# HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

## Project Information

1. **Proposal Title:**

   HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

2. **Proposal applicants:**

   David Stahle, University of Arkansas
   Daniel Cayan, Scripps Institution of Oceanography
   Michael Dettinger, U.S.Geological Survey
   David Meko, University of Arizona
   Kelly Redmond, Western Regional Climate Center

3. **Corresponding Contact Person:**

   David Stahle
   University of Arkansas
   Department of Geosciences 113 Ozark Hall University of Arkansas Fayetteville, AR 72701
   501 575-3703
   dstahle@uark.edu

4. **Project Keywords:**

   **Climate Change**
   **Hydrology**
   **Watershed Management**

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   Natural Flow Regimes

8. **Type of applicant:**

   University

9. **Location - GIS coordinates:**

   Latitude:

   Longitude:

   Datum:

   **Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.**

   Multiple study sites throughout drainage basin of San Francisco Bay.

10. **Location - Ecozone:**

    Code 15: Landscape

11. **Location - County:**

    Alameda, Alpine, Amador, Butte, Calaveras, Colusa, Contra Costa, El Dorado, Fresno, Glenn, Inyo, Kern, Kings, Lake, Lassen, Los Angeles, Madera, Marin, Mariposa, Mendocino, Merced, Modoc, Mono, Monterey, Napa, Nevada, Placer, Plumas, Sacramento, San Benito, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Shasta, Sierra, Solano, Stanislaus, Sutter, Tehama, Trinity, Tulare, Tuolumne, Ventura, Yolo, Yuba

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    Yes

    If yes, please list the city: Probably several cities, but yet to be determined upon random sampling of study sites.

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    Yes **If yes, please list the tribal lands:** Possibly, but yet to be determined.

14. **Location - Congressional District:**

    Several districts will be involved, but this is yet to be determined.

15. **Location:**

    **California State Senate District Number:** Several districts will be involved, but this is yet to be determined.

    **California Assembly District Number:** Several districts will be involved, but this is yet to be determined.

16. **How many years of funding are you requesting?**

    three (3)

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

       No

       If no, list single overhead rate and total requested funds:

       Single Overhead Rate: 42.5%

       Total Requested Funds: $747,741

    b) Do you have cost share partners <u>already identified</u>?

       No

    c) Do you have <u>potential</u> cost share partners?

       **No**

    d) Are you specifically seeking non-federal cost share funds through this solicitation?

       No

       If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

    No

    Have you previously received funding from CALFED for other projects not listed above?

    **No**

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

    **No**

    Have you previously received funding from CVPIA for other projects not listed above?

    No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

    No

**Please list suggested reviewers for your proposal.** (optional)

| | | | |
|---|---|---|---|
| **Edward R. Cook** | **Lamont-Doherty Earth Observatory** | **845-362-8618** | **drdendro@ldeo.columbia.edu** |
| **Maury Roos** | **California Dept. of Water Resources** | | |
| **Constance Millar** | **USDA Forest Service, Pacific Southwest Res. Station** | **510-559-6435** | |

21. **Comments:**

**This is a multi-institution collaborative research proposal concerning natural climate, streamflow, and estuarine variability, and the distribution of ancient blue oak woodlands within the drainage basin of San Francisco Bay. The University of Arkansas is the lead institution, collaborating with the University of Arizona, Scripps Institution of Oceanography, the USGS, and the Western Regional Climate Center at the University of Nevada.**

# Environmental Compliance Checklist

## HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No

   b) Will this project require compliance with NEPA?

      No

   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      This is a research project based on the analysis of increment cores from long-lived blue oak trees. The extraction of core samples is non-destructive, and advance permission will be obtained to conduct the proposed fieldwork from all landowners.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   <u>CEQA Lead Agency:</u>
   <u>NEPA Lead Agency (or co-lead:)</u>
   <u>NEPA Co-Lead Agency (if applicable):</u>

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   **CEQA**
   **-**Categorical Exemption
   **-**Negative Declaration or Mitigated Negative Declaration
   **-**EIR
   **X**none

   **NEPA**
   **-**Categorical Exclusion
   **-**Environmental Assessment/FONSI
   **-**EIS
   **X**none

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

      Not Applicable

   b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

**LOCAL PERMITS AND APPROVALS**

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other Required

**STATE PERMITS AND APPROVALS**

Scientific Collecting Permit Required

CESA Compliance: 2081

CESA Compliance: NCCP

1601/03

CWA 401 certification

Coastal Development Permit

Reclamation Board Approval

Notification of DPC or BCDC

Other

**FEDERAL PERMITS AND APPROVALS**

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit

Rivers and Harbors Act

CWA 404

Other Required

**PERMISSION TO ACCESS PROPERTY**

| | |
|---|---|
| Permission to access city, county or other local agency land.<br>Agency Name: yet to be determined | Required |
| Permission to access state land.<br>Agency Name: yet to be determined | Required |
| Permission to access federal land.<br>Agency Name: yet to be determined | Required |
| Permission to access private land.<br>Landowner Name: yet to be determined | Required |

6. **Comments.**

# Land Use Checklist

## HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   Yes

3. **Do the actions in the proposal involve physical changes in the land use?**

   **No**

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   research only

4. **Comments.**

   Permission to conduct the proposed nondestructive field study will be requested in advance from all landowners, public and private.

