design mitigations."

These statements remain true today. The Willard and Wildomar faults are branches of the active Elsinore Fault Zone (EFZ) mentioned in the Forest Service letter. GENTERRA concurs that more site-specific investigations will be needed to better identify the locations and nature of these and any other related splay or subsidiary faults that intersect or lie close to project components.

According to data compiled by the Southern California Earthquake Center (SCEC), the EFZ is a major right-lateral strike slip fault zone with probable magnitudes ranging from 6.5 to 7.5, and an estimated average slip rate of 4 millimeters (mm) per year (mm/yr)[1]. The United States Geological Survey Quaternary fault and fold database lists the slip rate of the EFZ as 4-5 mm/yr[2]. The SCEC lists the interval between major ruptures as roughly 250 years, with the last major rupture having occurred on May 15, 1910. This event reportedly produced no known rupture of the ground surface.

An earthquake of magnitude 6.5 to 7.5 occurring on the EFZ near the LEAPS site would be expected to produce peak ground accelerations exceeding 1g, which is consistent with the conclusions of the 2008 report.

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[1] Available at: http://scedc.caltech.edu/significant/elsinore.html

[2] Available at: https://earthquake.usgs.gov/cfusion/qfault/show_report_AB_archive.cfm?fault_id=126&section_id=d

With an average strain accumulation of 4-5 mm/yr, and a typical design life for critical infrastructure of 50 years, it is reasonable to expect that accumulated strain over 50 years could be on the order of 250mm, or approximately 10 inches. If the entire strain were to be released in a single rupture, and that rupture propagated without attenuation from the epicenter at depth to the ground surface at project component locations, then one might conservatively anticipate potential surface rupture of the ground at project components on the order of one foot, predominantly in a right-lateral direction. While this is presently an informed conjecture, it is consistent with the information available at the time of the earlier studies. GENTERRA concurs with the Forest Service that additional site-specific investigations of the EFZ will be needed to confirm or refine the rough estimate of potential surface rupture. The risk of surface rupture would only apply to the tailrace and Lake Elsinore inlet/outlet structure portions of the project.

With respect to the stated concerns for the upper reservoir including the dam and dike, the penstock, and the underground powerhouse portions of the LEAPS project, GENTERRA concurs that all of these issues require additional investigation during the pre-design and design phases. The specific details of planned studies for each portion of the project will be identified in one or more work plans.

In general, planned additional studies will consist of additional focused geologic mapping, detailed site-specific core drilling with detailed geologic logging of soil as well as rock cores, and measurement of rock properties such as Rock Quality Designation (RQD). Detailed core logging would be augmented by photography of all core, and description and measurement of spacing and orientation of all rock discontinuities such as shears, joints, and mechanical breaks. Core samples would be collected for additional geotechnical and rock mechanics testing in a laboratory.

Geophysical studies will also be conducted along transects oriented both parallel and perpendicular to key project components to attempt to locate abrupt changes in subsurface properties that might indicate faulting, and to refine the target locations for exploratory borings. These geophysical studies will be performed after the geologic mapping task to properly orient the geophysical survey lines and to maximize the benefit of the geophysical studies.

Finally, laboratory testing of soil and rock samples will be conducted to provide the data required to establish geotechnical design criteria.

## Geologic Hazards

The Forest Service letter addresses the importance of evaluating geologic hazards to maintaining healthy national forest watersheds. The letter states in part:

> *"The desired condition is that national forest watersheds are healthy, dynamic and resilient, and are capable of responding to natural and human caused disturbances while maintaining the integrity of their biological and physical processes…"*

and,

> *"Geologic hazards include landslides, seismic activity, subsidence, flooding, toxic minerals and mine drainage, and cliff erosion. Geologic hazards are the more violent or toxic forms of geologic processes that can cause great risk to human health and safety, and to other resources"*

GENTERRA concurs that the impacts from geologic hazards can be exacerbated by construction and operations activities. In the 2008 report, GENTERRA addressed geologic hazards for the various project components as follows:

### Upper Reservoir

No active or inactive faults have been identified within the vicinity of the dam axis, abutments, or upper reservoir area in general. It is likely that excavation of the upper reservoir area will expose old, inactive bedrock faults associated with the original intrusion of the pluton. Such older faults, if present, may require local foundation treatment such as over-excavation and grouting.

The dam and upper reservoir will likely be subjected to strong ground shaking during the design life of the project. Site-specific seismic hazard analyses should be performed to support design.

No landslides have been identified in the upper reservoir area. Landsliding should not be an issue owing to the presence of competent granitic bedrock at or near ground surface and the relatively gentle topography throughout the upper reservoir area. Localized slope stability issues may arise as a result of unfavorably oriented joints or fractures in the bedrock, primarily within the primary channel within the canyon. These issues can be mitigated with local remedial measures as required.

Rock slides and debris flows should not affect the upper reservoir due to the gentle nature of the natural slopes surrounding this area.

Liquefaction and seismic-induced settlement is not an issue in the upper reservoir area owing to the presence of competent granitic bedrock at or near ground surface.

### Shaft and Headrace Tunnel

No active or inactive faults have been identified within the vicinity of the shaft and headrace area. It is likely that excavation of the shaft and headrace will expose old, inactive bedrock faults associated with the original intrusion of the pluton. Such older faults, if present, may require local tunnel support measures such as rock bolting, steel ribs and concrete lining, or grouting if groundwater seepage is encountered.

As with other project components, the shaft and headrace tunnel will likely be subjected to strong ground shaking during the design life of the project. Site-specific seismic hazard analyses should be performed to support design.

The shaft and headrace components of the project are underground and will not be directly affected by landsliding. The ground surface above the lower headrace tunnel is locally very steep and may be subject to landslide hazards during the life of the project. This surface hazard might affect any planned ventilation shafts or other surface features within the headrace alignment. Tunnel portals for powerhouse access may also require significant structural support or design to mitigate potential localized landslide features.

As with landslides, rock slides or debris flows would only affect any surface facilities along the headrace alignment. The likelihood of seismically-induced rock slides in the very steep escarpment above the headrace and tailrace tunnels is high in the event of strong ground shaking from an earthquake.

Liquefaction and seismic-induced settlement are not concerns for the shaft and headrace tunnel owing to the presence of competent bedrock at planned shaft and tunnel elevations.

Powerhouse

The powerhouse will be very near mapped traces of the Willard fault, a branch of the active Elsinore fault zone. Though the Willard fault has not been identified as an active fault in the CGS model (CGS 2002), it is a part of the Elsinore fault zone and as such should be considered potentially active.

It is also likely that excavation of the powerhouse access shaft and cavern will expose old, inactive bedrock faults associated with the original intrusion of the pluton. Such older faults, if present, may require local tunnel support measures such as rock bolting, steel ribs and concrete lining, or grouting if groundwater seepage is encountered, as discussed above. It will also be important to conduct fault studies to determine whether any bedrock faults encountered in powerhouse excavations are tectonically associated with the Willard fault and therefore might be subject to displacement during an earthquake.

As with other project components, the underground powerhouse will likely be subjected to strong ground shaking during the design life of the project. Site-specific seismic hazard analyses should be performed to support design.

The powerhouse will be located underground and will therefore not be directly affected by landslides if they occur. The access tunnel(s) and ancillary surface components of the powerhouse complex would be subject to landslide impacts depending upon the final location of these features. The ground surface above the present powerhouse location is locally very steep and may be subject to landslide hazards during the life of the project.

As with landslides, rock slides or debris flows would only affect surface components of the powerhouse complex. The likelihood of seismically-induced rock slides in the very steep escarpment above the lower headrace tunnel and powerhouse is high in the event of strong ground shaking from an earthquake.

Liquefaction and seismic-induced settlement are not concerns since the powerhouse will be founded on competent rock.

Tailrace and Inlet/Outlet Structure

As mentioned above, the tailrace tunnels will cross mapped traces of the potentially active Willard and Wildomar faults. The tunnel will need to be designed to accommodate both lateral and vertical movement potentially generated by rupture along these faults.

As with other project components, the tailrace tunnels and inlet/outlet structure will likely be subjected to strong ground shaking during the design life of the project. Due to the proximity of the Elsinore fault zone, and soft foundation conditions, peak horizontal ground accelerations could exceed 1g. Site-specific seismic hazard analyses should be performed to support design.

A substantial portion of the tailrace tunnel alignment, and the inlet/outlet structure, will be founded on soft potentially liquefiable sediments that will likely need to be improved using ground improvement techniques. The depth and thickness of liquefiable materials beneath various portions of the tailrace alignment has not been determined, but extrapolation of information from nearby water wells outside the alignment, it is reasonable to assume that these materials could be several hundred feet thick or more. Drilling, testing and seismic surveys would be needed to better define the depth and thickness of liquefiable deposits beneath the structures.

Seiches (seismically-generated water waves within a closed water body such as a lake) may potentially be generated in Lake Elsinore by a significant earthquake on the Elsinore fault zone. The potential for a seiche should be evaluated and addressed in the design of the inlet/outlet structure. Flood inundation should also be evaluated and addressed for the inlet/outlet structure, since Lake Elsinore is a low point within a large watershed and has limited storage capacity.

# Attachment 2: Proposed Biological Resources Study Program

# 2018 Biological Study Program

## Introduction

The purpose of the proposed LEAPS Biological Study Program (study program) is to update field surveys and vegetation/habitat mapping for listed and special status species and biological communities likely to occur in the LEAPS Project Area, as a basis for Federal Energy Regulatory Commission (FERC) evaluation of the LEAPS Final License Application (FLA). Previous studies were conducted in 2006, and most comment letters received on the FLA identify a need to update them, due to such effects and changes as wildfires and urbanization.

The study program will begin with a "desktop site assessment" to determine whether field studies are indicated for any species of concern. *All field surveys described below in this study program are contingent upon a finding in the initial desktop site assessment that studies would be warranted.* Field study protocols have been suggested by agencies in comment letters submitted on the LEAPS Final License Application. Where the desktop site assessment confirms a need for field studies, agency-recommended protocols would be followed unless modified in consultation. This study program does not repeat details on study protocols provided in agency-recommended study protocols.

The desktop site assessment will be based on a previous desktop review of special-status species and critical habitats that was completed in August 2017 to update previous studies and reports completed for the LEAPS project. The 2017 desktop review has been used in preparing this study program to indicate which species and critical habitats have the potential to occur in the LEAPS Project Area (including a half-mile transmission line corridor). The 2017 desktop review included the CDFW California Natural Diversity Database (CDFW 2017a), USFWS Environmental Conservation Online System (USFWS 2017 a), CNPS online Inventory of Rare, Threatened, and Endangered Plants of California (CNPS 2017), and Carlsbad Fish & Wildlife Office Species Occurrence Data GIS shapefiles (USFWS 2017 b).

The 2017 desktop review will be expanded in the desktop site assessment as a basis for agency consultation to agree on a final suite of studies and protocols. Where differences exist between this initial recommended study program and agency comments on the FLA, they will be addressed as needed in consultation. The desktop site assessment will confirm the potential occurrence of listed federal and state species, and other special status species (collectively termed TESS species) based on available information. This will include review of agency databases, species occurrence records, previous project-related surveys, and other relevant and reputable survey or research data, as available. Databases and information sources to be consulted include:

- Aerial photographs, including Google Earth
- California Natural Diversity Database (CNDDB) (CDFW 2017a)
- California Native Plant Society (CNPS) online *Inventory of Rare, Threatened, and Endangered Plants of California* (USFWS 2017a)
- CALFIRE historical fire data for the period 2007 to 2016
- Carlsbad Fish & Wildlife Office Species Occurrence Data GIS shapefiles (USFS 2017b)
- eBird records
- Exhibit E, Environmental Report, Section 3, Fish, Wildlife and Botanical Resources" of the Final Application for License of Major Unconstructed Project (Exhibit E, Nevada Hydro 2017)
- Riverside County Multiple Species Habitat Conservation Plan (MSHCP 2017)

- Santa Ana Watershed Association (SAWA)
- U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) WebSoil website (USDA 2017)
- USFWS Environmental Conservation Online System
- United States Forest Service (USFS) Region 5 Regional Forester's 2013 Sensitive Plant Species List; Cleveland National Forest (USFS 2013)

As part of the desktop site assessment, vegetation communities/habitat types occurring within a 0.5 mi-buffer of the LEAPS project will be updated and mapped, and the resulting vegetation/habitat community map will be used as an initial indication of the potential occurrence of TESS species based on suitable habitat. Recorded and potential occurrence documented in the desktop site assessment will be among the criteria for determining which species and areas might require survey.

Field surveys and reporting will follow the appropriate federal and/or state survey protocols, where available and agreed in consultation. Most field surveys will be preceded by a reconnaissance level "initial field site assessment" to determine areas of suitable habitat to focus surveys. Biologists conducting field surveys will meet agency requirements for qualifications and will have the appropriate state and federal permits. Survey timing and protocols will generally follow agency-recommended protocols; any departures will be agreed upon in consultation with the agencies prior to initiation of field studies.

### Selection of Target Species and Habitats

The 2017 desktop review was based on CNDDB and CNPS searches that used a "nine-quad" search area. This included the U.S. Geological Survey (USGS) 7.5-minute quadrangles (quad) in which the Project Area is located (Lake Mathews, Lake Elsinore, Alberhill, Wildomar, Sitton Peak, Fallbrook, and Margarita Peak), and the adjoining quads (Perris, Steele Peak, Corona South, Romoland, Santiago Peak, Murrieta, Canada Gobernadora, Temecula, San Clemente, Bonsall, Morro Hill, Las Pulgas Canyon, and San Onofre Bluff). USFWS databases were queried using a half-mile transmission line corridor.

From the 2017 desktop review, a broad list of special status species having the potential to occur in the Project Area was compiled based on the presence of historic records (initially looking at records within five miles of project facilities) or potentially suitable habitat within the Project Area. This list was focused on species that could occur in the Project Area, based on the known range of the species, the occurrence of suitable habitat, known migration routes, and whether recorded occurrences represented historical or contemporary presence. The following general categories were defined:

- ***Observed:*** Previous surveys documented the presence of the species in the Project Area.
- ***High:*** The species has a strong likelihood to be found in the Project Area but has not been directly observed to date. The Project Area contains suitable habitat that meets the life history requirements on the species, either seasonally or perennially, and is within the know range of the species. Occurrences of the species have been documented outside of the Project Area, and no barriers to migration into the Project Area are known.
- ***Moderate****:* The species could possibly be found in the Project Area but it has not been directly observed to date. The Project Area contains potentially suitable habitat for the species.
- ***Low:*** The species has a low probability to occur in the Project Area, but the species potential presence cannot be discounted. The Project Area contains marginal habitat for the species, for

example because it is fragmented or small in size, and there may be known occurrences near the Project Area, but not within the area.

- ***Unlikely*:** Species for which there are no recorded occurrences within contemporary records (<25 years). If species is known from the vicinity, the required habitat is absent or the existing habitat has not been shown to be within the known range of the species.

Additional species were identified in a November 21, 2017 conference call/meeting with representatives of Nevada Hydro (NH), the U.S. Fish and Wildlife Service (USFWS), and the California Department of Fish and Wildlife (CDFW). The species identified during that call, and those found to have either a “Moderate” or “High” potential to occur, or which were “observed” and are state or federally listed, are included in this proposed LEAPS Biological Study Program for consideration for further field study. Those that have “Low” potential or which are “Unlikely” to occur are not recommended for further study. Further evaluation of the species and the corresponding study plans are discussed below.

## Vegetation

The LEAPS vegetation studies will include a desktop site assessment and field botanical surveys. The goal of the desktop site assessment is to identify the potential occurrence of federal, state, and species of concern (Special Status plants) based on available botanical databases, species occurrence records, and available surveys. An updated map of vegetation communities occurring within a 0.5 mi-buffer of the LEAPS project facilities will be developed and used to identify both suitable habitat for wildlife species and survey targets for special status plants. The field surveys and reporting will follow the California Department of Fish and Wildlife (CDFW) 2009 *Protocols for Surveying and Evaluating Impacts to Special Status Native Plant Populations and Native Communities* methods (CDFW 2009).

### *Study Purpose*

A general update of field plant surveys and vegetation community mapping for the LEAPS Project Area is needed to refresh information collected in 2006. Changes in vegetation community types and boundaries may have occurred due to impacts from wildfires, urbanization or other land-use changes. The purpose of this study is to update listed plants or plant species of concern, conduct field surveys of special status species, and to update the locations of any designated critical habitat(s) since the 2006 surveys.

### *Target Species and Communities*

Table 1 presents a preliminary list of target species for proposed plant surveys. The table includes species identified in initial consultation with USFWS and CDFW (November 21, 2017 call/meeting). The agencies recommended surveys for four federal and state- listed flowering plant species and one vegetation community of concern, the Engelmann’s oak woodland.

The Table may be expanded based on the identification of suitable habitats during the desktop site assessment. Table 1 is based on the 2017 desktop review, which reviewed studies and surveys conducted from 2001-2006 as well as Exhibit E, Environmental Report, Section 3, Fish, Wildlife and Botanical Resources” of the Final Application for License of Major Unconstructed Project (Exhibit E, Nevada Hydro 2017).

## Table 1 Preliminary List of Plant Species Proposed for Surveys

| Species | | Status | | | Life Form | Blooming Period | Habitat Association (elevation range [feet]) | Potential for Occurrence in Project Area |
|---|---|---|---|---|---|---|---|---|
| **Special-status Plant Species** | | | | | | | | |
| *Allium munzii* | Munz's onion | FE | ST | 1B.1<br>FS | Perennial herb; bulbiferous | Mar - May | Chaparral, coastal scrub, cismontane woodland, pinyon-juniper woodland, grassland (1,000 to 3,400) | **High** - Known from the immediate vicinity. Suitable habitat present in project area. |
| *Brodiaea filifolia* | Thread-leaved brodiaea | FT | SE | 1B.1<br>FS | Perennial herb; bulbiferous | Mar - Jun | Coastal scrub, cismontane woodland, coastal scrub, playas, valley and foothill grasslands, vernal pools, clay soils (80 to 3,700) | **Unlikely** - Not known from the vicinity. Project area lies outside the species' range. |
| *Dodecahema leptoceras* | Slenderhorned spineflower | FE | SE | 1B.1<br>FS | Annual herb | Apr - Jun | Sandy alluvial benches, floodplain terraces with alluvial fan sage scrub (650 to 2,500) | **High** - Known from Temescal Wash in the vicinity of the project area. Suitable habitat potentially present in the Temescal Wash in the project area. |
| **California Rare Plant 1B.1 Species** | | | | | | | | |
| *Arctostaphylos rainbowensis* | Rainbow manzanita | None | None | 1B.1<br>FS | Shrub; evergreen | Dec - Mar | Chaparral. USFS Cleveland NF listed (675 to 2,200) | **Observed** - Observed 2001-2006 during focused surveys. |
| *Abronia villosa* var. *aurita* | Chaparral sand-verbena | None | None | 1B.1<br>FS | Annual herb | (Jan) Mar - Sep | Sandy benches and floodplains with openings in coastal sage scrub or chaparral. USFS Cleveland NF listed (< 5,000) | **Unlikely** - Herbarium specimens collected near Lake Elsinore but no suitable habitat present in the coastal sage scrub in the project area. |
| *Centromadia pungens* ssp. *laevis* | Smooth tarplant | None | None | 1B.1 | Annual herb | Apr - Sep | Chenopod scrub, wet meadows, seeps, playas, riparian woodlands, valley and foothill grassland, alkaline soils (0 to 2,100) | **Unlikely** – Known from the vicinity of the project area. No suitable habitat present in the project area. |

| **Species** | | **Status** | | | **Life Form** | **Blooming Period** | **Habitat Association (elevation range [feet])** | **Potential for Occurrence in Project Area** |
|---|---|---|---|---|---|---|---|---|
| *Hesperocyparis forbesii* | Tecate cypress | None | None | 1B.1 FS | Tree; evergreen | N/A | Closed-cone coniferous forest, chaparral. USFS Cleveland FS listed (260 to 4,200) | **Moderate** - Known from the vicinity. Suitable habitat present in the project area. |
| **California Rare Plant 1B.2 Species** | | | | | | | | |
| *Chorizanthe polygonoides* var. *longispina* | Long-spined spineflower | None | None | 1B.2 FS | Annual herb | Apr - Jul | Chaparral, coastal scrub, meadows and seeps, valley and foothill grassland, vernal pools (100 to 5,200) | **High** - Known from the vicinity. Suitable habitat present in the project area. |
| *Dudleya multicaulis* | Manystemmed dudleya | None | None | 1B.2 FS | Perennial herb | Apr - Jul | Chaparral, coastal scrub, valley and foothill grassland. USFS Cleveland NF listed (50 to 2,600) | **High** - Known from the vicinity. Suitable habitat present in the project area. |
| *Tortula californica* | California screw-moss | None | None | 1B.2 | Moss | N/A | Chenopod scrub, valley and foothill grassland (32 to 4,800) | **Low** – Known from the vicinity of the project area. Marginally suitable habitat present in the project area. |
| *Brodiaea santarosae* | Santa Rosa basalt brodiaea | None | None | 1B.2 FS | Perennial herb; bulbiferous | May - Jun | Basaltic soils. Valley and foothill grassland. USFS Cleveland NF listed (1,855 to 3,430) | **Low** - Known from the vicinity. Marginally suitable habitat present in the project area |
| *Lilium parryi* | Lemon lily | None | None | 1B.2 FS | Perennial herb; bulbiferous | Jul - Aug | Lower montane coniferous forest, meadows and seeps, riparian scrub, upper montane coniferous forest. Mesic soils. USFS Cleveland NF listed (4,000 to 9,000) | **Low** - No recorded occurrence within the vicinity of the sites. Marginally suitable habitat present in the project area |
| *Sibaropsis hammittii* | Hammitt's clay-cress | None | None | 1B.2 FS | Annual herb | Mar - Apr | Chaparral openings, valley and foothill grasslands. USFS Cleveland NF listed (2,400 to 3,500) | **High** - Known from the immediate vicinity. Suitable habitat present in the project area. |
| *Dudleya viscida* | Sticky dudleya | None | None | 1B.2 FS | Perennial herb | May - Jun | Coastal scrub, cismontane woodland, coastal bluff scrub, chaparral. USFS Cleveland NF listed (<1,800) | **High** - Known from the vicinity. Suitable habitat present in the project area. |

### Study Approach

The initial desktop site assessment will identify potentially suitable habitat for California listed or plant species of concern based on available biological, geological, and soils databases and U.S. Geological Survey (USGS) topographic map data. Database information (as shapefiles and digital data), and aerial imagery (from the ESRI and Google Earth websites) will be downloaded into the Geographic Information System (GIS) ArcMap Version 10. Other specific databases will be selected that best identify current vegetation communities, soil types, designated critical habitats, and species occurrence records since the 2006 plant surveys. Databases to be consulted are listed in the introduction above.

Additional reports and environmental reviews or habitat assessments will be reviewed to identify species of concern occurrences or lack of occurrence (i.e., negative surveys), where these sources are readily available and have been conducted within the past 5 years for sensitive species pursuant to the California Environmental Quality Act (CEQA) in proximity to the Project Area.

In accordance with CDFW's *State and Federally Listed Endangered, Threatened, and Rare Plants of California* database (CDFW 2017b) and the California Native Plant Society *Inventory of Rare and Endangered Plants of California* (CNPS 2017), a plant species will be considered a species of concern if it met one or more of the following criteria:

- Listed as endangered or threatened, or candidate for listing under the federal Endangered Species Act
- Listed or a candidate for listing as endangered or threatened under the California Endangered Species Act
- Identified by the CDFW as a species of special concern or fully protected species
- Listed as rare under the California Native Plant Projection Act
- Included on Lists 1 and 2 of the California Rare Plant Ranks

TRC biologists will review available information on flowering time, conservation status, habitat preferences, phenology, geographic distribution, elevation, and known plant locations near the Project Area and develop a list of additional plant species for the field surveys as part of the desktop site assessment as described above.

The potential occurrence of Engelmann's oak woodlands will be identified from aerial imagery and vegetation community data during the desktop site analysis. Species-specific surveys will be used to identify the actual occurrence of Engelmann oak trees. The locations of mature Engelmann's oak located with the Project Area will be marked with a global positioning system (GPS) unit during the field surveys. The proposed list of federal and/or state-listed plant species and plant species of concern identified for potential field survey based on desktop site assessment will be compiled and be provided to the USFWS and CDFW during consultation to develop a final plant survey list.

### Study Timing and Iteration

Rare plant surveys will occur during the 2018 growing season, likely March through August, during each species' optimum flowering and/or fruiting period so the plants can be readily identified to species. The timing and the number of site visits will be determined by geographic location, the natural communities present, and the local weather patterns of the year(s) that the surveys are conducted. The species surveyed will be grouped based by flowering period, therefore multiple species will be surveyed for during a site visit and multiple site visits will likely be required. It is assumed that a minimum of 3 site visits will be required to determine species occurrence. The location of Engelmann's oak trees will also be ground-truthed during the field survey.

### *Geographic Scope*

Rare plant surveys would cover a half-mile buffer around the LEAPS transmission center line. The field plant surveys will be conducted within the disturbance footprint of other LEAPS project facilities:

- Lake Switchyard
- The 1.5mile underground transmission trench area
- Upper reservoir area (100-120 acres)
- Pull sites (25 sites)
- Temporary access roads
- Santa Rosa Substation Vertical Shaft site
- Penstock drill locations
- Staging areas
- Case Springs Substation site
- Lattice Tower pads plus a 200 ft buffer or other determined buffer to allow for possible micro-siting of the towers.

## Fish and Wildlife

The LEAPS fish and wildlife studies will begin with a desktop site assessment as described above, and field surveys as determined to be necessary. The goal of the desktop site assessment is to identify the potential occurrence of federal, state, and species of special concern based on available biological databases, species occurrence records, and available surveys. The studies will also include an updated map of potential habitat occurring within a 0.5 mi-buffer of the LEAPS project facilities.

### *Study Purpose*

A general update of field surveys and habitat mapping for the LEAPS Project Area is needed to refresh information collected in 2006. Changes in species distribution and abundance and habitat may have occurred due to impacts from wildfires, urbanization or other land-use changes. The purpose of this study is to update listed species or species of special concern, conduct field surveys of special status species, and to update the locations of any designated critical habitat(s) since the 2006 surveys.

### *Target Species and Communities*

Table 2 presents a preliminary list of potential target species for proposed invertebrate, wildlife and fish field studies. The table was compiled as described above and includes species identified in initial consultation with USFWS and CDFW (November 21, 2017 call/meeting).

The Table may be expanded based on the identification of potential occurrence of species or suitable habitats during the desktop site assessment. Table 2 is based on the 2017 desktop review, which reviewed studies and surveys conducted from 2001-2006 as well as Exhibit E, Environmental Report, Section 3, Fish, Wildlife and Botanical Resources of the Final Application for License of Major Unconstructed Project (Exhibit E, Nevada Hydro 2017).

Table 2. Preliminary List of Invertebrate, Wildlife, and Fish Species Proposed for Surveys

| Species | | Status | | | Required Habitat | Known Presence/Potential Habitat/Potential in Project area |
|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **USFWS** | **CDFW** | **Other** | | |
| **Invertebrates** | | | | | | |
| *Branchinecta lynchi* | Vernal pool fairy shrimp | FT | None | None | Vernal pools; other seasonal wetlands or pools that dry in summer | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Branchinecta sandiegonensis* | San Diego fairy shrimp | FE | None | None | Vernal pools; other seasonal wetlands or pools that dry in summer | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Streptocephalus woottoni* | Riverside fairy shrimp | FE | None | None | Vernal pools; other seasonal wetlands or pools that dry in summer | **Moderate** - No recorded occurrence within the vicinity of the Project Area. Suitable habitat present in the Project Area. Species noted during Nov. 21, 2017 meeting. |
| *Euphydryas editha quino* | Quino checkerspot butterfly | FE | None | None | Sparsely vegetated sage scrub/grassland mix with dwarf plantain and/or purple owl's clover | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. Fires from 2010 and 2013 burned approximately 3 miles of proposed transmission line rights-of-way approximately 4 miles west of known populations (CALFIRE 2017), representing potential new habitat. |
| **Fish** | | | | | | |
| *Oncorhynchus mykiss irideus* | Steelhead (southern California DPS) | FE | None | None | Migrate from marine environments to freshwater; gravel-bottomed, well oxygenated river and streams; feed primarily on zooplankton | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Oncorhynchus (=Salmo) mykiss irideus* | Steelhead (Central Valley DPS) | FT | None | None | | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| **Amphibians** | | | | | | |

| Species | | Status | | | Required Habitat | Known Presence/Potential Habitat/Potential in Project area |
|---|---|---|---|---|---|---|
| Scientific Name | Common Name | USFWS | CDFW | Other | | |
| *Anaxyrus californicus* | Arroyo toad | FE | CSC | None | Streams and arroyos, sandy banks | **High** - Recorded occurrence immediately adjacent to the transmission line route. Suitable habitat present in the Project Area. |
| *Spea hammondii hammondii* | Western spadefoot | None | CSC | BLM | Washes, floodplains, alluvial fans, playas, and alkali flats | **High** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Rana draytonii* | California red-legged frog | FT | CSC | None | Ponds, or permanent water ways with extensive vegetation | **Low** - No recorded occurrence within the vicinity of the Project Area. Marginally suitable habitat present in the Project Area. Species noted during Nov. 21, 2017 meeting. |
| *Taricha torosa torosa* | Coast Range newt | None | CSC | None | Coastal drainages; breeds in ponds, reservoirs, and slow moving streams | **Observed** - Observed 2001-2006 during focused surveys. |
| **Reptiles** | | | | | | |
| *Arizona elegans occidentalis* | California glossy snake | None | CSC | None | Arid scrub, rocky washes, grassland, chaparral | **Moderate** - No recorded occurrence within the vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Aspidoscelis tigris stejnegeri* | San Diegan tiger whiptail | None | CSC | None | Hot and dry open areas with sparse vegetation. Chaparral, woodland, and riparian areas | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Coleonyx variegatus abbotti* | San Diego banded gecko | None | CSC | None | Rocky areas in coastal sage and chaparral | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Crotalus ruber ruber* | Northern red-diamond rattlesnake | None | CSC | FS | Chaparral, desert scrub, rocky alluvial fans | **Observed** - Observed 2001-2006 during focused surveys. |

| **Species** | | **Status** | | | **Required Habitat** | **Known Presence/Potential Habitat/Potential in Project area** |
|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **USFWS** | **CDFW** | **Other** | | |
| *Emys marmorata* | Western pond turtle | None | CSC | FS; BLM | Permanent, or nearly permanent, fresh water areas | **Moderate** - No recorded occurrence within the vicinity of the Project Area. Potentially suitable habitat present in the Project Area. |
| *Lampropeltis zonata* (*pulchra*) | California mountain kingsnake (San Diego population) | None | CSC | FS; BLM | Moist woods, coniferous forest, woodland, and chaparral. Ranging from sea level high into the mountains | **Moderate** - No recorded occurrence within the vicinity of the Project Area. Potentially suitable habitat present in the Project Area. |
| *Phrynosoma blainvillii* | Blainsville's horned lizard | None | CSC | BLM | Open areas of sandy soil and low vegetation in valleys, foothills and semiarid mountains. Grasslands, coniferous forests, woodlands, and chaparral | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Thamnophis hammondii* | Two-striped garter snake | None | CSC | FS; BLM | Permanent fresh water, along stream with rocky bed bordered by willows or riparian growth | **Observed** - Observed 2001-2006 during focused surveys. |
| **Birds** | | | | | | |
| *Aquila chrysaetos* | Golden eagle | None | CSC, SFP, WL | BCC; BLM | Prefer semi-open to open habitats including tundra, shrublands, grasslands, and woodlands. Also occur in more mesic locations | **Moderate** – Recorded occurrence within vicinity of the Project Area. Suitable habitat potentially present in the Project Area. |
| *Asio otus* | Long-eared owl | None | CSC | None | Riparian bottomlands, belts of live oak | **Moderate** - No recorded occurrence within the vicinity of the Project Area. Potentially suitable habitat present in the Project Area. |
| *Athene cunicularia* | Burrowing owl | None | CSC | BLM | Grasslands, shrublands with low-growing cover | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |

| **Species** | | **Status** | | | **Required Habitat** | **Known Presence/Potential Habitat/Potential in Project area** |
|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **USFWS** | **CDFW** | **Other** | | |
| *Circus cyaneus* | Northern harrier | None | CSC | None | Marshes, fields, and prairies with a preference towards marshes | **Moderate -** Recorded occurrence in vicinity of the sites. Suitable habitat present in the sites. |
| *Elanus leucurus* | White-tailed kite | None | SFP | None | Open savanna, grasslands, and fields | **High** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Empidonax traillii extimus* | Southwestern willow flycatcher | FE | None | None | Drier willow thickets, alders | **Moderate** - Recorded occurrence in vicinity of the Project Area. Potentially suitable foraging habitat present in the Project Area. |
| *Eremophila alpestris actia* | California horned lark | None | CSC | None | Short-grass prairie, “bald” hills, mountain meadows, open coastal plains, fallow grain fields, alkali flats | **Observed** - Observed 2001-2006 during focused surveys. |
| *Haliaeetus leucocephalus* | Bald eagle | FT (FPD) | SE, SFP | FS | Ocean shorelines, lake margins, river courses | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable foraging habitat present in the Project Area. |
| *Icteria virens* | Yellow-breasted chat | None | CSC | None | Riparian thickets near watercourses | **High** - Observed within Temescal Wash. Suitable habitat present in the Project Area. |
| *Lanius ludovicianus* | Loggerhead shrike | None | CSC | None | Grasslands, coastal sage scrub, chaparral | **Observed** - Observed 2001-2006 during focused surveys. |
| *Pelecanus erythrorhynchos* | American white pelican | None | CSC | None | Brackish and freshwater lakes of inland US | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Polioptila californica californica* | Coastal California gnatcatcher | FT | CSC | None | Coastal scrub, dry washes, ravines | **Moderate** - Recorded occurrence in vicinity of the Project Area. Potentially suitable habitat present in the Project Area. |
| *Strix occidentalis occidentalis* | California spotted owl | None | CSC | FS; BLM | Coniferous forests, wooded canyons | **Observed** - Observed 2001-2006 during focused surveys. |

| Species | | Status | | | Required Habitat | Known Presence/Potential Habitat/Potential in Project area |
|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **USFWS** | **CDFW** | **Other** | | |
| *Vireo bellii pusillus* | Least Bell's vireo | FE | SE | None | Riparian areas, forest edges | **Moderate** - Recorded occurrence within the Project Area. Potentially suitable habitat present in the Project Area. |
| **Mammals** | | | | | | |
| *Chaetodipus fallax fallax* | Northwestern San Diego pocket mouse | None | CSC | None | Coastal scrub, chaparral, grasslands, sagebrush | **High** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area |
| *Dipodomys merriami parvus* | San Bernardino Merriam's kangaroo rat | FE | CSC | None | Alluvial scrub/coastal sage scrub habitats on gravelly and sandy soils adjoining river and stream terraces, and on alluvial fans | **Unlikely**- Not known from the vicinity. No suitable habitat in the Project Area. Species noted during Nov. 21, 2017 meeting. |
| *Dipodomys stephensi* | Stephens' kangaroo rat | FE | ST | None | Annual and perennial grassland, coastal scrub or sagebrush scrub | **High** - Recorded occurrence in the northern 3 miles of the Project Area, including 6 new survey results recorded 2008-2011. Suitable habitat present in the Project Area. |
| *Lepus californicus bennetii* | San Diego black-tailed jackrabbit | None | CSC | None | Coastal sage scrub habitat | **Moderate** - Recorded occurrence in vicinity of the Project Area. Suitable habitat present in the Project Area. |
| *Perognathus longimembris pacificus* | Pacific pocket mouse | FE | CSC | None | Coastal sage scrub habitat | **Moderate** – No recorded occurrences in vicinity of the Project Area. Suitable habitat in the Project Area. |
| *Puma concolor browni* | Yuma mountain lion | None | CSC | None | Lower Sonoran zone | **Moderate** – No recorded occurrences in vicinity of the Project Area. Suitable habitat in the Project Area. Species noted during Nov. 21, 2017 meeting. |

| Species | | Status | | | Required Habitat | Known Presence/Potential Habitat/Potential in Project area |
|---|---|---|---|---|---|---|
| Scientific Name | Common Name | USFWS | CDFW | Other | | |

**U.S. FISH AND WILDLIFE SERVICE**
FE Federally listed, endangered: species in danger of extinction throughout a significant portion of its range
FT Federally listed, threatened: species likely to become endangered within the foreseeable future
FPE Federally proposed endangered
FPD Federally delisted
BCC Bird of Conservation Concern

**CALIFORNIA DEPARTMENT OF FISH AND GAME**
SE State listed, endangered
ST State listed, threatened
CSC California Species of Special Concern: administrative designation for vertebrate species that appear vulnerable to extinction because of declining populations, limited ranges, and/or continuing threats
SP State protected species
SFP Fully protected

**CALIFORNIA NATIVE PLANT SOCIETY**
List 1B Plants rare, threatened, or endangered in California and elsewhere
List 2 Plants rare, threatened, or endangered in California but more common elsewhere
R Rarity: 1=rare but in sufficient number that extinction potential is low; 2=distribution in a limited number of occurrences; 3=distribution in highly restricted occurrences or present in small numbers

**OTHER**
FS United States Forestry Service Sensitive Species – Cleveland National Forest
BLM United States Bureau of Land Management Sensitive Species

### *Study Protocol*

As noted above, field study protocols have been recommended by agencies in comment letters submitted on the LEAPS Final License Application and this study program generally assumes that agency-recommended protocols would be followed unless modifications are agreed in consultation. However, several species listed in Table 2 lack a designated state or federal survey protocol. Survey protocols for such species would be developed in consultation. Any site observations of these species or their habitat during initial field site assessment would be documented on field reports of incidental sightings. If not already addressed by this study program, Nevada Hydro would consult to determine whether field studies are warranted. If additional studies are agreed, consultation will determine the appropriate survey methodology.

Species without designated survey protocol, and which are both listed as a California Species of Special Concern and have a “moderate” to “high” potential to be within the study area, or which have been previously “observed” include:

- Western spadefoot
- Coast range newt
- California glossy snake
- San Diegan tiger whiptail
- San Diego banded gecko
- Northern red-diamond rattlesnake
- California mountain kingsnake
- Blainsville’s horned lizard
- Two-striped garter snake
- Northewestern San Diego pocket mouse
- San Diego black-tailed jackrabbit
- San Bernadino Merriam’s kangaroo rat

## Fairy Shrimp

Three species of fairy shrimp were identified during the 2017 desktop review or by agencies during the November 21 conference call. These include: vernal pool fairy shrimp (FT), San Diego fairy shrimp (FE), and Riverside fairy shrimp (FE).

### *Study Purpose*

The purpose of the assessment will be to determine if any of the three species of fairy shrimp occurs within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

USFWS (2015) Large Listed Branchiopod survey protocols will be implemented. Prior to the first survey, a field site assessment will be conducted. Biologists conducting the surveys will have a current recovery permit pursuant to Section 10(a)(1)(A) of the *Endangered Species Act*, and a current CDFW Scientific Collecting Permit.

### *Study Timing and Iteration*

Surveys may occur during either the wet or dry season, depending on permit requirements and agency preference. Wet season sampling in Southwestern California occurs at 7-day intervals after initial habitat inundation and continues until either the habitat dries or 120 consecutive days of inundation have been recorded. Several wet season sampling evens may be required if a single wet season is determined to be unreliable in consultation with the USFWS.

### *Geographic Scope*

Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation.

## Quino Checkerspot Butterfly (QCB)

The QCB is listed as federally endangered, and has a moderate potential to occur within the Project Area, with suitable habitat present and recorded occurrences in the vicinity of the Project Area. However, USFWS-designated critical habitat currently occurs outside of the Project Area (USFWS 2017a).

### *Study Purpose*

The purpose of the assessment will be to determine if the QCB or its habitat occurs within the Project Area, and whether the project has the potential to adversely impact the population.

### *Study Approach*

QCB survey protocols will follow USFWS (2002). Prior to the first survey, an initial field site assessment will be conducted. Biologists conducting the surveys will have a current recovery permit pursuant to Section 10(a)(1)(A) of the *Endangered Species Act*, and a current CDFW Scientific Collecting Permit.

### *Study Timing and Iteration*

QCB surveys will be conducted weekly for at least 5 weeks during the flight season for non-excluded portions of the Project Area. The flight season generally begins in late February to early March, however the regional USFWS office will be contacted to determine the timing of the surveys, based on monitored reference sites throughout the species’ range.

### *Geographic Scope*

Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation.

## Arroyo Toad

The federally endangered arroyo toad has a high likelihood of occurrence within the Project Area, with recorded occurrences immediately adjacent to, and suitable habitat within the Project Area. USFWS-designated critical habitat occurs within the Project Area (USFWS 2017a).

### *Study Purpose*

The purpose of the assessment will be to determine if the arroyo toad or suitable habitat occurs within the Project Area, and if so, whether the project might pose potential adverse impacts to the population.

### *Study Approach*

Arroyo toad surveys will follow USFWS (1999) protocols. Under the 1999 standards, the biologists conducting the surveys are not required to have a current recovery permit pursuant to Section 10(a)(1)(A) of the *Endangered Species Act*. A current CDFW Scientific Collecting Permit may be required, however.

### *Study Timing and Iteration*

At least six survey sessions must be conducted during the breeding season (March 15 through July 1), with at least 7 days between each survey. At least one survey will be conducted in April, May, and June. Both the daytime and night-time components of the surveys will be included in the same 24-hr period unless toads are detected in the survey area.

### *Geographic Scope*

Arroyo toads can be found along streams, arroyos and on sandy banks.  Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation.

## California Red-legged Frog (CRLF)

Federally listed as threatened, and state listed as a species of special concern, the CRLF has a low probability of being located within the Project Area. Although agencies mentioned this species during the November 21, 2017 conference call, designated critical habitat for the species occurs outside of the Project Area (USFWS 2017) and it is not recommended for field study.

### *Study Purpose*

If field study is required by agencies, the purpose of the assessment would be to determine if the species or species habitat occurs within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

This species will be included in the initial desktop site assessment to confirm whether further study on this species is warranted. If field studies are warranted, California red-legged frogs would be surveyed following USFWS (2005) protocols. Per those guidelines, the biologists conducting the surveys are not required to have a current recovery permit pursuant to Section 10(a)(1)(A) of the *Endangered Species Act*, but must meet agency requirements to qualify to perform the surveys. More intensive surveys such as dip-netting larvae and adults would require the biologist conducting a survey to have a current recovery permit pursuant to Section 10(a)(1)(A), and a current CDFW Scientific Collecting Permit.

### *Study Timing and Iteration*

CFRLF habitat occurring within one mile of the Project Area will be reviewed in the initial desktop site assessment. Field surveys can be performed from January to September. Multiple surveys increase validity. The ideal survey period for Southern California is between February 25 and April 30. Two day and four night surveys are recommended during the breeding period, with each survey 7-days apart.

### *Geographic Scope*

CRLF utilize both upland and aquatic habitat. Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation or through use of agency-recommended protocols.

## Western Pond Turtle

While there are no recorded occurrences of the western pond turtle within the Project Area, there is a moderate potential that the species may present due to the presence of suitable habitat. A California special status species, the western pond turtle is cryptic and aquatic.

### *Study Purpose*

The purpose of the assessment will be to determine if the western pond turtle or its habitat occurs within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

The US Geological Survey (USGS) has developed the *USGS Western Pond Turtle (Emys marmorata) Visual Survey Protocol for the Southcoast Ecoregion* (2006). The "Southcoast Ecoregion" ranges from Santa Barbara, California to the Mexican border. The species is not federally listed and therefore surveys would only require state collectors permits. Surveyors are required to have a background knowledge of the biology of the pond turtle prior to the initiation of the survey.

### *Study Timing and Iteration*

Linear sites are visually assessed in 250-meter segments. Surveys should correlate with the breeding season which is typically May – July, though southern turtles may remain active and in the water year-round. More details on the study protocol are located in the official USGS document.

### *Geographic Scope*

The western pond turtle utilizes many types of waterbodies ranging from permanent to intermittent, and freshwater to brackish. Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation.

## Raptors, including Golden and Bald Eagles

Raptors and their nests, eggs, and young are protected by the Bald and Golden Eagle Protection Act (BGEPA) and the Migratory Bird Treaty Act of 1918 (MBTA).

### *Study Purpose*

The purpose of the assessment will be to determine if target species of raptors or suitable habitat occurs within the Project Area, and if so, whether the project might pose potential adverse impacts to the population. In addition to eagles, agencies mentioned peregrine falcons and white-tailed kites in the initial consultation meeting (November 21 meeting/call).

### *Study Approach*

Eagle surveys will follow CDFW *Bald Eagle Breeding Survey Instructions* (2017a) and the *Interim Golden Eagle Inventory and Monitoring Protocols* (Pagel, Whittington, and Allen 2010) and *Protocol for Golden Eagle Occupancy, Reproduction, and Prey Population Assessment* (Driscoll 2010). Based on the rugged and wooded terrain characterizing portions of the Project Area, raptor nest surveys may need to be conducted aerially, using a helicopter. Aerial surveys will focus on habitats suitable for nesting (e.g., cliff/rock outcrops, trees, large shrubs).  Ground-nesting raptors such as northern harriers generally are difficult to locate from aerial surveys. A sub-meter accurate Trimble GPS unit will be used to record nest locations, and photographs of nests will be taken.  Additional data to be recorded includes species, occupancy/activity status, nest condition, number of eggs or young, the presence of adults, nest substrate, date, and time.

### *Study Timing and Iteration*

At least three breeding season surveys would be required under the cited protocols:  late February-early March (early incubation), late April through May (early nesting period, nestlings), and the second week of June through mid-July (late nesting period, fedglings) (Jackman and Jenkins 2004).  At a minimum, one survey should be conducted in early March for eagles and owls, and a second survey be conducted in late April/early May for falcons, buteos, and other raptors for initial data.  This two-survey plan will cover the first of the three survey sessions identified by CDFW for bald eagles and will ensure that surveys cover nesting times for all raptor species. If further (e.g., productivity) eagle surveys are required, ground surveys may be considered, depending on the number of nests to be monitored, nest accessibility, and timing.

During initial consultation (November 21 call/meeting), agencies indicated urgency to conduct surveys in December or January. Based on comment letters, this appears to relate to occupancy surveys recommended for golden eagles.

### *Geographic Scope*

Raptor nesting surveys are generally required in the vicinity of a project including a one mile buffer.  In initial consultation (November 21, 2017 call/meeting), agencies expressed specific concern regarding golden eagles, particularly a pair within “disturbance distance” that may be impacted by the project, and noted that bald eagles historically have occurred in the vicinity of Lake Elsinore.

Aerial raptor nesting surveys conducted to identify nest locations and assess the raptor species would cover the Project Area, including a one mile buffer. Appropriate areas for ground survey will be determined in consultation.

## Western Burrowing Owl (BUOW)

Designated as a California species of special concern, the western burrowing owl has experienced population declines due to disturbance and habitat loss. Found in several western states, many state agencies and local groups have attempted to devise standard survey protocols for the species.

### *Study Purpose*

The purpose of the assessment will be to determine if the western burrowing owl or its habitat occurs within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

Surveys will follow the CDFW *Guidance for Burrowing Owl Conservation* (2008), which aids in evaluating if the species is utilizing the project site, and can aid in the designation of a buffer zone. Burrowing owls utilize annual and perennial grasslands, deserts, and scrublands with low-vegetation as well as the burrows of fossorial mammals. Burrowing owls can utilize numerous nests for breeding and perching, and can change burrows throughout the nesting season.

### *Study Timing and Iteration*

Survey frequency will be dependent on the length of the construction, and at a minimum should occur within 7-days prior to the start of construction, and at 14-day intervals as work continues.

### *Geographic Scope*

Surveys should occur within a minimum of 500 feet of the Project Area, where the ground should be 100 percent visually assessed. Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation or through use of agency-recommended protocols.

## Southwestern Willow Flycatcher (SWWF)

The federally endangered SWWF has a moderate potential to occur within the Project Area, with recorded occurrences and potential habitat in the vicinity of the Project Area. However, no USFWS-designated critical habitat occurs within the Project Area (USFWS 2017a).

### *Study Purpose*

The purpose of the assessment will be to determine if the SWWF or its habitat occurs within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

Surveys would follow the USGS *A Natural History Summary and Survey Protocol for the Southwestern Willow Flycatcher: Techniques and Methods 2A-10* (Sogg et al. 2010). This protocol will entail call playback by trained and permitted biologists. Biologists conducting the surveys will have a current recovery permit pursuant to Section 10(a)(1)(A) of the *Endangered Species Act*, and a current CDFW Scientific Collecting Permit.

### *Study Timing and Iteration*

Five surveys will be conducted during the nesting season as prescribed in Sogge et al. (2010), with at least one survey conducted between May 15 - May 31, at least two surveys conducted between June 1-24, and at least two surveys conducted between June 25 - July 17. Surveys must be separated by at least 5 days.

### *Geographic Scope*

SWWF inhabit riparian and adjacent willow thickets, alders, and tamarisk with thick understory growth. Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation or through use of agency-recommended protocols.

## Coastal California Gnatcatcher (CAGN)

This federally threatened and state designated special status species has a moderate potential to occur within the Project Area, with recorded occurrences and potential habitat in the vicinity of the Project Area. USFWS-designated critical habitat for the CAGN occurs within the Project Area (USFWS 2017a).

### *Study Purpose*

The purpose of the assessment will be to determine if the CAGN or its habitat occurs within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

CAGN will be surveyed following USFWS (1997) protocols. The appropriate regional USFWS office will be notified in writing at least 10 days prior to the anticipated survey start date to obtain approval for the surveys. The biologist conducting the survey is required to have a current recovery permit pursuant to Section 10(a)(1)(A), and a current CDFW Scientific Collecting Permit.

### *Study Timing and Iteration*

The breeding season for this species is February 15 – August 30, with most nesting activity occurring from mid-March to mid-May. While incubation takes 14 days, fledglings are associated with their parents for several months. Survey timing protocols depend upon whether or not the habitat falls into a “jurisdiction participating in the NCCP interim section 4(d) process”. Several surveys during breeding season are required for either type of jurisdiction. Non-participating jurisdictions also require non-breeding season surveys.

### *Geographic Scope*

CAGN inhabit coastal scrub, dry washes, alluvial fan scrub, chaparral, intermixed or adjacent areas of grassland and riparian areas, and ravines. Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation. After the initial field site assessment, determinations will be made as to whether the habitat falls into a jurisdiction participating in the Endangered Species Act NCCP interim Section 4(d) process and survey locations will be planned accordingly.

## California Spotted Owl

This California-designated special status species was observed within the Project Area during the 2001 – 2006 site surveys.

### *Study Purpose*

The purpose of the assessment will be to determine if the California Spotted Owl or its habitat occurs within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

California spotted owl will be surveyed utilizing the USFWS methodology listed in *Protocol for Surveying Proposed Management Activities that may Impact Northern Spotted Owls* (2012). The USFWS (1993) *Protocol for Surveying Spotted Owl in Proposed Management Activity Areas and Habitat Conservation*

*Areas* may also be referenced. The biologist conducting the survey is required to have a current CDFW Scientific Collecting Permit.

### Study Timing and Iteration

Typically, surveys occur between March 15 and August 15. Incubation nesting activity peaks around April 1. Calling stations and survey routes should be designed to cover all habitat within the survey area. Spot calling surveys occur at night. More details on the study protocol are located in the official USFWS document.

### Geographic Scope

The survey radius be based on identified habitat in the Project Area and consultation with the CDFW. Surveys should include areas where the owls may be nesting, roosting, or foraging. Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation or through use of agency-recommended protocols.

## Least Bell’s Vireo (LBEVI)

The federal and California endangered LBEVI has been observed within the Project Area, and suitable habitat is present. However, USFWS-designated critical habitat for the species is outside the Project Area (USFWS 2017a).

### Study Purpose

The purpose of the assessment will be to determine if the LBEVI or its habitat continue to occur within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### Study Approach

Methodology for LBEVI surveys will follow USFWS (2001) protocol, and will be conducted by trained and permitted biologists. Following the 2001 protocol, if vocalization tapes are not used, a recovery permit pursuant to Section 10(a)(1)(A) is not required. The biologist conducting the survey will likely be required to hold a current CDFW Scientific Collecting Permit.

### Study Timing and Iteration

The USFWS protocol for LBEVI surveys require at least eight survey sessions between April 10 and July 31, with at least 10 days between surveys.  Per USFWS (2001), small or marginal habitats may be exempted from the eight survey requirement, but such exemptions are rare. Due to similar ecological and seasonal requirements, surveys for LBEVI and SWWF may be conducted concurrently during some survey sessions.

### Geographic Scope

LBEVI inhabit riparian areas dominated by dense understory, including willows, mule fat, and California rose.  Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Suitable buffer areas will be determined in consultation or through use of agency-recommended protocols.

## Migratory Birds (Protected by the MBTA)

Migratory birds nesting or residing within the Project Area are protected by the federal MBTA. Many migratory raptor and passerine birds are listed in Table 2 above. However, Table 2 does not provide an all-inclusive summary of the migratory bird species with potential occurrence in or near the Project Area. Migratory bird species listed in Table 2 that do not have a designated survey protocol include long-eared owl, northern harrier, white-tailed kite, California horned lark, yellow-breasted chat, loggerhead shrike, and American white pelicans.

### *Study Purpose*

The purpose of the assessment will be to identify the presence of migratory birds within the Project Area, and whether the project has the potential to adversely impact their populations.

### *Study Approach*

Surveys will follow the USDA *Handbook of Field Methods for Monitoring Land Birds* (Ralph et al. 1993) as a methodology for finding nests during the breeding season. A recovery permit pursuant to Section 10(a)(1)(A) is not required for visual surveys, but training and experience will impact the reliability of the data collected. When surveying for nests record-keeping should include: censuses and nest searches, personnel information, a list of all birds seen or heard, weather data, plant information, and other interesting natural history observations. Surveying for nests includes observations of species behavior and cues. Survey methods will depend on the nesting behavior of the target species.

### *Study Timing and Iteration*

Nesting bird surveys are described in field protocols in reference to construction activities, and should occur 7-days prior to the start of construction and continue at 14-day intervals once construction has begun. Therefore nesting surveys are not recommended in this study program, but may be appropriate as part of license compliance.

### *Geographic Scope*

Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. Surveys are anticipated to be necessary along the full length of the transmission line. The extent of buffer areas would be agreed in consultation with agencies or through use of agency-recommended protocols.

## Steven's Kangaroo Rat (SKR)

The federally endangered Steven's kangaroo rat has a high potential to occur within the Project Area, and has known observations in the northern three miles of the transmission line, where six records were reported between 2008 and 2011. Although suitable habitat is present in the Project Area, no critical habitat is designated for this species in the area (USFWS 2017a). During initial consultation (November 21, 2017 meeting/call), agencies noted that the regulatory SKR core area does allow for new disturbances and/or construction. Pending consultation, field surveys are not recommended.

### *Study Purpose*

The purpose of any assessment would be to determine if the SKR and its habitat currently occur within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

While federally listed, the species does not currently have a USFWS approved survey protocol. A recovery permit pursuant to Section 10(a)(1)(A) is not currently required for visual surveys.

### *Study Timing and Iteration*

To be determined after initial assessment of potential habitat and subsequent consultation with USFWS.

### *Geographic Scope*

The SKR is found in annual and perennial grasslands, coastal scrub, and sagebrush scrub. Surveys would be conducted in suitable habitat in the Project Area based on the initial field site assessment. The extent of buffer areas would be agreed in consultation with agencies or through use of agency-recommended protocols.

## Pacific Pocket Mouse

The Pacific pocket mouse is federally endangered and a state designated species of special concern with a moderate potential to occur within the Project Area. While there are no known recorded occurrences within the vicinity of the Project Area, suitable habitat is known to occur. No critical habitat has been designated for this species (USFWS 2017). Pending consultation, field surveys are not recommended.

### *Study Purpose*

The purpose of the assessment will be to determine if the species or species habitat occurs within the Project Area, and whether the project might pose potential adverse impacts to the population.

### *Study Approach*

While federally listed, the species does not currently have a USFWS approved survey protocol. A recovery permit pursuant to Section 10(a)(1)(A) is required for visual surveys.

### *Study Timing and Iteration*

To be determined after initial assessment of potential habitat and consultation with USFWS.

### *Geographic Scope*

The Pacific pocket mouse is found in coastal sage scrub habitat. Surveys would be conducted in suitable habitat in the Project Area based on the initial field site assessment. The extent of buffer areas would be agreed in consultation with agencies or through use of agency-recommended protocols.

## Yuma Mountain Lion

The Yuma mountain lion is a state species of special concern, and the CDFW has identified mountain lions in the vicinity of the Project Area as a genetically isolated population at risk. During initial consultation (November 21, 2017 meeting/call), CDFW requested that the species be surveyed.

### *Study Purpose*

The purpose of the assessment will be to determine if the Yuma mountain lion or its habitat occur within the Project Area, and if so, whether the project has the potential to adversely impact the population. Pending the initial desktop site assessment and consultation, studies are not recommended.

### *Study Approach*

Available information will be compiled on the local population, territories, movement corridors, and other relevant information from recent published and acceptable unpublished data, including available data on radio-collared lions. This data will be used to provide CDFW with an overview of the potential for the project to impact the lion population. Should agreement to conduct surveys be reached in consultation, Nevada Hydro will work with CDFW to determine the timing, methodology, and specific locations to be surveyed.

### *Study Timing and Iteration*

The need for surveys, if any, will be determined by CDFW after assessing the habits, geographic distribution, and potential impacts posed by the project.  Surveys would be conducted according to CDFW required protocol, including designated locations.

### *Geographic Scope*

Surveys would be conducted in suitable habitat in the Project Area based on the initial field site assessment. The extent of buffer areas would be agreed in consultation with agencies or through use of agency-recommended protocols.

## Baseline Aquatic Ecological Inventory

The LEAPS Hydro Project would involve the direct utilization of Lake Elsinore, as well as the creation of an upper reservoir within Decker Canyon, within the Cleveland National Forest. To develop a current understanding of the health and ecological diversity within Lake Elsinore, a baseline ecological inventory may be considered for consultation. Such an inventory probably would include the perimeter of the lake, and the lake proper. It would not be recommended until the initial desktop site assessment is complete, including an evaluation of existing materials on the history of the lake and a review of projects designed to improve the health of the lake.

### *Study Purpose*

A study, if later determined to be desirable, would characterize aquatic habitat and observations on the presence, distribution, and relative abundance of special status aquatic species including fish, amphibians, and reptiles. Information could also be gathered on the use of Lake Elsinore by waterfowl and other foraging bird species.

### *Study Approach*

A literature review will be performed to determine known species within a 0.5 mile buffer of the lake. Visual encounter surveys may then be performed of the habitat and species within the study area. Further species-specific studies may be proposed based on the findings of the baseline ecological inventory.  Conservation areas would be mapped.

### *Study Timing and Iteration*

The CDFW recommends that visual encounter surveys associated with a baseline ecological inventory should occur over the course of one full season (CDFW 2017d). The full season surveys would coincide with key life cycle milestones of special status species.

### *Geographic Scope*

Surveys would be conducted in suitable habitat in the Project Area based on the initial field site assessment and would include all project work areas, temporary and permanent, that are associated with Lake Elsinore. Suitable buffer areas would be determined in consultation.

## Steelhead Survey

Steelhead (both the southern California distinct population segment [DPS] and the Central Valley DPS) have a moderate potential to occur within the Project Area. There are recorded occurrences of the species near the Project Area, and suitable habitat is present in the Project Area. The southern California DPS is federally endangered, and the Central Valley DPS is federally threatened.

### *Study Purpose*

The purpose of the assessment will be to determine if the species or species habitat occurs within the Project Area, and if so, whether the project has the potential to adversely impact the population.

### *Study Approach*

Study protocols will be agreed upon in consultation with agencies. When collecting fish in California for any purpose, a CDFW Scientific Collectors Permit is required. Federal permits required for the collection of anadromous species would be administered by the NMFS, and federal recovery permits for the collection of listed species under the ESA would be administered through the USFWS pursuant to Section 10(a)(1)(A).

### *Study Timing and Iteration*

To be determined after initial assessment of potential habitat and consultation with agencies.

### *Geographic Scope*

Surveys will be conducted in suitable habitat in the Project Area based on the initial field site assessment. The extent of buffer areas would be agreed in consultation with agencies or through use of agency-recommended protocols.

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# Attachment 3:  Copies of Select Reports from Dr. Anderson

# TECHNICAL ANALYSIS OF THE POTENTIAL WATER QUALITY IMPACTS OF THE LEAPS PROJECT ON LAKE ELSINORE

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## Introduction

Pumped-storage hydroelectric plants are widely recognized for their ability to rapidly produce electricity in response to peak demands, control supply frequency of the grid, store renewable energy and provide reserve generation capacity (Wicker, 2004; Sims, 1991). Pumped-storage plants are used extensively in Japan, where there are 16 such facilities, although plants are also located in Australia, China, Taiwan, Poland, Germany, Russia, Ireland, the UK and the US. Within California, the Castaic and Helms pumped-storage plants each provide in excess of 1000 MW capacity (FERC, 1998). Much smaller systems are operated by some irrigation districts as well (ITRC, 2001).

The Lake Elsinore Advanced Pump Storage (LEAPS) project currently under review would produce 500 MW at 83.3% wire-to-wire efficiency for electricity storage with no air quality impacts and shorter start-up times relative to combustion peaker plants (EVMWD, 2004). The environmental impacts on Lake Elsinore remain unclear, however. The SARWQCB has identified a number of possible water quality impacts associated with operation of the LEAPS facility that require consideration. This document summarizes some of the possible impacts, reviews available information from other pumped-storage hydroelectric plants, and considers potential physical, chemical and biological effects on Lake Elsinore resulting from LEAPS operation.

## 1. Physical Effects

The potential physical effects of pumping water from Lake Elsinore to the upper reservoir and the subsequent return of that water during the generation phase include: (a) regular exposure and subsequent inundation of shoreline sediments, (b) resuspension of bottom sediments resulting in an increase in lake turbidity, and (c) changes in thermal stratification and lake circulation and mixing.

(a) Regular oscillations in lake surface elevation will result in the exposure of shoreline sediments during pumping and subsequent inundation during generation.

As part of the FERC application process, The Nevada Hydro Company (THNC) indicated that the daily drawdown of Lake Elsinore would range from 2413 to 2942 acre-ft during the week and 5340 acre-ft on Saturday (THNC, 2005). These volumes would represent about 5 – 10% of the total volume of Lake Elsinore at a nominal volume of approximately 50,000 acre-ft. At the planned minimum operational lake level of 1240 ft or 38,519 acre-ft, these volumes represent a larger relative volume (6.3 – 13.9 %), while at a normal maximum operational lake level of 1247 ft (61,201 acre-ft) (THNC, 2005), these daily drawdowns represent a correspondingly smaller portion of the total lake volume (3.9 – 8.7 %). It should be mentioned that we have developed slightly more detailed area-volume-elevation relations based upon bathymetric measurements we made at lower lake levels than those originally developed by Black & Veatch and provided in the FERC application (referred to as FERC volume and area in Fig. 1), although the volumes above do not change substantially over the target surface elevations of 1240 – 1247 ft. Our bathymetric data indicated slightly lower minimum lake elevations than reported in the FERC response document (1218 vs. 1223 ft); surface area-elevation relationships also differed between the 2 datasets at lake levels <1250 ft (Fig. 1). Notwithstanding, withdrawal of water during pumping will result in exposure of sediments, while the subsequent generation cycle will result in inundation. Using the area-elevation data in the FERC response, one estimates that 49 acres will be alternately exposed and wetted during the weekday cycle that changes the lake level by about 1 ft, while the weekend (maximal) surface elevation change of 1.7 ft will expose about 83 acres (Table 1).

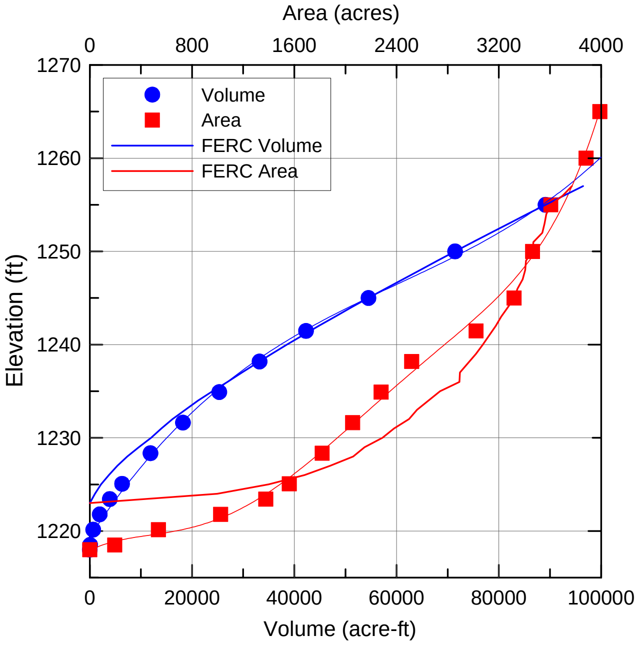

*Fig. 1. Hypsographic data for Lake Elsinore comparing Black and Veatch data used in original FERC documents and that obtained more recently by Anderson (2004).*

These values are in excellent agreement with those reported in the Response to FERC Deficiency Letter of 49 and 86 acres (THNC, 2005). A higher amount of sediments will be exposed at nominal (1240-1247 ft) lake levels assuming the area-elevation relationship that we developed holds (Table 1).

Table 1. Predicted areas of exposed sediments using alternate hypsographic data.

| | **Area of Exposed Sediments (acres)** | |
|---|---|---|
| **Elevation Change** | **THNC (2005)** | **Anderson (2004)** |
| 1.0 ft (weekday) | 49 | 79 |
| 1.7 ft (weekend) | 83 | 134 |

The bathymetry of the lake is such that comparatively little sediment area will be exposed along most of the shoreline (*e.g.*, weekday shoreline migration will be about 8 ft along the northern shores, although the southern portions of the lake will see greater shoreline migration, est. 40 ft). These values are broadly consistent with the 21 ft shoreline migration values indicated in Ch. 7 of Exhibit E of the FLA (e.g., Fig. 7-3). While that document addressed shoreline movement at parks on the lake, it is useful to also consider the extent of shoreline migration in response to LEAPS operation on other areas around the lake. The shallow embayments in the southern part of the lake will see the greatest daily oscillation in exposed sediments, where hundreds of feet of sediment may be exposed (Fig. 2). (Note that the number of depth measurements made in this portion of the lake was very limited, so the areal representation of exposed sediments is rather crudely approximated assuming a surface elevation of about 1242 ft).

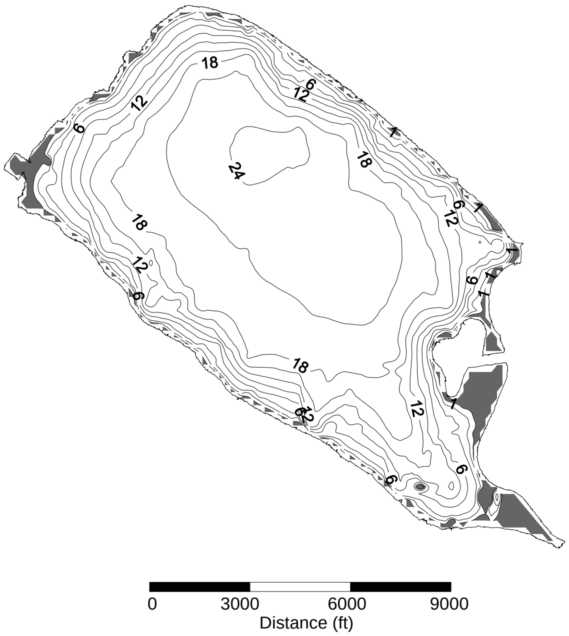

*Fig. 2. Lake bathymetry (surface elevation at approximately 1242 ft) and areal extent of sediment exposure/inundation resulting from 1 ft lake level changes (shaded areas).*

The alternate exposure and inundation of shoreline sediments is not expected to generate significant amounts of turbidity, however, since natural wave action from wind will keep fine material from accumulating near the active shoreline over much of the lake. This can be demonstrated from relationships that use wind speed, wind direction, fetch and depth to sediment to infer loci and extent of resuspension (*e.g.*, Carper & Bachmann, 1984). For example, it has been shown that resuspension and erosion of fine-textured bottom sediment occurs when deep-water waves enter water shallower than one-half the wave length (Bloesch, 1995). The wavelength, $L$, of a deepwater wave is related to its period, $T$, by the relation:

$$L = \frac{gT^2}{2\pi} \tag{1}$$

where $g$ is the gravitational constant (Martin & McCutcheon, 1999). A wave's period can be estimated using the empirical equation developed by the US Army Coastal Engineering Research Center (Carper & Bachmann, 1984) that states:

$$T = \frac{2.4\pi U \tanh\left[0.077\left(\frac{gF}{U^2}\right)^{0.25}\right]}{g} \tag{2}$$

where $U$ is the wind speed and $F$ is the fetch.

The hourly wind record from 2001 was used to calculate wavelengths (L) as a function of wind speed at an average fetch of 2.63 km using eqs 1 and 2; knowing the fraction of time in which the wind exceeded some value allows for the estimation of the probability of sediment resuspension as a function of depth (Fig. 3a). Thus we see that nearly 70% of the time, sufficient wind is present at the lake to mix and resuspend sediment to at least a depth of 1 ft (Fig. 3a).

