Flow Routing with Bottom Withdrawal to Improve Water Quality in Walnut Canyon Reservoir, CA

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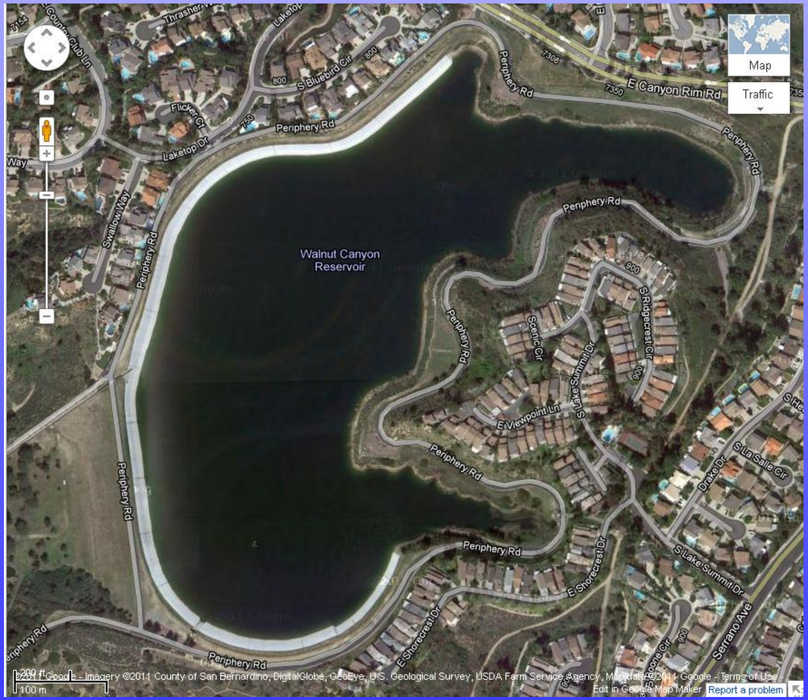
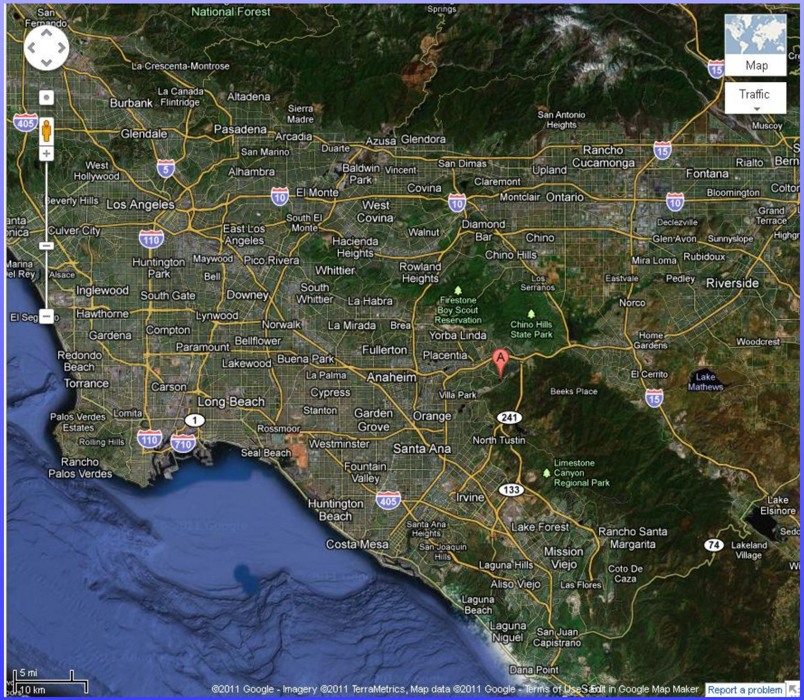
Introduction

- Stratification in lakes often result in anoxia in bottom waters and accumulation of dissolved nutrients, sulfide, and reduced forms of Fe and Mn
- In source drinking water reservoirs, this can constrain the use of the water or increase treatment costs
- As a result, diffused aeration systems, axial flow pump mixing/circulation systems, or other strategies are often used to enhance natural mixing processes
- These strategies can have high capital and O&M costs hower
- In this study, we evaluated the use of TKE input due to advective flow coupled with bottom withdrawal to help mix an off-line source drinking water reservoir

Study Site: *Walnut Canyon Reservoir*

- 3000 acre-ft source water reservoir
- 48 surface acres, maximum depth of 31 m
- Operated by the City of Anaheim, CA
- Water from MWD typically routed directly to plant





