

Title: Using Paleolimnological Techniques to Reconstruct Past Biotic Response to Disturbance and Watershed Vegetation Changes in Roosevelt Reservoir and the Salt River Watershed.

Project Summary: We will collect cores from the Salt River “arm” of Roosevelt Reservoir. These cores will be dated using Pb_{210} and Cs_{137} . Selected layers (i.e. “time intervals”) will be analyzed for a suite of metals, nutrients, organic carbon, fossilized diatom frustules, chironomid head capsules, pollen, algal pigments, and charcoal. This would be done to determine past biotic responses to disturbance, such as fire, and correlate this information to past vegetative changes within the watershed. Several determinations can be made from this data one of them being the direction of trophic state change and possible declines in water quality (if any) in Roosevelt Reservoir, an important water supply for the Phoenix Valley.

Duration: 08/2005 – 08/2007

Principal Investigators:

Owen K. Davis. Department of Geosciences

Co-Principal Investigators:

David Walker. School of Natural Resources/Soil, Water and Environmental Sciences Dept.

Paul T. Gremillion. Civil & Environmental Engineering Department, Northern Arizona University.

Peter Van Metre. United States Geological Survey, Austin Texas.

Susan Fitch. Arizona Department of Environmental Quality

Atasi Ray-Maitra. Department of Soil, Water and Environmental Sciences/Water Quality Center Laboratory.

TRIF Funds Requested: \$51,882 for year 1 and \$50,042 for year 2.

Matching Funds: ADEQ (in-kind; metal and nutrient analysis, equipment, consultation) \$20,000. USGS (in-kind; equipment, consultation) \$15,000.

Statement of Problem: In waters without historical data, it is often impossible to predict water quality trends or increases in trophic state. Even when some data has been collected, it is usually transient or relatively short-term compared to the age of the system in question. Additionally, it is impossible to quantify detrimental effects of anthropogenic land-use activities or natural disturbances (such as wildfire) in a watershed on receiving water quality unless a substantial amount of data has been collected prior to each disturbance or activity. The subtle accumulation of non-point sources of pollution also makes determination of trends in water quality, or ecosystem health, difficult to detect. Often, subtle declines in water quality go undetected until a problem becomes bad enough to warrant remedial action; actions that are often very expensive and logistically difficult to implement.

Paleolimnological techniques are often used to assess water quality trends in lakes and reservoirs over time. Incorporated in reservoir sediments is a record of the organisms that lived in and around the lake, as well as proxy data related to processes occurring in the lake, the composition of the lake water, the conditions in its watershed, and past climatological data. The information obtained from paleolimnological studies can greatly aid resource managers in detecting problems that otherwise would have gone unnoticed.

Statement of Results: The information obtained from this project will cover several aspects of water quality and surrounding land use in the Salt River watershed and Roosevelt reservoir as well as aquatic biota’s response to past perturbations. We will assess the impact of watershed vegetation changes over time on fire frequency and intensity which, in turn, has an effect on water quality in Roosevelt. This information becomes even more pertinent due to the as-of-yet unknown results the Rodeo-Chedeski fire will have on water quality in the Salt River, Roosevelt and downstream reservoirs. The effects of this event may have long-term consequences on municipal water quality delivered to the heavily populated Phoenix Metropolitan area. The authors are currently assessing water quality in all of these reservoirs and the results of this study would greatly enhance our knowledge of what kind of long-term effects on water quality large disturbances like the Rodeo-Chedeski may have. We will also assess the impact of anthropogenic land use activities, such as mining, on water quality in Roosevelt reservoir.

Nature, Scope, and Objectives: Watershed hydrology and the related transfer of materials from terrestrial to aquatic systems are a function of several factors, including the reservoir/watershed ratio, reservoir morphometry, local climate variables (e.g., rainfall, snowmelt, temperature, evapotranspiration, and atmospheric humidity), and watershed characteristics such as bedrock geology, soil type, topography, and vegetation cover and type (Mason et al. 1994, Street-Perrott 1995). Water quality of receiving water-bodies is directly affected by the type of materials delivered to it over time from the watershed as a result of all the aforementioned variables. It is often difficult to determine long-term trends in water quality, or changes in aquatic ecosystem structure or function, due to either natural or anthropogenic disturbance within the watershed. Historical data is often not available and even when it is, changing methodologies often make interpretation of trends impossible. In the case of natural disturbance such as wildfire, flood, and drought, it becomes necessary to delve even further into the past and many paleolimnological studies examine trends on millennial time scales.

The use of paleolimnological techniques to ascertain water quality trends in reservoirs is a relatively new technique. Previous studies have examined the accumulation of watershed-derived pollutants in sediment cores of reservoirs with rapidly urbanizing watersheds (Burton 2002, Callender & Van Metre 1997, Covay & Beck 2001, Ging et al. 1999, Van Metre et al. 2000). While these studies are of great merit and have shown definitive trends in pollutant accumulation rates with increasing urbanization, they often fail to address the consequences of these pollutants on aquatic biota or overall ecosystem processes. These studies have broken ground in their use of paleolimnological techniques to determine relatively short-term water quality trends and are often of high resolution within approximately the last 100 years. This is the most important time frame for studies examining detrimental pollutants of anthropogenic origin. Examples of paleolimnological studies examining longer term trends in aquatic resources include:

- Climate patterns including the changing relationship between evaporation and precipitation (Rosenmeir et al. 2002, Yu et al. 2002, Teranes & McKenzie 2001).
- Changes in surface water temperature and salinity (Bloom et al. 2003),
- Increases in trophic state (Shumate et al. 2003),
- Increasing hypolimnetic anoxia associated with increasing primary production (Quinlan & Smol 2002, Itoh et al. 2003),
- Estimation of past fire cycle, frequency, and interval (Davis et al. 2001, Hallett & Walker 2002, Pisarcic 2002, Philibert et al. 2003),
- Vegetative changes and their impact on water quality (Rosenmeir et al. 2002, Davis et al. 2001).

