Developing Late-Holocene Records of Flood-Producing Precipitation Variability from Small Lakes in Southern California (USA)

PI: Matt Kirby, California State University, Fullerton

Funded by: American Chemical Society – Petroleum Research Fund (ACS-PRF), 2004

6. **PROPOSED RESEARCH**. Begin with abstract, not to exceed 250 words, which presents the rationale of the research, its scientific objective, and an estimate of the significance to the field of research if the objective is reached. The body of the narrative may not exceed 1700 words, double-spaced, in at least 10-point type, excluding abstract, figures, and references. The narrative should expand on the abstract and include a description of the proposed research, its significance, and your general plan of procedure. Include pertinent literature citations, **with titles**. Do not attach reprints, preprints, or similar supporting material.

Developing Late-Holocene Records of Flood-Producing, Precipitation Variability From Small Lakes in Southern California (USA).

1. Abstract.

Flooding in Southern California is a direct response to precipitation variability. This is linked to a combination of processes including seasonal patterns of atmospheric circulation, El Niño-Southern Oscillation variability, and climate change. There are, however, no pre-historic, continuous records of precipitation variability for the region. To assess better the impact of future climate change on the frequency of floods in Southern California, it is critical to develop a pre-historic baseline of natural precipitation variability. Lakes in Southern California provide a natural archive of both regional precipitation and the drainage basin's response to precipitation. It is hypothesized that lake sediments from Southern California record extreme precipitation events, which produce characteristic flood sediment units. The proposal's objective is to develop a late-Holocene record of flood sediment units from two lakes in Southern California. The incorporation of two lakes is intended to reduce spurious sediment units unrelated to regional flooding. Using an age model, this research proposes to analyze the frequency distribution of flood sediment units over the late-Holocene for use as a baseline of natural flood-producing, precipitation variability. These results will be the first-ever produced for Southern California, and they will provide critical insight into the relationship between precipitation variability and flood frequency.

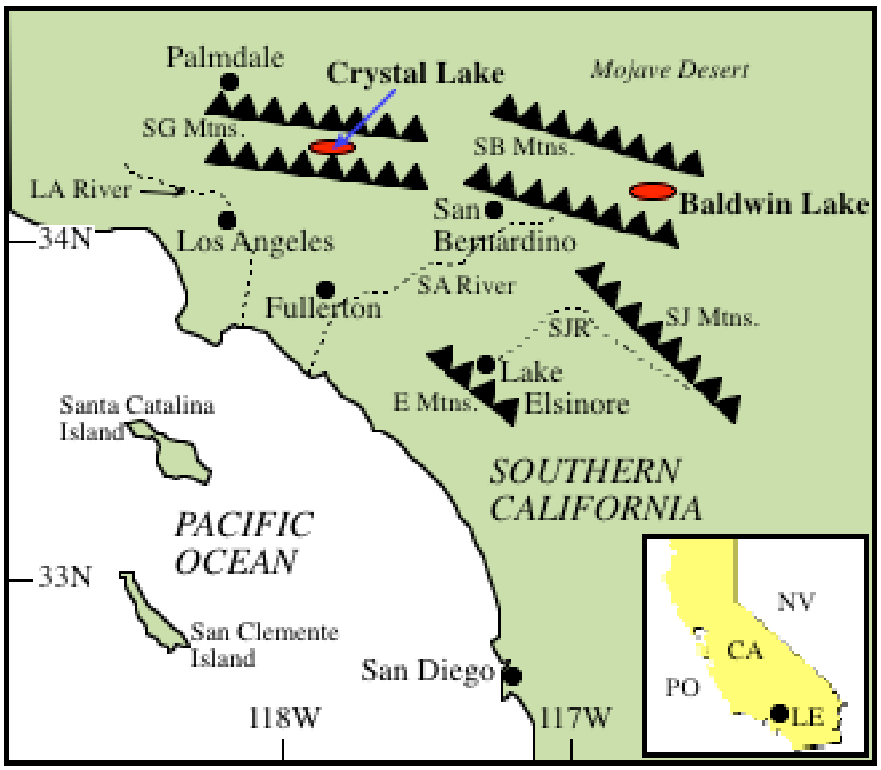

Figure 1. Location map with relevant regional information. SG = San Gabriel Mountains; SB = San Bernardino Mountains; SJ = San Jacinto Mountains; E = Elsinore Mountains; SA = Santa Ana River; SJR = San Jacinto River; LE = Lake Elsinore; PO = Pacific Ocean. Lakes are not to scale.