- Diffused aeration system historically operated through much of the summer each year
- In an effort to reduce O&M costs, a Solar Bee was installed near the outlet in 2009
- Water column measurements in 2010 (with only operation of Solar Bee) indicated presence of strong stratification and resulting water quality problems:
  - anoxia in hypolimnion
  - high concentrations of Mn^{2+}, Fe^{2+} and S^{2-}
  - limited use of reservoir as source and emergency water supply

Objectives

- Assess alternatives to improve water quality in reservoir using analytical calculations and numerical simulations of:
  - Baseline/no action
  - Diffused aeration
  - Hypolimnetic oxygenation
  - Flow routing with bottom withdrawal
- Implement recommended action and assess water column properties and water quality in 2011

Approach

- Turbulent kinetic energy (TKE) calculations made using analytical equations
- 1-D hydrodynamic-water quality modeling conducted using DYRESM-CAEDYM
- Meteorological data averaged from CIMIS stations #75 (Irvine) and #78 (Pomona)
- Inflow-outflow data provided by staff at the August F. Lenain Treatment plant
- Aeration simulated using the diffused aeration subroutine with single diffuser line with 160 ports at a rate of 0.04 m^3/s at the diffuser

- Hypolimnetic oxygenation simulated by assigning a positive oxygen flux that slightly exceeded SOD rate
- Deep hypolimnetic withdrawal simulated by removing water at approximately 10 af/d at the bottom outlet port located at 742 ft above MSL
- Operation of the Solar Bee with a 20 ft draft tube was included in the baseline simulation
- Water column measurements made over 2-yr period by PACE

Results

TKE Calculations

- Wind-forcing and convective processes responsible for mixing of the water column in most lakes
- Turbulent kinetic energy (TKE) input due to wind shear on a lake surface is function of windspeed:

$$TKE_{wind} = C_k^* \left(\frac{C_D \rho_a}{\rho_w} \right)^{3/2} U_w^3$$

- Ck* is efficiency factor, C_D is drag coefficient

- ρ_a, ρ_w are densities of air and water, respectively

- U_w is the wind speed 10 m from surface

- The average TKE input due to wind shear at the reservoir was calculated at 1.8×10^{-6} W m^{-2}

- TKE input due to flow is a function of flow rate and flow velocity:

$$TKE_{flow} = \frac{Q_{flow} U_{flow}^2 \rho_w}{2A_0}$$

- Q_{flow} is flow rate at the inlet
- U_{flow} is flow velocity
- ρ_w is density of water
- A_0 is surface area of lake

- TKE_{flow} input calculated at $3.1\text{x}10^{-5}$ W m^{-2}
- TKE_{flow} is 17x TKE_{wind}, so significantly supplements mixing energy available from wind

- We can compare these values with stability of the water column S (J m^{-2}), calculated from temperature data as:

$$S = \frac{g}{A_0} \int_{z_0}^{z_m} (z - z^*)(\rho_z - \rho^*) A_z \, dz$$

- g is acceleration due to gravity
- A_0 is the lake surface area
- A_z is the area at depth z,
- ρ_z is the density at depth z,
- ρ^* is the mean water column density
- z^* is the depth of mean density

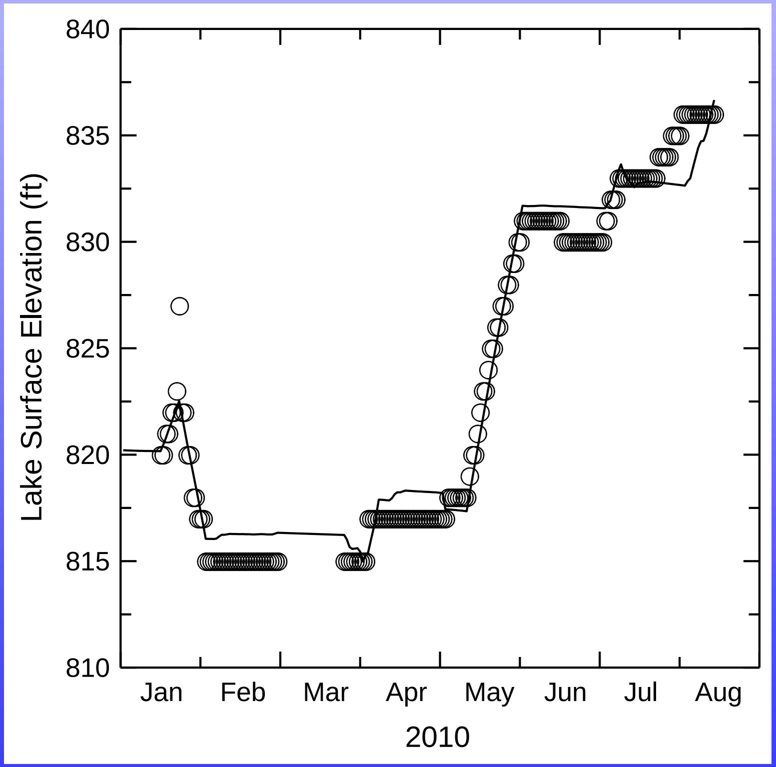
- Stability was calculated to be very high in the summer (e.g., 533 J m^{-2} on July 22, 2010)