We propose to use established paleolimnological techniques to obtain and analyze sediment cores from Roosevelt reservoir in Central Arizona. Theodore Roosevelt Lake ("Roosevelt Reservoir") is a bilaterally shaped impoundment of the Salt River entering from the east and Tonto Creek entering from the north (Fig. 1). It was created with the construction of Theodore Roosevelt Dam from 1904 – 1911 and was the first of a series of reservoirs to be created for the Salt River Project with federal funding from the U.S. Bureau of Reclamation. The construction of Roosevelt Dam was the first reclamation project in the United States. The reservoirs initial use was flood control for agriculture but it's role has expanded in recent years to include power generation and as an important source of potable and irrigation water for the Greater Phoenix Metropolitan area.

Roosevelt reservoir is in the Central Highlands province which is a transitional zone between the Plateau Uplands to the northeast and the Basin and Range province to the southwest. The Central Highlands are characterized by rugged and steep-walled canyons and dissected by ephemeral streams (Sellers & Hill 1974). Climate in the region immediately surrounding the reservoir is characterized by hot, dry summers and mild winters. Average air temperatures from June to September are above 29°C and range from 24°C to 40°C during the hottest months of July and August (Sellers & Hill 1974). Approximately 46% of the annual precipitation at the reservoir occurs from December to March and 30% from July to September (Sellers & Hill 1974).

The major tributary to the reservoir is the Salt River. The total drainage area of the Salt River above Roosevelt is 1,115,300 ha (Boner et. al. 1992). The watershed above the reservoir is sparsely populated and major land uses consist of timber harvesting, cattle grazing, and mining. The average discharge of the Salt River into Roosevelt reservoir from 1913-1991 was 25 m³/s but typical of streams in Arizona, discharge varied greatly and is often event-driven. The maximum recorded discharge between 1913 and 1991 was in March of 1941 with 3314 m³/s and the minimum discharge was 1.7m³/s in July 1955 (Boner et. al. 1992).

We plan to collect between 3 and 5 sediment cores from the Salt River arm of Roosevelt reservoir using a Wright-Livingston square rod piston corer. These cores will then be age dated using lead-210 (Pb₂₁₀) and/or cesium-137 (Cs₁₃₇) radionuclides. The objectives of this work are many but all pertain to quantifying long-term water quality trends in Roosevelt and the Salt River watershed, determining how these watershed determinants define water quality within the reservoir, and how aquatic biota respond to these water quality changes. While the focus of our research will be post-impoundment, local geography indicates that a pre-impoundment wetland or playa may have existed. We anticipate the cores being long enough to capture pre-impoundment environmental conditions. The extent of time that will be captured from the cores is currently unknown because this work has never been performed in Roosevelt. Paleolimnological studies in lakes often capture time frames in the thousands and sometimes tens of thousands of years before the present.

Analytes derived from age-dated cores, and the reason for their analysis, will be:

- *Fossilized pollen analysis (palynology)*: To determine watershed vegetative changes. The amount and/or composition of watershed vegetation will vary as a result of changing climate, wildfire, or human removal. Decreases in watershed vegetation can reduce transpiration and soil moisture storage which can increase water and material transferred to a reservoir (Stednick 1996). Rates of water and material transfer, in turn, can strongly influence biogeochemical processes within the affected reservoir.
- *Fossilized diatom frustules ("valves")*: Diatoms are the most frequently used organisms in paleolimnological studies. Diatoms often occur in relatively high abundances and diversities, are ubiquitous, and readily identified to low taxonomic levels (Kienel & Kumke 2002). Diatoms contain many species with relatively limited ecological tolerances. Additionally, their short life cycles mean that they respond rapidly to changing environmental conditions. Siliceous diatom valves are well-preserved in lake sediments and are a direct reflection of environmental conditions at the time of deposition. Diatoms have been used to infer a wide array of water quality characteristics including pH, salinity, temperature, and nutrient availability (as reviewed in Stoermer & Smol 1999).
- *Fossilized chironomid (midge fly) head capsules*: Larval chironomids have long been recognized as excellent indicators of water quality conditions and especially as indicators of hypolimnetic anoxia in lakes and reservoirs (Brundin 1951, Saether 1975). They also make excellent indicators of paleoecological environmental condition (Walker 1987, Clerk et. al. 2000, Korhola et. al. 2000, Merlainen et. al. 2000). Chironomid taxa exhibit marked differences in individual responses to water quality degradation leading to anoxia, such as nutrient accumulation or other forms of natural or anthropogenic eutrophication, as a result of physiological adaptations. Important among these physiological adaptations to tolerate and even proliferate under anoxic conditions are the possession and concentration of hemoglobin (Cranston 1998, Int Panis et. al. 1996), behavioral ventilation (Heinis et. al. 1994), body size (Int Panis et. al. 1996), and metabolic rate (Heinis et. al. 1994). Additionally, chironomid's highly sclerotized head capsules are abundant and usually well-preserved in lake sediments, and, like diatoms, can be identified to low taxonomic levels (genus or lower).
- *Charcoal analysis*: To determine past fire cycle, frequency, and intensity. The consequences of fire on water chemistry in the Salt River watershed and Roosevelt reservoir is a timely and important issue considering current drought conditions, infestation of pine bark beetles, and the recent devastating effects of the Rodeo-

Chedeski fire. Following the fire, large amounts of pollutants were introduced into the reservoir (Fig. 2 & 3). The PI's have been examining limnological processes in all of the reservoirs along the Salt River continuously since 1999 and while the effects of the Rodeo-Chedeski fire are still negatively impacting these reservoirs, the full effect of this disturbance may not be realized for years. By examining the past response to disturbance (i.e. wildfire), we will devise a model to evaluate what may occur in the Salt River reservoirs as a result of the Rodeo-Chedeski fire and possible future wildfire events.

