# Sierran stream discharge forecasting based on Tulare Lake-level reconstructions

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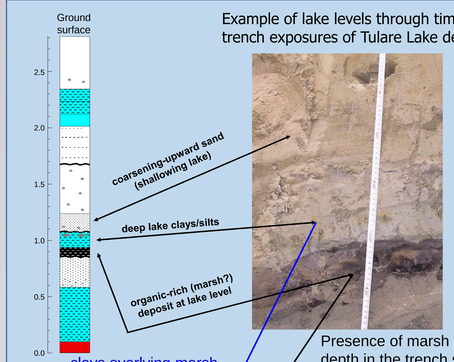
## Abstract 1

The CSU Bakersfield Tulare Lake project team is studying outcrops, trench exposures and cores of lake sediments to build a high resolution record of lake-level change for Tulare Lake over the past 10,000 years. Because the level of Tulare Lake has been shown to be closely related to the collective discharge of its four major Sierran feeder rivers (Atwater et al., 1986), this record will also represent stream discharge into the southern San Joaquin Valley throughout the Holocene. Future comparisons of this record with Pacific sea-surface temperature (SST) records will establish a link between SSTs and Sierran river discharge to forecast Sierran discharge over the next few decades.

The oldest part of the record (~19,000-18,000 cal yr BP) is an interval of elevated sand and silt percentages and slightly higher CN ratios that are interpreted to collectively indicate runoff. Increasing clay content, along with undetectable levels of inorganic carbon from 18,000-14,500 cal yr BP suggests a steadily increasing, freshwater lake. From 14,500-10,300 cal yr BP, lake conditions were stable including deposition of sediments with a grain size distribution consisting of equal parts (50%) clay and silt-sized grains. Both inorganic and organic carbon were below detection limits in this interval. From 10,300-9000 cal yr BP the clay/silt ratio increased after an initial pulse of fine sand, suggesting a highstand of the lake. Two spikes in inorganic carbon separating an interval of undetectable TIC between 8,000 and 6,300 cal yr BP are suggestive of shallow evaporative lake conditions before and after a lake highstand at ~7,500-6,500 cal yr BP that is again consistent in age with previously published results. Tulare Lake is relatively low from 8,000-3,000 cal yr BP and experienced moderately fluctuating lake levels until 3,000 cal yr BP. Significant fluctuation in lake-level occurs through 1,800 cal yr BP where the record ends.

## West Side Sites: Trenches 3




Example of lake levels through time inferred from trench exposures of Tulare Lake deposits



clays overlying marsh deposits suggests deep lake after marsh

Presence of marsh deposits at this depth in the trench suggests that Tulare lake level was at 61 meters above sea level 6900 cal yr B.P.

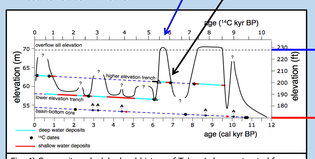



Fig. 4) Composite paleolake-level history of Tulare Lake constructed from two highstand trenches and a depocenter core (Negrini et al, 2006).

~10 km³/yr (8,000,000 acre ft/yr)

*corresponding total stream discharge of 4 Sierran Rivers*

< 2 km³/yr (< 1,600,000 acre ft/yr)

Consistent timing of deep lakes between Tulare Lake and southern California lakes over past 10,000 years

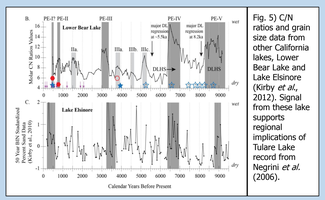
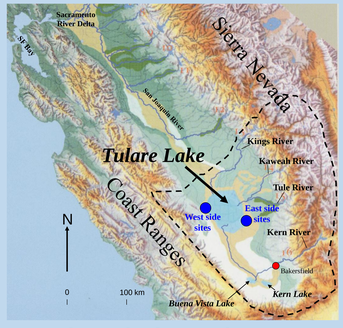


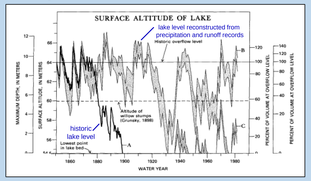

Fig. 5) C/N ratios and grain size data from other California lakes, Lower Bear Lake and Lake Elsinore (Kirby *et al.*, 2012). Signal from these lake supports regional implications of Tulare Lake record from Negrini *et al.* (2006).

