On the Mechanism of Temporal Variability of Vertical Distribution of Density in Reservoir Lake Arlington.

Meza Tovar, O.L.[1], Winguth, A.M.E.[1]

(1) Department of Earth and Environmental Sciences, University of Texas Arlington, Arlington, Texas, United States

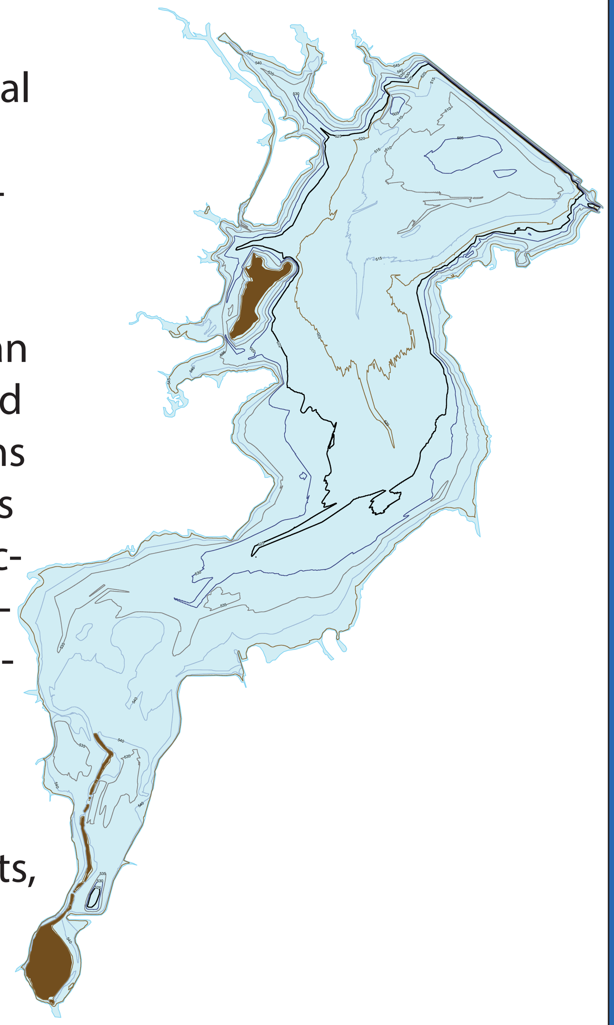
Abstract

Temporal variability of density and dissolved oxygen (DO) in subtropical reservoirs is complex since it depends on momentum and buoyancy forcing as well as in and outflow into the reservoir and is of importance for ecosystems, recreation, water quality, and water resource management. In addition, heat sources from the cooling of power plants may affect the density and DO. In this study, we combine weekly meteorological, temperature, and DO data collection on the lake with a one-dimensional (1-D) heat diffusion model to simulate vertical density gradients in Lake Arlington to test the hypothesis that complex 1-D models may be sufficient to explain the seasonal variability in reservoirs. The 1-D heat-diffusion model will be improved in the first step by considering the depth-dependent eddy diffusivity coefficient that depends on both the wind speed and the vertical density gradient. In the second step, a solar heating term will be added to the diffusion equation, and in the third step, this equation will expanded by a heating term induced by the powerplant. Finally, a vertical convective term will be introduced to consider buoyancy-induced cooling by, e.g., a frontal system. Preliminary findings reveal distinct thermocline and oxycline patterns due to surface heating in early Fall. With a decline in solar radiation and convective cooling by frontal systems, the reservoir is more mixed. In the future steps, we assimilate a portion of the observations in the reservoir model and compare the outcome with independent observation.