2. Introduction.

As global climate changes in response to increased greenhouse gases, it is predicted that the magnitude, frequency, and duration of severe precipitation events will increase and its associated flooding (Knox, 1993; IPCC, 2001). It is also expected that ENSO variability and its occurrence will increase, which will modulate regional precipitation dynamics (IPCC, 2001). As a result, the growing population of Southern California faces a potential increase in flood events and their associated side effects (e.g., landslides) including their economic impact.

A significant area of Southern California, including Los Angeles and Orange Counties, is located within large river drainage basins (Fig. 1). These river basins drain the coastal mountains of Southern California (e.g., San Bernardino and San Jacinto Mountains; Fig. 1). As the highest terrain in Southern California (up to ~3000m above sea level), these barriers play an important role in the modulation of atmospheric circulation and regional precipitation (Weaver, 1962; Bailey, 1966; Pyke, 1972; Minnich, 1986). Through orographic uplift, significant precipitation is produced along the mountains' windward sides. The passage of cyclones has, in historical times, produced enough precipitation to induce local and regional flooding (Fig. 2; Ely, 1997; Enzel and Wells, 1997). Flooding frequency increases during strong El Niño years when the frequency of cyclones crossing over Southern California becomes more common (Schonher and Nicholson, 1989; Redmond and Koch, 1991; Piechota et al., 1997). Based on the relationship between precipitation and regional flooding, ***it is hypothesized*** that changes in flood-producing, precipitation variability over the late-Holocene can be reconstructed through a frequency analysis of lake sediment units formed during flood producing precipitation events.

Here, I propose a <u>start-up study</u> to develop a baseline of late-Holocene flood-producing, precipitation variability using a multi-proxy methodology. This research will focus on the identification of short-lived hydrologic events as recorded in small, closed-catchment lake basin sediments. My ***research objective*** is to use an age model to reconstruct the frequency distribution of late-Holocene flood-producing, precipitation events in Southern California. The results will be compared to other precipitation proxies from western North America over the late-Holocene (e.g., Pyramid Lake $\delta^{18}O_{(calcite)}$ record [e.g., Benson et al., 2002]; Santa Barbara $\delta^{18}O_{(calcite)}$ record [e.g., Friddell et al., 2003]; Silver Lake Playa ephemeral lake record [e.g., Enzel and Wells, 1997]). Precipitation variability will be documented using a series of sedimentological analyses that record catchment-basin run-off dynamics (see section 4: research Methods).

3. Background.

3.1 Regional Meteorology and Climate.

Regional meteorology for Southern California is fairly straightforward. Owing to the Mediterranean climate, all seasons, except winter (N-F), are relatively dry (Bailey, 1966). During the winter, the polar front jet stream migrates south, which increases the frequency of cyclones and their associated precipitation across Southern California (Pyke, 1972; Lau, 1988; Namias et al., 1988); this tendency is amplified during years of strong El Niño (Schonher and Nicholson, 1989). As these storms impinge upon the near coast mountains of Southern California, they lose their moisture to forced orographic lifting. If the amount of moisture loss is significant, local and/or regional flooding may occur. An analysis of annual discharge data for the Los Angeles River, the Santa Ana River, and the San Jacinto River indicates that there have been eleven floods of regional scale in the greater Los Angeles region during the twentieth century; seven of these floods have occurred during strong to medium El Niño years (Fig. 2; Viles and Goudie, 2003; USGS Surface Water Data [http://waterdata.usgs.gov/nwis/sw]; NCDC Weather Station Locator Data [lwf.ncdc.noaa.gov/oa/climate/stationlocator.html]).

