LEAPS: Results from 2006-2007 Studies Conducted for SARWQCB and Nevada Hydro

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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
  - provide reserve generation capacity
- Pumped-storage plants are used extensively in Japan, where there are at least 16 such facilities, with plants also located in Australia, China, Taiwan, Poland, Germany, Russia, Ireland, Switzerland, the UK and the US
- Within California, the Castaic and Helms pumped-storage plants each provide in excess of 1000 MW capacity

- The ability to store renewable energy (wind and solar) has greatly increased interest in pumped-storage plants throughout the world
- In response to the proposal put forth by Nevada Hydro to construct a pumped-storage hydroelectric plant at Lake Elsinore, the SARWQCB requested an analysis of possible water quality impacts of the project
- I was fortunate to work jointly with the SARWQCB (Mark Adelson, David Woelfel) and Nevada Hydro (Rex Wait, David Kates) to make a quantitative assessment of impacts at Lake Elsinore
- The work was conducted between November 2005 – May 2007 and involved development of several Final Reports

Reports

1. *Technical Analysis of the Potential Water Quality Impacts of the LEAPS Project on Lake Elsinore.* Report submitted to the SARWQCB (January 21, 2006). 30 pp.
2. *Lake Heating, Cooling and Stratification During LEAPS Operation.* Report submitted to the SARWQCB (August 28, 2006). 25 pp.
3. *Effects of LEAPS Operation on Lake Elsinore: Predictions from 3-D Hydrodynamic Modeling.* Report submitted to the SARWQCB (April 23, 2007). 49 pp.
4. *Ecological Impacts form LEAPS Operation: Predictions Using a Simple Linear Food Chain Model.* Report submitted to the SARWQCB (May 29, 2007). 22 pp.

1. Technical Analysis of the Potential Water Quality Impacts of the LEAPS Project on Lake Elsinore.

- Analytical calculations indicate that turbulent kinetic energy (TKE) inputs during generation exceed that of natural wind-forcing by 2.9x
- This additional TKE may help weaken thermal stratification in lake and increase DO levels
- TKE inputs have potential to increase sediment resuspension and nutrient release, but this is expected to be short-term event as sediments come into equilibrium with new energy regime (e.g., chronic turbidity resulting from operation of the 40 MW Olivehain-Hodges pumped-storage plant not evident)
- Lake level variation of 1.0 – 1.7 ft over a pump-generation cycle estimated to expose 49-134 acres (mostly in southern embayment)

1. Technical Analysis of the Potential Water Quality Impacts of the LEAPS Project on Lake Elsinore (cont'd)

- Shoreline migration is expected to be modest over most of lake (8-20 ft)
- Entrainment and mortality of zooplankton and larval fish could be substantial; a filter curtain is projected to reduce larval fish loss to 8-29% and zooplankton loss of 7-25%. No significant impact on phytoplankton populations were predicted (1-4% reduction)
- Daily variations in lake level resulting from pump/generation are modest compared with annual lake elevation changes without adequate supplemental water
- LEAPS can provide funding for acquisition of supplemental water and thus can help maintain lake level & potentially help establish littoral community

2. Lake Heating, Cooling and Stratification During LEAPS Operation

- Heat budget and related calculations were undertaken to quantify effect of LEAPS on stratification and mixing in Lake Elsinore
- Modified densiometric Froude numbers indicate that a weakly stratified or intermittently mixed water column will be in place
- Heat budget calculations indicate that pumping, short term storage in upper reservoir and generation will have minimal effects on water temperature ($\pm$0.2°C or less depending upon season)
- Operation of LEAPS predicted to lower thermal stability by <20 J m^{-2} and not impart sufficient TKE to strongly alter thermal stratification and mixing in lake

3. Effects of LEAPS Operation on Lake Elsinore: Predictions from 3-D Hydrodynamic Modeling

- 3-D hydrodynamic simulations were conducted using Environmental Fluid Dynamics Code (EFDC) originally developed by Hamrick and included in the USEPA's TMDL toolbox
- A Cartesian 100 m x 100 m computational grid was constructed from bathymetric data that yielded 1402 horizontal water cells
- The vertical dimension was represented with an 8-layer sigma vertical coordinate system
- 150 m wide shore-mounted I/O structure with bottom intake channel at 1220'
- I/O alternately sited at Santa Rosa and Ortega Oaks sites