Lorem ipsum

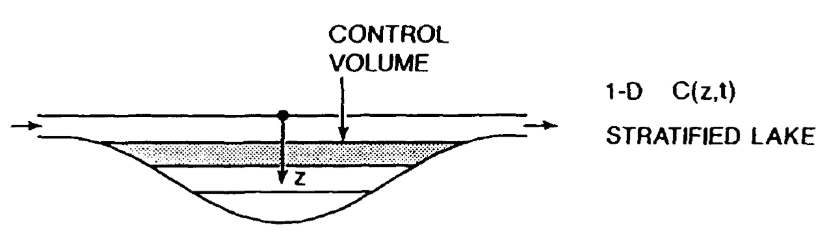
Study Site

Lake Arlington, a reservoir positioned in a subtropical zone with hot summers and mild winters, is vital for ecological balance, recreation, water quality, and resource management. As a crucial water source for three cities and a local power plant, this reservoir faces challenges from both natural forces and human activities. It holds up to 45,710 acre-feet of water and is classified as eutrophic, susceptible to algae blooms due to nutrient levels. Spanning 7.8 km^2 with depths reaching 15.6 meters, it is a warm, shallow monomictic lake, meaning an annual mixing period to distribute oxygen and nutrients evenly. To grasp its temporal variability, extensive efforts include weekly sampling at the lake's deepest point, using advanced tools like the YSI ProSolo meter for measuring temperature, dissolved oxygen, and salinity. These efforts, despite equipment issues and adverse weather, are essential in understanding and managing the lake's dynamic environment.



Model Description

Adapting Stefan's 1-D water quality model, we aim to capture Lake Arlington's thermal dynamics, evolving from basic heat diffusion to depth-variable eddy diffusivity and incorporating solar and power plant heat sources.



Basic Heat Diffusion Equation

Equation 1:

$$\frac{\partial T}{\partial t} = K\frac{\partial^2 T}{\partial z^2} \quad (1)$$

T= temperature (°C), t = time (s), z = depth (m), K = constant eddy diffusion coefficient

Depth-dependent Eddy Diffusivity in Lakes

Equation 2:

$$A(z)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K(z)A(z)\frac{\partial T}{\partial z}\right) \quad (2)$$

A(z) = area at depth z,
K(z) = depth-dependent eddy diffusion coefficient,
$\frac{\partial}{\partial z}\left(K(z)A(z)\frac{\partial T}{\partial z}\right)$ = heat flux changes with depth

Incorporating External Heat Source

Equation 3:

$$A(z)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_Z(z)A(z)\frac{\partial T}{\partial z}\right) + \frac{H}{\rho c} \quad (3)$$

H = internal heat souce due to solar radiation (W/m^3)
ρ = density of water (kg/m^3)
c = specific heat capacity of water (J/kg·K)

Heating Source by Power Plant

Equation 4:

$$A(z)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_Z(z)A(z)\frac{\partial T}{\partial z}\right) + \frac{H}{\rho c} + Q_{pp} \quad (4)$$

Q_{PP} = thermal input from a power plant
$Q_{pp} = \frac{\Delta T}{k}$
ΔT: Observed temperature change (°C)
k: Time constant for the process

Methods

Sampling Approach:

- Weekly samples were gathered from Lake Arlington using the City of Arlington's patrol boat, precisely locating the sampling site with a Lowrance Hook echosounder equipped with GPS.

Parameter Measurements:

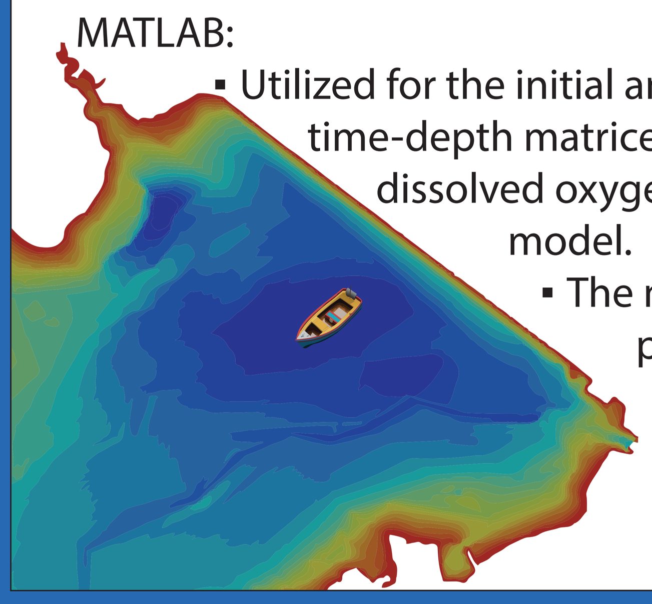
- YSI ProSolo Meter: Measured temperature, salinity, and dissolved oxygen (% saturation and mg/L).
- Milwaukee BEM802: Captured surface pH, electrical conductivity, and total dissolved solids (TDS).
- Secchi Disk: Assessed water transparency to estimate light attenuation.

Meteorological Data:

- Recorded concurrent meteorological conditions, including air temperature, wind speed and direction, and solar radiation, to correlate with aquatic environmental changes.