3.2 Lake Sediments and Paleoclimate Archives.

Lake sediments are natural archives of lake catchment-basin dynamics. Several researchers have either suggested and/or demonstrated that lake sediments record precipitation events (Rodbell et al., 1999; Brown et al., 2002; Noren et al., 2002). Using multiple proxies, it is possible to deconvolve precipitation-produced sediment units (i.e., flood units) from ambient lake sedimentation facies (Brown et al., 2002). I suggest that the small lakes of Southern California contain a sediment record of flood-producing, precipitation variability as recorded by characteristic sediment units. Although a flood-produced sediment unit does not reveal information about absolute flood magnitude, a flood unit is considered evidence that the magnitude and duration of the precipitation event exceeded an important, but arbitrary, erosive threshold in the lake's catchment basin. I will use this assumption to infer that the precipitation event was large enough to produce regional flooding.

4. Research Methods.

The initial study focuses on two lakes: Crystal Lake (1768m asl) and Baldwin Lake (2044m asl) (Fig. 1). The selection criteria include:

1) small, closed-catchment drainage basins;

2) sensitivity to precipitation variability; and,

3) regional separation.

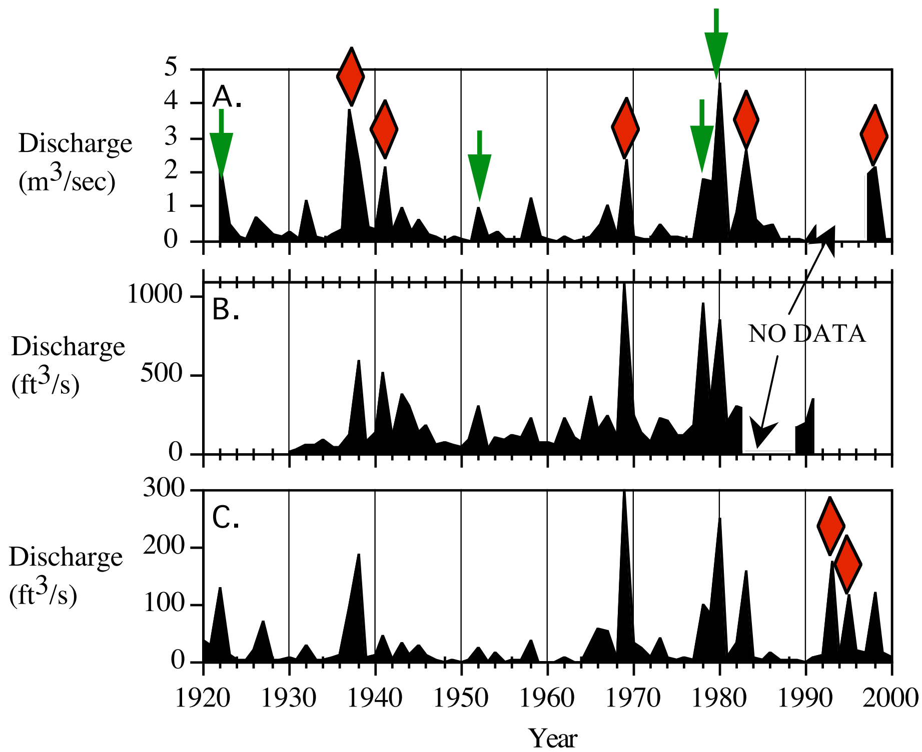

Figure 2. Annual mean river discharge for (A) San Jacinto River; (B) Los Angeles River; and, (C) Santa Ana River. Red diamonds = flood year during moderate to strong El Niño events (Viles and Goudie, 2003). Arrows = floods without moderate to

Both Crystal Lake and Baldwin Lake have been cored. Several sediment layers from Crystal Lake exhibit properties that indicate deposition by mass transport processes such as flood-induced sedimentation (Fig. 3); Baldwin Lake sediments have not been analyzed at present.