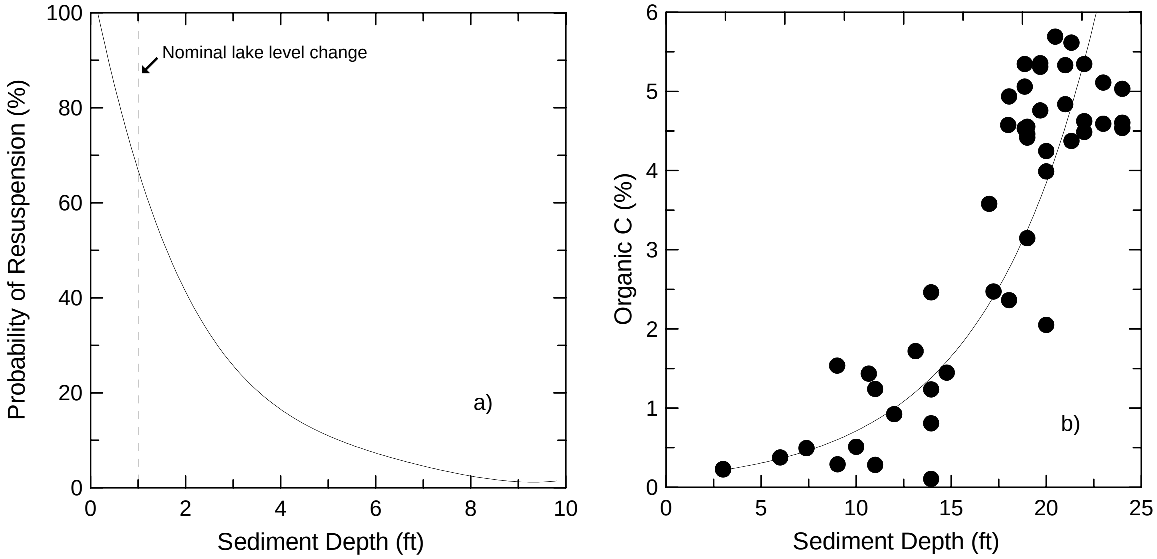

*Fig. 3. Plots showing: a) probability of mixing/resuspension as a function of sediment depth, and b) organic C content of sediments vs. sediment depth.*

This wind energy will keep fines from settling there, leaving only coarse-textured inorganic sediments that are highly stable against resuspension. Measurements of sediment properties in Lake Elsinore support this, where % organic C increased exponentially with depth, with very little organic C present in the shallow sediments (Fig. 3b). An exception to this will be the protected embayments at the southern end of the lake where, because the strong winds out of the southwest or less frequently east (data not shown) result in a very limited fetch and lower wave energy there.

(b) Resuspension of bottom sediments near inlet/outlet and increased turbidity as a result of pumping and generation.

The potential exists for substantial resuspension of bottom sediments near the inlet/outlet of LEAPS due to the large flows and high velocities there. Flows of 2000 – 3000 cfs are expected, with a stated maximum discharge velocity of 1.5/1.8 ft per second (THNC, 2005). In their deficiency letter response, THNC (2005) indicates that these LEAPS discharge velocities are comparable to those found near the recycled water inlet, and that no evidence for resuspension there was found. While they correctly conclude that there was no evidence for chronic resuspension, the channel did cut and migrate during high flow conditions, so some erosion and transport of soil/sediment materials did occur. As indicated above however, the sediments near the shoreline were very coarse textured (sandy-rocky) there. These materials require very high shear velocities to mobilize them. This is in contrast to the fine, high organic matter sediments found deeper in the lake (Fig. 3b). These sediments are potentially much more mobile, and thus are expected to be resuspended and redistributed away from the inlet/outlet during the generation cycle, although they may be brought back and redeposited near the inlet-outlet during pumping.

Sediment resuspension has been observed in other pumped-storage reservoirs. For example, operation of the Mt. Elbert pumped-storage hydroelectric plant lowered water column transparency and light penetration due to resuspension of fine bottom sediments as well as increased nutrients (USBR, 1993).

Thus, while it seems clear that LEAPS will generate substantial turbidity during construction and start-up, the *persistence* of turbidity induced by sediment resuspension from regular LEAPS operation is not clear. In a regular unidirectional flow, one would expect sediment resuspension would occur upon start-up, although the sediments would quickly redistribute and equilibrate with the new flow/energy environment. This has been observed with the axial flow pumps, where the bottom sediments have been recontoured in response to the locally high energy inputs there (Fig. 4, bold solid lower line), although chronic increased turbidity levels near the pumps have not been observed. Here acoustic backscatter profiles measured using an RDI 600-kHz Workhorse Sentinel acoustic Doppler current profiler (ADCP) in bottom-tracking mode show a redistribution of sediment away from the pumps, with sediment erosion out to about 8 m from the pumps and net sediment deposition occurring at distances of 8 – 16 m from the edge of the pumps (Fig. 4, bold solid lower line).

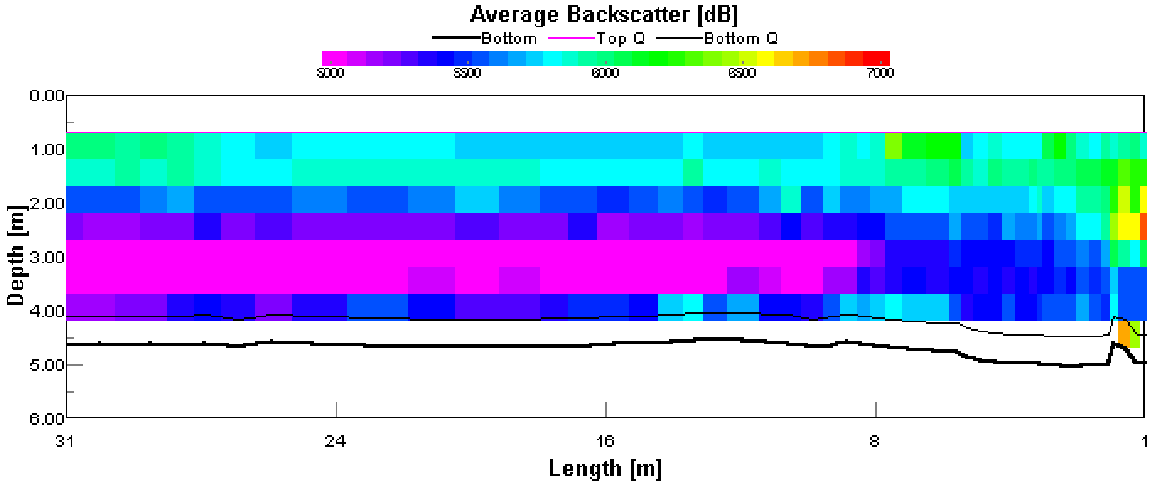

*Fig. 4. ADCP transect away from axial flow pumps showing uniform acoustic backscatter profiles (measure of turbidity) beyond about 8 m.*

A vertical gradient in scatterers (i.e., turbidity) was present, with 5000-6000 dB backscatter in the upper 2 m, and lower backscatter at greater depths. No clear gradient with distance away from the axial flow pumps was present beyond about 10 m (Fig. 4). Higher backscatter adjacent to the pumps is attributed to some entrainment of air bubbles. Hydrolab measurements of turbidity also do not indicate the presence of a turbidity plume away from the pumps (data not shown). Thus, although currents are extending out some modest distance from the pumps, turbidity levels are not correspondingly elevated.

The reversal of flows during LEAPS operation could, in principle resuspend bottom sediments and pull them into the inlet-outlet during initial pumping, and then resuspend and push them away from the inlet-outlet during generation. The sediments near the middle (deepest) part of the lake are fine-textured and enriched in organic C (Fig. 3b) (so-called type III sediments, with an average of 4.1 % sand, 44.8% silt, 51.2% clay, and 4.8% organic C) (Anderson, 2001). As a result, they could be resuspended with velocities as low as 0.7 ft/s (Gordon et al., 1992). Velocities of 1.5 – 1.8 ft/s produced by LEAPS operation could thus resuspend these sediments, although it seems that redistribution and deposition of the fine sediments out of the zone of influence of the inlet-outlet would eventually lower the amount of sediment available for resuspension so that, longer-term, the sediments would also come to equilibrium with respect to the kinetic energy inputs during operation of LEAPS. Some sediment is expected to accumulate near the inlet/outlet structure and other high-energy zones during non-operation however, so limited sediment resuspension would also be expected upon start-up each spring. Such resuspension events should be quite minor compared to that during construction and initial start-up of the plant.

### (c) Operation of LEAPS may alter thermal stratification and lake mixing dynamics in Lake Elsinore.

Operation of pumped-storage hydroelectric plants has been found to significantly alter seasonal stratification and mixing processes in lakes. Kinetic energy inputs from Mt. Elbert powerplant operation shortened the duration of thermal stratification and the strength of that stratification in both the Lower and Upper Twin Lakes (USBR, 1993). Operation of the Lake Oconee pumped-storage facility in 1980 was also found to substantively alter the physical properties of the reservoir, effectively destratifying the lake (Potter et al., 1982). A mathematical model further demonstrated that operation of a pumped-storage plant delayed the onset of thermal stratification of a Swiss lake in the spring by approximately 2 months, increased thermal heat content during the summer, and lowered it during the winter (Imboden, 1980).

The natural stratification and mixing regime in Lake Elsinore is a complex function of lake level and meteorological conditions. The lake is polymictic, i.e., mixes frequently, with the frequency of mixing increasing with decreasing lake level. For example, at low lake levels as found during the summer of 2002-2004 ($Z_{max}$ <5 m), relatively strong daytime stratification set up, although the afternoon winds combined with convective cooling at night routinely eliminated any vertical gradients in temperature by early morning (Fig. 5a). This was not necessarily the case at greater lake levels; for example, on July 14, 2005, when the lake was about 10 m deep, isothermal conditions were not found at any time (Fig. 5b).

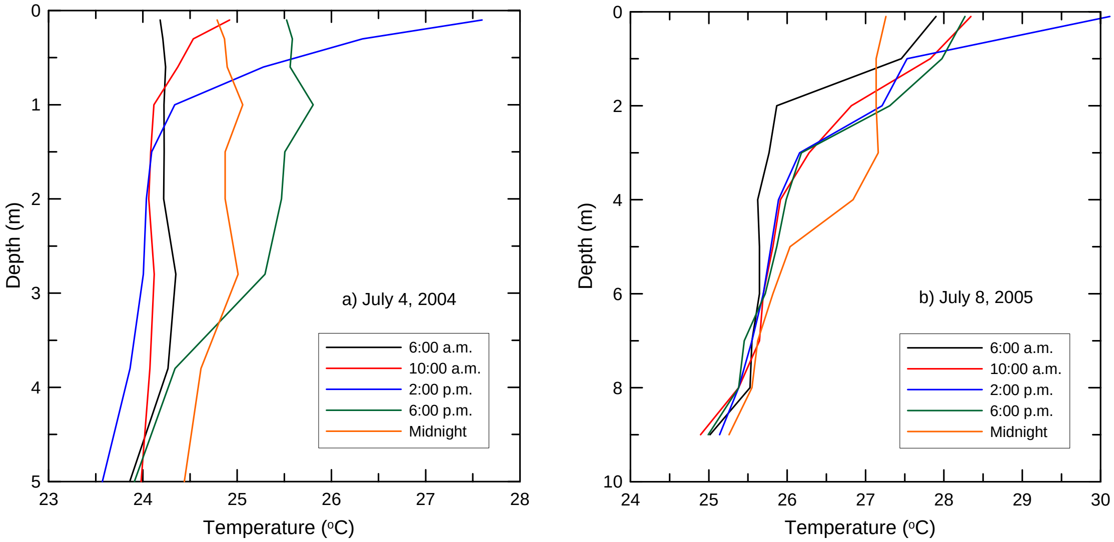

*Fig. 5. Diel variation in temperature profiles at two different lake levels and maximum depths: a) 5 m and b) 10 m.*

The operation of the axial flow pumps was not found to alter these findings significantly, implying very large inefficiencies in the transfer of their mechanical energy to the water column (Anderson, 2005). Velocity measurements made near the pumps using the ADCP confirm excessive local turbulence immediately adjacent to the pumps with very limited advective currents developed. Recent retrofitting of draft tubes and flow deflectors to Docking Station 1 substantially improved mixing efficiencies there (Anderson, unpubl. data), although the cumulative effect on lakewide stratification will have to await empirical assessment later this summer.

Operation of LEAPS will input additional mechanical energy to the lake, thus supplementing the natural mechanical energy inputs due to wind and convective mixing, as well as the energy inputs from the axial flow pumps and, when installed, the diffused aeration system. This will alter the lake's energy balance and should further weaken or even eliminate thermal stratification. Detailed hydrodynamic modeling will be necessary to fully quantify the impacts of pumped-storage operation on stratification and mixing in Lake Elsinore, although such modeling is beyond the scope of this assessment.

Nevertheless, analytical calculations can provide some insight. As indicated above, wind-forcing is a major source of energy input to lakes. The turbulent kinetic energy input from wind per unit area and time ($\eta_w$) can be calculated from:

$$\eta_w = \rho_w \left(\frac{C_D \rho_a}{\rho_w}\right)^{\frac{3}{2}} U_w^3 \tag{3}$$

where $\rho_w$ is the density of water (kg/m$^3$), $C_D$ is the drag coefficient, $\rho_a$ is the density of air, and $U_w$ is the wind speed (m/s). From our weather station deployed at the lake, we estimate the average $U_w^3$ at Lake Elsinore at about 41.3 (m/s)$^3$. Assuming a drag coefficient of 1.3x10$^{-3}$ (Martin and McCutcheon,1999) and water and air densities of 997 and 1.2 kg/m$^3$, respectively, one calculates the average turbulent kinetic energy input to Lake Elsinore due to wind is 8.06x10$^{-5}$ W/m$^2$.

The turbulent kinetic energy input during power generation ($\eta_T$) can be calculated from (Imboden, 1980):

$$n_T = \frac{Q_T U_T \rho_{in}}{2A_0} \tag{4}$$

where $Q_T$ is the flow rate at the turbines ($m^3/s$), $U_T$ is the turbine outflow velocity (m/s), $\rho_{in}$ is the density of inflowing water ($kg/m^3$) and $A_0$ is the lake surface area ($m^2$). Assuming a flow rate through the turbines of 2000 cfs (56.7 $m^3/s$), an outflow velocity of 1.5 ft/s (0.46 m/s) and a lake surface area of 3000 acres ($1.21 \times 10^7$ $m^2$), one estimates an energy input of $4.94 \times 10^{-4}$ $W/m^2$. However, since generation is slated for about 80 h/week (whereas wind blows at some velocity all the time), $\eta_T$ during to the generation cycle is reduced to a weekly-averaged value of $2.35 \times 10^{-4}$ $W/m^2$. Nonetheless, one notes that the turbulent kinetic energy input to Lake Elsinore from turbination ($2.35 \times 10^{-4}$ $W/m^2$) is predicted to be 2.9x *greater* than that due to natural wind-mixing ($8.05 \times 10^{-5}$ $W/m^2$). Not included in this calculation is the turbulent kinetic energy input to the lake due to natural convective mixing nor from the effects of pumping, but it nevertheless indicates that that operation of LEAPS will *substantially* increase the kinetic energy available for mixing the water column. The frequency and duration of thermal stratification is thus expected to be substantially reduced relative to natural conditions at the lake. The effects of this on water quality are discussed below.

## 2. Chemical Effects

Operation of LEAPS may also alter the chemical conditions in Lake Elsinore, including: (a) increased or decreased nutrient release from sediments, (b) increased DO levels, especially near the sediments, and (c) resuspension of particle-associated contaminants.

(a) Increased turbulent kinetic energy from pump-generation cycles may alter the rate of nutrient release from sediments.

Laboratory and field studies have shown that the rate of nutrient release from sediments can be enhanced with increased turbulence and flow near the sediment-water interface (Holdren and Armstrong, 1980; Reddy et al., 1996). Sediment resuspension (discussed in 1.b above) will certainly increase the concentrations of particulate-associated N and P in the water during the initial start-up of LEAPS; dissolved forms of N and P may also be increased, especially if anoxic conditions persist near the sediments since nutrient diffusive flux will be hastened due to advective processes. The flux of dissolved P may be reduced, however, if the enhanced mixing also conveys significant amounts of DO to the sediment-water interface such that an oxic layer with $Fe(OH)_3$ forms; the presence of $Fe(OH)_3$ limits $PO_4$-P release because of the very high affinity of the ferric hydroxide solid phase for phosphate (Lijklema, 1980).

Review of the literature indicates that the longer-term effects of pumped-storage plant operation may be to either increase or lower nutrient levels in the lake. The Mt. Elbert powerplant increased nutrient levels in Twin Lakes, CO (USBR, 1993), while plant operation lowered nutrient levels in Lake Oconee, GA (Potter et al., 1982). Chronic sediment resuspension was apparently responsible for the increased nutrient levels in Twin Lakes, while the destratification increased DO levels near the sediments of Lake Oconee, thereby lowering SRP flux and dissolved phosphate levels in the water column (USBR, 1993; Potter et al., 1982).

Which of these 2 possible effects on nutrient levels will occur in Lake Elsinore? The lake does have a high sediment oxygen demand as well as high water oxygen demand that must be met before oxic conditions will develop at the sediment-water interface (Anderson, 2005). Moreover, as is often found in arid regions, the sediments are rich in calcium carbonate and relatively deficient in Fe (Anderson, 2001). Thus the P cycle in Lake Elsinore is thought to be controlled to some extent at least by Ca rather than Fe. The high level of productivity in the lake and high oxygen demand has resulted in a high rate of sulfate reduction; the hydrogen sulfide formed from this microbial process has resulted in very low levels of $Fe^{2+}$ in the porewater of the sediments and precipitation of pyritic phases (Anderson, 2001). Thus, sufficient DO must be supplied to eliminate sulfate reduction and free up Fe for precipitation as the sorptive $Fe(OH)_3$ phase. This will be a challenge, although natural mixing processes combined with the increased efficiency of the axial flow pumps, installation of the diffused aeration system and LEAPS should all help to achieve oxic conditions in the subsurface.

Oxic conditions have been shown to reduce SRP flux by about 30% in previous core-flux measurements (Anderson, 2002).

(b) The operation of LEAPS may favorably affect the DO level in Lake Elsinore.

As indicated in 1(c) and 2(a) above, the operation of LEAPS will weaken thermal stratification, enhance mixing and may also increase DO levels in Lake Elsinore. Improved vertical mixing will help mix high DO surface water produced as a result of photosynthesis deeper into the water column during the day, and also allow greater exchange of $O_2$ between the atmosphere and the entire water column that is especially important at night. Increased sediment resuspension, however, could increase overall oxygen demand within the water column and actually lower DO levels. This effect is likely to occur during initial testing and operation, and should decrease over time as the long-term $O_2$-demand in the system is met.

In the response document, THNC (2005) indicates that operation of the turbines can increase DO levels by 0.5 – 1 mg/L, so there may be some additional incremental increase in DO concentrations during power generation as well.

(c) Resuspension of sediment-associated contaminants may also occur during pumpback and generation cycles.

Many contaminants in lakes are associated with the sediments. PCBs, DDT, PAHs and other hydrophobic organic contaminants all preferentially sorb to sediments that are enriched in natural organic matter (Schwarzenbach et al., 2003). Trace elements such as Cu, Hg and As are often also found in sediments (Ankley et al., 1996). The sediments in Lake Elsinore contain on average 3.19% organic C, with the deepwater sediments found near the center of the lake averaging 4.84% (Anderson, 2001), and so have the capacity to retain large amounts of hydrophobic organic contaminants and many metals. The resuspension of bottom sediments can thus reintroduce particle-associated forms of these contaminants into the water column, where they may become bioavailable or simply be redeposited elsewhere in the lake.

The sediments of Lake Elsinore do contain trace elements that sometimes exceed "lowest effect levels" (LELs) as reported by Persaud et al. (1992) and Long and Morgan (1990). The LEL is defined as the lowest concentration or amount of a substance found to have an adverse effect on growth, development, functional capacity or life span of a target organism. For example, LELs range from 0.15 ug/g for Hg to 2.0% for Fe. Severe effect levels (SELs) are typically 2-10x higher than the corresponding LEL. Considering the 26 samples for which metals analyses were reported in the LEAPS documentation (Vol. 7, Water Quality Related Reports), none of the sediment samples exceeded the LEL for Hg (0.15 μg/g) or Cd (0.6 μg/g), while 6 (23%) of the samples exceeded the LEL for As (6.0 μg/g), 15 (58%) exceeded the LEL for Cr (26.0 μg/g) and 18 (69%) of the samples exceeded the LEL for Cu (16.0 μg/g). Excluding Fe, none of the samples exceeded SELs for any of the metals. Concentrations of trace organic contaminants (e.g., pesticides, PCBs) were not included in this documentation, although concentrations in water samples from the lake were all below detection limits for pesticides and PCBs. Notwithstanding, arsenic, DDE and PCBs were all detected in fish tissue samples that often exceeded MTRL and/or OEHHA screening values. This was especially true for total PCBs in fish tissue samples that almost always exceeded these threshold values.

While an incomplete understanding of the forms and distribution of organic and metal contaminants in the sediments of the lake currently exists, it is reasonable to assume that much of the contaminants are associated with fine organic material that has been preferentially focused to the deep portions of the lake. Thus any resuspension that does occur due to shoreline migration (expected to be minimal, as indicated in 1.a above) is not expected to result in significant release of contaminants. Operation of LEAPS may have a greater impact, however, on the deeper sediments near the inflow/outflow, especially during construction and initial operation. Just as with nutrients and sediments, however, the longer-term effect of plant operation on resuspension of sediment-associated contaminants is unclear. Moreover, maintenance of oxic conditions near the sediments may also favor retention of some trace metals (*e.g.*, Cu, Cr, Pb, Zn) that, like phosphate, have a high affinity for $Fe(OH)_3$ solid phase. Alternatively, oxic conditions may enhance release of some metalloids (*e.g.*, Se) whose oxidized form is more mobile than its reduced form.

## 3. Biological Effects

The pumped-storage hydroelectric plant planned for Lake Elsinore may also affect the biotic community in the lake. Impacts may include: (a) changes in the types and abundance of algae in the lake as a result of changes in nutrient levels and due to entrainment, (b) possible entrainment of zooplankton and fish, resulting in direct mortality and/or reduced reproductive capacity, and (c) increased difficulty in establishing and maintaining aquatic macrophytes in the littoral zone of the lake.

(a) Operation of LEAPS may alter the types and abundance of phytoplankton in the lake due to changes in water column nutrient levels and through entrainment.

Sediment resuspension and increased shear near the sediment-water interface may serve to increase the rate of nutrient release to the water column, although if oxic conditions prevail, may actually lower phosphate levels. Assuming that algal populations are constrained by the availability of phosphate, LEAPS may thus alternately increase or decrease algal production, chlorophyll concentrations and transparencies in the lake. Currently the lake is not limited by nutrients; rather it appears that top-down control through grazing by *Daphnia* and other cladocerans has generally been limiting phytoplankton levels in the past year (2005). Nutrient limitations and apparent light limitation have been in place over the past several years, however. Given the highly dynamic nature of external (and internal) loading of nutrients to the lake, it seems reasonable to conclude that any effects of LEAPS on nutrient levels will be within the wide natural range of conditions there. As a result, it may be empirically difficult to demonstrate a clear effect one way or the other when compared with the range in nutrient concentrations and water quality witnessed over the past several years.

Direct entrainment of phytoplankton through pumping may result in increased mortality of phytoplankton, especially buoyant blue-green algae that possess gas vacuoles that aid in buoyancy regulation. As suggested by Horne (2005), the generation cycle will subject entrained phytoplankton to severe pressure changes that will likely rupture the gas vacuoles, resulting in mortality; thus pumped-generation will help control these nuisance algae in Lake Elsinore. To have a significant effect on the cyanobacteria levels, however, the loss of phytoplankton will have to exceed the rate at which natural reproduction would replace any lost organisms. To assess the extent of this beneficial impact, I will assume that the growth of blue-green algae in the lake can be described using a carrying capacity model, where the change in the phytoplankton population over time (dP/dt) is given by:

$$\frac{dP}{dt} = \frac{\mu(K-P)}{K}P \qquad (5)$$

In this equation, $\mu$ is the phytoplankton growth rate constant ($d^{-1}$), $K$ is the carrying capacity, and $P$ is the phytoplankton population. The growth rate constant varies with availability of nutrients and light, as well as temperature; at a summer temperature near 25 °C, the work of Eppley (1972) and others point to a value of $\mu$ near 2.5 $d^{-1}$ (Thomann and Mueller, 1987). The carrying capacity of the lake also varies as a function of nutrients, light and other factors; here I set $K$ to 100 and thus refer to populations as a percentage of the carrying capacity.

Loss of phytoplankton due to entrainment and generation is simply a function of the daily pumping rate $Q$ relative to the lake volume $V$; thus reductions in phytoplankton population over time due to LEAPS operation can be written as:

$$\frac{dP}{dt} = -m\frac{Q}{V}fP \qquad (6)$$

where $m$ is the fraction of organisms killed during a pump-generation cycle, and $f$ is a factor that accounts for daily operation 5 days out of 7 during a week (i.e., $f$ is 5/7 or 0.714).

At steady-state, dP/dt=0, and the steady-state population is thus given by:

$$P = \left(1 - \frac{mQf}{\mu V}\right)K \qquad (7)$$

Assuming 100 % mortality of entrained organisms (i.e., *m* is 1.0), one predicts a steady-state phytoplankton population that is reduced only slightly from the carrying capacity for the lake. A Q/V of 0.039 (i.e., pumping only 3.9% of the lake volume each day, as found when the lake is at its nominal maximum operating level) lowered the predicted phytoplankton population *P* by only 1.1% (a steady-state population of 98.9 % of *K*). Exchanging the lake volume more frequently (Q/V of 0.139, as found when the lake is at its lowest operational elevation and volume), lowered the steady-state phytoplankton population 4% to 96.0% of the lake's carrying capacity for phytoplankton. Thus, the rapid reproduction rate of the phytoplankton will make it difficult to substantially lower their population in the lake under the proposed pumping schedule. For comparison, a Q/V ratio exceeding 1.7 would be needed to reduce the predicted phytoplankton populations by 50%.

(b) The pumpback and generation cycles will result in entrainment of zooplankton and fish, with possible injury, loss of reproductive capacity, and death.

Although entrainment of cyanobacteria and other phytoplankton was not predicted to substantially alter their populations in the lake due to their rapid growth rates, entrainment of slower growing zooplankton and fish could have a significant effect on the lake ecosystem. As noted above, a large volume of water will be exchanged each day (3.9 – 13.9% of the lake volume, depending upon conditions and assumptions). Entrainment of organisms within these volumes during pumping, and their subsequent return to the lake during generation, will result in significant mortality.

(i) Fish - Heisey and Mathur (1980) found 40% mortality of larval catfish that had been entrained during pumping from the Muddy Run Pumped Storage Project, while mortality was somewhat lower for larval carp (17% mortality). Adult fish entrained during operation of the plant experienced 75% mortality, although the authors acknowledged that this value may have been biased to the high side given the nature of their methodology (Heisey and Mathur, 1980). They also noted that about 6.5x more larval fish were entrained during pumping than generation, with compositions of entrained larval fish similar to that found in the lower reservoir. Similar to the findings of Heisey and Mathur (1980), Prince and Mengel (1980) also found (6x) more larval fish entrained during pumping than generation at the Jocassee Pumped Storage Station; they attributed this to the configuration of the basin around the penstocks, the diel depth distribution of the larvae, and the time of day of plant operation. Mortality resulting from entrainment, pumping and generation was taken as 63% in model calculations, with operation of the plant resulting in 7 – 24% loss of fish larvae for the whole lake (Prince and Mengel, 1980). Serchuk (1976) found passage mortalities of marked juvenile and adult fish of 56 – 68% at the Ludington Pumped Storage Power Project in Michigan. In their review, Miracle and Gardner (1980) reported 68 - 85% of mortality resulted from abrasion and collision/contact with intake pipes, turbine blades and other fixed or moving objects within the system. Mortality also resulted from pressure changes, especially due to low pressure conditions and cavitation, and shear forces due to strong velocity changes. Acceleration effects were recognized as a possible factor as well, although this effect was not considered a significant source of mortality. The percent mortality was proportional to size (i.e., mortality decreased with decreasing size, in the order adult>juvenile>larval forms).

The physical characteristics of the plant and lower and upper reservoirs and the operational schedule play strong roles in the overall impacts on the fishery (Miracle and Gardner, 1980). Increased mortality is found during spawning season; habitat preference also plays a large role in what species are entrained and the total number of individuals impacted, both during spawning season and during the rest of the year. Related to this, the depth and location where water is drawn, and other physical characteristics of the facilities, directly influence the impacts on the fishery (and other aspects of the ecosystem). Moreover, spawning habitat can be reduced during plant operation. Turbidity can also affect fish populations by direct mortality, modification of reproduction rates, changing of growth rates, altering habitat and changing behavior (Miracle and Gardner, 1980). Other water quality changes (e.g., water temperature and DO levels) can also affect the fishery (e.g., Oliver and Hudson, 1980).

(ii) Zooplankton - Direct measurements of entrainment and mortality of zooplankton during pumping and generation do not appear to have been made. In an assessment of possible zooplankton effects from pumped-storage plant operation on Lake Ivosjon in southern Sweden, Horst (1980) assumed mortality rates of 10, 50 and 100% for individuals entrained during plant operation in a finite-segment model that also included advective-dispersive exchange and natural production. His model predicted overall reductions in zooplankton populations in the lake that were generally modest (e.g., 2 - 12% reduction in *Bosmina* population in the lake depending upon assumed mortality rates of 10 – 100%) and within the natural observed variability in zooplankton levels there (Horst, 1980). The volumes exchanged during pumping and generation were not provided, although the volumes of the upper reservoir and Lake Ivosjon ($2.5\text{x}10^7$ and $6.0\text{x}10^8$ $m^3$, respectively), indicates that daily exchange rate must necessarily be fairly low (<4.2%). This compares with the relative exchange rate of 3.9 – 13.9% projected for L. Elsinore, so impacts might be expected to be comparable or up to 3x or more greater for L. Elsinore.

To minimize entrainment of fish and other organisms, use of the Gunderboom Marine Life Exclusion System (MLES$^{TM}$) filtering curtain has been proposed for the lake. The MLES includes a compressed air system to periodically clear the filter barrier of entrapped material and maintain flow through the curtain. Ichthyoplankton monitoring at a conventional fossil-fueled steam electric plant on the Hudson River found approximately 80% efficiency in its reduction of larval fish entrainment (Raffenberg et al., in THNC, 2005).

The model of Prince and Mengel (1980) can be used to estimate the impacts of LEAPS operation on ichthyoplankton levels in Lake Elsinore. The benefit from use of the MLES can also be estimated. The model assumes that the % loss of ichthyoplankton from the lake (*L*) is a function of larval concentrations in the pumped volume ($C_p$), the volume-averaged larvae population in the whole lake (if different than the pumped volume) ($C_v$), the mean flow through the plant ($Q_p$), the net mortality rate within the pumped volume ($m$), the volume of the lake ($V$), and the number of days before hatched fish are of sufficient size and developmental stage to no longer be considered planktonic ($T$). That is:

$$L = \frac{\frac{mC_p}{C_v} Q_p T}{V} x100 \qquad (8)$$

In their model calculations, Prince and Mengel (1980) assumed 63% net mortality from entrainment and that the time to mature to free-swimming forms was 29 days. Using a slightly more conservative assumption for net mortality (50%) and assuming the concentration of larval fish in the pumped volume is equivalent to the lake-wide average concentration, one calculates a 40.4% loss of larval fish from pumped-storage operation when operated at the highest nominal lake volume and 100% loss when operated at low pool (Table 2). Although not explicitly stated in their study, we assume *m* defines net mortality that results from both pumping and subsequent return to the lake during generation; for the calculations as used here we assigned *m* a value of 50%, based upon 30% mortality (70% survival) on each side of the pumping and generation cycle. This mortality rate is consistent with the averaged rate from the findings of Heisey and Mathur (1980) for carp (17%) and catfish (40%). Although a simplified model, the findings imply potentially strong effects on larval survival and recruitment from operation of LEAPS during spawning season. While loss of larval sport fish should be mitigated against, this may actually prove to be an efficient way to control unwanted rough fish in the lake. That is, most sport fish spawn between 17 and 21°C, while carp typically spawn under warmer conditions, peaking at 22-26 °C. Thus, the scheduling of LEAPS operation should consider spawning seasons, with limited operation during spawning season for the sport fish (April, based upon historical temperature records for the lake), and regular use during the carp spawning season (May-June) (assuming no additional mitigation, *e.g.*, through use of the MLES).

The use of the MLES, if adopted, would lower the pumped concentration ($C_p$) relative to that in the lake ($C_v$); if the Gunderboom system can reduce entrainment of larval fish by 80%, then $C_p$ in eq 8 is simply $0.2C_v$. Under these operating conditions, one predicts % ichthyoplankton loss in Lake Elsinore of 8 – 29% (Table 2). This presumes that widespread larval fish mortality does not occur through entrapment in the filter curtain, nor during periodic pulsed air - pressure cleaning, or from increased predation near the curtain.

Table 2. Predicted % reductions in ichthyoplankton due to LEAPS operation.

| | **% Reduction in Ichthyoplankton due to LEAPS** | |
|---|---|---|
| | **Minimum lake level** | **Maximum lake level** |
| LEAPS | 100% | 40.4% |
| LEAPS+Gunderboom | 29.0% | 8.1 % |

Although not part of this assessment, more detailed calculations could be made to predict longer-term changes in fish populations due to LEAPS operation with and without the Gunderboom system, including optimization of the system to minimize sport-fishery impact and to maximize mortality of larval carp. Such an optimization may thus allow for a favorable shift in the fish ecology of Lake Elsinore.

The effects of LEAPS operation on the zooplankton of the lake can also be calculated; following the approach outlined above for phytoplankton, the change in the zooplankton population ($P_Z$) over time ($t$) can be predicted assuming:

$$\frac{dP_Z}{dt} = (\mu_Z(\frac{K_Z - P_Z}{K_Z}) - m_Z \frac{Q}{V} f)P_Z \qquad (9)$$

where $\mu_Z$ is the zooplankton birth rate constant, $K_Z$ is the zooplankton carrying capacity of the lake, $m_Z$ is the net mortality rate for zooplankton entrained during LEAPS operation, $Q$ is the daily flow rate, $V$ is the volume of the lake and $f$ is an operational factor (to correct for planned summer operation of 5 days per week).

The steady-state solution to eq 9 is of the same form as eq 7, however zooplankton reproduce more slowly than phytoplankton ($\mu$ often near 0.4 $d^{-1}$), so entrainment results in greater reductions in predicted steady-state populations relative to phytoplankton (Table 3). Assuming complete mortality of entrained organisms, the operation of LEAPS is predicted to lower the steady-state zooplankton population by 7.0 – 24.8 %, depending upon lake level (Table 3). For comparison, entrainment lowered phytoplankton populations only 1.1 – 4.0 %. The Gunderboom MLES system will lower the number of zooplankton entrained during pumpback-generation; for illustration, I will assume the Gunderboom system will lower the pumped concentration by 50%. Under these conditions, LEAPS operation is expected to have less of an effect on zooplankton levels, lowering zooplankton populations by only 3.5 – 12.4 % (Table 3). As with the ichthyoplankton, it is implicitly assumed that the filter curtain will not result in mortality to zooplankton from contact, cleaning or increased predation.

Table 3. Predicted reductions in steady-state zooplankton populations as a result of LEAPS operation.

| | **% Reduction in Zooplankton Population** | |
|---|---|---|
| | **Minimum lake level** | **Maximum lake level** |
| LEAPS Operation | 24.8 % | 7.0 % |
| LEAPS+Gunderboom | 12.4 % | 3.5 % |

While a number of assumptions were made in the model predictions for phytoplankton (eq 7), larval fish (eq 8) and zooplankton (eq 9), some general trends are clear. First of all, the impact of LEAPS will be more pronounced when the lake is at a comparatively low volume, that is, when the relative pumping rate is high. Secondly, the impacts from pumped-storage operation will be larger for the higher trophic level organisms whose reproduction rate is slow compared to the relative pumping rate; thus, bacteria and phytoplankton, with rapid doubling times, will be minimally affected by plant operation, while zooplankton will be impacted to an intermediate degree and, other things being equal, fish will be impacted to the largest degree. Thirdly, careful design of the inlet/outlet, combined with judicious operational scheduling and implementation of other strategies to reduce entrainment can help minimize any negative ecological impacts from LEAPS operation.

(c) Effects of LEAPS on the establishment and maintenance of aquatic macrophytes in the lake.

One of the goals of the restoration plan for Lake Elsinore is to stabilize the lake level and foster the growth of aquatic macrophytes. Macrophytes provide shelter for zooplankton and ichthyoplankton, serve as habitat for sport fish, and compete with phytoplankton for light and nutrients (Moss, 1998). There will be a significant financial incentive to maintain the lake level within the previously identified operational range of 1240-1247 ft above MSL, and so the >20 ft oscillations in surface elevation seen over the past decade (1233.5 to over 1255 ft) are expected to be diminished. The potential for revenue from power generation should help ensure that the low lake levels witnessed in 2002-2004 do not recur, so on that basis, LEAPS should be considered to have a positive effect on the lake. Of course, lake level variations need to be controlled more carefully than simply to fall within 1240-1247 ft range to enhance macrophyte development within the littoral zone. Since lake level fluctuations of 1.0 – 1.7 ft are anticipated during LEAPS operation, the shallowest waters near the shoreline will be regularly exposed and then rewetted. This level of daily shoreline migration is not expected to limit overall colonization and growth of aquatic macrophytes in the lake, however, since these near-shore waters over much of the lake will be subjected to regular wind mixing, turbulence and sediment resuspension. These natural processes would limit macrophyte growth in this high energy region anyway. Regions of the lake that receive lower wind energy inputs, such as the southern embayments, should be able to foster some emergent macrophytes, even with daily drawdown and rewetting, since they can inhabit both submerged sediments as well as saturated soils. Rather, the major limiting factors to establishment of aquatic macrophytes in Lake Elsinore will more likely be the overall turbidity of the water column, and the larger annual variations in lake surface elevation that can exceed 3-4 ft.

As previously discussed, LEAPS operation may increase turbidity in the lake directly through sediment resuspension and indirectly through additional inputs of nutrients. The contributions of LEAPS to the overall turbidity in the lake are not entirely clear although, as noted, it is expected that, longer-term, the sediments would come into equilibrium with the kinetic energy inputs from operation of LEAPS. Reductions in the annual variation of lake level through flow augmentation to the lake should improve the prospects for establishing an aquatic macrophyte community in the lake.

## Additional Studies

While this analysis identified both positive as well as negative impacts from operation of LEAPS, several key studies are still needed to better quantify water quality impacts, reduce uncertainty in predicted effects, and improve the design and operation of LEAPS.

First of all, heat calculations should be made for the upper storage reservoir and for Lake Elsinore. As indicated by Prof. Horne (2005), one would like the water that is returned to the lake during generation to be cooler and more dense that the lake water, resulting in an underflow condition that will help keep the relatively well-aerated water moving above the sediment-water interface (assuming that the shear force is not so large that it results in extensive sediment resuspension). Pumping will heat the water, however, so temperature of the water as it is pumped into upper reservoir should initially be warmer than that at the lower withdrawal depths of the lake; greater convective cooling at the higher elevation may subsequently lower the water temperature. Turbination during the generation phase will also heat the water, however, so it is unclear whether the water discharged to the lake will be warmer, cooler or at the same temperature as that in the lake. The temperature of the released water will dictate where the resulting jet inserts into the water column (Martin and McCutcheon, 1999). If the temperature of the water released to the lake were warmer than the surface waters, an overflow condition would result, although since water would be released during the day when strong surface heating occurs, this seems unlikely. The heating from the pumping and generation phases may be sufficient to create an interflow condition, however, with the water released during generation being intermediate in temperature and thus inserting into a neutrally buoyant position within the water column (Martin and McCutcheon (1999). Thus, the balance of heat inputs from pumping and generation, and heat loss due to nighttime convective cooling, needs to be determined.

While the heat calculations can be made using relatively simple analytical expressions, there exists a very strong need for development and application of a 3-D hydrodynamic model for the lake. A 3-D hydrodynamic model will be able to predict velocity fields near the intake/outlet, quantify shear stress at the sediment-water interface and thus resuspension effects, assess impacts of operation on thermal stratification and DO levels (including overflow, interflow and underflow conditions), and predict turbulent kinetic energy inputs, mixing and circulation. Moreover, it is my view that hydrodynamic simulations should be used as part of the design process for the intake/outlet structure.

Finally, there is also a need for an ecological model to better understand the trophic cascades that may result from LEAPS operation. For example, in the above analyses, phytoplankton, zooplankton and fish were all treated as isolated sets of organisms whose populations were assumed to be controlled by their respective reproduction rates, the lake’s carrying capacities for these organisms, and rates of entrainment and mortality from pumping. In reality, of course, the dynamics of these organisms are all coupled to each other in a complex way through the food web in the lake. Development and application of an ecological model would allow one to quantify, for example, how enhanced nutrient levels, reduced transparency and loss of zooplankton through entrainment affects phytoplankton levels in Lake Elsinore.

## Summary

Installation and operation of the proposed pumped-storage hydroelectric plant at Lake Elsinore is expected to have a number of impacts on its limnology and water quality. Substantial turbulent kinetic energy will be input into the water column through the operation of LEAPS, with calculations indicating energy inputs during generation that exceed natural wind-forcing by a factor of approximately 2.9. This additional energy input is expected to substantially weaken or eliminate the periodic thermal stratification present in the lake, thereby assisting the axial flow pumps in achieving a well-mixed condition in Lake Elsinore. The increased mixing will also help distribute DO throughout the water column and should improve the redox status near the sediments. Depending upon productivity levels in the lake, sufficient DO may be present to satisfy the oxygen demand of the surficial sediments and promote formation of a sorptive $Fe(OH)_3$ layer that will slow the rate of $PO_4$-P release. The additional mechanical energy inputs during pumping and generation do, however, also have the potential to resuspend bottom sediments and increase turbidity, total and dissolved nutrient concentrations, and contaminant levels in the water column. Sediment resuspension may also increase oxygen demand and *lower* DO levels, especially during construction, testing and early operation. That is, short-term negative effects are expected during initial testing and operation of the facility, although the persistence of these effects are difficult to judge without detailed hydrodynamic modeling. It appears likely that the longer-term effects will overall be modest, with the bottom sediments coming into relative equilibrium with the new (higher) energy environment there. Thus chronic, severe sediment resuspension and the attendant water quality problems seem somewhat unlikely.

Lake level variation of 1 – 1.7 ft over a pump/generation cycle is estimated to expose 49 – 134 acres depending upon the hypsographic data set used; sediment exposure will be most extensive in the shallow embayments in the southern part of the lake. Shoreline migration is expected to be modest (8 – 20 ft) over much of the lake, although daily shoreline migration will be larger in the southern embayments. In addition to the physical and chemical impacts from

LEAPS operation, there will also be biological/ecological impacts. Pumping between 3.9 and 13.9% of the lake volume each day (at the nominal maximum and minimum lake operating levels, respectively) will result in entrainment of significant numbers of organisms. Of particular concern is the entrainment and mortality of zooplankton and fish.

Model calculations suggest that ichthyoplankton (larval fish) levels could be reduced by LEAPS operation from 40 – 100% depending upon the lake level, assuming that the plant ran through spawning season and did not include any mitigation measures to reduce entrainment. With installation of a filter curtain that reduced entrainment by 80%, the calculated loss of larval fish through LEAPS operation decreases to 8 – 29% (assuming that widespread larval fish mortality does not occur through entrapment in the filter, nor during periodic pulsed air-pressure cleaning, or from increased predation near the curtain). The use of a filter curtain would also keep juvenile and adult fish from becoming entrained; the mortality rate is 2-4x higher for juvenile and adult fish than larval forms. The entrainment of larval fish could be used to advantage, however, if LEAPS operation (without the filter curtain) was coordinated with the carp spawn. This could offer a more efficient way to control the carp population in the lake than current netting efforts.

Entrainment of zooplankton is also a concern, since zooplankton, especially *Daphnia*, can exert strong grazing pressure on phytoplankton that can keep algal levels in check; high levels of mortality within the entrained zooplankton population would lower grazing pressure and result in elevated algal levels in the lake. Calculations made assuming 100% mortality of entrained organisms indicate that LEAPS operation could lower zooplankton populations by as much as 7.0 – 24.8% depending upon the volume of the lake. With either a lowered mortality rate of one-half for the entrained organisms during pumping/generation, or assuming the filter curtain reduces the pumped concentration by one-half, steady-state zooplankton populations were calculated to decline less (predicted reductions of 3.5 – 12.4 %). The use of the filter curtain could thus lower the amount of entrainment and also reduce loss of zooplankton (subject to the previous assumptions about limited mortality at the filter curtain due to entanglement, mortality during pulsed air cleaning of the filter, and no increased predation there). Pumped-storage was not predicted to alter phytoplankton populations however (1.1 – 4.0 % reduction). The LEAPS project could enhance the development of an aquatic macrophyte community in the lake by providing greater long-term stability to the lake level. The comparatively modest daily variations in lake level that result from pumping and generation are not thought to represent a serious limitation to the development of a healthy littoral zone assuming that nutrient concentrations and algal and non-algal turbidity levels are low.

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# EFFECTS OF LEAPS OPERATION ON LAKE ELSINORE:
# PREDICTIONS FROM 3-D HYDRODYNAMIC MODELING

DRAFT FINAL REPORT

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23 April 2007

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## Executive Summary

Three-dimensional hydrodynamic simulations were conducted using the Environmental Fluid Dynamics Code (EFDC) to evaluate the effects of operation of the proposed Lake Elsinore Advanced Pumped Storage project (LEAPS) on stratification, mixing and sediment resuspension in Lake Elsinore. A Cartesian 100 m x 100 m computational grid was constructed from available bathymetric data that yielded 1402 horizontal water cells. The vertical dimension was represented with an 8-layer sigma vertical coordinate system. The model was calibrated using available meteorological and water column data from the March – September 2006 period. This period was chosen because the lake level was approximately 1247', the proposed upper operating elevation of LEAPS. The model reasonably reproduced observed temperature profiles in the lake when the evaporative and convective heat flux constants were increased from default values of 1.5 to 2.0. The model also adequately reproduced temperature and velocity measurements made in the southwest corner of the lake. The model was then validated using data collected in 2001; this period was chosen for model validation-verification since the lake was much lower than the level during calibration (1241.5'), water column temperature profile measurements were available on 30-min intervals, and this lake level approached the nominal minimum operating level of 1240'. The model adequately reproduced observed temperature conditions, with 0.9% average error between predicted and observed bottom temperatures and 4.9% average error in surface temperatures.

Following grid development and model calibration and validation, LEAPS operation was incorporated into the model. LEAPS operation was assumed to proceed 5 days a week throughout the year, with flows during pumping and generation of 86.3 and 64.7 $m^3/s$, respectively. Supplemental flows sufficient to maintain the lake level at approximately 1247' and 1240' were also provided. The preliminary intake specifications provided by Nevada Hydro included a 150 m wide shore-mounted structure with a bottom intake channel at 1220'. Simulations were conducted in which the intake was located at the Santa Rosa and Ortega Oaks sites on the west site of the lake. The effect of narrowed gate and slot widths were included in the assessment to evaluate selective withdrawal and delivery.

Model simulations demonstrated regular variations in the lake surface elevation associated with pumping and generation. Pumping that commenced at the end of the day Friday lowered the predicted lake level by a predicted 1.6 ft, before generation during the weekdays incrementally increased the lake level by 0.8 ft while pumping subsequently decreased the lake level by about 0.6 ft per day, for a net daily increase of approximately 0.2 m/d during the week.

Velocities near the intake varied vertically and with increasing distance from the intake as a function of LEAPS operation, intake configuration and lake surface elevation. LEAPS operated near the nominal maximum operational surface elevation of 1247' yielded predicted velocities during generation near the intake averaged about 3.9 cm/s at the Santa Rosa site and 4.1 cm/s at the Ortega Oaks site. Somewhat higher velocities were predicted near the intake during pumping (5.2 - 5.3 cm/s). Predicted velocities were slower near the sediments than higher in the water column due to frictional losses at the sediment-water interface. Velocities also generally increased out about 100 - 140 m from the intake as flows were forced over a shallow sill formed from excavation and construction of the intake structure. Velocities slowed at greater distances from the intake, with little effect of LEAPS on velocities found beyond 500 – 600 m from the intake. Velocities exerted a shear force on the bottom sediment, although the magnitude of the bottom shear near the intake (on the order of 0.01 – 0.02 N $m^{-2}$) was well below the critical threshold for resuspension of 0.1 N $m^{-2}$. As a result, LEAPS operation at 1247' was not predicted to induce significant sediment resuspension. The additional turbulent kinetic energy inputs to the lake from pumping-generation were also predicted to have only small impact on stratification and mixing in the lake. LEAPS operation at the Santa Rosa site lowered the thermal gradient ($\Delta T$) between surface and bottom waters by about 1.2 ºC in late May, reduced the number of days where the lake was at least weakly stratified ($\Delta T>1$ ºC at 6 a.m.) by 11 (from 121 to 110 days over the course of the simulation year), but overall had no substantive impact on stratification in the lake. Operation at the Ortega Oaks site had even less of an effect (e.g., lowering $\Delta T$ in late May by <0.5 ºC and reducing the number of days where $\Delta T$ exceeded 1 ºC by 5 days). The number of days in the simulation year with strong stratification ($\Delta T>3$ ºC) was minimally affected (51 days under natural conditions vs. 48 and 51 days for LEAPS operation at the Santa Rosa and Ortega Oaks sites, respectively).

Velocities and bottom shear production near the intake increased at the nominal minimum operational lake level of 1240', although predicted bottom shear remained below the critical value for resuspension. The lower lake level (without LEAPS operation) reduced the number of days of strong stratification from 51 at 1247' to 38 days at 1240'; thus, declining lake level had more dramatic of an effect than LEAPS operation at 1247', where 48 and 51 days of strong stratification were predicted for the Santa Rosa and Ortega Oaks sites. The average duration of stratification was also reduced, from 8.5 days at 1247’ to 6.3 days at 1240’. LEAPS operation at 1240’ lowered the number of days of strong stratification from 38 (without LEAPS) to 33 and 35 days for the 2 intakes, although no effect on the average duration of stratification was predicted. Thus, even at this lower lake level, LEAPS was not found to alter, in either beneficial or negative ways, water column properties in the lake when the full cross-sectional area of intake conveyed flow.

Additional simulations were also conducted at 1247’ to evaluate the potential for selective withdrawal-return to alter water column properties. The selective withdrawal of water during pumping, combined with the focusing of return flows during generation, may weaken stratification and help maintain oxic conditions near the sediments more effectively than using the full cross-sectional area of the intake for flow. Simulations found no significant effect of selective withdrawal-return through 1-m wide slot widths on stratification and mixing, while bottom release created areas of locally high bottom shear that ranged from 6 - 20 acres in size. The effect was quite dramatic as intake gate widths were narrowed from 150 m to 10 m, with local predicted suspended solids concentrations potentially exceeding 5000 mg/L for a 10 m x 1 m gate dimension at the Ortega Oaks site. The high level of local suspended solids would neither be chronic nor greatly affect lakewide suspended solids concentrations, however.

In summary then, the EFDC model predicted only small effects of LEAPS operation on water column properties in Lake Elsinore. This is thought to be the result of 2 factors. Most importantly, the proposed shore-based intake (at either site) is located a substantial distance from deep water, and is separated by a shallow sill that is approximately 2.7 – 5 m deep depending upon lake elevation. The local bottom topography near the intake thus limits efficient momentum flux to the deeper regions of the lake, and instead promotes local turbulence and short-circuiting of flow. Counter-current flow was in fact predicted under all selective withdrawal-return intake configurations. Moreover, this sill constrains the pumping of water from the warmer, upper portion of the water column. The 2nd factor thought to influence predicted results stems from the small net effect on water temperature of pumping, storage and generation (Anderson, 2006b). That is, the water is withdrawn and returned at comparable temperatures and densities so that buoyant forces are not expected to help focus flows to either surface and bottom depths in the lake.

## 1.0 Introduction

Operation of the Lake Elsinore Advanced Pumped Storage project (LEAPS) will result in significant volumes of water being transferred between the upper storage reservoir and Lake Elsinore on a daily basis during active pumping and generation. Previous calculations suggested that 3.9 – 13.9 % of the lake volume would be pumped each day at the nominal maximum and minimum operating levels of 1247' and 1240', respectively (Anderson, 2006a). The physical effects of this include regular exposure and inundation of shoreline sediments and potential for resuspension of bottom sediments, as well as changes in stratification and mixing (Anderson, 2006a). Sediment resuspension and alteration of stratification and mixing have been reported in some pumped-storage reservoirs (USBR, 1993; Potter et al., 1982).

Sediment resuspension is important since it can hasten the release of nutrients, increase oxygen demand in the water column, lower transparency, and alter the productivity and ecology of the lake. Enhanced turbulent kinetic energy inputs associated with LEAPS operation may also weaken stratification and enhance dissolved oxygen (DO) levels in the lake (Anderson, 2006a).

To better understand these potentially critical effects of LEAPS operation on the water column properties of Lake Elsinore, a 3-dimensional (3-D) hydrodynamic modeling study was undertaken. For this assessment, the Environmental Fluid Dynamics Code (EFDC) originally developed by Hamrick (1992) was used. The EFDC model has been used in over a hundred TMDL studies across the country and is included in the USEPA's TMDL Modeling Toolbox (USEPA, 2007).

## 2.0 EFDC Model

The EFDC model solves the 3-D, vertically hydrostatic, free surface, turbulent averaged equations of motion for a variable density fluid. The model uses a sigma (stretched) vertical coordinate system with a Cartesian or curvilinear horizontal coordinate grid.

For this study, a Cartesian 100 m x 100 m computational grid was constructed from available bathymetric data that yielded 1402 water cells (Fig. 1). The vertical dimension was represented with an 8-layer sigma vertical coordinate system (that is, each cell was divided into 8 horizontal layers irrespective of cell depth).

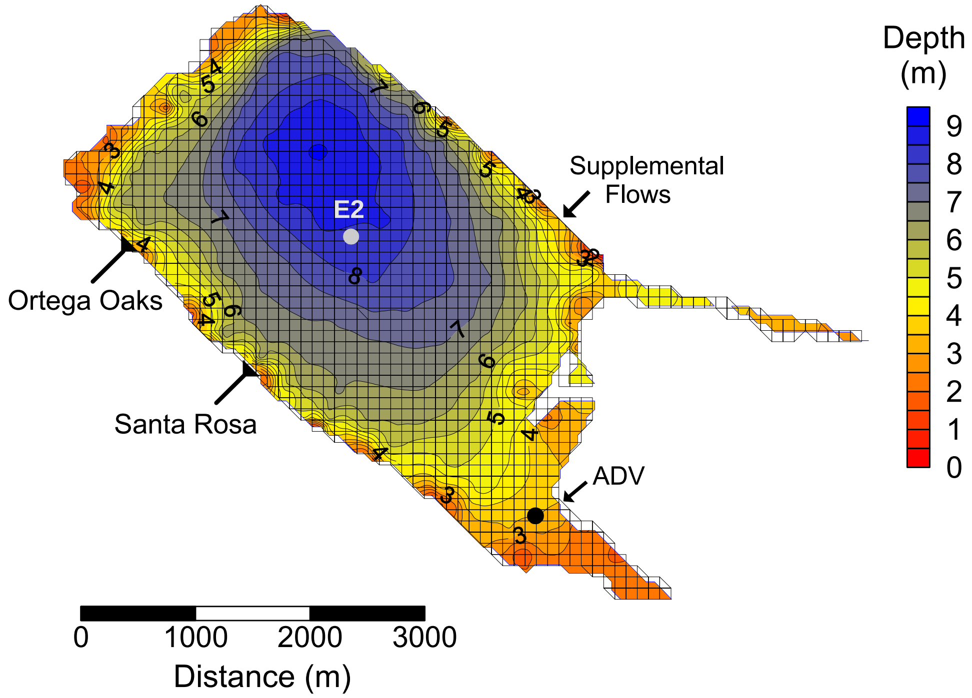

*Fig. 1. Lake computational grid consisting of 1402 horizontal water cells and 8 vertical layers (not shown in this view). The bathymetry of the lake was developed from 293 depth soundings made in 16 transects across the lake in October 2006 and corrected to 1247' surface elevation. Site E2 is the water quality sampling station used for model calibration; the ADV site refers to the location of ADV velocity measurements made in August 2006.*

The two proposed locations for the intake/outlet structure (referred to subsequently simply as the intake) for LEAPS was provided by Nevada Hydro. The two proposed sites for the intake are both located on the west side of the lake, with the Ortega Oaks site located in the north end of the lake, while the Santa Rosa site is near the middle of the western shore (Fig. 1).

## 2.1 Model Calibration

Following development of the computational grid, meteorological data were assembled and used with available water column data to calibrate the model. The period from March 1 – September 2006 was selected for model calibration since it represented at that time the current lake condition, was very close to the proposed upper operating range of LEAPS (1247'), and monitoring data (including temperature and velocity measurements) were available (Lawson and Anderson, 2006).

Air temperature, wind speed and wind direction data from a weather station a short distance away from the lake were provided by Elsinore Valley Municipal Water

District (EVMWD). Relative humidity, rainfall and solar radiation was taken from the California Irrigation Management Information System (CIMIS) meteorological station at UCR. Hourly data were used. Strong seasonal and diurnal changes in air temperature were observed (Fig. 2a). Marked diurnal variation in solar flux and wind speed were also observed (Fig. 2b,c).

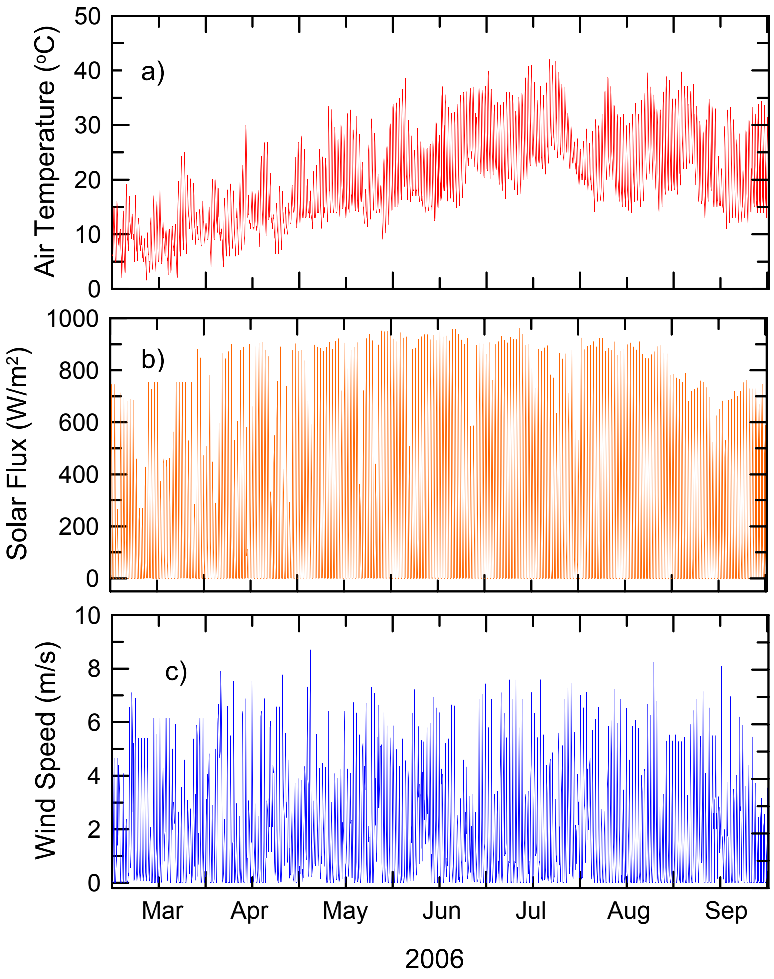

*Fig. 2. Meteorological conditions used in the model calibration: a) air temperature, b) solar flux and c) wind speed.*

With appropriate meteorological data to drive the model, the only water column property that also needed to be specified was the light attenuation coefficient; this coefficient was calculated from the average Secchi depth measured at the lake ($Z_{SD}$=1.2 m). Default values were used for all other parameters as specified in the model or taken from a recent study of Lake Okeechobee (Jin et al., 2000). A 1-minute timestep was used in the model calibration process.

Using the default values, the model over-predicted daytime surface temperatures by 2 – 3 ºC through much of the summer and under-predicted evaporative losses (data not shown). This suggested that the evaporative (and thus also convective) heat flux constants were too low. These two constants, which have the same numerical value in most applications, were thus varied to calibrate the model. Reasonable agreement between predicted (lines) and observed water column temperatures (symbols) was achieved when these two constants were increased from values of 1.5 to 2.0 (Fig. 3). The model captured the seasonal trend of strong heating of the both the surface and bottom waters beginning in the spring, predicting stratification over the period from May – June (with mixing events not captured in the biweekly field sampling) and mixing of the water column at the end of July (Fig. 3).

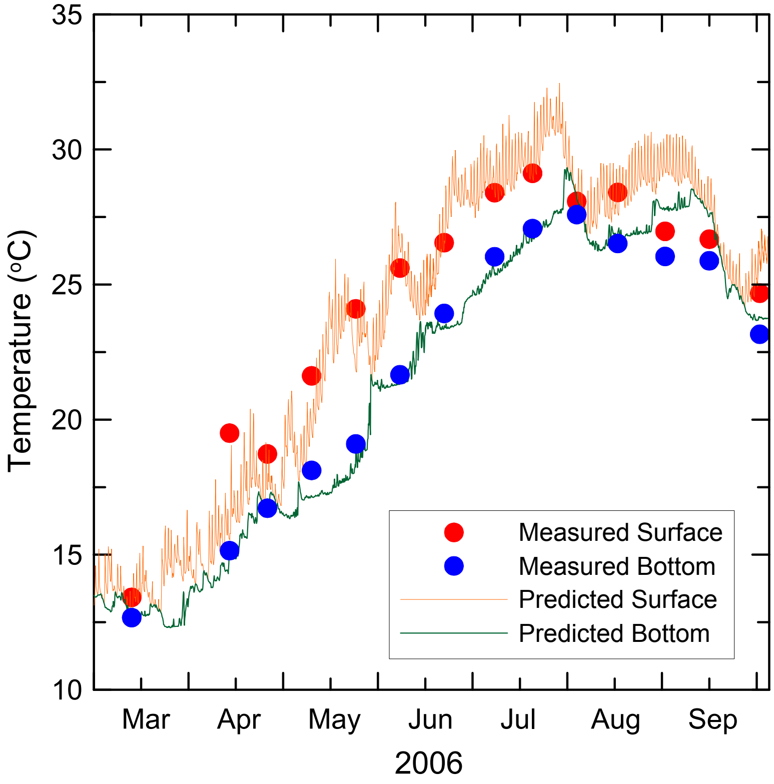

*Fig. 3. Predicted and observed surface and bottom water temperatures at site E2 near the center of the lake (Fig. 1).*

The model did over-predict temperatures in late August compared with observed surface and bottom temperatures, but reasonably reproduced temperatures in September (Fig. 3). The model also reasonably reproduced observed temperature profiles at the main lake sampling station on most dates (e.g., Fig. 4). For example, the model quite accurately captured the temperature profiles measured on April 25th and May 23rd, including the late morning surface temperatures and diurnal thermocline that is typically present in the uppermost 1 m, as well as the thermocline that was present at 7-8 m depth (Fig. 4). While the model generally predicted temperature profiles in very good agreement with measured profiles, the model did over-predict temperatures in the upper 6 m of the water column on July 18th, although the predicted trend in temperature was similar to that observed (Fig. 4, Jul 18). The model also correctly predicted isothermal conditions on August 1st, and was within about 0.4 ºC of the measured values.

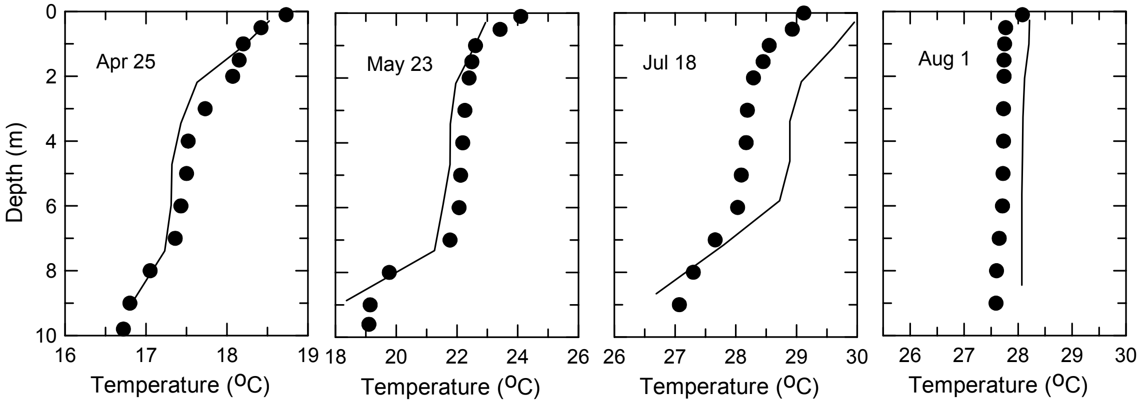

*Fig. 4. Predicted (lines) and observed temperature profiles (circles) at site E2 near the center of the lake (Fig.1).*

Measurements of bottom temperatures and water velocities made in the latter part of July in the shallow embayment in the southwest corner of the lake (Fig. 1, ADV site) were also used to assess the capacity of the model to reproduce conditions away from the central portion of the lake. This represents a rigorous test of the model since it includes both temperature and water velocities measured every 30 min in a shallow embayment that is subject to convective currents due to differential heating as well as advective currents which result from strong afternoon winds that blow from the northwest and into this embayment. The model predicted temperatures of 29-30 ºC about 50 cm off of the bottom sediments, in good agreement with measured values (Fig. 5a, red line), especially when one recognizes that the initial conditions were specified almost 150 days prior. The acoustic Doppler velocimeter (ADV) recorded temperature (and velocity) every 30 min and thus allows a comparison of the diurnal variations in these properties with those predicted by the model (Fig. 5, inset). As one can see, the model also reasonably reproduced the diurnal trends in temperature, increasing sharply in the afternoons of July 26-28 while being rather muted on July 25th (Fig. 5, inset). The model did underpredict the magnitude of these diurnal spikes in temperature associated with the downward mixing of warm surface layers due to the afternoon winds, but over this interval the average predicted temperature of 29.62 ºC was only 0.62 ºC higher that the average measured value of 28.98 ºC (2.2 % error). The observed differences may be due in part to the slightly different depths for the measured and predicted values (approximately 50 cm and 25 cm off of the bottom, respectively).

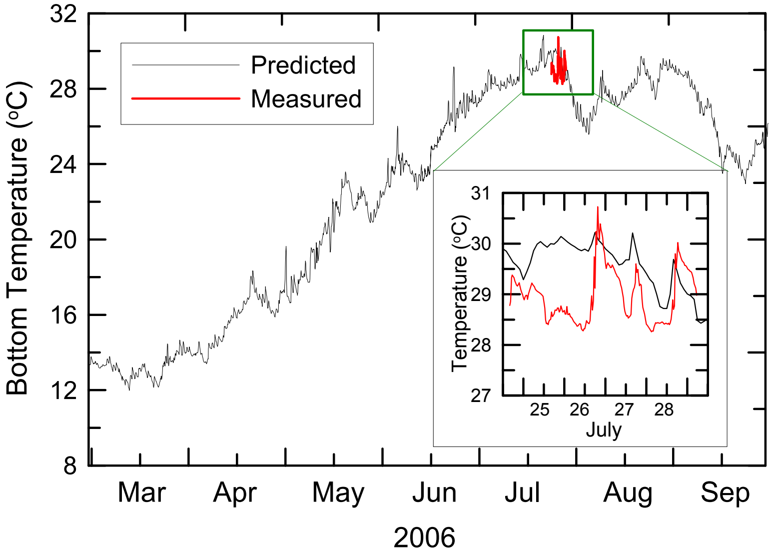

*Fig. 5. Predicted and observed bottom water temperatures at the ADV site in the southwest corner of the lake (Fig. 1).*

The ADV measures both the east and north components of the horizontal water velocity vectors and allows for ready comparison with the predicted velocity vectors from the EFDC model (Fig. 6). Negative values refer to components of the velocity vectors in the opposite direction (i.e., in the west and south directions). Measured velocities exhibited strong swings in direction and magnitude, with currents above the sediments and near the mouth of the embayment directed in the southerly and westerly directions in the afternoon, and moving somewhat slower and to the north and east later in the day (Fig. 6). The model captured these swings in velocities reasonably well, but predicted quite a bit lower velocity magnitudes (Fig. 6). The disagreement in the magnitudes of velocity may also be a product of slightly different depths between that measured and predicted, especially since velocities can decrease exponentially near a surface.

Notwithstanding, this is considered to be adequate agreement between measured and predicted velocities given the rigor of this test.

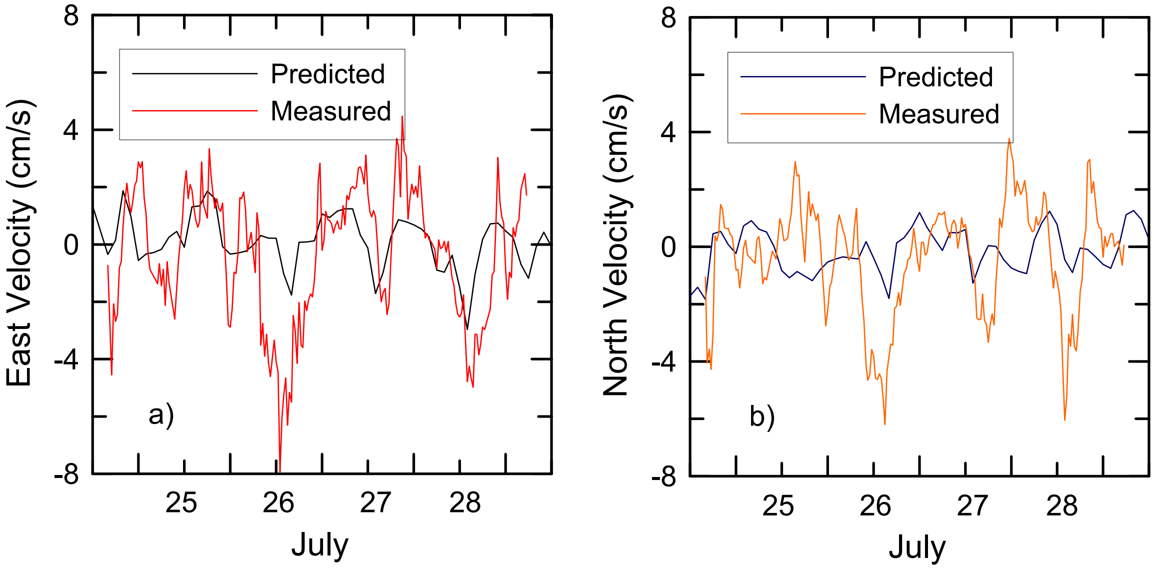

*Fig. 6. Predicted and observed bottom water velocities at the ADV site (Fig. 1): a) east component of the velocity vector and b) north component of the velocity vector.*

## 2.2 Model Verification

Following the model development and calibration described above, the next step was to verify the model using an independent data set. For model verification, a very different lake condition was selected. Specifically, 2001 was chosen since it represented a much lower lake level than that used for calibration (approximately 1241.5' lake surface elevation) and since a fairly extensive set of water column profile measurements were made (Anderson, 2001). The grid developed for 1247' was used as the starting condition for the lake on January 1. The lake was quickly brought down to approximately 1241.5' by withdrawing water from the lake at a rate of 51 $m^3/s$ over the next 7 days. The model was run through Julian day 180 (June 29th) for comparison with available temperature profiles. A 4-second timestep was necessary for this simulation due to the rapid drying of shallow regions of the lake.