MATLAB:

- Utilized for the initial analysis of collected data, by developing time-depth matrices in MATLAB to visualize temperature and dissolved oxygen variations, laying groundwork for our model.
- The model, while still under refinement, incorporates these matrices alongside meteorological impacts to simulate Lake Arling-



Results

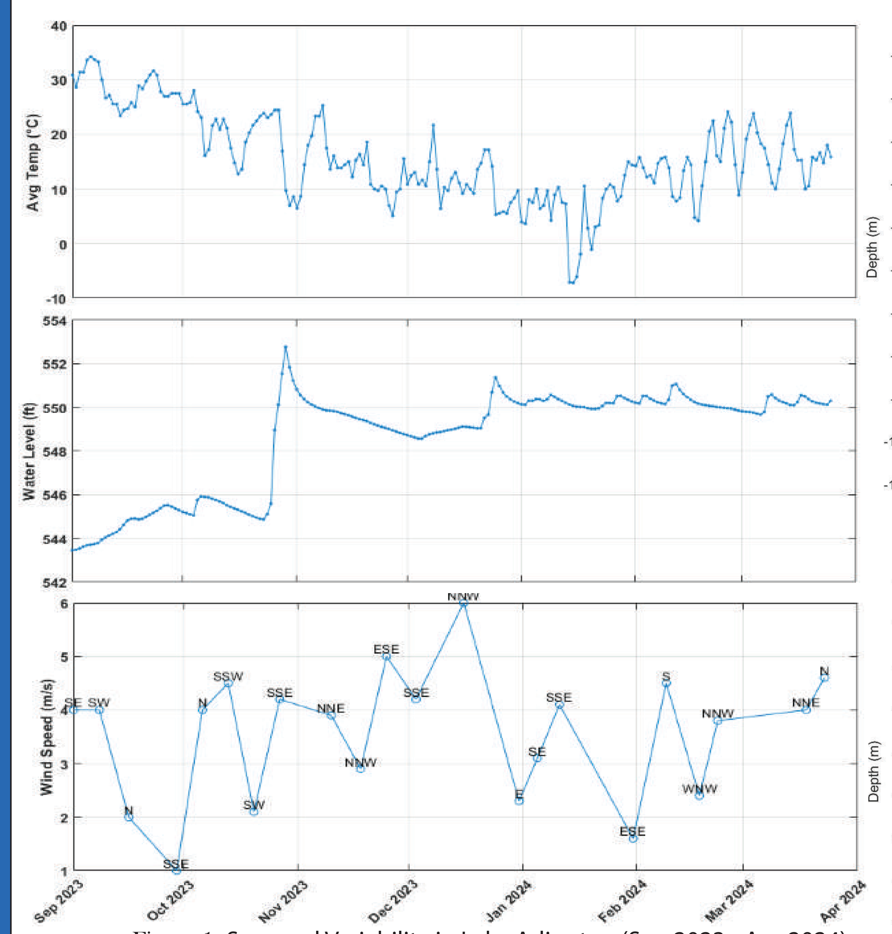


Figure 1: Seasonal Variability in Lake Arlington (Sep 2023 - Apr 2024)

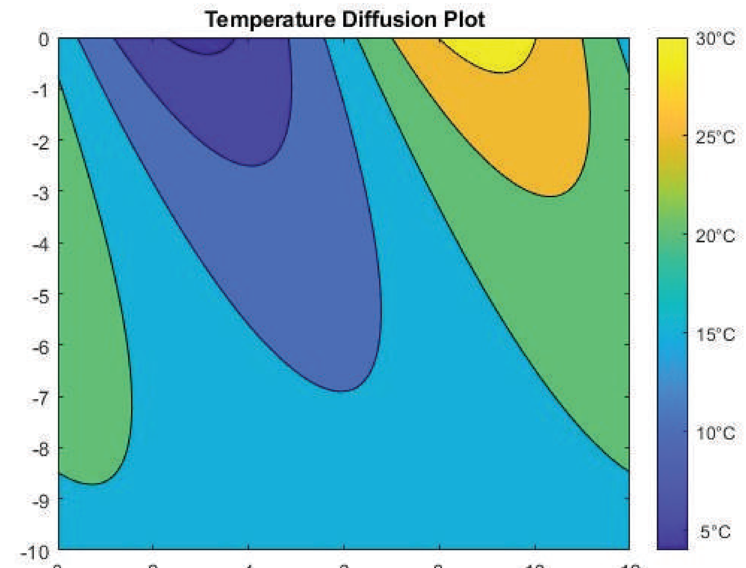


Figure 2: Preliminary 1-D Model Output of Thermal Diffusion through the water column of Lake Arlington over a 12-month cycle starting from November(0). The gradients indicate how surface temperatures transition with depth.