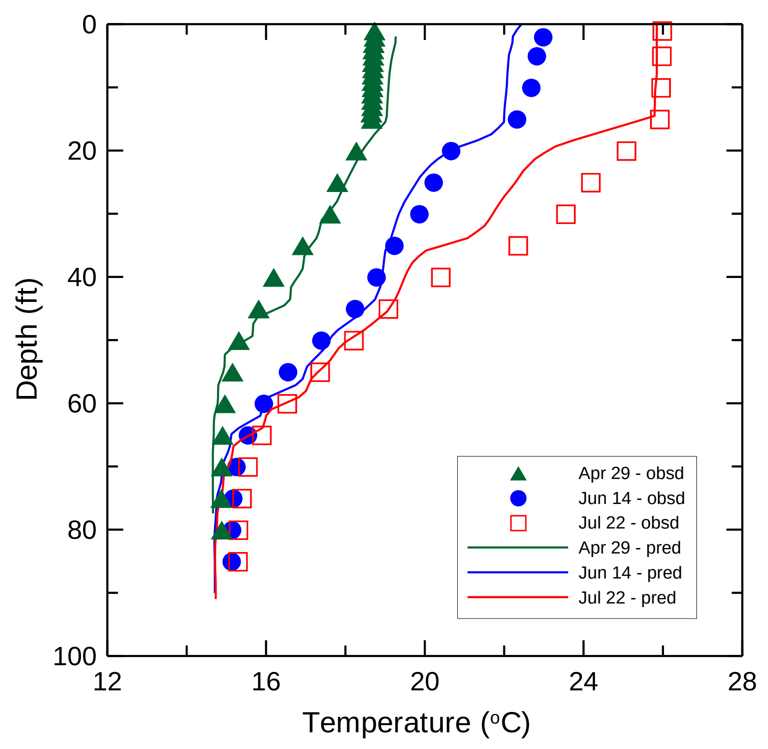
- We can compare TKE inputs with the stability of the water column
- Ignoring seasonal changes in heat budget, varying meteorological conditions, convective mixing and so on, it would take several months to mix the water column
- Bottom water withdrawal will substantially alter the heat distribution and stability of water column however
- To properly account for these coupled processes, 1-D hydrodynamic simulations were conducted using DYRESM-CAEDYM

DYRESM-CAEDYM Simulations

Model Calibration

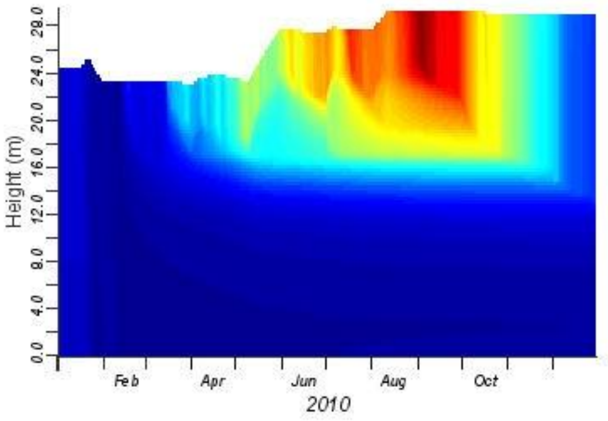
- Model reasonably reproduced measured lake surface elevations and temperature (and DO) profiles in 2010