All meteorological data were taken from a weather station deployed at the lake (rainfall, air temperature, relative humidity, wind speed, and wind direction) except solar radiation, which was taken from the CIMIS station at UCR as done in the model calibration phase described above. Simulations results were compared with high resolution water column temperature data collected in May-June 2001 using 10 Onset temperature loggers deployed from 0.3 – 7.3 m depth near site E2.

Temperature loggers revealed an interval of strong stratification in early May that weakened through the month (Fig. 7a). The water column then mixed and warmed to approximately 26 ºC in late June. Daytime surface temperatures often exceeded 28 ºC (Fig. 7a).

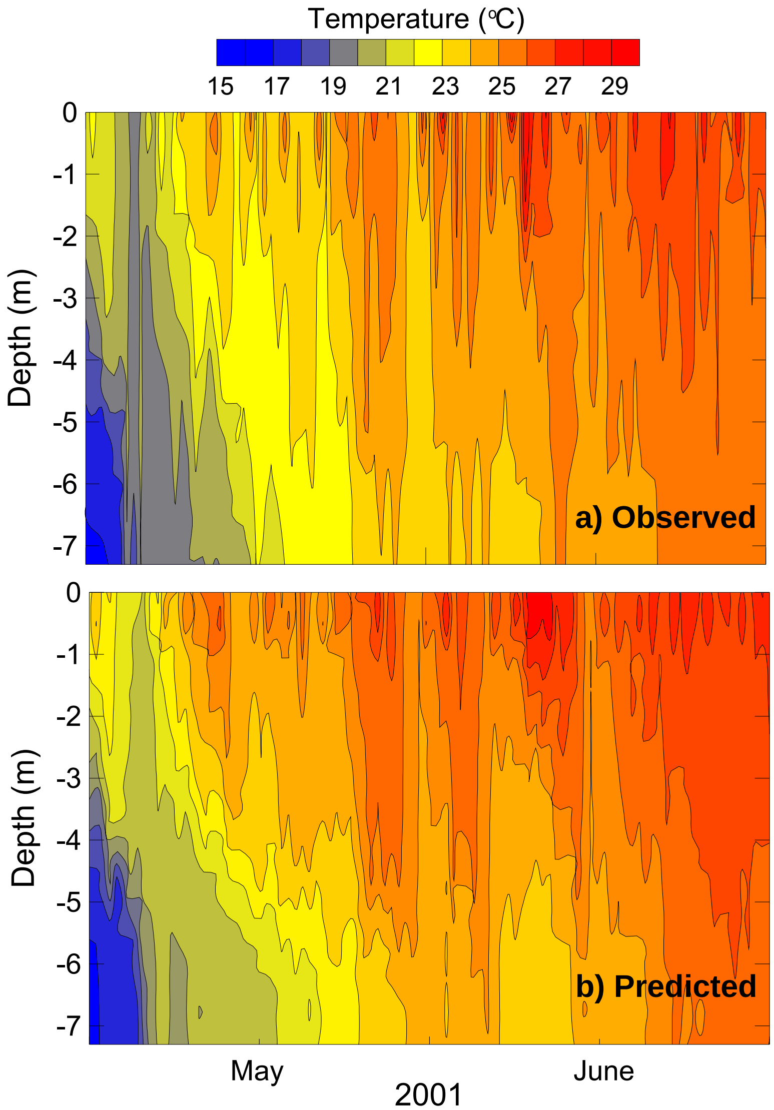

*Fig. 7. Water column temperatures at site E2: a) observed and b) predicted temperature profiles over time.*

The model reproduced quite satisfactorily the major features found in the measured temperature profiles during this period (Fig. 7b). That is, it predicted stratification in early May, with cool (~16 ºC) temperatures present below about 5 m depth that increased to about 20 ºC by mid-May (Fig. 7b). The model also predicted intervals of somewhat weaker, transient stratification later in May and into June and temperatures exceeding 26 ºC by late June.

Looking more carefully at the predicted and observed temperatures near the surface (about 0.3 m depth) and bottom (about 7 m depth), one sees that the model reasonably predicted the strong diurnal trends in surface temperatures as well as longer term trends, although slightly over-predicted their absolute values (Fig. 8). The model yielded predicted bottom temperatures in fair agreement with measured values as well.

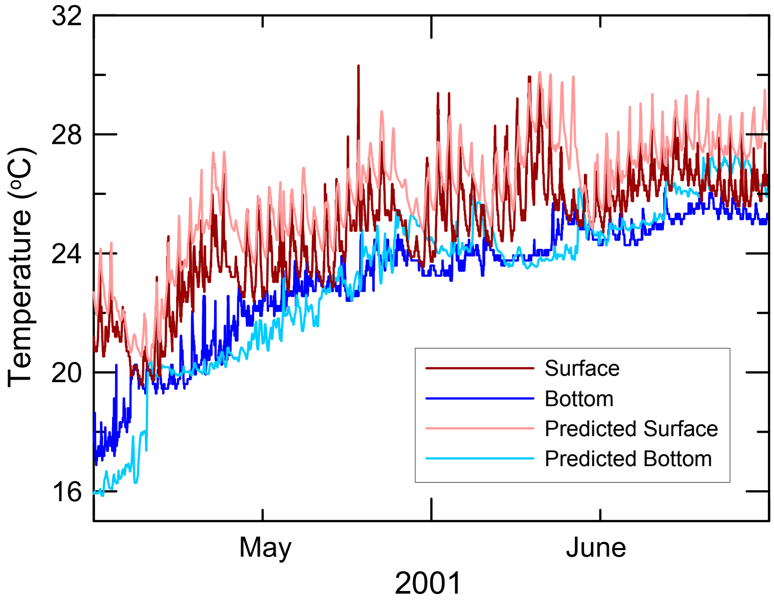

*Fig. 8. Predicted and observed surface and bottom water temperatures at site E2.*

The model did yield surface and bottom temperatures that consistently exceeded measured values (Table 1). The modeled surface temperature was on average 1.18 ºC warmer than the measured values, while somewhat better agreement was found between the predicted and measured bottom temperatures (Table 1). The relative % error ($T_{error}$/measured temperature) averaged about 5% and 1% for the surface and bottom temperatures, respectively (Table 1).

Table 1. Error analysis for model validation (data shown in Fig. 8).

| | Surface | Bottom |
|---|---|---|
| $T_{error}$ (ºC) (Pred-Obsd) | 1.18 ± 0.75 | 0.26 ± 0.79 |
| Relative Error (%) | 4.92 ± 3.09 | 0.94 ± .57 |

Based upon these findings, it may be that the evaporative and convective heat loss constants could be increased slightly higher to take a little more heat out of the surface of the lake. Notwithstanding, the overall very good agreement between predicted and observed temperatures for both 2001 (low lake level) and 2006 (high lake level), as well as the adequate agreement with water velocity measurements made in 2006, indicates that the model should provide accurate and valuable insights in the effects of LEAPS operation on the physical properties of Lake Elsinore.

## 3.0 LEAPS Simulations

Simulations were conducted to represent a number of different design and operational scenarios. Two different sites (Fig. 1), and 2 different lake surface elevations (1247' and 1240' were evaluated. The Santa Rosa site has emerged as the preferred site, although simulations were also conducted for the Ortega Oaks site to explore the effect of intake location on lake circulation and mixing. The details of the intake structure are expected to have a potentially substantial effect on water column properties during operation. As a result, 4 different configurations were evaluated. In the 1st configuration, the full wetted cross-sectional area of the proposed 150 m wide intake structure was assumed to provide flow during pumping and generation. Alternative scenarios were also investigated in which the intake dimensions were varied from 150 m wide to gate widths of 40 and 10 m. Horne (2005) suggested that the elevation of intake and discharge may also be used to advantage, e.g., to preferentially entrain buoyant blue-green algae and also enhance DO conditions near the bottom sediments. As a result, the effect of discharge elevation was also investigated in some detail for the two sites.

Before these simulations were conducted, however, some additional information was added to the model

### 3.1 Flows

Two different sets of flows were added to the model. The first was supplemental water proposed to be added to help stabilize the lake level (Nevada Hydro, 2005). Water as added at the outlet channel previously used in a pilot project to help stabilize lake level with recycled water provided by EVMWD (Fig. 1). Based upon historical data about observed declines in lake level, supplemental water was added to the lake from April through November. Rainfall and runoff in amounts that are not known *a priori* make it difficult to forecast suitable supplemental flows during the winter, so no water was added from December – March (Fig. 9). Using predicted changes in lake surface elevation from previously described simulations, supplemental water was added at rates up to 1 $m^3/s$ (Fig. 9).

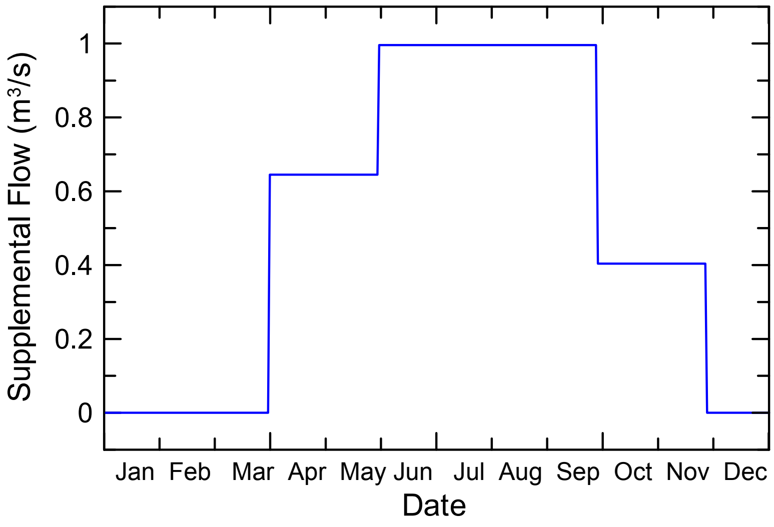

*Fig. 9. Supplemental flows to Lake Elsinore to maintain lake elevation.*

Flows associated with LEAPS operation were varied regularly, with 5 days of generation (Monday-Friday) on a schedule with 7 hours of pumping and 15 hours of generation per day during the week (Fig. 10). Pumping proceeded for 21 h on Saturday to restore the net drawdown that occurred during the week as a result of daily generation flows exceeding that of pumping. Operation was assumed throughout the year.

## 3.2 Intake Structure Design

Intake specifications were provided by Nevada Hydro (R. Wait, pers. comm.) and included:

- overall shore structure approximately 42 ft high x 500 ft long
- elevation of intake channel at 1220 ft
- bottom elevation of intake gate at 1223 ft
- excavation out approximately 200 ft from intake to recontour bottom to slope to 1220 ft and place rip rap

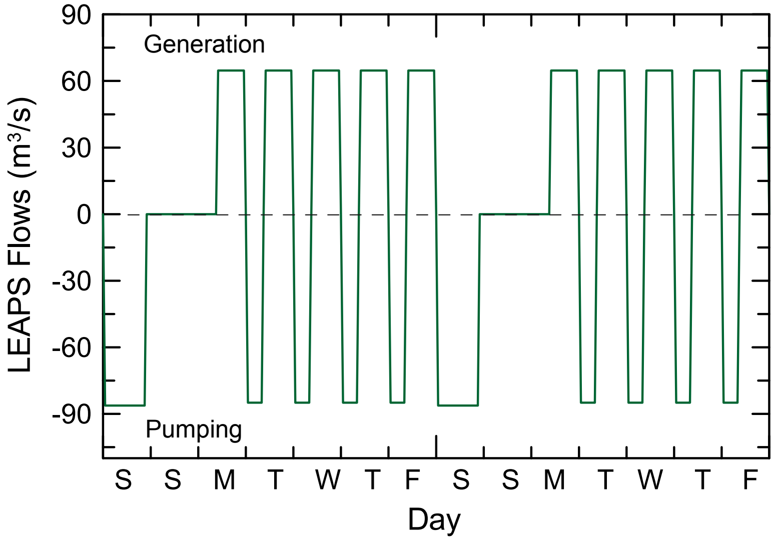

*Fig. 10. Withdrawal and return flows due to LEAPS operation. This weekly pumping schedule was applied through the year.*

The intake structure was placed at the existing 1240 ft bottom contour at the proposed Santa Rosa site (Fig. 1). Using available bathymetric data, it is proposed that the Santa Rosa site will look something like that shown in Fig. 11. The existing bottom contour out to 600 m perpendicular to the intake is shown, as well as the region that would require excavation (Fig. 11, shaded area). Based upon very limited depth soundings in this region, it appears that about 24,000 $m^3$ of sediment would have to be removed to complete this design. Detailed surveying in the region is needed to more accurately estimate excavation requirements and final bottom contours.

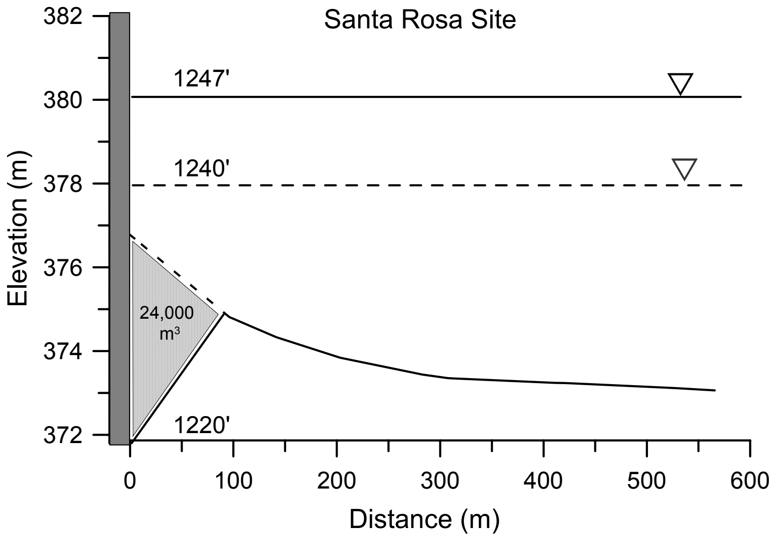

*Fig. 11. Approximate longitudinal cross-section near intake showing bottom contour and zone of sediment excavation: Santa Rosa site.*

Available bathymetric data and specific assumptions about placement of the intake suggest that the Ortega Oaks site (Fig. 1) is located in slightly shallower water, although the cross-section is very similar to that of the Santa Rosa site (Fig. 12). As a result, slightly more material would need to be excavated (an estimated 26,000 $m^3$).

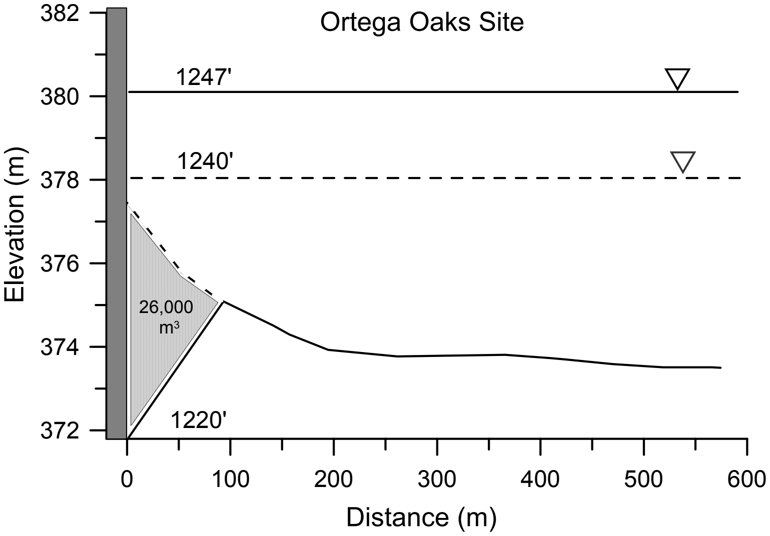

*Fig. 12. Approximate longitudinal cross-section near intake showing bottom contour and zone of sediment excavation: Ortega Oaks site.*

Flow at the intake structures was simulated using the standard river-type flow boundary condition for simulations assuming the full cross-sectional area of the structure delivers flow, while the withdrawal-return subroutine of the EFDC was used to simulate selective withdrawal and return flows at specific depths. Momentum flux was specified at the lake side of the intake structure following Hamrick (pers. comm.). For these latter simulations, withdrawal (pumping) removed water from the 4th layer (out of 8) for the 1247' scenarios, reflecting withdrawal through a 150 m x 1 m gate for the proposed intake design. To make the computational layers a comparable thickness at the intake at the 1240' surface elevation, 6 vertical layers with withdrawal at the 3rd layer (out of 6 total) were used. The effect of varying width of the intake-outlet structure was also evaluated (widths of 40 m and 10 m were used in these simulations).

## 4.0 Simulation Results

### 4.1 Lake Surface Elevation Changes During Operation

The pumping-generation scheme of LEAPS (Fig. 10) resulted in regular oscillation in the lake surface elevation (Fig. 13). The maximal lake elevation occurs at the end of the day Friday; the lake level then experiences its greatest daily decline as pumping through the day on Saturday was predicted to lower the lake level by 1.6 ft (Fig. 13), in good agreement with previous estimates of 1.7 ft (TNHC, 2004). Since no pumping was simulated for Sunday and early Monday, the lake level remained low until generation began near the start of the work day (Fig. 10). Generation through the day and into the early evening increased the lake level by about 0.8 ft, before pumping initiated at midnight began to lower the predicted lake level. Since daily volumes released during generation exceeded the amount of water pumped, lake levels increased incrementally each day through the week until, by the end of the day Friday, the cycle repeats (Fig. 13). While these results were predicted assuming a nominal lake level of 1247 ft, only modest differences would be expected at other lake levels (e.g., slightly greater daily and weekly oscillations in surface elevation).

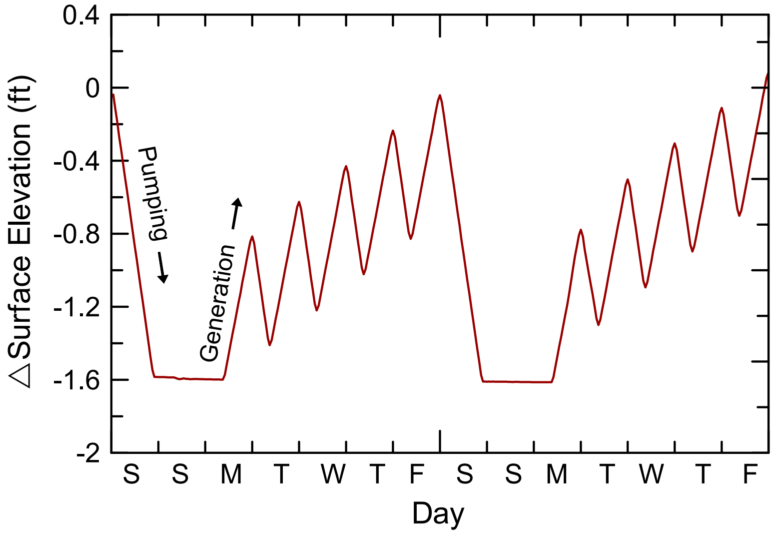

*Fig. 13. Predicted elevation changes for Lake Elsinore during LEAPS operation (assuming a nominal surface elevation of 1247 ft and the pumping routine depicted in Fig. 10).*

### 4.2 Velocities Near Intake

The pumping and generation phases of operation move significant volumes of water each day; plant operation can thus be expected to induce potentially strong currents near the intake. The velocity field perpendicular to the face of the intake varied depending upon phase (pumping or generation), as well as the cross-sectional area for flow, and depth of withdrawal and return flows. In this section, predicted velocities near the intake will be presented for the operational scenario where the full wetted cross-sectional area of the intake (Figs. 11 and 12) conveys flow. The effects of selective withdrawal will be discussed in section 4.5.

### *4.2.1 Predicted Velocities Near Intake at 1247 ft*

The EFDC model predicted a relatively uniform vertical velocity profile adjacent to the intake at the Santa Rosa site, although boundary layer effects slow the velocities above the sediments (Fig. 14). During pumping, an average velocity of 5.2 cm/s directed toward the intake was predicted near its face, with slightly higher velocities predicted closer to the surface (up to 6.2 cm/s at the uppermost simulation layer), and lower predicted velocities near the sediments (3.1 cm/s) (Fig. 14a). Velocities decayed at increasing distance from the intake, to a depth-averaged value of 3.7 cm/s at 140 m, 1.2 cm/s at 280 m and 0.6 cm/s about 420 m away (Fig. 14a).

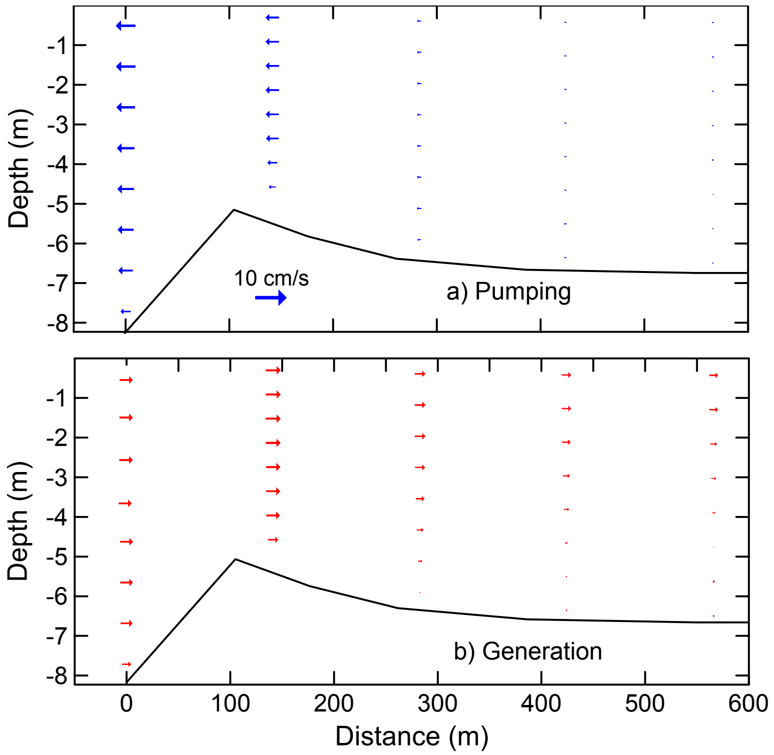

*Fig. 14. Predicted velocity field perpendicular to the intake at the Santa Rosa site at 1247': a) pumping and b) generation. Active intake dimensions 150 m x 8 m with reversible flow across the full wetted cross-sectional area of the intake. Note reference velocity scale in upper panel.*

The direction of flow reversed during generation, with lower velocities than found during generation, reflecting the lower volumetric flow rates during generation when compared with pumping (Fig. 10). Velocities were somewhat lower near the sediments than found closer to the lake surface (e.g., 2.76 cm/s in the lowest simulation layer compared with 4.18 cm/s 1.5 m below the surface near the intake) (Fig. 14b). Vertically-averaged velocities increased from 3.87 cm/s near the intake to 4.34 cm/s at 140 m due to the shallower depth there, and then declined to average values of 2.34, 1.54 and 1.09 cm/s at increasing distances (Fig. 14b).

For comparison, predicted velocities near the intake during periods of non-operation averaged approximately 0.2 cm/s during intervals of comparatively low winds, although velocities exceeding 1 cm/s are often present during the afternoon when strong winds are often found. Thus, the demonstrable effects of LEAPS operation on the local velocity field under this operational scenario are predicted to extend out about 500 - 600 m from the intake.

The effect of locating the intake at the Ortega Oaks site was also evaluated, with the same set of meteorological and hydrological conditions as used in the Santa Rosa simulations to drive the model. The Ortega Oaks site differed from the Santa Rosa site in its location relative to the center of the lake as well as its local bathymetry (Fig. 1). Specifically, the Ortega Oaks site is shallower both in its longitudinal profile away from the intake (Fig. 12), as well as laterally (Fig. 1). At any given distance away from the proposed intake, the Ortega Oaks site is 2-9 % shallower than the Santa Rosa site. These relatively modest differences in local bottom contours and position on the lake may nonetheless potentially alter the lake response to the operation of LEAPS.

Assuming the full wetted cross-sectional area of the intake is available for flow, the EFDC model predicted velocities during pumping that were rather slow in the deepest layers adjacent to the intake (2.93 cm/s) and increased towards the lake surface (to values of 6.21 cm/s). The velocities at all depths increased out approximately 140 m from the intake to values of 3.46-6.05 cm/s and then slowed quite substantially at greater distances (Fig. 15a). Slightly slower velocities directed away from the intake and into the lake were predicted at any give depth and distance from the intake during generation (e.g., 2.77 – 4.42 cm/s adjacent to the intake) (Fig. 15b), velocities that were slightly faster than found at the Santa Rosa site (Fig. 14b).

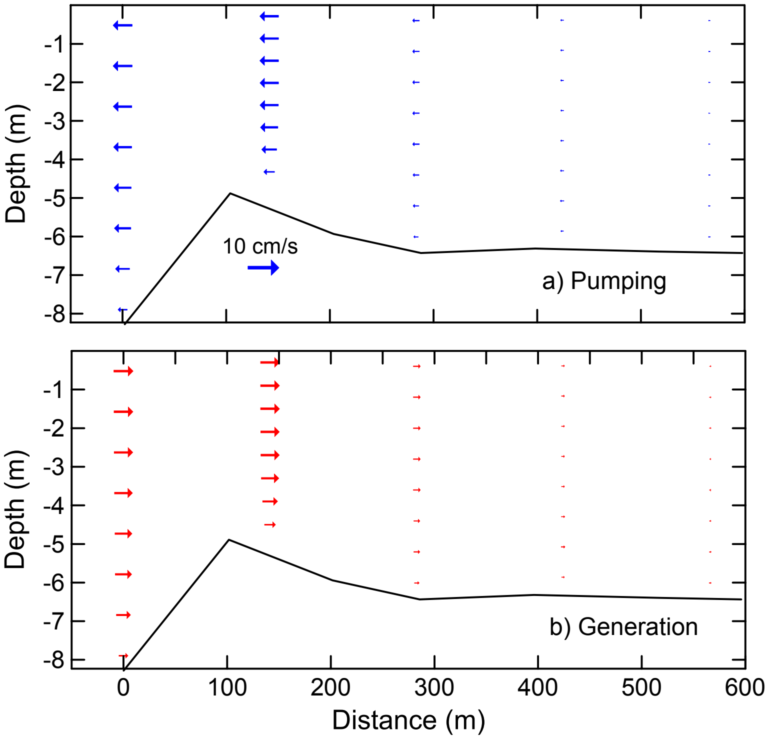

*Fig. 15. Predicted velocity field perpendicular to the intake at the Ortega Oaks site at 1247': a) pumping and b) generation. Active intake dimensions 150 m x 8 m with reversible flow across the full wetted cross-sectional area of the intake. Note reference velocity scale in upper panel.*

### *4.2.2 Predicted Velocities Near Intake at 1240 ft*

The lower lake level functionally reduces the intake cross-sectional area available for flow, so one would expect greater velocities under these conditions. The lowered lake level in fact had a significant effect on velocities near the intake (e.g., compare Fig. 16 with Fig. 14). Velocities adjacent to the intake at the Santa Rosa site during both pumping and generation (Fig. 16) were on average 1.45x higher than the velocities predicted during pumping when the lake level was at 1247' (Fig. 14). This increase is due in large measure to the smaller depth and thus lower cross-sectional area available for flow, although increased channeling of flow due to the lower depths of neighboring regions of the lake also appears to have increased flow velocities perpendicular to the face of the intake. This can be seen when one considers that, based only on cross-sectional areas, one would expect an increase of about 1.35x, while velocities adjacent to the intake increased by a larger amount, to 3-4 cm/s near the sediment and greater than 9 cm/s near the lake surface. High velocities were also present 140 m from the intake as flow was squeezed into a smaller depth, but declined at further distances as the water deepened (Fig. 16).

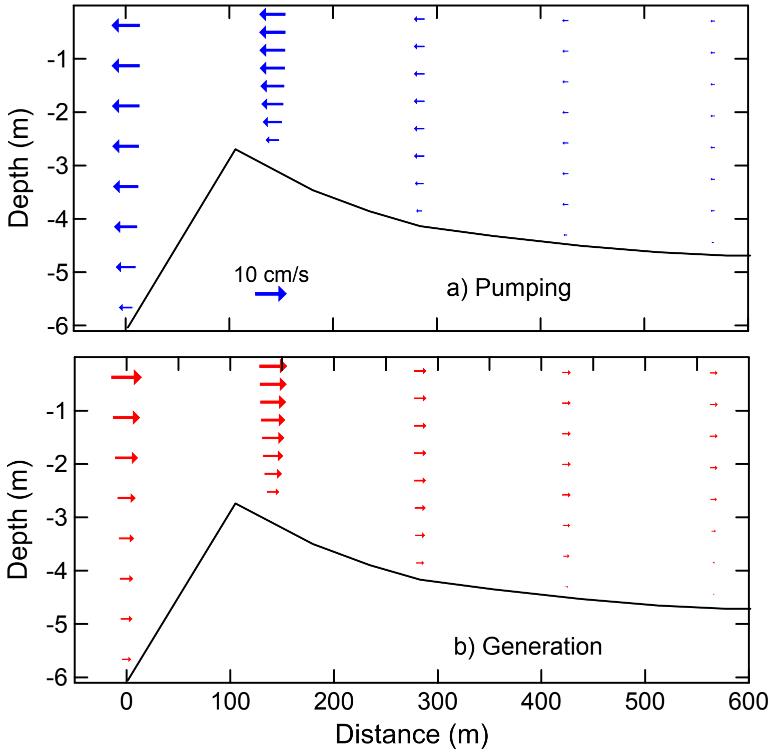

*Fig. 16. Predicted velocity field perpendicular to the intake at the Santa Rosa site at 1240': a) pumping and b) generation. Active intake dimensions 150 m x 6 m with reversible flow across the full wetted cross-sectional area of the intake. Note reference velocity scale in upper panel.*

The 1240' elevation had more pronounced of an effect on the predicted velocity profiles at the Ortega Oaks site than predicted for the 1247' surface elevation, especially 140 m from the intake where the velocities reached 13 cm/s during pumping and exceeded 11 cm/s during generation (Fig. 17). Higher velocities were also predicted at greater distances from the intake, and on average were 1.5x higher than observed at 1247'.

At an equivalent lake elevation of 1240', the two sites also differed in their relative velocities. The Ortega Oaks site yielded velocities that were, on average, 1.4x higher during pumping and 1.2x higher during generation than predicted for the Santa Rosa site.

Water velocities near the intake are important since they influence turbulent kinetic energy inputs to the water column that can alter stratification and mixing in the lake, as well as lead to sediment resuspension, entrainment, and other processes. We turn our attention now to the potential for LEAPS operation to resuspend bottom sediments and thus alter turbidity, dissolved oxygen and nutrient levels in the lake.

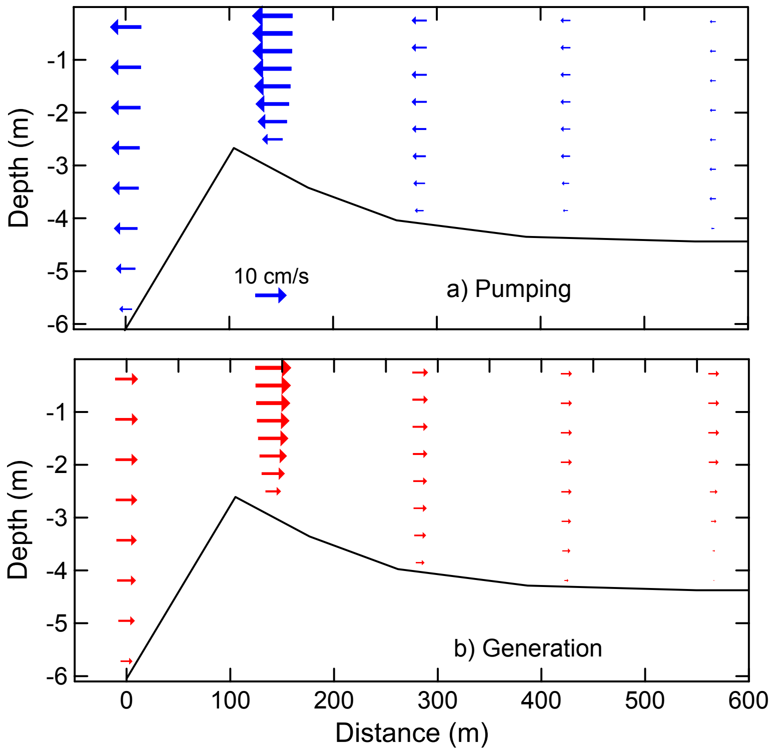

*Fig. 17. Predicted velocity field perpendicular to the intake at the Ortega Oaks site at 1240': a) pumping and b) generation. Active intake dimensions 150 m x 6 m with reversible flow across the full wetted cross-sectional area of the intake. Note reference velocity scale in upper panel.*

## 4.3 Bottom Shear and Sediment Resuspension

### *4.3.1 Predicted Bottom Shear at 1247 ft*

Water flowing over the sediment surface creates a shear stress ($\tau$) that can potentially resuspend bottom sediments. Specifically, resuspension occurs when $\tau$ exceeds a critical shear stress (i.e., when $\tau > \tau_c$). Typical values for $\tau_c$ are 0.1-0.2 N $m^{-2}$ (Chapra, 1997). In a study of sediment resuspension in Lake Okeechobee, Ji and Jin (2005) used a critical shear stress value of 0.18 N $m^{-2}$. For this analysis, I assumed a $\tau_c$ of 0.1 N $m^{-2}$. For reference, the average afternoon bottom shear across the lake was about 0.004 N $m^{-2}$ from simulations without LEAPS operation, although values exceeding 0.1 N $m^{-2}$ can be found in shallow regions of the lake during high winds.

The mass of sediments scoured from the bottom ($\varepsilon$) can be calculated from bottom shear by (Chapra, 1997):

$$\varepsilon = \frac{\alpha_0}{t_d^2}(\tau - \tau_c)^3 \qquad (1)$$

where $\alpha_0$ and $t_d$ are constants. Importantly, one notes that $\varepsilon$ increases as the cube of the difference between bottom shear and the critical shear; thus an increase in bottom shear will result in an exponential increase in mass of sediment scoured. Studies have shown that the entrainment of bottom sediments at a given shear stress occurs over a period of about an hour, with no additional entrainment occurring unless shear stress is increased (Chapra, 1997). That is, the sediment comes into equilibrium with the local energy environment relatively quickly, thus resuspension is expected only during transition periods when shear increases. The concentration of suspended solids ($C_{ss}$) can be estimated from $\varepsilon$ and the depth of the water column ($H$) from:

$$C_{ss} = \frac{\varepsilon}{H} \tag{2}$$

Predicted bottom shear during pumping and generation across the intake at 1247 ft surface elevation (velocity field depicted in Fig. 14) indicate that levels higher than typical background levels were restricted to relatively small areas proximal to the Santa Rosa site, although the values were below critical shear values that would result in sediment resuspension (Fig. 18). Shear stress reached maximum values of only about 0.02 N m$^{-2}$ adjacent to the intake during pumping and 0.01 N m$^{-2}$ during generation, and decreased quickly with distance. This is consistent with velocity profiles that showed that bottom velocities decreased rather strongly within a few hundred meters of the intake (Fig. 14).

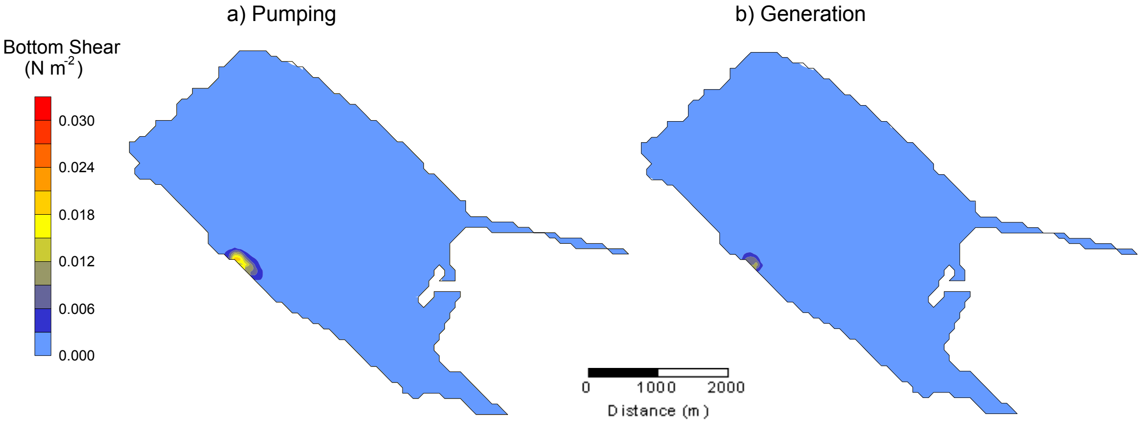

*Fig. 18. Predicted bottom shear at the Santa Rosa site at 1247 ft lake surface elevation.*

Importantly then, predicted bottom shear remained below the critical value of 0.1 N $m^{-2}$ (Fig. 18), so LEAPS operation in this configuration is not expected to resuspend bottom sediments (the area immediately in front of the intake is excluded since rip-rap placed there is not considered a significant source of resuspended sediment).

Similar to that predicted fro the Santa Rosa site, predicted bottom shear at the Ortega Oaks site during pumping and generation phases indicate that levels higher than typical background shear levels were restricted to relatively small areas proximal to the intake (Fig. 19). Under this operational scenario, in which the full width and height of the intake was used during pumping and generation, bottom shear values at the Ortega Oaks site also remained below the assumed critical value of 0.1 N $m^{-2}$ and fell quickly away from the intake (Fig. 19).

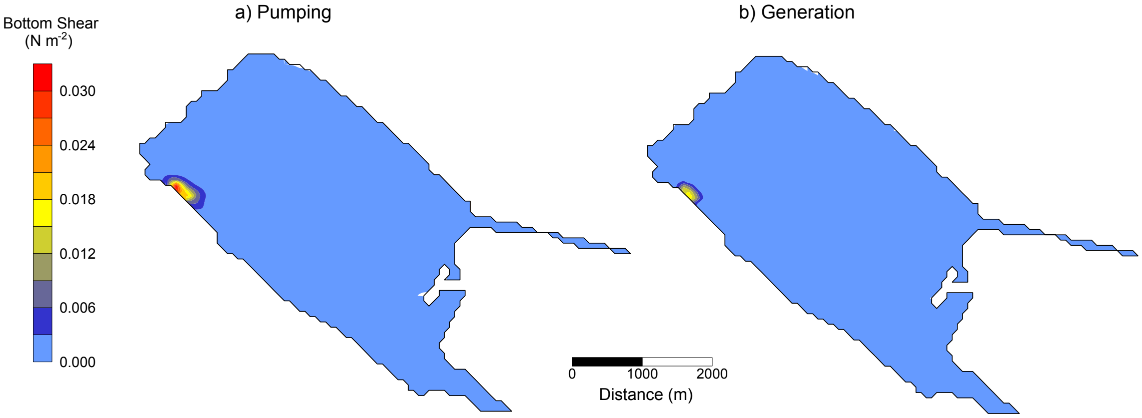

*Fig. 19. Predicted bottom shear at the Ortega Oaks site (1247 ft lake surface elevation).*

### *4.3.2 Predicted Bottom Shear at 1240 ft*

Operation of LEAPS at the nominal minimal lake elevation of 1240 ft was previously shown to increase the velocities near the intake due to the lower effective cross-sectional area available for flow (e.g., Figs. 15 and 17). Since bottom shear increases with increasing velocity, one expects greater bottom shear and potential for sediment resuspension at lower lake levels. This is borne out in model predictions, where higher values of bottom shear and larger overall areas of elevated bottom shear were found at both the Santa Rosa and Ortega Oaks sites (e.g., Fig. 20) relative to those found at 1247 ft surface elevation (Fig. 18b, 19b). Note that the results in Fig. 20 are for the generation phase of LEAPS operation, where resuspended sediment would potentially lower light transparency and increase nutrients in Lake Elsinore.

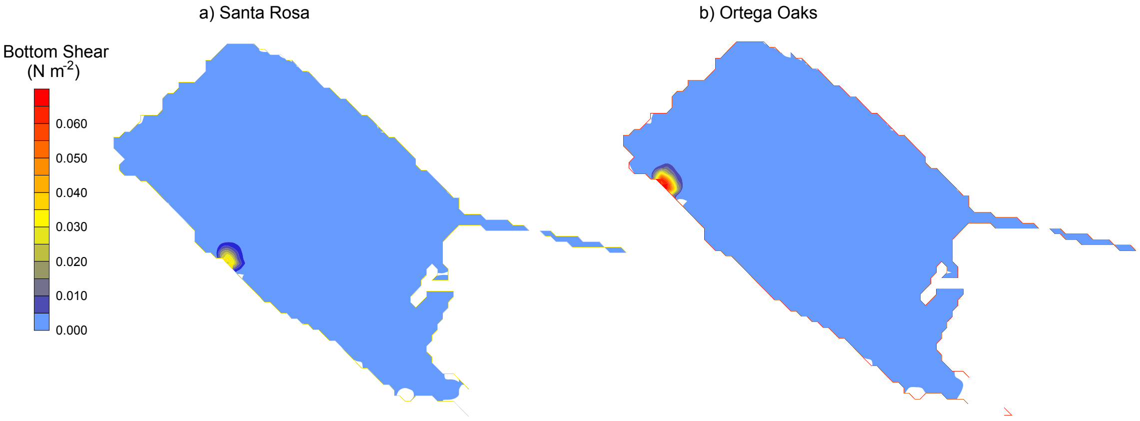

*Fig. 20. Predicted bottom shear during generation at the a) Santa Rosa and b) Ortega Oaks site (1240 ft lake surface elevation).*

Importantly, however, using the full face of the intake for withdrawal and return flows yielded predicted shear values that remained below levels expected to resuspend bottom sediments. Thus, even at a lake level of 1240’, sediment resuspension is not expected to be a significant concern using the full wetted cross-sectional area of the intake. (The effect of selective withdrawal, especially bottom return flows, on sediment resuspension is greater, as will be discussed later in section 4.5.)

We now turn our attention to the influence on stratification and mixing of additional TKE inputs to the lake due to plant operation.

## 4.4 Effect on Stratification and Mixing

### *4.4.1 Stratification and Mixing at 1247 ft*

The potential for the operation of LEAPS to alter stratification and mixing in the lake was also evaluated. The predicted thermal regime of the lake at 1247’ without LEAPS operation (but with supplemental flows to maintain lake level) was similar to that seen previously as part of the model calibration and verification process. Cool, isothermal conditions were predicted for January and February, with strong stratification setting up in March (Fig. 21). Stratification in March has also been seen each spring in the lake monitoring we have conducted for the past several years. Surface waters were then predicted to cool, resulting in the weakening of stratification and mixing in April, followed by subsequent surface heating to yield temperatures reaching about 28 ºC in the summer (Fig. 21). The lake was then predicted to cool beginning in September, with isothermal conditions present through the fall when temperatures again returned to approximately 10-12 ºC in December.

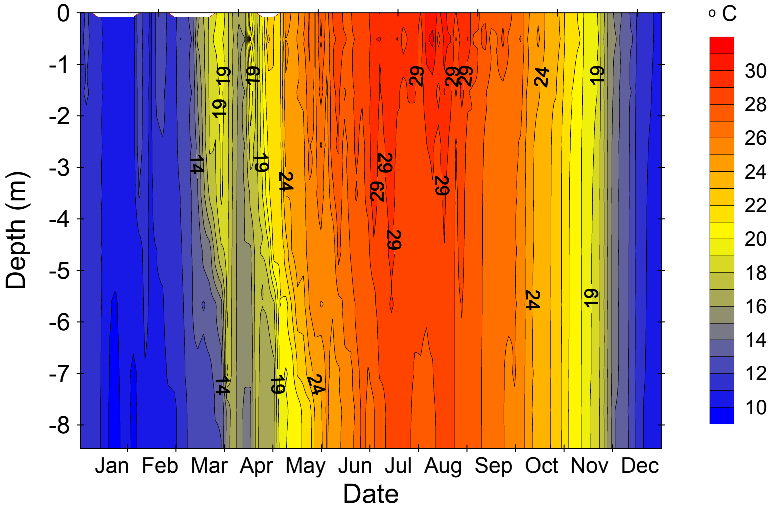

*Fig. 21. Predicted water column temperatures at site E2 without LEAPS operation (1247 ft lake surface elevation).*

The presence of thermal stratification can be seen more readily in Fig. 22, where ΔT values, taken here as the difference in temperatures at site E2 (Fig. 1) at the 2nd and 8th computational layers (corresponding to 1.2 and 7.6 m depths), are plotted over time. Low values of ΔT correspond to weak thermal stratification and indicate there is only a small and transient energy barrier to mixing; such a condition would generally indicate that dissolved oxygen (DO) levels would not decline strongly in the bottom waters, and $NH_3$ and $H_2S$ concentrations would remain low. Strong stratification, on the other hand, would generally persist for longer periods of time and allow severe depletion of DO and accumulation of potentially high levels of reduced species in the lower water column.

Comparatively low predicted values of ΔT were generally present in January and February, although ΔT did briefly exceed 3ºC in early February (Fig. 22). The lake strongly stratified in March, with ΔT exceeding 6 ºC, but ΔT declined quickly with the water column mixing briefly in April, before restratifying later in April and May (Fig. 22). The intensity of stratification began to weaken in June, however, as the lake volume continued to warm (Fig. 21). Quite low values of ΔT were in place beginning in

September, with very low values from October to December indicating well-mixed conditions (Fig. 22).

These seasonal trends were in place for all 3 scenarios (the reference condition, in which LEAPS was not in operation, as well as during operation at the Santa Rosa and Ortega Oaks sites) (Fig. 22). It was in fact difficult to see the reference (no LEAPS) case on the figure, being obscured by the other lines, although it does appear that operation of LEAPS at the Santa Rosa site weakened slightly the strength of stratification relative to LEAPS operation at the Ortega Oaks site and at the reference condition (Fig. 22).

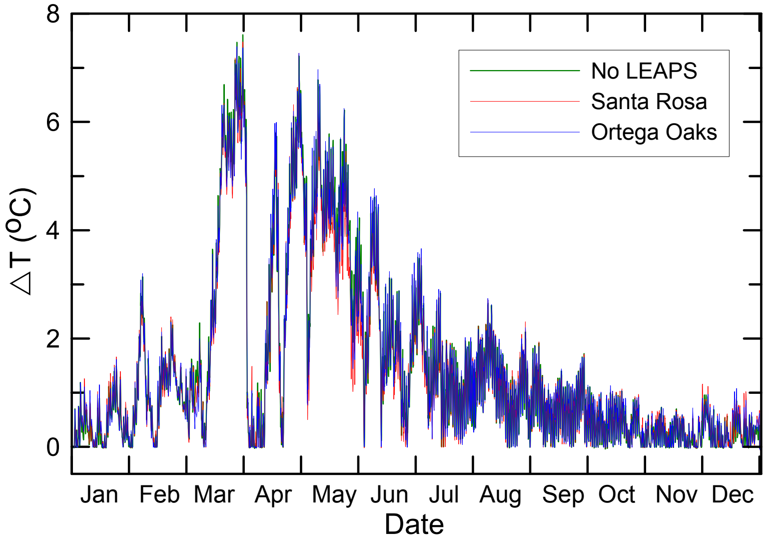

*Fig. 22. Temperature differential (ΔT) between surface and bottom waters without LEAPS operation and operation at the Santa Rosa and Ortega Oaks sites, 1247 ft surface elevation.*

To highlight more clearly the effects of LEAPS operation on the strength of stratification, the ΔT values calculated for the Santa Rosa and Ortega Oaks sites were subtracted from the ΔT value at any given time predicted when LEAPS was not in operation (Fig. 23). If there was no effect whatsoever, one would expect a straight line at the 0 value across all dates; we do see some modest differences however, indicating that LEAPS operation at these 2 sites did affect the strength of stratification at the mid-lake monitoring station. The effect was a bit stronger when LEAPS was located at the Santa Rosa site, due no doubt in part to its closer proximity to the middle of the lake and site E2 (Fig. 1). Thus, LEAPS operation at the Santa Rosa site at a lake level of 1247' and with flows across the full face of the intake, weakened the thermal stratification by about 1.2 ºC in late May and the beginning of June, with less of an effect other times of the year (Fig. 23). Operation at the Ortega Oaks site had less of an effect, generally weakening stratification by <0.5 ºC. Over the entire simulation period, operation of LEAPS at the Santa Rosa site altered thermal stratification on average only -0.05 ºC, while the effect was even less for the Ortega Oaks site (-0.01 ºC). The average values include intervals where LEAPS operation increased slightly the temperature at the mid-lake site (Fig. 23).

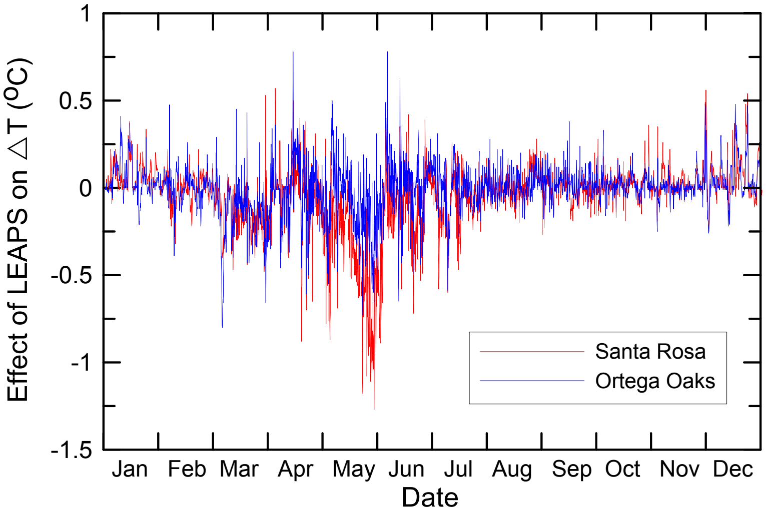

*Fig. 23. Effect of LEAPS operation on predicted ΔT values normalized to those predicted for the lake without operation: flow across full wetted cross-sectional area, 1247 ft lake surface elevation.*

Using the ΔT value at site E2 at 6:00 a.m. as our measure of the strength of stratification, we see that the lake was at least weakly stratified (defined here as ΔT >1ºC) for 121 days without LEAPS operation, while operation at the Santa Rosa and Ortega Oaks sites slightly decreased the number of days of weak stratification, to 110 and 116, respectively (Table 2). Operation of LEAPS at the Santa Rosa site also lowered slightly the number of days of strong stratification (taken here as ΔT>3ºC) from 51 days to 48 days and lowered the average duration of strong stratification from 8.5 days without LEAPS operation to 8.0 days (Table 2). Siting of LEAPS at Ortega Oaks did not affect the number of days of strong stratification nor its average duration relative to the reference case, however. Thus LEAPS operation at the Santa Rosa site had a small weakening effect on the predicted intensity and duration of stratification, while operation at the Ortega Oaks site had less of an effect. Neither meaningfully altered the predicted thermal properties of the lake at a surface elevation of approximately 1247’, however.

Table 2. Intensity and duration of stratification at a lake elevation of 1247’ with and without LEAPS operation.

| | **No LEAPS** | **Santa Rosa** | **Ortega Oaks** |
|---|---|---|---|
| ΔT < 1 ºC (mixed) | 244 (66.8%) | 265 (72.6%) | 249 (68.2%) |
| ΔT > 1 ºC (stratified) | 121 (33.2%) | 110 (27.4%) | 116 (31.8%) |
| ΔT > 3 ºC (strongly stratified) | 51 (14.0%) | 48 (13.2%) | 51 (14.0%) |
| Average Duration (ΔT > 3 ºC) | 8.5 | 8.0 | 8.7 |

### *4.4.2 Stratification and Mixing at 1240 ft*

Variation in lake level was shown to alter velocities near the intake and also influence bottom shear production; the intensity of stratification and frequency of mixing may also be affected.

The ΔT values calculated from predicted temperature profiles at site E2 at this lower lake level of 1240’ were generally quite similar to those calculated at 1247’. The lake exhibited 2 weeks of relatively strong and continuous stratification in the latter part of March, with mixing in early April, followed by shorter intervals of stratification later in April and in early May (Fig. 24). The maximum ΔT value at 1240’ was slightly lower than found at 1247’, with LEAPS operation at the two sites weakening somewhat the strength of stratification at the end of March and in mid-May (Fig. 24), although the effect is subtle.

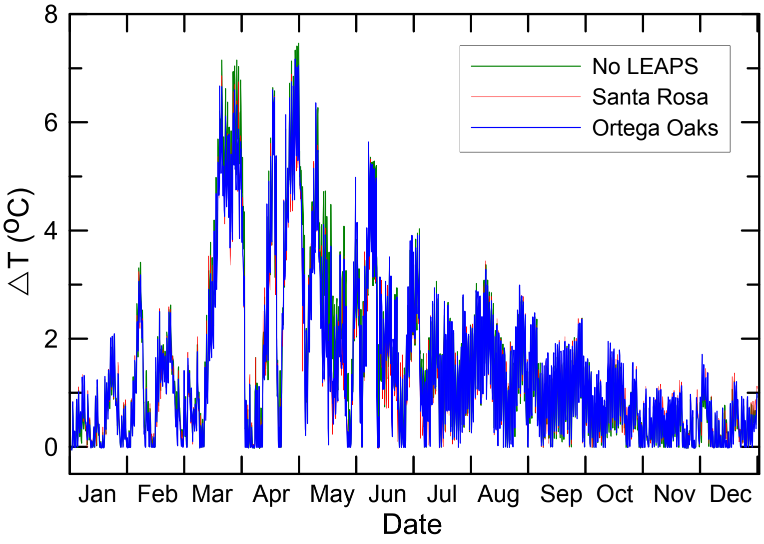

*Fig. 24. Temperature differential (ΔT) between surface and bottom waters without LEAPS operation and operation at the Santa Rosa and Ortega Oaks sites, 1240 ft surface elevation.*

To better highlight differences in the ΔT values calculated from LEAPS simulations at 1240' with those found at these lake levels without LEAPS operation, the difference between these values were again determined. As found at the higher lake level, operation of LEAPS (at either site) at 1240' had a modest effect on stratification (Fig. 25). LEAPS operation did lower the ΔT values predicted in May by about 1.5ºC, an effect larger than predicted at 1247' (Fig. 23).

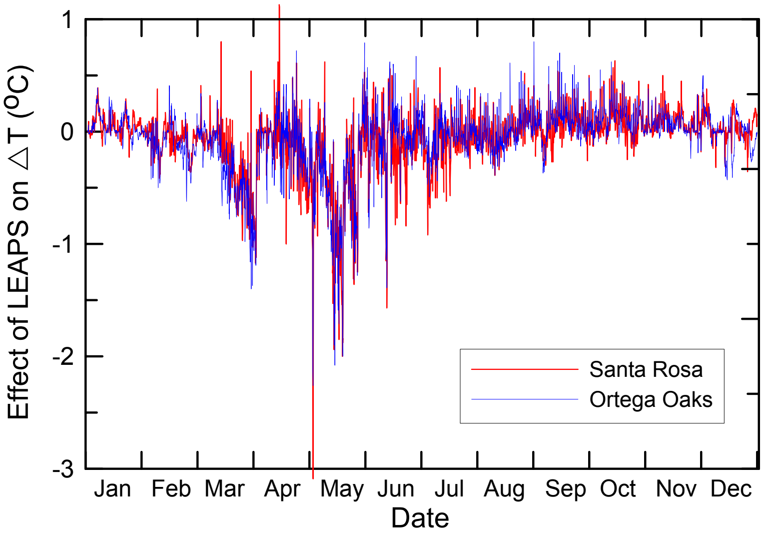

*Fig. 25. Effect of LEAPS operation on predicted ΔT values normalized to those predicted for the lake without operation: flow across full wetted cross-sectional area, 1240 ft lake surface elevation.*

Without LEAPS operation and under the meteorological conditions used in the simulation, the lake was predicted to be relatively well-mixed (ΔT<1ºC) 69% of the year at 1240' (Table 3), slightly more frequently than the 66.8% predicted for 1247' (Table 2). The average duration of strongly stratified conditions (ΔT>3ºC) at the lake was also predicted to decrease from 8.5 days at 1247' (without LEAPS) to 6.3 days at 1240'.

Table 2. Intensity and duration of stratification at 1240' with and without LEAPS operation.

| | **1240'** | **Santa Rosa** | **Ortega Oaks** |
|---|---|---|---|
| ΔT < 1 ºC (mixed) | 252 (69.0%) | 273 (74.8%) | 261 (71.5%) |
| ΔT > 1 ºC (stratified) | 113 (31.0%) | 92 (25.2%) | 104 (28.5%) |
| ΔT > 3 ºC (strongly stratified) | 38 (10.4%) | 33 (9.0%) | 35 (9.6%) |
| Average Duration (ΔT > 3 ºC) | 6.3 | 6.6 | 7.0 |

We can thus conclude that lake level is overall a stronger determinant of the strength and duration of stratification than LEAPS operation, at least at when using the proposed shoreline structure and at these 2 lake levels that have been proposed as the typical operational range for the project.

## 4.5 Selective Withdrawal

It was proposed by Horne (2005) that withdrawal and return flows at selected depths may be a way to more effectively weaken stratification and maximize DO levels above the sediments. To evaluate this, a series of additional simulations were conducted in which gate thickness and width were varied. That is, rather than flowing water through the full width and wetted height (that varies with lake level) of the intake, withdrawal and return flows were directed into specific depths using the withdrawal-return pair subroutine of EFDC (Hamrick, pers. comm.). While a large number of possible permutations could be evaluated, gate heights of 1 m were assumed with the lake level maintained at approximately 1247'. Pumping was assumed to withdraw water from near the middle of the water column (computational layer 4, corresponding to a depth of 4-5 m). Withdrawal from near the middle of the water column should help weaken local stratification by pulling water from the thermocline. Generation flows were directed alternately to the lowest vertical layer next to the rip-rap and bottom sediments or to the surface layer.

### *4.5.1 Velocities Near Intake*

The local velocity field near the intake at the Santa Rosa site reflected this selective withdrawal and return (Fig. 26). Not unexpectedly, high velocities were predicted near the center of the water column adjacent to the intake during pumping (Fig. 26a). Velocities exceeding 12 cm/s were predicted at 4.6 m depth, with values declining both above and below this depth. Velocities near the bottom sediments declined to 3 cm/s, while flow at the surface slowed to 0.4 cm/s and actually reversed direction (i.e., unlike the other depths with flows directed toward the intake, the uppermost 1-m of water was predicted to move *away* from the intake during pumping) (Fig. 26a).

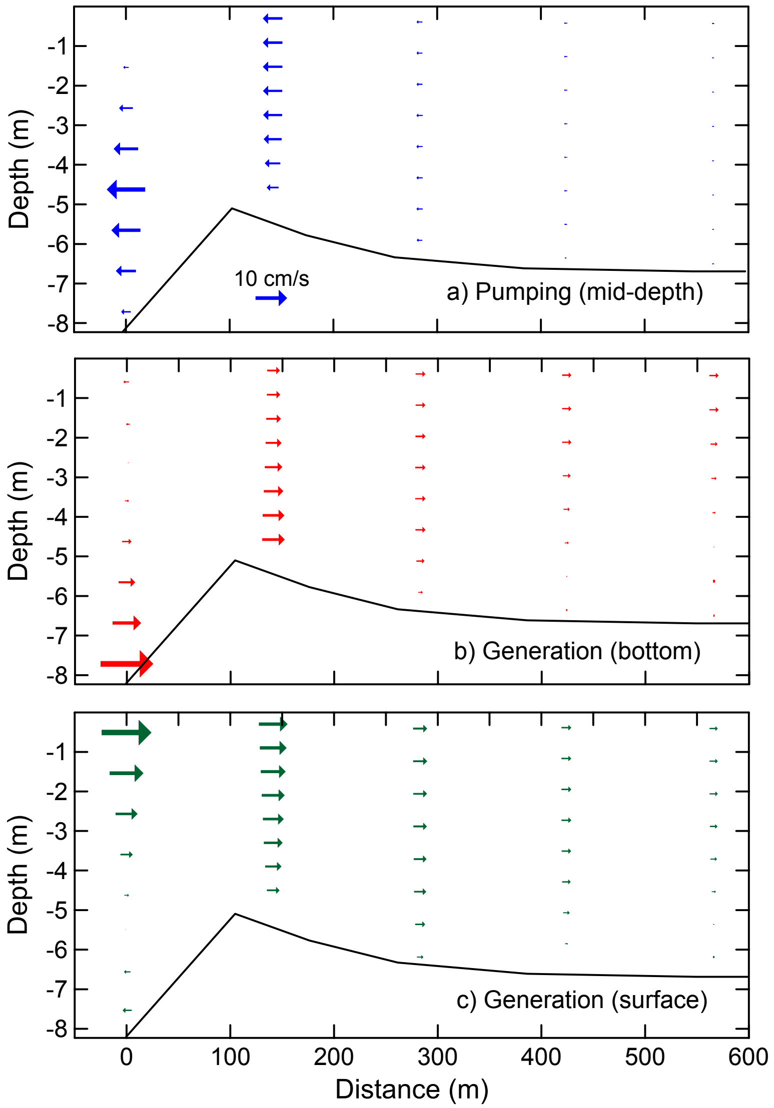

*Fig. 26. Predicted velocity field perpendicular to the intake at the Santa Rosa site at 1247'. Active intake dimensions 150 m x 1 m, with a) withdrawal at 4-5 m depth, b) bottom generation (7-8 m depth), and c) surface generation (0-1 m depth). Note reference velocity scale in upper panel.*

This strong vertical gradient in velocity was damped out quickly with distance, however, with much more uniform predicted velocity profiles, although lower velocities were still present near the sediments. For example, velocities varied from 3.65 cm/s near the sediments to 6.14 cm/s near the lake surface at 140 m distance from the intake (Fig. 26a). The depth-averaged velocity was nonetheless slightly higher at this distance than closer to the intake (5.55 vs. 5.49 cm/s, respectively). While velocities would be expected to decrease with distance as flows enter the lake, as previously discussed, the bottom topography forces water flow into a shallower region that, through conservation of momentum, requires velocities to accelerate. Lateral flow (not shown in this transect) as well as frictional losses to the rip-rap and bottom sediments also dissipates available momentum. Depth-averaged velocities were observed to decrease at greater distances, however, to 2.73 cm/s at 280 m distance, 1.63 cm/s at 420 m, and 1.1 cm/s at 560 m (Fig. 26a).

Return flows directed to the bottom layer during generation resulted in high velocities near the sediments at the intake (16.8 cm/s) that decreased sharply away from the lake bottom (Fig. 26b). What is particularly interesting is the reversal of flow found in the uppermost 3 m of the lake adjacent to the intake (Fig. 26b). This indicates that a strong eddy with local short-circuiting of flow would be present under this operational scenario. The vertical gradient in velocity weakens with increasing distance from the intake, although the depth-averaged velocity increases from 4.0 cm/s near the intake to 5.4 cm/s 140 m downstream, before declining to 1.1 cm/s 560 m away (Fig. 26b).

Directing flows to the surface layer during generation resulted in velocities near the intake that decreased dramatically with depth, from 15.9 cm/s at the surface to 2.8 cm/s above the sediments (Fig. 26c). As found with bottom release, a flow reversal was found; here water in the bottom 3 m was flowing toward the intake so that an eddy was also predicted for surface generation flows. A stronger vertical gradient was in place away from the intake than the bottom release, however. For example, at 140 m downstream, surface currents were predicted to be 9.0 cm/s, with velocities declining to 3.9 cm/s above the sediment in this shallower region. Depth-averaged velocities declined to 3.7, 2.5 and 1.6 cm/s at 280-560 m away from the intake (Fig. 26c). Bottom velocities declined to <0.5 cm/s.

The effect of narrower intake structures that are more typical of pump-storage hydroelectric plants was also evaluated. In this simulation, a 1 m vertical gate was maintained, while the width of the intake was narrowed from 150 m to 40 m. Pumping water at equivalent flow rates through this narrower intake necessarily increased the velocities near the structure. Velocities of 20 cm/s were predicted for the 4.6 m depth; velocities declined to <0.1 cm/s within 3 m above or below this depth interval (Fig. 27a). Even with these high local velocities, however, predicted velocities declined to 0.5 cm/s 560 m away. Directing flows through the bottom 1 m of the intake yielded quite high velocities there (30.7 cm/s), with countercurrent flow setting up in the upper 4 m of the water column and reaching 7.7 cm/s at 0.5 m depth (Fig. 27b). Predicted velocities remained higher near the sediments than in prior simulations (Fig. 26), but still declined with increasing distance from the intake (e.g., 0.8 cm/s above the sediments at a distance 420 m away) (Fig. 27b).

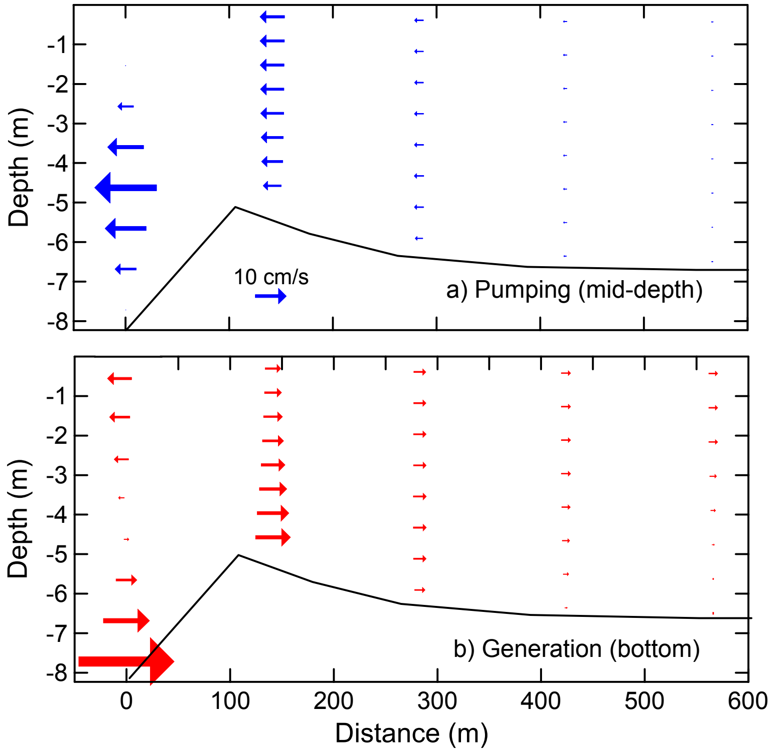

*Fig. 27. Predicted velocity field perpendicular to the intake at the Santa Rosa site at 1247'. Active intake dimensions 40 m x 1 m, with a) withdrawal at 4-5 m depth, and b) bottom generation (7-8 m depth). Note reference velocity scale in upper panel.*

A final set of simulations were conducted for the Santa Rosa site at a lake surface elevation of 1247 ft to evaluate the velocities profiles produced using a narrow (10 m) gate with a 1 m vertical opening. This small (10 $m^2$) cross-sectional area would be similar to a single 3.6 m (or ~12 ft) diameter pipe. While locally very high velocities and strong counter-current flows are predicted near the intake (velocities up to 34 cm/s during pumping and 59 cm/s during bottom release generation), velocities nevertheless decreased markedly with distance from the intake (Fig. 28). The depth-averaged velocities at 560 m during pumping (3.4 cm/s) and generation (2.3 cm/s) were considerably higher than found under the other operational scenarios, however, reflecting the much smaller cross-sectional area available for flow.

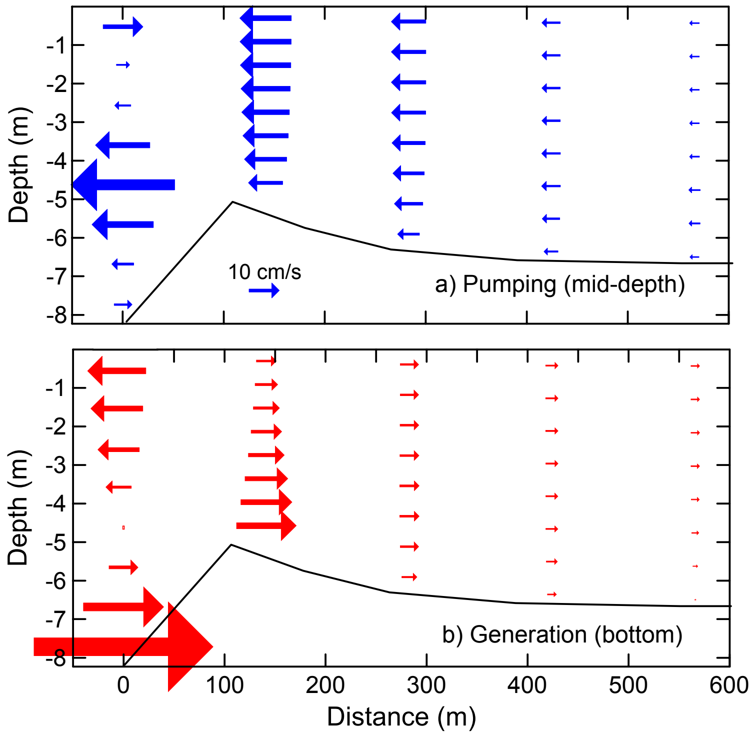

*Fig. 28. Predicted velocity field perpendicular to the intake at the Santa Rosa site at 1247'. Active intake dimensions 10 m x 1 m, with a) withdrawal at 4-5 m depth, and b) bottom generation (7-8 m depth). Note reference velocity scale in upper panel.*

Selective withdrawal and return flows were evaluated for the Ortega Oaks site as well. As previously noted, withdrawal during pumping was assigned to the 4$^{th}$ vertical layer from the bottom for these simulations. The effect of this was a predicted velocity profile similar to that found for the Santa Rosa site (Fig. 26a), with maximal velocities of 12.2 cm/s directed toward the intake at this depth, with velocities adjacent to the face of the intake decreasing both above and below this middle water column depth (Fig. 29a). In this configuration, velocities decreased to approximately 3 cm/s near the sediment, while velocities slowed and reversed direction near the surface (horizontal velocities of 0.4 cm/s *away* from the intake) (Fig. 29a).