- *Nutrients and heavy metals:* We will obtain samples at selected locations of the core for nutrients (including organic carbon) related to eutrophication and metals associated with either anthropogenic activity (e.g., mining) or atmospheric input. Nutrients will include total N, total P, and total organic carbon. Metals will include arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, vanadium, and zinc. Figure 4 is provided as an example of metal trends in Amistad International reservoir on the Texas/Mexico border (courtesy of Peter C. Van Metre).

Specifically, the objectives of this project are listed below.

1) Determination of watershed vegetation changes over time and how this has affected, and has been affected by, fire cycle, frequency and intensity. This information will then be correlated with other water quality variables such as % carbon, metals, nutrients, charcoal, and the biotic response via the chironomid head capsule and diatom data to observe past biotic response to wildfire events. Wildfire also has substantial effects upon water quality and often results in pulses of pollutants brought to the reservoir and non-attenuation of flood peaks. These types of disturbance have real and profound effects on biogeochemical cycling within reservoirs. It is this alteration in biogeochemical cycling of pulses of pollutants brought in during events that often have long-term detrimental effects on water quality and ecosystem structure and function. The extent of these detrimental effects is impossible to accurately predict *a priori* and only by knowing past responses can future trends be determined.

2) Determining the effect of anthropogenic activities within the watershed on water quality delivered to Roosevelt reservoir. The watershed immediately surrounding the reservoir has a long history of mining activity as well as complaints about the effects these mines have had on water quality within Roosevelt. In 1984, a complaint was filed against Inspiration Consolidated Copper Company after an 18 inch in diameter main tailings line ruptured directly into Miami Wash which flows into Pinal Creek before it's confluence with the Salt River (Ham 1995). In 1991, complaints were filed about a hydrogen sulfide odor at the mouth of Pinal Creek at the Salt River just upstream of the reservoir. Samples collected near the upper most portions of Pinal Creek by ADEQ had a pH of 5.9 and 72 mg/L of manganese, 0.76 mg/L of nickel, and 0.055 mg/L of copper while water from downstream sites had near neutral pH and lower concentrations of metals (Ham 1995). The water from the upstream areas was black due to increased manganese levels. In 1993, unnaturally turquoise to blue colored water was noticed at the lower portions of Miami Wash. The pH at this site was 4.7. In Pinal Creek, downstream from Miami Wash, pH had increased 3 units, conductivity was reduced in half, and flow had increased five fold. The water from upstream was being diluted with less polluted water farther downstream and as the pH was neutralized, copper was deposited on stream sediments (Ham 1995). The cumulative effect of all of the past episodic events from mining on water quality within Roosevelt can be quantified by age dating and analysis of the cores.

3) The information obtained from this work could be used by ADEQ as an aid in determining biocriteria for reservoirs within the state. While there has been some biocriteria established for perennial, wadeable streams in Arizona, biocriteria for lacustrine environments is lacking. Part of the difficulty in choosing indicator species for biological assessment of lakes and reservoirs may be that these habitats are seemingly homogenous when compared to flowing water systems. Outside of episodic events or extreme eutrophication, correlation of lacustrine

aquatic biota with pollutants or trophic state, is often nebulous. This project would provide the long-term associations between specific aquatic biota and either pollutant loads or trophic state needed to assess correlations. If these correlations are proven to be reproducible, it would add considerable insight to assessment of individual reservoirs within the state.

4) While we are focusing on the post-impoundment time period (especially in regard to anthropogenic activities), we may be able to assess long-term climatic trends depending on the length of the core obtained. This would also depend upon whether a wetland or playa existed in the area prior to the construction of Roosevelt Dam. This information would enable assessment of long-term trends regarding watershed and ecosystem "health".

Approach, Methods, Procedures, and Facilities: We are extremely fortunate to have expertise from Peter Van Metre of the USGS provided as an in-kind contribution on this project. Peter has worked on numerous reservoirs in the U.S. examining human land use impacts as they manifest themselves in sediments of reservoirs and several of the techniques described here are attributable to him.

The cores will be collected mainly from the deeper areas of Roosevelt because this is where the least amount of disturbance is likely (Van Metre pers. comm.). If sediments at a chosen site are longer than 3 m (maximum corer length) than it is possible to switch to an off-channel site where sedimentation rates are lower while still deriving the same amount of information. Sediment deposition rates are usually focused in the pre-impoundment river channel and decreases from the river inflow to the dam (Van Metre et. al. 2001). Typical of rivers in the arid southwest, the Salt River often carries a high bedload which may result in very high depositional rates in the Salt River arm. This is actually a benefit because it is thought that relatively high sedimentation rates may reduce diagenetic effects (Callender 2000) and mixing of the sediments after deposition (Robbins 1986). Higher depositional rates of sediment also mean that subsampling the core temporally is easier.