3. Effects of LEAPS Operation on Lake Elsinore: Predictions from 3-D Hydrodynamic Modeling (cont'd)

- Model predicted regular variations in lake surface elevation
  - Pumping lowered lake level by 0.6 ft
  - Generation raised lake level by 0.8 ft
  - Difference due to assymetric schedule over 1-week
- Average velocities near intake less than 6 cm s^{-1} due to large cross-sectional area of I/O structure
- Shear force below critical threshold for sediment resuspension near I/O, so limited resuspension effects (rip-rap immediately adjacent to I/O)
- 3-D simulations further support analytical calculations indicating little effect on stratification-mixing with large shore-mounted I/O structure
- Narrowing I/O widths from 150 m to 10 m with 1-m vertical gate greatly increased local resuspension, but effects were short-lived and did not greatly affect lakewide TSS concentrations.

4. Ecological Impacts form LEAPS Operation: Predictions Using a Simple Linear Food Chain Model

- A simple linear food web model was developed to evaluate potential trophic cascades as a result of entrainment of organisms during LEAPS operation (foodweb model for EFDC not available at time of study)
- Calculations demonstrate that the structure of the foodweb will have a dramatic effect on water quality in lake, an effect that outweighs effects due to LEAPS
  - A foodweb terminated with zooplankton was predicted to yield excellent water quality
  - A foodweb terminated with zooplanktivores (e.g., shad) was predicted to have very poor water quality
  - Presence of piscivores restored water quality and yielded high predicted clarities

4. Ecological Impacts form LEAPS Operation: Predictions Using a Simple Linear Food Chain Model (cont'd)

- LEAPS operation without filter curtain was found to lower slightly predicted water quality in food webs terminated with zooplankton or piscivores but effect was modest
- LEAPS operation without filter curtain was predicted to slightly improve water quality in foodwebs terminated with phytoplankton or zooplanktivores
- Use of filter curtain improved water quality for full food web, 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
- EFDC simulations with particle-tracking indicate that pumping can alter trajectory and entrain planktonic organisms within 750-870 m of intake (or about 6.6% of lake area)

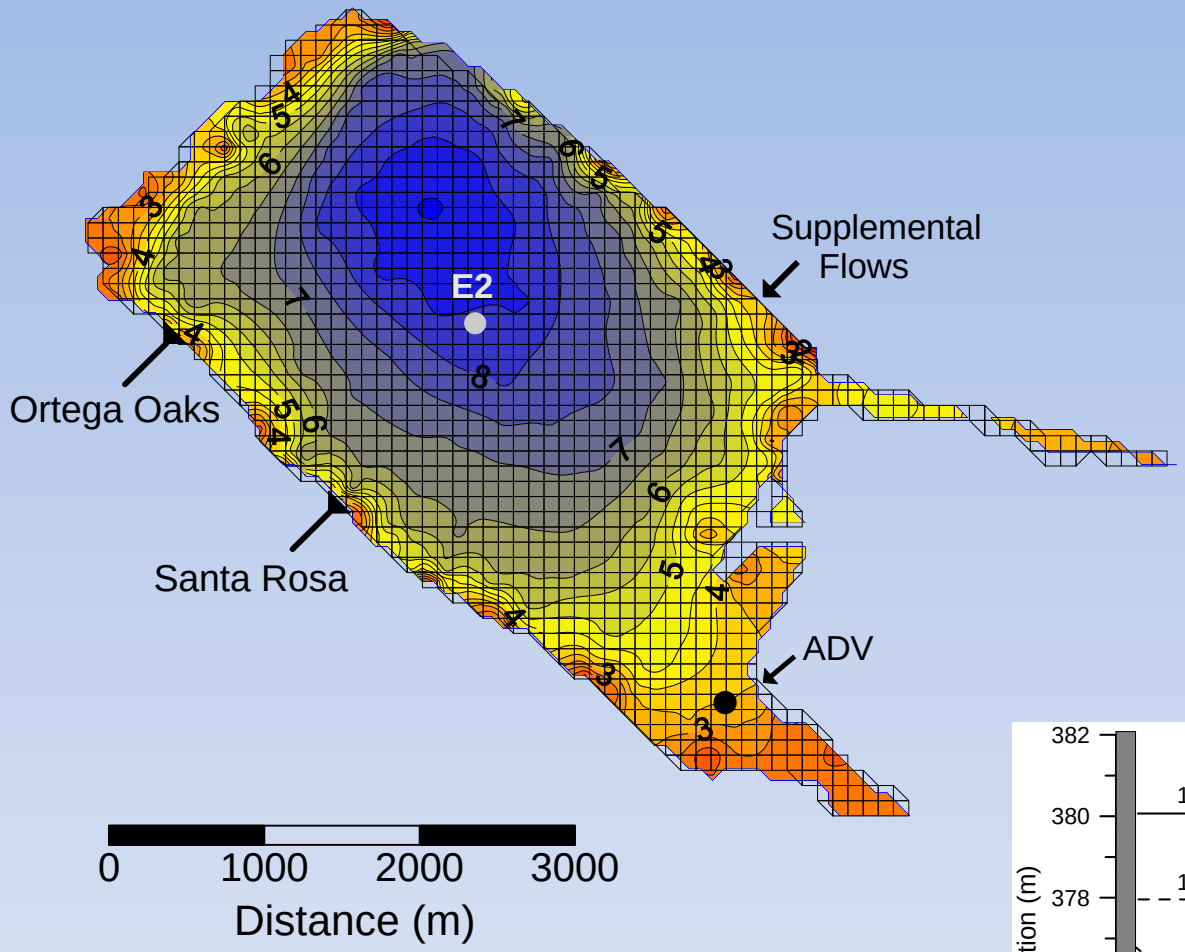
$$\eta_w = \rho_w \left(\frac{C_D \rho_a}{\rho_w}\right)^{\frac{3}{2}} U_w^3$$