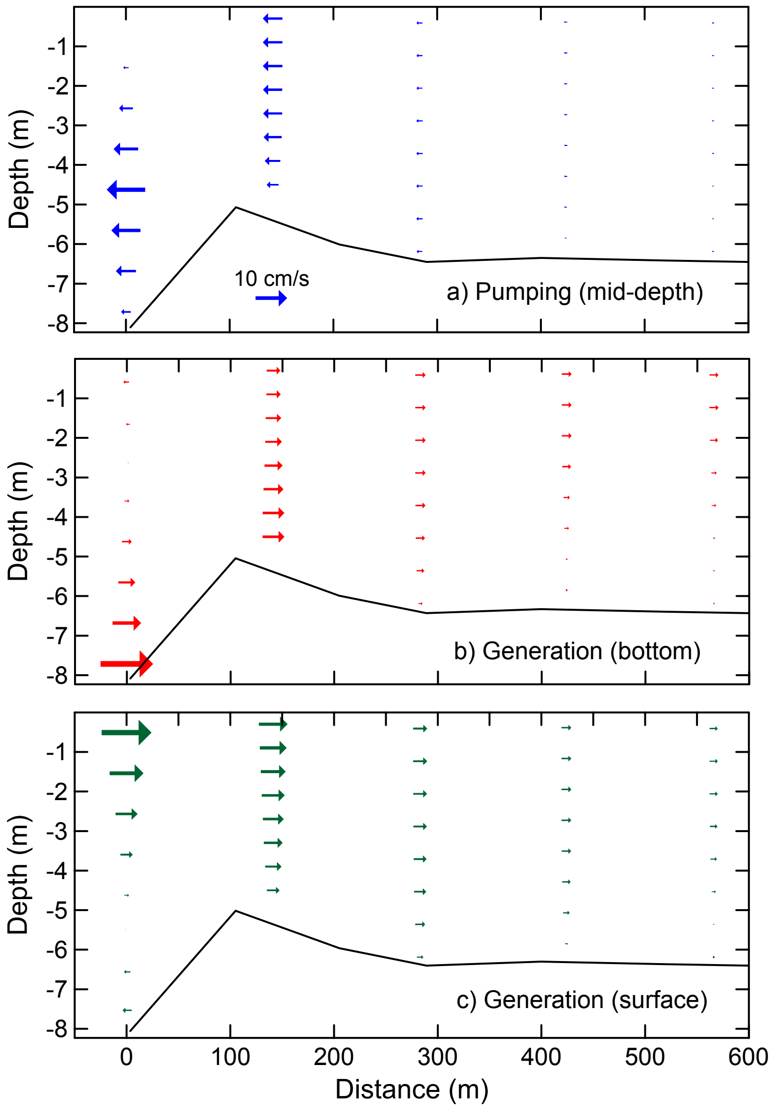

*Fig. 29. Predicted velocity field perpendicular to the intake at the Ortega Oaks site at 1247. Active intake dimensions 150 m x 1 m, with a) withdrawal at 4-5 m depth, b) bottom generation (7-8 m depth), and c) surface generation (0-1 m depth). Note reference velocity scale in upper panel.*

Thus there is some local short-circuiting of flow predicted during generation at this site, similar to that found at the Santa Rosa site. Out about 140 m from the intake, a more uniform velocity profile was predicted, with velocities ranging from 3.6 cm/s above the sediments to 6.1 cm/s near the lake surface. Depth-averaged velocities decreased with increasing distance from the intake, to about 1.8 cm/s at 280 m out perpendicular to the intake, to 0.76 and 0.47 cm/s at 420 and 560 m, respectively (Fig. 29a). Predicted velocities were generally slightly lower near the sediments when compared with other depths due to some frictional losses there. These velocities were taken from a simulation interval when natural wind-forcing was minimal to better illustrate the effects of LEAPS operation on local circulation. Since velocities near this site are typically about 0.5 cm/s during the early morning, it would likely be difficult under most circumstances to identify flow effects due to pumping that extend out more than about 500 m from the intake.

The effects of generation on local velocity field was assessed for both bottom discharge (Fig. 29b) and surface discharge (Fig. 29c). Irrespective of depth of discharge, generation resulted in velocities opposite in direction to those predicted during pumping, i.e., directed *away from* the intake structure (e.g., Fig. 29b). Bottom discharge yielded predicted velocities near the sediments as high as 16.8 cm/s, although velocities decreased rapidly with distance above the sediments (Fig. 29b). The model in fact predicted a quiescent zone at a depth of about 2.5 m, above which flows reversed to 1.6 cm/s directed toward the intake. Thus, as found during generation, some local counter-current flows are expected to form during LEAPS operation. Velocities out 140 m from the intake were more uniform with depth, with the depth-averaged velocity at this distance from the intake (5.53 cm/s) actually slightly higher than that at the intake (4.1 cm/s), again due to the decreasing depth out about 100 m from the intake wherein conservation of momentum requires that the average velocity increase. Beyond this distance, velocities slowed to depth-averaged values of 2.7 at 280 m and 1.8 and 1.3 cm/s at 420 and 560 m, respectively (Fig. 29b). Bottom velocities were 30 – 90% lower than surface values, however, due in part to the physical obstruction of flow created by the sill formed from excavation of bottom sediment near the intake (Fig. 29b).

Surface discharge yielded velocity profiles that were essentially the mirror image of those found with bottom discharge. That is, high velocities directed away from the intake were present near the lake surface (15.9 cm/s) that decreased with depth until reversing direction in the bottom 2-3 m. (Fig. 29c) Velocities were more uniform 140 m from the intake, although they did vary from 3.9 cm/s near the sediments to 9.0 cm/s near the lake surface. Velocities slowed further at increasing distance as flows spread out away from the intake (Fig. 29c).

To assess the impact of smaller intake structures at the Ortega Oaks site, simulations were also conducted in which the intake gate was 40 m wide (Fig. 30) and 10 m wide (Fig. 31). As predicted for the Santa Rosa site, velocities near the intake were much higher when compared with those present when the full wetted cross-sectional area of the intake provided flow. For example, the 40 m wide intake gate yielded withdrawal velocities as high as 19.1 cm/s during pumping and discharge velocities as high 30.8 cm/s directed away from the intake during generation (Fig. 30). Strong counter-current flows were set up near the intake during bottom discharge (e.g., predicted surface velocities toward the intake of 7.8 cm/s). Depth-averaged velocities were 20-60% higher 140 m from the intake than adjacent to the intake. Low velocities with some weak counter-current flows were predicted out past 400 m during bottom discharge (Fig. 30b).

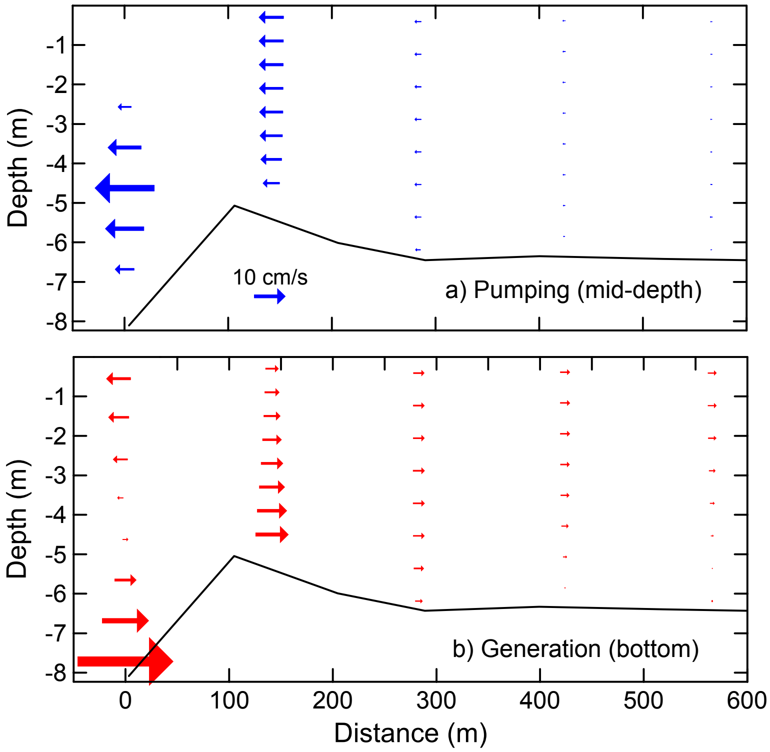

*Fig. 30. Predicted velocity field perpendicular to the intake at the Ortega Oaks site at 1247'. Active intake dimensions 40 m x 1 m, with a) withdrawal at 4-5 m depth, and b) bottom generation (7-8 m depth). Note reference velocity scale in upper panel.*

These effects were even more pronounced when a 10 m wide intake structure was used (Fig. 31). Pumping yielded predicted velocities >30 cm/s between 4-5 m depth, with flows reversing direction both near the sediments and near the surface of the lake (Fig. 31a). An even more dramatic counter-current flow was set up with bottom discharge. Under this scenario, bottom velocities were predicted to reach as high as 59 cm/s, with a thin quiescent shear layer at about 5 m depth and surface velocities as high as 20 cm/s and flowing in the opposite direction to that closer to the sediments (Fig. 31b). Interestingly, even at these high local velocities, the average velocities at 400-600 m from the intake (0.7-2.1 cm/s) were similar to those found in the wider intakes (1.3-1.8 cm/s).

The similarities between the velocity profiles found at the Santa Rosa and Ortega Oaks sites indicate that the structural and operational features of LEAPS dominates the flow regimes, and subtle bathymetric differences between the 2 sites have only small effects on predicted velocity fields at these lake elevations.

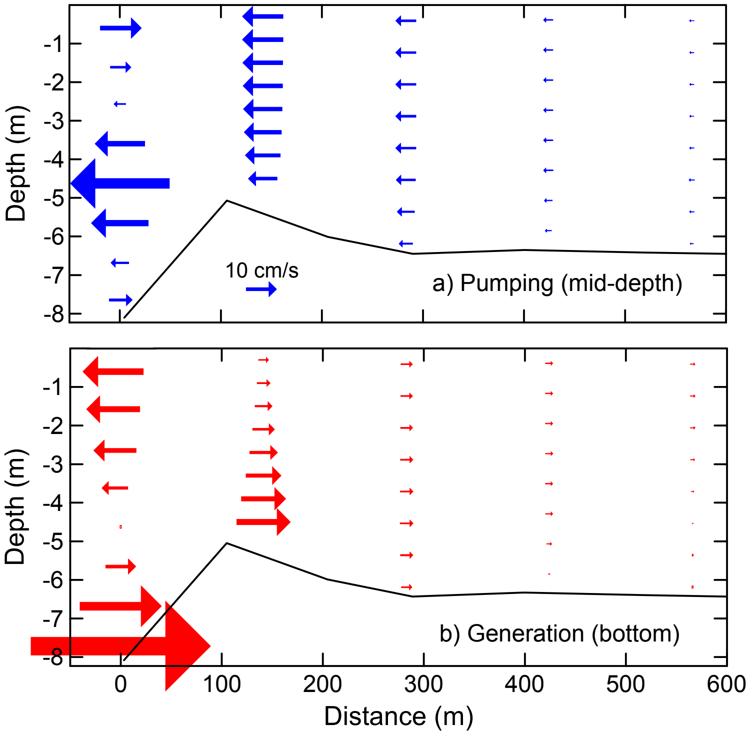

*Fig. 31. Predicted velocity field perpendicular to the intake at the Ortega Oaks site at 1247'. Active intake dimensions 10 m x 1 m, with a) withdrawal at 4-5 m depth, and b) bottom generation (7-8 m depth). Note reference velocity scale in upper panel.*

### *4.5.2 Bottom Shear and Sediment Resuspension*

While LEAPS operation increased bottom shear near the intake, at nominal surface elevations of 1240 – 1247', predicted bottom shear remained below predicted critical values when flow was provided across the full wetted cross-sectional area of the intake (Figs. 18 and 19). Directing flow lower in the water column may help maintain aerobic conditions there, but the high predicted velocities are expected to generate substantial bottom shear. Bottom shear, in fact, exceeded critical values under these conditions (Fig. 32), where the colored regions represent the areas where $\tau > \tau_c$ (i.e., the regions of predicted sediment resuspension). Bottom shear for a 150 m x 1 m gate reached a maximum value of 0.38 N $m^{-2}$, while maximum shear values increased with decreasing gate width (1.3 and 5.5 N $m^{-2}$, respectively, for 40 m and 10 m gate widths) (Fig. 32).

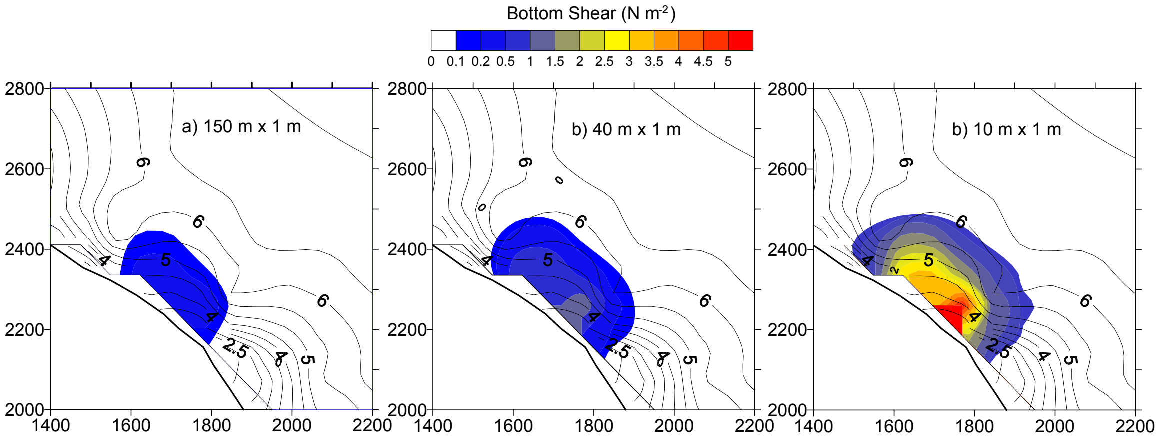

*Fig. 32. Predicted bottom shear during generation at the Santa Rosa site (1247 ft lake surface elevation) for 3 different gate dimensions: a) 150 m x 1 m, b) 40 m x 1 m and c) 10 m x 1 m.*

The average shear within the resuspension zone was inversely related to intake width, and increased from 0.28 N $m^{-2}$ for a 150 m wide intake to 1.61 N $m^{-2}$ for a 10 m intake gate (Table 2). The area of scour also increased from an estimated 38,000 $m^2$ to 80,000 $m^2$. More significantly, however, the mass of sediment scoured per unit area increased dramatically as a result of the exponential relationship in eq 1 (Table 4).

Table 4. Predicted sediment resuspension at the Santa Rosa site (1247 ft lake surface elevation).

| Intake Width x Height (m) | Area of Scour ($m^2$) | Average Shear (N $m^{-2}$) | Scour ($\varepsilon$) (g $m^{-2}$) | Total Mass Scoured (kg) | Local $C_{ss}$ (mg/L) | Lakewide $C_{ss}$ (mg/L) |
|---|---|---|---|---|---|---|
| 150 x 1 | 38,000 | 0.24 | 4.5 | 170 | 0.99 | 0.002 |
| 40 x 1 | 61,000 | 0.54 | 138 | 8470 | 28.3 | 0.11 |
| 10 x 1 | 80,000 | 1.61 | 5612 | $4.39\times10^5$ | 1100 | 5.72 |

The total mass scoured increased with decreasing intake width due to both the very large increase in $\varepsilon$ and the increase in area of scour, from 170 kg for the 150 m wide intake to $4.49\times10^5$ kg for the narrowest gate. The estimated suspended solids concentrations *within the resuspension zone* ranged from <0.1 mg/L to 1,100 mg/L (Table 4). The concentration of suspended solids would decrease as a result of mixing with the rest of the lake, however. Assuming 3400 surface acres, a mean depth of 5.7 m and instantaneous mixing throughout the lake, the suspended solids concentrations would be below detection for all except the 10 m x 1 m gate configuration, where an instantaneous suspended solids concentration due to generation during LEAPS operation would reach 5.72 mg/L (Table 4). It is recognized that the TSS concentration would be lower and rapidly decrease over time due to particle settling.

Predicted bottom shear at the Ortega Oaks site exhibited similar behavior and increased in both magnitude and spatial extent with decreasing gate width (Fig. 33). The area of resuspension ($\tau$>0.1 N m$^{-2}$) also increased.

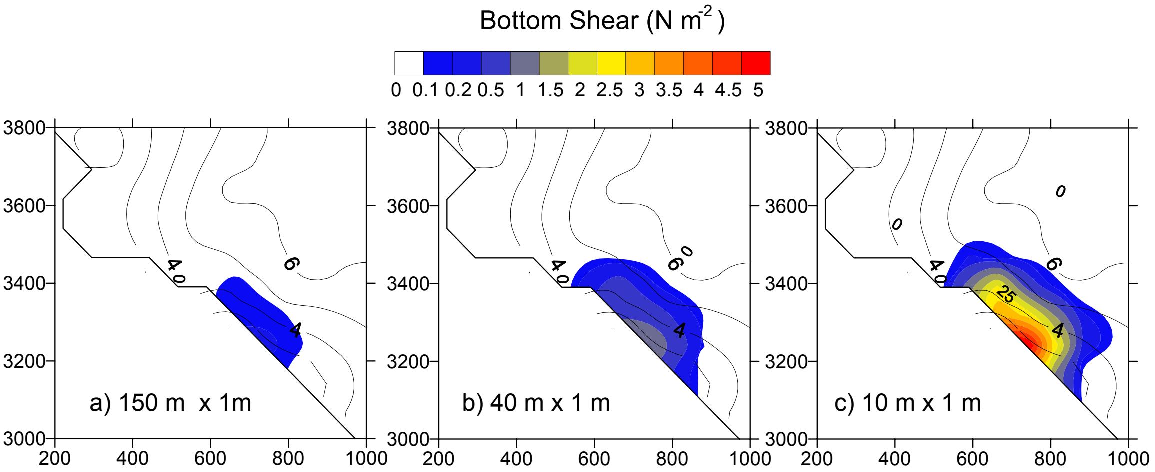

*Fig. 33. Predicted bottom shear during generation at the Ortega Oaks site (1247 ft lake surface elevation) for 3 different gate dimensions: a) 150 m x 1 m, b) 40 m x 1 m and c) 10 m x 1 m.*

The average shear within the resuspension zone was inversely related to intake width, and increased from 0.48 N m$^{-2}$ at a 150 m x 1 m intake to a value of 2.78 N m$^{-2}$ for a 10 m x 1 m intake (Table 5). The predicted area of scour also increased from <5,000 m$^2$ to 83,000 m$^2$. More significantly, however, the mass of sediment scoured per unit area increased dramatically as previously noted, due to the exponential relationship in eq 1 (Table 5). The total mass scoured increased from 2030 kg for the 150 m wide intake to 2.60x10$^6$ kg for the narrowest intake. The estimated suspended solids concentrations *within the resuspension zone* ranged from <0.1 mg/L to 5,229 mg/L, while the theoretical lake-wide concentration ranged from <0.03 to 33.1 mg/L (Table 5).

Table 5. Predicted sediment resuspension at the Ortega Oaks site (1247 ft lake surface elevation)

| Intake Width x Height (m) | Area of Scour (m$^2$) | Average Shear (N m$^{-2}$) | Scour ($\varepsilon$) (g m$^{-2}$) | Total Mass Scoured (kg) | Local $C_{ss}$ (mg/L) | Lakewide $C_{ss}$ (mg/L) |
|---|---|---|---|---|---|---|
| 150 x 1 | 22,700 | 0.48 | 89.4 | 2030 | 14.9 | 0.03 |
| 40 x 1 | 53,200 | 0.90 | 834 | 44,399 | 139 | 0..57 |
| 10 x 1 | 83,000 | 2.78 | 31,376 | 2.60x10$^6$ | 5229 | 33.1 |

These suspended solids concentrations are higher than predicted for the Santa Rosa site (Table 4). The somewhat shallower depths near the site resulted in only slightly higher velocities and bottom shear, but much higher mass of sediment potentially scoured from the bottom sediments (again following the cubic relationship between scour and difference between predicted and critical shear (eq 1).

For comparison, the background TSS concentration in Lake Elsinore averaged 25.5 mg/L in 2003-2005, with >50% attributed to inorganic solids (Veiga-Nascimento and Anderson, 2005). Thus LEAPS operation is not predicted to substantially increase lake-wide suspended solids concentrations, even immediately after start-up. Chronic resuspension effects are not expected since the sediments will quickly come into equilibrium with the local velocity fields induced by LEAPS operation.

### *4.5.3 Stratification and Mixing*

The effect of different intake configurations on the intensity of stratification at 1247' was also investigated. For example, bottom release of water through a 150 m intake with a 1 m slot width affected the relative strength of stratification in a manner quite similar to flows through the full face of the intake, although this configuration had less of an effect for the Santa Rosa site and a somewhat greater effect for the Ortega Oaks site (Fig. 34).

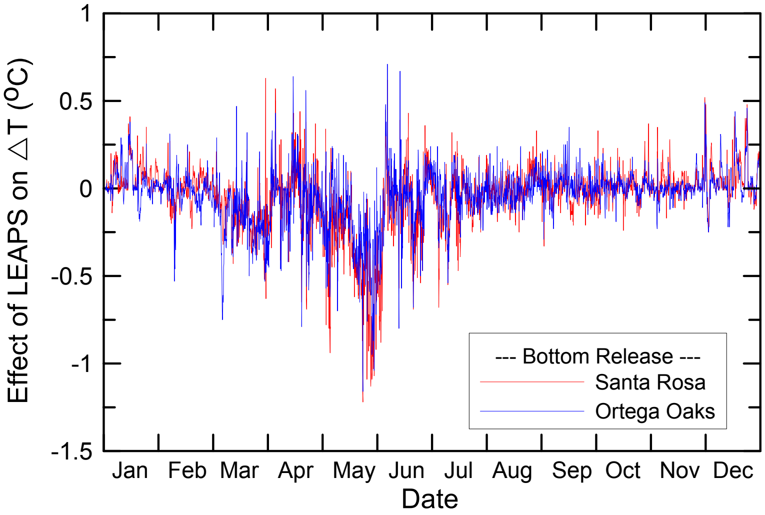

*Fig. 34. Effect of LEAPS operation on predicted ∆T values normalized to those predicted for the lake without operation: 150 m x 1 m intake gate, bottom release, 1247 ft lake surface elevation.*

The effect of intake width (previously shown to strongly influence bottom shear stress and sediment resuspension) had much less of an effect on far-field water column thermal properties (Fig. 35). That is, even gate widths as narrow as 10 m altered thermal stability in a manner similar to other configurations, although the effect was slightly greater than, e.g., 40 m (Fig. 30). For example, a 10 m x 1 m gate at the Ortega Oaks site altered average ΔT in late May by –0.71 ºC, a value slightly larger than that for 40 or 150 m wide gates, that reduced ΔT values by –0.49 and –0.42 ºC, respectively.

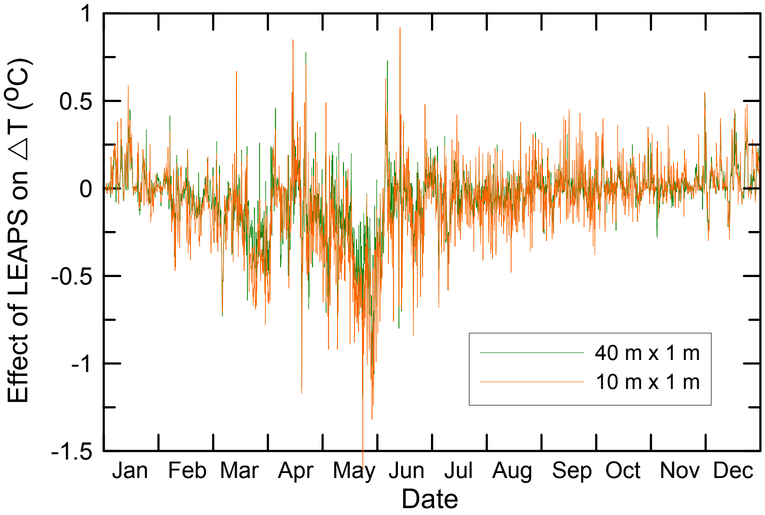

*Fig. 35. Effect of LEAPS operation on predicted ΔT values normalized to those predicted for the lake without operation: 40 m x 1 m and 10 m x 1 m intake gate, bottom release, 1247 ft lake surface elevation.*

The depth of discharge (surface, middle or bottom release) also yielded very similar (and minimal) effects on the strength of thermal stratification (not shown). For example, surface and bottom release at the Ortega Oaks site assuming a 150 m x 1 m intake both weakened average ΔT in late May by –0.42 ºC, while mid-water column release weakened it by –0.46 ºC.

## 5.0 Discussion

The hydrodynamic simulations provided valuable insights into the expected behavior and impacts of LEAPS operation on water column properties. While a number of different combinations of intake locations, configurations, and lake levels were evaluated, overall the effects of LEAPS operation on predicted water column properties were generally quite modest.

For example, irrespective of the specific location of the intake (Santa Rosa or Ortega Oaks sites), the operation of LEAPS increased local velocities only relatively short distances from the intake. The proposed shore-based intake design that is approximately 150 m wide and with a lower intake channel elevation of 1220 ft above MSL offers a very large cross-sectional area for flow, on the order of 1200 $m^2$ at a lake surface elevation of 1247'. This large cross-section keeps velocities low near the face of the intake. For example, the velocity adjacent to the intake at the Santa Rosa site during pumping at this lake surface elevation averaged 5.2 cm/s while a lower average velocity was predicted during generation (3.9 cm/s) due to the lower volumetric flow rate (Fig. 14). Velocities during generation increased somewhat out about 100 - 150 m perpendicular to the face of the intake due to the sill formed from excavation at the site. The decreasing depth away from the intake and toward the sill necessarily accelerated water velocities through this region. Velocities then slowed at greater distances, to average velocities of about 1 cm/s nearly 600 m from the intake. The predicted velocity profiles perpendicular to the intake located at the Ortega Oaks site were quite similar to those at the Santa Rosa site, with only slightly higher average velocities that reflect the somewhat shallower conditions near that site. For comparison, water velocities exceeding 1 cm/s are common throughout most of the lake, with velocities often exceeding 5 cm/s, especially in the southern end of the lake (e.g., Fig. 6).

These velocities did result in locally higher levels of bottom shear than typically found near the intake sites, at least under relatively quiescent conditions, although the levels remained below the assumed critical shear value of 0.1 N $m^{-2}$. The consequence of this is that sediment resuspension induced by LEAPS operation for this intake design and surface elevation (1247') is not expected to be a concern, especially with the emplacement of rip rap near the intake.

Moreover, the turbulent kinetic energy inputs into the lake as a result of pumping and generation were predicted to minimally alter stratification and mixing processes in the lake. Based upon predicted temperature profiles at a mid-lake location previously used in model calibration and validation (E2 in Fig. 1), the regular (5 day a week) operation of LEAPS over the year minimally altered the intensity and duration of stratification. Using the predicted temperature difference ($\Delta T$) between the 2nd and 8th computational layer that corresponds to the 1.2 and 7.6 m depths at the site, operation of LEAPS at the Santa Rosa site weakened stratification by about 1.2ºC in late May, but otherwise had generally little effect. Operation of LEAPS at the Ortega Oaks site weakened thermal stratification <0.5ºC over this same time period. In the absence of LEAPS operation and at a surface elevation of 1247’, the lake was predicted to be at least weakly stratified (ΔT>1ºC at 6:00 a.m.) for 121 days or one-third of the year, and more strongly stratified (ΔT>3ºC at 6:00 a.m.) for 51 days (14.0% of the year). Operation of LEAPS at the Santa Rosa site slightly lowered the number of days each year with at least weak stratification, to 110 days, and with strong stratification to 48 days (13.2% of the year). The average duration of strong stratification also decreased slightly, from 8.5 days to 8.0 days. The effect of operation at the Ortega Oaks site was even smaller (the number of days with at least weak stratification decreased by 1.4%, with no effect on duration of strong stratification).

Based upon this, one can conclude that LEAPS operation using the proposed intake design near nominal maximum operating depth of 1247’ will have minimal impacts on stratification, mixing and sediment resuspension in the lake. Modified densiometric Froude numbers previously calculated for the lake with LEAPS operation suggested that the lake would remain neither strongly stratified nor strongly mixed (Anderson, 2006b), and this 3-D hydrodynamic analysis supports this finding. The shore-mounted intake structure with a large cross-sectional area, combined with the recontoured lake bottom that yields a sill proximal to the intake, create low velocities and also appears to create sufficient turbulence to limit direct momentum flux into the deeper waters in the lake.

Comparable simulations were also conducted at a lake surface elevation of 1240’, considered the nominal minimal operating elevation for LEAPS. The effect of a lower lake level reduces the depth of water at the face of the intake and thus also directly lowers the wetted cross-sectional area of the intake. On that basis, then, one would expect roughly 25% higher velocities near the intakes, although velocities increased by about 45%. This additional increase in velocity is attributed to greater channeling of flow perpendicular to the face of the intake due to the shallower neighboring sediment depths. Even greater acceleration over the shallow sill region was predicted, reflecting the greater relative change in depth there at lower lake surface elevations.

Shear stress increases as the square of velocity (Martin and McCutcheon, 1999), so the greater velocities predicted for 1240’ produced substantially higher levels of bottom shear, e.g., a maximum bottom shear of 0.021 N $m^{-2}$ was predicted adjacent to the intake during generation at the Ortega Oaks site at a surface elevation of 1247’, while maximum bottom shear increased to 0.075 N $m^{-2}$ at 1240’. The levels remained below critical values, however, so even at the lower end of the expected operating surface elevation range, sediment resuspension is not expected to be a significant problem with this intake configuration.

The lower lake level was found to reduce the duration and intensity of stratification of the reference case (i.e., without LEAPS operation) compared with that predicted for 1247’. The number of days where ∆T exceeded 3 ºC declined by almost 2 weeks, from 51 days per year at 1247’ to 38 days at 1240’ . The average duration of strong stratification also declined, from 8.5 days to 6.3 days. LEAPS operation had only a small incremental effect on duration of stratification, lowering the number of days where ∆T exceeded 3 ºC by an additional 3-5 days. Strong stratification was predicted to persist an average of 6.6-7.0 days and still occur 33-35 days each year.

LEAPS was predicted to have more dramatic effects on velocities and bottom shear near the intake when withdrawal and return flows were focused into discrete depths there. For example, reducing the gate height at the Santa Rosa site from the full water depth at the intake (approximately 6-8 m at 1240-1247’) to a 1 m slot width substantively altered the velocity profiles. Velocities exceeding 12 cm/s were predicted during pumping from mid-depth within the water column, while surface and bottom release during generation yielded velocities of 16 – 17 cm/s. The model further predicted counter-current flows setting up, e.g., flows toward the intake during generation when bottom release was employed.

Narrowing the intake from the150 m to 40 m while maintaining a 1 m slot width yielded even greater velocities (20 – 30 cm/s during pumping and generation, respectively), with a more pronounced countercurrent flow regime in place. Narrowing the intake further, to 10 m width, produced velocities of 34 cm/s during mid-depth pumping and 59 cm/s during bottom release generation, with dramatic countercurrent flows (exceeding 19 cm/s and directed toward the intake during generation). These velocities would create entrainment concerns not only for larval fish and other planktonic organisms but also would likely entrain weak swimming juveniles and some adults as well.

Despite the high velocities near the intake, water currents slowed dramatically away from the intake, such that even with velocities approaching 60 cm/s at the intake, values declined to <3 cm/s at 560 m distance; this is a velocity lower than values often seen in lake under typical daily meteorological conditions.

The high velocities near the intake due to use of narrow gates and slot widths did generate a great deal of bottom shear stress however, such that an estimated 22,700 – 83,000 $m^2$ (6 - 21 acres) of lake bottom could be prone to resuspension. While the 150 m x 1 m intake gate was predicted to scour little sediment (170 and 2030 kg for the Santa Rosa and Ortega Oaks sites, respectively), the very narrow 10 m x 1 m intake gate with bottom release was predicted to scour in excess of 2,600,000 kg at the Ortega Oaks site. Despite the high local velocities, even these narrow intake gates and slot widths had a minimal influence on thermal stratification, lowering for example, $\Delta T$ at site E2 by 0.49 – 0.71 ºC for 40 m and 10 m intake gate widths when operated at the Santa Rosa site.

The focusing of flow to discrete depths within the water column through the use of gate structures appears to offer little benefit. Selective withdrawal and return flow was not predicted to substantively weaken stratification or improve mixing in the lake. Moreover, a very narrow gate was predicted to create velocities of sufficient magnitude that entrainment of nearby free-swimming organisms would be possible during pumping, while bottom release through a very narrow gate could unnecessarily create sediment resuspension problems, at least upon initial start-up and after intervals of non-operation.

## 6.0 Conclusions

Model simulations indicate that LEAPS is not predicted to substantially alter the natural stratification and mixing processes in the lake, nor resuspend significant quantities of sediments unless a very narrow gate structure is used. These are rather surprising results in some ways, since a substantial amount of turbulent kinetic energy is introduced to the water column during operation (Anderson, 2006). Two factors are thought to account for these observations. First of all, previous heat budget calculations (Anderson 2006b) indicated that LEAPS operation is not expected to alter the temperature of the water returned during generation. Thus, strong overflow or underflow conditions due to differences in density of water delivered to the lake are not expected. That is, water will be removed and returned to equivalent depths during operation; as a result, buoyant forces would not be able to focus flow to narrow depth regions that could allow water to move comparatively large distances from the intake at higher velocities relative to flow mixed into a larger vertical region.

The 2nd factor that is thought to greatly affect observed behavior concerns the bottom topography near the intake. Since the intake is a shore-mounted structure, it is located in shallow water that requires removal of an estimated 24,000 – 26,000 m$^3$ of sediment. This excavation will create a substantial sill located approximately 100 m into the lake (Figs. 11 and 12). Water withdrawn or returned through the intake flows over the sill and thus water will be added to or removed from the upper water column (the upper ~5 m when the lake is at 1247' and the uppermost ~3 m when the lake level is near the lower operational range of 1240'). Moreover, the sill that necessarily encircles the intake tends to promote a high degree of turbulence and formation of eddies and counter-current flows that further restrict efficient transfer of momentum into the deeper portions of the lake. These factors thus limit the potential for enhanced mixing of the water column away from the immediate effect of the intake.

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# ECOLOGICAL IMPACTS FROM LEAPS OPERATION: PREDICTIONS USING A SIMPLE LINEAR FOOD CHAIN MODEL

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## Introduction

Pumped-storage hydroelectric plants withdraw and return substantial volumes of water from the source reservoir in a short period of time; operation can thus potentially entrain a large number of organisms that lack sufficient motility to avoid being drawn into the turbines. Larval fish (ichthyoplankton) are particularly susceptible to entrainment and mortality (Miracle and Gardner, 1980). For example, Prince and Mengel 1980) reported 7 – 24% loss of fish larvae as a result of pumped-storage operation at the Keowee Reservoir. Similar loss of larval fish were predicted for the Jocassee Pumped Storage Station based upon a simple analytical model (Prince and Mengel, 1980). Application of this model to Lake Elsinore suggested that 40 – 100 % of larval fish could be lost as a result of regular (5 days a week) LEAPS operation depending upon lake level and assuming uniform dispersal of ichthyoplankton throughout the lake (Anderson, 2006). Use of a filter curtain that was assumed to reduce entrainment by 80% yielded much lower % reductions in larval fish (8.1 – 29%) (Anderson, 2006). Mortality rates generally increase with increasing size, from 17 – 40 % mortality for larval fish passing through a pumped-storage plant (Heisey and Mathur, 1980) to 56-68 % for juvenile and adult fish (Serchuk, 1976). Entrainment of juvenile and adult fish is lower, however, since most would be strong enough to avoid being drawn into the system during pumping.

Zooplankton (including both larval and adult forms) would also be subject to entrainment. Less is known about changes in zooplankton populations as a result of pumped-storage plant operation. Predicted impacts to zooplankton populations from plant operation on Lake Ivosjon in southern Sweden were modest (2-12 %) and within the natural observed variability there (Horst, 1980).

Preliminary model calculations for Lake Elsinore based upon a steady-state solution to a carrying-capacity model that included entrainment and mortality indicated less dramatic an effect on zooplankton populations than predicted for larval fish. LEAPS operation was predicted to lower zooplankton levels by 7 – 24.8 % depending upon lake level and pumping rate (Anderson, 2006); use of a filter curtain that reduced entrainment by 50% was predicted to yield reductions of 3.5 – 12.4 %.

Entrainment and potential loss of phytoplankton was also assessed using a carrying-capacity model with entrainment and mortality; the rapid natural reproduction rate of most phytoplankton (e.g., Eppley, 1972) was found to keep pace with loss from entrainment. As a result, LEAPS operation was assumed to lower phytoplankton levels by only 1.1 – 4 % from the reference (no operation) case (Anderson, 2006).

Preliminary calculations made for Lake Elsinore thus indicate that LEAPS operation would have a negligible impact on phytoplankton, a modest impact on zooplankton and the greatest impact on fish. These calculations treated each group of organisms (phytoplankton, zooplankton and larval fish) as isolated organisms whose populations were a function of the lake's carrying capacity for each group of organisms, their reproductive rate and the relative rate of pumping to overall lake volume that defined the probability of entrainment. While instructive, this approach does not allow for the interactions between these different groups of organisms. In reality, of course, the populations of phytoplankton, zooplankton and fish are all connected to each other through the food web of the lake. Thus, one may expect there to be a trophic cascade (Carpenter et al., 1985) that would result from loss of, *e.g.*, larval fish or zooplankton, due to LEAPS operation.

The objective of this study was to consider slightly more carefully the changes in the ecosystem of Lake Elsinore that may result from LEAPS operation.

## 1. Predicted Ecological Impacts from LEAPS Operation

The potential consequences of LEAPS operation on the food web of the Lake Elsinore was evaluated through development and application of a simple ecological model. While highly sophisticated lake ecosystem models have been developed that allow, e.g., prediction of blue-green algal densities at a specific time, location and depth in a lake, the development and successful application of such a comprehensive lake ecosystem is an extremely challenging task that requires a tremendous amount of information about the study site. The questions to be addressed in this study are more simple. Specifically, through a simplified linear food web model for Lake Elsinore, will LEAPS operation alter the ecology of the lake relative to no pumped-storage plant operation?

To address this question, a simple linear food web was proposed (EIP, 2004) (Fig. 1). The model is necessarily a simplification of the food web in the lake, and includes the lumping together of a number of different species and age classes into common trophic levels and ecological niches. Nonetheless, it is expected to provide a reasonable representation of the food web for the purposes herein.

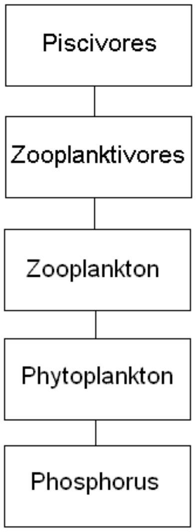

*Fig. 1. Simplified food web for Lake Elsinore (explicitly linked to available phosphorus)*

Phosphorus was taken as the biologically-available fraction that was assumed to be supplied to the water column via internal recycling and lost through the process of assimilation by phytoplankton. The population of phytoplankton (modeled explicitly as chlorophyll a concentration) was a function of phytoplankton growth that was limited by available P and modeled using Monod kinetics, and phytoplankton loss through grazing by zooplankton, settling and entrainment (for LEAPS simulations) (Fig. 1). The zooplankton population (especially large-bodied cladocerans) in the model was controlled by availability of phytoplankton, predation by zooplanktivores (e.g., larval and juvenile fish and adult shad), respiratory losses and death, and entrainment, while zooplanktivore levels in the lake were a function of availability of zooplankton, predation by piscivores (e.g., crappie, striped bass), other mortality and entrainment. Piscivore populations were constrained by the availability of prey (zooplanktivores), natural mortality and entrainment, although entrainment (during LEAPS simulations) was considered low since piscivores were assumed to be juveniles or adults and thus generally able to avoid entrainment under most circumstances.

The differential equation to describe biologically-available P [BAP} in the lake was written as:

$$\frac{d[BAP]}{dt} = \frac{J_{IL}}{Z} - \frac{\mu_{\max}\{BAP\}}{K_M + [BAP]}\frac{[Phyto]}{Y} \qquad (1)$$

where *[BAP]* is the concentration of biologically-available P (mg m$^{-3}$), *t* is time (d), $J_{IL}$ is the internal recycling rate (mg m$^{-2}$ d$^{-1}$), *Z* is the mean depth of the lake (m), $\mu_{max}$ is the maximum growth rate constant (d$^{-1}$), $K_M$ is the Monod constant (mg m$^{-3}$), *[Phyto]* is the concentration of phytoplankton (chlorophyll) (mg m$^{-3}$), and *Y* is the yield (amount of chlorophyll produced per unit mass of BAP) (mg chlorophyll mg$^{-1}$ BAP).

The change in phytoplankton population over time was written as:

$$\frac{d[Phyto]}{dt} = \frac{\mu_{\max}\{BAP\}}{K_M + [BAP]}[Phyto] - g_z[Zoo][Phyto] - \frac{\nu}{Z}[Phyto] \qquad (2)$$
$$- m_{LLEAPS}^{Phyto} f_p \frac{Q}{V}[Phyto]$$

where $g_z$ is the average grazing rate (or filtration rate) of each zooplankton (m$^3$ indiividual$^{-1}$ d$^{-1}$), *[Zoo]* is the zooplankton population (# individuals m$^{-3}$), $\nu$ is the algal settling velocity (m d-1), $m_{LEAPS}$ is the phytoplankton mortality during entrainment, $f_p$ is the fraction of phytoplankton within the pumped volume entrained, $Q$ is the average daily pumping flow rate (m$^3$ d$^{-1}$), and $V$ is the volume of the lake (m$^3$).

The change in zooplankton population over time was taken as:

$$\frac{d[Zoo]}{dt} = g_z \varepsilon_z [Zoo][Phyto] - g_{f1}[Zoo][Fish1] - m_z [Zoo] - m_{LEAPS}^{Zpp} f_z \frac{Q}{V} [Zoo] \qquad (3)$$

where $\varepsilon_z$ is the zooplankton production term (# zooplankton mg$^{-1}$ chlorophyll, $g_{f1}$ is the zooplanktivore grazing rate (m$^3$ individual$^{-1}$ d$^{-1}$), $[Fish1]$ is the population of the zooplanktivore (# individuals m$^{-3}$), $m_{LEAPS}$ is the zooplankton mortality during entrainment, and $f_z$ is the fraction of zooplankton within the pumped volume that are entrained.

The change in zooplanktivore population with time was given by an expression similar to that of eq 3:

$$\frac{d[Fish1]}{dt} = g_{f1} \varepsilon_{f1} [Fish1][Zoo] - g_{f2}[Fish1][Fish2] - m_{f1}[Fish1] - m_{LEAPS}^{Fish1} f_{f1} \frac{Q}{V} [Fish1] \qquad (4)$$

where $\varepsilon_{f1}$ is the zooplanktivore production term ( zooplanktivores zooplankton$^{-1}$), $g_{f1}$ is the predation rate of piscivores (m$^3$ inidividual$^{-1}$ d$^{-1}$), $m_{f1}$ is the natural mortality rate of the zooplanktivores (due e.g., to disease) (d$^{-1}$), $m_{LEAPS}$ is the zooplanktivore mortality during entrainment, and $f_{f1}$ is the fraction of zooplanktivore within the pumped volume that are entrained.

The final expression describes the change in piscivore population *(Fish2)* over time:

$$\frac{d[Fish2]}{dt} = g_{f2} \varepsilon_{f2} [Fish2][Fish1] - m_{f2}[Fish2] - m_{LEAPS}^{Fish2} f_{f2} \frac{Q}{V} [Fish2] \qquad (5)$$

where $\varepsilon_{f2}$ is the piscivore production term (# piscivores zooplantktivore$^{-1}$), $m_{f2}$ is the mortality rate of the piscivores (d$^{-1}$), $m_{LEAPS}$ is the piscivore mortality during entrainment, and $f_{f2}$ is the fraction of piscivores within the pumped volume that are entrained.

These 5 ordinary differential equations form the food web model, and are all coupled to each other (*e.g.*, the phytoplankton population appears in both eqs 1 and 2, the zooplankton term appears in eqs 2 and 3, and so on), and thus require a numerical solution. The equations were solved using a simple forward-difference integration scheme with a 0.05 d timestep. Simulations were run for 4 months to ensure approach to a steady-state solution to eliminate variable time dependencies and facilitate comparison between different conditions.

The constants used in the calculations were derived from a variety of sources, including Thomann and Mueller (1987), Chapra, 1997), Lorenzen (1996), Sammons et al. (1998), and are summarized in Table 1.

Table 1. Model parameters and values used in simulations.

| **Parameter** | **Value** | **Parameter** | **Value** |
|---|---|---|---|
| $J_{IL}$ | 8 mg $m^{-2}$ $d^{-1}$ | $\varepsilon_z$ | 2500 ind $ind^{-1}$ $d^{-1}$ |
| Z | 4.0 - 5.6 m | $g_{f1}$ | 1 $m^3$ $ind^{-1}$ $d^{-1}$ |
| $\mu_{max}$ | 2.0 $d^{-1}$ | $f_z$ | 1.0 |
| $K_m$ | 5 mg $m^{-3}$ | $m_z$ | 0.03 $d^{-1}$ |
| Y | 2.5 mg $mg^{-1}$ | $\varepsilon_{f1}$ | $2.5\times10^{-6}$ ind $ind^{-1}$ |
| $g_z$ | $5\times10^{-6}$ $m^3$ $ind^{-1}$ $d^{-1}$ | $m_{f1}$ | 0.019 $d^{-1}$ |
| $\nu$ | 0.1 m $d^{-1}$ | $g_{f2}$ | 10 $m^3$ $ind^{-1}$ $d^{-1}$ |
| $m_{LEAPS}$ | 0.5 | $f_{f1}$ | 0.5 |
| $f_p$ | 1.0 | $\varepsilon_{f2}$ | 0.01 ind $ind^{-1}$ |
| Q | $2.83\times10^6$ $m^3$ | $m_{f2}$ | 0.005 $d^{-1}$ |
| V | $4.85\times10^7$ -$7.4\times10^7$ $m^3$ | $f_{f2}$ | 0.01 |

The values provided in Table 1 for the volumes and average depths represent the range expected for the lake based upon the bathymetric data of Anderson (2006). The fraction of organisms within the pumped volume that were entrained were assumed to be 100% (i.e., $f_p$=1) for phytoplankton and zooplankton, while one-half of the planktivorous fish were assumed to be larval or juvenile forms that would be susceptible to entrainment, while only a very small fraction of the piscivores were assumed to be entrained (1%). For those organisms entrained, mortality was assumed to increase with increasing size (Miracle and Gardner, 1980), from 20% for phytoplankton, to 50% for entrained zooplankton and zooplanktivores, and 70% of the larger piscivores.

Model calculations were performed assuming increasing complexity of the food web to demonstrate the effects that high trophic levels can exert on chlorophyll and nutrient concentrations in Lake Elsinore. As a result, a total of 4 different food webs were assessed. The simplest food web assumed internal loading supplied biologically-available phosphorus (BAP) to fuel phytoplankton growth. The effect of zooplankton on predicted chlorophyll and BAP was then assessed, followed by the inclusion of zooplanktivorous fish, and then finally the effect of piscivores. This latter scenario thus represents the full food web depicted in Fig. 1. The reference case, when LEAPS was not in place, was compared with LEAPS operation at an average daily pumping rate (including 2 days of non-operation each week) of 2294 af $d^{-1}$ at nominal lake levels of 1247 and 1240 ft above MSL (relative average pumping rates, Q/V, of 0.039 and 0.060 $d^{-1}$).

In the simplest food web that includes just BAP and phytoplankton, phytoplankton growth kept predicted BAP concentrations very low (<0.5 $\mu g\ L^{-1}$) (Fig. 2a), while chlorophyll levels were predicted to reach a steady-state concentration of 200 $\mu g\ L^{-1}$ (Fig. 2b). Operation of LEAPS was found to lower chlorophyll concentrations by 30-40% through entrainment and mortality, although concentrations remained high (Fig. 2b).

Addition of zooplankton to the food web yielded a much higher BAP concentration and a dramatically lower predicted chlorophyll concentration (Fig. 2). Grazing by zooplankton exerted a very strong effect on phytoplankton levels and thus also altered available nutrient levels in the lake. LEAPS operation increased slightly predicted chlorophyll levels and reduced BAP concentrations as a result of lower predation by zooplankters.

Incorporation of zooplanktivorous fish (including larval forms of almost all species, as well as adult shad and other planktivores) into the food web of Lake Elsinore lowered predicted BAP concentrations and increased quite substantially chlorophyll concentrations relative to the phytoplankton+zooplankton food web (chlorophyll levels of 36 – 64 $\mu$g L$^{-1}$) (Fig. 2b). These concentrations do remain below the phytoplankton-only food web, however. LEAPS operation was predicted to lower somewhat predicted chlorophyll levels.

The penultimate food web for the lake would include a large population of piscivorous sport fish; it can be seen that a healthy population of piscivores would also maintain quite low predicted chlorophyll levels in the lake (7 - 10 $\mu$g L$^{-1}$).

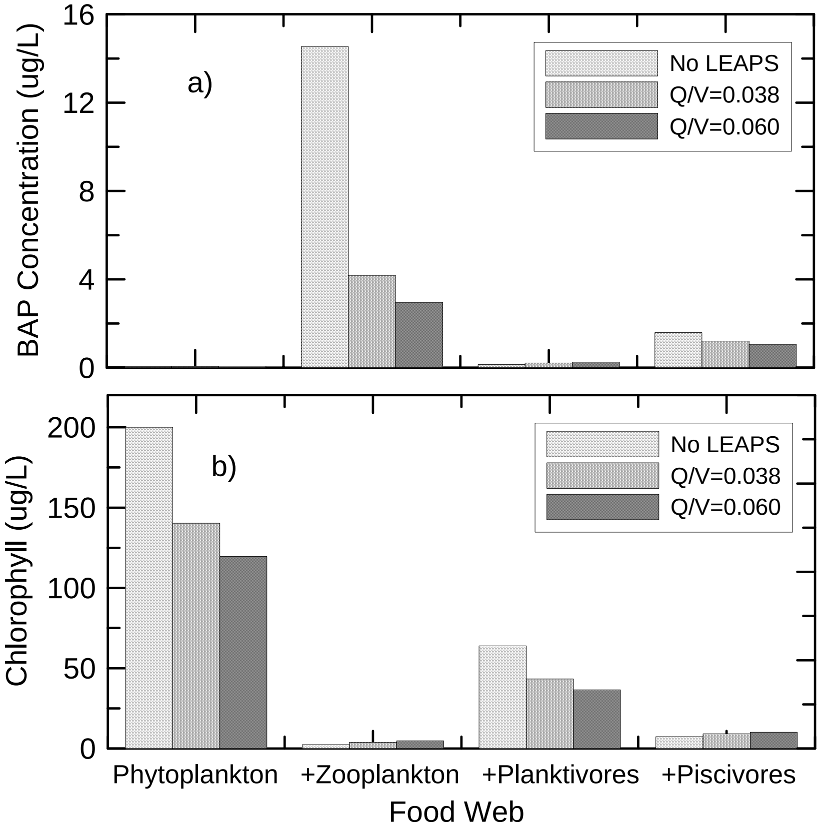

*Fig. 2. Predicted a) BAP and b) chlorophyll concentrations in Lake Elsinore for food webs of increasing complexity (from left to right). The natural condition (no LEAPS) and LEAPS operation at two relative pumping rates (Q/V) are shown.*

The higher trophic levels help explain the trends observed in Fig. 2. For example, with the phytoplankton-only system, chlorophyll levels are controlled by the balance of algal production and loss due to settling. Since algal settling rates are low (~0.1 m $d^{-1}$), high predicted chlorophyll levels result from the rapid rate of internal recycling in the lake (taken in these calculations as 8 mg $m^{-2}$ $d^{-1}$) (Anderson, 2001). These high levels of phytoplankton production could in principle support a substantial large-bodied zooplankton population in the lake. The model in fact predicts a zooplankton population of nearly 300 individuals $L^{-1}$ (Fig. 3a). Zooplankton effectively grazed down chlorophyll to very low levels (Fig. 2b) as phytoplankton production was converted to zooplankton biomass (Fig. 3a). LEAPS operation lowered zooplankton populations by up to 51% at the higher relative pumping rate. This reduced zooplankton population was less effective at algal control, however (Fig. 2b). The higher algal population utilized more BAP, thus lowering its predicted concentrations from >14 to <4 μg $L^{-1}$ (Fig. 2a).

The high zooplankton production potential in Lake Elsinore that results from internally recycled P fueling algal growth could, in turn, support a large population of larval, juvenile and adult planktivorous fish (Fig. 3b). With some admittedly simple assumptions, the model predicted planktivore abundances potentially approaching 1 per $m^3$; the effect of the planktivores was to substantially lower the zooplankton population in the lake (Fig. 3a, +planktivores) relative to the food web without predation on zooplankters (Fig. 3a, +zooplankton). Reductions in zooplankton populations of 90-97% were predicted. LEAPS operation did also negatively impact planktivore levels (Fig. 3b); reductions in zooplanktivores increased zooplankton levels in the lake (Fig. 3a) that in turn led to a “trophic cascade”, wherein the higher zooplankton population yielded lower predicted chlorophyll concentrations (Fig. 2b). That is, chlorophyll levels are inversely related to zooplankton populations and thus tied to the relative abundance of planktivores in the lake (↑ planktivores: ↓ zooplankton: ↑ chlorophyll).

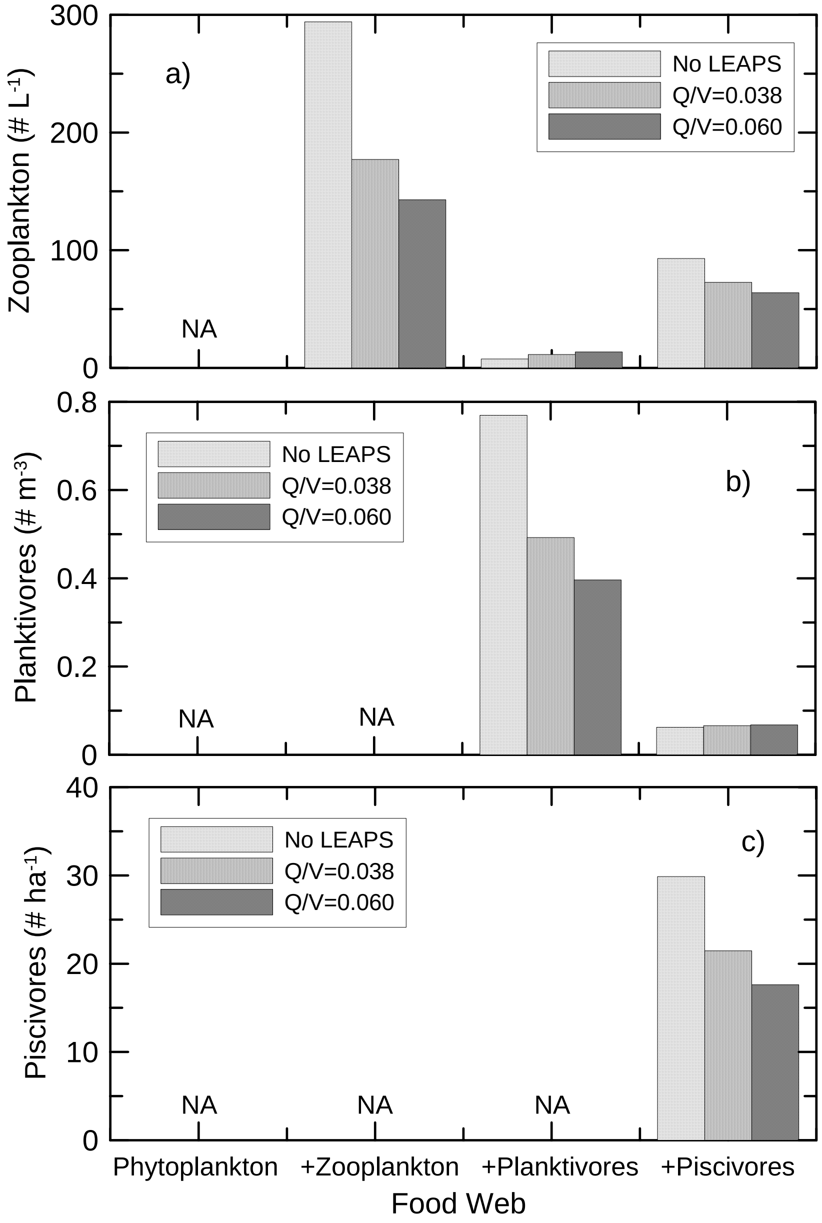

*Fig. 3. Predicted a) zooplankton, b) planktivore and c) piscivore populations in Lake Elsinore for food webs of increasing complexity (from left to right). The natural condition (no LEAPS) and LEAPS operation at two relative pumping rates (Q/V) are shown. (Simple food webs lack the higher trophic levels, and so are represented as NA.)*

One of the primary goals of the fisheries management plan is to maintain a viable sport fishery with piscivores capable of controlling planktivore (e.g., shad) levels in Lake Elsinore (EIP, 2004). Since algal levels are tied to planktivore abundance, piscivores would favorably shift the ecosystem to a zooplankton-rich food web with limited chlorophyll concentrations (↑ piscivores: ↓ planktivores: ↑ zooplankton: ↓ chlorophyll). The model suggests that piscivores could effectively control planktivore levels in the lake, and that would in turn help maintain a strong zooplankton community (Fig. 3) and help achieve low chlorophyll levels in the lake (Fig. 2b). LEAPS operation was predicted to affect the piscivore population and that effect cascaded through the food web, although the overall effect on chlorophyll levels was modest (Fig. 2b). It appears that the cumulative effect of entrainment and mortality to phytoplankton, zooplankton, planktivorous fish and piscivores tended to damp out slightly the trophic cascade through the food web.

Since transparency is probably the most useful index of the aesthetics and overall water quality in a recreational lake, predicted chlorophyll concentrations (Fig. 2b) were used to predict a mean Secchi depth ($Z_{sd}$) based upon the empirical equation developed by Veiga-Nascimento (2004). The equation was developed using 2001-2004 transparency and chlorophyll measurements (*Chl*) taken at Lake Elsinore, and is of the form:

$$Z_{sd}\ (m) = 47.48\ /[Chl\ (\mu g\ L\text{-}1) + 24.81] \qquad (6)$$

The time period from which this equation was developed represented generally very poor water quality (e.g., Secchi depths in all instances <1 m), so the equation is considered more accurate for higher chlorophyll levels. Notwithstanding, the simple ecosystem model (eqs 1-5), combined with eq 6, yielded transparencies <0.35 m for the algal-dominated (phytoplankton only) state, irrespective of LEAPS operation (Fig. 4). The presence of zooplankton yielded much improved Secchi depths (predicted transparencies of 1.6 – 1.75 m), while the presence of planktivorous fish, through the trophic cascade described above, resulted in a marked loss of water clarity (Fig. 4). Piscivores (including fish-eating birds, although they were not explicitly modeled in this analysis) were predicted to maintain transparencies that were 4-7x greater than the algal-dominated state and 2-3x that found for the planktivore-dominated food web.

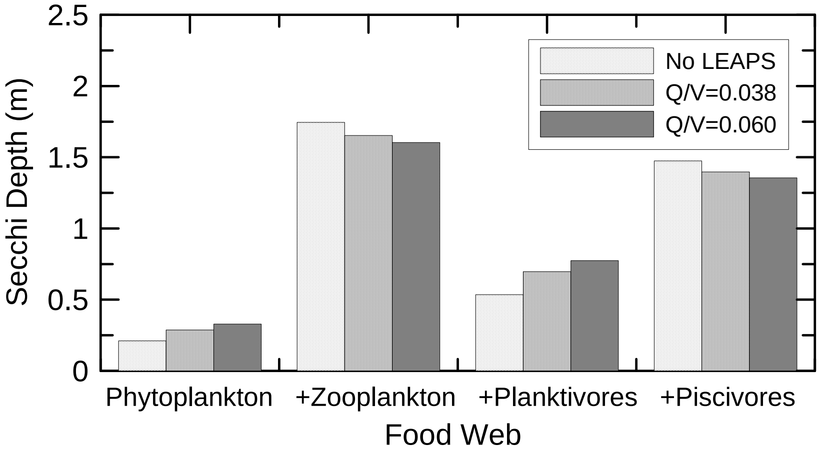

*Fig. 4. Predicted Secchi depth in Lake Elsinore for food webs of increasing complexity (from left to right). The natural condition (no LEAPS) and LEAPS operation at two relative pumping rates (Q/V) are shown.*

The effect of LEAPS on predicted transparency is more subtle than that of the food web composition and alternately improves or worsens Secchi depth depending specifically how the food web is terminated. Food webs that directly or indirectly favor zooplankton production (and algal consumption) were negatively impacted by LEAPS operation, although predicted reductions in Secchi depth were <10%. The effect of LEAPS operation on those food webs that favored algal production (*e.g.*, phytoplankton-only or the food web terminated with planktivores) were predicted to actually benefit from the entrainment and mortality of these organisms, although transparencies were predicted to increase only about 0.1 – 0.2 m.

A reasonable question, then, is which food web best represents Lake Elsinore? An incomplete picture of the lake’s food web persists at present; in particular, little information is available concerning the abundance of threadfin shad (*Dorosoma petenense*). Previous die-offs indicate that shad populations have, at times, been extremely large, and threadfin shad are thought to be the most abundant fish in Lake Elsinore (EIP, 2004). A die-off in 1998, in which an estimated 8 – 12 million shad died, indicates that the population at that time was at least 0.1 – 0.2 shad $m^{-3}$.

Notwithstanding the lack of information about the threadfin shad population, mark-and-recapture and other efforts over the past few years have provided valuable information about the fishery of the lake. What is clear from these efforts is that the food web in Lake Elsinore has varied quite substantially in the recent past, with a cladoceran-deficient zooplankton community (Veiga-Nasciemento, 2004) and carp-dominated fishery present in 2003-2004 (EIP, 2004). This was replaced by a more diverse food web following the winter storms in 2005. The food web in 2005 and 2006 included abundant *Daphnia* and other beneficial zooplankton (unpubl. data), as well as crappie, catfish and other (generally piscivorous) sport fish (Kilroy, pers. comm.).

This natural variation in the ecology of Lake Elsinore thus makes it difficult to focus on a single food web and the effects of LEAPS on that ecosystem structure. One could argue that in 2003-2004, the food web may have been best described as the simple algal ecosystem with no meaningful higher trophic levels (benthivorous carp, while abundant, would not generally be considered strong planktivores nor piscivores but would help fuel internal loading of nutrients). Anecdotal evidence suggests that the shad population may have been low during this time period based upon the absence of large-bodied zooplankton and the limited numbers of fish-eating birds relative to those present in 2001 or 2005-2006. The high levels of salinity at that time were demonstrated in laboratory studies to limit reproduction and induce direct mortality of *Daphnia* and *Ceriodaphnia* (Veiga-Nascimento, 2004). Moreover, the phytoplankton community that was dominated by *Oscillatoria* at that time (Oza, 2003) would have also clogged daphnid feeding-filtering apparatus and thus served as a very poor food resource (Infante and Abella, 1985). The levels of salinity present in the lake would have also been high enough inhibit successful reproduction of many species of freshwater fish. (Note that the ecosystem model developed above does not explicitly account for such factors, and thus is useful for describing waters that can support natural zooplankton and fishery reproduction, with a suitable phytoplankton community to serve as a food resource for zooplankton in the lake.)

The more recent conditions in Lake Elsinore, that include much higher lake levels and substantially reduced salinities (Lawson and Anderson, 2005), are thought to have provided conditions more favorable for reproduction of zooplankton and fish. This seems to be borne out where, as mentioned above, much higher *Daphnia* populations, combined with large numbers of young catfish, crappies and other sport-fish are now found in the lake. A vast number of fish-eating birds were observed through the past 2 years, with piscivorous bird densities approaching an estimated 200 $ha^{-1}$ in the open water some winter mornings. This implies a large abundance of small fish, likely shad (which favor open water), that would also be subject to intense predation. It seems reasonable to conclude that the food web for 2005-2006 most closely resembles the full food web with phytoplankton, zooplankton, zooplanktivores and piscivores (both sport fish and birds).

Qualitatively, then, the model does not seem out of line in terms of its predictions. 2003-2004 were in fact characterized by very poor water quality, with chlorophyll routinely exceeding 100 $\mu g\ L^{-1}$ and averaged somewhere near 200 $\mu g\ L^{-1}$ and Secchi depths that averaged 20-30 cm (Veiga-Nascimento, 2004). These values are in rather surprisingly good agreement with model predictions for the phytoplankton based food web (Fig.2 and 4, respectively), although this is no doubt partly serendipity. The more recent water quality condition at the lake appears to be reasonably represented with the full food web; predicted transparencies near 1.5 m (Fig. 4) are broadly consistent with measured values in 2005 and 2006 (1 – 2 m), although recent values indicate poorer water quality is returning (Secchi depths ~0.5 m). Chlorophyll values were generally 2-4x higher in 2005-2006 than that predicted by the model however (Lawson and Anderson, 2006).

Importantly, the effect of LEAPS operation on predicted water quality is small compared with the predicted (and observed) sensitivity of water quality to the structure of the food web. Thus, against a backdrop of a strongly varying ecosystem and dramatic variations in water quality, it is difficult to conclude that LEAPS operation will have a profound influence on the ecology and resulting water quality in the lake. Moreover, as noted previously, depending upon the particular food web in place, LEAPS operation may, albeit modestly, alternately improve or degrade water quality.

Assuming however, that improved control of lake level, salinity and other factors can maintain a functional phytoplankton-zooplankton-planktivore-piscivore food web, LEAPS operation would modestly negatively impact piscivore and zooplankton populations in the lake that would yield slightly higher chlorophyll concentrations and lower transparencies (Figs. 2-4). The use of a filter curtain would reduce entrainment of all planktonic organisms as well as some nekton. Simulations were thus conducted assuming exclusion and reductions of entrainment of larval fish by 80% and zooplankton by 50% following Anderson (2006). Entrainment of phytoplankton was assumed to be reduced more modestly (20%).

The installation of a filter curtain benefited overall water quality relative to LEAPS operated without the benefit of entrainment control. At an average relative pumping rate of 0.038 $d^{-1}$ (corresponding to the daily pumping rate averaged over a weekly cycle that included off-time on Sunday at the nominal upper operating elevation of 1247 ft above MSL), use of a filter curtain lowered predicted chlorophyll concentrations by 11% and planktivore abundance by 6% (Table 2).

Table 2. Predicted steady-state lake properties with LEAPS operation with and without a filter curtain to limit entrainment.

| **Property** | **Q/V=0.038** | **Q/V = 0.038 + Curtain** | **Q/V = 0.060** | **Q/V = 0. 060 +Curtain** |
|---|---|---|---|---|
| Chlorophyll ($\mu$g $L^{-1}$) | 9.2 | 8.2 (-11%) | 10.2 | 8.6 (-15%) |
| Zooplankton (# $L^{-1}$) | 72.7 | 82.8 (+14%) | 63.9 | 77.6 (+21%) |
| Planktivores (# $m^{-3}$) | 0.066 | 0.062 (-6%) | 0.068 | 0.062 (-9%) |
| Piscivores (# $ha^{-1}$) | 21.4 | 25.6 (+20%) | 17.6 | 23.4 (+33%) |
| Secchi depth (m) | 1.40 | 1.44 (+3%) | 1.36 | 1.42 (+4%) |

At the same time, the filter curtain increased zooplankton populations by 14% and piscivore levels by 20%. The effect was more pronounced at the higher relative pumping rate (corresponding with LEAPS operation at 1240 ft above MSL) (Table 2). Use of the filter curtain appears to offer the greatest benefit to the piscivores (and thus also the sport fishery). Food webs terminated with either phytoplankton or planktivores would experience a moderate decrease in water quality through the use of a filter curtain, however.

## 2. EFDC Simulations of Entrainment Potential Near Intakes

EFDC simulations were previously conducted to quantify the effects of LEAPS operation of thermal stratification, mixing and potential for sediment resuspension in Lake Elsinore (Anderson, 2007). In this analysis, the drifter subroutine in the EFDC model was activated to better understand the effects of LEAPS operation at the Santa Rosa and Ortega Oaks sites on the entrainment of planktonic organisms. Simulations were conducted in which neutrally buoyant particles were released at site E2 (near the center of the lake) in the 2$^{nd}$ computational layer from the top (about 2 m depth) and their positions recorded every 2 hours over a 15 day simulation period. The particles were thus moved due to advective motion set up by wind-forcing, from convective flows due to heating and cooling and, when LEAPS was in operation, due to flows induced by pumping and generation at the Santa Rosa or Ortega Oaks sites.

There is a certain randomness to the observed trajectories, because the particular time, depth and location of release will move particles in vastly different ways, so the observed trajectories represent only 1 realization in an infinite range of paths and thus do not have any unique relevance. However, since all particles were released at the same time and location, the deflection in the particle trajectory can be attributed to LEAPS operation.