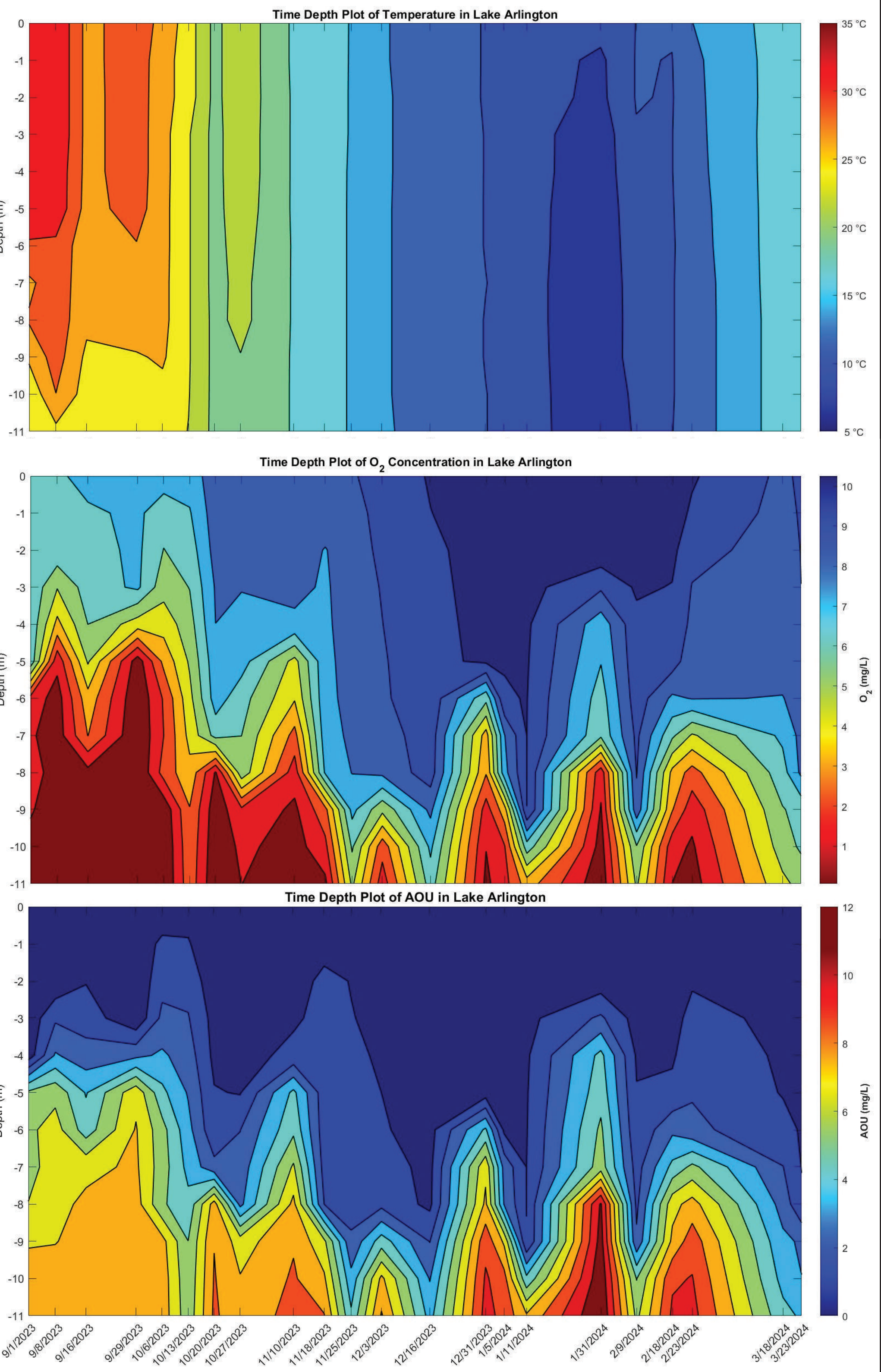


Figure 3: Temperature (top), dissolved oxygen (middle), and apparent oxygen utilization (AOU, bottom) from weekly testing in Lake Arlington over several months. The contours map the thermal stratification, oxygen distribution, and oxygen consumption within the water column.