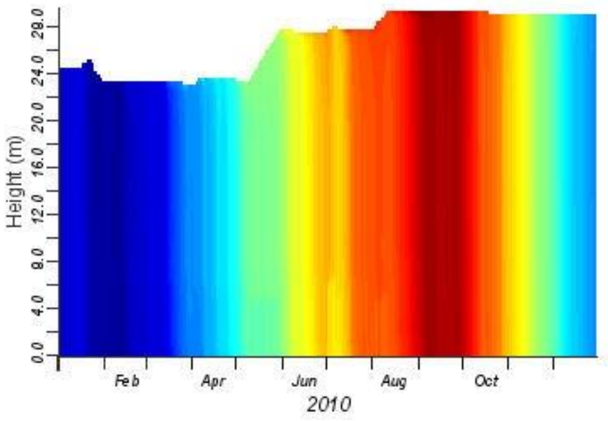


Temperature

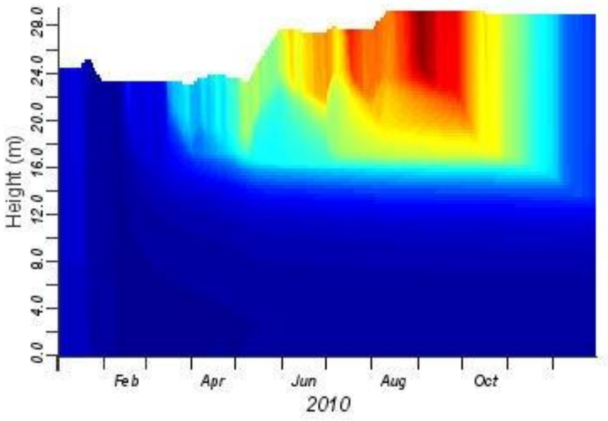
a) No action



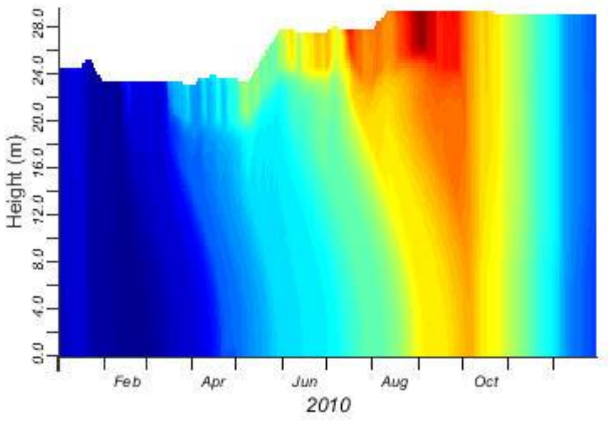
b) Diffused aeration

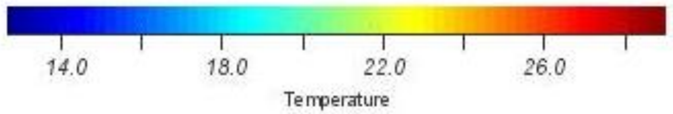


c) Hypolimnetic oxygenation



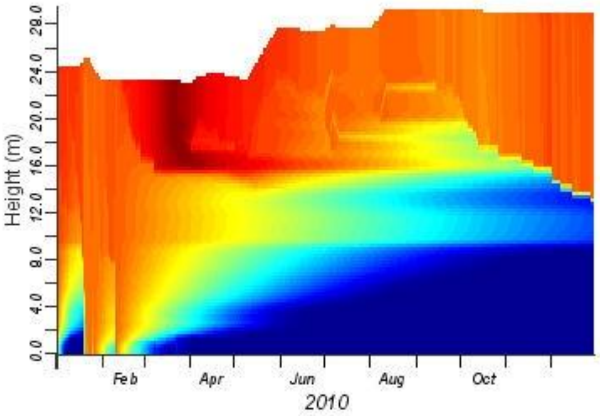
d) Flow routing+bottom withdrawal



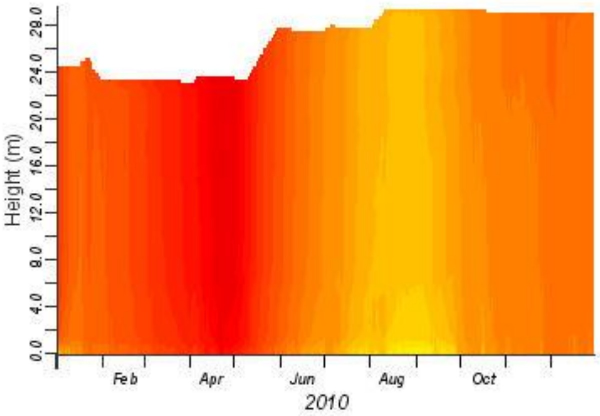


Dissolved Oxygen

a) No action