Duplicate cores (~4m total length) will be extracted from each of the two lakes. Cores will be described for initial sediment characterization. In many cases, anomalous sediment units can be observed for description easily by the unaided eye. When observed, the anomalous sediment units will be measured to the nearest millimeter.

Age control will be determined from AMS ^{14}C dates on either total carbon from bulk sediments or discrete organic detritus. Funds for radiocarbon dates comprise a significant portion of the total budget. Depths for age analysis will be determined after core description and magnetic susceptibility measurements to reduce reworked dates. Additional dates will be determined after the completion of all analyses. All events will be considered instantaneous. Their respective thicknesses will be subtracted from the core's total length prior to calculation of an age model and flood frequency distribution analysis. Due to the limitations of age dating, it is not possible to directly cross-correlate sediment units from basin to basin on a per year basis. The number of sediments units, however, between the closely spaced dates will be determined for each core and assessed between the two lake basins. The analysis of more than one lake, and duplicate cores, will help to reduce the number of non-flood produced sediment units in the final flood frequency distribution analysis. Processes forming non-flood produced sediment units include increased erosion caused by forest fires, local convective precipitation-induced flooding, and turbidites produced by local basin sediment overloading.

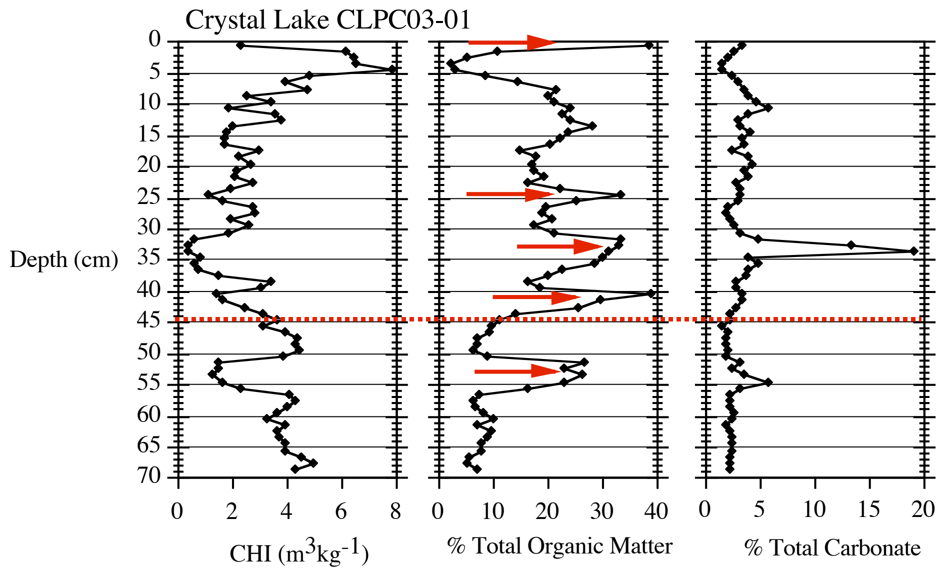

Figure 3. Mass magnetic susceptibility, percentage organic matter, and percentage total carbonate from a reconnaissance core from Crystal Lake. Red dashed line indicates the approximate "anthropocene" boundary estimated at ~1880 A.D. based on Crystal Lake State Park historical records and fire data (DeRose, in prep.). Notice the abrupt rise in average total organic matter after ~1880 A.D. associated with human-caused changes in the

Mass magnetic susceptibility (χ = CHI) will be run at 1.0 cm intervals per core to assess the relative contribution of magnetic minerals into the lake basin (Thompson et al., 1975). Generally, magnetic susceptibility increases during flood events in response to an increase in the flux of inorganic magnetic minerals. Of course, in some lake basins, flood events may increase the flux of organic detritus, which may actually produce lower magnetic susceptibility values (Fig. 3). To deal with this contingency, the contribution of organic matter will be determined by LOI analysis (550°C) at 1.0 cm intervals (Dean, 1974; Heiri et al., 2001). The potential impact of forest fires on the formation of mass transport sediment units will be assessed by simple charcoal counts converted to number of charcoal pieces per 5 grams dry sediment weight. Charcoal counts will be determined at 5.0 cm, or less, depending on the results. Finally, using a newly purchased, Malvern automated laser diffraction grain size analyzer, grain size analysis will be determined at 1.0 cm intervals (0.2 – 2000 microns). Flood events often increase the flux of coarse-grained sediments to the lake's profundal region. They may also produce fining upward grain size sequences that reflect turbidite formation or other velocity-related mass transport processes.