Site selection within Roosevelt will require reconnaissance. We may be able to obtain images of the sediment using side-scanning sonar instead of blindly attempting to obtain samples. Even with the use of side scanning sonar, several reconnaissance cores will be obtained prior to site selection. These reconnaissance cores will be obtained in a linear fashion from the mouth of the Salt River toward the dam.

After a site has been selected and identified using GPS, we will assign each core an ID in the field and note the depth of sediment recovered. Cores will be subsampled on shore immediately after collection using a circular saw and utility knife to cut through the polybuterate liner (Van Metre 2003). Visual descriptors of the core will include color, texture, odor, and the presence/absence of biota and detritus (Van Metre 2003, Fig. 5). Cores will be sectioned into discrete samples by vertical extrusion and each discrete sample labeled with the core ID followed by the depth interval of the sample in centimeters (Van Metre 2003). All samples will then be placed in polypropylene jars and chilled and/or frozen for storage prior to individual analysis.

Cores will be dated using cesium-137 and/or lead-210. Cs₁₃₇ can provide one or two dates in addition to being used as an evaluation of the relative amount of disturbance after deposition (Van Metre 2003). The peak atmospheric fallout of Cs₁₃₇ was in 1963 so the peak found in the core will be given the date of 1964. Another, somewhat smaller peak of Cs₁₃₇ occurred in 1952 which which correlates with the first detectable fallout soon after large-scale atmospheric nuclear weapons by the United States (Beck et. al. 1990).

Lead-210 dating of the cores will use either the constant rate of supply (CRS) or the constant flux, constant sedimentation rate model (Appleby & Oldfield 1992). The CRS model implies that any change in the initial Pb²¹⁰ activity in sediment intervals varies inversely with the mass accumulation rate (Van Metre 2003). The CF:CS model assumes that the mass accumulation

rate and the flux of Pb^{210} to the reservoir are constant over time (Appleby & Oldfield 1992). Both models assume that the initial unsupported Pb^{210} in newly deposited sediments is constant leading to an exponential decrease in Pb^{210} with depth in the core (Van Metre 2003).

Pollen and charcoal analysis of all the cores will be performed by Owen Davis in the UA Geosciences department. Diatoms and chironomid head capsules will be performed by David Walker at the UA Environmental Research Laboratory. Nutrients and metals will be provided as an in-kind contribution by ADEQ and will be performed by Aquatic Consulting and Testing (ACT), a state certified laboratory.

Related Research: The U.S. Geological Survey Reconstructed Trends Study, as part of the National Water Quality Assessment (NAWQA) Program, collected sediment cores from 56 lakes and reservoirs between 1992 and 2001 in 17 U.S. states (Van Metre et. al. 2003). Arizona was not one of the states chosen for inclusion in this study. While this study was mostly concerned with sources of organic pollution including organochlorine pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons, pollutants not suspect in Roosevelt reservoir or the Salt River watershed, it was nonetheless instrumental in setting the groundwork for general methodological procedures for obtaining and age dating core samples collected from reservoirs. Very little, if any, biological work (pollen, diatoms, etc.) was done during this study and that is where this project differs.

The literature (e.g., the Journal of Paleolimnology) is replete with articles/projects that have focused on certain aspects of what we have proposed, but none in reservoirs within the arid southwest and few as comprehensive as what we have proposed.

Dr. Paul Gremillion (NAU) has cored several lakes/reservoirs in the northern part of the state for ADEQ (see Fig. 6). Dr. Gremillion has gained valuable insight into determining core chronologies and history of erosion events, fire records, and mercury/heavy metal accumulation rates. Dr. Gremillion's expertise will greatly enhance the overall scope of this project.

Training Potential: This project can support one, 0.5 time student worker (graduate or undergraduate). This project would make an excellent thesis or dissertation topic for the chosen student if they are a graduate. Numerous undergraduate students will gain valuable experience both in the field and laboratory from this project.

Information Transfer: The results of this project will be published in peer-reviewed journal articles and at bi-annual Water Quality Center meetings. The methodology applied to this project may be used in other reservoirs within the state of Arizona and the arid southwestern U.S. in general. As previously stated, the results from this project would greatly aid the determination of selected biocriteria of lacustrine habitats within the state.

Interaction with Water Centers: This project exactly matches the mission and goals of the National Science Foundation/University of Arizona Water Quality Center. Roosevelt reservoir is a potable drinking water supply for the Phoenix metropolitan area, the most heavily populated area of the state and this project would examine the physical, chemical, and biological aspects as they pertain to this very important resource. The information gleaned from this project would greatly enhance the knowledge base of government agencies (ADEQ and USGS) and the general public while simultaneously providing excellent research opportunities for graduate and undergraduate students in several disciplines.

Partnerships: Arizona Department of Environmental Quality: \$20,000 in-kind contribution (metal and nutrient analyses). United States Geological Survey: \$15,000 in-kind contribution (consultation, equipment, expertise, logistics).