b) Diffused aeration



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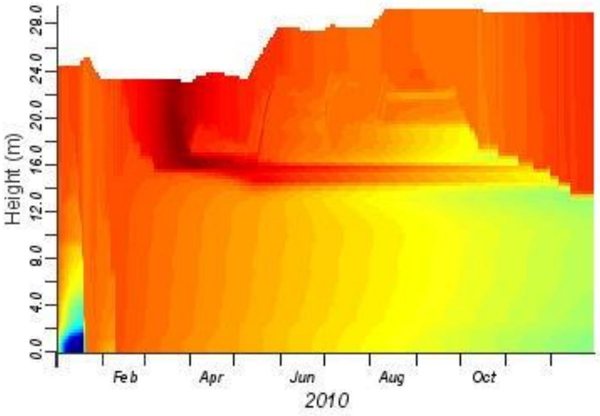
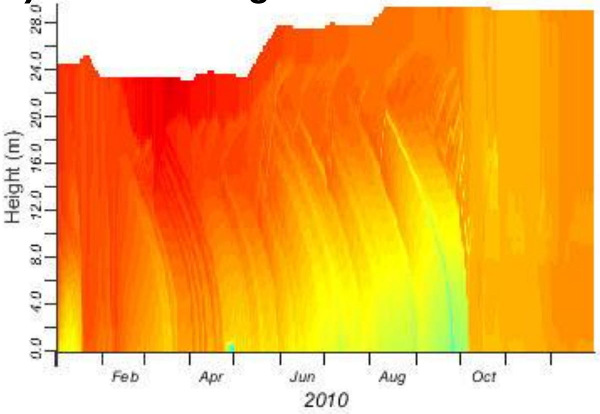
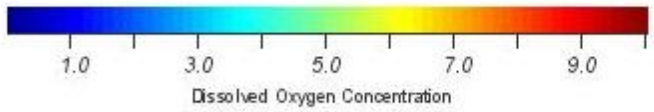


d) Flow routing+bottom withdrawal





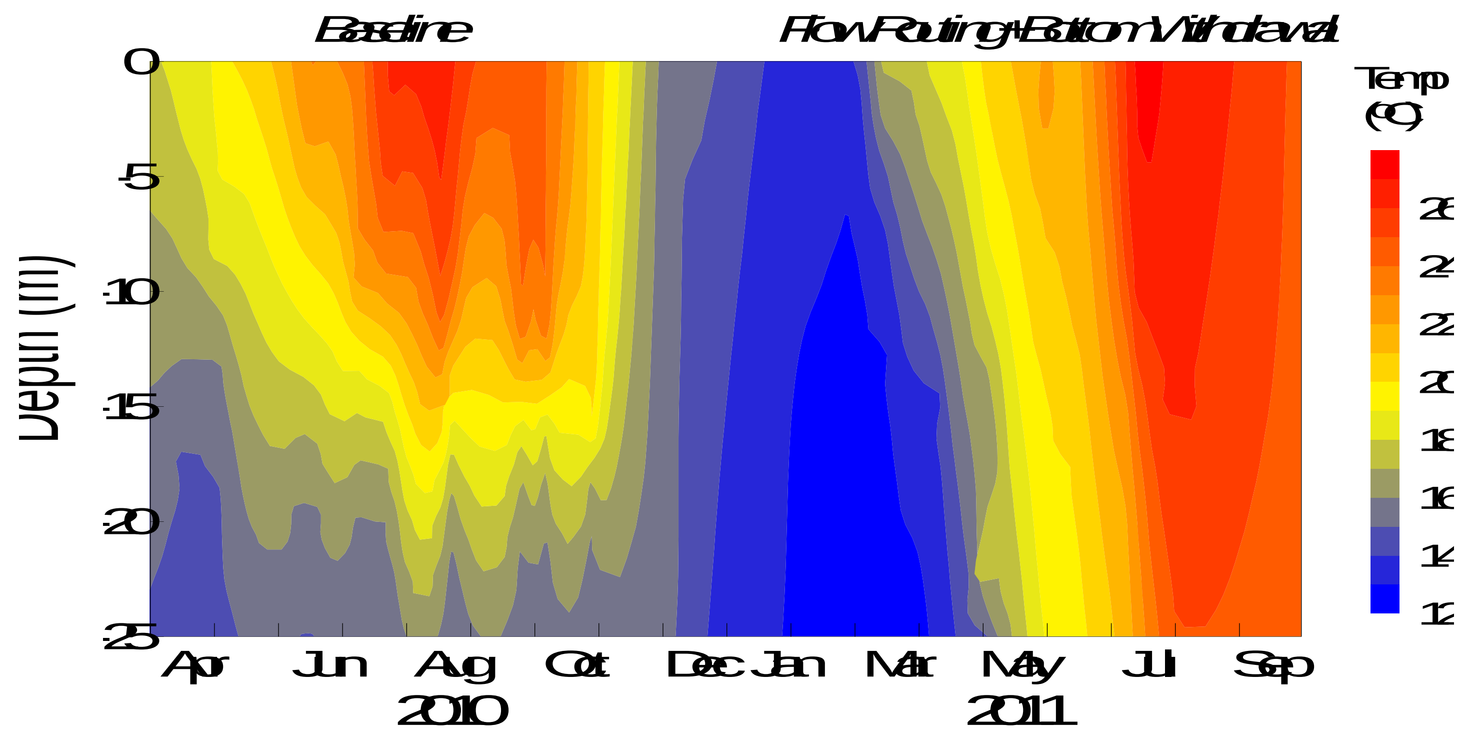
- Different in-lake strategies also yielded different predicted dissolved concentrations above bottom sediments