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

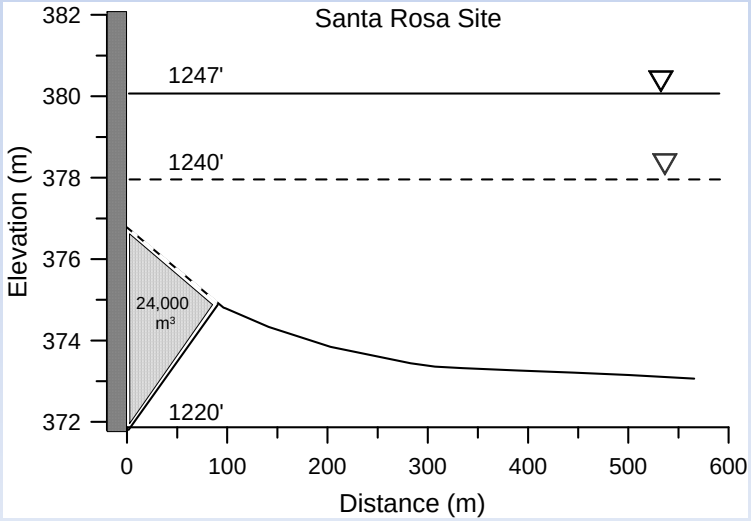
$$\frac{dP_Z}{dt} = \left(\mu_Z \left(\frac{K_Z - P_Z}{K_Z}\right) - m_Z \frac{Q}{V} f\right) P_Z$$

$$F_d = \sqrt{\frac{1}{ge}} \frac{LQ}{D_m V}$$

$$H_O = \frac{H_{SC}}{r^2} \left\{ \sin\left(\frac{\pi\theta}{180}\right) \sin(\delta) \_ \frac{12}{\pi} \cos\left(\frac{\pi\theta}{180}\right) \cos(\delta) \left[\sin(h_e) - \sin(h_b)\right] \right\} \Gamma$$


E2
Supplemental Flows
Ortega Oaks
Santa Rosa
ADV
0
1000
2000
3000
Distance (m)


Depth (m)
9
8
7
6
5
4
3
2
1
0


Santa Rosa Site
1247'
1240'
1220'
24,000 m³
Elevation (m)
382
380
378
376
374
372
0
100
200
300
400
500
600
Distance (m)