Literature Cited

- Appleby, P.G. and Oldfield, F. 1992. Application of lead-210 to sedimentation studies. *In:* (M. Ivanovich and S. Harmon eds.) *Uranium-series Disequilibrium: Applications to Earth, Marine, and Environmental Sciences*, 2nd edition. Clarendon Press, Oxford. 910 p.
- Beck, H.L., I.K. Helfer, A. Boulville, and M. Deicer. 1990. Estimates of fallout in the continental U.S. from Nevada weapons testing based on gummed-file monitoring data. *Health Physics*. **59**. 565-576.
- Bloom, A.M., K.A. Moser, D.F. Porinchu, and G.M. MacDonald. 2003. Diatom-inference models for surface-water temperature and salinity developed from a 57-lake calibration set from the Sierra Nevada, California, USA. *J. Paleolim.* **29**. 235-255.
- Boner, F.C., R.G. Davis, and N.R. Duet. 1992. Water resources data for Arizona, water year 1991: U.S. Geological Survey Water Data Report AZ-91-1, 411 p.
- Brundin, L., 1951. The relation of O₂ microstratification at the mud surface to the ecology of the profundal bottom fauna. *Inst. of Freshw. Res. Drot.* **37**. 32-42.
- Burton, C.A., 2002. Effects of urbanization and long-term rainfall on the occurrence of organic compounds in bottom sediment, lower Charles River, Massachusetts. U.S. Geological Survey Water Resources Investigations. WRI 00-4180. 70 p.
- Callender, E., 2000. Geochemical effects of rapid sedimentation in aquatic systems; minimal diagenesis and the preservation of historical metal signatures. *J. Paleolim.* **23**. 243-260.
- Callender, E., and P.C. Van Metre. 1997. Reservoir sediment cores show U.S. lead declines. *Env. Sci. and Tech.* **31**. 424A-428A.
- Clerk, S., R.I. Hall, R. Quinlan, and J.P. Smol. 2000. Quantitative inference of past hypolimnetic anoxia and nutrient levels from a Canadian Precambrian Shield Lake. *J. Paleolim.* **23**. 319-336.
- Covay, K.J. and D.A. Beck. 2001. Sediment-deposition rates and organic compounds in bottom sediment at four sites in Lake Mead, Nevada, May 1998. U.S. Geological Survey Open File Report OF 01-0282. 34 p.
- Cranston, P.S. 1988. Allergens of non-biting midges (Diptera:Chironomidae): a systematic survey of chironomid haemoglobins. *Med. Vet. Entomol.* **2**. 117-127.
- Davis, O.K., T. Minckley T. Moutoux, T. Jull and R. Kalin. 2001. The transformation of Sonoran Desert wetlands following the historic decrease of burning. *J. Arid Lands*. **50**. 393-412.
- Ging, P.B., P.C. Van Metre and E. Callender. 1999. Bottom sediments of Lorange Creek Lake, San Antonio, Texas, reflect contaminant trends in an urbanizing watershed. U.S. Geological Survey Fact Sheet FS-149-99. 4p.
- Hallett, D.J. and R.C. Walker. 2000. Paleocology and its application to fire and vegetation management in Kootenay National Park, British Columbia. *J. Paleolim.* **24**. 401-414.
- Ham, L.K., 1995. Historical overview and limnological reconnaissance of Theodore Roosevelt Lake, Arizona. U.S. Geological Survey, Water Resources Investigations Report 95-4053.

- Heinis, F., J.P. Sweerts, and E. Loopik. 1994. Micro-environment of chironomid larvae in the littoral and profundal zones of Lake Maarsseveen I, The Netherlands. *Arch. Hydrobiol.* **130**. 53-67.
- Int Panis, L., B. Godeeris and R. Verheyen. 1996. On the relationship between vertical microdistribution and adaptations to oxygen stress in littoral Chironomidae (Diptera). *Hydrobiol.* **318**. 61-67.
- Itoh, N., T. Yukinori, T. Nagatani, and M. Soma. 2003. Phototrophic activity and redox condition in Lake Hamana, Japan, indicated by sedimentary photosynthetic pigments and molybdenum over the last ~250 years. *J. Paleolim.* **29**. 403-422.
- Kienel, U. and T. Kumke. 2002. Combining ordination techniques and geostatistics to determine the patterns of diatom distributions at Lake Lama, Central Siberia. **28**. 181-194
- Korhola, A., H. Olander and T. Blom. 2000. Cladoceran and chironomid assemblages as quantitative indicators of water depth in subarctic Fennoscandian lakes. *J. Paleolim.* **23**. 319-336.
- Mason, I.M.M., A.J. Guzkowska, C.G. Rapley, and F.A. Street-Perrott. 1994. The response of lake levels and areas to climatic change. *Clim. Change.* **27**. 161-197.
- Merlainen, J.J., J. Hynynen, A. Palomaki, P. Reinikainen, A. Teppo, and K. Granberg. 2000. Importance of diffuse nutrient loading and lake level changes to the eutrophication of an originally oligotrophic boreal lake: a paleolimnological diatom and chironomid analysis. *J. Paleolim.* **24**. 43-54.
- Philibert, A., Y.T. Prairie, and C. Carcaillet. 2003. 1200 years of fire impact on biogeochemistry as inferred from high resolution diatom analysis in a kettle lake from the *Picea mariana*-moss domain (Quebec, Canada). *J. Paleolim.* **30**. 167-181.
- Pisaric, M.F.J. 2002. Long distance transport of terrestrial plant material by convection resulting from forest fires. *J. Paleolim.* **28**. 349-354.
- Quinlan, R. and J.P. Smol. 2002. Regional assessment of long-term hypolimnetic oxygen changes in Ontario (Canada) shield lakes using subfossil chironomids. *J. Paleolim.* **27**. 249-260.
- Robbins, J.A. 1986. Model for particle-selective transport of tracers in sediments with conveyor belt deposit feeders. *J. of Geophys. Res.* **91**. 8542-8558.
- Rosenmeir, M.F. D.A. Hodell, M. Brenner, J.H. Curtis, J.B. Martin, F.S. Anselmetti, D. Ariztegui, and T.P. Guilderson. 2002. Influence of vegetation change on watershed hydrology: implications for paleoclimatic interpretation of lacustrine $\delta^{18}\text{O}$ records. *J. Paleolim.* **27**. 117-131.
- Saether, O.A. 1975. Chironomid communities as water quality indicators. *Holarc. Ecol.* **2**. 65-74.
- Sellers, W.D., and R.H. Hill. 1974. *Arizona Climate*. University of Arizona Press, Tucson, AZ. 616 p.
- Shumate, B.C. C.L. Schelske, T.L. Crisman, and W.F. Kenney. 2002. Response of the cladoceran community to trophic state change in Lake Apopka, Florida. *J. Paleolim.* **27**.