# Conflict of Interest Checklist

## HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

**Applicant(s):**

David Stahle, University of Arkansas
Daniel Cayan, Scripps Institution of Oceanography
Michael Dettinger, U.S.Geological Survey
David Meko, University of Arizona
Kelly Redmond, Western Regional Climate Center

**Subcontractor(s):**

Are specific subcontractors identified in this proposal? No

**Helped with proposal development:**

Are there persons who helped with proposal development?

No

**Comments:**

The applicants listed on the Project Information form from the University of Arizona, Scripps Institution of Oceangraphy, USGS, and the Western Regional Climate Center all helped write the proposal, along with the University of Arkansas. All collaborating institutions will be paid under a subcontract from the University of Arkansas.

# Budget Summary

## HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

Independent of Fund Source

| Year 1 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Task No.** | **Task Description** | **Direct Labor Hours** | **Salary *(per year)*** | **Benefits *(per year)*** | **Travel** | **Supplies & Expendables** | **Services or Consultants** | **Equipment** | **Other Direct Costs** | **Total Direct Costs** | **Indirect Costs** | **Total Cost** |
| 1 | Stahle research (field and lab), management, and public/professional outreach | 173.333 | 9556 | 2272 | 13000 | 5000 | | | | 29828.0 | 25662 | 55490.00 |
| 2 | Cleaveland research | 86.67 | 3150 | 749 | | | | | | 3899.0 | | 3899.00 |
| 3 | Techician field and lab research | 520 | 7000 | 1665 | | | | | | 8665.0 | | 8665.00 |
| 4 | Hourly research assistance for field and lab | 2080 | 16640 | 1350 | | | | | | 17990.0 | | 17990.00 |
| 5 | University of Arizona (D. Meko) research collaboration | | | | | | 37989 | | | 37989.0 | 10625 | 48614.00 |
| 6 | Scripps Institution of Oceanography (D. Cayan) research collaboration | | | | | | 47700 | | | 47700.0 | 10625 | 58325.00 |
| 7 | USGS (M. Dettinger) research collaboration | | | | | | 15111 | | | 15111.0 | 6422 | 21533.00 |
| 8 | Western Regional Climate Center (K. Redmond) research collaboration | | | | | | 47545 | | | 47545.0 | 10625 | 58170.00 |
| | | 2860 | 36346.00 | 6036.00 | 13000.00 | 5000.00 | 148345.00 | 0.00 | 0.00 | 208727.00 | 63959.00 | 272686.00 |

| Year 2 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Task No.** | **Task Description** | **Direct Labor Hours** | **Salary** ***(per year)*** | **Benefits** ***(per year)*** | **Travel** | **Supplies & Expendables** | **Services or Consultants** | **Equipment** | **Other Direct Costs** | **Total Direct Costs** | **Indirect Costs** | **Total Cost** |
| 1 | Stahle research (field and lab), management, and public/professional outreach | 173.333 | 9938 | 2363 | 13000 | 5000 | | | | 30301.0 | 26077 | 56378.00 |
| 2 | Cleaveland research | 86.67 | 3276 | 779 | | | | | | 4055.0 | | 4055.00 |
| 3 | Techician field and lab research | 520 | 7280 | 1731 | | | | | | 9011.0 | | 9011.00 |
| 4 | Hourly research assistance for field and lab | 2080 | 16640 | 1350 | | | | | | 17990.0 | | 17990.00 |
| 5 | University of Arizona (D. Meko) research collaboration | | | | | | 41771 | | | 41771.0 | | 41771.00 |
| 6 | Scripps Institution of Oceanography (D. Cayan) research collaboration | | | | | | 46325 | | | 46325.0 | | 46325.00 |
| 7 | USGS (M. Dettinger) research collaboration | | | | | | 15111 | | | 15111.0 | 4203 | 19314.00 |
| 8 | Western Regional Climate Center (K. Redmond) research collaboration | | | | | | 49754 | | | 49754.0 | | 49754.00 |
| | | 2860 | 37134.00 | 6223.00 | 13000.00 | 5000.00 | 152961.00 | 0.00 | 0.00 | 214318.00 | 30280.00 | 244598.00 |

| Year 3 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Task No.** | **Task Description** | **Direct Labor Hours** | **Salary *(per year)*** | **Benefits *(per year)*** | **Travel** | **Supplies & Expendables** | **Services or Consultants** | **Equipment** | **Other Direct Costs** | **Total Direct Costs** | **Indirect Costs** | **Total Cost** |
| 1 | Stahle research (field and lab), management, and public/professional outreach | 173.333 | 10336 | 2458 | 9000 | 3000 | | | | 24794.0 | 23958 | 48752.00 |
| 2 | Cleaveland research | 86.67 | 3407 | 810 | | | | | | 4217.0 | | 4217.00 |
| 3 | Techician field and lab research | 520 | 7571 | 1800 | | | | | | 9371.0 | | 9371.00 |
| 4 | Hourly research assistance for field and lab | 2080 | 16640 | 1350 | | | | | | 17990.0 | | 17990.00 |
| 5 | University of Arizona (D. Meko) research collaboration | | | | | | 36441 | | | 36441.0 | | 36441.00 |
| 6 | Scripps Institution of Oceanography (D. Cayan) research collaboration | | | | | | 47490 | | | 47490.0 | | 47490.00 |
| 7 | USGS (M. Dettinger) research collaboration | | | | | | 15111 | | | 15111.0 | | 15111.00 |
| 8 | Western Regional Climate Center (K. Redmond) research collaboration | | | | | | 51085 | | | 51085.0 | | 51085.00 |
| | | 2860 | 37954.00 | 6418.00 | 9000.00 | 3000.00 | 150127.00 | 0.00 | 0.00 | 206499.00 | 23958.00 | 230457.00 |

**Grand Total=747741.00**

**Comments.**

The University of Arkansas (UAF) will be administering the subcontracts with our collaborators at Arizona, Scripps, the USGS, and the WRCC (itemized under "Services and Consultants"). The UAF requests indirect costs of 42.5% for the first $25,000 of each subcontract, and these charges are listed under "Indirect Costs" for years 1 and 2, only.