Conclusions

Over the course of this year-long study, our developing 1-D model aims to elucidate Lake Arlington's thermal dynamics. Initial thermal stratification and oxygen distribution maps suggest the significant role of seasonal changes. These preliminary insights underscore the complex interactions within the lake and their implications for management practices.

This work lays the foundation for a nuanced understanding of subtropical reservoir behavior and offers a glimpse into the potential for informed data-driven management practices. As our dataset grows with continued monitoring, we expect to enhance the model's sophistication, incorporating the full spectrum of meteorological, hydrological, and anthropogenic factors that define Lake Arlington's unique environment.

Future Work

In the next phase of our research, we will continue to expand our data collection through September '24 to capture a complete seasonal cycle. Key future initiatives include:

- Further refining of the heat diffusion equation to capture the full thermal processes of Lake Arlington.
- Applying Idso's formulas for lake stability, detailed in 'On the Concept of Lake Stability' by Sherwood B. Idso, to our 1-D model enhances its capacity to depict and predict the lake's stratification and overall stability.
- Developing an energy profile to graph Lake Arlington's steady state and quantify the energy transitions needed for mixing layers, which will form the foundation for our forthcoming paper.
- Undertaking a comprehensive stability analysis using Idso's layer-by-layer work function approach to explore the total energy dynamics within the lake, thereby addressing pivotal limnological questions.
- Expanding the model to include dissolved oxygen (DO) dynamics and apparent oxygen utilization (AOU), to better understand the biological consequences of the lake's thermal stratification.

Refrences

Chrzanowski, Thomas H., and James G. Hubbard. "Primary and Bacterial Secondary Production in a Southwestern Reservoir." Applied and Environmental Microbiology, vol. 54, no. 3, Mar. 1988, pp. 661–669, https://doi.org/10.1128/aem.54.3.661-669.1988. Accessed 23 Jan. 2022.

Idso, Sherwood B. "On the Concept of Lake Stability." Limnology and Oceanography, vol. 18, no. 4, 1 July 1973, pp. 681–683, https://-doi.org/10.4319/lo.1973.18.4.0681. Accessed 29 Mar. 2024.

Lake Arlington (Trinity River Basin) | Texas Water Development Board. (n.d.). Www.twdb.texas.gov. Retrieved November 17, 2023, from https://www.twdb.texas.gov/surfacewater/rivers/reservoirs/arlington/index.asp

Stefan, Heinz G, et al. "Formulation of Water Quality Models for Streams, Lakes, and Reservoirs : Modeler's Perspective." This Digital Resource Was Created from Scans of the Print Resource, 1 July 1989. Accessed 29 Mar. 2024.

Lewis Jr., W. M. (1983). A Revised Classification of Lakes Based on Mixing. Canadian Journal of Fisheries and Aquatic Sciences, 40(10), 1779–1787. https://doi.org/10.1139/f83-207

USGS 08049200 Lk Arlington at Arlington, TX. (n.d.). Waterdata.usgs.gov. Retrieved November 17, 2023, from https://waterdata.usgs.gov/nwis/inventory/?site_no=08049200

Volumetric Survey of LAKE ARLINGTON December 2007 Survey The Texas Water Development Board. (2008). https://www.twdb.texas.gov/hydro_survey/arlington/2007-12/Arlington2007_FinalReport.pdf

Walker, W. W., & Kennedy, R. SIMPLIFIED TECHNIQUES FOR ASSESSING EUTROPHICATION-RELATED PROBLEMS IN RESERVOIRS.

Acknowledgments

I extend my gratitude to the Department of Earth and Environmental Sciences for their support and to all who played a pivotal role in this research. Special thanks to Dr. Arne Winguth, my supervising professor, whose guidance and expertise were invaluable to this study. I am also grateful to the Parks and Recreation Department of the City of Arlington for granting access to the lake patrol boat for field measurements. Lastly, I must acknowledge my fellow lake attendant, Tom Wilson, whose diligent efforts significantly improved the quality of our data. Without the contributions of each of these individuals and organizations, this research would not have been possible.