Predicted late summer maximum bottom water concentrations (mg L^{-1})				
Species	**Baseline**	**Aeration**	**Oxygenation**	**Flow + Withdrawal**
NH_4-N	3.5	0.065	0.080	0.080
PO_4-P	1.2	0.005	0.011	0.006
Mn^{2+}	14.0	0.010	0.065	0.016
Fe^{2+}	0.35	0.002	0.016	0.002

- TKE calculations indicate routing of flow through reservoir will markedly increase mixing energy to water column
- DYRESM-CAEDYM simulations further demonstrate effective mixing and maintenance of
  - high DO concentrations in bottom waters
  - low concentrations of dissolved nutrients, Fe and Mn
- Based upon these findings, the City of Anaheim changed operation of their system in 2011 to route flows through the reservoir with bottom withdrawal
- Water column measurements made in 2011 to assess effectiveness of this strategy

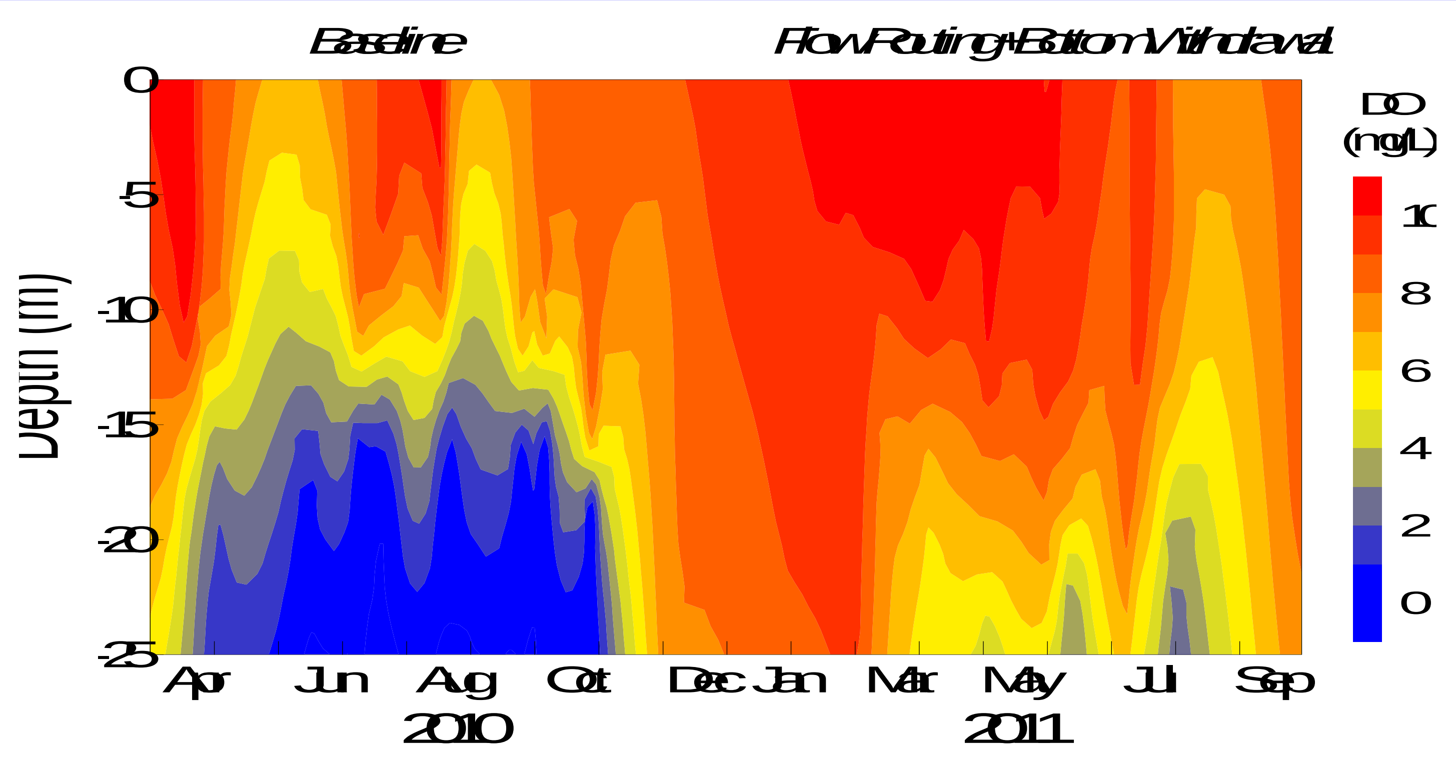
Measured Water Column Conditions

Temperature



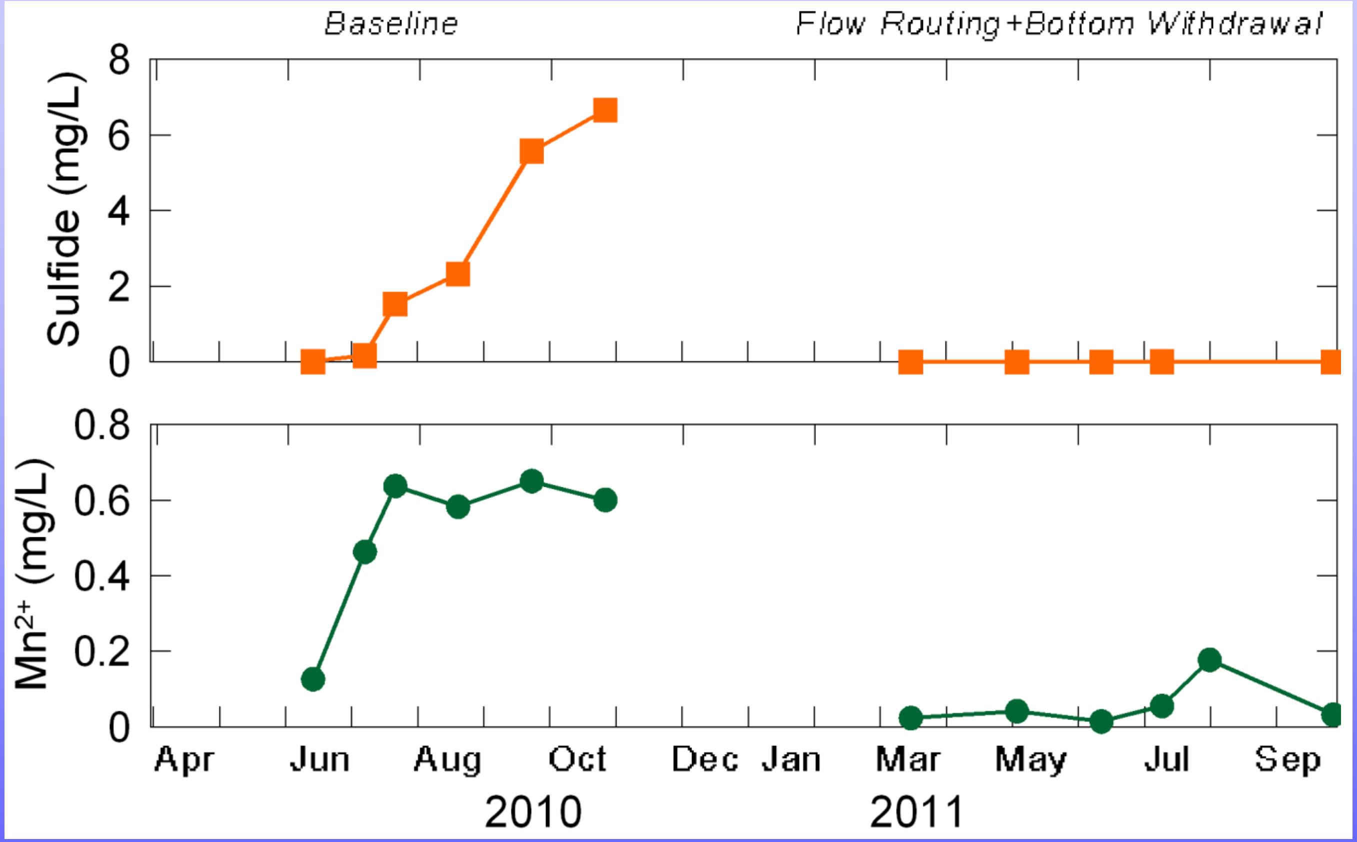
- Stratification present from May-Oct in 2010
- Very little thermal gradient present with flow routing+bottom withdrawal in 2011

Dissolved Oxygen



- DO <1 mg/L in bottom 5-10 m of water column from Jun-Oct in 2010
- Flow routing+bottom withdrawal in 2011 maintained DO >4 mg/L except on 1 sampling date (2.8 mg/L)