- 71-77.
- Stednick, J.D. 1996. Monitoring the effect of timber harvest on annual water yield. *J. Hydrol.* **176**. 79-95.
- Stoermer, E.F., and J.P. Smol. 1999. *The Diatoms: Applications for the Environmental and Earth Sciences*. Cambridge University Press, Cambridge. 469 p.
- Street-Perrot, F.A. 1995. Natural variability of tropical climates on 10-100 year time scales: Limnological and paleolimnological evidence. *In* Martinson, D.G., K. Bryan, M. Ghil, M.M. Hall, T.R. Karl, E.S. Sarachik, S. Sorooshian, and L.D. Talley (eds.), *Natural Climate Variability on Decade to Century Time Scales*. National Academy Press, Washington, D.C. 506-511.
- Teranes, J.L., and J.A. McKenzie. 2001. Lacustrine oxygen isotope record of 20th century climate change in central Europe: evaluation of climatic controls on oxygen isotopes in precipitation. *J. Paleolim.* **26**. 131-146.
- Van Metre, P.C., B.J. Mahler, and E. Callender. 1997. Water-quality trends in the Rio Grande/Rio Bravo Basin using sediment cores from reservoirs: U.S. Geological Survey Factsheet FS-221-96, 8 p.
- Van Metre, P.C., B.J. Mahler, and E. Callender. 2000. Urban sprawl leaves its PAH signature. *Env. Sci. & Tech.* **32**. 3312-3317.
- Van Metre, P.C., E. Callender, B.J. Mahler, J.T. Wilson, M.E. Dorsey. 2001. Differences in lake and reservoir sedimentation; implications for sediment coring studies. *Proceedings of the Seventh Federal Interagency Sedimentation Conference*. **2**. IX12-IX19. Reno Nevada, U.S. March 25-29, 2001.
- Van Meter, P.C., J.T. Wilson, C.C. Fuller, E. Callender, and B.J. Mahler. 2003. Methods and age dating of sediment cores for 56 U.S. Lakes and reservoirs sampled by the U.S. Geological Survey, 1992-2001. U.S. Geological Survey Investigations Report. *in review*.
- Walker, I.R., 1987. Chironomidae (Diptera) in paleoecology. *Quat. Sci. Rev.* **6**. 29-40.
- Yu, Z., E. Ito, and D.R. Engstrom. 2002. Water isotopic and hydrochemical evolution of a lake chain in the northern Great Plains and its paleoclimatic implications. *J. Paleolim.* **28**. 207-217.

