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

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Introduction

• The large flows resulting from operation of LEAPS may have significant effects on Lake Elsinore

• LEAPS operation may:
  – Alter circulation in the lake
  – Resuspend bottom sediments
  – Weaken stratification & improve vertical mixing

• The EFDC model, originally developed by Hamrick (1992) and slated to become part of the USEPA’s TMDL toolbox, was used to conduct 3-D hydrodynamic simulations
Approach

• A Cartesian 100 m x 100 m computational grid was constructed from available bathymetric data that yielded 1402 water cells

• The vertical dimension was represented by an 8-layer sigma (stretched) vertical coordinate system

• Locations and initial configuration of the LEAPS I/O provided by Nevada Hydro
Computational Grid with Proposed LEAPS Sites

Depth (m)
0 1000 2000 3000
Distance (m)

Ortega
Santa Rosa
Model Calibration

- The 2006 year was selected for model calibration since it represents the current condition, is near the upper operating range of LEAPS (1247 ft), and monitoring data (including limited velocity measurements) were available.

- Air temperature, wind speed and wind directions were provided by EVMWD; relative humidity, rainfall and solar radiation was taken from the CIMIS weather station at UCR.

- Light attenuation coefficient was calculated from mean measured Secchi depth.
• A simulation using default parameter values (e.g., those previously used in the Lake Okeechobee study) was initially conducted for the March-October period

• The model over-predicted surface temperatures and under-predicted evaporative losses with default values

• This suggested that the evaporative (and thus also convective) heat flux constants were a bit too low

• These were thus varied to calibrate the model

• Reasonable agreement was achieved when values were increased from 1.5 to 2.0
The model captured seasonal trends in both the surface and bottom temperatures.

It also properly predicted:
- Weak diurnal stratification in April
- Strong stratification in May-July
- Mixing event in late July
• The model accurately reproduced temperature profiles, e.g., at site E2
• Nonetheless, modest differences between predicted and observed values were sometimes found
• Temperatures and water velocities were also measured every 30 min using an ADV in the shallow southwest bay in July

• The model did a good job of predicting:
  – bottom temperatures in this embayment
  – diurnal variations in temperatures
The predicted east and north components of the water velocity vectors were also compared with measured values.

The model captured the trends in velocities but often underpredicted the magnitudes.

Nonetheless, given the location and rigor of this test, this was considered adequate performance.
Model Verification

• Model verification was conducted using 2001 data when the lake was ~1241.5 ft

• Meteorological data from a weather station deployed at the lake was used to drive the model

• Simulation results were compared with high resolution water column temperature data collected in May-June using Onset temperature loggers
• May-June 2001 included an interval of strong stratification in early May that weakened through the month.

• The water column mixed and warmed to ~26 °C in late June.

• The model reproduced major features found in the field data.
• Looking more carefully at the predicted and observed surface and bottom temperatures
  – Model reasonably reproduced the strong diurnal trends in surface temperature although slightly overpredicted temperatures
  – Reasonable agreement also found in bottom temperatures

<table>
<thead>
<tr>
<th></th>
<th>Surface Temp</th>
<th>Bottom Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{error}}$ (°C) (Pred-Obsd)</td>
<td>1.18 ± 0.75</td>
<td>0.26 ± 0.79</td>
</tr>
<tr>
<td>CV (%)</td>
<td>4.92 ± 3.09</td>
<td>0.94 ± 3.57</td>
</tr>
</tbody>
</table>
LEAPS Simulations

• Simulations were conducted to represent LEAPS operation

• 2 different sites (the Ortega Oaks and Santa Rosa sites) and 3 different lake elevations (1247, 1240 and 1237 ft) were evaluated

• The effect of discharge elevation was also investigated
LEAPS Flow Regime

- Supplemental flows sufficient to offset evaporative losses were added at the outflow channel on the east side of the lake.
• Flows associated with LEAPS operation varied regularly, with 5 days of generation (M-F), 7 h pumping + 15 h generation per day.
Based on the flow cycle that moved 2500-3000 af each way during a cycle, LEAPS operation resulted in regular oscillation in the lake surface elevation.
Simulations were conducted for both the Ortega Oaks and Santa Rosa sites.