One example of such trajectories is provided in Fig. 5. Without LEAPS operation, the particle drifted in a clockwise direction near the center of the lake. The particle traveled a total of 8.96 km over the 15 days, thus yielding an average velocity of approximately 0.7 cm $s^{-1}$. Release of a particle at the beginning of the pumping cycle during LEAPS operation at the Santa Rosa site did yield a different trajectory, with movement in a more counter clockwise direction, although the particle remained near the center of the lake. The particle was transported a greater distance (12.67 km) at an average velocity of 1.0 cm $s^{-1}$, but was not entrained during pumping.

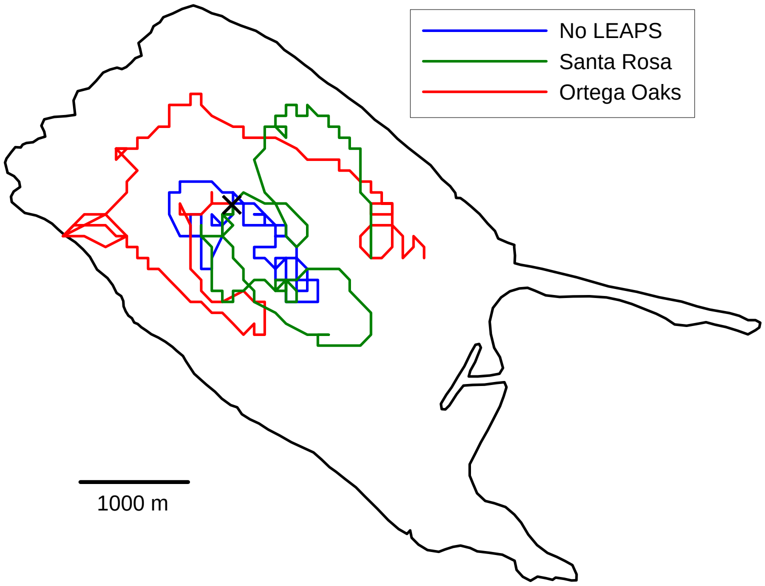

*Fig. 5.Predicted 15-day drifter trajectories following release at site E2 (shown with an X), comparing the natural trajectory with those resulting from LEAPS operation at the Santa Rosa and Ortega Oaks sites.*

Release of a particle during LEAPS operation at the Ortega Oaks site yielded greater total transport (14.76 km) and at a higher mean velocity (1.1 cm $s^{-1}$) (Fig. 5). More importantly, the particle was drawn into the intake on 2 separate events. Thus, advective currents transported the particle into the capture zone during a pumping cycle, the particle was then discharged during generation, and drawn back in during a 2nd pumping cycle before successfully migrating beyond the capture zone of the intake during pumping. Fig. 5 suggests that the capture zone extends about 600 – 800 m from the intake.

This was evaluated more rigorously for the Santa Rosa site by release of particles at grid locations extending at least 1200 m from the intake during the pumping cycle at the end of the week. This represents the largest drawdown and thus offers the greatest opportunity for entrainment. The median operational lake level of 1243.5 ft about MSL was used for the simulations with the meteorological condition the same as that used for previous velocity predictions near the intakes (Anderson, 2007). Trajectories were evaluated to determine whether entrainment from that initial location was observed. The radius of entrainment was then mapped (Fig. 6).

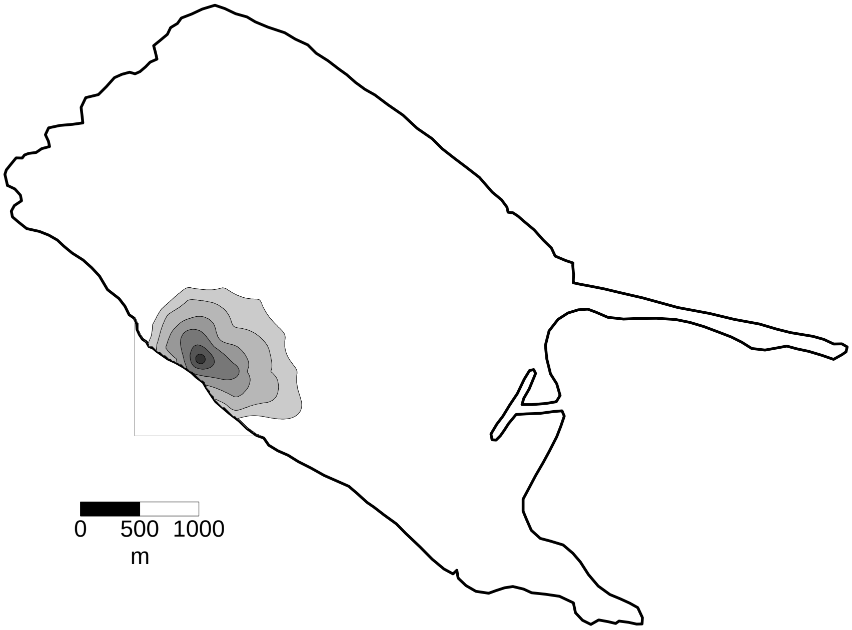

*Fig. 6. Predicted capture zone during maximum pumping at the Santa Rosa site.*

The entrainment or capture zone during maximal pumping was found to extend out 870 m in a perpendicular direction to the intake and up to 1500 m laterally (Fig. 6). The entrainment area comprised about 208 acres or 6.6% of the lake area. A smaller area would be expected during weekday pumping since the volume of water pumped is lower. Although not explicitly evaluated, broadly similar findings would be expected for the Ortega Oaks site based upon previous predictions of velocity profiles and bottom shear for the 2 sites (Anderson, 2007).

## Summary

A simple linear food web model was developed for Lake Elsinore to evaluate potential trophic cascades as a result of entrainment of planktonic organisms during LEAPS operation. The model assumed phosphorus was the limiting nutrient in the lake and supplied to the water column through internal recycling. Biologically-available phosphorus was available for uptake by phytoplankton assuming Monod kinetics, with phytoplankton subject to losses due to zooplankton grazing and due to settling. Zooplankton population growth was in turn dependent upon phytoplankton availability, predation by (zoo)planktivores that included larval, juvenile and adult forms, and an additional mortality term due to non-grazing losses. Planktivore growth was taken as a linear function of a predation rate and zooplankton abundance, while predation by piscivores and additional mortality terms were used to define loss. Piscivore populations were a function of planktivore (prey) availability and natural mortality rate. The effects of LEAPS operation were included in additional simulations through incorporation of entrainment and mortality.

Since available information about the food web in Lake Elsinore indicates that substantial variation has existed over the past several years, separate simulations were conducted for food webs terminated with phytoplankton, zooplankton, planktivores and piscivores. The effects of LEAPS operation on population dynamics and water quality for each of the different food webs was assessed at relative pumping rates of 0.038 and 0.060 $d^{-1}$.

The simple ecological model demonstrated that the structure of the food web will have a dramatic effect on water quality in Lake Elsinore, an effect that outweighs that due to LEAPS operation. High chlorophyll concentrations and low transparencies were predicted for a phytoplankton-dominated food web (that may include a large population of benthivorous fish such as carp). A theoretical food web terminated with zooplankton was predicted to have excellent water quality, although such a food web is found in nature only under very unusual circumstances. A food web terminated with zooplanktivores was predicted to have poor water quality due to excessive predation on large-bodied zooplankton that would allow algal levels to build up to substantial levels. The presence of piscivores, however, were predicted to yield very low chlorophyll concentrations and high transparencies.

LEAPS operation (without filter curtains or other provisions for limiting entrainment) was found to lower slightly predicted water quality in food webs terminated with zooplankton or piscivores, although the effect overall was modest. Conversely, LEAPS operation was predicted to improve somewhat the water quality for food webs terminated with phytoplankton and zooplantivorous fish due to entrainment and enhanced mortality of these organisms.

Use of a filter curtain was predicted to improve water quality and ecosystem health for a full food web that included sport fish and other piscivores, with chlorophyll levels declining by up to 15% and sport fish abundance increasing by up to 33% relative to LEAPS operation without efforts to control entrainment.

Three-dimensional EFDC simulations indicate that pumping can alter the trajectory of planktonic species in the lake, with planktonic organisms within 750-870 m radius of the intake, or about 6.6% of the lake area, prone to entrainment during pumping.

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## *Technical Memorandum*

**Task 1.0:** Surface Elevation and Salinity in Lake Elsinore: 1916-2014

### Objective

The objective of this initial task was to develop and calibrate a 1-D hydrodynamic model for Lake Elsinore to simulate volume, surface elevation and salinity in Lake Elsinore for the period 1916-2014, and compares model-predicted values with available observations.

### Approach

The DYRESM model was used to simulate conditions in Lake Elsinore under the 1-D assumption, *i.e.*, that lateral differences in water column properties are small and that the primary gradients in properties occur in the vertical dimension. The 1-D assumption is appropriate given the lake's relatively simple basin shape and the long time horizon of interest. Specifically, this assessment evaluated the time period from 1916-2014 (99 yrs). This time interval was selected because of availability of flow, rainfall and air temperature data for this full period.

Daily flows of the San Jacinto River into Lake Elsinore at USGS gage #11070500 were downloaded from USGS. Daily rainfall records were provided by RCFCD for the Quail Valley, (1958-2014), San Jacinto (1940-2014) and Hemet (1916-2014) rain gauges to estimate runoff from the local 13,340 acre watershed not captured by gaged San Jacinto River flows (Anderson, 2006). The available Quail Valley rainfall data were used for the 1958-2014 period without any correction. Regression equations developed between measured Quail Valley precipitation and that at San Jacinto ($r^2$=0.70) and Hemet $r^2$=0.52) were used to predict rainfall at Quail Valley for 1940-1958 and 1916-1940, respectively. Daily average air temperature, relative humidity/vapor pressure, shortwave radiation, and windspeed for 1985-2014 were taken from CIMIS station #057 at UC Riverside. Air temperature records for 1916-1985 were downloaded from the NOAA National Climatic Data Center for the Corona station that provided the longest nearby continuous record. Average shortwave solar radiation, vapor pressure and windspeed from CIMIS station #057 for each calendar day were used for the earlier part of the record when measurements of these meteorological attributes were not available (pre 1985).

The elevation-area data for the natural lake basin was used from the 1916-1995 period (*i.e.*, pre-LEMP), while the current reconfigured basin (*i.e.*, post-LEMP) was used for the period 1996-2014. A 10-minute time-step was used for the simulations.

## Meteorological and Flow Records

Analysis of meteorological and flow data over the past 99 years highlights the inter-annual variability present in the region. Annual rainfall within the local watershed of Lake Elsinore ranged from 2.04 inches in 2006 (based on water year) to 26.97 inches in 1977 (Fig. 1). Precipitation averaged 10.1 inches over this period, while the median was 8.89 inches. As suggested in Fig. 1, precipitation was not normally-distributed about the mean value; precipitation was found to be log-normally distributed however (mean log rainfall 0.96±0.21).

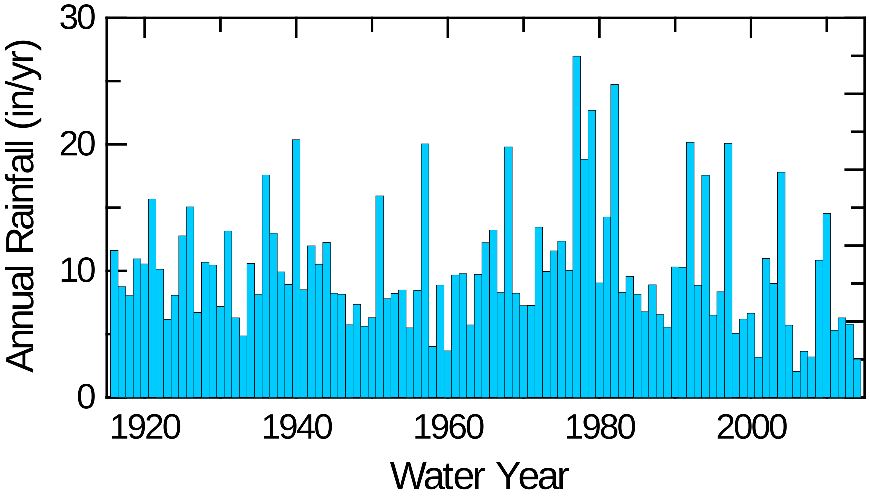

*Fig. 1. Annual rainfall to local watershed adjacent to Lake Elsinore.*

The mean annual air temperature has also varied over the past 99 years (Fig. 2). Temperature has averaged 17.08±0.81 °C over this interval, with a minimum value of 15.4 in 1934 and a maximum temperature of 19.5 °C in 1984, with a statistically significant increase ($p<0.001$) in average annual air temperature at a mean rate of 0.016°C/yr, or an increase of almost 1.6°C over the study period. This rate of change is larger than the global mean surface temperature increase of approximately 1.0°C over this same time period.

Annual runoff to Lake Elsinore measured at the USGS gage exhibited even more dramatic variation (Fig. 3). There were 5 years where virtually no flow was recorded at the gage, and 25% of the time, annual flow was <100 AF/yr. At the other end of the spectrum, 22 years were found to have flows >10,000 AF/yr, supporting the general notion of an El Nino-type event on average every 4-5 years. Low flows are difficult to see on this figure due to the periodic very large flows (e.g., water years 1916 and 1980).

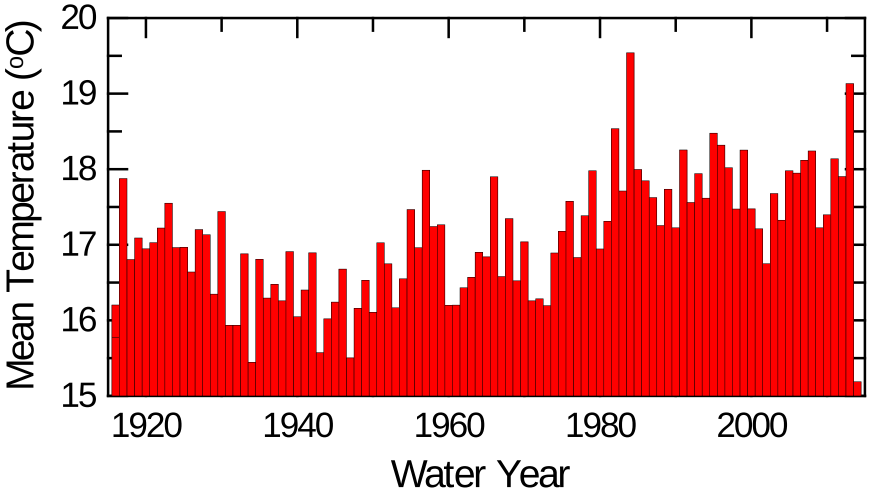

*Fig. 2. Mean annual temperature at Corona (NOAA)*

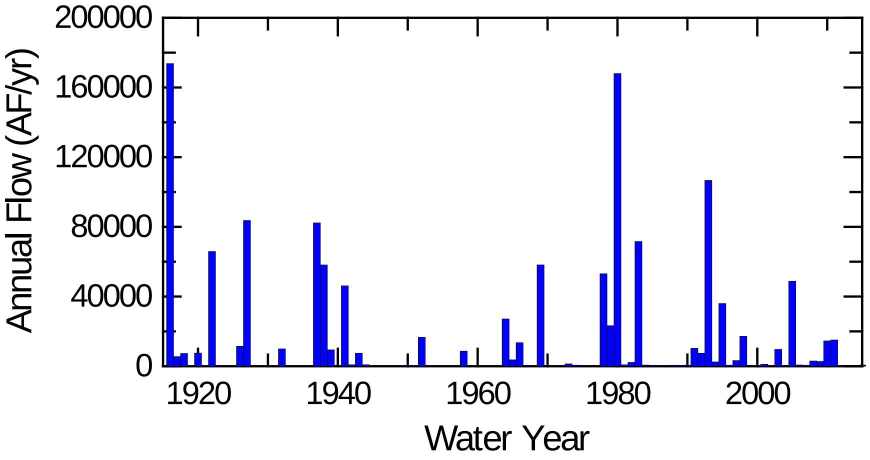

*Fig. 3. Annual flow at USGS gage #11070500 (San Jacinto River near Lake Elsinore)*

Local rainfall values (Fig. 1) were used to estimate local runoff flows to the lake (i.e., runoff from the land areas surrounding the lake and not captured by the USGS gage) (Fig. 4, orange bars). Previous measurements at the lake suggested a local runoff coefficient of about 0.3, or about 30% of precipitation contributed to runoff (Anderson, 2006), while 70% was on average retained by the soil through infiltration and storage within the porosity of the soil and weathered bedrock. Since runoff in urban and suburban-type watersheds is strongly influenced by the amount of impermeable surfaces (roads, parking lots, driveways and rooftops), an assumption was made that the runoff coefficient measured a few years ago adequately reflects current levels of development, but that the runoff coefficient would likely have been lower earlier in the study period. Specifically, a runoff coefficient of 0.2 was assumed from 1916-1960, 0.25 for 1961-

1980, and 0.3 for 1981-present. Local runoff averaged 2813 AF/yr. Recycled water was also recently added over a number of years (Fig. 4, green bars).

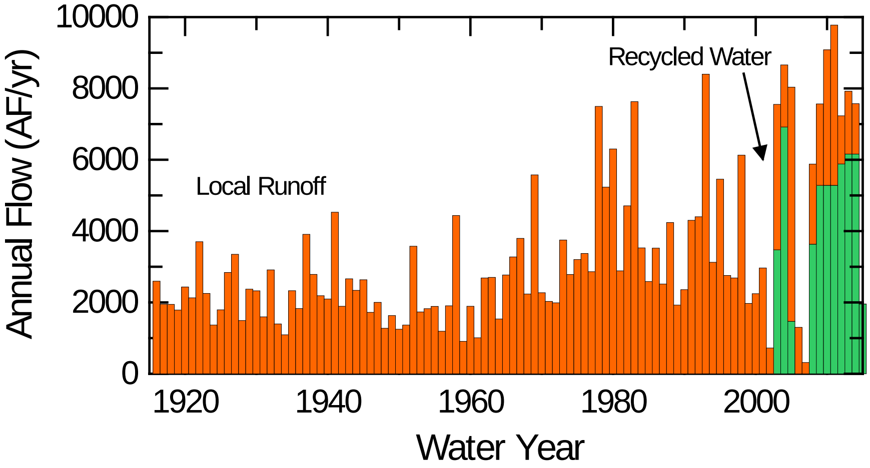

*Fig. 4. Annual flows to Lake Elsinore due to local runoff (orange bars) estimated from precipitation and runoff coefficient and recycled water additions (green bars).*

## Model Calibration: 1964-2014

### *Lake Level*

Daily average values for meteorological parameters were used in conjunction with daily flow data to predict volume, surface elevation, and salinity in Lake Elsinore over time. Lake surface elevation has been recorded regularly by Elsinore Valley Municipal Water District staff since 1964, following the dry lake bed from approximately 1954-1964 and beginning with importation and delivery of Colorado River Aqueduct water. Recorded lake level data were provided by Jesus Gastelum and used to calibrate the model with respect to the water budget.

Preliminary simulations used January 1, 1964 as the starting point with the introduction of Colorado River water beginning on February1, 1964 with model default parameter values; the model was found to over-predict water levels and surface water temperatures. More detailed analysis indicated that the model was under-predicting evaporation when compared with theoretical $ET_0$ values measured at UCR CIMIS station #057. This appears to be due to use of daily average values for air temperature, vapor pressure and windspeed, which do not adequately reflect the warm dry afternoon winds that result in much of the evaporative heat flux and water loss that occurs at the lake. To account for this, the bulk aerodynamic transport coefficient was lowered from $1.3 \times 10^{-3}$ to $0.3 \times 10^{-3}$ and non-neutral atmospheric stability was assumed; this was found to yield an annual evaporation rate from the lake that matched the rate of 1.47 m/yr reported at the UCR CIMIS station. Using these parameter values, predicted lake surface elevations from simulations matched much more closely measured values over the 1964-2014 period, except immediately following a large runoff event that dramatically increased lake level and wetted lake area. This discrepancy was attributed to rapid infiltration into dry lake bed sediment and surrounding soils and potential groundwater recharge. This was especially evident in 1964 when water was introduced in the lake basin following an approximately decade-long dry lake bed, and in 1970 and 1980 when large volumes of runoff was delivered to the lake (Fig. 3). Following the major runoff event in 1980, about 40% of the runoff delivered to the lake was estimated to have saturated soils and recharged groundwater as a result of rewetting more than 2000 acres of the lake's approximately 6000 acre natural basin. Infiltration rates were estimated to be 0.7 cm/d. Subject to these corrections, the model predicted lake surface elevations that very closely followed measured values (Fig. 5). Note that the natural 6000 acre basin was assumed to be in place through 1995, at which time the LEMP project was completed which reduced lake area and increased mean depth.

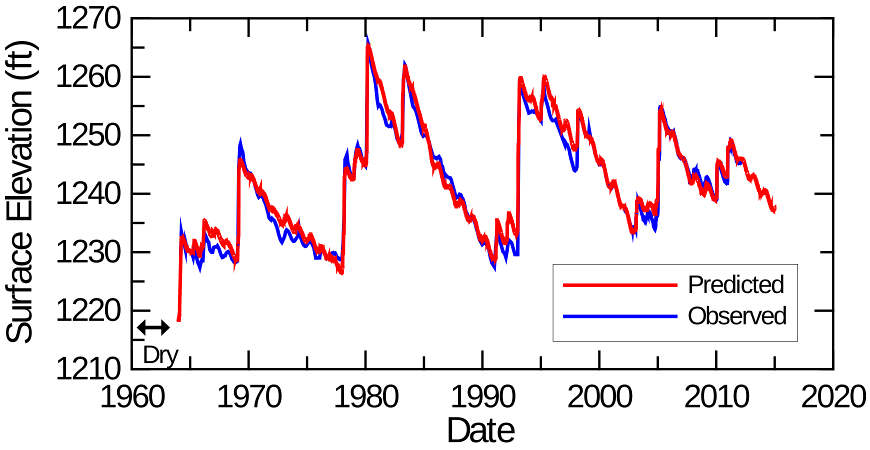

*Fig. 5. Surface elevation of Lake Elsinore: 1964-2014 (blue line represents measured values; red line represents predicted values).*

The model quite reasonably reproduced lake level in the post-LEMP basin (1996-2014) without any corrections for infiltration so none were applied over this interval (Fig. 5). This is thought to be a result of the tight clay layer present across much of the lower part of the lake basin that limits deep percolation and minimizes loss to unsaturated soil or groundwater. The reconfiguration of the basin as a result of LEMP thus not only reduced evaporative loss but all quite substantially reduced losses to unsaturated soils and groundwater. Root-mean square error (RMSE) of model-predicted surface elevations was 0.0047 ft.

### *Salinity*

Salinity in the lake is a function of runoff volumes, salinities of those flows, and evapoconcentration. Based upon available measurements and reports, average TDS values for the San Jacinto River, local runoff and recycled water were taken as 300, 150 and 700 mg/L. TDS levels would also vary markedly as a result of rewetting of a dry evaporite lake bed, and during episodes of evapoconcentration as well as large runoff events. The amount of salt deposited during the approach to and subsequent decade-long dessication period of 1954-1964 is not known, but local accounts do report frequent episodes of intense blowing dust and salt. It is likely that wind erosion was a mechanism by which a significant amount of salt was exported from the lake basin. Based upon water budget calculations (Fig. 5) and other factors, initial salinity was varied and model results were compared with observed values. Reasonable agreement was found when initial salinity was set at 7,500 mg/L TDS with a maximum water depth of 18 cm. Importantly, this TDS value was in good agreement with the TDS value of 8,000 mg/L measured in sediment porewater above the clay dessication layer from a core collected from the deepest part of the lake (unpublished data). (The model requires at least 18 cm of water be present in the lake and also requires that the salinity of the water remain below about 42,000 mg/L based upon the UNESCO equation of state for water that governs vapor pressure, specific heat and other thermodynamic properties of water.) The model predicted wide swings in TDS, with extended periods of evapoconcentration and increasing salinity followed by rapid declines as a result of large runoff events (Fig. 6). Model predicted TDS levels were in good overall agreement with measured TDS values available over the past 15 years when studies began in earnest at the lake (Fig. 6). RMSE of model-predicted TDS concentrations was 203 mg/L.

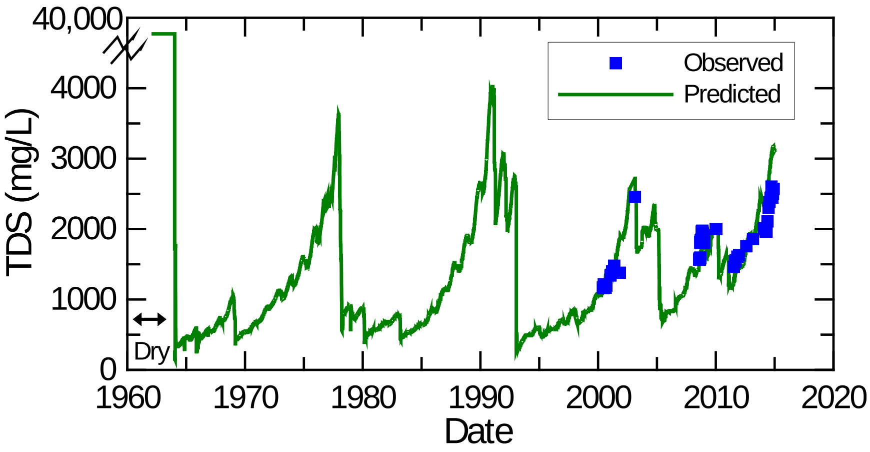

*Fig. 6. Total dissolved solids (TDS) concentration in Lake Elsinore: 1964-2014 (blue symbols represents measured values; green line represents predicted values).*

The model accurately reproduced measured lake surface elevations (Fig. 5) and also reasonably reproduced measured TDS concentrations (Fig. 6). The model was thus deemed suitable for predicting water balances and salt balances in Lake Elsinore over the longer 1916-2014 time period, and also serves as an appropriate starting point for simulations of water quality over the past century.

<u>1916-2014</u>

The period from 1916-1964 was then simulated and appended to 1964-2014 model results (Fig. 7). The initial condition for the lake on January 1, 1916 was not precisely known, but the average depth of 5 m, temperature of 12°C and TDS of 250 mg/L was assumed based upon historical accounts of lake levels in the late 1930s and 1950s. To account for loss to unsaturated soils and groundwater following large runoff events into the large shallow natural basin, flows were reduced by an average value of 30% based upon detailed water accounting over the 1964-1995 period previously described. The results from 1916-1950's should thus be considered provisional; notwithstanding, this period also demonstrated considerable variation in lake level (Fig. 7).

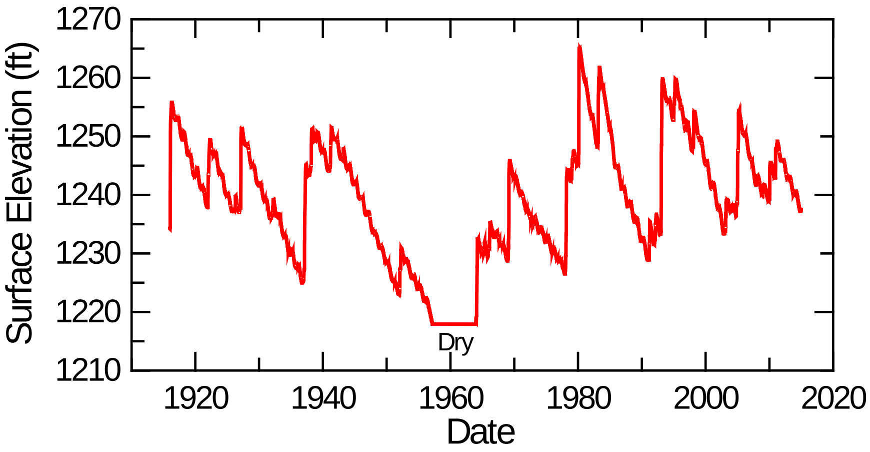

*Fig. 7. Model-predicted surface elevations of Lake Elsinore: 1916-2014.*

The model predicted low lake levels in 1935, with a minimum surface elevation of 1225.3 ft and depth of 2.3 m in December 1936 before spring rains in 1937 increased lake level to 1245.2 ft and depth of 8.34 m (Fig. 7). Rainfall and runoff the following spring (1938) further increased lake level to 1251.3 ft. The surface area of the lake increased from 1450 to 4895 acres over this time period (Fig. 8). The model predicted the lake level to decline through much of the 1940's, fully dry out by early 1957 and remain essentially dry until February 1964 (Figs. 7, 8). Historical accounts suggest the lake dried out somewhat earlier than that, potentially by 1954 or 1955.

Salinity varied inversely with surface elevation and lake area, with very large increases in TDS present as a result of evapoconcentration at low lake levels (Fig. 9). Values exceeding 3000 mg/L were predicted in the 1930s, 1940s-1964, 1978 and 1990 (Fig. 9). The TDS was predicted to exceed that of seawater upon complete dessication in the late 1950s.

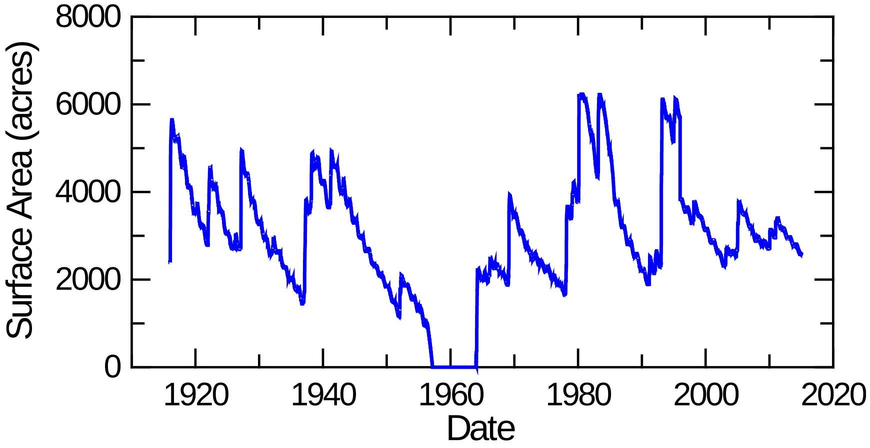

*Fig. 8. Model-predicted surface area of Lake Elsinore: 1916-2014.*

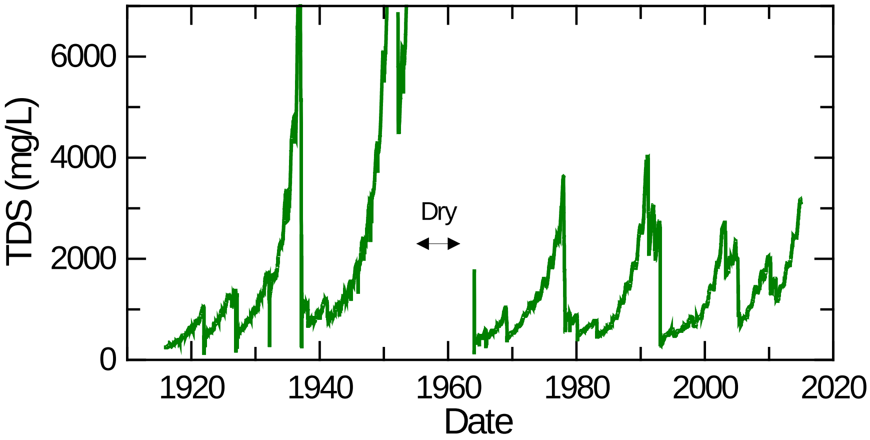

*Fig. 9. Model-predicted TDS concentrations in Lake Elsinore: 1916-2014.*

The simulation results presented in Fig. 9 can also be used to track salt accumulation within the lake basin. While it is difficult to visually track salinity given the highly dynamic lake level that concentrates and then dilutes the salt load, TDS concentrations at a common surface elevation, and thus also lake volume, provides a straightforward way to estimate of the rate of salt accumulation within the lake. At a constant lake level of 1240 ft, TDS concentration was observed to increase at a rate of 39 mg/L/yr between 1920-1950 ($r^2$=1.00) for the large shallow natural lake basin (Fig. 10). The rate of salt accumulation at constant elevation was similar for the period 1970-2002 (30 mg/L/yr) even though the post-LEMP data point shifted the slope of the line down somewhat. Most notably, addition of recycled water at rates shown in Fig. 4 approximately quadrupled the rate of salt accumulation, to 136 mg/L/yr ($r^2$=1.00), despite the smaller deeper (post-LEMP) lake basin that would be expected to reduce the rate of evapoconcentration of salts relative to the natural basin (Fig. 4). This provides the first quantitative estimate of effect of recycled water addition on salt load in Lake Elsinore.

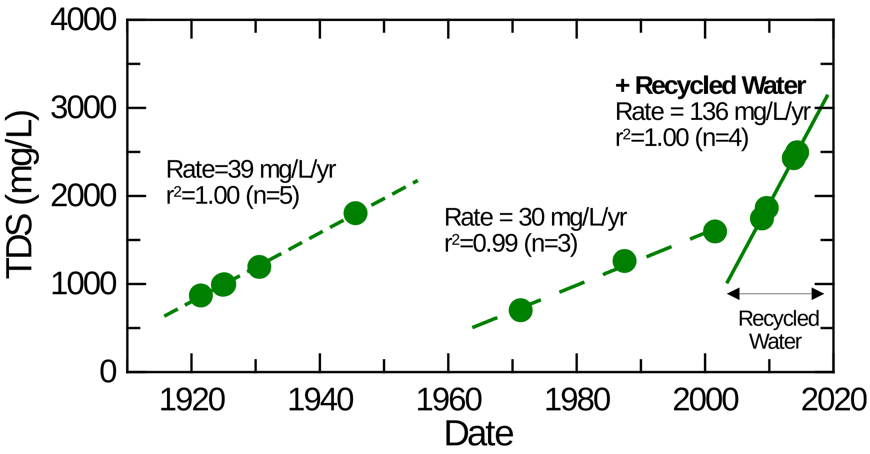

*Fig.10. Model-predicted TDS concentrations in Lake Elsinore at constant lake elevation of 1240 ft showing marked increase in rate of salt accumulation since recycled water additions began in late 2002.*

Part of the interest in simulating the early part of the past century was to include this longer record in a probabilistic description of the range of conditions in the lake and the frequency of low lake levels and high salinities that would have profoundly negatively affected its beneficial uses. The results from Figs. 7-9 were used to develop cumulative distribution functions that describe the exceedance frequency of a given condition, *e.g.*, frequency over the past 99 years that the lake level was below 1240 ft, or salinity exceeded some critical biological threshold (Fig. 11).

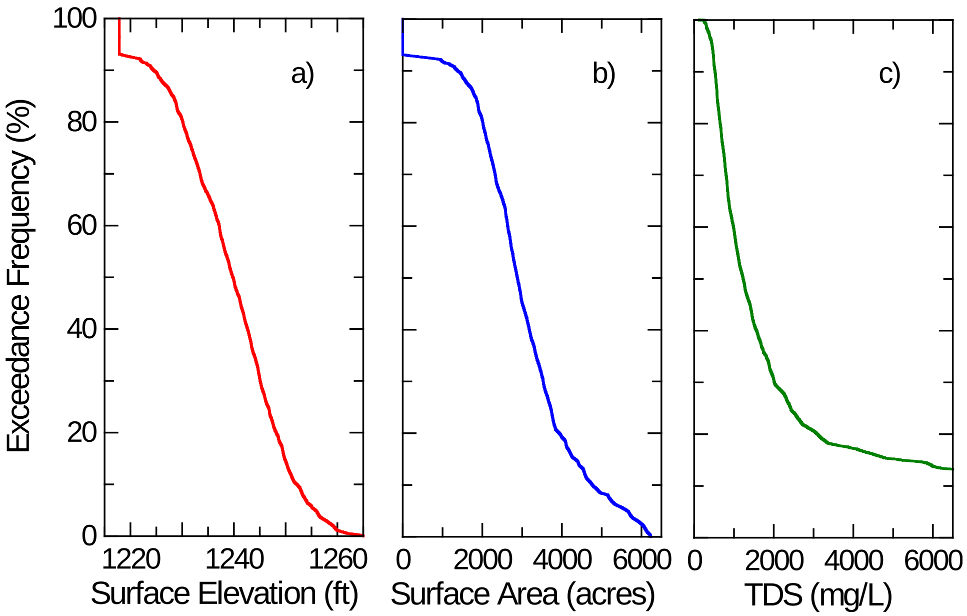

*Fig. 11. Exceedance frequencies for a) lake surface elevation, b) lake surface area, and c) TDS concentration.*

Based upon model predictions, the lake was dry 6.8 of the past 99 years, with a surface elevation <1218 ft and no wetted surface area (Fig. 11). The frequency of exceeding a given lake elevation and area decreased with increasing values. Selected exceedance frequencies are provided in Table 1. The lake property at an exceedance frequency of 50% corresponds to the median value over the simulated period; thus, the median lake level was at 1239.8 ft, surface area was 2881.4, and TDS was 1232 mg/L (Table 1). Values higher than these were found less frequently, e.g., 5% of the time, the TDS was predicted to exceed that of ocean water (when the lake was essentially dry).

Table 1. Values of surface elevation, area and TDS concentration in Lake Elsinore at selected exceedance frequencies based upon simulations for 1916-2014..

| **Exceedance Freq (%)** | **Elevation (ft)** | **Area (acres)** | **TDS (mg/L)** |
|---|---|---|---|
| 90 | 1224.5 | 1380.2 | 524 |
| 50 | 1239.8 | 2881.4 | 1232 |
| 10 | 1252.1 | 4766.7 | 13,786 |
| 5 | 1255.8 | 5641.7 | >42,000 |
| 1 | 1260.4 | 6137.6 | >42,000 |

It is worth noting that a 90% exceedance frequency for a lake surface elevation of 1224.5 ft or surface area of 1380.2 acres (Table 1), also corresponds to a 10% frequency of being *less* than these values. Thus using the 99 year record as an index, 10 years out of the past 99 years would yield elevations and areas below these values.

## Conclusions

Results from these initial simulations indicate:

(i) the model accurately predicted measured lake surface elevations and available TDS concentrations;

(ii) significant loss of water to unsaturated soil and groundwater occurred in the large shallow natural basin (i.e., pre-LEMP) following large runoff events;

(iii) losses to unsaturated soils and groundwater were not apparent for the reconfigured (post-LEMP) basin;

(iv) over the past 99 years, the model predicts that the lake was dry for 6.8 years, with salinity near or exceeding that of sea water when the lake approached dessication;

(v) salt has accumulated in Lake Elsinore at a predicted rate of 30-39 mg/L/yr at a surface elevation of 1240 ft for much of the past century;

(vi) addition of recycled water has accelerated the predicted rate of salt accumulation at 1240 ft elevation to 136 mg/L/yr since addition of recycled water began in late 2002.

## Next Step

The next step will be to simulate Lake Elsinore using the reconfigured (post-LEMP) basin for the entire 1916-2014 period, with and without recycled water additions, to compare effects of recycled water on lake surface elevation, area and salinity. Comparison will also be made with the results reported herein for the natural basin (1916- 1995) and transition to the reconfigured basin (1996-2014).

## References

Anderson, M.A. 2006. *Predicted Effects of Restoration Efforts on Water Quality in Lake Elsinore: Model Development and Results.* Final Report to LESJWA. 33 pp.

## *Technical Memorandum*

**Task 1.1:** Influence of Recycled Water Supplementation on Surface Elevation and Salinity in Lake Elsinore: Model Predictions for 1916-2014 with Current (post-LEMP) Basin

### Objective

The objective of this task was to simulate Lake Elsinore using the current (post-LEMP) basin for the entire 1916-2014 period, with and without recycled water additions, to compare effects of recycled water on lake surface elevation, area and salinity.

### Approach

The calibrated DYRESM model used in Tech Memo 1.0 that simulated lake level and salinity in Lake Elsinore under conditions present at the lake from 1916-2014 (Anderson, 2015) will be used with the current (post-LEMP) basin. The lake will be simulated (i) assuming San Jacinto River flow and local runoff with TDS concentrations of 300 and 150 mg/L, respectively, and (ii) water supplemented with up to 5000 acre-feet of recycled water with a TDS concentration of 700 mg/L when the lake level drops below 1240 ft. Crest elevation was set to 1255 feet; the model assumes that the discharge capacity when the lake reaches crest elevation is effectively unlimited. All other model parameters will remain unchanged from those described in Tech Memo 1.0. The reader is referred to that document for details.

### Results

Runoff from the San Jacinto River and local watershed into Lake Elsinore (with post-LEMP basin) for the 1916-2014 period were predicted to yield wide swings in lake surface elevation (Fig. 1, solid orange line). The model predicted that the lake level would remain above 1240 ft from early 1916 -1931, with water flowing out of the lake in 1916, 1922, and 1927. The water surface elevation decreased to about 1229 ft above MSL in 1936 before rainfall and runoff increased the lake level sufficient for water to again flow out of the lake in 1937 (Fig. 1, orange line). Limited runoff from 1943-1964 failed to meet evaporative losses and resulted in the lake level declining and eventually going dry in 1961-1964. Importantly then, while LEMP has a pronounced benefit helping maintain water level relative to the natural basin (Anderson, 2013), the re-engineered smaller basin is nonetheless unable to maintain water in the lake during periods of prolonged drought (Fig. 1, orange line).

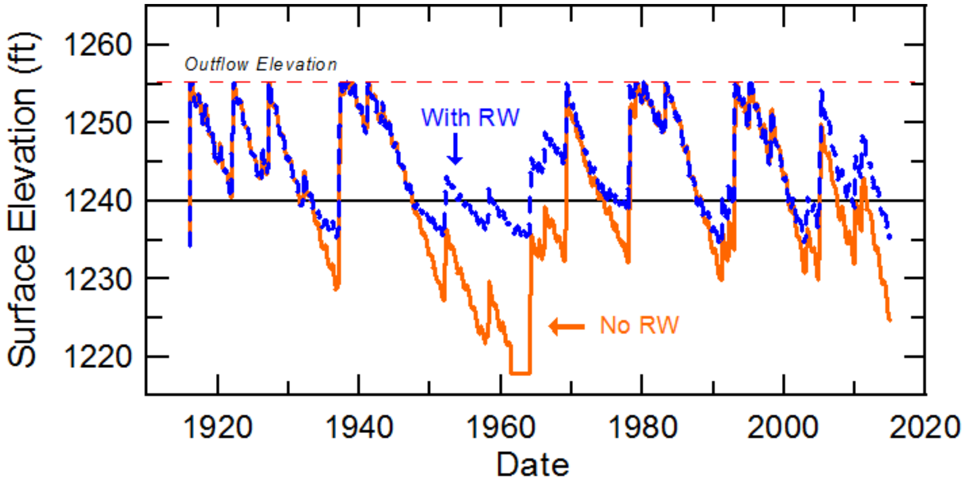

*Fig. 1. Lake surface elevation with LEMP basin and natural flows (solid orange line) and supplemented inflows with recycled water (dashed blue line).*

Supplementation of natural inflows with recycled water when the lake level declined below 1240 ft helped support higher lake levels and was predicted to maintain surface elevations above 1234.5 ft throughout the entire 99-yr period (Fig.1, dashed blue line). The re-engineered basin together with supplementation with recycled water helps prevent extremely low lake levels.

The increased lake surface elevations resulting from recycled water additions also had a marked effect on lake surface area (Fig. 2).The lake area rarely dropped below 2500 acres (range 2372 – 3844 acres) and averaged 3088 acres with recycled water supplementation. In contrast, a much wider range of surface areas were predicted with natural flows, from 0 acres (i.e., dry lake bed) in early 1960s to 3844 acres (full pool) during strong El Nino events (Fig. 2). The lake averaged 2772 acres over the duration of the simulation. Recycled water additions thus help ensure greater recreational opportunities and provide more substantial habitat when compared with natural inflows only.

The re-engineered basin also resulted in lake surface elevations that periodically reached the crest elevation of 1255 ft, resulting in overflows and some flushing of the lake (Fig. 3). The DYRESM model assumes no limits on outflow rates when surface elevations exceed crest elevation, so the predicted daily outflow rates in many cases exceed the capacity of the outflow channel. In the short-term then, lake surface elevations and volumes would exceed those predicted by the model, although values would approach model-predicted values as water is discharged downstream.

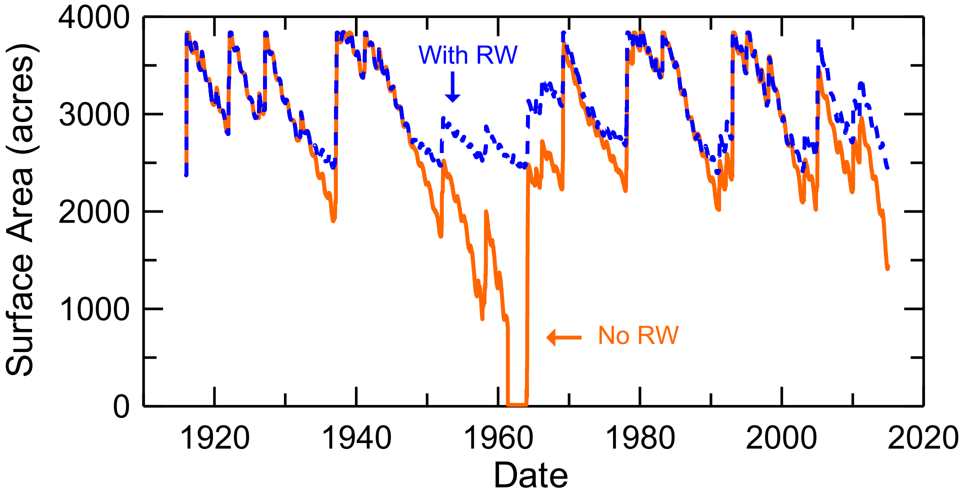

*Fig. 2. Lake surface area with LEMP basin and natural flows (solid orange line) and supplemented inflows with recycled water (dashed blue line).*

While it is difficult to discern from Fig. 3, outflows often occurred for several weeks or more, with the duration governed by the intensity and duration of runoff events (i.e., features in Fig 3 represent many days, rather than a single day). Also not necessarily evident, supplementation with recycled water increases the amount of water discharged to the outflow and Temescal Creek on similar dates, especially evident in late 1969 and 1979. For example, outflow occurred for an additional 53 days in winter 1969 with recycled water added, at a flow rate up to more than 5000 af/d and resulting in a cumulative additional outflow of 29,071 af (Fig. 4).

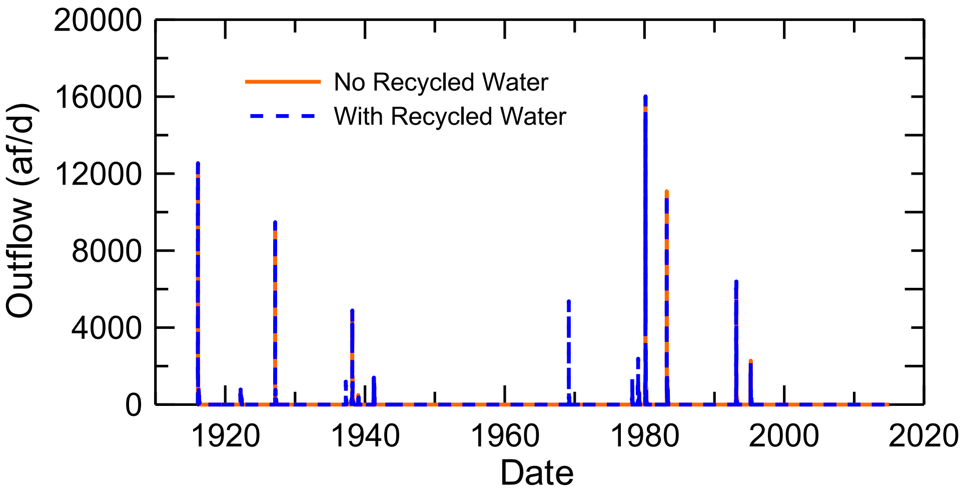

*Fig. 3. Daily lake outflow from LEMP basin with natural flows (solid orange line) and inflows supplemented with recycled water (dashed blue line).*

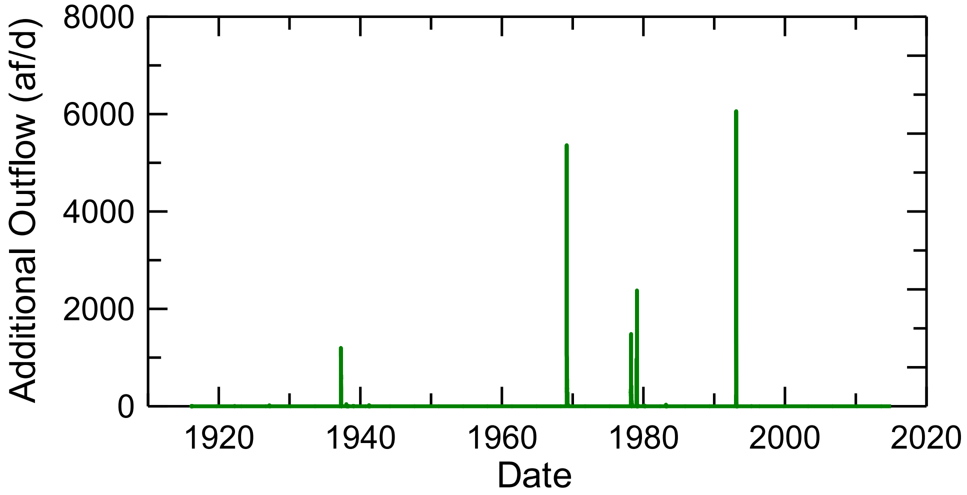

*Fig. 4. Additional daily outflow from LEMP basin beyond that predicted for natural flows resulting from supplementation with recycled water.*

Supplementation with recycled water also had a clear effect on total dissolved solids (TDS) concentrations in the lake (Fig. 5). Most notably, addition of recycled water eliminated the extreme TDS values (>10,000 mg/L) predicted for mid- to late-1950's through 1964 when lake surface elevation dropped to very low levels (Fig. 1) and eventually went dry (Fig. 2). Since supplementation with recycled water helps maintain water in the lake, TDS concentrations do not reach the extreme values present when the lake levels drops to exceedingly low values, thus providing a ceiling to TDS levels that is a function of TDS concentration in recycled water and the frequency and intensity of outflow-flushing events (Fig. 5).

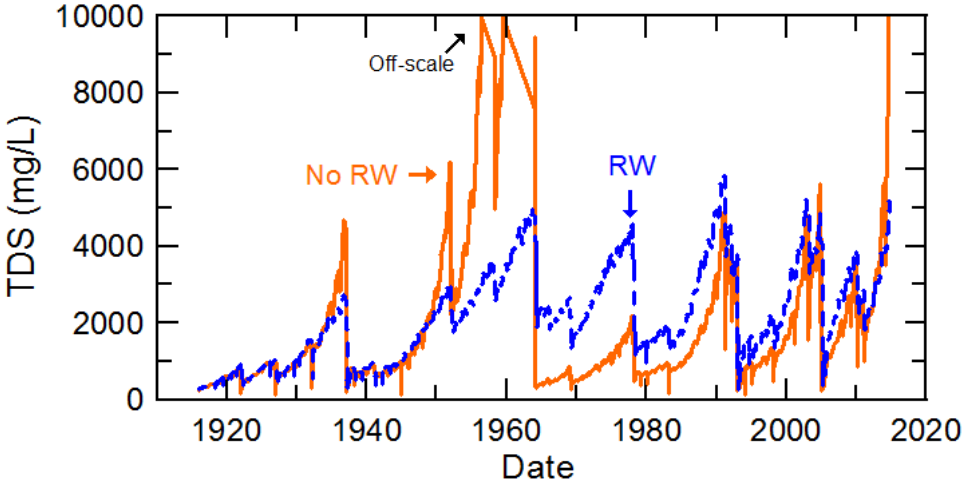

*Fig. 5. TDS concentrations over time with LEMP basin and natural flows (solid orange line) and inflows supplemented with recycled water (dashed blue line).*

The addition of recycled water also constrains the lower range of TDS predicted in the lake (Fig. 5). For the simulated interval since about 1960, recycled water supplementation yielded TDS levels that rarely dropped below 1,000 mg/L and were more typically predicted to be 2,000-4,000 mg/L (Fig. 5, blue line). Minimum TDS concentrations were much lower without recycled water additions (Fig. 5, orange line).

This can be seen from a cumulative distribution function for TDS with and without recycled water additions (Fig. 6). One notes that the exceedance probabilities differ significantly for the 2 scenarios, with lower TDS values predicted over 80% of the time for natural inflows relative to those with recycled water supplementation, although TDS values were dramatically higher without recycled water supplementation about 15% of the simulation period (Fig. 6). On no day was TDS predicted to exceed 6,000 mg/L with recycled water additions, while TDS values with only natural flows exceeded 6,000 mg/L 9.3% of the time (over 3300 days or >9 yrs out of 99). The median TDS value for the 99-yr simulation period under natural flows was 1,163 mg/L while the value increased to 2,055 mg/L with recycled water supplementation. Recycled water supplementation thus constrained TDS values to <6,000 mg/L, but also increased TDS levels much of the time. If we assume that TDS values >2,000 mg/L negatively impact the ecology of the lake, some salinity-impairments would be expected about 52% of the time with recycled water additions and 32% of the time with natural flows.

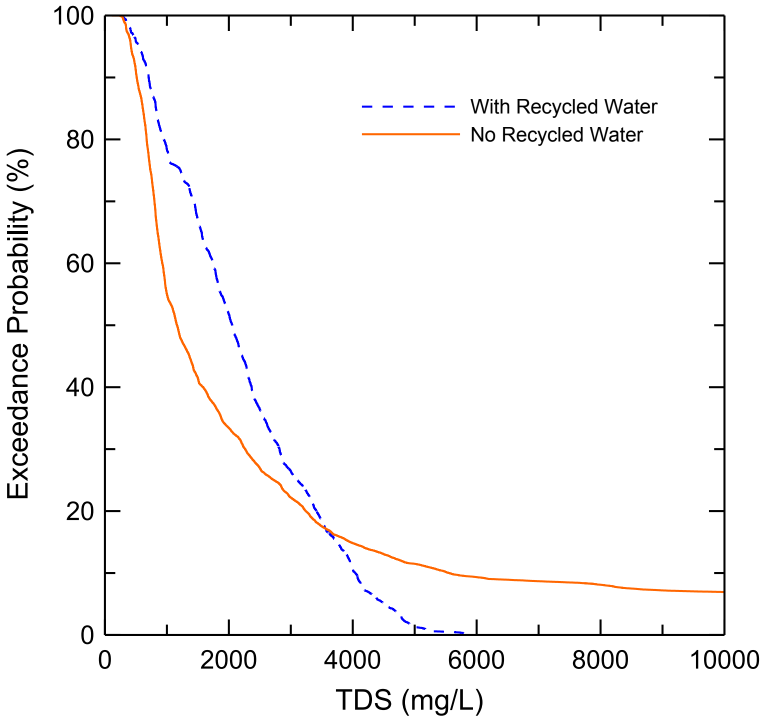

*Fig. 6. Cumulative distribution function showing exceedance probability for TDS concentrations for the LEMP basin with natural flows (solid orange line) and inflows supplemented with recycled water (dashed blue line).*

Of course, far less extreme conditions are predicted with recycled water (Fig. 6); most would probably agree that moderate lake levels (>1235 ft) (Fig. 1) and TDS values below 6,000 mg/L (Figs. 5 and 6) are preferable to very low lake levels, limited lake area, sea-water salinities or dry lake bed conditions predicted periodically with only natural inflows.

Importantly, the LEMP basin allows for periodic outflow and export of salt from the lake (Table 1). Natural flows delivered 1.55 MAF to the lake over the 1916-2014 simulation period, with 0.51 MAF (33%) flowing out in a limited number of years (Fig. 3). Supplementation with recycled water increased inflows to 1.77 MAF and outflows by 76,940 acre-feet to 0.58 MAF (Table 1). These outflows also exported salt; nearly 41% of the salt delivered to the basin with natural flows was removed with outflow, while a smaller fraction of a larger salt load, associated with recycled water inputs, was exported (35%) (Table 1). The 200,000 metric ton larger salt load to the lake with recycled water results from the higher salinity of that water relative to natural flows.

**Table 1. Predicted total flows and salt budget for LEMP basin (99-yr simulation).**

| Scenario | Total Flow In (af) | Total Flow Out (af) | Total Salt In (tonnes) | Total Salt Out (tonnes) |
|---|---|---|---|---|
| No Recycled $H_2O$ | 1,546,230 | 506,982 | 535,972 | 219,245 |
| + Recycled $H_2O$ | 1,771,860 | 583,922 | 735,858 | 258,121 |

## Conclusions

Simulations for Lake Elsinore using meteorological and runoff records from the past 99 yrs (1916-2014) with and without recycled water supplementation indicate:

(i) recycled water supplementation significantly increases lake surface elevation and lake area compared with natural inflows into the lake during periods of limited precipitation and runoff;

(ii) recycled water supplementation maintained predicted lake elevations >1234.5 ft and lake areas >2370 acres, while natural inflows resulted in complete desiccation of the lake for almost 3 yrs during the extreme drought that began in the late 1950s and continued into the early 1960s;

(iii) recycled water supplementation prevented extreme TDS levels from developing in the lake (keeping TDS concentrations <6000 mg/L) but also increased average TDS concentrations by about 900 mg/L, from 1,163 mg/L to 2,055 mg/L over the 99-yr (1916-2014) simulation period;

## Next Step

The next step will be to extend this comparison of natural inflows with recycled water supplementation beyond lake level and salinity, and assess impacts of recycled water on concentrations of nutrients, dissolved oxygen, chlorophyll and other properties.

## References

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

Anderson, M.A. 2013. *Predicted Effects of Lake Elsinore Management Project (LEMP) on Lake Level and Water Quality of Lake Elsinore.*

## *Technical Memorandum*

**Task 1.2:** Water Quality in Lake Elsinore Under Selected Scenarios: Model Predictions for 1916-2014 with Current (post-LEMP) Basin

### Objective

The objective of this task was to simulate water quality in Lake Elsinore using the current (post-LEMP) basin for the entire 1916-2014 period, comparing predicted water quality in the lake under selected conditions and management scenarios. For this assessment, the current (post-LEMP) basin will be used for the entire 99-yr simulation period.

### Approach

The Computational Aquatic Ecosystem Dynamics Model (CAEDYM v.3) was linked to the 1-D Dynamic Reservoir Simulation Model (DYRESM v.4) model used in Tech Memos 1.0 and 1.1 that simulated lake level and salinity in Lake Elsinore for the period 1916-2014 (Anderson, 2015a,b). The CAEDYM model is a highly complex ecosystem model capable of simulating a vast array of water quality and ecological parameters. In addition to the daily average meteorological conditions and runoff-streamflow volumes required by DYRESM, CAEDYM requirements information or assumptions about the structure of the food web, dynamics within the food web, rates of reactions for photosynthesis, nutrient uptake, excretion, mineralization, and transformations, as well as nutrient concentrations in runoff and streamflow and a large number of other parameters and variables. The reader is referred to the CAEDYM Science Manual v.3.2 for additional details (Hipsey et al., 2014). For these simulations, 3 algal groups (blue-green algae, green algae and freshwater diatoms), 2 zooplankton groups (copepods and cladocerans), and 2 fish groups (approximating threadfin shad and larger piscivores such as bass and crappie) were represented. Consistent with the TMDL developed for Lake Elsinore, this study focused on 4 key water quality parameters: total N, total P, dissolved oxygen (DO) and total chlorophyll a, and systematically evaluated their response to different external conditions and management scenarios for the lake.

### *Model Calibration: 2000-2014*

Key Input Parameters

The coupled DYRESM-CAEDYM model was calibrated against available data for 2000-2014. Meteorological conditions that drive the hydrodynamics in the 1-D DYRESM model were taken from the CIMIS station #44 at UCR (Fig. 1). Key forcing factors driving the heating, cooling and mixing of Lake Elsinore include the shortwave solar heat flux (300-3000 nm) that includes photosynthetically available radiation (PAR, 400-700 nm), as well as near-UV (300-400 nm) and near-IR and IR (700-3000 nm) (Fig. 1a), air temperature (Fig. 1b) and windspeed (Fig. 1c). Values are represented as daily average values. The strong seasonal trend in solar shortwave heat flux is evident in the figure, with daily average shortwave flux values of about 350 W/m$^2$ in the summer and 50-100 W/m$^2$ during the winter (Fig. 1a). Daily average air temperatures exhibit a similar seasonal pattern, with daily-averaged summer temperatures near 30°C and daily average winter temperatures generally 7-10°C (Fig. 1b).

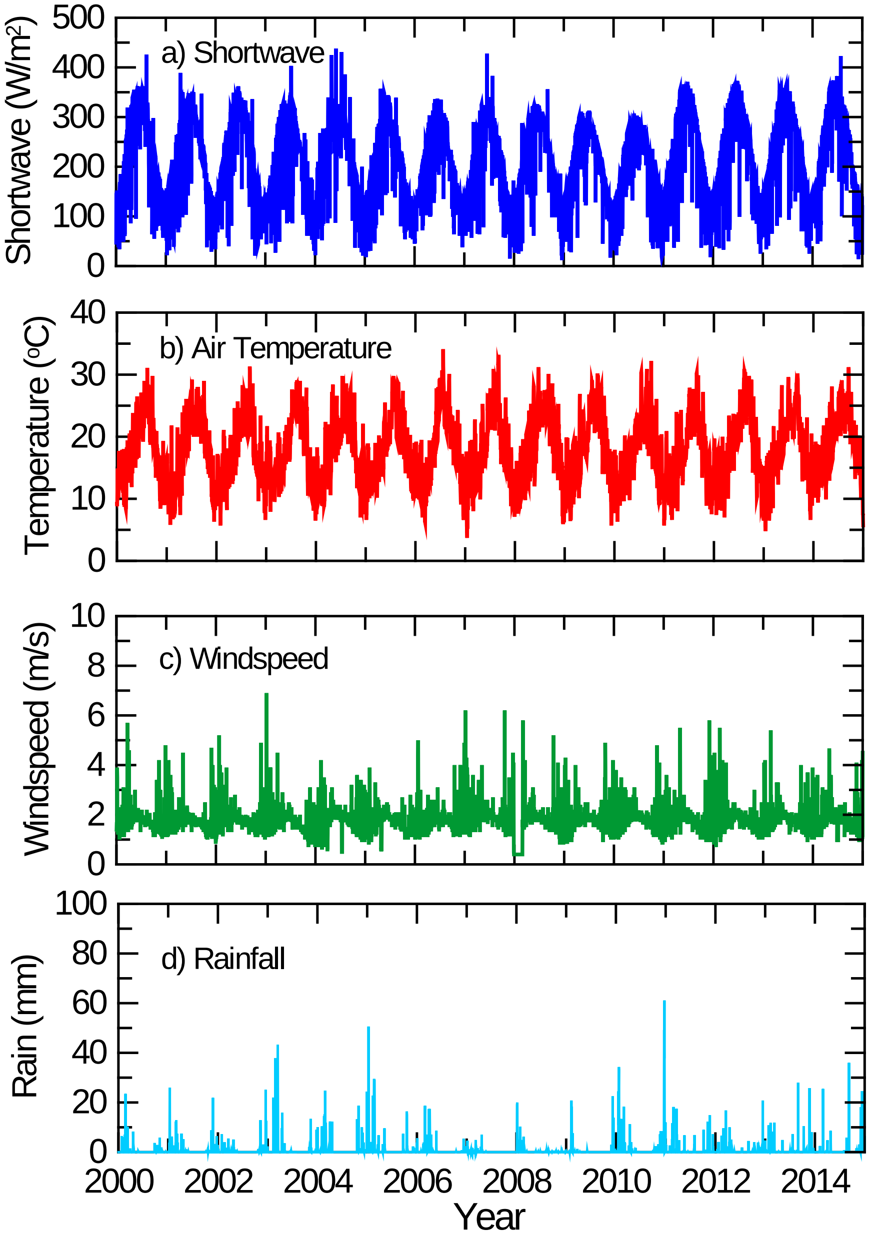

*Fig. 1. Daily average a) shortwave radiation, b) air temperature, c) windspeed and d) rainfall used in model simulations for the calibration period 2000-2014.*

Daily average windspeeds averaged near 2 m/s and exhibited some seasonality as did daily rainfall rates that also showed annual variability (Fig. 1c,d).

In addition to direct precipitation on the lake surface, water delivered to the lake included San Jacinto River flows (as recorded at the USGS gage #11070500), runoff from the local watershed (Anderson, 2015a), and supplemental water that included recycled water from EVMWD as well as recycled water from EMWD and water pumped from island wells in 2003-2004 (collectively represented as recycled water) (Fig. 2).

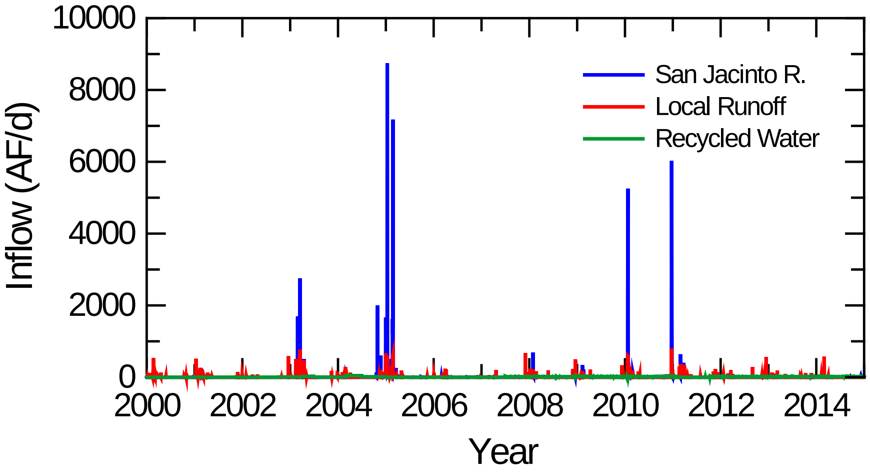

*Fig. 2. Daily inflows to Lake Elsinore for the calibration period 2000-2014.*

External loading of nutrients was derived from inflows from the San Jacinto River, local runoff and recycled water (Fig. 2). A limited number of large runoff events delivered most of the flows from the San Jacinto River during this time period, including the very large runoff events at the beginning of 2005, that included daily flow exceeding 8,000 acre-feet (Fig. 2, blue line). Shorter duration high flow runoff events were also present in January 2010 and December 2011. Precipitation generated runoff from the local watershed as well, although daily flows were much smaller than the very large runoff events noted in 2005, 2010 and 2011 (Fig. 2). Recycled water flows were much lower than runoff volumes and barely perceptible on Fig. 2 (green line). Presented as cumulative flows however, we see that recycled water inputs exceeded that of local runoff and contributed about 50,000 acre-feet since inputs began in late 2002 (Fig. 3). Based upon these values, a total of 187,926 acre-feet of water was delivered to Lake Elsinore over this 2000-2014 period, with approximately 53% derived from San Jacinto River flows, 20% from local runoff and 27% from recycled water (Fig. 3).

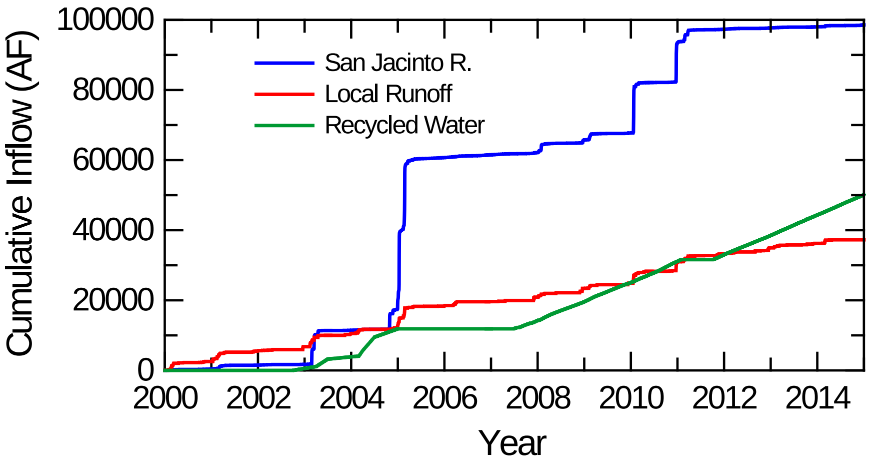

*Fig. 3. Cumulative inflow to Lake Elsinore from the San Jacinto River, local runoff and recycled water for the calibration period 2000-2014.*

Concentrations of nutrients in these inflows vary depending upon a number of factors, including intensity and duration of storms, interval of time between storms and other factors (including treatment plant operation for recycled water inputs). Average concentration values derived from runoff sampling within the watershed and treatment plant data were used in model simulations (Table 1).

Table 1. Nutrient concentrations of inflows to Lake Elsinore used in model simulations.

| Source | $PO_4$-P | Total P | $NH_4$-N | $NO_3$-N | Total N |
|---|---|---|---|---|---|
| San Jacinto R. | 0.28 | 0.50 | 0.22 | 0.57 | 1.62 |
| Local Runoff | 0.20 | 0.48 | 0.22 | 0.80 | 1.82 |
| Recycled H2O[a] | 0.32 | 0.41 | 0.36 | 1.62 | 2.87 |

*[a]Recycled water concentrations for EVMWD 2007-present.Higher concentrations of $PO_4$-P, $NH_4$-N and $NO_3$-N were present for the 2002-2004 period which included significant volumes of island well and EMWD flows (concentrations for this period of 0.82, 0.24 and 10 mg/L, respectively).*

Total external nutrient loading over the calibration period was calculated from flow data (Fig. 2) and nutrient concentrations (Table 1). Flows from the San Jacinto River delivered 47% of the total external load of $PO_4$-P (71,848 kg) added between 2000-2014, with 40% from recycled water supplementation, and 13% from local watershed runoff (Fig. 4). Recycled water contributed 63% of the total TIN load, while San Jacinto River and local runoff contributed 25 and 12%, respectively. From Fig. 4, we note that the contributions of $PO_4$-P from the 3 sources are broadly comparable to their volumetric flow contributions owing to fairly similar $PO_4$-P concentrations, while recycled water contributes a disproportionately large amount of TIN owing to its larger $NO_3$-N concentration (Table 1).