Figure 1. Aerial Photo of Roosevelt Reservoir, Tonto Creek and the Salt River

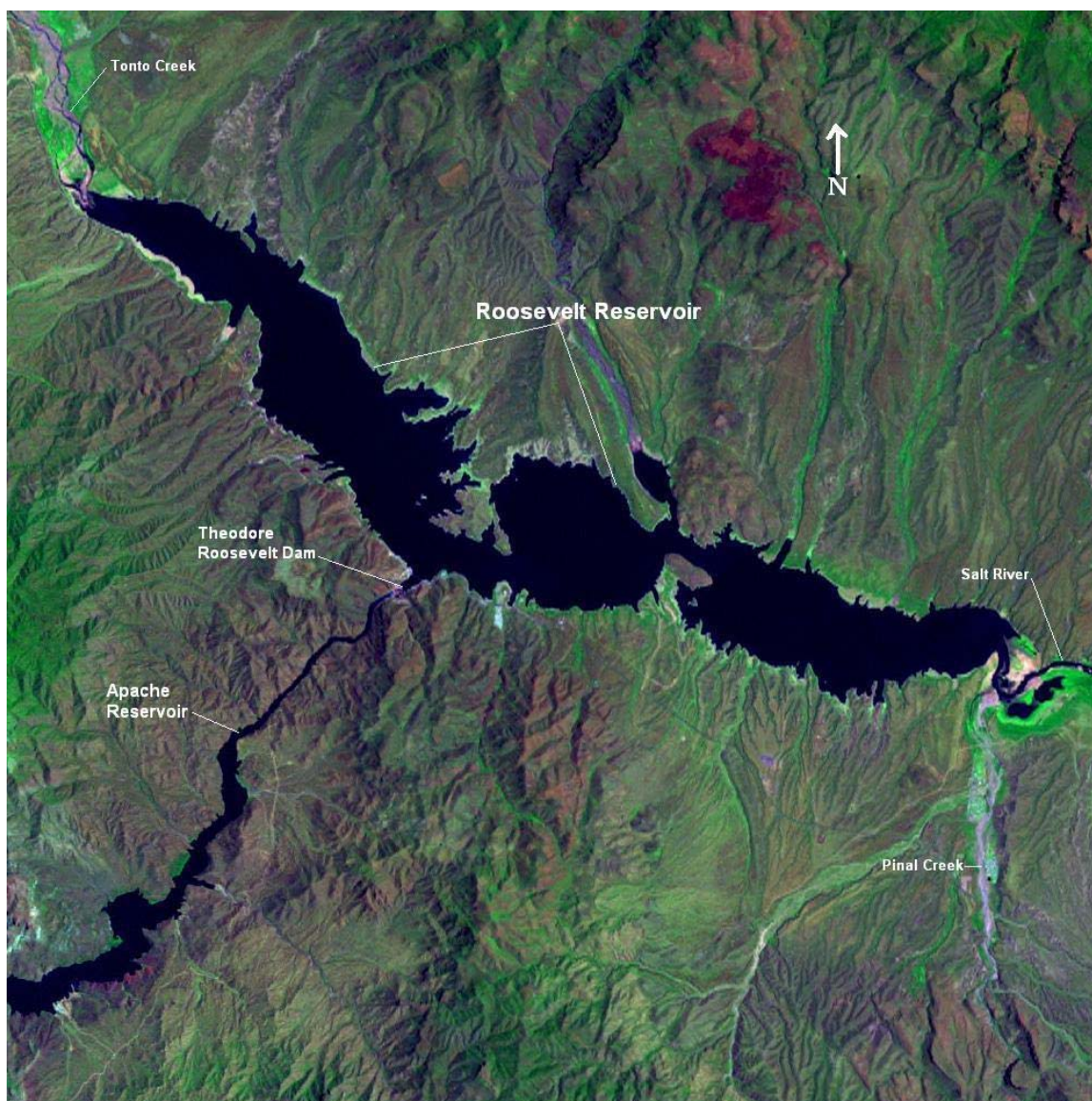


Figure 2. Approximate Burn Area from the Rodeo-Chediski Fire in Relation to the Salt River and Roosevelt Reservoir.

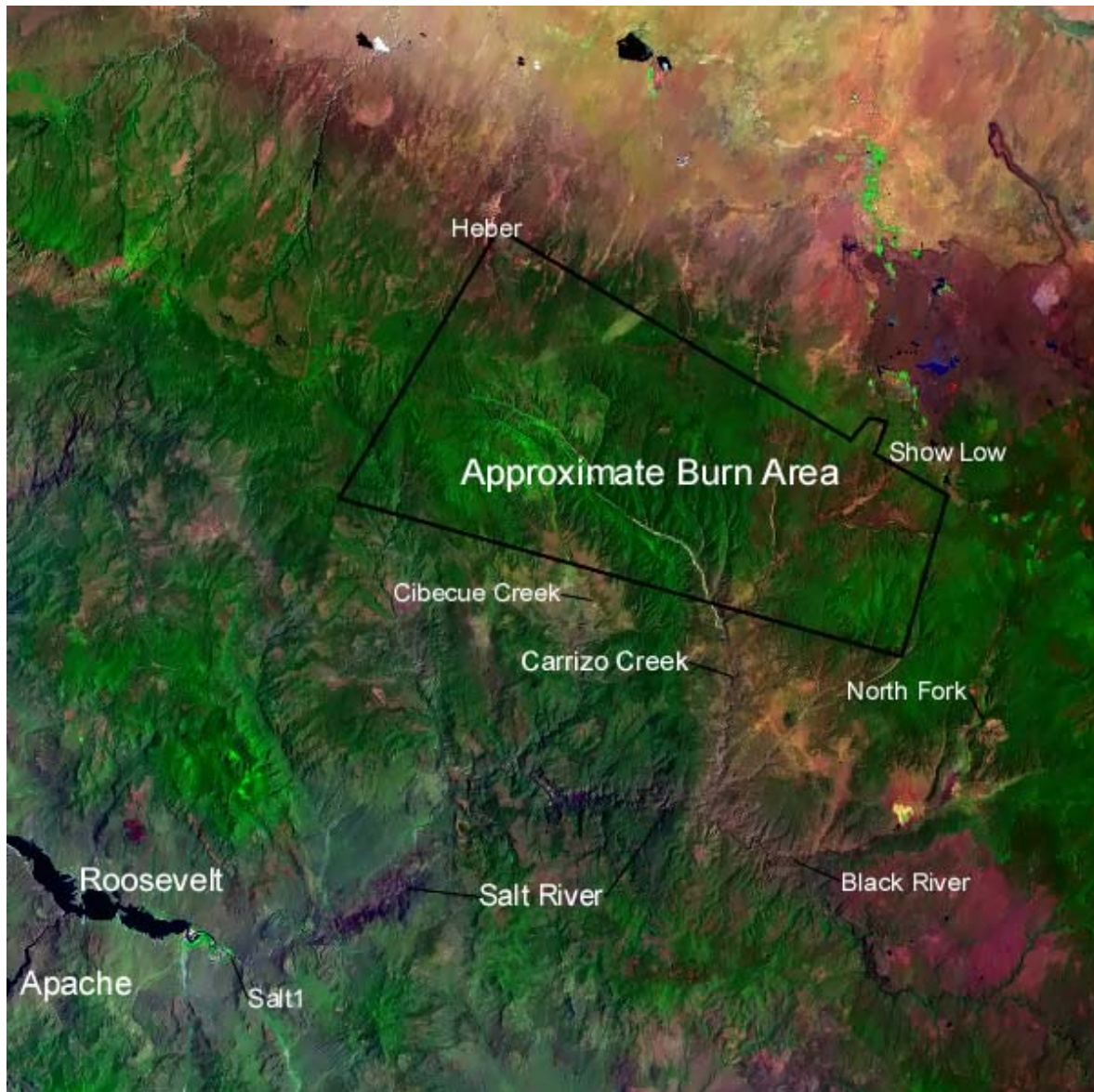


Figure 3. Concentration of Total Metals and Nutrients from the Salt River above Roosevelt Reservoir on 7/19/02 (data collected by Arizona Dept. of Environmental Quality). Flow was > 8000 cfs.