# Budget Justification

## HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

**Direct Labor Hours.** Provide estimated hours proposed for each individual.

Year 1: D. Stahle 173.333 hours M. Cleaveland 86.67 hours Research Technician 520 hours Hourly Assistant 2080 Year 2: D. Stahle 173.333 hours M. Cleaveland 86.67 hours Research Technician 520 hours Hourly Assistant 2080 Year 3: D. Stahle 173.333 hours M. Cleaveland 86.67 hours Research Technician 520 hours Hourly Assistant 2080

**Salary.** Provide estimated rate of compensation proposed for each individual.

Year 1: D. Stahle $55.13 per hour M. Cleaveland $36.34 per hour Research Technician $13.46 per hour Hourly Assistant $8.00 per hour Year 1: D. Stahle $57.33 per hour M. Cleaveland $37.80 per hour Research Technician $14.00 per hour Hourly Assistant $8.00 per hour Year 1: D. Stahle $59.63 per hour M. Cleaveland $39.31 per hour Research Technician $14.56 per hour Hourly Assistant $8.00 per hour

**Benefits.** Provide the overall benefit rate applicable to each category of employee proposed in the project.

University of Arkansas fringe benefit rates: 1. Classified employees (i.e., including Stahle, Cleaveland, and research technician) = 23.78% salary 2. Hourly (non-student) = 8.11% salary/wages

**Travel.** Provide purpose and estimate costs for all non-local travel.

Travel for the University of Arkansas: The proposed research involves intensive and widespread fieldwork to obtain the tree-ring samples needed for hydroclimatic reconstruction, and to obtain the field data needed to test and refine the predictive model/mapping of ancient blue oak woodlands in the drainage basin of San Francisco Bay. We estimate that $13,000 will be needed for each of Year 1 and Year 2, and that $9,000 will be needed for travel in Year 3. We estimate that 2 to 4 days will be needed to obtain the tree-ring and field data from each of the 50 collection sites (including travel time between sites). We plan on completing the tree-ring collections during the first two years. So estimating 25 sites per year we think it will take 50 to 100 days in each of Year 1 and 2 to complete the field collections. The fieldwork will be conducted by at least two qualified dendrochronologists. This works out to between $130 and $260 to cover all airline, vehicle, lodging and meal expenses for the two people in each of Year 1 and 2. However, travel expenses will also be used to cover the travel costs involved in PI research and professional meetings during each year. In Year 3 we request $9,000 for travel to cover the costs of field testing the refined predictive model at 50 locations (1-2 days should be sufficient to complete this work at each site). These Year 3 travel funds will also cover the costs of trips to PI research and professional meetings. The travel expenses for the collaborating scientists from Arizona, Scripps, USGS, and WRCC are included in the budget estimates for their individual subcontracts (see Services and Consultants).

**Supplies & Expendables.** Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

Laboratory supplies: sanding equipment and supplies, saw blades, core mount material and labor, etc. Computing supplies: software Field supplies: expendable Swedish increment borers, chain saw and supplies

**Services or Consultants.** Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

Dr. Meko will assist the proposed research with field research, programming, reconstruction, and analysis. Dr. Meko's participation in the proposed research is estimated to cost $37989, $41771, and $36441 in years 1-3. These estimates include $12964, $13612, and $4300 in salary for Dr. Meko in years 1-3, fringe benefits at 20.1%, and operational support at $2300, $2800, and $1200 in years 1-3. Costs also include undergraduate support ($3900, $4095, and $4300 for years 1-3) and travel expenses ($3243, $4263, and $1320 for years 1-3). The indirect costs for the University of Arizona are set at 51.5%. Dr. Cayan will assist with the regional and large scale climate analyses. Dr. Cayan's participation in the proposed research is estimated to cost $47700, $46325, and $47490 in years 1-3. These costs include $18781,$19361, and $19961 in years 1-3 for salaries and benefits, $6625, $6715, and $6808 for travel in years 1-3, and miscellaneous supply, computer, and communication costs. The on-campus indirect cost rate for SIO is set at 52% of modified total direct costs. Dr. Dettinger will assist with the hydrological reconstructions and analyses. Dr. Dettinger's proposed budget is (for each of three years of study, with juggling to cover inflation by erosion of hours spent): Labor: (salary for 108 hours at $59.hr, including $12.78/hr in benefits) = $6264 Contracts: (office expenses at UCSD1) = $500 Travel: PI meeting and conference attendance = $500 Reports Assessment: (12% of net) = $978 USGS Overhead2 = $6756 TOTAL each year = $15111 Dr. Dettinger maintains an office at SIO and acrues office costs. The indirect costs of the USGS are a combination of National (WOTSC) and District (DOTSC) costs. Dr. Redmond will assist with the hydroclimatic analyses. Dr. Redmond and the WRCC are requesting $47545, $49754, and $51085 for his collaboration on the proposed research in years 1, 2, and 3, respectively. These estimates cover 332 hours per year of Dr. Redmond's time (totalling $16544, 17205, and $17894 in salaries in years 1-3). Travel expenses are estimated at $2890, $3225, and $2890 for years 1-3, and operating expenses (i.e., communications, registrations, network charges) are estimated at $1420, $1440, and $1570 in years 1-3. Indirect costs for the WRCC are set a 69% of total direct costs, and fringe benefits are set at 44% of professional salaries.