The intake specifications included:

- Overall shore structure approximately 42 ft high x 500 ft long
- Elevation of intake channel = 1220 ft
- Bottom elevation of intake gate = 1223 ft
- Excavation out approximately 200 ft from intake to recontour bottom to slope to 1220 ft and place rip rap
- Simulations included surface, middle and bottom discharge during generation and mid-depth withdrawal during pumping
Based on available bathymetric data, the Ortega Oaks site near the intake would look something like this:
• The Santa Rosa site would look quite similar, although would be slightly deeper:
Velocity Profiles Away from Ortega Oaks Intake:

150 m x 1 m Intake/Outlet

- Pumping at mid-depth (4-5 m) resulted in a normal distribution of flow that damped quickly with distance

- Bottom and surface releases during generation yielded an exponential-type velocity distribution with depth
Velocity Profiles Away from Ortega Oaks Intake:

40 m x 1 m Intake/Outlet

- Using a narrower gate while pumping at mid-depth resulted in higher local velocities (10-20 cm/s)

- Bottom release during generation yielded high velocity there (30 cm/s), 4-10 cm/s velocities 100 m away, and counter-current surface flows
Using a very narrow gate while pumping resulted in high local velocities
- 30+ cm/s during pumping
- Almost 60 cm/s bottom velocities during generation
- Strong counter-current flow near intake during generation also predicted
Predicted Bottom Shear

- Shear stress ($\tau$) acting on the sediments results in resuspension when $\tau$ exceeds the critical shear stress (i.e., $\tau > \tau_c$)

- Typical values for $\tau_c$ are 0.1-0.2 N/m$^2$; I assumed $\tau_c=0.1$ N/m$^2$

- The average afternoon bottom shear across the lake is $\sim 0.004$ N/m$^2$

- Higher values were found near the intake during LEAPS operation
• Predicted bottom shear ($\tau$) increases in both magnitude and extent with decreasing gate width.

• Area of resuspension ($\tau >0.1\ N/m^2$, indicated by solid black line on each figure) also increases.

<table>
<thead>
<tr>
<th>Area:</th>
<th>22,700 m$^2$</th>
<th>45,000 m$^2$</th>
<th>60,000 m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Shear:</td>
<td>0.27 N/m$^2$</td>
<td>0.92 N/m$^2$</td>
<td>2.7 N/m$^2$</td>
</tr>
</tbody>
</table>
• The mass of sediments scoured from the bottom ($\varepsilon$) can in turn be calculated from bottom shear:

$$\varepsilon = \alpha_0/t_d^2(\tau-\tau_c)^3$$

• Entrainment of bottom sediments at a constant shear occurs over about an hour (Chapra, 1997), thus resuspension is expected only during transition periods when shear increases.

• The concentration of suspended solids ($C_{ss}$) can be calculated from $\varepsilon$ and the depth of the water column ($H$) simply from:

$$C_{ss} = \varepsilon/H$$
The planned intake width (150 m) with a 1 m gate height is predicted to generate low bottom shear, little scour and minimally increase local suspended solids concentrations.

Narrower gates increased shear stress and greatly increased predicted TSS levels near the intake.

<table>
<thead>
<tr>
<th>Intake Dimension</th>
<th>Avg Shear ($\tau$) (N/m$^2$)</th>
<th>Scour ($\varepsilon$) (g/m$^2$)</th>
<th>Area of Scour (m$^2$)</th>
<th>Total Mass Scoured (kg)</th>
<th>Suspended Solids (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150m x 1m</td>
<td>0.27</td>
<td>8.7</td>
<td>22,700</td>
<td>198.3</td>
<td>1.5</td>
</tr>
<tr>
<td>40m x 1m</td>
<td>0.92</td>
<td>897.7</td>
<td>45,000</td>
<td>40,443</td>
<td>149.8</td>
</tr>
<tr>
<td>10m x 1m</td>
<td>2.7</td>
<td>28,600</td>
<td>60,000</td>
<td>1.72x10$^6$</td>
<td>4,775</td>
</tr>
</tbody>
</table>
• Note that the predicted TSS concentrations are the local concentrations (not whole-lake)