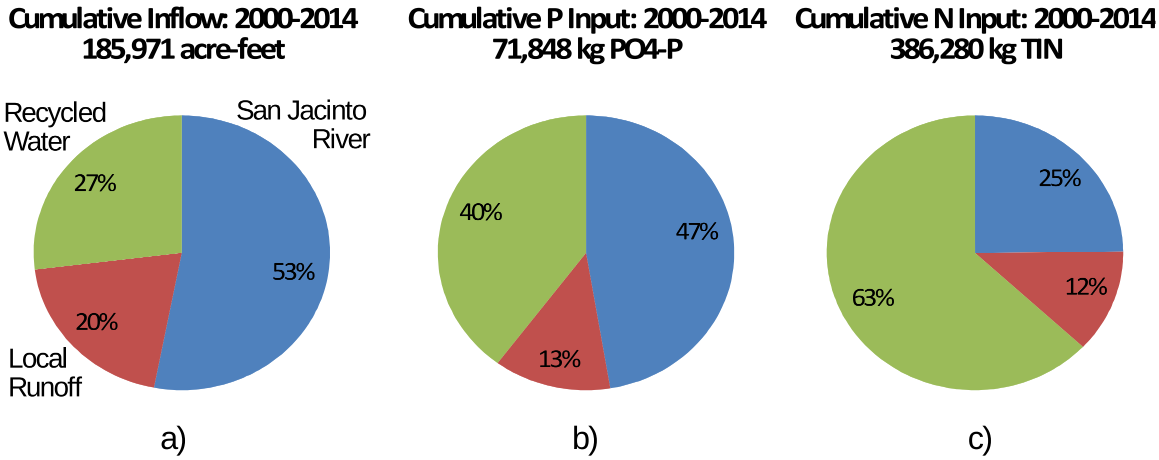

*Fig. 4. Total inflow, P and N inputs to Lake Elsinore for the calibration period 2000-2014.*

## Calibration Results

### *Lake Elevation*

The first step in assessing the model effectiveness in reproducing conditions in Lake Elsinore was to compare measured lake surface elevations with predicted values (Fig. 5). Measured and predicted values are in very good agreement, showing synchronous marked declines from 2000-2003, dramatic increase at the end of 2004 and in early 2005, and subsequent declines through 2010 (Fig. 5). Modest differences were occasionally found (e.g., in 2004), but given the tremendous range in rainfall, runoff and surface elevations witnessed over this time period, agreement is thought to be quite good.

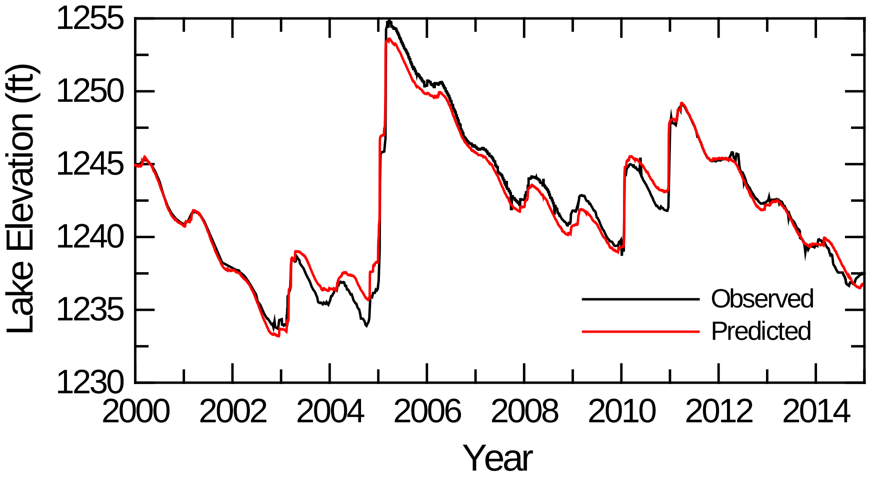

*Fig. 5. Predicted and observed lake surface elevation for the calibration period 2000-2014.*

### *Lake Salinity*

Salinity in the lake varied from approximately 700 - 2600 mg/L TDS, with low concentrations following the very large runoff in winter 2015 (Fig. 6, solid circles). The model captured trends in TDS reasonably well, including the high TDS concentrations measured in late fall 2002 and the marked decline in TDS in 2015 (Fig. 6, line). The only discrepancy was found in 2014, when the model over-predicted TDS in the lake.

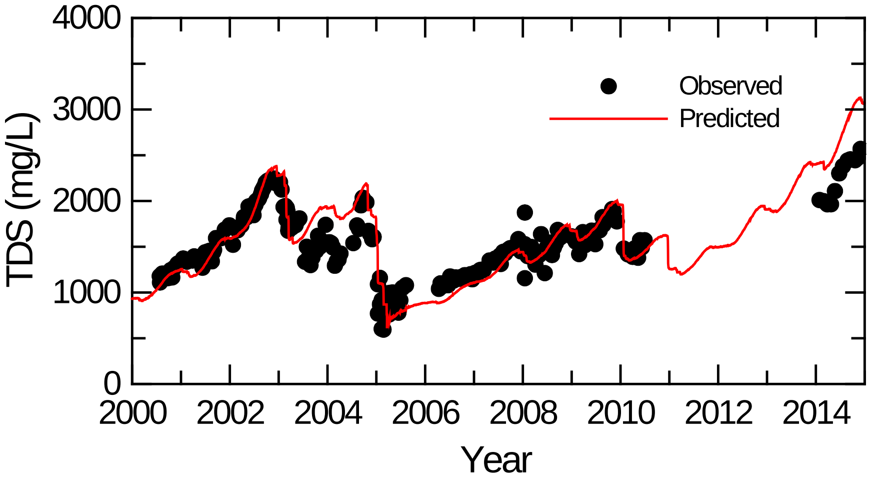

*Fig. 6. Predicted and observed TDS concentrations for the calibration period 2000-2014.*

*Temperature*

The model reasonably captured measured temperature values in Lake Elsinore (Fig. 7). The model correctly predicted strong seasonal trends in water column temperature that reflects seasonal trends in solar shortwave heat flux (Fig. 1a) and air temperature (Fig. 1b). The model predicted summer values near 27°C and winter minimum values near 10°C, with little difference between depths reflecting weak stratification or mixed conditions commonly present in the lake (Fig. 7).

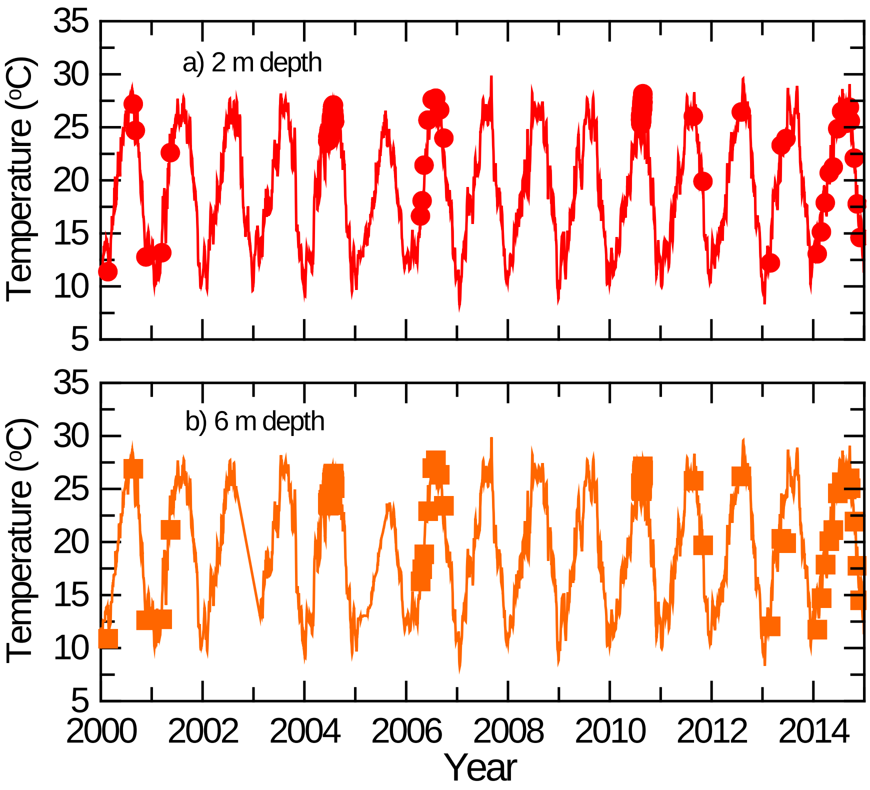

*Fig. 7. Predicted and observed temperature at a) 2 m depth and b) 6 m depth for the calibration period 2000-2014.*

*Dissolved Oxygen*

Dissolved oxygen (DO) in the lake varied seasonally and with depth (Fig. 8). The temperature effect on oxygen solubility was evident in model predictions for the 2 m depth, with DO values generally near 10 mg/L in the winter and 7-8 mg/L in the summer (Fig. 8a). At the same time, supersaturation was periodically predicted (e.g., in spring 2011 when concentrations reached 17 mg/L). The model predicted DO concentrations deeper in the water column to be often quite similar to near-surface values, but did also correctly predict periods of anoxia in the summer of 2003, 2004, 2006 and 2010 (Fig. 8b).

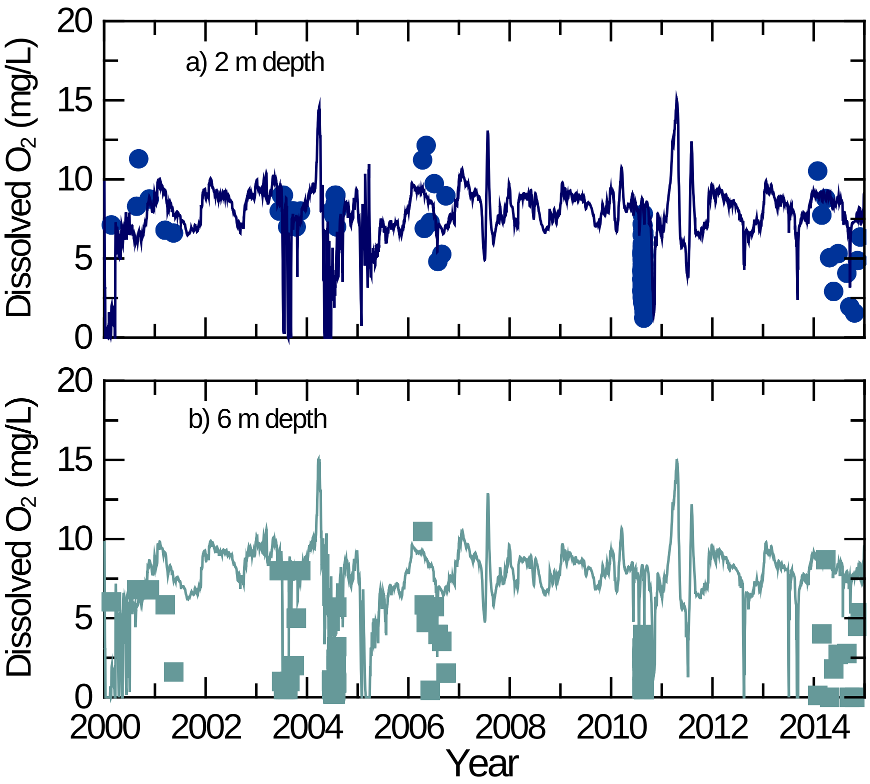

*Fig. 8. Predicted and observed dissolved oxygen concentrations at a) 2 m depth and b) 6 m depth for the calibration period 2000-2014.*

*Total N*

The model did a fair job of capturing the dramatic trends in concentrations of total N in the lake between 2000 and 2020 (Fig. 9). Concentrations increased from about 2 mg/L in 2000 to greater than 8 mg/L by late 2004, and then declined sharply with the very large runoff volumes delivered in winter of 2005 that quadrupled the volume of the lake. Total N concentrations then edged up over several years before declining slightly in 2010 (Fig. 9). While the model captured trends reasonably well, it did not reproduce the more significant apparent swings observed, e.g., in 2008, when reported concentrations over the period of a few months ranged from <1 to >8 mg/L. It may be that sampling bias or analytical challenges crept into the time series data, exaggerating short term trends.

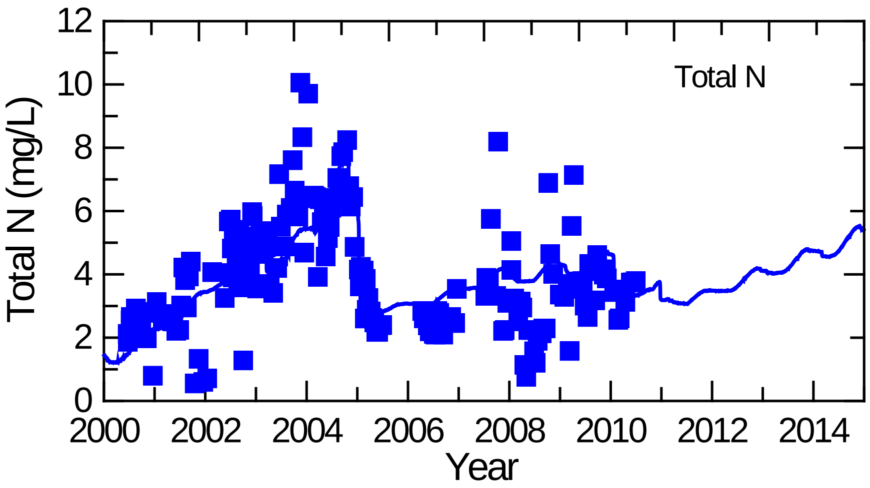

*Fig. 9. Predicted and observed total N concentrations for the calibration period 2000-2014.*

Total P concentrations also varied quite dramatically over this calibration period, from about 0.1 mg/L in 2000 to >0.6 mg/L in late 2004 before declining to a value near 0.2 mg/L (Fig. 10). The model generally captured trends but under predicted concentrations somewhat in 2003-2004, although it did predict a maximum value of about 0.6 mg/L in late 2004 (Fig. 10).

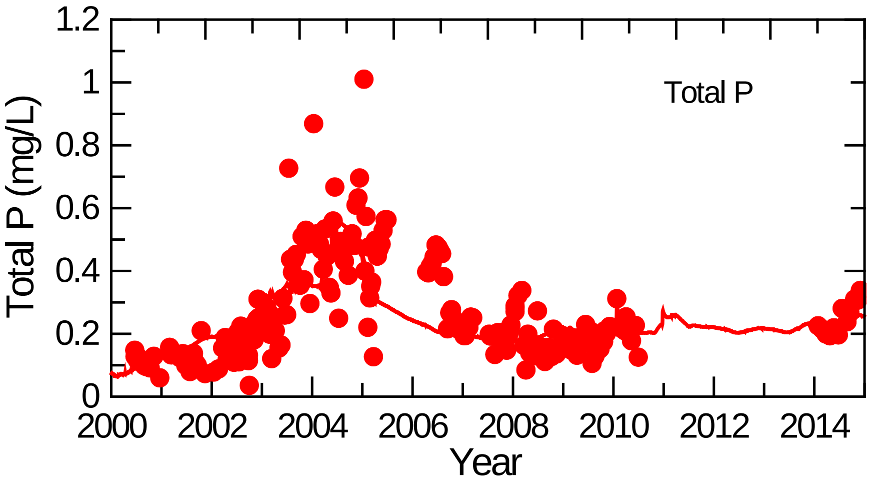

*Fig. 10. Predicted and observed total P concentrations for the calibration period 2000-2014.*

*Chlorophyll a*

Measured chlorophyll a concentrations exhibited pronounced seasonal and interannual variability, ranging from <10 µg/L in some winters to >300 µg/L in 2002, 2004 and 2014 (Fig. 11, solid symbols). The model did a fair job overall in reproducing these complex trends and corrected predicted summer maximum chlorophyll a concentrations in 2000-2004 (Fig. 11, line). The model did not do as well predicting the winter minimum values however, and also missed the particularly high concentrations observed in 2014

(Fig. 11). Notwithstanding, the agreement between predicted and observed concentrations was considered passable given the highly dynamic algal community in the lake and the complex dependence of chlorophyll a concentrations on nutrient availability and ecosystem structure.

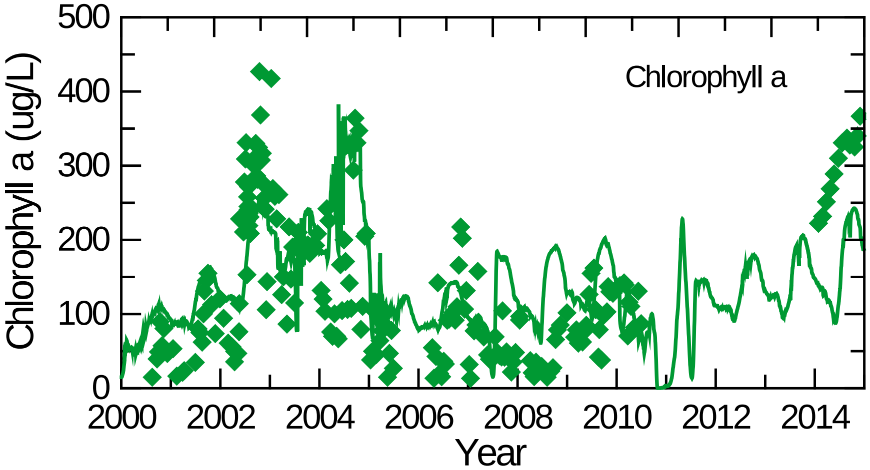

*Fig. 11. Predicted and observed chlorophyll a concentrations for the calibration period 2000-2014.*

The overall goodness of fit of the model results to measured concentrations of total N, total P and chlorophyll a was assessed using the relative percent error between predicted and observed average concentrations (Table 2). Total N averaged 3.98 mg/L over this period, while the model yielded an average value of 3.88 mg/L, representing a 2.5% underestimate (Table 2). The average observed total P concentration over this period was 0.265 mg/L while the predicted average concentration was 0.235 mg/L, an 11.3% underestimate. Predicted and observed chlorophyll a concentrations were 130 and 137 µg/L, corresponding to a relative % error of 5.4%. Given the extreme range in conditions experienced at the lake over this 2000-2014 period, the model was considered to reasonably predict water quality in Lake Elsinore under a wide range of hydrologic, chemical and ecological conditions, allowing for comparison of water quality under different conditions and scenarios.

Table 2. Mean observed and predicted values of key water quality parameters for calibration period (2000-2014).

| | **Observed** | **Predicted** | **% Error** |
|---|---|---|---|
| Total N | 3.98 | 3.88 | -2.5 |
| Total P | 0.265 | 0.235 | -11.3 |
| Chlorophyll a | 130 | 137 | +5.4 |

### *99-yr Simulations Using Current (LEMP) Basin*

With reasonable agreement between measured and predicted water quality for the 2000-2014 calibration period, simulations were conducted for the much wider 99-yr period from 1916-2014. The goal of these simulations was to understand how water quality in Lake Elsinore might be expected to vary under a wide range of meteorological and hydrologic conditions. Water quality was predicted for the lake using the current (post-LEMP) basin and the 99-year meteorological and flow record for the period 1916-2014 (Anderson, 2015). These calculations are not simulating actual conditions in the lake for the period 1916-2014 since the natural lake basin was much larger than currently configured for most of this period of time; rather, the goal is to evaluate water quality in the current lake basin under the natural range of meteorological and runoff conditions previously witnessed in the watershed and at the lake, thus extending the previous approach that used high-, average- and low-runoff conditions develop the TMDL for Lake Elsinore. The advantage of this more comprehensive simulation approach is that it provides more thorough understanding of dynamic conditions in the lake, allows for more statistical power and a probabilistic presentation of results, and more clearly demonstrates accrued impacts on water quality of multi-year droughts and extreme runoff events. The following section on meteorological and flow records is excerpted from Anderson (2015a) and provided here to highlight major features for this extended 99-yr simulation period.

#### Meteorological and Flow Records: 1916-2014

Daily flows of the San Jacinto River into Lake Elsinore at USGS gage #11070500 were downloaded from USGS as previously noted. Daily rainfall records were provided by Riverside County Flood Control District for the Quail Valley, (1958-2014), San Jacinto (1940-2014) and Hemet (1916-1940) rain gauges to estimate runoff from the local 13,340 acre watershed not captured by gaged San Jacinto River flows (Anderson, 2006). The available Quail Valley rainfall data were used for the 1958-2014 period without any correction. Regression equations developed between measured Quail Valley precipitation and that at San Jacinto ($r^2$=0.70) and Hemet $r^2$=0.52) were used to predict rainfall at Quail Valley for 1940-1958 and 1916-1940, respectively. Daily average air temperature, relative humidity/vapor pressure, shortwave radiation, and windspeed for 1985-2014 were taken from CIMIS station #057 at UC Riverside. Air temperature records for 1916-1985 were downloaded from the NOAA National Climatic Data Center for the Corona station that provided the longest nearby continuous record. Average shortwave solar radiation, vapor pressure and windspeed from CIMIS station #057 for each calendar day were used for the earlier part of the record when measurements of these meteorological attributes were not available.

Meteorological and flow data over the past 99 years highlight the inter-annual variability present in the region. Annual rainfall within the local watershed of Lake

Elsinore ranged from 2.04 inches in 2006 (based on water year) to 26.97 inches in 1977 (Fig. 12). Precipitation averaged 10.1 inches over this period, while the median was 8.89 inches. As suggested in Fig. 12, precipitation was not normally-distributed about the mean value; precipitation was found to be log-normally distributed however (mean log inches of rainfall 0.96±0.21).

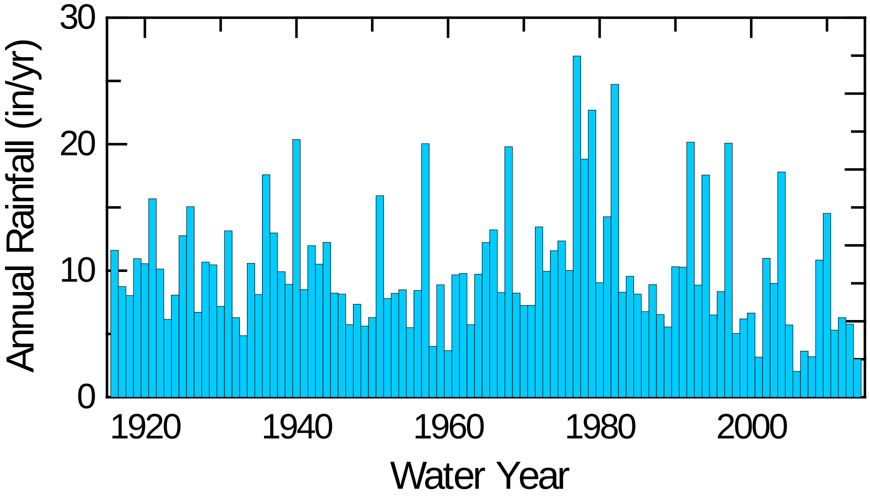

*Fig. 12. Annual rainfall to local watershed adjacent to Lake Elsinore.*

The mean annual air temperature has also varied over the past 99 years (Fig. 13). Temperature has averaged 17.08±0.81 °C over this interval, with a minimum value of 15.4 in 1934 and a maximum temperature of 19.5 °C in 1984, with a statistically significant increase ($p<0.001$) in average annual air temperature at a mean rate of 0.016°C/yr, or an increase of almost 1.6°C over the study period. This rate of change is larger than the global mean surface temperature increase of approximately 1.0°C over this same time period.

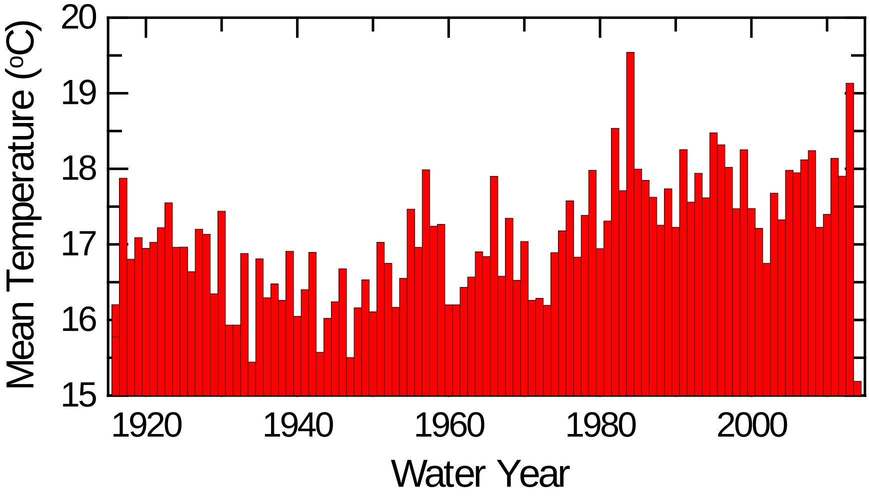

*Fig. 13. Mean annual temperature at Corona (NOAA)*

Annual runoff to Lake Elsinore measured at the USGS gage exhibited even more dramatic variation (Fig. 14). There were 5 years where virtually no flow was recorded at the gage, and 25% of the time, annual flow was <100 AF/yr. At the other end of the spectrum, 22 years were found to have flows >10,000 AF/yr, supporting the general notion of an El Nino-type event on average every 4-5 years. Low flows are difficult to see on this figure due to the periodic very large flows (e.g., water years 1916 and 1980).

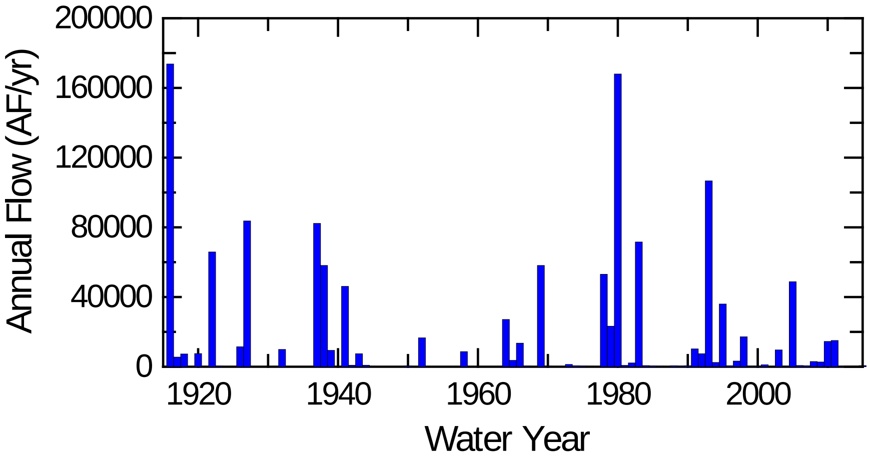

*Fig. 14. Annual flow at USGS gage #11070500 (San Jacinto River near Lake Elsinore)*

Local rainfall values (Fig. 12) were used to estimate local runoff flows to the lake (i.e., runoff from the land areas surrounding the lake and not captured by the USGS gage) (Fig. 15). Previous measurements at the lake suggested a local runoff coefficient of about 0.3, or about 30% of precipitation contributed to runoff (Anderson, 2006), while 70% was on average retained by the soil through infiltration and storage within the porosity of the soil and weathered bedrock.

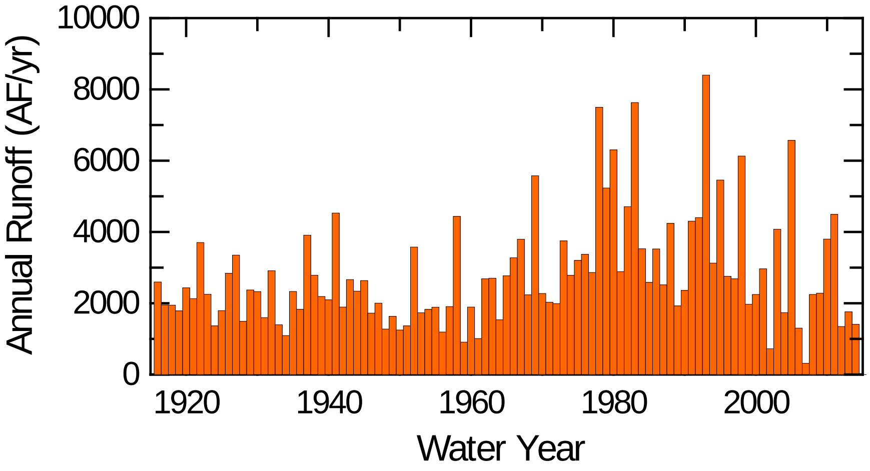

*Fig. 15. Annual flows to Lake Elsinore due to local runoff estimated from precipitation and runoff coefficient.*

Since runoff in urban and suburban-type watersheds is strongly influenced by the amount of impermeable surfaces (roads, parking lots, driveways and rooftops), an assumption was made that the runoff coefficient measured a few years ago adequately reflects current levels of development, but that the runoff coefficient would likely have been lower earlier in the study period. Specifically, a runoff coefficient of 0.2 was assumed from 1916-1960, 0.25 for 1961-1980, and 0.3 for 1981-present. Local runoff averaged 2813 AF/yr.

In addition to direct precipitation on the lake (Fig. 12), flows from the San Jacinto River (Fig. 3) and runoff from the local watershed (Fig. 15), recycled water represents an important additional water source for the lake, especially during year of limited rainfall and runoff. In an agreement between the EVMWD and the City of Lake Elsinore, EVMWD provides up to 5,000 acre-feet of recycled water annually when the lake level drops below 1240' above MSL.

### Scenarios

The model was subsequently used to evaluate water quality under a number of different conditions and management actions. Specifically, the following scenarios were simulated:

**1. Pre-development** - using natural rainfall and runoff with (low) concentrations of nutrients (based upon TetraTech estimates)

**2. Natural runoff** - with natural rainfall and runoff with (higher) concentrations of nutrients (based chiefly upon watershed sampling results)

**3. Recycled water** – rainfall and runoff supplemented with recycled water when lake level drops below 1240' above MSL

**4. Recycled water + Aeration** – rainfall and runoff supplemented with recycled water, and daytime operation of diffused aeration system

**5. Recycled water + Aeration (no Zooplankton, no Fish)** - rainfall and runoff supplemented with recycled water, and daytime operation of diffused aeration system; altered food web such that no zooplankton or fish are present (phytoplankton only)

**6. Recycled water + Aeration (Zooplankton only)** – rainfall and runoff supplemented with recycled water, and daytime operation of diffused aeration system; food web limited to phytoplankton and zooplankton (no fish)

**7. Recycled water + Aeration (no Carp)** – rainfall and runoff supplemented with recycled water, and daytime operation of diffused aeration system; no bioturbation or enhanced release of nutrients from sediments (achieved via carp removal)

**8. Recycled water (0.1 mg/L $PO_4$-P) + Aeration** – rainfall and runoff supplemented with recycled water at reduced $PO_4$-P concentration (0.1 mg/L), and daytime operation of diffused aeration system

## Results

Key results from 99-yr simulations for each of the 8 scenarios are presented below.

### Scenario 1. Pre-Development

Pre-development conditions were simulated using the current (LEMP) basin with the meteorological and runoff conditions reported for 1916-2014 (e.g., Figs. 12-15). Under natural flows (i.e., no recycled water inputs), extreme variations in lake level were predicted, e.g., with the lake going dry by late 1958 (Fig. 16a).

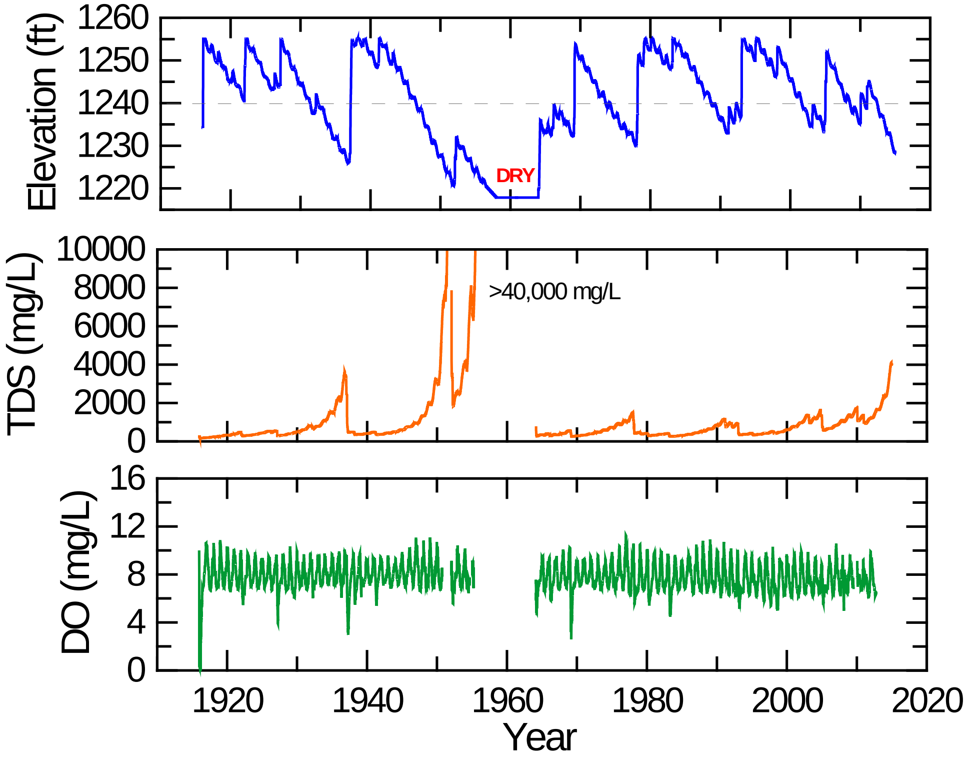

*Fig. 16. Predicted lake surface elevation, TDS and dissolved oxgyen concentrations in Lake Elsinore: Pre-development scenario.*

The simulation predicts that the lake was dry for 6 years (1959-1964) during this 99-year period, with lake levels below 1240' predicted 45% of the time (Fig. 16a). Decliining lake levels corresponded to increasing salinity values as a result of evapoconcentration of salts (Fig. 16b). Salinities exceeding that of ocean water were present preceding dessication in 1958, although concentrations near or above 4000 mg/L TDS were also present in late 1930's, early 1950's and near the end of the simulation (Fig. 16b).Dissolved oxygen (DO) concentrations were generally between 7-11 mg/L and followed the temperature dependence of Henry's law constant, with lower concentrations when the water is warm during the summer, and higher concentrations during the cool winter months (Fig. 16c).

Water quality was generally very good, with typically very low concentrations of total N, total P and, as a result, chlorophyll a (Fig. 17). Notwithstanding, during very low lake levels, high concentrations of nutrients and chlophyll a were predicted, with total N, total P and chlorophyll a reaching concentrations >10 mg/L, 0.3 mg/L and 300 µg/L, respectively (Fig. 17).

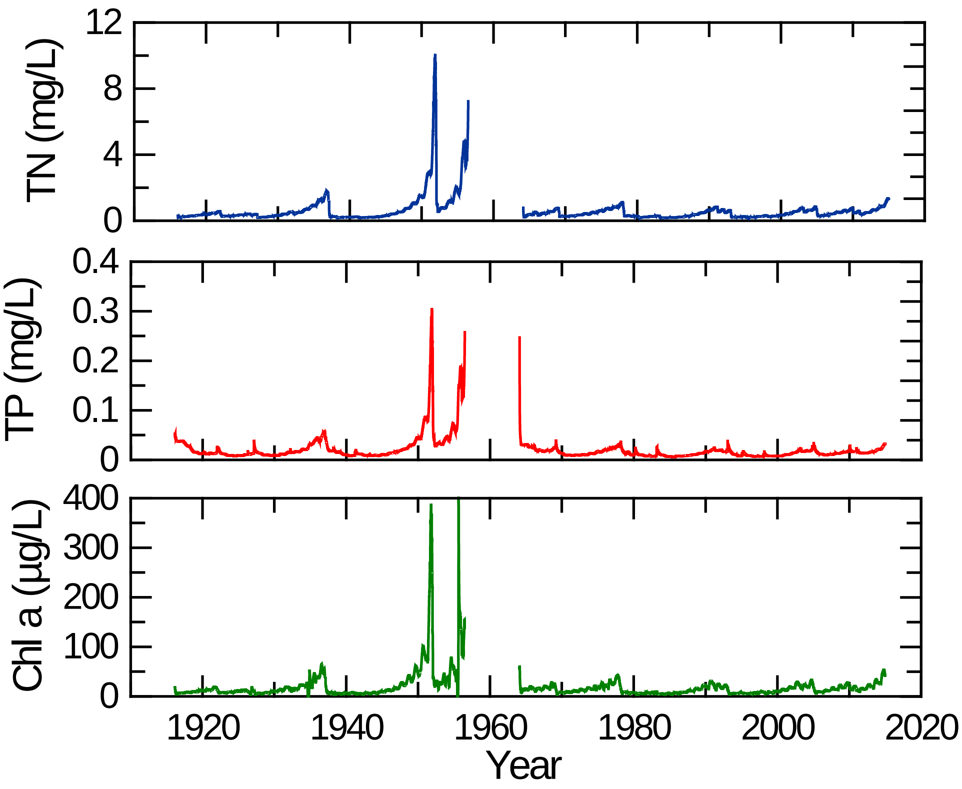

*Fig. 17. Predicted lake total N, total P anc chlorophyll a concentrations in Lake Elsinore: Pre-development scenario.*

**Scenarios 2 and 3. Natural Runoff and Supplementation with Recycled water.**

Addition of recycled water significantly alters the hydrologic and nutrient budgets for the lake. To highlight the effects of recycled water addition, scenario 2 (natural runoff without any supplementation) and scenario 3 (with recycled water supplementation) will be graphed and discussed together.

The lake surface elevation under current conditions (Fig. 18, blue line) does not differ from the pre-development scenario previously discussed (Fig. 16a), as the only difference is in the nutrient concentrations in the local runoff and San Jacinto River flow. As a result, the lake (still) goes dry in late 1950's and into 1960's (Fig. 18, blue line). Supplementation with recycled water protected the lake from extremely low (or dry) conditions, with the lake level generally above 1232' and in all instances above 1230.3'. This is a key finding; even in an extended drought such as witnessed in 1950's-1960's, addition of recycled water, at rates up to 5,000 acre-feet per year when the lake level drops below 1240', ensures a reasonable lake level.

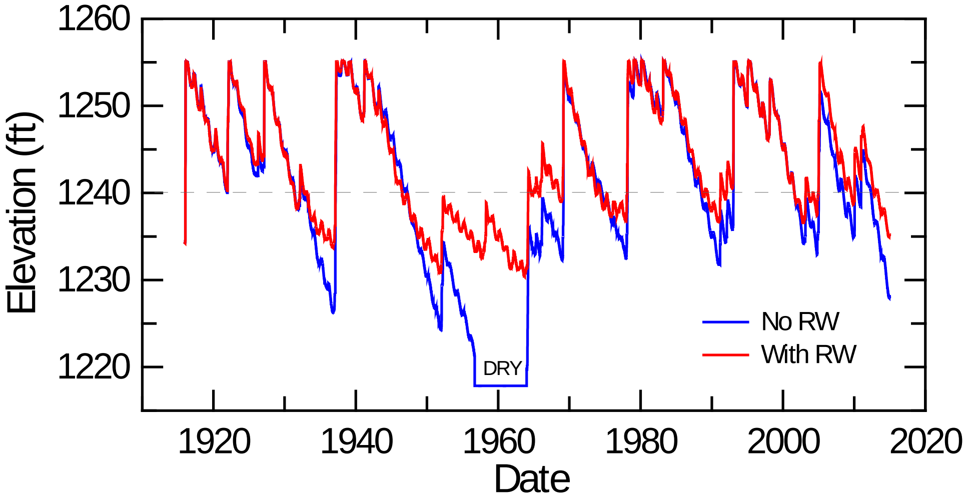

*Fig. 18. Predicted lake surface elevations with natural runoff (no RW) and when supplemented with recycled water (with RW).*

The addition of recycled water also protects the lake from extreme salinity events (Fig. 19). For example, natural rainfall and runoff yielded a lake level of 1226.5' in 1936 (Fig. 18, blue line) with a salinity of about 9,000 mg/L TDS (Fig. 19, blue line); supplementation with recycled water supported a lake level of 1234.2' and TDS near 3,500 mg/L. Addition of recycled water also prevented the hypersaline brine from forming as the lake approached desiccation in the late 1950's. Interestingly, TDS levels were much higher in the 1960's-1970's with recycled water inputs compared with natural flows; this results from desiccation and wind-blown salt transport out of the lake basin (estimated that 85% of dried salt in basin was exported) (Fig. 19). The extreme runoff event in 1978-1979 (Fig. 14) flushed out a substantial amount of salt that remained with recycled water, such that subsequent salinity levels were similar in subsequent years

(Fig. 19). Salt is thus periodically exported from the lake with large runoff inputs and downstream discharge events. At least some water was discharged downstream and some salt exported in 15 years out of 99 with recycled water supplementation (compared with 12 years under natural flows) (Fig. 18).

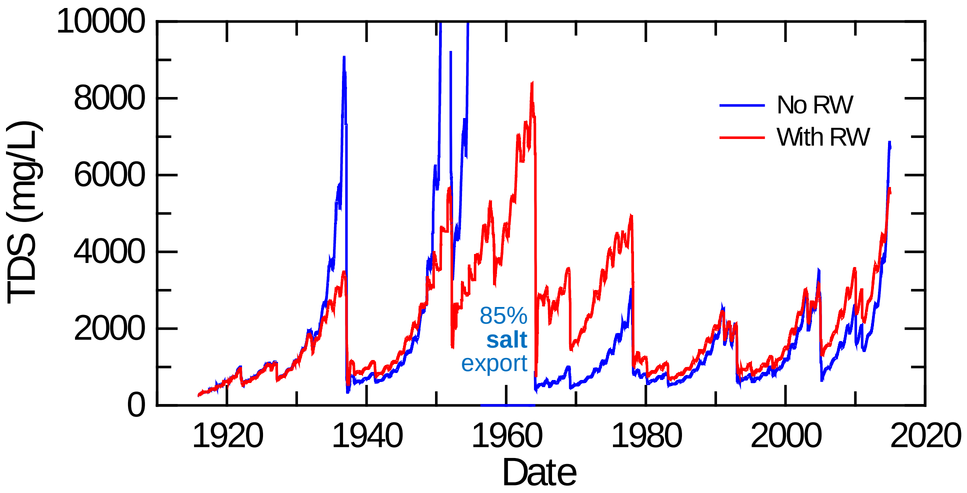

*Fig. 19. Predicted TDS concentrations with natural runoff (no RW) and when supplemented with recycled water (with RW).*

Nutrient concentrations also exhibited some meaningful similarities as well as differences. Total N concentrations without recycled water inputs varied in response to watershed inputs and evapoconcentration. Collectively, nitrogen fixation and denitrification did not appear to have a dramatic effect on total N concentrations. Recycled water inputs prevented the very high concentrations of total N found during low lake levels from occuring in the lake; thus, for example, total N reached only about 7 mg/L with recycled water, compared with 17 mg/L with only natural flows in 1936 (Fig. 20). Beyond these low lake level events where evapoconcentration resulted in higher total N concentrations under natural flows compared with recycled water inputs, concentrations of total N tended to track quite closely under both conditions (Fig. 20). This is due in part to the not dissimilar total N concentrations in runoff and San Jacinto River flows (1.82 and 1.62 mg/L, respectively), and recycled water (2.87 mg/L) (Table 1), and to periodic flushing events that tended to normalize concentrations.

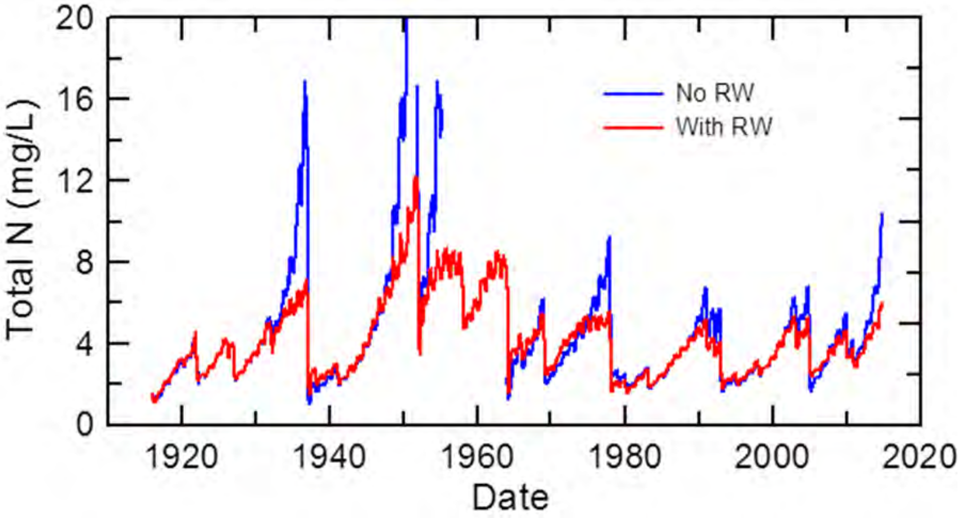

*Fig. 20. Predicted total N concentrations with natural runoff (no RW) and when supplemented with recycled water (with RW).*

Trends in total P concentrations followed total N, with similar concentrations in the lake both with and without recycled water additions except during strong divergences in lake surface elevations, when recycled water inputs markedly decreased total P (Fig. 21). The reductions resulted from dilution during periods of otherwise strong evapoconcentration, and incorporation into foodweb and subsequent settling.

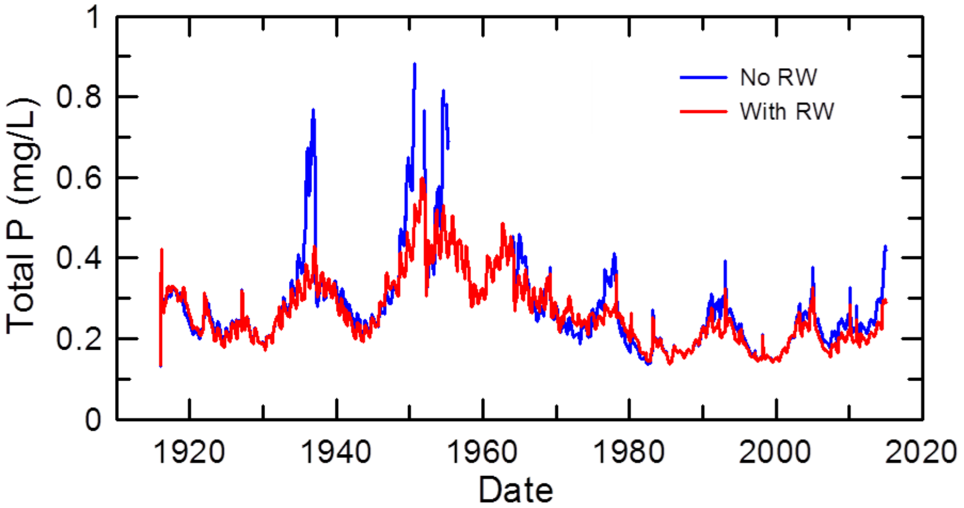

*Fig. 21. Predicted total N concentrations with natural runoff (no RW) and when supplemented with recycled water (with RW).*

Concentrations of chlorophyll a exhibited much greater variability, including variability over short (week-month) time scales, than the other water quality parameters (Fig. 22). Predicted concentrations reached 1000 µg/L in 1950 and again in 1957-58 when lake levels were very low (Fig. 18) and nutrient concentrations were very high

(Figs. 20,21). Concentrations were also often very low (<10 µg/L). Recycled water addtions had little effect on chlorophyll a concentrations owing to the similar nutrient concentrations (especially total P) in runoff and recycled water (Table 1).

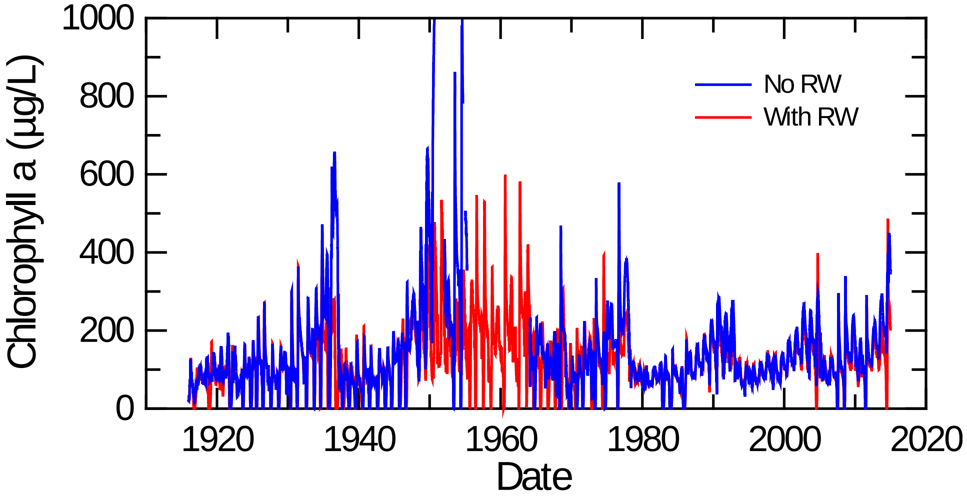

*Fig. 22. Predicted chlorophyll a concentrations with natural runoff (no RW) and when supplemented with recycled water (with RW).*

**Statistical Analysis of Scenarios**

A key feature of this study is the very long period of time over which conditions were simulated, necessitated by the complex hydrology of the region that includes extnded droughts and extreme El Nino events. This very long period of time allowed for statistical representations of conditions in Lake Elsinore under different management strategies. In particular, probabilistic representations are useful because they allow us to understand the probability and frequency of a given set of conditions. Thus, while time-series graphs could be developed for each of the additional scenarios, results henceforth will be presented using cumulative distribuiton functions and other statistical representations, focusing on the following key attributes of Lake Elsinore:

- lake surface elevation
- lake area
- TDS
- total P
- total N
- DO
- chlorophyll a

*Lake Surface Elevation*

As evident from Fig. 18, surface elevation can vary dramatically at Lake Elsinore. Presented using cumulative distribution functions ( CDFs), we see that under natural flows (without addition of recycled water), the lake surface elevation exceeded the minimum bottom elevation of 1217.8 ft on 93.9% of the simulation days for the 1916-2014 simulation period (i.e., the lake was dry for 6 years or 6.1% of the time) (Fig. 23, blue line). In contrast, with recycled water added when the lake level dropped below 1240 ft, the lake level always exceeded 1230.3 ft above MSL (Fig. 23, red line). The two water management alternatives thus yielded dramatically different CDFs, especially below 1240 ft. Little difference was found above approximately 1245 ft, however, with natural flow and with recycled water supplementation scenarios both yielding these higher lake levels about 40% of the time. Under the rules of the water transfer agreement, recycled water would not be a part of the water budget at these higher lake levels, so levels would be controlled by flows from the San Jacinto River and local runoff. As previously noted, the model assumes outflow is rapid when the lake level exceeds the outlet/spillway elevation, so lake level does not substantively exceed 1255 ft above MSL. A 3-D model of the lake could more readily accommodate filling of the back basin and other, more complex hydraulic conditions.

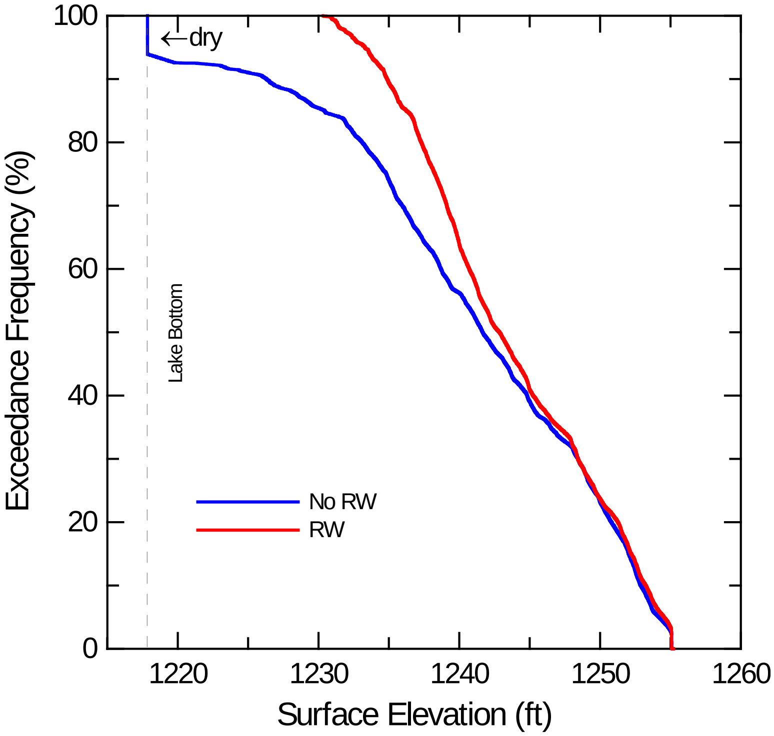

*Fig. 23. Cumulative distribution functions showing lake surface elevation under natural flow (No RW) and with recycled water supplementation (RW) scenarios.*

*Lake Surface Area*

A $3^{rd}$-order polynomial used to represent the hypsography of Lake Elsinore allowed surface area (Fig. 24) to be calculated from predicted lake surface elevation (Fig. 23). As indicated in Fig. 23, the lake was dry (lake area essentially 0 acres) for 6.1% of the 99-year period, while the lake was never smaller than 2060 acres with recyclced water supplementation (Fig. 24). With only natural flow, lake levels were below the minimum level maintained with recycled water (2060 acres) for 15 years. While substantial differences were present at lower surface areas, the median (50% exceedance frequency) values with and without recycled water supplementation were not dramatically different (2956 vs. 2875 acres, respectively, for a difference of 81 acres). As noted with lake surface elevation, differences in lake area were effectively absent at exceedance frequencies <40%, which is to say that recycled water supplementation did not increase the frequency of very high lake surface areas due in part to the model assumption of rapid discharge when the lake exceeded the outlet/spillway elevation (Fig. 24).

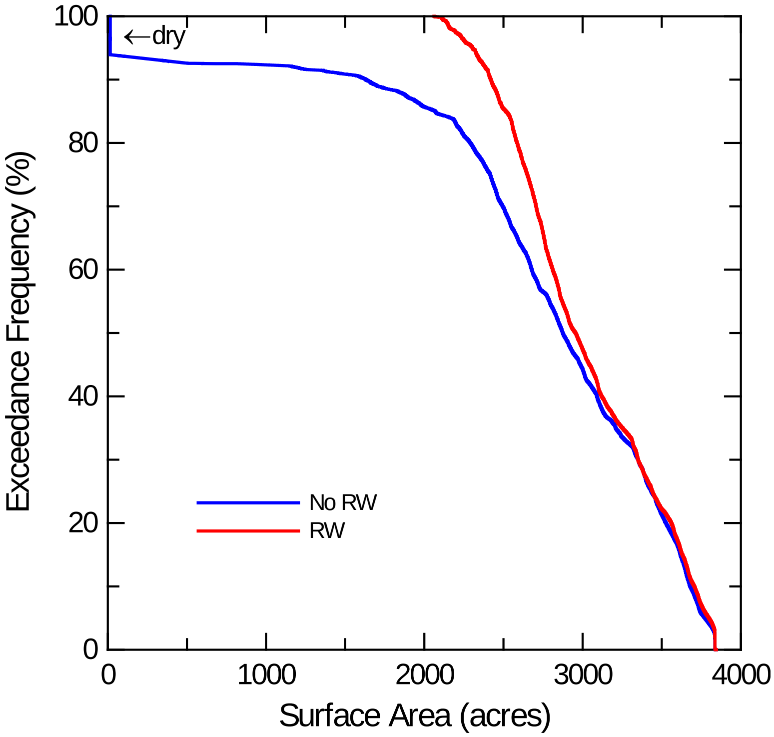

*Fig. 24. Cumulative distribution functions showing lake surface area under natural flow (No RW) and with recycled water supplementation (RW) scenarios.*

*Total Dissolved Solids (TDS)*

Recycled water supplementation did alter TDS concentrations in the lake across the full range of conditions, however, with distinct TDS-frequency relationships (Fig. 25).

Minimum TDS values of about 250 mg/L were present both with and without recycled water supplementation (Fig. 25), with >99.95% probability that TDS values in the lake will exceed this minimum value. The two CDFs diverged quickly, with TDS values with natural flows to the lake (no recycled water supplementation) lower than values present in the lake with recycled water addition 80.3% of the time (the cross-over point on the curves, occurring at 3345 mg/L TDS) (Fig. 25). By extension, natural flows would have yielded had a greater lake TDS value than that with recycled water supplementation 19.7% of the time the lake. The maximum TDS value with recycled water reached 8400 mg/L, while this TDS value was exceeded 11.7% of the 1916-2014 simulation period and reached very high levels (greater that that of sea water at very low lake levels, before becoming a salt encrusted playa upon complete dessication). Salinity-induced mortality can occur at higher TDS values which vary depending upon the individual species, as well as temperature and other factors.

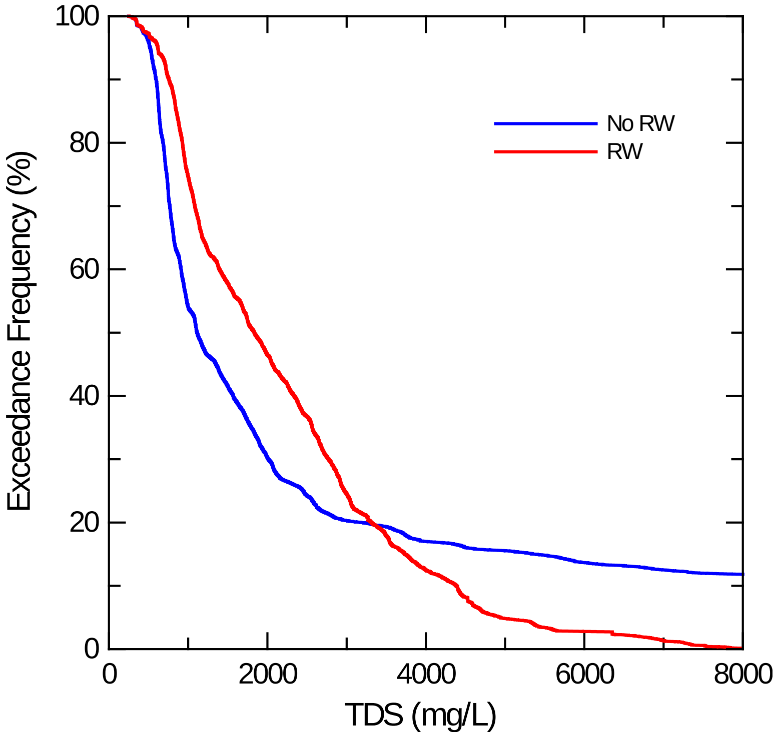

*Fig. 25. Cumulative distribution functions showing TDS concentrations under natural flow (No RW) and with recycled water supplementation (RW) scenarios.*

Approximate maximum salinity values for important species in Lake Elsinore were taken from available references. Black crappie appear to be the species most sensitive to salinity, with an upward limit of about 2,000 mg/L (Table 3). This threshold is shown by the dashed line; from the intercept of the two curves with this 2,000 mg/L line, we see that with recycled water additions, TDS exceeds this value 46.5% of the time (indicating that suitable salinity conditions are expected to be present in the lake 53.5%

of the time). With natural flows, TDS levels in the lake exceeded this value less frequently (30.3%), yielding suitable salinity conditions 69.7% of the time. Largemouth bass can tolerate a higher level of salinity than black crappie, with values exceeding the threshold of 4,000 mg/L 12.5% of the time with recycled water supplementation and 17.0% with natural flows (Table 3). Hybrid striped bass and common carp are more tolerant of high salinity, with threshold values of approximately 8,000 and 7,300 mg/L, respectively. Lake Elsinore is expected to support these species under essentially all conditions (<1% exceedance probability) with recycled water supplemention, while salinities would have exceeded these threshold values about 12% of the time under natural flows (Table 3). Notwithstanding, complete extirpation of all fish in Lake Elsinore would have occurred upon dessication under natural flow conditions in 1958-1964. The upper limit of salinity for *Daphnia pulex* has been reported in literature (e.g., Latta et al., 2012) to be approximately 4,000 mg/L, indicating that widespread mortality of this important cladocern would occur 17% of time under natural flow conditions to the lake which is reduced to 12.5% with recycled water additions (Table 3). Reproduction and recruitment are inhibited at salinity values below those reported in Table 3, although well-defined values are not available.

Table 3. Salinity tolerances and threshold exceedances as percentage of total simulation time (1916-2014).

| | Max Salinity (mg/L) | Threshold Exceedance (%) | |
|---|---|---|---|
| | | No RW | RW |
| Daphnia pulex | 4,000 | 17.0 | 12.5 |
| Threadfin Shad | 15,000 | 10.0 | 0 |
| Bluegill | 3,600 | 18.9 | 16.2 |
| Black Crappie | 2,000 | 30.3 | 46.5 |
| Largemouth Bass | 4,000 | 17.0 | 12.5 |
| Striped bass | 8,000 | 11.8 | 0.1 |
| Common carp | 7,300 | 12.2 | 0.9 |

Lake elevation, area and salinity levels differ only between scenarios comparing natural flows and those with recycled water supplementation; these properties are not affected by operation of diffused aeration, alteration of the food web, or other management actions or scenarios. This is not the case with concentrations of nutrients, DO and chlorophyll a concentrations. As a result, more complex CDFs were developed for these water quality parameters that included a wide range of scenarios.

Cumulative distribution functions for these key water quality parameters are presented for scenarios that include (i) no recycled water added (No RW), (ii) supplementation with recycled water (RW), (iii) supplementation with recycled water and daytime operation of the diffused aeration system (RW+Aeration), and (iv) supplementation with recycled water with 0.1 mg/L $PO_4$-P and aeration (RW (0.1 mg/L P)+Aeration). In each of these 4 scenarios, the full food web (with cladocerans, copepods, threadfin shad, and piscivores) is operating. Although carp are not explicitly simulated, their effect on bioturbation and enhanced release of $NH_4^+$ and $PO_4$-P from bottom sediments was also included based upon Anderson (2006). Three additional scenarios explored food-web effects explicitly, with (vi a simulation that removed zooplankton, threadfin shad and piscivores (RW+Aeration, no Zoo, no Fish), (vi) a simulation with only zooplankton grazing and no fish (RW+Aeration+Zoo), and (vii) a simulation that explored effect of complete carp control that eliminated bioturbation-enhanced sedimebnt nutrient flux (RW+Aeration, no Carp).

*Total N*

Across this set of scenarios and over the 99-yr simulation period, total N concentrations varied from about 1 mg/L to >10 mg/L (Fig. 20). This was also shown in Fig. 20, which presented the total N time-series comparing No RW and RW scenarios. Notable in this figure is that for all scenarios, including aeration and food web alterations, at no time did total N concentration meet the final TMDL target of 0.75 mg/L (i.e., 100% exceedance frequency for total N concentration was > 1 mg/L) (Fig. 26). Comparatively little difference across the scenarios was seen at low TN concentrations (<3 mg/L) (Fig. 20) associated with high lake levels following large runoff events (Fig. 18). This makes sense since the conditions in the lake are driven to a large extent by external hydrologic forcing with comparatively little opportunity for extensive management effects on nutrient concentrations. The CDFs deviate at higher concentrations however, as evapo-concentration, ecological and management actions exert a greater effect (Fig. 26). For example, removal of carp and corresponding reductions in internal nutrient loading had a noticeable benefit, shifting the CDFf to lower total N concentration between 20-60% exceedance frequency (Fig. 26, light blue dashed line). At the other end of the spectrum, elimination of algal grazing by zooplankton and food web effects shifted the CDF to higher total N concentrations at a given exceedance frequency (Fig. 26, orange line).

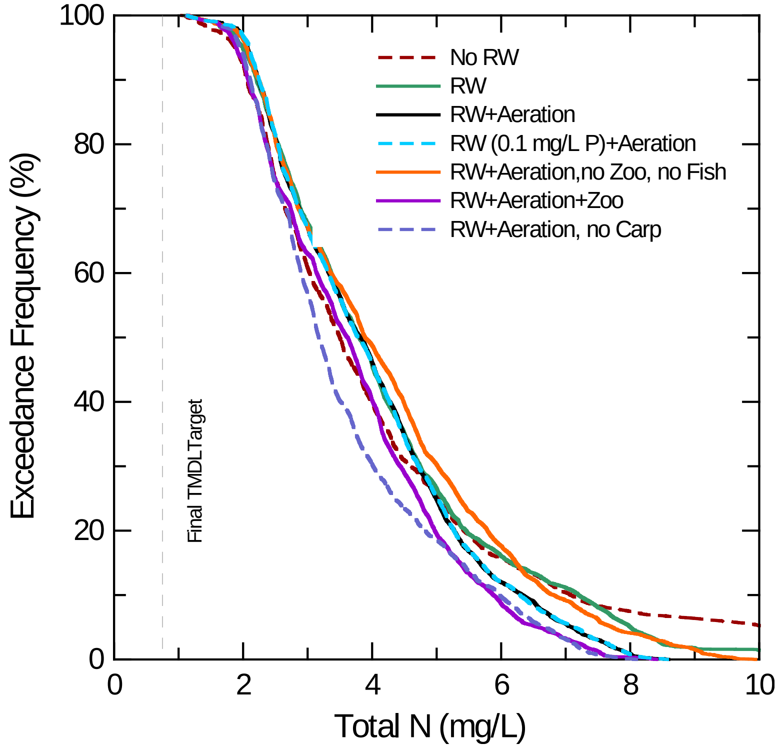

*Fig. 26. Cumulative distribution functions showing total N concentrations under natural flow (No RW) and with recycled water supplementation (RW) scenarios.*

Key values were pulled off the CDF and are presented in Table 4. The arithmetic mean concentrations of total N for the scenarios ranged from 3.6 mg/L for the scenario in which carp have been removed, to 4.27 mg/L for the scenario with no recycled water addition (Table 4). Median concentrations, corresponding to the 50% exceedance frequencies, were lower than mean values, indicating a non-Gaussian distribution in concentrations that are skewed to higher values, as demonstrated in the CDFs. Median values were again lowest for the no carp scenario, but in this case highest for the no zooplankton/no fish scenario in which top-down control of algal production was excluded (Table 4). Maximum concentration varied most dramatically, as very high total N concentrations were predicted for the natural flow scenario (no RW) at low lake levels, exceeding 24 mg/L as the lake approached dryness. Aeration (RW+Aeration) was shown to reduce total N concentrations compared with recycled water addition alone (No RW), with maximum concentrations reduced from 12.25 to 8.60 mg/L, and 10% exceedance frequency concentrations reduced from 7.20 to 6.33 mg/L (Table 4). At the 10% exceedance frequency, zooplankton grazing without fish pressures yielded the lowest predicted concentration of total N for all evaluated scenarios.

Table 4. Total N concentrations for Lake Elsinore simulation scenarios.

| Scenario | Mean | Median | Min | Max | 90% | 10% |
|---|---|---|---|---|---|---|
| No RW | 4.27 | 3.50 | 1.05 | >24.0 | 2.06 | 7.08 |
| RW | 4.20 | 3.80 | 1.10 | 12.25 | 2.21 | 7.20 |
| RW+Aeration | 4.01 | 3.82 | 1.14 | 8.60 | 2.24 | 6.33 |
| RW(0.1 mg/L P)+Aeration | 4.01 | 3.78 | 1.14 | 8.58 | 2.25 | 6.29 |
| RW+Aeration, no Zoo, no Fish | 4.23 | 3.89 | 1.16 | 9.95 | 2.24 | 6.81 |
| RW+Aeration+Zoo | 3.77 | 3.62 | 1.15 | 8.41 | 2.08 | 5.88 |
| RW+Aeration, no Carp | 3.60 | 3.17 | 1.13 | 8.10 | 2.11 | 5.97 |

### *Total P*

Results for total P differ in some interesting ways from total N. Beyond much lower concentrations than total N, greater separation in CDFs was witnessed between the different scenarios. As with total N, predicted total P concentrations exceeded the TMDL target of 0.1 mg/L (Fig. 27), although it bears noting that while model calibration reasonably captured average concentrations and trends, the model tended to over-predict observed low concentrations and under predict somewhat the observed high values (despite considerable effort) (Fig. 10). On that basis, the CDFs for total P are somewhat “steeper” than might be expected, with reduced tails (that would represent low probability events) at both low concentrations and high concentrations (Fig. 27). Notwithstanding, the main features of the CDFs, including mean and median concentrations, as well as relative trends for the different scenarios are well represented.

Lowest predicted concentrations across all scenarios were predicted for recycled water supplementation with reduced (0.1 mg/L) $PO_4$-P concentrations with aeration (and full food web) (Fig. 27, light blue dashed line). Somewhat lower predicted total P concentrations were also predicted for the RW+Aeration, No Zoo, No Fish scenario, attributed to slightly lower dissolved organic P levels that results from reduced processing by zooplankton and greater proportion of particulate organic P that settled more quickly through the water column. The other simulations tended to track somewhat more closely, although natural flows (No RW) yielded higher concentrations than most of the other scenarios at low exceedance frequencies (Fig. 27). Somewhat surprisingly, recycled water with aeration also yielded high total concentrations at low exceedance frequencies that would be associated with low lake levels and high evapoconcentration, underscoring the complexity of controls and uptake, processing and loss of P in the lake.

Median total P concentrations ranged from 0.21 – 0.26 mg/L, with carp removal yielding the lowest predicted median value and RW+Aeration+Zoo (i.e., no fish predation) yielding the highest value (Table 5). Reduced PO4-P concentrations in recycled water coupled with aeration yielded the consistently lowest predicted total P concentrations (Fig. 27, Table 5).