**Equipment.** Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

none

**Project Management.** Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

We estimate that half of the time committments of D. Stahle and M. Cleaveland in Years 1, 2, and 3 of the proposed research will be required to manage the research, budget, prepare reports, respond to inquiries, and make presentations related to the project. We have also allocated travel funds during each year to cover the expenses involved in participating in CALFED meetings, and in making professional presentations in a variety of venues.

**Other Direct Costs.** Provide any other direct costs not already covered.

none

**Indirect Costs.** Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

The indirect cost rate of the University of Arkansas (UAF) is 42.5% of all direct costs, excluding permanent equipment. The University's Facilities & Administrative Costs (Indirect Costs) has been negotiated with the U.S. Department of Health & Human Services dated June 12, 2001. The UAF will be administering the subcontracts with our collaborators at Arizona, Scripps, the USGS, and the WRCC (itemized under "Services and Consultants"). The UAF requests indirect costs of 42.5% for the first $25,000 of each subcontract, and these charges are listed under "Indirect Costs" for years 1 and 2, only.

# Executive Summary

## HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

The impact of natural climate and hydrologic variability on ecosystem dynamics and water management is a major uncertainty confronting the CALFED Ecosystem Restoration Program. This research project will develop high quality climate and hydrologic reconstructions for up to 500-years using an unparalleled network of 50 tree-ring chronologies from moisture-sensitive blue oak trees in the drainage basin of San Francisco Bay. These ancient blue oak contain one of the strongest precipitation signals ever detected in biological or geological proxies of climate. Just five oak chronologies have explained 81% of the variance in San Francisco Bay salinity (1922-1952), and helped quantify the anthropogenic impact on estuarine salinity (Stahle et al., 2001). At least 75 climate and hydrologic reconstructions will be developed and analyzed across the drainage basin of San Francisco Bay, including cool-season precipitation for the 50-site grid, regional precipitation within major drainage subdivisions, full natural flow (FNF) for the Sacramento, San Joaquin, and major tributaries, Delta inflow, San Francisco Bay salinity, and the longitudinal position of the null zone (X2). These reconstructions will be used to test hypotheses about hydroclimatic variability over California, and will help define the natural hydrodynamic regimes that the CALFED ERP is designed to establish and maintain. Ancient blue oak woodlands are a dominant land cover type in the watersheds of some of the highest quality salmon habitat left in California, and contribute to the protection of water yield and water quality. A second major goal of the proposed research will be to develop, field test, and refine a predictive model designed to estimate and accurately map the ancient blue oak woodlands that remain scattered across the complex landscape mosaic of California. Accurate mapping of these ancient "foothill oak" woodlands presently does not exist, and will contribute to the conservation of a native biotic community that covers some 6% of the watershed of San Francisco Bay.

# Proposal

## University of Arkansas

## HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY

David Stahle, University of Arkansas
Daniel Cayan, Scripps Institution of Oceanography
Michael Dettinger, U.S.Geological Survey
David Meko, University of Arizona
Kelly Redmond, Western Regional Climate Center

**HYDROCLIMATIC RECONSTRUCTION AND ANCIENT BLUE OAK MAPPING OVER THE DRAINAGE BASIN OF SAN FRANCISCO BAY**

## A. PROJECT DESCRIPTION

### 1. Introduction to the Problem

In a state famous for remarkable forests, the blue oak (*Quercus douglasii*) woodlands of California must be considered among the most exceptional. Blue oak woodlands and savannas are the most widespread hardwood cover type in California and grace almost three million acres on the foothills of the Coast Range and Sierra Nevada (Figures 1,2,3). This proposal outlines a project to use these picturesque blue oak to help solve two major problems confronting the CALFED ERP: 1) the impact of hydroclimatic variability on ecosystem function and water management, and 2) the protection and restoration of stream quality for at-risk species in the drainage basin of San Francisco Bay.

The radial growth of blue oak is critically dependent upon precipitation totals during the winter-spring, and tree-ring chronologies derived from these moisture-sensitive oaks record one of the most accurate paleoclimatic histories of precipitation amounts ever found (e.g., Stahle et al. 2001). Experiments with a reconnaissance sample of 12 blue oak chronologies indicate that these tree-ring data can explain between 70 and 90% of the variance in instrumental precipitation data during subperiods of the 20th century (e.g., Figure 4). The few existing oak chronologies have been used to reconstruct precipitation (Therrell and Stahle 2000), Sacramento River streamflow (Meko et al. 2001), and San Francisco Bay salinity (Stahle et al. 2001). The salinity reconstruction explained 81% of the variance in January-July average salinity at Ft. Point from 1922-1952 (Figure 5), and revealed that the post World War II era of high salinity in San Francisco Bay has been unprecedented over the past 400 years (Figure 6).

The fractions of instrumental hydroclimatic variance explained by these exceptional blue oak tree-ring chronologies are as high as have ever been achieved with biological or geological proxies of climate. We believe that this strong climate signal strength justifies development of a more densely replicated and carefully crafted blue oak chronology network.