## Background 2

Tulare Lake is located in the San Joaquin Valley of California between the Sierra Nevada and Coast Ranges. Prior to agriculture diversion beginning in the late 1800s, Tulare Lake was the largest fresh water lake in the U.S. west of the Great Lakes. Approximately 95% of runoff into Tulare Lake occurs from the Sierra Nevadan Kings, Kaweah, Tule, and Kern Rivers. Small streams from the Kettleman Hills account for the remaining influx. Historically, Tulare Lake occupied an area of up to 1600 km² with lake-level reaching as high as 12 m at which point water spilled northward over an alluvial fan formed sill into the San Joaquin Valley river system (Atwater, 1986).




Tulare Lake drainage basin

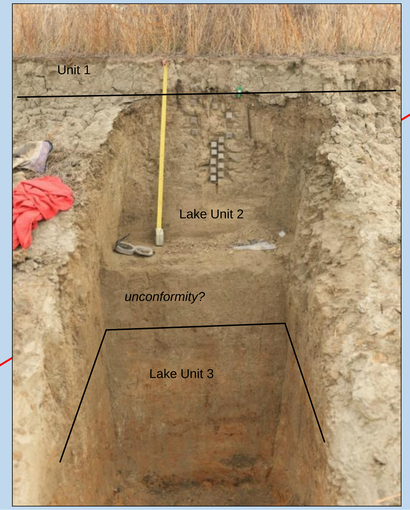


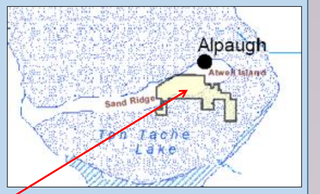

Tulare Lake levels before drainage diversions were closely related to Sierran stream discharge as per hydrologic balance model (Atwater et al., 1986). This results suggests that ***paleolake levels can be used to generate a prehistoric record of stream discharge.***

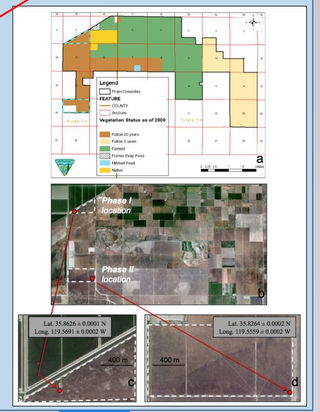
## East Side Site: Pixley NWR 5



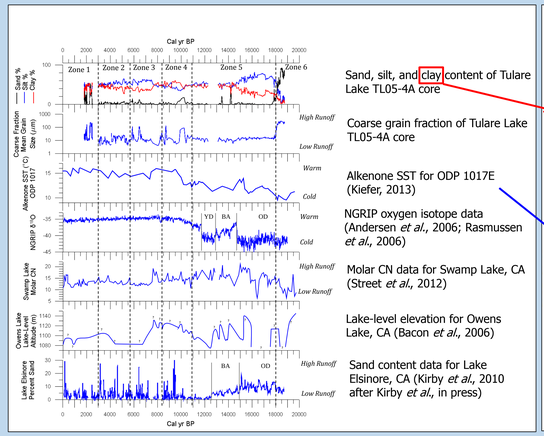

*Initial excavations in PNWR borrow pit: Detailed record of most recent 1000 yrs?*




## West Side Sites: Improving trench records with detailed core studies. Toward multidecadal resolution? 4




Sand, silt, and clay content of Tulare Lake TL05-4A core

Coarse grain fraction of Tulare Lake TL05-4A core

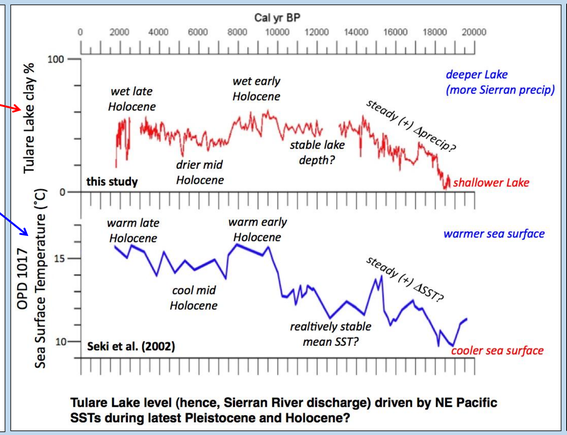
Alkenone SST for ODP 1017E (Kiefer, 2013)