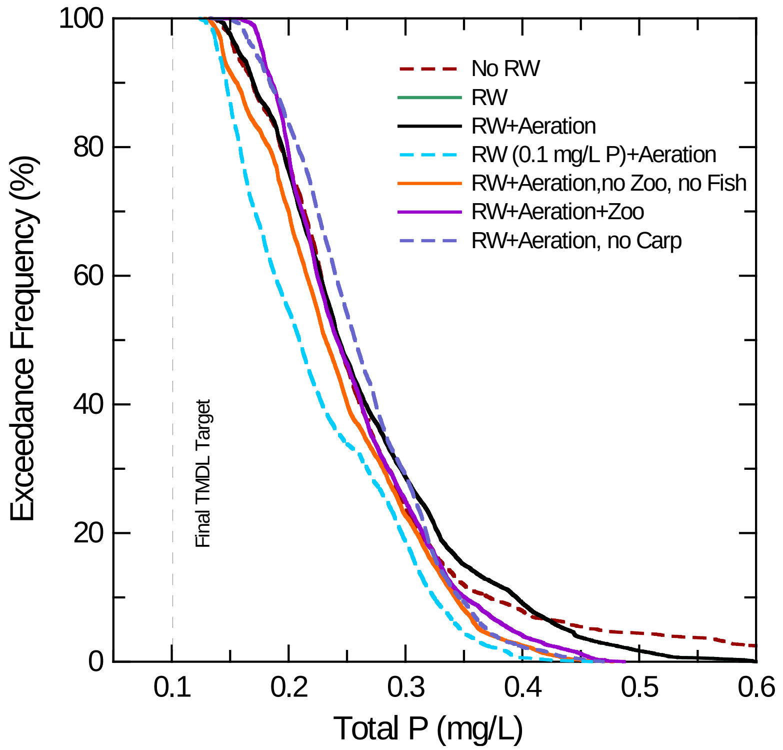

*Fig. 27. Cumulative distribution functions showing total P concentrations under natural flow (No RW) and with recycled water supplementation (RW) scenarios.*

Table 5. Total P concentrations for Lake Elsinore simulation scenarios.

| Scenario | Mean | Median | Min | Max | 90% | 10% |
|---|---|---|---|---|---|---|
| No RW | 0.27 | 0.24 | 0.13 | 0.88 | 0.17 | 0.37 |
| RW | 0.26 | 0.24 | 0.13 | >0.60 | 0.17 | 0.39 |
| RW+Aeration | 0.24 | 0.23 | 0.13 | 0.48 | 0.17 | 0.39 |
| RW(0.1 mg/L P)+Aeration | 0.23 | 0.22 | 0.13 | 0.42 | 0.15 | 0.32 |
| RW+Aeration, no Zoo, no Fish | 0.26 | 0.24 | 0.13 | 0.49 | 0.16 | 0.34 |
| RW+Aeration+Zoo | 0.26 | 0.26 | 0.13 | 0.47 | 0.19 | 0.35 |
| RW+Aeration, no Carp | 0.22 | 0.21 | 0.12 | 0.46 | 0.18 | 0.35 |

### *Chlorophyll a*

Cumulative distribution functions for predicted chlorophyll a concentrations exhibited trends different from either total N or total P (Fig. 28). The effect of no zooplankton grazing or other food web effects yielded dramatically higher chlorophyll a concentrations than any other scenario except at very low exceedance frequency when the No RW scenario overtook it at nearly 300 µg/L, and occurring at about or less than 10% exceedance frequency (Fig. 28). This observation highlights the control on algal abundance in Lake Elsinore that zooplankton grazing and higher food web effects exert.

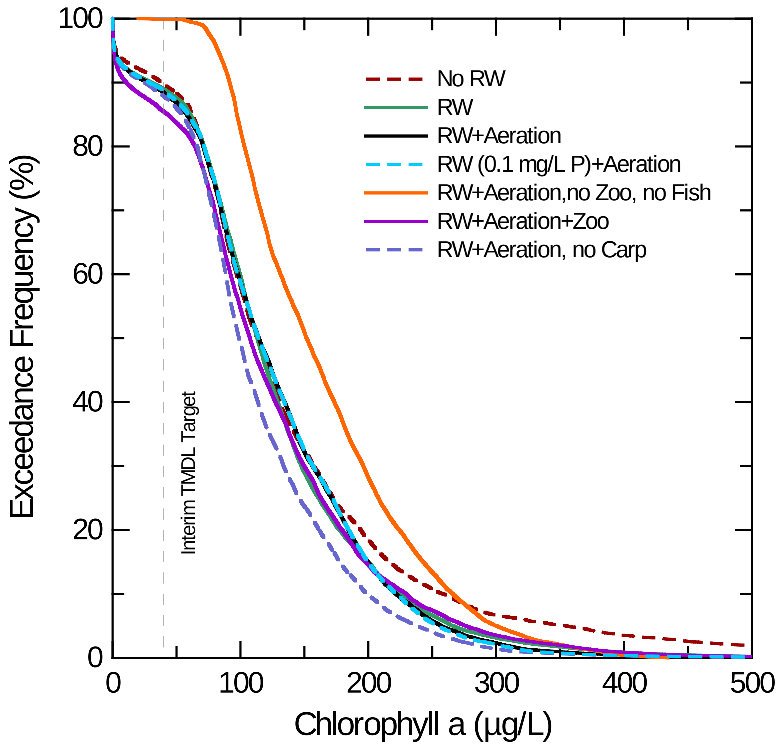

*Fig. 28. Cumulative distribution functions showing chlorophyll a concentrations under natural flow (No RW) and with recycled water supplementation (RW) scenarios.*

Zooplankton grazing alone yielded slightly lower chlorophyll a concentrations compared with the other scenarios between approximately 80-90% exceedance frequencies, suggesting some subtle food web effects under low nutrient/low carbon conditions. Carp removal yielded lower predicted chlorophyll a levels at lower exceedance frequencies (<60%) than most of the other scenarios (Fig. 28). Included in this figure is the interim TMDL target of summer-averaged chlorophyll a concentration of 40 µg/L, although CDFs were developed using daily data from the entire 99-yr simulation period, and thus can not be directly compared with the summer-average target value.

These trends in chlorophyll a concentrations can also been seen in Table 6, where complete carp removal yielded lowest mean and median chlorophyll a concentrations, followed by zooplankton grazing with no fish predation. The no-food web effects scenario (RW+Aeration, no Zoo, No Fish) yielded universally and dramatically higher concentrations for all metrics excluding the maximum concentration predicted at very low lake levels as the lake evapoconcentrated and approached desiccation (Table 6).

Table 6. Chlorophyll a concentrations for Lake Elsinore simulation scenarios.

| Scenario | Mean | Median | Min | Max | 90% | 10% |
|---|---|---|---|---|---|---|
| No RW | 140 | 113 | <1 | >1400 | 38 | 258 |
| RW | 125 | 113 | <1 | 599 | 30 | 224 |
| RW+Aeration | 125 | 114 | <1 | 647 | 27 | 222 |
| RW(0.1 mg/L P)+Aeration | 125 | 114 | <1 | 666 | 29 | 222 |
| RW+Aeration, no Zoo, no Fish | 167 | 152 | 20 | 434 | 92 | 266 |
| RW+Aeration+Zoo | 122 | 107 | <1 | 716 | 11 | 230 |
| RW+Aeration, no Carp | 111 | 99 | <1 | 568 | 25 | 199 |

### *Dissolved Oxygen*

Dissolved oxygen concentrations demonstrated less variation across the different scenarios than the other key water quality parameters. Unlike the other parameters where higher concentrations for a given scenario and exceedance frequency represented poorer water quality conditions, higher values for DO indicates improved conditions. The upper portions of the CDFs thus are of particular interest. Recycled water supplementation without aeration yielded the lowest water column-averaged DO concentrations of the scenarios, with anoxic (<1 mg/L) conditions present on 4.9% of all days in the 1916-2014 simulation period (Fig. 29, green line). In contrast, aeration with recycled water addition limited anoxia to 0.4% of the simulation period (Fig. 29, black line); under natural flow (no RW) (and no aeration), whole-water column anoxia was present 1.4% of the time (Fig. 29). The no Zoo/no Fish scenario (Fig. 29, orange line) provided the lowest amount of anoxia (0.2%), and also minimized conditions of extreme supersaturation present at low exceedance frequencies for the other scenarios. This suggests that grazing and resulting production of ammonia and oxidizable organic matter plays a greater role in DO dynamics that simply algal photosynthesis and respiration.

The frequency in which the 5 mg/L water column-averaged interim TMDL target was not met varied from 13.3% for recycled water addition without aeration (RW), to 5.6% for recycled water with aeration (RW+Aeration), and 2.3% without food web effects (RW+Aeration, no Zoo, no Fish) (Fig. 29).

Recycled water addition without aeration (RW) yielded the lowest mean and median DO concentrations, while RW+Aeration yielded the highest values (Table 7). All scenarios were predicted to produce whole-water column DO concentrations <0.01 mg/L at least 22 days out of the 99-year simulation period, and RW without aeration over 1300 days. Such conditions would be expected to produce widespread fish kills. Strongly supersaturated conditions associated with very high chlorophyll a concentrations were also predicted to occur for almost all scenarios with some frequency as well; DO levels exceeded 15 mg/L about 3% of the simulation days (Fig. 29).

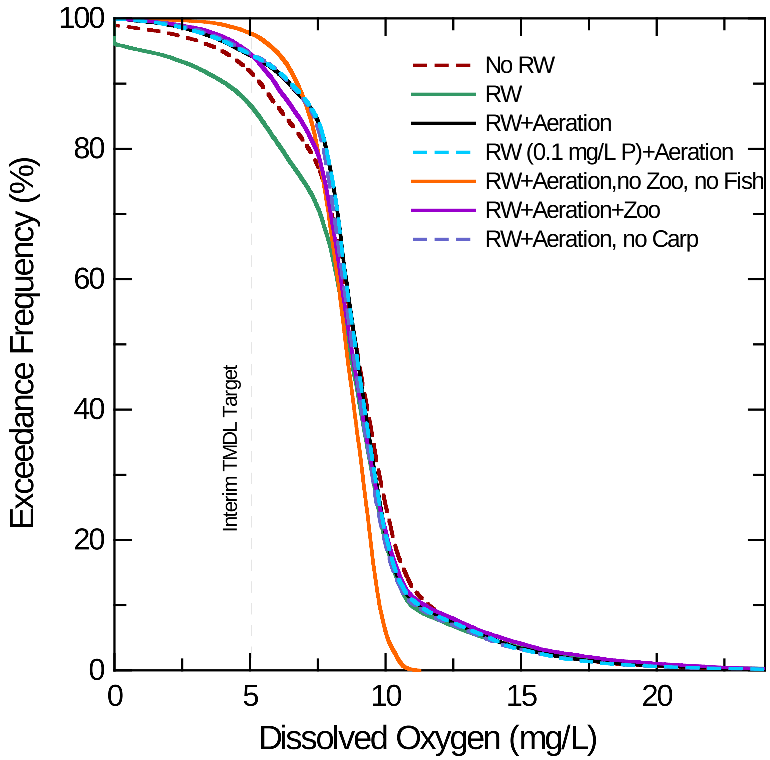

*Fig. 29. Cumulative distribution functions showing dissolved oxygen concentrations under natural flow (No RW) and with recycled water supplementation (RW) scenarios.*

Table 7. Dissolved oxygen concentrations for Lake Elsinore simulation scenarios.

| Scenario | Mean | Median | Min | Max | 90% | 10% |
|---|---|---|---|---|---|---|
| No RW | 8.85 | 8.90 | <0.01 | 34.0 | 5.39 | 11.6 |
| RW | 8.30 | 8.64 | <0.01 | 31.7 | 4.10 | 11.0 |
| RW+Aeration | 9.03 | 8.90 | <0.01 | 28.1 | 6.45 | 11.3 |
| RW(0.1 mg/L P)+Aeration | 9.02 | 8.87 | <0.01 | 29.4 | 6.51 | 11.2 |
| RW+Aeration, no Zoo, no Fish | 8.36 | 8.53 | <0.01 | 11.3 | 6.75 | 9.78 |
| RW+Aeration+Zoo | 8.94 | 8.72 | <0.01 | 30.0 | 5.94 | 11.4 |
| RW+Aeration, no Carp | 8.93 | 8.76 | <0.01 | 29.6 | 6.46 | 11.1 |

## Conclusions

Simulations for Lake Elsinore under a number of different scenarios indicate:

(i) water quality in Lake Elsinore varies dramatically over time;

(ii) water quality under pre-development conditions is substantially improved relative to current conditions, although under natural runoff, Lake Elsinore is nonetheless predicted to go dry for a number of years, with resultant poor water quality at very low lake levels;

(iii) recycled water supplementation significantly increases lake surface elevation and lake area compared with natural inflows into the lake during periods of limited precipitation and runoff, preventing drying up of the lake and extreme salinities seen under natural flow conditions;

(iv) recycled water supplementation did not substantively increase total N or total P concentrations in the lake, in large part since nutrient concentrations are not dramatically different than levels in runoff;

(v) aeration lowered slightly the mean and maximum concentrations of total N and total P, increased DO concentrations and reduced frequency of anoxia, although average chlorophyll a levels were not altered;

(vi) reduction in the $PO_4$-P concentration in recycled water to 0.1 mg/L reduced slightly total P in the lake but did not alter predicted chlorophyll a or dissolved oxygen concentrations;

(vii) removal of carp to reduce internal nutrient loading via bioturbation by carp yielded the lowest predicted average nutrient and chlorophyll a concentrations of all the scenarios evaluated, although reductions were modest;

(viii) elimination of food-web effects had a strong effect on predicted chlorophyll a concentrations, underscoring the value of zooplankton grazing and its beneficial effect on water quality in Lake Elsinore;

(ix) with the exception of the pre-development scenario, all scenarios yielded nutrient, chlorophyll a and DO concentrations that were routinely well-above current TMDL targets.

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## *Technical Memorandum*

**Task 2.1:** Stable Isotope, Elemental and Mobile-P Measurements in Lake Elsinore Sediments*

### Objective

The objectives of this task were to quantify properties of Lake Elsinore sediments over time and correlate observed properties with hydrologic conditions, management actions and other factors.

### Approach

Sample Collection

Two replicate cores were collected from profundal sediment (“Site 6”, 33.66879° N, 117.35127° W) in Lake Elsinore on July 17, 2014 with a 1 meter polycarbonate tube with a 6.5 cm diameter. Water was carefully siphoned off the top of each core and the sediment was sectioned into 1 cm (for the top 10 cm) or 2 cm (for sediment deeper than 10 cm) intervals. Each section was homogenized and stored at 4°C under $N_2$ (g) in 50 mL polypropylene centrifuge tubes. A subsample from each interval was used for water content determination. To calculate water content, the wet sediment was pre-weighed into small aluminum pans and oven-dried at 105°C until reaching a constant weight (1-2 days).

Water was collected from 0.5 m depth at Site 6 on September 17, 2014 and June 18, 2015 and analyzed for isotopic composition of suspended organic matter (mainly phytoplankton). The water was stored in 20 L Nalgene jugs at 4°C until later filtration. The water collected in 2014 was stored for six months, over which it experienced an unknown period of time at 25°C, due to technical issues. Therefore suspended organic matter (SOM) experienced some decay over this period of time, but is thought to reflect, to at least some degree, natural decomposition processes operating within the lake.

Elemental Composition (XRF)

Bulk elemental composition was determined on sediment samples using a Spectro XEPOS HE Benchtop X-ray Fluorescence Spectrometer flushed with 85 L $hr^{-1}$ of helium gas (EPA Method 6200). Approximately 5 g of wet sediment from sediment core interval was dried at 50°C and ground with a mortar and pestle prior to X-ray fluorescence analysis. Four different source energies/excitation targets were utilized per sample at count times of 200 seconds: excitation energy of 40 kiloelectron volts (kV) and 1 mA current; 60 kV and 0.66 mA; 25 kV and 1.6 mA; 20 kV and 2 mA.

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**This technical memorandum was developed from Chapter 2 of the M.S. thesis of Simone Boudreau (2015).*

## Phosphorus Forms

Forms of P in bottom sediment were extracted using the fractionation scheme described in Pilgrim et al. (2007). 0.2-0.25 grams of wet sediment was added to 50 mL polycarbonate centrifuge tubes, followed by a sequential phosphate extraction which utilized different reagents to measure the amount of phosphate in three different fractions within the sediment. The reagent solutions were 1M ammonium chloride ($NH_4Cl$) which extracts pore-water and loosely-sorbed P, followed by bicarbonate buffered dithionite solution (0.11M $NaHCO_3$/0.11M $NaS_2O_4$) to extract redox-sensitive P bound to iron and manganese hydroxides (Fe-P), and lastly 0.1M sodium hydroxide, NaOH, to extract non-reducible, aluminum-bound P (Al-P). The sum of the phosphate extracted in the first two steps represents mobile phosphorus, or phosphorus that can be re-released to the water column under low DO conditions. Aluminum-bound phosphate is generally considered to be a recalcitrant form that will not be re-released. 10 mL of each extract was added to the centrifuge tube. After each sequential reagent addition, the samples were placed on a shaker table for varying amounts of time: two hours for loosely-sorbed P, one hour for Fe-P, and 16 hours for Al-P (Pilgrim et al., 2007). Subsequent to each reagent addition and mixing, samples were centrifuged at 3,000 rpm for 20 minutes. The supernatant was decanted, filtered through 0.45 μm membrane filters, and stored in 20 mL HDPE scintillation vials in the freezer until analysis. The residual sediment continued on in the procedure after the supernatant from each step was decanted. One out of every 10 samples was replicated and 2 method blanks per core were used (no sediment, just reagent and centrifugation). Soluble reactive phosphorus was determined colorimetrically for each supernatant on a Seal AQ2 discrete analyzer following the automated ascorbic acid reduction method 4500-P F (Standard Methods for the Examination of Water and Wastewater, 20th edition). Absorbance was measured at 880 nm. Calibration control blank and calibration control verifications were used to verify accuracy.

## Stable Isotopic Composition

Sediment subsamples were dried at 50°C and ground to a homogenous mixture with a mortar and pestle. The dried sediment was fumigated with concentrated HCl (12N) in a desiccator for 24 hours in order to remove inorganic C. Replicate samples were analyzed without fumigation to ensure all $CaCO_3$ had been removed. Suspended organic matter from epilimnetic water was filtered through 47 mm Whatman glass microfiber filters and then oven-dried at 50°C. Stable C and N isotope compositions as well as %OC (weight percent) and %N were analyzed on a Costech elemental analyzer coupled to a Delta V Advantage Isotope Ratio Mass Spectrometer at the Facility for Isotope Ratio Mass Spectrometry (FIRMS) at University of California, Riverside. One in every ten samples was replicated.

## Results

Using the sedimentation rate of 1.27 cm/year previously determined by Byrne et al. (2004), the dates corresponding to given sediment depths were calculated using the formula shown below and plotted on each depth profile as a secondary y-axis to allow comparison of sediment properties over time and with lake management activities.

$$t = t_0 - (z/1.27\ cm\ yr^{-1}) \qquad (1)$$

where $t$ = date (decimal year) at sediment depth $z$

$t_0$ = date at time of sediment collection (2014.5)

$z$ = sediment depth (cm)

Historical lake management activities are summarized in Fig. 1 for reference. Prior to the completion of the Lake Elsinore Management Project (LEMP) in 1995, Lake Elsinore was larger and shallower with presumably greater mixing and circulation. The completion of the project in 1995 marks the transition to a deeper lake with a reduced surface area. Addition of supplemental recycled wastewater began in 2002 and continued through 2004 and from 2008-present. Lake level varied strong over this period due to periodic drought and El Nino events.

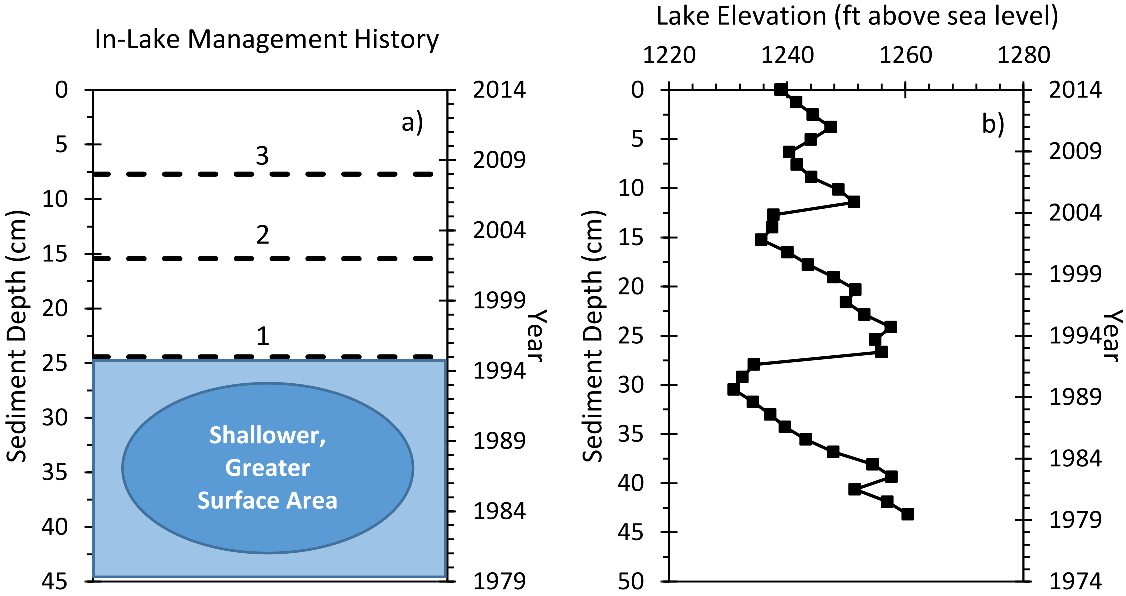

*Fig. 1. Lake Elsinore: a). historical lake management: 1=Completion of LEMP, 1995. 2=Supplemental recycled wastewater begins, 2002. 3=Aeration system begins operating, 2008; b) lake surface elevation in feet above sea level.*

### Water Content

Water content of sediment increased with decreasing depth (and time), from about 70% to 90%, with the exception of a decrease in water content (which is reflected in both replicates) from depth of 22 cm to 10-16 cm in cores 6-A and 6-B (Fig. 2).

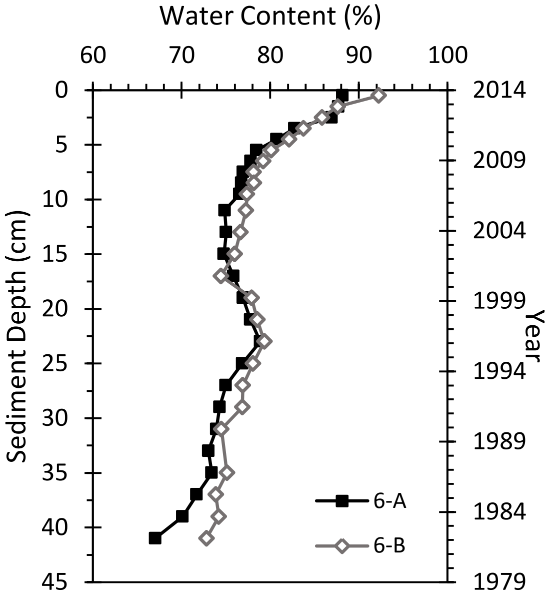

*Fig. 2. Water content (%) with sediment depth at Site 6.*

Elemental Composition

Organic carbon increases by 5% (from approximately 2% to 7%) from the bottom to the top of the cores (representing freshly deposited sediment). Organic carbon and total nitrogen concentrations reflect an increase from 30 cm to 25 cm as well as an increase up-core in the top 10 cm. Nitrogen increases from 0.25 to 0.75% throughout the length of the cores. Organic carbon and nitrogen are significantly correlated in both cores (r=0.97) (Table 1). The gradual increase in OC in the top 10 cm reflects an exponential increasing trend with decreasing depth, as the data better fit an exponential function (average $r^2$=0.77 ) than a linear function (average $r^2$=0.70). Similarly, the up-core increase in N in the top 10 cm better fits an exponential function ($r^2$=0.70) than a linear function ($r^2$=0.62). OC:N remains relatively constant with depth in both cores, at a value of 10, with minor fluctuations. OC:N of suspended organic matter collected in June 2015 was 6.9±0.2. Total phosphorus increases from 0.1% at the bottom of the core to 0.15% at the top of the core. TP exhibits an up-core exponential increase in the top 10 cm ($r^2$ =0.74 vs $r^2$ =0.71 for linear fit). The depth profiles for silicon and aluminum reveal an increase between 25 and 30 cm after which the concentrations return to background levels and remain relatively constant to the top of the cores. Silicon and aluminum are significantly correlated (r =0.99), and their stoichiometric ratios suggest the presence of alumino-silicate minerals such as montmorillonite (Wetzel, 2001) which has a 2:1 molar ratio of Si to Al. Calculation of the ratio of moles of Si per gram (0.006) to moles Al per gram (0.003) in Lake Elsinore sediments resulted in a value of 2. Sulfur (S) increases from 6000 µg/g in 1989 to 2000 µg/g in 1994 after which it remains constant with sediment depth. Calcium (Ca) increases from 4% at the bottom of the core to 10% at the top. The increase is not a gradual, constant increase. Instead calcium increases from the bottom of the core to 25 cm (1994). It remains constant from 1994 to 10 cm (2007), after which it increases exponentially to the top of the core ($r^2$ = 0.86 for exponential fit, vs. $r^2$ =0.83 for linear fit).

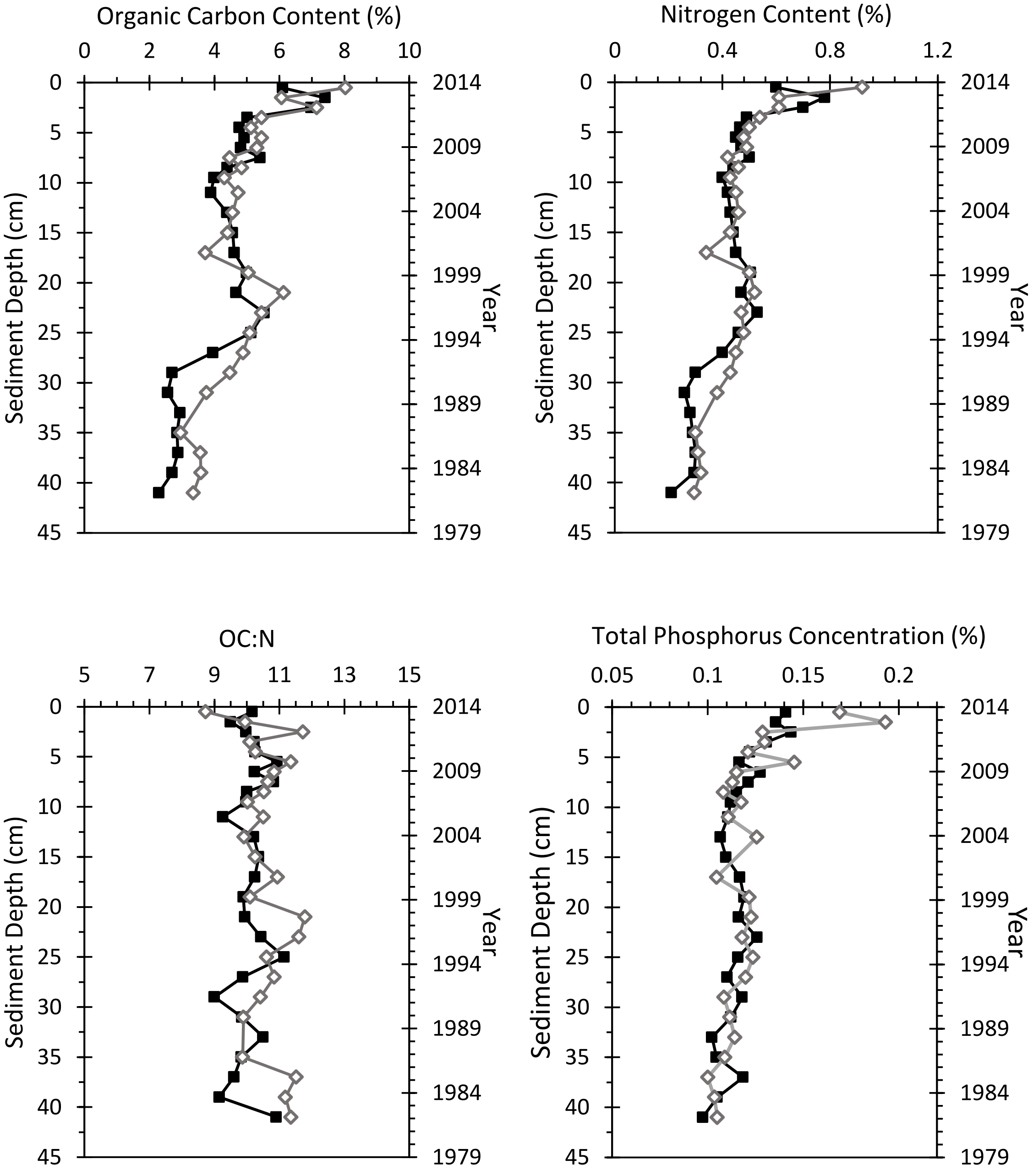

*Fig. 3. Organic carbon content, total nitrogen content, OC:N ratio, and total phosphorus concentration in Lake Elsinore sediment. Solid squares represent data points in core 6-A. Open diamonds represent data points in core 6-B.*

Calcium also exhibits a significant correlation with OC and N (Table 1). Iron shows a similar but opposite trend as calcium, decreasing until 1994, remaining relatively constant until 2006, then decreasing to the top of the core. The overall decline in concentration is 6.25 to 5%. Iron and calcium are significantly negatively correlated (Table 1).

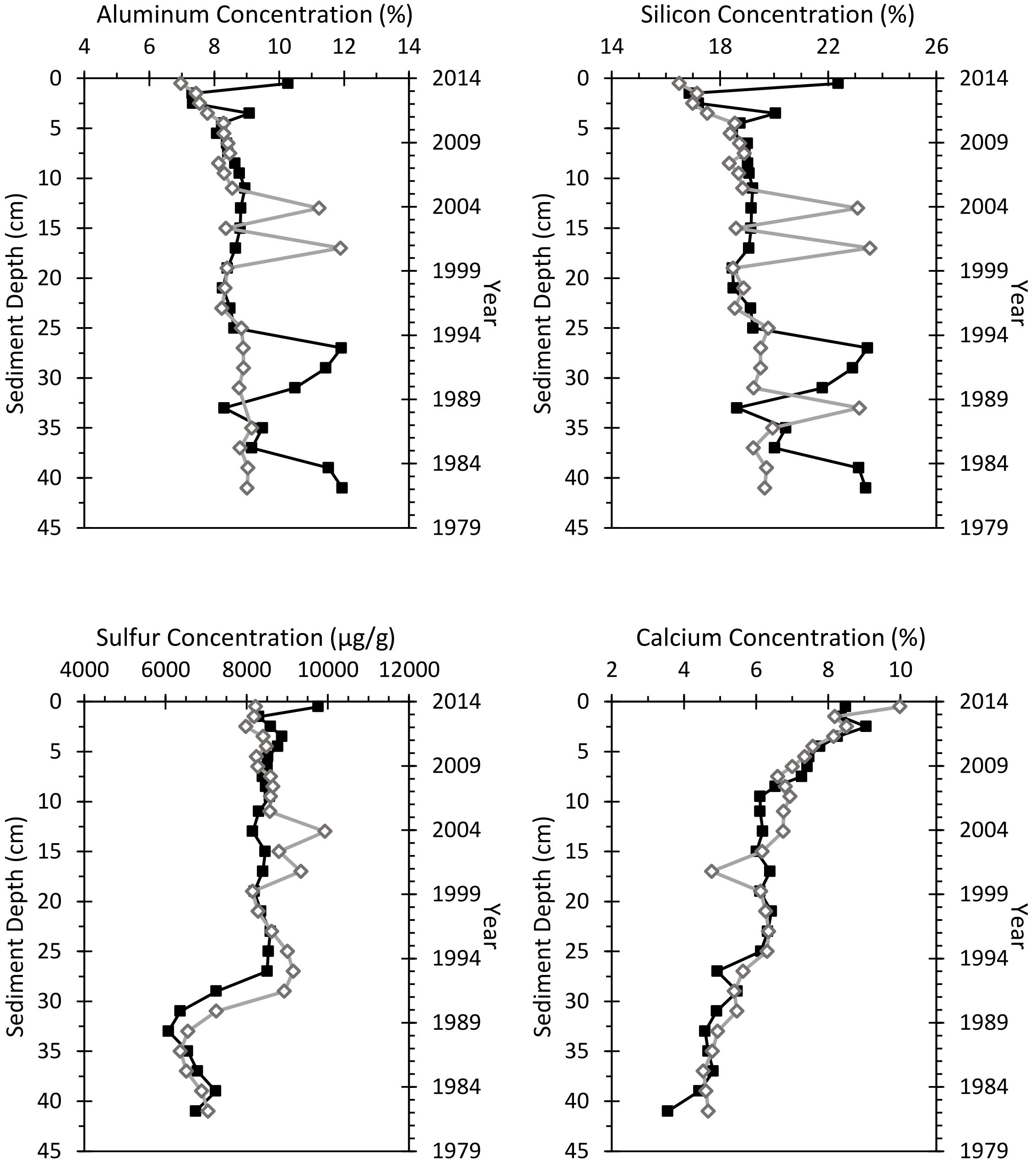

*Fig. 4. Aluminum, silicon, sulfur, and calcium depth profiles of Lake Elsinore sediment. Solid squares represent data points in core 6-A. Open diamonds represent data points in core 6-B.*

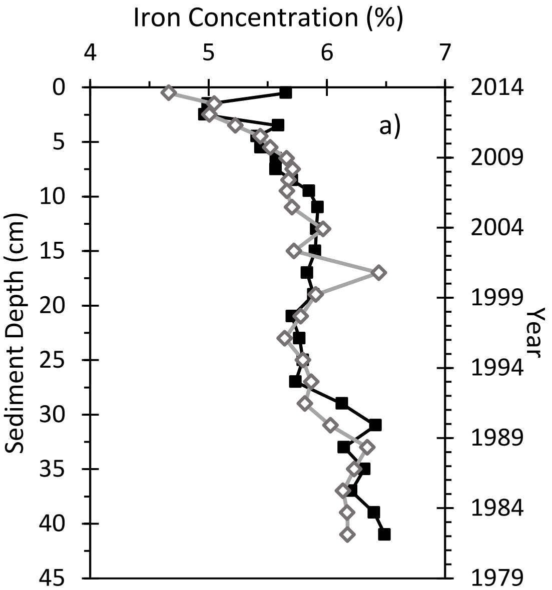

*Fig. 5. Iron concentration profiles for Lake Elsinore sediment. Solid squares represent data points in core 6-A. Open diamonds represent data points in core 6-B.*

Table 1. Correlation table showing r values for bulk elemental properties in Lake Elsinore sediment. With n=26, an r value of 0.51 is statistically significant at p=0.001.

| | Depth | Water | %OC | %N | Al | Si | P | S | K | Ca | Ti | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | 1.00 | | | | | | | | | | | |
| Water | -0.79 | 1.00 | | | | | | | | | | |
| %OC | -0.75 | 0.89 | 1.00 | | | | | | | | | |
| %N | -0.75 | 0.91 | 0.97 | 1.00 | | | | | | | | |
| Al | 0.48 | -0.56 | -0.62 | -0.59 | 1.00 | | | | | | | |
| Si | 0.48 | -0.53 | -0.60 | -0.57 | 0.99 | 1.00 | | | | | | |
| P | -0.57 | 0.72 | 0.63 | 0.68 | -0.39 | -0.35 | 1.00 | | | | | |
| S | -0.67 | 0.49 | 0.58 | 0.57 | -0.04 | -0.02 | 0.43 | 1.00 | | | | |
| K | 0.91 | -0.79 | -0.86 | -0.85 | 0.58 | 0.58 | -0.58 | -0.73 | 1.00 | | | |
| Ca | -0.90 | 0.94 | 0.88 | 0.90 | -0.60 | -0.58 | 0.70 | 0.56 | -0.88 | 1.00 | | |
| Ti | 0.88 | -0.87 | -0.87 | -0.87 | 0.50 | 0.50 | -0.65 | -0.66 | 0.95 | -0.93 | 1.00 | |
| Fe | 0.81 | -0.89 | -0.89 | -0.90 | 0.70 | 0.69 | -0.66 | -0.49 | 0.91 | -0.93 | 0.94 | 1.00 |

Phosphorus Forms

Redox-sensitive phosphate is the least abundant fraction, averaging about 75 µg/g dry weight (dw) throughout the length of the cores and remaining constant with depth (Fig. 6, open diamonds). Loosely-sorbed and pore-water phosphate represents the majority of the mobile-P (~60%) (Fig. 6, solid triangles). With the exception of two noticeable increases at 20 and 35 cm, loosely-sorbed/pore-water P remains at about 150 µg/g dw below 10 cm depth. In the upper 10 cm, the fluctuations stabilize, and smaller variations center around 125 µg/g dry weight. This signifies a shift to lower pore-water P concentrations in more recently deposited sediment. Aluminum-bound P was the most abundant of the fractions measured using the sequential extraction procedure, with concentrations ~135 µg/g dw at the bottom of the core (Fig. 6, solid squares). The concentration exhibits a large increase to ~200 µg/g dw at about 25 cm, followed by a shift to greater concentrations in depths <25 cm, averaging 150-160 µg/g dw. The increase and subsequent shift to greater mean concentrations occurred in 1994, around the same time the Lake Elsinore Management Project was completed (Figs. 1, 6).

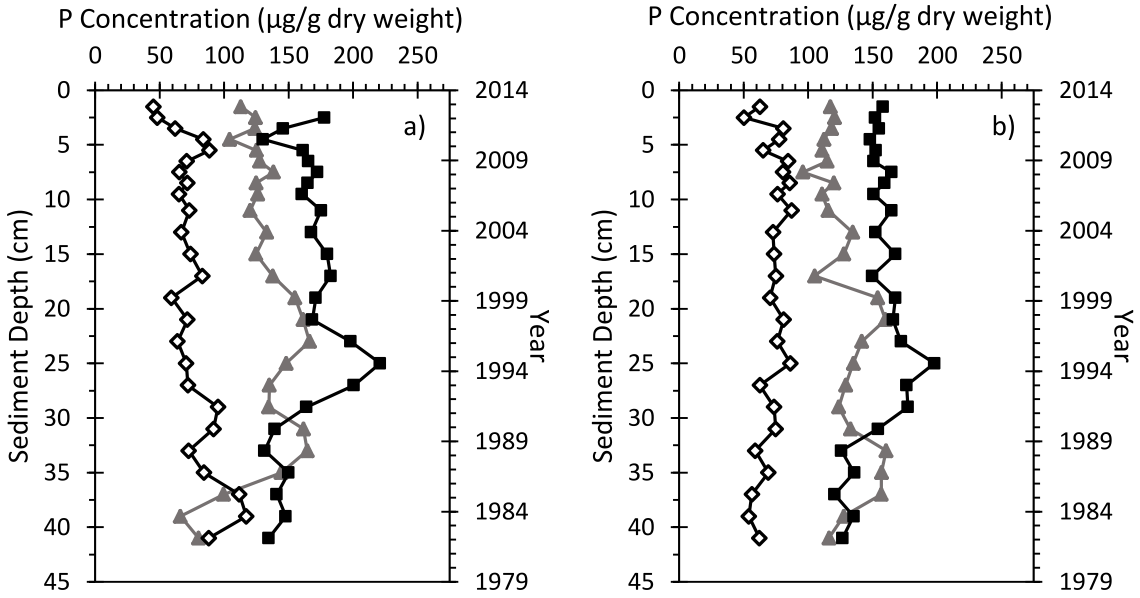

*Fig. 6. Phosphorus concentrations in three different sediment forms. Panel a shows core 6-A. Panel b shows core 6-B. Open diamonds=Fe-P. Solid triangles= loosely-sorbed/pore-water P. Solid squares=Al-P. Mobile-P is taken as the sum of loosely-sorbed/pore-water P and Fe-P.*

Stable Isotopic Composition

Stable isotopic composition results are presented in delta notation relative to Vienna Pee Dee Belemnite Standard (for C) and Air $N_2$ standard (for N) and calculated using the equation, exemplified below for $^{13}$C:

$$\delta^{13}C = \left[\left(\frac{{}^{13}C/{}^{12}C_{sample}}{{}^{13}C/{}^{12}C_{standard}}\right) - 1\right] * 1000 \qquad (2)$$

The filters exhibited suspended organic matter (SOM) with $\delta^{13}C$ values of -20.2±0.6‰ and -23.7±0.4‰ in the fresh and decomposed samples, respectively (Table 2). The measured $\delta^{15}N$ of the SOM was 5.8±0.2‰ and 10.2±1.6‰ in the fresh and decomposed samples, respectively. The decomposed SOM exhibited about a 3‰ higher $\delta^{15}N$ than the top of the sediment core and about a 4‰ more negative $\delta^{13}C$ than the top sediment. Fresh SOM reflected the same $\delta^{13}C$ values as the top sediment and slightly lower (0.7‰ difference) $\delta^{15}N$.

$\delta^{13}C$ values are gradually increasing in both cores from approximately -24‰ at 29 cm to -20‰ at the top of the cores (Fig. 7). In core 6-A, $\delta^{13}C$ increases from -25‰ at the bottom of the core to -20‰ at the top of the core. This gradual 5‰ increase towards the top of the core represents a significant change with depth ($r^2$=0.72).

The $\delta^{15}N$ depth profiles reflect three distinct periods which have significantly different mean values. From 41 to 35 cm (the bottom section of the core), mean $\delta^{15}N$ values are 6.2±0.4‰ and 6.5±0.4‰ for cores 6-A and 6-B, respectively. This section represents the time frame from approximately 1982 to 1988, when the lake was shallow, prior to completion of the Lake Elsinore Management Project. After 1988, during the transition from a shallower, larger surface area lake to a deeper lake with a smaller surface area, $\delta^{15}N$ shifts to lower, more variable values with means 5.3±0.5‰ and 5.8±0.4‰. This period lasts from 31 cm to 17 cm (1990-2001), after which point the signatures increase to 7.1±0.4‰ and 6.9±0.6‰ in cores 6-A and 6-B, respectively. In the top layer of sediment, $\delta^{15}N$ values vary little and the high values extend to the top of the cores.

Table 2. Stable isotopic composition of suspended organic matter (SOM)

| Suspended Organic Matter | $\delta^{13}C$ (‰ vs. VPDB) | $\delta^{15}N$ (‰ vs. Air $N_2$) |
|---|---|---|
| Fresh | -20.2±0.6 | 5.8±0.2 |
| Decayed | -23.7±0.4 | 10.2±1.6 |

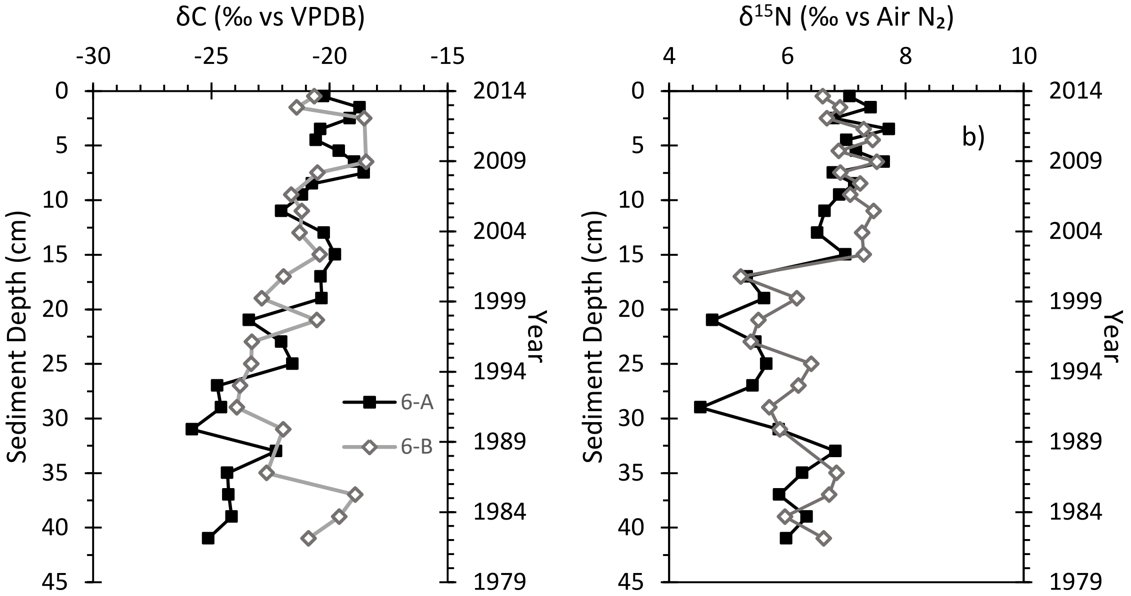

*Fig. 7. Stable carbon (panel a) and nitrogen (panel b) isotopic composition of Lake Elsinore sediment relative to standards. Solid squares represent data points in core 6-A. Open diamonds represent data points in core 6-B.*

## Discussion

### Elemental Composition

The organic carbon and total nitrogen concentrations (Fig. 3) increase around the same time that the Lake Elsinore Management Project was completed, surface areas was reduced and mean lake depth increased (Fig. 1b). A greater water depth would have resulted in enhanced organic matter preservation due to increased stratification, less mixing and, thus, more frequent depleted oxygen levels. Another possible explanation for the increase is the amount of organic matter delivered to a given surface area of sediment would have increased when the lake surface area decreased and depth increased. An exponential decrease with depth in the top sediments of organic carbon and nitrogen profiles is generally representative of decomposition (Wetzel, 2001). Sediment at the top of the core has experienced less diagenetic degradation than sediment at 10 cm depth and therefore will contain more organic matter. The fact that OC and N are significantly correlated (Table 1) is further evidence that the decrease is due to decomposition because N is utilized by bacteria during respiration and conversion of organic carbon into $CO_2$, and N typically decomposes at a similar rate as OC (DiToro, 2001). In addition, water column total N data do not indicate higher concentrations over the past 8-10 years; concentrations vary with no significant trend (Fig. 8). Anderson (2010) indicated that total N content in sediment grab samples (top 10 cm) from fine-textured profundal sediment collected in 2000 and 2010 did not significantly change. This observation further supports the argument that the exponential increase in N toward the top of the sediment is due to degradation processes rather than differences in concentration or loading (Fig. 8).

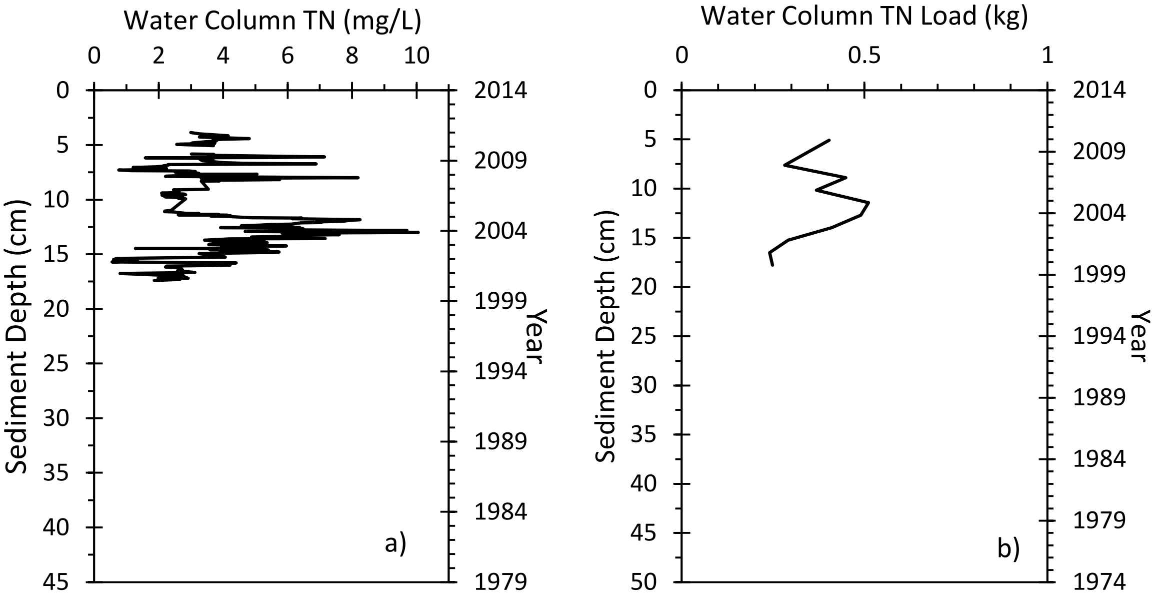

*Fig. 8. Average water column total nitrogen concentrations (a) and total nitrogen load (b) in Lake Elsinore.*

It is common for C:N of organic matter to increase with depth in the sediment as N is preferentially utilized (Lehman et al., 2002). The fact that OC:N in Lake Elsinore sediment remains approximately constant with depth (Fig. 3) suggests that OM is already highly mineralized in the water column, before it reaches the sediment. The OC:N of suspended organic matter was 6.9, which is 3.1 lower than the sediment, indicating N is selectively recycled as organic matter is settling and/or resuspended. These results are similar to those detected in 2003 in which C and N content of sediment traps was compared to that of the sediment. C and N both decreased from the sediment trap to the sediment and C:N increased from 7.7 to 8.6, indicating greater recycling of N relative to C, although both elements showed evidence of recycling in the water column. From the results of the study, it was concluded that there is substantial recycling occurring on settling particles in the water column (Anderson, 2011). In a study on Lake Simcoe, Canada, in 2011, the deepest bay, Kempenfelt Bay, exhibited constant C:N with sediment depth and this was attributed to the OM being highly recycled in the water column prior to sedimentation (Hiriart-Baer et al., 2011).

Average total TP concentration in Lake Elsinore sediment (0.125% or 1,250 µg/g) (Fig. 3) is consistent with concentrations quantified on other eutrophic lake sediments, which typically range from 1,000 to 1,900 µg/g in surficial sediments (Rydin, 2000; Kapanen, 2012; Dittrich et al., 2013). The depth profile for total phosphorus also reflects an exponential decrease in concentration with sediment depth in the top 10 cm. This exponential decrease in total phosphorus is typical for eutrophic lakes and generally represents mineralization of organic phosphorus (Carey and Rydin, 2011). Fitting an exponential equation to total P concentration in the top 10 cm results in $r^2$=0.72 and 0.63 for cores 6-A and 6-B respectively, verifying the exponential trend. We assume that this trend is in fact due to the decomposition of organic matter and not due to increased total phosphorus loading to the lake because organic carbon and TP are significantly correlated in the top 10 cm and the decrease in OC with sediment depth is assumed to be the result of decomposition (see above).

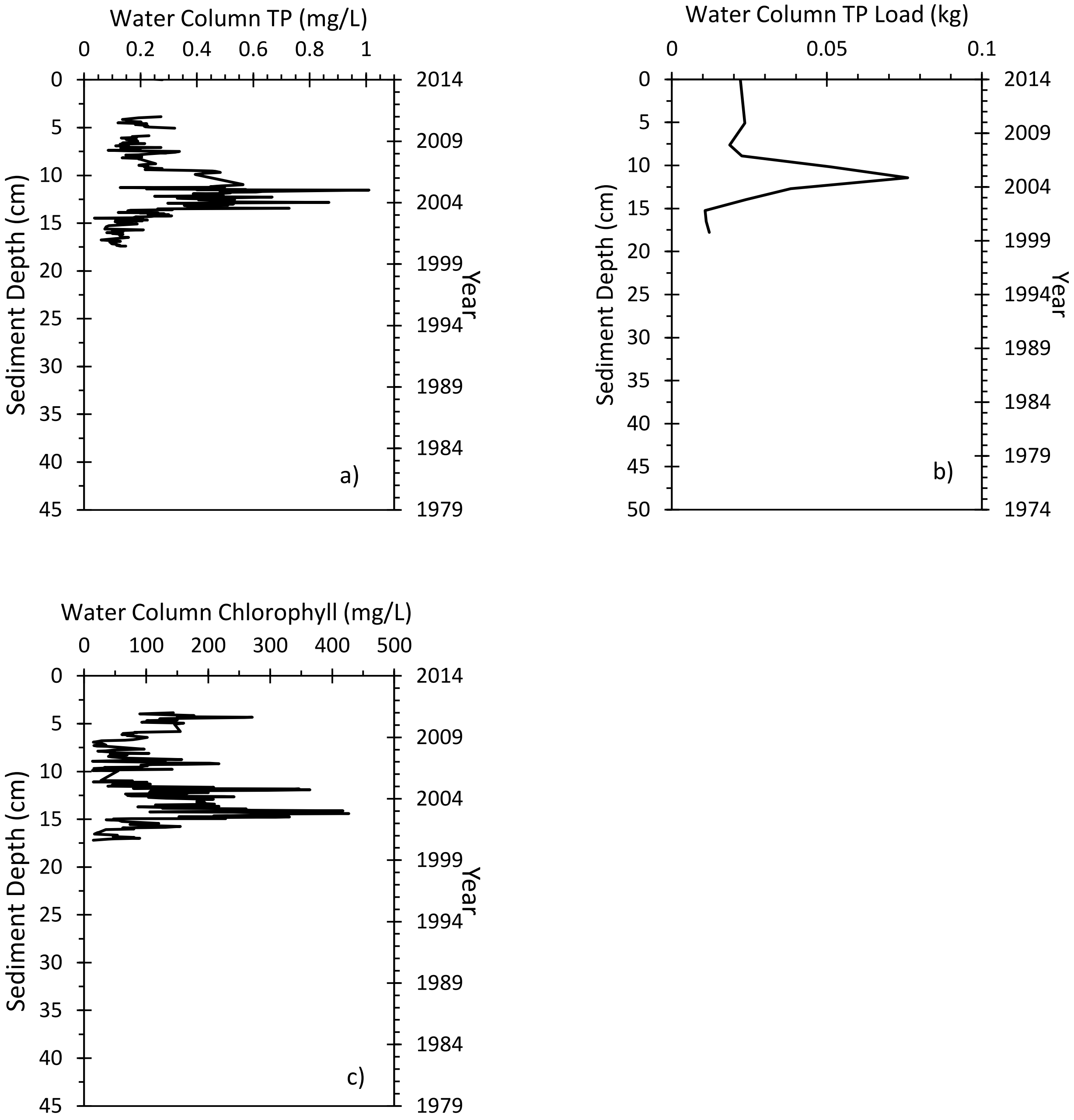

*Fig. 9. Average water column a) total phosphorus concentration, b) total phosphorus load, and c) chlorophyll concentrations in Lake Elsinore.*

Correlation of total P to OC could in some cases reflect increasing chlorophyll biomass (OC) due to increase in total P loading. However, water column chlorophyll a concentrations in Lake Elsinore do not reflect similar trends (Fig. 9c). Also, external P loading has not been increasing in the past 8-10 years as revealed in the water column TP concentrations from 2000 to 2014 (Fig. 9a). Total phosphorus concentration and load in the water column peaked in 2005 and has been variable since then, rather than exponentially increasing (Anderson, 2010). Anderson (2010) measured a decrease in mean TP concentrations in sediment grab samples from 916 mg/kg in 2000 to 785 mg/kg in 2010, although the difference was not statistically significant. These results further demonstrate that the strongest diagenetic processes are occurring in the surficial sediment. If the increase in TP toward the top of the sediment reflected increased TP concentrations, TP in the grab samples would be expected to increase from 2000 to 2010, not decrease or remain the same. He also concluded that pore-water P concentrations were significantly correlated with organic carbon ($r^2 = 0.87$). A study on a core collected from Lake Elsinore in 2001, however, found that TP was unchanged with depth but that organic P showed an exponential decrease. This difference is interesting, in that it suggests a greater contribution of other P forms to total P in 2001 compared to 2014 (CNRP, 2013).

Calcium and organic carbon are significantly correlated in both cores (Table 1). This correlation suggests calcium carbonate ($CaCO_3$) co-precipitation with organic matter. This process occurs in the epilimnion, when primary production raises the pH, enabling calcite precipitation, and organic matter serves as nuclei for the precipitation (Wetzel, 2001). Anderson (2010) attributed the increase in $CaCO_3$ of sediment grab samples collected from Lake Elsinore from 2000 to 2010 to increased precipitation of calcite in the water column due to erosion of Ca from the watershed in El Niño year 2005 as well as increased productivity and TDS in 2003 and 2004 (Anderson, 2010). The decrease of Ca concentration with depth in the top 10 cm, as well as the correlation with organic carbon, suggests this decrease is due to $CaCO_3$ dissolution coupled to organic matter decomposition (Fig. 4). Respiration leads to increasing carbon dioxide in pore-water which lowers the pH and causes dissolution of $CaCO_3$. Considerable $CO_2$ concentrations were measured in Lake Elsinore sediments in 2010 (concentrations reaching 3.8±0.6%) which is about 100x atmospheric concentrations, confirming the presence of elevated amounts of $CO_2$ in pore-water that can contribute to $CaCO_3$ dissolution, the proposed mechanism for decline in Ca with depth (Anderson, 2010). Similar to OC and N (Fig. 3), calcium concentrations increase around the year 1994 due to increased preservation of OC, which is precipitated with Ca, resulting in increased preservation of Ca as well (Fig. 4).

In order to confirm that diagenesis is the driving force for the decreasing trends in the top 10 cm of OC, N, TP, and Ca profiles, the data was fit to an exponential function, because organic matter decomposition is an (exponential) first order decay process (Wetzel, 2001).

$$C_t = C_0 e^{-kt} \tag{3}$$

Fitting the data to an exponential function also enables the calculation of the rate constants, depicting the rate of mineralization, or loss of the element. In the equation above, k is the slope of the function and represents rate change per depth in the sediment with units of

$cm^{-1}$. To calculate the rate per time, $k_r$, the k is multiplied by sedimentation rate. Once k is calculated, half-life can be calculated following the equation below. Rate constants for the exponential decline in OC, N, and TP concentrations in the top 10 cm with depth were calculated to confirm diagenesis is the driving force for these trends. Rate constants for each element were averaged between the two replicate cores and that average was used to calculate half-life, using the equation:

$$t_{1/2} = 0.693/k_r \qquad (4)$$

The exponential fit to OC was statistically significant at p=0.001 with $r^2$=0.73 and 0.76. The exponential fit to N was statistically significant at 0.01 but the goodness of fit wasn't as strong, with $r^2$=0.68 and 0.72 (for 6-B p=0.001). TP fit the exponential function at p=0.001 with $r^2$=0.79 and 0.64 (p=0.01). This discrepancy may have skewed the TP average half-life. For 6-A the calculated half-life was 21.5 years and for 6-B the half-life was 12.16 years, yielding an average of 15.4 years (Table 1), although it may be a little longer than that, due to 6-A (half-life 21.5 years) demonstrating a better fit to the exponential function. The exponential fit to calcium in Lake Elsinore sediment was significant at 0.001 with $r^2$=0.9 and 0.81. The goodness of fit for calcium was greater than the other three elements. The significance of the goodness of fit of each element to an exponential function indicates that the decrease in depth can be attributed to sedimentary diagenesis, or decomposition.

The rate constants for OC an N were slightly greater than those for TP and Ca, suggesting that OC and N mineralize at about 1.5x the rate than TP and Ca, indicating that OC and N do not remain bioavailable for as long as TP and Ca. OC and N had very similar rate constants and therefore very similar half-lives, of about 10 years (Table 3). These values are lower from the half-life for OC and N determined on a core collected in 2001, which were calculated to be 24 and 30 years, respectively, using a 1-phase model, but similar to the half-lives calculated using a 2-phase model (Anderson, 2011). In the present analysis, the uppermost 10 cm was fitted, while the 2-phase model represented labile recently deposited material as well as an older less reactive phase. The 95% upper and lower confidence intervals represent the error in fitting the data to an exponential curve (Table 3). The half-lives calculated for the upper and lower rate constants confidence intervals were about 18 and 6.5.

The half-lives for calcium and total phosphorus were similar, at around 15 years. This similarity further corroborates the concept of $CaCO_3$ dissolution with increasing sediment depth due to decreasing pH and subsequent SRP and $Ca^{2+}$ release to pore-water. The average half-life for total phosphorus was 15.4 years, but the error was greater than that for OC and N. Similar to the results from calculations for organic phosphorus from 2001, TP had a rate constant that was lower than those for OC and N, indicating slower mineralization and longer period of recycling of P in the sediment. However, taking error estimates into consideration, the half-life for TP calculated in this study (15.4 yrs, with upper confidence interval of 37.2 yrs) is about half of that calculated for organic P in 2001 using a 2-phase model (29.7 years) (Anderson, 2011). Notwithstanding, the large uncertainty in the calculated half-life for total P (95% CI of 7.8 – 37.2 yrs) and comparison between values calculated for total P in this study and organic-P in Anderson (2001) make it difficult to draw any firm conclusions between sediment cores collected in 2001 and 2014.

Table 3. Rate constants and half-lives for organic carbon, total nitrogen, total phosphorus, and calcium.

| | $k_r$ ($yr^{-1}$) | $t_{1/2}$ ($yr^{-1}$) | Upper 95% C.I. | Lower 95% C.I. |
|---|---|---|---|---|
| Organic Carbon | 0.066±0.003 | 10.5 | 18.8 | 6.9 |
| Total Nitrogen | 0.073±0.0 | 9.5 | 17.8 | 6.3 |
| Total Phosphorus | 0.045±0.018 | 15.4 | 37.2 | 7.8 |
| Calcium | 0.046±0.003 | 15.1 | 24.9 | 11.5 |

The iron content of sediments decreases from 6.2% prior to 1990 to 5.8% by about 1994 and then is constant until about 2006, before declining more recently (Fig. 5). Similarly, sulfur (S) increases in 1994 and is constant to the top of the core (Fig. 4). Following completion of LEMP in 1994/1995, lake depth increased and presumably there was less circulation and less DO reaching the sediment surface and hypolimnion. This would lead to chemical reduction of iron and sulfate and cause precipitation of FeS, which may explain why the two elements exhibit similar trends during this time. Prior to this time, the redox conditions may have resulted in iron reduction and release to the water column but the redox conditions were not low enough to enable sulfate reduction until the lake deepened. Iron increases with depth in the top 10 cm due to increasing precipitation of FeS with depth, as more and more sulfate is reduced during organic matter decomposition. According to Wakefield (2001), sulfate concentrations in Lake Elsinore pore-water decreased with depth and sulfide concentrations increased which she attributed to increased FeS precipitation with depth as sulfate reduction takes place (greater with depth because DO in sediment decreases with depth). This iron then becomes locked up and is no longer able to bind to P.

The increase in silicon and aluminum concentrations between 25 and 30 cm in core 6-A corresponds to the time period when the Lake Elsinore Management Project was in progress (Fig. 4). Levee construction and construction of a new inlet and outlet channel would have resulted in increased erosion and dredging, causing a large influx of inorganic particles (silt and clay minerals) to the sediment, although this was not observed in core 6-B. The transition from a large and shallow mean depth lake to a deeper mean depth lake, however, did not result in lasting changes to these elements' concentrations in the sediment, as after 1995, concentrations returned to background levels.

Correlation analysis comparing sediment properties with sources of inflow and physical hydrologic characteristics of the lake revealed a few notable significant relationships at $p<0.05$ (Table 4; Table 5). The correlation between local runoff and aluminum, silicon, potassium, titanium, and iron reflects erosional inputs to the lake from the surrounding watershed during precipitation events (Table 4). The significant negative correlation of organic carbon, nitrogen, and calcium with local runoff suggests dilution of organic constituents corresponding to an influx of large amounts of inorganic elements in local runoff (Table 4). In comparison, inflow from the San Jacinto River exhibits weaker, non-significant relationships with elements, which can be attributed to sediment trapping in upstream Canyon Lake (Table 4). Recycled water inputs appear to be significantly correlated with OC and N, suggesting contribution to organic matter production in the lake through increased nutrient inputs in wastewater, although diagenetic processes operating over this same timeframe complicate interpretation of these r-values. Given the small n-size and importance of diagenesis, no clear conclusion can be drawn from this simple statistical calculation.

Table 4. Correlation table showing r values for hydrologic properties and inflows to Lake Elsinore for period 1981-2014 (entire core length). With n=26, an r value of 0.38 is statistically significant at $p<0.05$, and 0.51 is statistically significant at $p<0.001$. USGS data from gage #11070500.

| Property | Avg. Area | SJ Inflow | Local Runoff | Recycled $H_2O$ | Avg. Elev. |
|---|---|---|---|---|---|
| δ 13C | -0.14 | -0.19 | -0.30 | 0.50 | -0.07 |
| δ15N | -0.24 | -0.23 | -0.55 | -0.63 | -0.16 |
| %OC | -0.22 | -0.16 | -0.42 | 0.89 | 0.01 |
| %N | -0.27 | -0.16 | -0.44 | 0.82 | -0.06 |
| Al-P | 0.04 | 0.22 | 0.16 | -0.08 | 0.08 |
| Mobile-P | -0.10 | -0.05 | 0.14 | -0.12 | -0.25 |
| Al | 0.20 | 0.36 | 0.43 | -0.16 | -0.48 |
| Si | 0.22 | 0.36 | 0.43 | -0.15 | -0.48 |
| P | -0.30 | -0.22 | -0.39 | 0.27 | -0.76 |
| S | -0.21 | 0.12 | -0.18 | -0.07 | -0.26 |
| K | 0.38 | 0.12 | 0.49 | -0.41 | 0.61 |
| Ca | -0.41 | -0.29 | -0.62 | 0.55 | 0.78 |
| Ti | 0.33 | 0.11 | 0.50 | -0.55 | -0.81 |
| Fe | 0.30 | 0.17 | 0.49 | -0.46 | -0.71 |

### Phosphorus Forms

The average concentration of loosely-sorbed/pore-water P in Lake Elsinore (125 µg/g) is greater than many other studied eutrophic lakes, including Lake Peipsi, Estonia (11 µg/g) and Lake Erken, Sweden (53 µg/g) (Rydin, 2000; Kapanen, 2012). Generally in eutrophic lakes, mobile P (specifically loosely-sorbed/pore-water P) will increase toward the sediment surface which indicates diffusion toward the water column (Rydin, 2000). However, in such a shallow lake as Lake Elsinore, with bioturbation and strong bottom shear during periods of high wind speeds, diffusion may be very rapid, such that a concentration gradient toward the sediment surface is not depicted in the profiles (Fig. 6). In addition, the ebullition of $CH_4$ gas bubbles generated by microbes can stimulate the diffusion of P toward the water column (Wetzel, 2001, Kapanen, 2012). Martinez and Anderson (2013) measured elevated levels of $CH_4$ gas in the sediment and ebullition at numerous sites on Lake Elsinore, including site 6 where cores were collected.

The high concentrations of loosely-sorbed ($NH_4Cl$-extractable) P and relatively low concentrations of iron-bound P in Lake Elsinore sediment are unusual compared to other lakes in the region (Table 5), and eutrophic lakes more generally which exhibit very little contribution of loosely-sorbed phosphate to mobile P (Pilgrim et al., 2007). In the Lake Elsinore sediment cores, $NH_4Cl$-P averaged about 120 µg/g and 63% of the mobile-P in the upper 10 cm, while Fe-P averaged about 70 µg/g (Table 5). In Big Bear Lake, a mesotrophic lake also located in the San Bernardino mountains, only 1 µg/g NH4Cl-extractable P was present in the sediments, with essentially all (99%) of the mobile-P of surface sediments there present as a reducible Fe-P phase. Canyon Lake, the reservoir located upstream from Lake Elsinore, contains 5x greater Fe-P (average of 386 µg/g and 87% of mobile-P) than Lake Elsinore and one-half the amount of $NH_4Cl$-extractable P (Table 5). The disparity between Fe-P in Lake Elsinore compared with other lakes in the region and with many other eutrophic lakes may be explained by a low influx of iron to the lake due to sedimentation of particulate iron within Canyon Lake.

Table 5. Comparison of concentrations of P in different forms within sediments of selected lakes in Southern California.

| **Lake** | **Mean Phosphorus Fractionation in Sediments (µg $g^{-1}$ dw)** | | | |
|---|---|---|---|---|
| **(n=# sites)** | **$NH_4Cl$-P** | **Fe-P** | **Mobile-P** | **NaOH (Al)-P** |
| Big Bear L. (n=15) | 1 (1%) | 129 (99%) | 130 | 191 |
| Canyon L. (n=5) | 59 (13%) | 386 (87%) | 459 | 890 |
| L. Elsinore (n=2) | 120 (63%) | 70 (37%) | 190 | 150 |
| Diamond Valley L (n=20) | 1 (1%) | 91 (99%) | 92 | 268 |

The increased amount of Al-P in lake sediment around a depth of 25 cm is reflected in aluminum and silicon profiles and corresponds approximately to 1994 which is around the time of completion of the LEMP. The construction involved in the project likely increased suspension, erosion and deposition of inorganic particles to the sediment and increased precipitation of aluminum-bound phosphate (see Elemental Composition discussion above).

## Stable Isotopic Composition

The gradual increase in $\delta^{13}C$ toward the top of the sediment core (Fig. 7) may result from either diagenetic processes or from increasing eutrophic conditions in the lake. Diagenetic processing of organic matter in the sediment typically accounts for a decrease of 1.6-1.8‰ due to selective decomposition of enriched carbohydrates and proteins, which are easier to degrade, as well as the addition of depleted microbial biomass (Lehmann et al., 2002). A study on Lake Lugano found that sediment was depleted by 1.5‰ compared to sediment traps corresponding to the same time (Lehmann et al., 2002). However, suspended organic matter bore a $\delta^{13}C$ of -20‰, which is the same as the sediment. If OC is being degraded in the water column, as evidenced in Anderson (2010), then this indicates that at least during early diagenesis, there is very little fractionation effect or change on $\delta^{13}C$ values. The decomposed suspended organic matter resulted in a $\delta^{13}C$ of -23.7‰, which indicates a -3.7‰ shift during diagenesis. However, because this SOM spent an unknown amount of time incubating under room temperature, it may have undergone more decomposition than SOM typically would in Lake Elsinore before sedimentation and permanent burial (less prone to decay with increased burial).