The former coverage of virgin blue oak has been drastically reduced by 150 years of agricultural and urban development, but large areas of old growth still exist because blue oak does not produce commercially valuable saw timber (Standiford 1997) and has never been systematically logged. Our extensive fieldwork indicates that a sizeable fraction of the remaining blue oak woodland is dominated by a canopy of ancient trees in the 150- to 500-year age class. The great antiquity of many canopy blue oak is not well known, and greater public appreciation of the widespread survival of *ancient* blue oak dating from presettlement California will contribute to the conservation management of these woodlands, and their associated wildlife habitat and stream quality.

Blue oak woodlands cover approximately 6% of the drainage basin of San Francisco Bay, and the ecological integrity of the estuary cannot be divorced from the land use and land cover status within the drainage basin. In fact, blue oak woodland is a dominant land cover type in watersheds with some of the highest quality salmon habitat left in California (e.g., Battle Creek, Deer Creek, Mill Creek; Figure 3). We believe that ancient blue oak represent one of the largest old-growth forest types left in California, and constitute one of the least altered land cover types in the drainage basin of San Francisco Bay. The distribution of *ancient* blue oak woodlands has never been estimated or mapped, but accurate mapping could stimulate significant landowner support for the conservation management of these threatened woodlands, which would contribute to the long-term maintenance of ecosystem function in the watershed of San Francisco Bay.

This proposal outlines a three-year project to develop 50 moisture-sensitive tree-ring chronologies from ancient oaks, to reconstruct a suite of precipitation and hydrological variables, and to map ancient blue oak forests in the drainage basin of San Francisco Bay. The proposed reconstructions of precipitation, streamflow, and estuarine salinity will be the most comprehensive ever produced for the Sacramento-San Joaquin system. These reconstructions will define the background hydroclimatology for the past 500-years, and will help segregate natural vs. anthropogenic impacts on the Bay-Delta ecosystem. The estimated cost of the proposed three-year collaborative research project is $747,741, and will involve the Tree-Ring Laboratories of the University of Arkansas (UAF TRL, $296,308) and the University of Arizona (UAZ, $116,201), the Scripps Institution of Oceanography (SIO, $141,515), the U.S. Geological Survey (USGS, $45,333), and the Western Regional Climate Center (WRC, $148,384).

## 2. Objectives and Justification

This research proposal addresses two general questions that are fundamental to the understanding and management of the San Francisco Bay watershed: 1) what is the nature of interannual to interdecadal hydroclimatic variability in the drainage basin over the past 500 years, how is it related to larger scale climate variability over the Pacific basin, and how does the recent instrumental history compare with the past 500 years? 2) What is the distribution of *ancient* blue oak woodlands in California, particularly within the watersheds of streams most critical to the restoration of at-risk species? To address these research questions, an intensive and widespread field campaign is proposed with two major and strongly interacting objectives: 1) to develop a densely replicated network of 300- to 500-year long tree-ring chronologies of blue oak for detailed spatial-temporal reconstructions and analyses of hydroclimatic variability in the drainage basin of San Francisco Bay, and 2) to accurately map the geographical distribution of *ancient* blue oak remnants in California.

**2a. Hydroclimatic Reconstruction and Analysis**

A network of 50 blue oak tree-ring chronologies will be used to develop a new generation of precipitation, streamflow, null zone position, and San Francisco Bay salinity reconstructions that will be used to analyze spatial-temporal patterns of hydroclimatic variability in California for the past 500 years. The 12 existing blue oak chronologies have an excellent precipitation signal, and accurately represent the primary spatial modes of precipitation variance across California evident during the 20th century (Redmond et al. 2001). However, much more can be learned about the nature of hydroclimatic variability from a dense array of these exceptional climate proxies.

Blue oak has an elevation range from 200 to over 1400 meters. We propose to target a selection of sites near the lowest and highest elevations, as part of a larger strategy to discriminate between spatial precipitation regimes in prehistory. When coupled with the dense and widespread network, we will be able to reconstruct the fine spatial detail of past precipitation anomalies. The proposed network will help distinguish between the north-south, east-west, and elevational influences on precipitation variability. Precipitation usually increases with elevation, but the rate of increase varies on daily to decadal timescales. In some years (e.g., 2000-01), normal precipitation is recorded at low elevation, but drought is witnessed over the Sierra headwaters. In other years the opposite may occur, but we do not know why. The angle at which moisture-laden winds intercept the topographic gradient is one reason, but what causes this angle to vary is a more fundamental question we very much want to answer.

The proposed reconstructions will allow us to document temporal variability in the directional displacement of zonal mean storm tracks, and to test a series of questions/hypotheses about the nature and causes of hydroclimatic variability over California. These research questions will include: 1) to what extent are precipitation variations over the Central Valley synchronous from north to south over the past five centuries? 2) To what extent, under what circumstances do the Sacramento and San Joaquin basins exhibit anti-phase hydroclimatic variability? 3) To what extent do the Sierra Nevada and Coast Ranges exhibit coherent or anti-phase hydroclimatic behavior? 4) Does the north-south or east-west hydroclimatic variability alter the probability for drought or wetness extremes on an annual or decadal basis? 5) Can the dense spatial array of tree-ring chronologies improve our understanding of how the zonal vs. meridional orientation of the mean winter storm track relative to the orographic barriers affects moisture storage in snowpack (i.e., zonal) or heavy low-elevation precipitation and flood hazard (meridional)? 6) Can the dense network of oak chronologies be used to discriminate between warm-wet vs. cool-wet and warm-dry vs. cool-dry winter-spring conditions over the past 500 years (the highest and lowest flows tend to occur during warm-wet and cool-dry conditions, respectively). 7) Can the extended tree-ring record of California climate help identify the influence and temporal stability of large-scale climate features associated with California precipitation (e.g., atmospheric circulation, Pacific SST's)? 8) What is the likelihood of N-year sequences in any of the foregoing behavior (i.e., persistence of unusual patterns)? 9) How common have "regime shifts" been in the hydroclimatic history of California? Answers to these questions will provide an important context for the potential future climate that is likely to be experienced during and beyond the Bay-Delta restoration time frame.