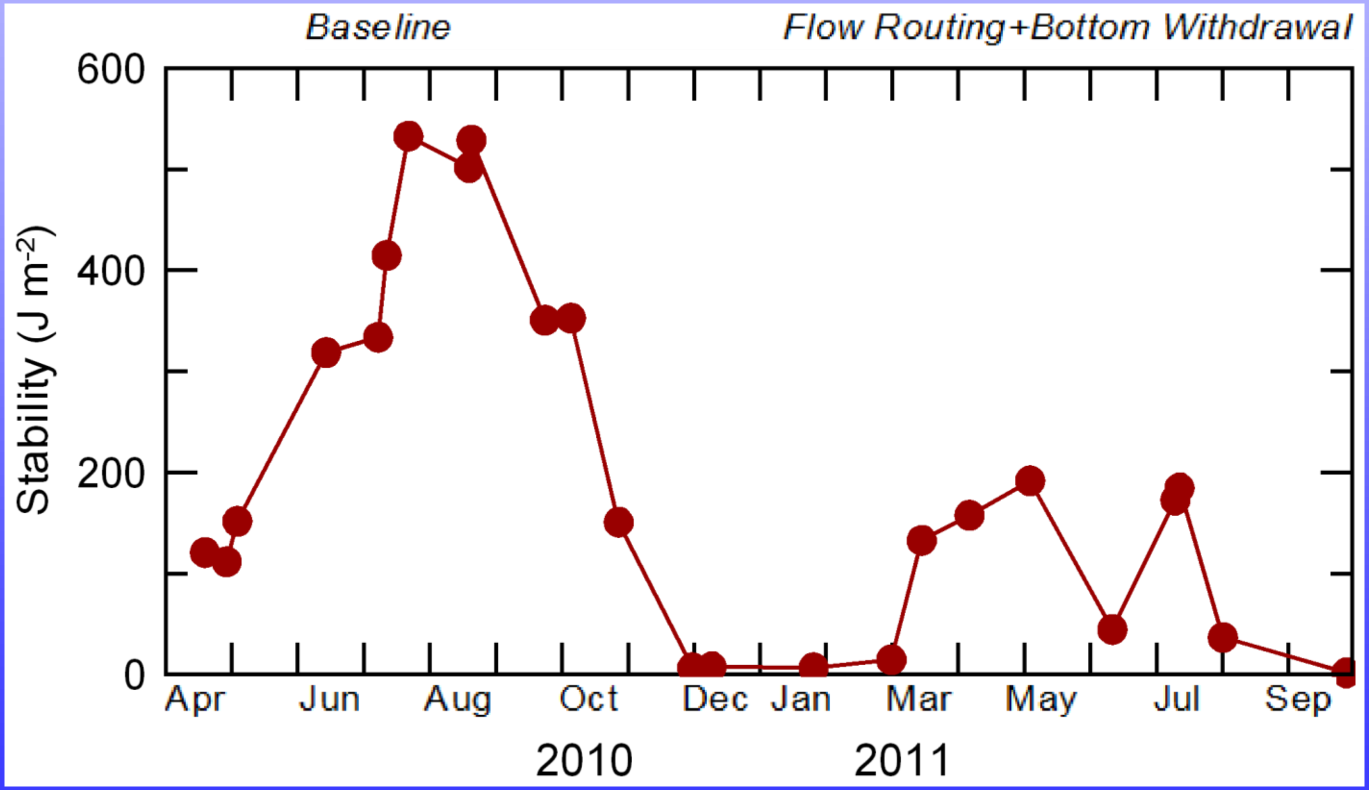
Reduced Species



- Sulfide and Mn^{2+} accumulated to very high concentrations above the sediments in 2010
- Flow routing+bottom withdrawal in 2011 maintained negligible S^{2-} and much lower Mn^{2+} concentrations

Thermal Stability

- Flow routing+bottom withdrawal also markedly reduced thermal stability of the water column
- Transition from cool winter conditions to warm summer conditions represented greatest challenge



Conclusions

- 1-D hydrodynamic-water quality simulations suggested that flow routing+bottom withdrawal would minimize stratification and maintain DO in bottom waters
- Routing of flow through Walnut Canyon Reservoir increased TKE input to the water column 17x that due to wind
- At same time, bottom withdrawal reduced thermal gradient, lowered stability, and prevented reduced species from accumulating

- This approach proved to be a simple, effective (and free) way to improve water quality in Walnut Canyon Reservoir *without* operation of diffused aeration or hypolimnetic oxygenation systems
- Applicability to other systems is a function of
  - Size of reservoir
  - Inflow rate, velocity, temperature and depth
  - Withdrawal rate and depth
  - Meteorological conditions
- Numerical modeling especially useful to evaluate potential effectiveness of this approach