All of the above analyses, except dating, will be determined in the PI's laboratory at zero cost (except time and labor). Based on the current rate of analysis in my lab, I am confident that I can continue to produce up to 200 magnetic susceptibility, 84 loss on ignition, 50 grain size analyses per week, and 15 microfossil counts, certainly more with student research aid. In other words, the number of total analyses (n = 5120 total analyses, or approx. 49 total combined analyses per week) assuming two 4 meter cores per lake for this proposal over two years is a reasonable expectation.

The multi-lake approach and multi-proxy combination of magnetic susceptibility, total organic matter, charcoal counts, and grain size distribution make possible the determination and characterization of the frequency distribution of late-Holocene flood units in Southern California.

5. Research Plan.

Year	Objective
One	Obtain additional cores, if necessary.
One and Two	Magnetic Susceptibility, LOI, and Grain Size Analyses; Charcoal Analysis; Initial Dating
Two	Final Dating
Two	Data Analysis con't., Interpretation, and Regional Comparison
Two	Presentation of results at National Meeting (GSA, AGU)
Two	Research write-up for publication in peer-reviewed scientific journal

6. Expected Results and Significance

Southern California is freshwater impaired; yet, there is very little known about the region's natural precipitation variability, especially over the late-Holocene. Furthermore, Southern California is susceptible to economically catastrophic flooding. Here again, there is very little known about the pre-historic natural baseline of flood-generating, precipitation variability. The results of my research will provide the ***first data*** on late-Holocene precipitation variability for Southern California, specifically flood-generating precipitation events. These results will provide a baseline of natural precipitation variability for the assessment of future climate change and its impact of Southern California's hydrology (Weaver, 1962; Knox, 1993).

7. Educational Impact.

This research will involve a combination of undergraduate and master's level students. Due to the CSUF graduation requirement of a senior research thesis in the Department of Geological Sciences, there is a steady line of students whom are looking for new and exciting research theses (approximately 12-15 majors per year). Currently, Margie DeRose (B.Sc.) is working on sediments from Crystal Lake; she received a Grants-In-Aid-of-Research grant from Sigma Xi for her research. Some of her initial results are shown in Figure 3. I also have five master's students working on a variety of climate-related projects; four of the master's students are working towards a M.Sc. in Environmental Studies, a popular program at Cal-State Fullerton.

Since CSUF is one of the nation's most diverse universities (US News and Weekly Report Rankings, 2003), my department has the unique opportunity to attract a diverse population of geology majors. Socially relevant projects, such as this proposal concerning flood-producing, precipitation variability and flood history, are particularly attractive to students who are well aware of the water crisis that faces their home region. For an urban school like Cal-State Fullerton it is very common that many of the students work full or part-time to pay their tuition. To accommodate financial concerns that face many CSUF students, this research proposal contains funds for hiring two summer student researchers for two summers.

8. Relationship to Petroleum Research.

Fossils fuels are derived from the burial and transformation of organic carbon. It is estimated that the annual production and deposition of organic carbon in lakes, reservoirs, and wetlands is more than three times that of the oceans (Dean and Gorham, 1998). As a result, ancient lake deposits may contain significant fossil fuel reservoirs. This research will provide additional information about the interactions of lake sedimentation and organic carbon burial over time, especially organic carbon deposition as modulated by climate change.

9. References.

Bailey, H.P. 1966, The Climate of Southern California: University of California Press, 87 pp.

Benson, L., Kashgarian, M., Lund, S., Paillet, F., Smoot, J., Kester, C., Meko, D., Lindstrom, S., Mensing, S., and Rye, R. 2002, Multidecadal and multicentennial droughts affecting Northern California and Nevada: implication for the future of the West: Quaternary Research, v. 21, no. 4-6, p. 659-682.