**2b. Ancient Blue Oak Mapping**

The ecology and conservation of California oaks have been the subject of intensive research (e.g., "Year of the Oak" in *Fremontia* July 1990; and *Oaks of California*, 1991, by Pavlik et al). In spite of these and many other excellent oak studies, the widespread survival of centuries-old, presettlement blue oak woodlands in California is not widely realized. These remnant blue oak woodlands are often dominated by a canopy of remarkably old trees (i.e., 300- to 500-year old individuals, at or near the maximum longevity for *Q. douglasii* or for any species in the genus *Quercus*). These woodlands are not necessarily free of past human disturbances such as grazing, altered fire regimes, and changes in the species composition of grasses and herbaceous plants. However, the magnitude of these human disturbances varies greatly, and we hypothesize that ancient blue oak remnants can include some of the least altered ecosystems left in the drainage basin of San Francisco Bay. Unfortunately, many of these presettlement blue oak remnants are imperiled by continued agricultural expansion, suburban and exurban development, and by slow or highly episodic natural regeneration. The root rot fungus (*Phytophthora*) has yet to widely impact blue oak, but this fungus is responsible for heavy mortality in native coast live oak (*Q. agrifolia*) and tanoak (*Lithocarpus densiflora*) woodlands of California and the threat to blue oak remains very real (e.g., Raabe 1990).

Blue oak cover has been previously mapped (Figure 1), but this mapping does not discriminate relatively undisturbed old-growth blue oak forests from second and third-growth blue oak stands that have been more heavily disturbed by human activities. Accurate mapping of these *ancient* blue oak forests will provide public and private land managers with information that presently does not exist, but is necessary for conservation management of these important woodland and watershed resources.

To accurately locate and map old-growth blue oak, we will field test and then analytically refine a predictive model for the specific spatial distribution of ancient blue oak woodlands in California. The initial predictive model will be based simply on the blue oak cover illustrated in Figure 1. In many parts of California "blue oak cover" and "*ancient* blue oak woodlands" are identical, but this not true everywhere, of course. The proposed research will specifically field test the hypothesis stating that a sizeable fraction (>25%) of the blue oak cover illustrated in Figure 1 does indeed include canopy dominant blue oak trees in the 150- to 500-year age class. We have previously visited a number of areas identified in Figure 1, and have found extensive tracts of truly ancient blue oak woodlands.

## 3. APPROACH

### 3a. Tree-Ring Chronology Development

We will randomly select 50 ancient blue oak forests throughout the natural range of the species (Figure 1) to develop the tree-ring chronologies and to estimate and map ancient blue oak woodlands still left in the drainage basin of San Francisco Bay (see section 3e below). To maximize the tree growth response to wet as well as dry extremes, we will extract nondestructive increment cores from a random sample of 40 trees ≥10cm DBH (diameter at breast height). Each chronology will be based on these 40 trees of all age classes, and will be augmented with selective core samples from the oldest trees and relic wood to maximize chronology length (for a total of 50 to 60 trees per site). All chronologies should be 300-years long, and many should extend back 450- to 500-years. We will constrain the random sample of 50 collection sites to ensure that the full latitudinal, longitudinal, and vertical distribution of the species is adequately sampled (for a total of 50 site chronologies).

The existing network of only 12 blue oak chronologies is not sufficient to reproduce the detailed spatial structure of winter-spring precipitation anomalies over California (Figure 7). Furthermore, the 12 available chronologies are slightly asymmetrical in response to precipitation extremes, with a faithful reproduction of the driest years, but a tendency to underestimate precipitation in the extreme wet years (Figures 4,8). This truncation effect is well known in dendroclimatology (see the law of limiting factors in Fritts 1976), and although comparatively modest in these exceptionally sensitive blue oak, it will be difficult to overcome without including explicit measures in the sampling design of the proxy network. This is one motivation for proposing the dense network of 50 new tree-ring chronologies, the random selection of trees in all age classes (including young, vigorous trees), and sampling near the upper and lower elevational limits of the species distribution, all in order to help maximize the growth response to heavy precipitation extremes. Tree-ring chronologies from young and mature trees are often more variable and responsive to precipitation than senescent trees, and our random sampling will help ensure that "young" trees (e.g., <100 years old) contribute to chronology variance during all time periods. We will also carefully record the microsite conditions for each sample tree to identify the environmental setting under which blue oak growth responds most favorably to extremely wet years (e.g., ridgeline, mid slope, toe slope), and then use this particular environmental subsample of trees in the reconstruction of wet years.