• Assuming 3400 surface acres, a mean depth of 5.7 m, and instantaneous mixing throughout the lake, the TSS concentrations would be:
  – 0.0025 mg/L for the 150 m x 1 m intake gate
  – 0.52 mg/L for 40 m x 1 m intake gate
  – 21.9 mg/L for the 10 m x 1 m intake gate

• The actual TSS concentration would be lower and decrease over time due to particle settling

• The background TSS 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 not predicted to substantially increase lake-wide suspended solids concentrations

• Results from Santa Rosa site are very similar to that found for Ortega Oaks:
  – Low predicted shear stress under planned intake design, resulting in low mass scoured and low local TSS concentrations
  – Moving discharge level away from sediments decreased local velocities and lowered the potential for resuspension, while narrower gates increased velocities and sediment resuspension
Effects on Stratification

• The predicted thermal regime of the lake without LEAPS operation was similar to that seen previously
• Plots of $\Delta T$ (surface-bottom temperatures) more clearly show intensity and duration of stratification and frequency of mixing.

• Operation of LEAPS at both Ortega Oaks and Santa Rosa sites yielded essentially identical results as that found without LEAPS operation.
• The difference in predicted $\Delta T$ values for the supplemental flow-only case with those with LEAPS operation reveal small differences due to LEAPS
  
  – LEAPS operation at the Ortega Oaks site weakened stratification in March and May by 0.2-0.8 °C
  – Siting LEAPS at Santa Rosa lowered stratification slightly more (up to about 1 °C in May

![Graph showing temperature difference over time]
• The effect of intake width (previously shown to strongly influence bottom shear stress and sediment resuspension) had less of an effect on far-field water column thermal properties.

• Nonetheless, a very narrow intake affected stratification more than the proposed project design.
The effect of intake discharge depth had no discernible effect on predicted thermal stratification at the mid-lake site (E2)
Effect of Lake Elevation

- Lowered lake levels increased the extent of sediment resuspension during LEAPS operation.

<table>
<thead>
<tr>
<th>Lake Elevation (ft)</th>
<th>Avg Shear ($\tau$) (N/m$^2$)</th>
<th>Scour ($\varepsilon$) (g/m$^2$)</th>
<th>Area of Scour (m$^2$)</th>
<th>Total Mass Scoured (kg)</th>
<th>Suspended Solids (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1240</td>
<td>3.27</td>
<td>19.1</td>
<td>40,800</td>
<td>778</td>
<td>4.8</td>
</tr>
<tr>
<td>1237</td>
<td>3.30</td>
<td>19.8</td>
<td>57,600</td>
<td>1142</td>
<td>6.6</td>
</tr>
</tbody>
</table>
Conclusions

• The design and operational characteristics of LEAPS do affect water column properties in Lake Elsinore

• EFDC model simulations indicate that the primary effect of LEAPS operation will be on sediment resuspension and local suspended solids concentrations

• The intake design planned for LEAPS will have a minimal effect on TSS levels at 1247’, although increased effects are predicted at lower lake levels (TSS concentrations increasing from 1.5 to 4.8 and 6.6 mg/L at 1247’, 1240’ and 1237’, respectively)
• Narrower intake widths (e.g., 10 – 40 m) will have much more substantial effects, even at high lake levels (local TSS concentrations up to 4,775 mg/L)

• Effects could be mitigated somewhat by mid-depth or surface discharge

• Placing the intake at the Santa Rosa site did not significantly alter predicted results relative to that found for Ortega Oaks

• Operation of LEAPS did not alter in a meaningful way the stratification and vertical mixing in the lake