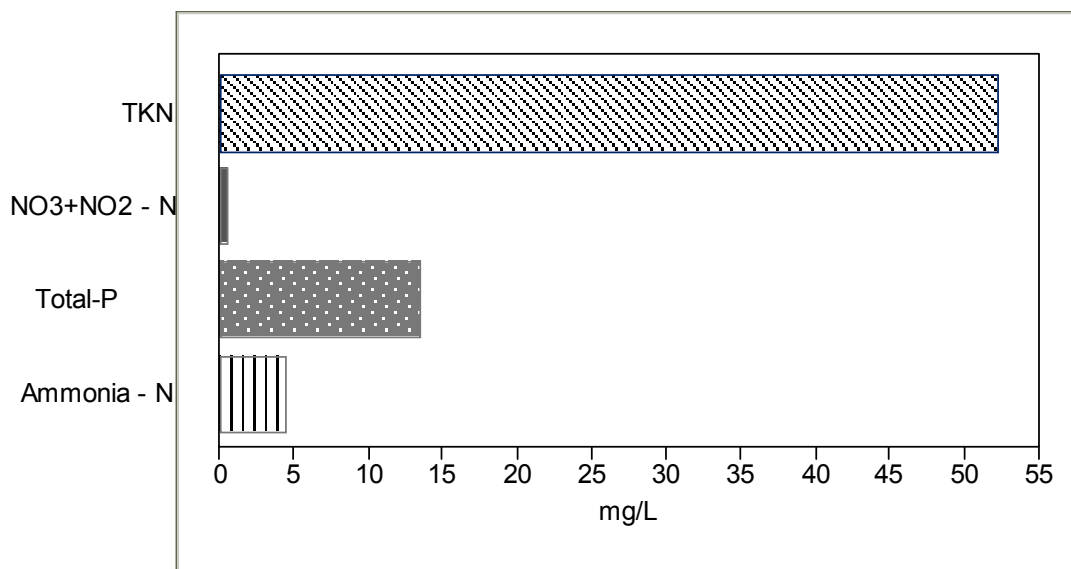
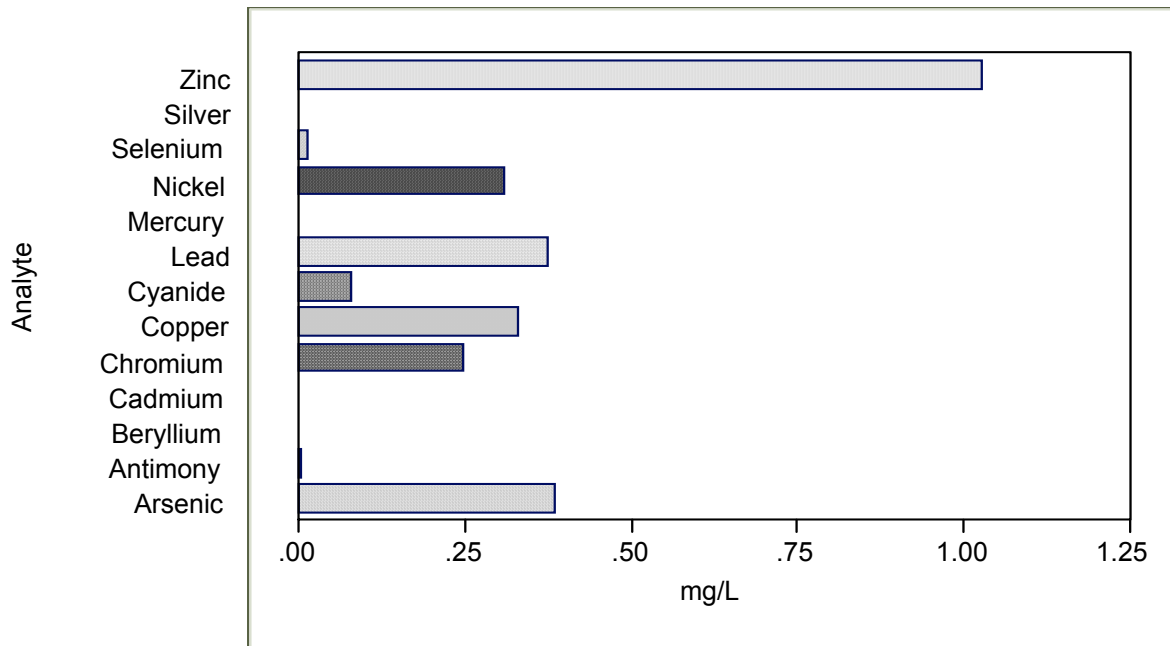


Figure 4. Trends in Eight Metals in Amistad International Reservoir Cores *From* Van Metre et. al. 1997.



Figure 4. Trends in eight metals in Amistad International Reservoir cores.

Figure 5. A. Describing a gravity corer. B. Gravity core in extrusion stand. C. Slicing a subsample from a gravity core. *From* . Van Metre et. al. 2003.



Figure 6. Laboratory notes describing the lithology of the third drive core taken by Dr. Gremillion from Lyman Lake. The descriptions reflect both the distinct depositional zones in the sediment as well as the intermittent presence of charcoal, a clear indication of past wildfire events. *Courtesy Paul Gremillion, NAU.*