The tree-ring cores will be exactly dated using the Douglass (1941) method of crossdating, and all dated rings will be measured with a microscope and stage micrometer to 0.001mm. The computer program COFECHA (Holmes 1983) will be used to ensure tree-ring dating and measurement accuracy. The computer program ARSTAN (Cook 1985) will be used to develop mean ring-width index chronologies for all 50 sample sites. Age/size related growth trends will be removed from the ring-width time series for each tree using curve-fitting procedures (i.e., negative exponential, straight lines, or cubic smoothing spines will be fit to each time series, and the ring-width index will be computed as a ratio of the fitted curve value to the actual ring-width measurement for each year; Cook 1985). The ring-width index time series from each tree will be averaged by true calendar year into the mean ring-width index chronology for each site, using a robust mean value function (Cook 1985). The mean index chronology will also be prewhitened with autoregressive modeling techniques. The derived time series will be normally distributed white noise, which tends to also be true of divisional cool season precipitation totals in California. The distribution of cool-season precipitation for individual stations may deviate from normality.

**3b. Single-Station Precipitation Reconstructions**

The widely distributed and well replicated network of 50 blue oak tree-ring chronologies will be used to develop a suite of precipitation and streamflow reconstructions in the drainage basin of San Francisco Bay. The proposed single-station reconstructions will be used for detailed analysis of the temporal and spatial variability in precipitation and runoff over the past 300- to 500-years.

The blue oak tree-ring chronologies measure spring-summer tree growth that in turn is correlated with cool season precipitation (Oct-April). The standardized monthly precipitation anomalies for several weather stations closest to each tree-ring chronology will be interpolated to the tree-ring site locations using inverse distance weighting (Jones and Hulme 1996). This method has been recently applied by one of the PI's in the regionalization of summer precipitation in Arizona (Meko and Baisan 2001). Only those precipitation records in or near the elevation range of blue oak will be used for interpolation. These monthly data will then be seasonalized into cool season precipitation totals for the immediate vicinity of each tree-ring chronology. We expect to reconstruct cool-season totals (e.g., October-April), but the final choice of season will depend on exploratory data analysis.

Each tree-ring chronology can then be calibrated with its associated seasonal precipitation data using regression (e.g., Fritts 1976, Cook and Kairiukstis 1990, Stahle and Cleaveland 1992). This will result in an irregular grid of 50 single-station precipitation reconstructions for the cool season covering most of California and the San Francisco Bay drainage basin.

Because of possible nonlinearity in the relationship between tree rings and river flows, we will explore field and statistical methods for optimizing the tree-ring reconstruction of extremely low or high annual flows. Field notes will allow us to later stratify the tree-ring data into predictor subsets according to soil moisture characteristics of the collection site. All tree-ring predictors will then be entered into candidate statistical models with the goal of accurate reconstruction of both extreme low and high flows. Models to be considered will include classification and regression trees (e.g., Meko and Baisan 2001) and neural networks (Zhang et al. 1999; Woodhouse 1999).

The length of calibration series will depend on screening of the instrumental precipitation data. The Jones and Hulme (1996) method will allow the interpolated data to extend back to the start of the earliest instrumental precipitation series with a continuous record in a region. But each interpolated series may not be statistically stable until sample depth (number of stations) increases to perhaps three or more. Many instrumental precipitation records for California are quite long compared with records elsewhere in the western United States. Fairly good records for several locations are available back to the 1870s. For example, one study by the California Department of Water Resources used a network of 19 precipitation records with data back to 1872 and "good regional coverage" of the Sacramento Basin and along the coast (Roos 1973). The oldest precipitation records in California extend back to 1850, but the early decades are of questionable quality (Roos 1973). Monthly precipitation data will be obtained from Web sites of the California Department of Water Resources (http://cdec.water.ca.gov/selectQuery.html) and the Western Regional Climate Center (www.wrcc.dri.edu). Some adjacent single-station tree-ring reconstructions may end up sharing one or two instrumental precipitation series for calibration, but we believe this redundancy can be minimized. The grid of 50 precipitation reconstructions finally derived will be extremely valuable for detailed mapping of seasonal precipitation anomalies over the drainage basin of San Francisco Bay for every year during the past 500-years.

**3c. Regional Precipitation Reconstruction**

The instrumental precipitation data will then be grouped geographically so that separate reconstructions can be generated for five major subdivisions within the drainage basin of San Francisco Bay (northern Sacramento River above Bend Bridge, southern Sacramento River below Bend Bridge, San Joaquin River, Tulare Lake, and San Francisco Bay). We are splitting the Sacramento Province into northern and southern provinces because the Sacramento River basin is huge and has important north/south gradients in moisture. An additional stratification will be the high-elevation and low-elevation subsets of stations for the Sacramento, San Joaquin and Tulare provinces. These provinces include steep elevational gradients from the Central Valley floor up into the important runoff producing parts of the Sierra Nevada. Separate reconstructions for the upper and lower portions of the blue oak range will enable us to study possible elevation dependence in the strength of hydrologic signal in the oak tree rings, particularly during wet extremes. Given the data stratification, cool seasonal precipitation time series will be reconstructed for 13 large regional subdivisions (Table 1).