NGRIP oxygen isotope data (Andersen *et al.*, 2006; Rasmussen *et al.*, 2006)

Molar CN data for Swamp Lake, CA (Street *et al.*, 2012)

Lake-level elevation for Owens Lake, CA (Bacon *et al.*, 2006)

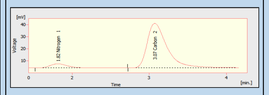
Sand content data for Lake Elsinore, CA (Kirby *et al.*, 2010 after Kirby *et al.*, in press)




**Tulare Lake level (hence, Sierran River discharge) driven by NE Pacific SSTs during latest Pleistocene and Holocene?**

### Carbon-Nitrogen Ratio

Samples were powdered and placed in a 105˚C oven for at least 24 hours to remove any $H_2O$. 20-25 mg of each sample was measured and wrapped in tin foil cups then placed in the Costech 4010 Elemental Analyzer for analysis by flash combustion chromatographic separation, which yields nitrogen and total carbon weight percents. Total organic carbon is found by subtracting TIC values from TC values. High C/N ratio of may indicate flooding.

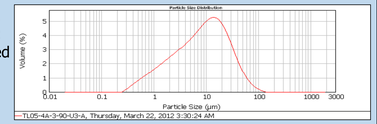



### Total Inorganic Carbon

Each sample was ground and placed into a 105˚C oven at least 24 hours. Approximately 100 mg sub-samples were analyzed for total inorganic carbon using a UIC acidifier module and coulometer CM135. High TIC often indicates low lake levels.

### Grain Size Analysis

0.5 g of each sample was sieved to <1 mm. Samples were analyzed using four methods: 1) splitter, 2) vigorously stirred, 3) suspended grains, and 4) settled grains with a Malvern Mastersizer 2000. Abundant sand in otherwise silty sediment suggests flooding.




## References


- Atwater, B.F., Adam, D.P, Bradbury, J.P., Forrester, R.M., Mark, R.K., Lettis, W.R., Fisher, G.R., Gobalet, K.W., Robinson, S.W., 1986. A fan dam for Tulare Lake, California, and implications for the Wisconsin glacial history of the Sierra Nevada. *Geological Society of America Bulletin* 97, p. 97-109.
- Benson, L.V., 2004. Western lakes, in: Gillespie, A.R., Porter, S.C., Atwater, B.F. (eds.), The Quaternary Period of the United States, Elsevier, Amsterdam, p. 185-204.
- Cohen, A.S., 2003. Paleolimnology, Oxford Univ. Press, 500 p.
- Evans, M.E., F. Heller, 2003. Environmental Magnetism, Academic Press, 299 p.
- Kirby, M.E., S.R. Zimmerman, W.P. Patterson, J.J. Rivera, 2012. A 9170-Year Record of Centennial-to-Multi Centennial Scale Pluvial Events From Coastal Southwest North America: A Role for Atmospheric Rivers, *Quaternary Science Reviews*.
- Negrini, R.M., Wigand, P.E., Drauker, S., Gobalet, K., Gardner, J.K., Sutton, M.Q., Yohe II, R.M., 2006. The Rambla highstand shoreline and the Holocene lake-level history of Tulare, Lake, California, USA. *Quaternary Science Reviews* 25, p. 1599-1618.
- Sperazza, M., Moore, J. N., Hendrix, M. S., 2004. High-resolution particle size analysis of naturally occurring very fine-grained sediment through laser diffractometry. *Journal of Sedimentary Research* 74, p. 736-743.


## Future Work

- ¹⁴C and paleomagnetic secular variation dating of west-side and east side sites.
- Geochemical and geophysical proxy measurments for east-side sediments
- Micropaleontology for all sites
- Location and excavation/coring of 4-5 more sites
- Compilation of composite multidecadal lake-level/stream discharge record and comparison with sea-surface temperature records to establish an SST/Sierran discharge transform function

## Acknowledgements

Funding for the purchase of the UIC Coulometer CM135, Costech 4010 Elemental Analyzer, and Malvern Mastersizer 2000 laser particle analyzer was provided by the US Department of Education Award #P031C080013-09. Funding for research was provided by the NSF DHR CREST Award #1137774, the United States Department of Agriculture in cooperation with the Water Resources Institute at CSUSB, and from the Chevron sponsored REVS-UP program.