Brown, S., Bierman, P., Lini, A., Davis, P.T., and Southon, J. 2002, Reconstructing lake and drainage basin history using terrestrial sediment layers: analysis of cores from a post-glacial lake in New England: Journal of Paleolimnology, v. 28, p. 219-236.

Dean, W.E. Jr. 1974, Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods: Journal of Sedimentary Petrology, v. 44, p. 242-248.

Dean, W.E. and Gorham, E. 1998, Magnitude and significance of carbon burial in lakes, reservoirs, and peatlands: Geology, v. 26, p. 535-538.

Ely, L.L. 1997, Response of extreme floods in the southwestern United States to climatic variations in the late Holocene: Geomorphology, v. 19, p. 175-201.

Enzel, Y. and Wells, S.G. 1997, Extracting Holocene paleohydrology and paleoclimatology information from modern extreme flood events: An example from Southern California: Geomorphology, v. 19, p. 203-226.

Fridell, J.E., Thunell, R.C., Guilderson, T.P., and Kashgarian, M. 2003, Increased northeast Pacific climate variability during the warm middle Holocene: Geophysical Research Letters, v. 30, p. 14-1 to 14-4.

Heiri, O., Lotter, A.F., and Lemcke, G. 2001, Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results: Journal of Paleolimnology, v. 25, p. 101-110.

IPCC Working Group, 2001, Summary for policy makers: http://www.ipcc.ch

Knox, J.C. 1993, Large increases in flood magnitude in response to modest changes in climate: Nature, v. 361, p. 430-432.

Lau, N-C. 1988, Variability of the observed midlatitude storm tracks in relation to low-frequency changes in the circulation pattern: Journal of the Atmospheric Sciences, v. 45, p. 2718-2743.

Minnich, R.A. 1986, Snow levels and amounts in the mountains of Southern California: Journal of Hydrology, v. 89, p. 37-58.

Namias, J., Yuan, X., and Cayan, D.R. 1988, Persistence of North Pacific sea surface temperature and atmospheric flow patterns: Journal of Climate, v. 1, p. 682-703.

Noren, A.J., Bierman, P.R., Steig, E.J., Lini, A., and Southon, J. 2002, Millennial-scale storminess variability in the northeastern United States during the Holocene epoch: Nature, v. 419, p. 821-824.

Piechota, T.C., Dracup, J.A., and Fovell, R.G. 1997, Western US streamflow and atmospheric circulation patterns during El-Niño-Southern Oscillation: Journal of Hydrology, v. 201, p. 249-271.

Pyke, C.B. 1972, Some Meteorological Aspects of the Seasonal Distribution of Precipitation in the Western United States and Baja California: University of California Water Resources Center, No. 139, 215pp.

Redmond, K.T. and Koch, R.W. 1991, Surface climate and streamflow variability in the Western United States and their relationship to large-scale circulation indices: Water Resources Research, v. 27, p. 2381-2399.

Rodbell, D.T., Seltzer, G.O., Anderson, D.M., Abbott, M.B., Enfield, D.B., and Newman, J.H. 1999, An 15,000-year record of El Niño-driven alluviation in southwestern Ecuador: Science, v. 283, p. 516-520.

Schonher, T. and Nicholson, S.E. 1989, The Relationship Between California Rainfall and ENSO Events: Journal of Climate, v. 2, no. 11, p. 1258-1269.

Thompson, R., Battarbee, R.W., O'Sullivan, P.E., and Oldfield, F. 1975, Magnetic susceptibility of lake sediments: Limnology and Oceanography, v. 20, p. 687-698.

Viles, H.A. and Goudie, A.S. 2003, Interannual, decadal and multidecadal scale climatic variability and geomorphology: Earth Science Review, v. 61, p. 105-131.

Weaver, R.L. 1962, Meteorology of Hydrologically Critical Storms in California: Hydrometeorological Report No. 37, U.S. Weather Bureau, Washington, D.C., 110pp.