Increasing eutrophication has also been determined to lead to increases in $\delta^{13}C$ of sediment. A study of three Florida lakes of different trophic levels reported that $\delta^{13}C$ was lowest in the oligotrophic lake and highest in the eutrophic lake and that in the hypereutrophic lake, Lake Apopka, $\delta^{13}C$ increased up-core from -23 to -18 (Torres et al., 2012), which is approximately the same magnitude increase as in the Lake Elsinore sediment (Fig. 7). A study on Lake Ontario found a progressive increase in $\delta^{13}C$ of organic matter with increasing phosphorus loading and water column P concentrations, which also supports the hypothesis that $\delta^{13}C$ reflects lacustrine productivity. In that study, $\delta^{13}C$ increased from -27 to -25. A significant correlation between organic carbon and calcium carbonate was observed in Lake Ontario as well, which suggests photosynthesis generated calcite co-precipitation increases the sedimentation of organic matter and enhances its preservation in the sediment (Hodell and Schelske, 1998). If this is the case in Lake Elsinore, diagenesis may only be affecting $\delta^{13}C$ for a short period of time before permanent burial preserves the $\delta^{13}C$ signature of organic matter. Without water quality data dating back to the early 1980s, it is difficult to determine whether the increasing trend in $\delta^{13}C$ toward the top of the core is due to increasing primary production or simply reflects sedimentary diagenesis.

The $\delta^{15}N$ results reflect three distinct periods in Lake Elsinore's recent history. The section at bottom of the core from 41 to 35 cm corresponds to the period of time when the lake was shallow, with presumably greater circulation and mixing. The transition to a deeper lake with the completion of the Lake Elsinore Management Project resulted in a decrease in sedimentary $\delta^{15}N$. The reason for this decline lies predominantly in the fact that increased lake depth led to a decrease in circulation and increase in stratification and anoxia. With the completion of the Lake Elsinore Management Project and resulting increase in lake depth, nitrate-nitrogen would have been less available than ammonium, and increasing incorporation of ammonium by phytoplankton could have resulted in the decrease in $\delta^{15}N$. During assimilation, phytoplankton fractionate ammonium by about -10‰ and nitrate by -1 to -3.4‰, so increased ammonium uptake relative to nitrate-nitrogen would result in a decline in $\delta^{15}N$ of algal biomass (Teranes and Bernasconi, 2000; Lu et al., 2010). Also, the majority of $NH_4$ is generated from organic matter mineralization in which $^{14}N$ is preferentially mineralized over $^{15}N$ during organic matter hydrolysis so ammonium is more depleted in $^{15}N$ than nitrate even before uptake by phytoplankton (Torres et al., 2012; Lehmann et al., 2002).

In addition to an increased utilization of ammonium over nitrate, during oxic decomposition of algal biomass, there is typically very little change in $\delta^{15}N$, but during anoxic decay (in the sediments or anoxic bottom water), $\delta^{15}N$ typically decreases by 2.5 to 4‰ due to the input of depleted microbial biomass (Lehmann et al., 2002). Bacterial growth and consumption of the depleted ammonium from decomposition in addition to fractionation during bacterial excretion of ammonia which preferentially excretes $^{15}N$ leads to the depletion of $\delta^{15}N$ of bacterial biomass (Lehmann et al., 2002). When there is a large amount of bacterial growth and activity in the sediment, as is usually the case in stratified lakes with anoxic bottom water, it can cause a reduction in the $\delta^{15}N$ of sediment (Lehman et al., 2002).

Increasing autochthonous productivity can lead to increases in sedimentary $\delta^{15}N$ signatures when phytoplankton become more enriched in $^{15}N$. However, this only occurs if surface waters become depleted in N, which typically only happens if a lake is nitrogen-limited (Torres et al., 2012; Teranes et al., 2000). Analysis of sedimentary $\delta^{15}N$ in Lake Simcoe, a eutrophic lake in Canada, revealed an up-core increase from 4.5‰ to 7.3‰ due to increasing productivity (Hiriart-Baer et al., 2011). The N:P in the water column in Lake Elsinore (17.4) indicates that Lake Elsinore is generally not N-limited and water column concentrations of TN do not wane in recent years, therefore the increase to higher $\delta^{15}N$ values around 2002 cannot be attributed to changes in N loading and availability in the water column (Fig. 8) (CNRP, 2013).

The shift to higher $\delta^{15}N$ values around the year 2002 is more likely due to the input of supplemental wastewater. Sewage, composed of human and animal waste, has nitrate with $\delta^{15}N$ between 10 and 20‰. Nitrate input from soils and terrestrial organic matter in the watershed has values between 2-5‰ while fertilizers exhibit lower $\delta^{15}N$, approximately 3‰ (Teranes and Bernasconi, 2000; Machiwa, 2010; Torres et al., 2012). Assuming a $\delta^{15}N$ value of 3‰ for nitrate input from local runoff and San Jacinto River inflow and a value of 15‰ for nitrate input from recycled wastewater, one can calculate predicted $\delta^{15}N$ values of Lake Elsinore sediment. Using assumed N isotope signatures for each source of water to the lake as well as average annual inflow (2008-present) of 10,000 acre-feet from local runoff/San Jacinto River and 5,600 acre-feet from recycled wastewater, the predicted $\delta^{15}N$ value is calculated as 7.37‰. The actual $\delta^{15}N$ at site 6 in Lake Elsinore was on average 7.12‰ from 2001 to present which is very similar to the predicted value with a 3.5% error.

Denitrification in the water column also results in $\delta^{15}N$ enrichment of the sediment because denitrification preferentially reduces $^{14}N$ over $^{15}N$, leaving residual nitrate enriched in $^{15}N$ (Teranes and Bernasconi, 2000; Lu et al., 2010). In Lake Ontario, Canada, an increase in $\delta^{15}N$ of 0.3‰ over a period of ten years, and subsequent stabilization of $\delta^{15}N$ were attributed to denitrification (Hodell and Schelske, 1998). Prior to wastewater additions, denitrification rates in the water column were fairly low due to low concentrations of nitrate (Horne, 2009). Therefore, wastewater input may be enabling denitrification by providing $NO_3$ for the reaction. Denitrification is likely occurring in the water column near the sediment-water interface because sedimentary denitrification does not result in a fractionation effect and $\delta^{15}N$ of suspended organic matter (5.8‰) was lower than the surficial sediment values, indicating that denitrification is occurring in the benthic boundary layer or bottom of the water column prior to permanent sedimentation (Terranes and Bernasconi, 2000). Another reason that suspended organic matter is more depleted in $\delta^{15}N$ than sediment is that as it is settling, OM degradation results in enrichment of residual OM as $^{14}N$ ammonium is preferentially released (Torres et al., 2012;

Lehmann et al., 2002). The suspended organic matter sample that experienced decomposition resulted in a $\delta^{15}N$ of 10‰, which is greater than the top sediment isotopic signature. This discrepancy suggests that the algal biomass experienced greater decay than it would have in the lake, where it would be progressively buried in the sediment (N recycling decreases with increasing sediment depth, see Elemental Composition section above).

## Conclusions

The isotopic and elemental analysis of sediment cores from Lake Elsinore provided new insights into the depositional history and biogeochemical cycling of organic matter and nutrients in this eutrophic lake:

(i) organic matter is highly mineralized in the water column prior to permanent sedimentation;

(ii) the transition from shallow to deeper lake with the completion of LEMP resulted in increased organic matter preservation in the sediment, evidenced by an increase in OC, N, Ca, and S during this time;

(iii) a lack of correlation between iron and phosphorus, yet significant correlation between phosphorus and organic carbon and calcium in the top 10 cm suggests P cycling is controlled by calcium and organic matter rather than redox conditions and corresponding Fe geochemistry;.

(iv) fitting exponential functions to OC, TN, TP, and calcium data revealed that their decline with sediment depth is due to diagenetic processes rather than changes in water column concentrations.

(v) Lake Elsinore sediments have much higher concentrations of $NH_4Cl$-extractable P and lower Fe-P than other lakes in the region, with dramatically different values than Canyon Lake that are attributed to retention of particulate Fe and Al phases in Canyon Lake;

(vi) $\delta^{15}N$ values in sediment declined with completion of LEMP and the corresponding average increased mean depth of the lake;

(vii) $\delta^{15}N$ values in sediment subsequently increased due to wastewater input and denitrification.

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## *Technical Memorandum*

**Task 2.2:** Fishery Hydroacoustic Survey and Ecology of Lake Elsinore: Spring 2015

### Objective

The objective of this task was to quantify the fishery in Lake Elsinore for comparison with earlier survey results. A limited sampling of the phytoplankton and zooplankton communities was also conducted.

### Approach

Zooplankton were sampled on March 7, 2015 near the deep-water site (site 6 or E2) and near the San Jacinto River channel/ski school site via vertical tows with an 80 µm Wisconsin net. Samples were preserved with 70% ethanol in the field, returned to the laboratory and inspected under Nikon compound and dissecting microscopes. Approximately 250 individuals were inspected and counted from each site. Water samples were also collected at about 0.3 m depth into 125 mL polypropylene bottles at the 2 sites, returned to the laboratory and the phytoplankton community was inspected under a Nikon compound microscope. Total dissolved solid (TDS) concentrations of the water samples were calculated from measured electrical conductance values.

A hydroacoustic survey was conducted on April 2, 20125 to quantify the fishery in the lake for comparison with earlier survey results. The survey was conducted using a BioSonics DT-X echosounder with a 201-kHz split beam transducer. Data were acquired at 5 pps. The transducer was calibrated using a tungsten-carbide calibration sphere in the field prior to collection of acoustic data and at the end of the day's survey. Echograms were analyzed using BioSonics VisualAnalyzer.

### Results

Lake level and TDS

Four years of drought had substantially lowered the level of Lake Elsinore; surface elevation was approximately 1236.6 ft above MSL at the time of these measurements in spring 2015. The TDS concentrations reached 2700 mg/L which were the highest since regular monitoring began in 2000. This value exceeded the previous high of about 2300 mg/L in late 2003.

Phytoplankton

Transparency of the lake was very poor throughout the spring and summer of 2015, with Secchi depth values <10 – 15 cm throughout this period. The poor clarity resulted from excessive amounts of phytoplankton in the water column, with the phytoplankton community strongly dominated (>95%) by the filamentous blue-green algae *Pseudanabaena* (formerly *Oscillatoria*). This phytoplankton dominated the community during the very poor transparencies and very high chlorophyll a concentrations observed in 2002-2004, but was also the dominant phytoplankton during the summer of 2010 as well, when Secchi depths averaged 30 - 40 cm (*P. limnetica* comprised 75-90% of biomass in June-August 2010) (Anderson et al., 2011). This species appears to have a unique adaptation to shallow, relatively well-mixed high TDS conditions at Lake Elsinore. The species is also a poor food resource for filter-feeding *Daphnia* and other large-bodied cladocera, since the filaments are too large to enter the mouth and further interfere with filtration of smaller phytoplankton.

## Zooplankton

A total of 489 individuals were inspected and counted from the two sites sampled on March 7, 2015. Adult copepods dominated the zooplankton community, comprising 83.8% of the total individuals counted (Table 1; Fig. 1a,b). Juvenile copepods (nauplii) were the second most abundant group of zooplankton at 14.7% of the community (Table 1; Fig 1a). Rotifers were absent at site 6, although 4 individuals were identified in the sample collected near the San Jacinto River inlet site (Table 1). A single *Daphnia* was present in the samples (Fig. 1c), corresponding to a relative abundance of 0.2% within the zooplankton community. Also depicted in Fig. 1 as small filaments are *Pseudanabaena.*

Table 1. Zooplankton community in Lake Elsinore: March 7, 2015.

| Site | Copepods | Nauplii | Rotifers | *Daphnia* | Total |
|---|---|---|---|---|---|
| SJR Inlet | 180 | 55 | 4 | 1 | 242 |
| Site 6 (E2) | 230 | 17 | 0 | 0 | 247 |

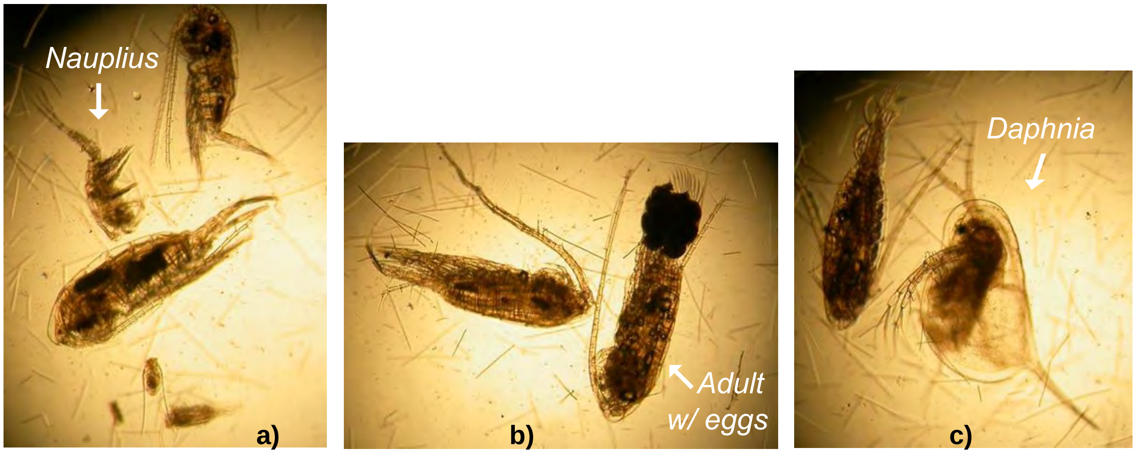

*Fig. 1. Images of zooplankton in Lake Elsinore: a) adult copepods and nauplius; b) adult copepods, including reproductive adult; c) the single Daphnia present in samples. Filaments are Pseudanabaena.*

This low proportion of *Daphnia* within the zooplankton community is consistent with findings from 2003-4 and 2009-10 when cladocerans comprised <0.6% of the community (Anderson et al., 2011). High TDS and/or high threadfin shad populations are thought to be responsible (Veiga-Nascimento, 2005).

## Fishery

The hydroacoustic survey was conducted along the 7 transverse transects as in previous surveys (Fig. 2). The short longitudinal transect in the southern end of the lake was not surveyed due to the very shallow depth over most of the transect.

*Fig. 2. Hydroacoustic survey transects.*

Aggregating the transect data, population estimates were determined for 16 acoustic size classes from -30 to -70 dB (2.5 dB/bin) (Fig. 3). Love's equation (Love, 1970) was used to estimate fish length (Fig. 3, upper x-axis) from the acoustic target strength (Fig. 3, lower x-axis) as done in previous surveys (eq 1):

$$TS = 19.1 \log L - 0.9 \log F - 62.0 \qquad (1)$$

where $TS$ is the target strength (dB) and $F$ is the echosounder acoustic frequency (kHz). As noted in Anderson et al. (2011), these length estimates are thought to be biased low based upon paired hydroacoustic and gill net measurements, but are retained here for comparison with other reported values and survey results. One sees that numerical abundance of fish in Lake Elsinore are dominated by small fish <3.5 cm in length (Fig. 3). These small fish comprise 95.6% of the total number of fish targets identified in the survey and are estimated to be present at an areal density of approximately 54,100 fish/acre. This approximate size class (1-3.5 cm) is consistent with threadfin shad, which are thought to dominate the fishery. In contrast, the population density for fish >20 cm in length is estimated to be 12.3 fish/acre.

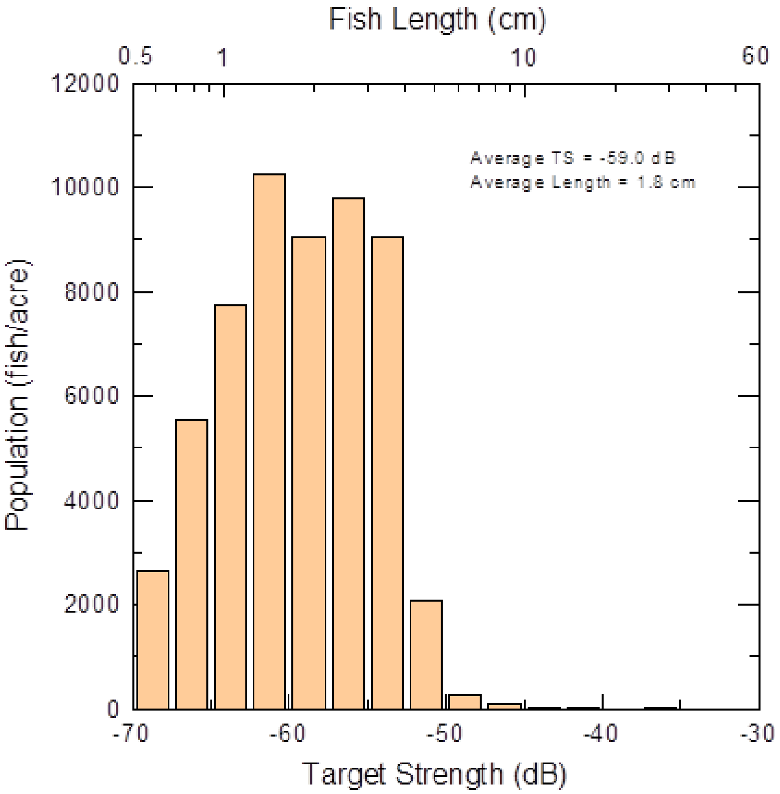

*Fig. 3. Population estimates (fish/acre) vs. target strength (dB) (lower x-axis) and approximate fish length based upon Love's equation (upper x-axis).*

The results from this survey can be compared with other hydroacoustic surveys conducted at the lake (Table 2). The April 24, 2008 survey yielded a population estimate of 18,090 fish/acre with a mean size of 4.7 cm. Fish >20 cm, which would principally represent piscivores and carp, number 1,050 fish/acre and comprise 5.8% of the entire fish population. The survey conducted following the fish kill in the summer of 2009 found dramatically reduced total population (2,2867 fish/acre) with slightly lower mean size that found in April 2008 (Table 2). Density of fish >20 cm was only 6/acre and constituted only 0.2% of the total population. Populations had rebounded quickly by December 1, 2010, reaching 27,720 fish/acre with a mean size of 4.3 cm; abundance of fish >20 cm in length increased slower, but did reach 273 fish/acre and 1.0% of the total population.

Table 2. Fish survey results comparing current survey (April 2, 2015) with surveys conducted in 2008 and 2010.

| Date | Population (fish/acre) | Mean Size[a] (cm) | Size Range[a] (cm) | Fish >20 cm[a] (fish/acre) |
|---|---|---|---|---|
| April 24, 2008 | 18,090 | 4.7 | 0.5 - 100 | 1,050 (5.8%) |
| March 15, 2010[b] | 2,867 | 4.0 | 0.5 – 29 | 6 (0.2%) |
| December 1, 2010 | 27,720 | 4.3 | 0.5 – 61 | 273 (1.0%) |
| April 2, 2015 | 56,600 | 1.8 | 0.5 - 30 | 12 (0.02%) |

[a] *Based on Loves' equation.*

[b] *March 15, 2010 survey was conducted after fish kill in summer of 2009.*

The present survey, conducted on April 2, 2015, found the largest population of fish in the lake (56,600 fish/acre), although the fish were much smaller in size than in other surveys (mean length of 1.8 cm) (Table 2). Moreover, very few fish larger fish (>20 cm) were present at the time of this survey. As previously noted, the TDS at the time of this survey was the highest at any time since regular monitoring began at the lake, and values were markedly higher than observed in 2008 and 2010. Threadfin shad are tolerant of salinities as high as 15,000 mg/L; in contrast, black crappie have a maximum salinity tolerance of about 2,000 mg/L. Black crappie were the dominant piscivore present in Lake Elsinore in 2006-2007 based upon beach seine observations during carp removal efforts at the lake, but are thought to be effectively absent in 2015. Largemouth bass can tolerate higher salinities than black crappie, although literature suggests reproduction and recruitment can be impaired at TDS values greater that about 2,000-2,500 mg/L.

Based upon these findings, the lake in spring 2015 was in very poor ecological condition, with a very large amount of *Pseudanabaena*, limited capacity for zooplankton grazing of phytoplankton, and susceptible to a large fish kill. A modest fish kill was observed beginning August 4, 2015.

## Conclusions

The results of these ecological measurements made at Lake Elsinore in spring 2015 indicate:

(i) very poor water quality, with TDS at levels not seen at the lake since regular monitoring began in 2000, and Secchi depth values <10-15 cm;

(ii) a zooplankton community dominated by copepods and nauplii, with negligible numbers of rotifers and a single Daphnia identified in samples;

(iii) an ecologically unsustainable fishery, with a very large number of small threadfin shad and low relative number of larger fish;

(iv) the subsequent fish kill in the summer of 2015 may have helped rebalance the fishery and food web in the lake, although reduction in the TDS concentration and inundation of shoreline vegetation providing new habitat is thought to provide greater ecological value.

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## *Technical Memorandum*

**Task 2.3:** Bathymetric Survey and Sediment Hydroacoustic Study of Canyon Lake

### Objectives

The overall objective of this task was to better understand the basin characteristics of Canyon Lake. Specific objectives were to:

- Develop up-to-date bathymetric map
- Derive up-to-date storage curve for the reservoir
- Estimate volume of sediment deposited and its distribution
- Characterize distribution of sediment properties across the basin

### Approach

A hydroacoustic survey was conducted at Canyon Lake over 2-days on December 16-17, 2014. The survey was conducted using a BioSonics DTX echosounder with multiplexed 38- and 430-kHz single beam transducers with integrated pitch-roll sensors and a 201-kHz split beam transducer (Table 1). Transducers were operated at 5 pps on each frequency, with 0.4 ms pulse duration. Transducers were mounted 0.5 m below the water surface with position recorded using a JRC 202W real-time differential GPS. Data were acquired using BioSonics VisualAcquisition v.6.0 software on a Dell ATG laptop. Calibrations were conducted each day using tungsten carbide spheres of known target strength. Data files were processed using BioSonics VBT software.

Table 1. Transducer configurations used in this study.

| Property | DTX-38 | DTX-200 | DTX-420 |
|---|---|---|---|
| Frequency (kHz) | 38 | 201 | 430 |
| Beam angle (°) | 10.0 | 6.6 | 7.0 |
| Source level (dB $\mu Pa^{-1}$) | 217.0 | 221.3 | 220.0 |
| Receive sensitivity (dbC $\mu Pa^{-1}$) | -41.1 | -57.6 | -62.9 |
| Pulse length (ms) | 0.4 | 0.4 | 0.4 |
| Pings per second (pps) | 5 | 5 | 5 |

Water column and sediments were also sampled. Water temperature and conductivity profiles were measured daily with an YSI CastAway CTD. Bottom sediments were sampled with an Ekman dredge at 5 sites across the lake, homogenized and subsampled into 500-mL widemouth glass jars with Teflon lined screw top lids, and returned to the lab for basic characterization. Phosphorus in bottom sediments of lakes exists in numerous forms, including a mobile form (mobile-P) that includes soluble/exchangeable forms as well as that associated with iron (Fe)(III) phases that can be released upon reduction of Fe(III) under low dissolved oxygen (DO) conditions (Reitzel et al., 2005; Pilgrim et al., 2007). Mobile-P in surficial sediments has been shown to be strongly correlated with internal recycling rates (Pilgrim et al., 2007), with the mobile-P pool reduced by amounts consistent with that released to the water column (Reitzel et al., 2005).

Sediment grab samples were subsampled for dry-weight determination and extracted for mobile-P following Pilgrim et al. (2007). Water content was determined on subsamples that were heated overnight at 105 °C. Total C and N were measured by dry-combustion methods using a Thermo Flash EA NC soil analyzer (Nelson and Sommers, 1982). Inorganic C and $CaCO_3$ were determined manometrically following Loeppert and Suarez (1996), with organic C taken as the difference between total C and inorganic C. Duplicate analyses were conducted at a rate of at least one every 10 samples within an analytical batch.

## Results

### Bathymetry

Depth varied widely across the lake, with predictably greatest values located near the dam in the main basin of the lake, exceeding 17 m at full pool (Fig. 1). The north and east basins possessed lower depths, with less than about 11 m in the east basin near the causeway, and less than about 7 m throughout the north basin (Fig. 1).

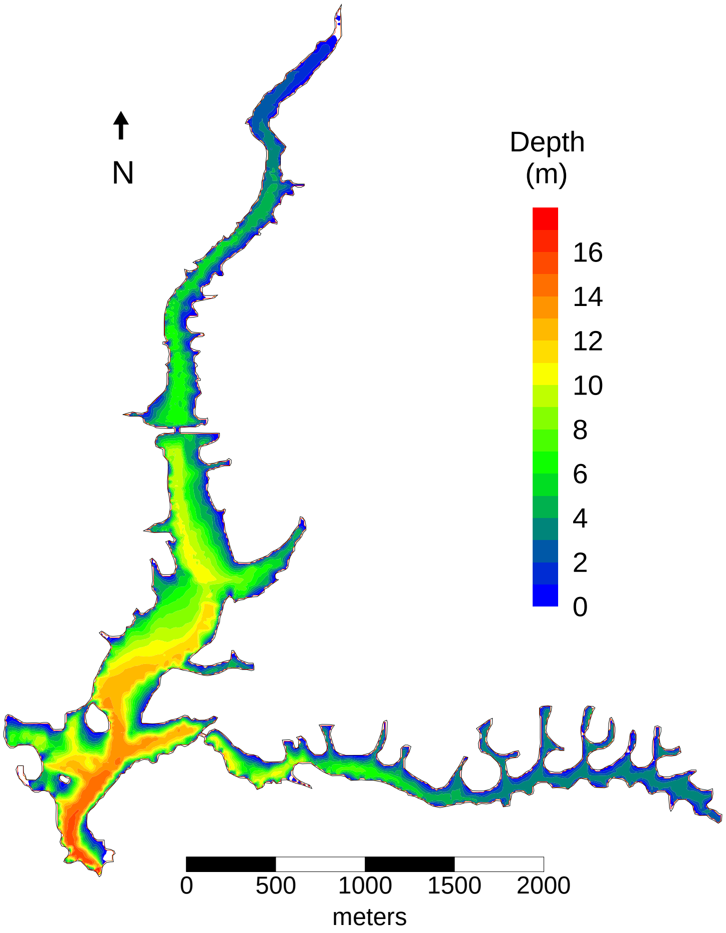

*Fig. 1. Bathymetry of Canyon Lake.*

Very shallow conditions were present near the inflows of the San Jacinto River and Salt Creek, reflecting natural topography and the deposition of material eroded from the watershed. Bathymetric measurements also revealed the original channel for the San Jacinto River which was located on the western side of the lake through the north basin and into the main basin (Fig. 1). The channel was not clearly defined near the mid-portion of the main basin due presumably to deposition of material there, likely derived from construction activities during development of the community. The channel is again evident in the southern part of the lake, representing its deepest region (Fig. 1).

The bathymetric data were used to develop an up-to-date storage curve and elevation-area curve for the lake (Fig. 2). Included is storage curve provided by EVMWD (Fig. 2a, dashed line). The interpolation assumed the shoreline throughout the north basin and most of the main basin to grade to 0 m at full pool, while the shoreline of east basin was defined by sea walls with an assumed depth of 0.6 m. The basin elevation ranged from a minimum value of 1323.36 ft (above MSL), immediately adjacent to the dam face, to the spillway elevation of 1381.76 ft. The full pool volume of Canyon Lake was calculated to be 8758 acre-feet, a value that is 3110 acre-feet less than EVMWD's prior storage curve apparently developed in 1993. The downward displacement of lake volume at a given surface elevation represents loss of storage; measurements thus indicate that the lake has lost significant storage over time.

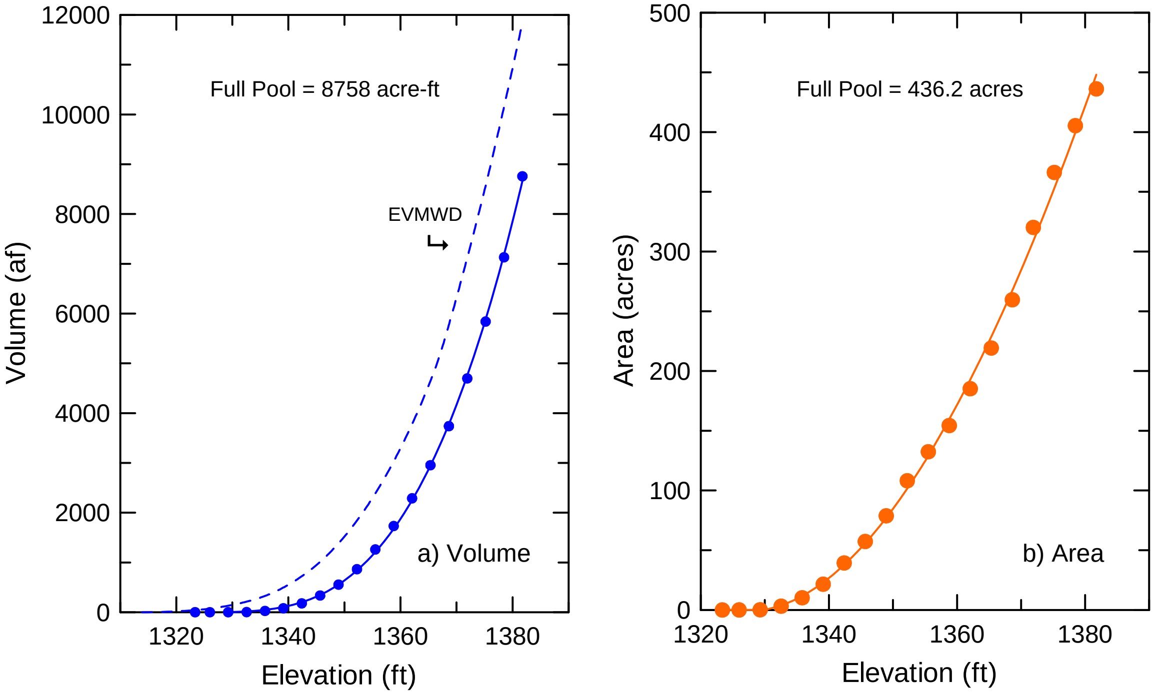

*Fig. 2. Canyon Lake hypsography: a) volume vs. elevation (dashed line is EVMWD data from 1993), and b) surface area vs. elevation.*

The lake volume was well-fit ($r^2$=0.9998) by the 3rd-order polynomial of the form:

$$Vol\ (af) = -129913027.7 + 293417.3 \cdot Elev - 220.9033 \cdot Elev^2 + 0.0554373 \cdot Elev^3 \qquad (1)$$

The surface area at full pool was calculated to be 436.2 acres (Fig. 2b). Lake surface area was reasonably described ($r^2$=0.9980) with the 3rd-order polynomial:

$$Area\ (acres) = 1271585.1 - 2645.223 \cdot Elev + 1.82046 \cdot Elev^2 - 0.00041385 \cdot Elev^3 \qquad (2)$$

In addition, the elevation-area-volume relations for the individual basins were also developed. The main basin contributes the largest area and volume to the lake, at 252.8 acres and 6439.8 acre-feet, representing 58.0% of the total area and 73.5 % of the total volume, respectively (Table 1). The east and north basins collectively comprise over 40% of the lake area, but contribute only about 25% of the total lake volume (at full pool) (Table 2).

Table 2. Individual basin and total lake metrics.

| | Area (acres) | Volume (acre-ft) | Mean Depth (ft) | Maximum Depth (ft) |
|---|---|---|---|---|
| Main Basin | 252.8 (58.0%) | 6439.8 (73.5%) | 25.5 | 58.4 |
| East Basin | 102.5 (23.5%) | 1406.8 (16.1%) | 13.78 | 38.7 |
| North Basin | 80.9 (18.5%) | 911.2 (10.4%) | 11.3 | 26.2 |
| Total | 436.2 (100%) | 8757.9 (100%) | 20.1 | 58.4 |

Storage curves for individual basins were also extracted from bathymetric data (Fig. 3).

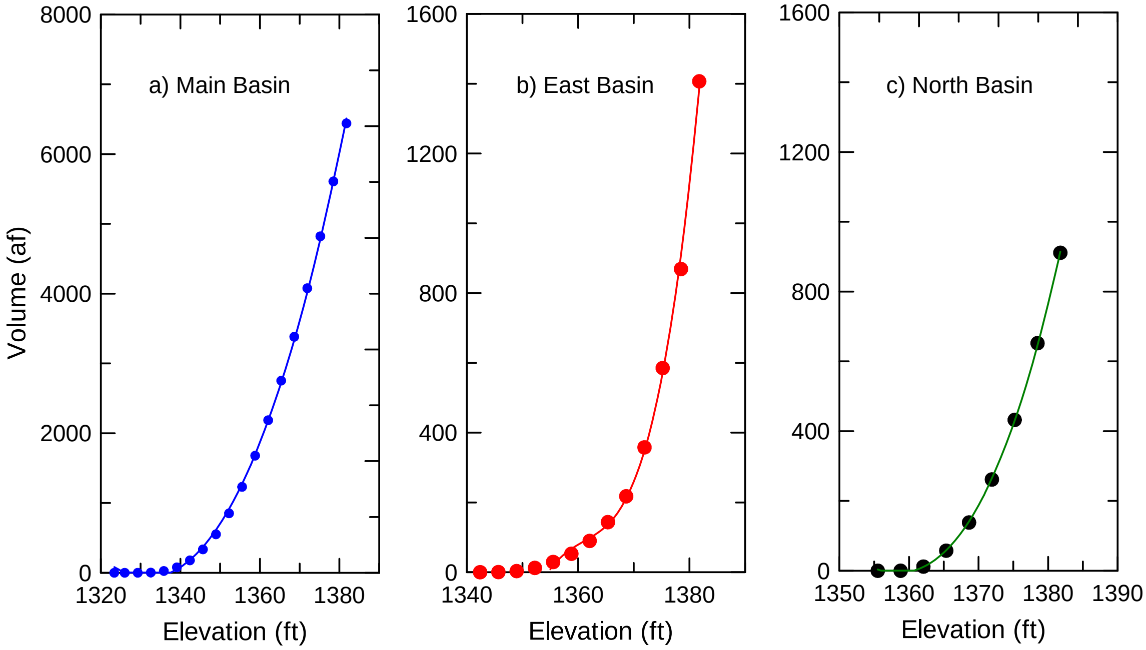

*Fig. 3. Volume-elevation relationships for a) main basin, b) east basin and c) north basin.*

The volumes of the individual basins were also reasonably-described ($r^2$>0.998) by 3rd-order polynomials:

$$Vol_{main} = -18099718.1 + 43668.02*Elev - 34.9638*Elev^2 + 0.0092954*Elev^3 \quad (3)$$

$$Vol_{east} = -312755907.3 + 689395.0*Elev - 506.541*Elev^2 + 0.1240641*Elev^3 \quad (4)$$

$$Vol_{north} = -50991062.6 + 114231.5*Elev - 85.2843*E*Elev^2 + 0.0212201*Elev^3 \quad (5)$$

Sediment Thickness

Thickness of the sediment was derived from echograms based upon the penetration and attenuation of the 38-kHz sound wave within the sediments. Very hard sediments limit penetration of the sound wave, while fine-textured organic-rich sediments with high water contents allow penetration of the sound wave to considerable depths within the sediments before reverberation from harder weathered bedrock or soil. Thickness of the sediment ranged from 0 – 8 m, and varied across the basin in a complex way, with some evidence of infilling of the original San Jacinto River and Salt Creek channels, deposition of material derived from grading and construction within the local watershed and from erosion from upper watersheds (Fig. 4).

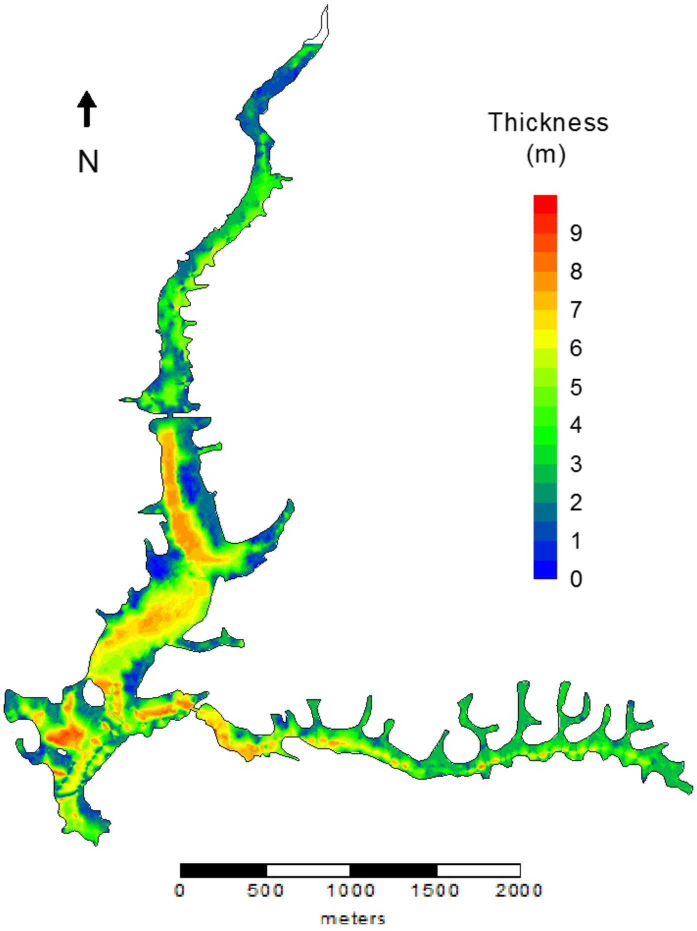

*Fig. 4. Sediment thickness in Canyon Lake.*

Based upon these measurements, it is estimated that sedimentation over the past 88 yrs since the dam was constructed has reduced the capacity of the reservoir by >5000 acre-feet and potentially as much as 8000 acre-feet or more.

Sediment Organic C Content

The attributes of the bottom echo have been found to be correlated with surficial sediment physical and chemical properties (Anderson and Pacheco, 2011). For example the fractal (box) dimension of the bottom echo at 430-kHz was very strongly correlated with the organic C content of surficial bottom sediments. The regression equation developed in that study was used to estimate the organic C content of sediments in Canyon Lake (Fig. 5).

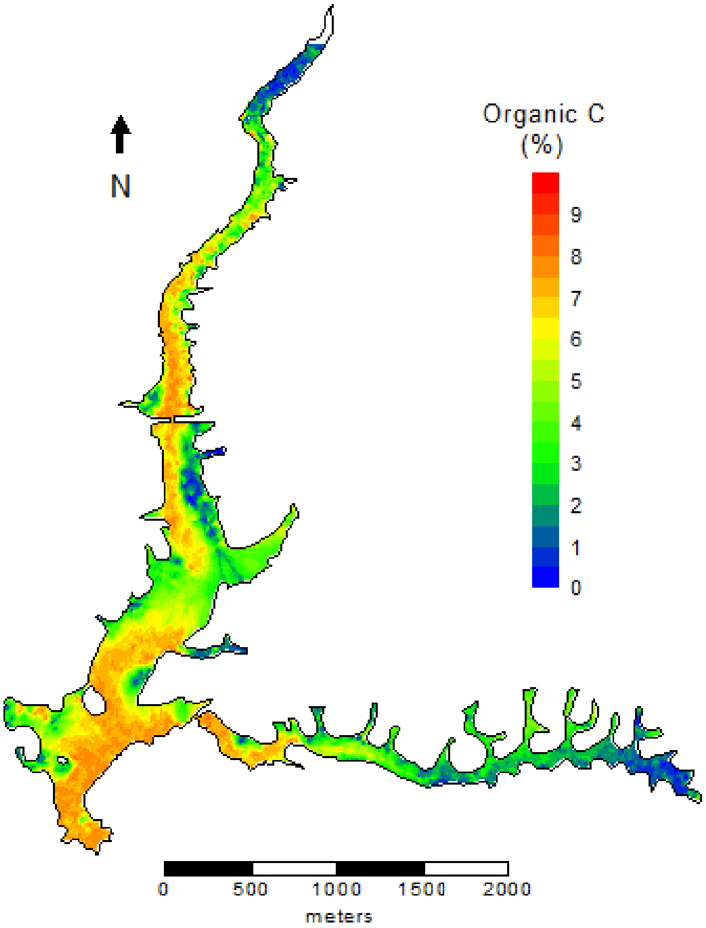

*Fig. 5. Sediment organic C content in Canyon Lake.*

Organic C contents of surficial sediments were very low near the influent of San Jacinto River and Salt Creek (<1%) as a result of deposition of coarse-textured material eroded from the watershed, and due to scouring and further transport of finer-textured material during inflow events. Organic C contents increased at greater distances into east and north basins, with strong focusing of organic matter in the deeper waters of the main basin, especially near the dam (Fig. 5).

Sediment Mobile-P Content

The mobile-P content of sediments has been found to be strongly correlated with P flux from sediments under low DO conditions and is now commonly used to guide alum treatments of lakes. Mobile-P was quanitifed on sediment grab samples from 5 sites on the lake when hydroacoustic measurements were also conducted. A nonlinear relationship was found between the fractal dimension of the bottom echo envelope and mobile-P content (Fig. 6).

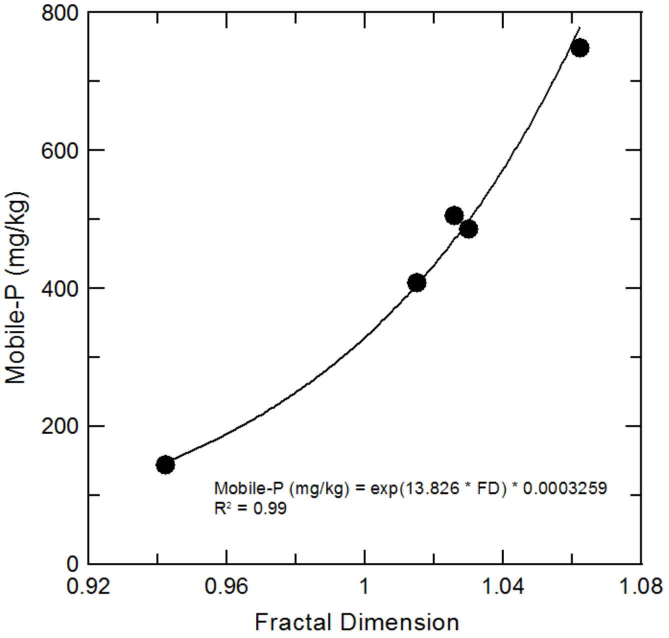

*Fig. 6. Mobile-P content in surficial sediment vs. fractal dimension of bottom echo at 430-kHz.*

This allowed us to remotely sense mobile-P content of sediments and to develop a map of its distribution across the lake (Fig. 7). Mobile-P content of surficial sediments was enriched in original river channel in the north basin; mobile-P was also elevated in deeper sediments near closer to dam (Fig. 7). Understanding of the distribution of mobile-P helps guide alum treatment for sediment P inactivation. Thus, alum treatments designed to inactivate mobile-P in the main basin sediments of Canyon Lake would be most effective when targeting the large inventories at the southern end of the lake. The limited exchange between basins during most of the year (excluding large runoff and flushing events) requires that each basin be treated essentially as an independent lake.

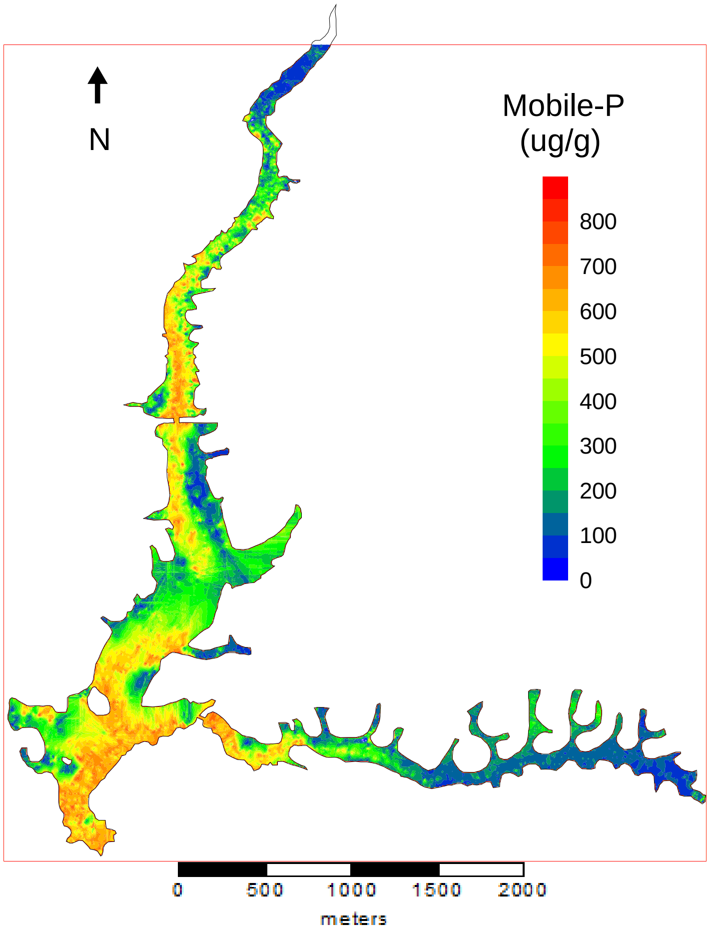

*Fig. 7. Sediment mobile-P content in Canyon Lake.*

## Conclusions

The hydroacoustic study provided valuable new insights in the characteristics of Canyon Lake:

- The hydroacoustic survey provides up to date bathymetry and elevation-area-volume relations for Canyon Lake
- Measurements also provided new detailed understanding of the distribution, properties and thickness of sediment within the lake
- Sedimentation is projected to have reduced storage capacity by >5000 acre-feet and potentially as much as 8000 acre-feet or more since dam construction in 1927

- Sediments enriched in mobile-P and organic matter were deposited in deeper regions of lake, and represent regions of greater nutrient flux and oxygen demand

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## *Technical Memorandum*

**Task 2.4:** Mobile-P and Internal Phosphorus Recycling Rates in Canyon Lake

### Objective

The objective of this task was to improve understanding of phosphorus biogeochemistry in Canyon Lake sediments and the factors affecting P recycling through measurements of mobile-P contents and internal recycling rates of sediments.

### Approach

Measurements of mobile-P, Al-P and internal P recycling rates in Canyon Lake were conducted to assess progress made by alum additions in sequestering bioavailable/mobile-P. Mobile-P and Al-P contents of sediments were determined on grab samples and cores collected from the 5 sites previously sampled for water quality and nutrient flux measurements (Fig. 1) following Pilgrim et al. (2007). In additional P flux measurements were made on triplicated intact sediment cores following Anderson (2001).

*Fig. 1. Sampling sites on Canyon Lake.*

An Ekman dredge was used to collect a grab sample, which was then subsampled by carefully inserting a 30.5 cm by 6.3 cm diameter Lucite tube approximately 10 cm into the sediment. The bottom of the core was sealed using a rubber stopper. The core was then carefully topped off with bottom water sampled using a van Dorn sampler, stoppered with zero headspace and transported back to the lab.

Cores were then incubated in the dark at the temperature and DO levels measured at the time of sampling. Approximately 10 mL of water were removed daily, filtered and analyzed for soluble $PO_4$-P using a Seal discrete analyzer following standard methods (APHA, 1989). Dissolved oxygen concentrations were measured using a YSI Model 55 DO meter, with the water briefly sparged with $N_2$ or lab air as needed to maintain DO and to very gently mix the water column within the core. The measured change in concentration was used in conjunction with water volume and sediment-water interfacial area to calculate nutrient flux rates and compared with previously measured values.

## Results

### P Internal Recycling Rates

The flux of $PO_4$-P from bottom sediments sampled in August 2014 was lower at 4 out of 5 sites compared with average values measured in 2001, 2002 and 2006 (Fig. 2).

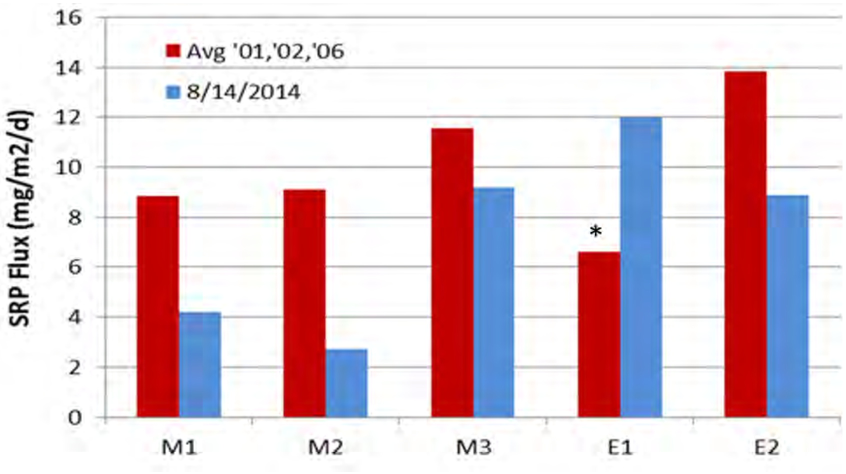

*Fig. 2. $PO_4$-P flux rates measured at the 5 sampling station comparing the average values from 2001, 2002 and 2006 with rates measured on August 14, 2014. *Data available only for 2006 at site E1.*

Average values do obscure strong inter-annual variability, however. In particular, the very large runoff events in 2005 increased subsequent $PO_4$-P flux rates at sites M1 and E2 (Fig. 3). If we ignore the 2006 data and its impact on average values, alum treatments in F'13 and W'14 appear to have had more modest and variable impacts on $PO_4$-P flux (Fig. 3). Inter-annual variability in rate of sediment release of $PO_4$-P makes it difficult to draw conclusions about effects of alum applications on P recycling from sediments as of the time of these measurements. It is thought that speciation of P within the sediments may provide a more sensitive measure of alum effects; moreover, mobile-P measurements are increasingly used to design alum treatment projects and determine appropriate alum application rates (Pilgrim et al., 2007).

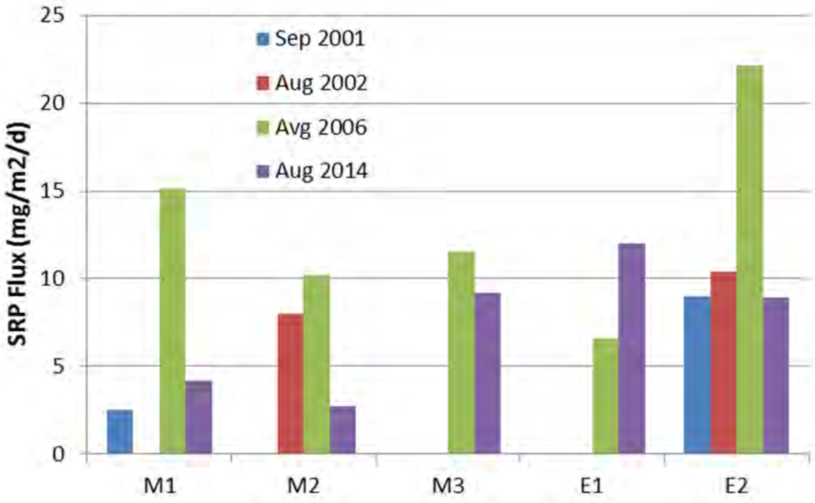

*Fig. 3. Summer $PO_4$-P flux rates from intact cores collected from Canyon Lake.*

Mobile-P and Al-P Contents

Mobile-P contents in sediments of Canyon Lake were markedly higher than concentrations recently measured in Lake Elsinore and Big Bear Lake (Fig. 4). The concentration at site M1 was 749 µg/g, a value nearly 4x larger than the highest concentration measured at Lake Elsinore and 2.8x higher than the highest concentration in Big Bear Lake (Fig. 4). Concentrations of mobile-P at sites M2, M3 and E1 were 409 – 506 µg/g, while site E2 in East Bay was 145 µg/g.

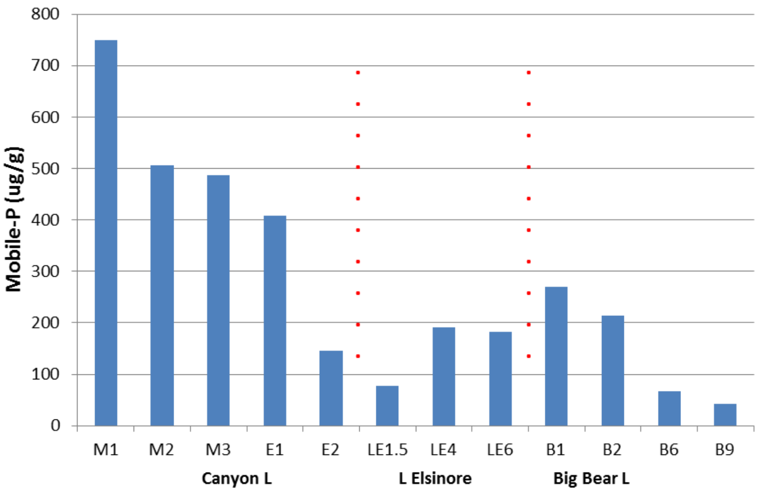

*Fig. 4. Mobile-P content (µg/g) of sediment samples collected from Canyon Lake, Lake Elsinore and Big Bear Lake.*

Mobile-P is generally better expressed on an areal basis since it better correlates with flux rates and allows for calculation of alum dose. Assuming a reactive depth of 10 cm, the range of mobile-P contents is reduced among the 3 lakes, but Canyon Lake is still consistently the highest at an average concentration of 6.68 g mobile-P/m$^2$ (Fig. 5).

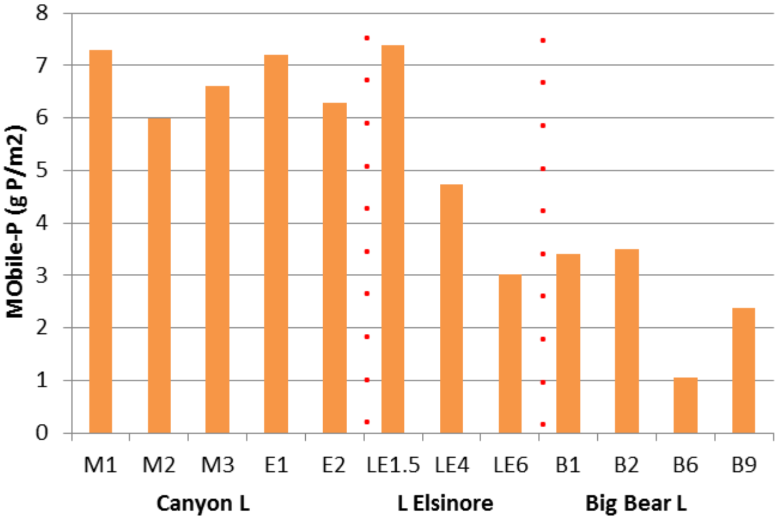

*Fig. 5. Mobile-P content, expressed on areal basis (g P/m$^2$), of sediment samples collected from Canyon Lake, Lake Elsinore and Big Bear Lake.*

Assuming a 20:1 Al:P ratio for the alum floc (Berkowitz et al, 2006), the mobile-P pool in the sediments of Canyon Lake may require up to 140 g Al/m$^2$, an average value much higher than that for Lake Elsinore or Big Bear Lake, although comparably high application rates would be needed for some regions on Lake Elsinore (Fig. 6).

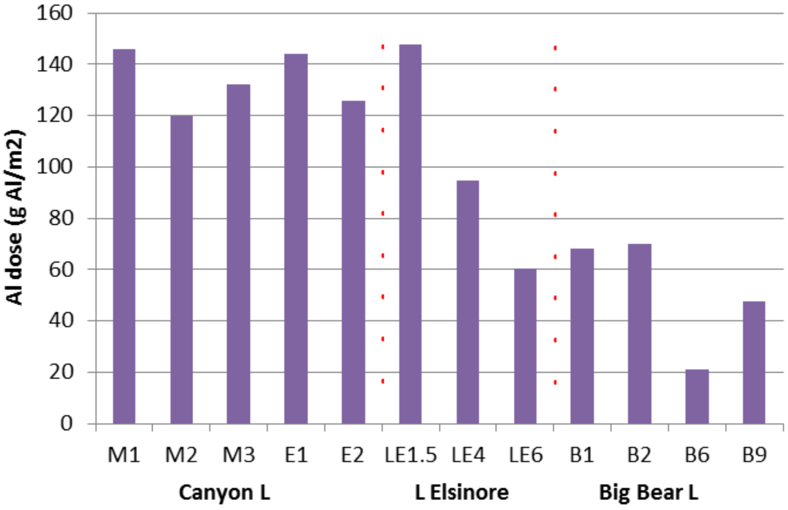

*Fig. 6. Alum dose, expressed as g Al/m$^2$, based upon mobile-P values assuming 20:1 Al:P ratio.*

The hydroacoustic survey conducted on Canyon Lake in December 2014 (Task 2.3) quantified the acoustic properties of bottom sediments as well as bathymetry. The fractal dimension of the bottom echo envelope was strongly correlated with mobile-P content of bottom sediments (Fig. 7), allowing development of a map showing mobile-P distribution across the lake (Fig. 8, previously presented in the Task 2.3 tech memo).

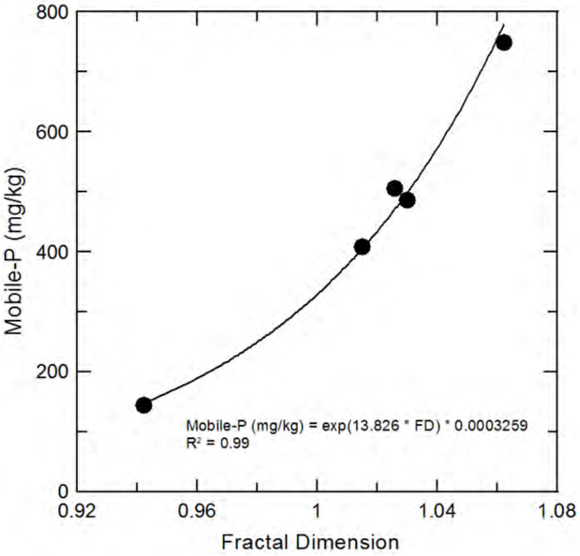

*Fig. 7. Mobile-P content of Canyon Lake sediment vs fractal dimension of bottom echo envelope.*

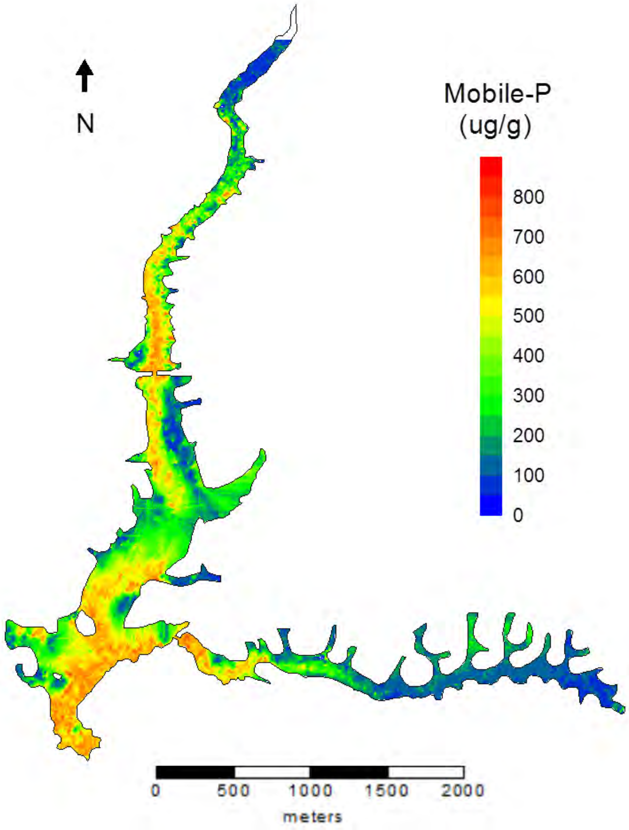

*Fig. 8. Distribution of mobile-P in bottom sediments of Canyon Lake.*

The results presented above were based upon grab samples collected using an Ekman dredge that samples to approximately 10-15 cm depth in soft cohesive sediments and less in coarser textured uncohesive material. Intact sediment cores were also collected from each of the 5 sampling sites on Canyon Lake and sectioned into 1 cm increments that were subsequently extracted for mobile-P and Al-P (Fig. 9).

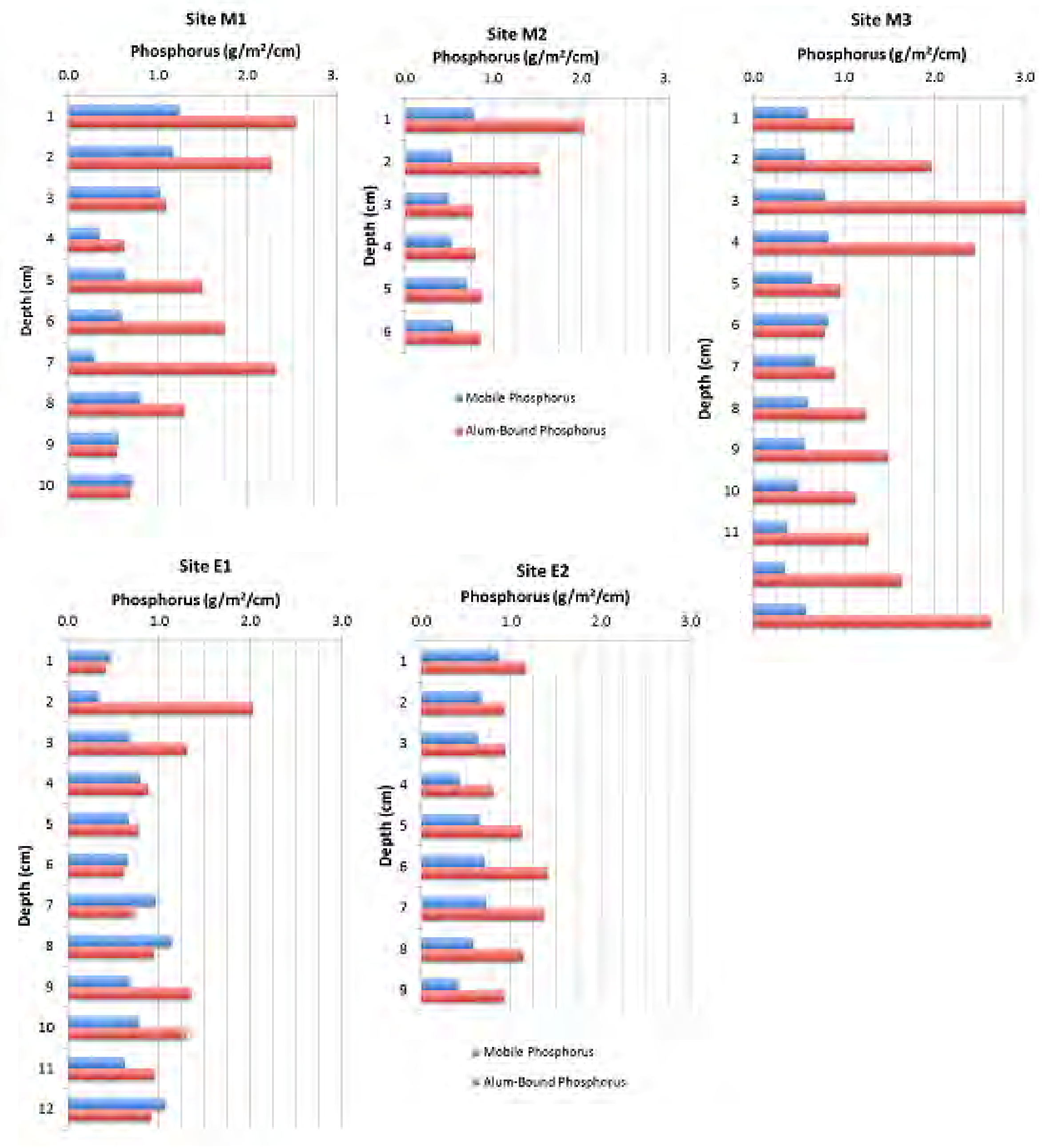

*Fig. 9. Vertical distribution of mobile-P and Al-P in sediments of Canyon Lake.*

Phosphorus extracted with NaOH and assigned to the aluminum-bound pool (that would include P bound to both natural Al phases as well as added alum) (Fig. 9, red bars) typically exceeded concentrations of mobile-P, often by a relatively wide margin (Fig. 9 blue bars), although clear vertical trends across the sites are not apparent. Ideally, a reduction in mobile-P and a corresponding increase in Al-P would result from an alum treatment and signify the conversion of labile forms of P to unreactive forms. The 7 cm depth at site M1 might be conjectured to conform to this, but would require added alum floc to have settled to this depth within the sediments in a relatively narrow band. Watershed inputs of inorganic particles with large runoff events, intervals of drought, and other processes would also be expected to alter properties with depth.

Despite this complexity, it is interesting to compare P fractionation results from sediment samples collected in December 2006 (Whiteford et al., 2007), following the tremendous runoff and siltation to Canyon Lake from winter 2005 storms, with results in this study (Fig. 10). The results for 2014 and 2006 are presented side-by-side as stacked bar charts for the $NH_4Cl$-P, Fe-P and Al-P fractions, with sites separated from each other by dashed lines. Soluble and readily exchangeable P ($NH_4Cl$-P) comprised a small fraction of P in the sediments in both 2006 and 2014 (Fig. 10, dark red bar), while Fe-P comprised a much larger fraction (Fig. 10, pale blue bar). The sum of these 2 phases is taken as mobile-P;  what is clear is the Fe-P and mobile-P contents were much higher at all sites in 2006 when compared with 2014 (Fig. 10). Encouragingly, Al-P contents were often quite a bit higher in 2014 than 2006, potentially indicating the alum treatments had some success in lowering mobile-P and increasing the fraction bound to Al.

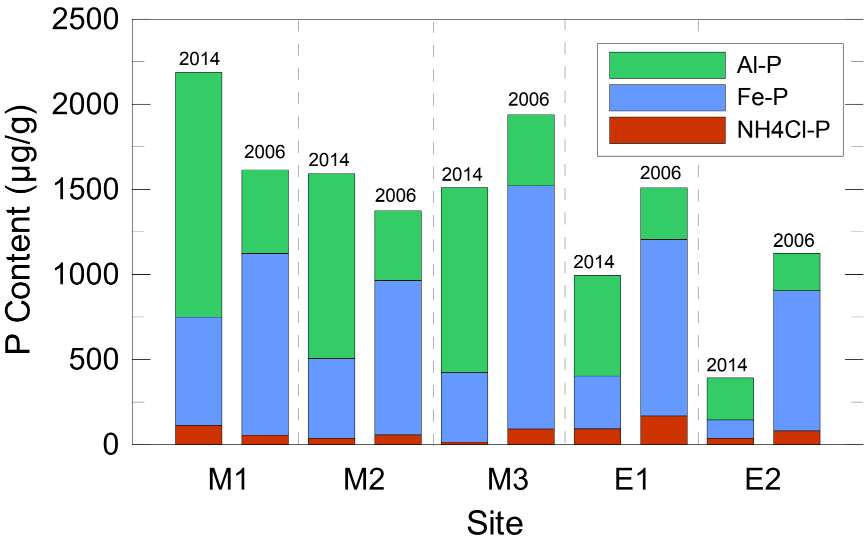

*Fig. 10. Phosphorus fractionation in sediments of Canyon Lake comparing results from samples collected in this study with those from 2006 (Whiteford et al., 2007).*

There are interesting lake management implications from the P fractionation results for Canyon Lake and Lake Elsinore. The differences between these 2 lakes can be attributed in part to the San Jacinto River that delivers a substantial amount of inorganic particulate material, eroded from the watershed, which is retained within Canyon Lake. As a result, Canyon Lake has much higher mobile-P contents, chiefly as Fe-P, than Lake Elsinore (Task 2.1 Tech Memo). With high reducible Fe-bound P phases in Canyon Lake, Canyon Lake would likely be more responsive to aeration/ oxygenation than Lake Elsinore. The limited amount of Fe delivered to Lake Elsinore, and the previously established formation of $FeS_2$(s) phases within the sediments (Anderson, 2001) is thought to constrain effectiveness of aeration at sequestering sediment $PO_4$-P there.

## Conclusions

The results of these measurements indicate:

(i) Canyon Lake has much higher mobile-P contents than Lake Elsinore and Big Bear Lake;

(ii) the mobile-P pool in Canyon Lake is chiefly comprised of $PO_4$-P associated with reducible Fe phases (Fe-P), making it more amenable to aeration/oxygenation for sequestering PO4-P within the sediments than Lake Elsinore with very little Fe-P.

(iii) mobile-P concentrations are generally much higher in deeper regions of the lake as a result of sediment focusing processes;

(ii) P fractionation results indicate a reduction in mobile-P and increase in Al-P contents since 2006 in Canyon Lake that may result from differences in hydrologic conditions, alum applications, or other factors.

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# Attachment 4: Letter from the Company to the Temecula Band of Luiseño Mission Indians

LEAPS | THE HYDRO COMPANY

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December 12, 2017

Mr. Mark Macarro
Tribal Chairman
Pechanga Tribal Council
12705 Pechanga Road
P.O. Box 1477
Temecula, CA 92593

Dear Mr. Macarro:

On behalf of The Nevada Hydro Company, I would like to thank the Pechanga Band of Luiseño Indians for their thoughtful letter filed with the Federal Energy Regulatory Commission (FERC) requesting additional scientific studies and consultation with the Tribe. We appreciate your contribution to the regulatory review of the Final License Application for the Lake Elsinore Advanced Pumped Storage project (LEAPS).

You may be aware that we have once again retained the services of the Chambers Group, Inc. to assist with issues relating to historic properties and cultural resources. Chambers was involved in the previous LEAPS Project, and authored the Historic Properties Management Plan. As such, we have asked them to engage and collaborate with the Pechanga Cultural Resources Department.

We believe the LEAPS project, in conjunction with other regional water management efforts, will have significant beneficial impacts on both the quality and, in time, quantity of water in Lake Elsinore. As well, in close collaboration with the Pechanga Cultural Resources Department, we hope to learn and understand more about the Pechanga's Traditional Cultural Property, and increase the understanding of our neighbours.

I personally am committed to working with the Tribal Council, Tribal Elders, and members of the community who value the Traditional Cultural Property as outlined in your FERC filing. We respect the historic role of the Pechanga in the region and the importance of Lake Elsinore to your culture. I request and look forward to attending a senior-level introductory meeting at your convenience, which I and my colleagues trust will lead to engagement and insights from the Tribe, its leadership, and its Elders.

Respectfully,

Rexford J. Wait
President & CEO