The single station and regional precipitation reconstructions will be used to document interannual to decadal hydroclimatic variability over the drainage basin of San Francisco Bay. The centuries-long reconstructions will be searched for possible analogs to major 20th century anomalies in precipitation (e.g., the pluvials from 1906-1911 and 1940-1943, and the extended droughts from 1929-1934 and 1987-1992). The frequency of two-year drought extremes such as 1976-1977 can also be explored in the spatial/temporal patterns of past precipitation. Analyses of the available blue oak chronologies reveals significant spectral power in the 6- to 8-year range over the past 400 years (Redmond et al. 2001). This suggests wet and dry spells of similar duration, as witnessed during the 20$^{th}$ century. The 8-year Sierra drought and subsequent 5-year wet episode in the 1980's and 1990's are the latest examples, and pose a particular challenge to water and ecosystem management. We are also interested in testing the conditional probability of drought and wetness extremes (for example, is there a significant increase in drought risk following a drought extreme?); and exploring the possible non-stationary interaction of large-scale climate forcing of California precipitation from the tropical and north Pacific Ocean.

## 3d. Hydrological Reconstructions

"Full natural flow" (FNF) time series for selected river gages and river systems will be reconstructed from tree rings. Full natural flow, also called "unimpaired runoff," is the natural water production of a river basin unaltered by upstream diversions, storage, evaporation from reservoirs, or by export or import of water to or from other watersheds. FNF data updated regularly are available from the Web site of the Department of Water Resources, State of California, for all major rivers in California.

The FNF reconstructions will complement the precipitation reconstructions described above in unraveling the hydroclimatic history of the region. Blue oak growth is highly correlated with both precipitation and FNF in the few sectors of the San Francisco Bay drainage basin studied thus far, but it is unclear in advance whether FNF or precipitation will be more strongly recorded by the oaks. Favoring precipitation is the fact that much of the river runoff originates from outside the immediate region sampled by the oak. The FNF signal in this case depends on spatial correlation of precipitation anomalies from the oak sites to, say, the remote higher elevations of the Sierra Nevada. Favoring FNF is the fact that runoff reflects precipitation summed over a large region relative to individual climate stations. This accumulation may lead to less localized noise in FNF than in precipitation. Also favoring FNF is that FNF is a residual of precipitation minus evapotranspiration, a residual also expected to be associated with drought stress in trees. Regardless of which hydroclimatic variable is best, the FNF reconstructions will be valuable in their own right for their direct information on time series variation in water supply from rivers of interest.

The statistical method for FNF reconstruction will be multiple linear regression (Weisberg 1985), possibly with principal components transformation of predictors (Mardia et al. 1979). Depending on results of exploratory data analysis, data may be transformed beforehand to ensure that the linear model is appropriate. To maintain the subregional integrity of the flow reconstructions, only those tree-ring chronologies geographically near or within the watershed will be used in reconstructing any particular flow series.

At the regional scale, the remarkable sensitivity and wide distribution of blue oak in the Central Valley make them prime candidates for the reconstruction of flow in individual rivers. We will develop as many 500-year long river-by-river reconstructions as possible, evaluating the best regions, seasons, and statistical methods. From these individual river results, two additional sets of analyses will be conducted to characterize regional streamflow: 1) multivariate singular-spectrum analysis to identify the dominant spatial patterns that have characterized tree growth and streamflow on distinct timescales (e.g., ENSO and North Pacific timescales), and 2) a modified form of principal component analysis (PCA) related to the multivariate alteration detection algorithm. These modifications attempt to more accurately segregate “noise” and “memory” from climate “signal” in the tree ring and streamflow series.

At a larger scale, separate reconstructions will be made of FNF series for the Sacramento and San Joaquin Rivers, as defined by the California Department of Water Resources. Sacramento River runoff, also known as the Sacramento River Index, is the sum of Sacramento River flow at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River flow at Smartville, and American River inflow to Folsom Lake. San Joaquin River runoff is the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake. Time series of the ratio or difference of the two reconstructions over five centuries will be analyzed to identify variability in the north/south coherence of anomalous runoff contributions from the Sacramento and San Joaquin Rivers. This information is important to water supply planning for California, and will also help us identify time series changes in dominance of zonal versus meridional precipitation delivery systems.

At the largest basin-wide scale, we will also reconstruct seasonal Delta inflow, the longitudinal position of the null zone (the freshwater-seawater interface, or X2), and San Francisco Bay salinity. These hydrological parameters massively integrate precipitation and streamflow over time and space, and appear to be important to biological productivity and population levels of certain at-risk species. We have already demonstrated that blue oak chronologies can provide an excellent proxy for San Francisco Bay salinity

(Stahle et al., 2001), and believe that high quality estimates of Delta inflow and X2 can also be derived.

**3e. The Influence of Large Scale Climate Variability**

This project will explore the connection between observed and reconstructed precipitation and streamflow variability and large-scale climate patterns. These analyses will help determine how well wet and dry spells might be predicted, and how projected anthropogenic climate change might impact natural hydroclimatic variability over California.

PCA will be used to identify modes of precipitation and streamflow varaibility during the instrumental and preinstrumental periods (nominally 1900-present and 1500-1900, respectively). Large-scale climate variability during the instrumental period will be represented by PCA of sea level pressure and geopotential height over the Northern Hemisphere, global sea surface temperature (SST), global surface air temperature, selected large-scale circulation indices (e.g., ENSO, the Pacific-Decadal Oscillation, and the North Atlantic Oscillation), and the station precipitation and temperature data for North America. Large-scale climate variability during the preinstrumental period will be represented by various proxy reconstructions of ENSO, PDO, global mean temperature, and continent-wide temperature and drought estimates.

These data and analyses will be used to address the following questions: 1) What fraction of Bay-Delta hydrological variability is controlled by large-scale ocean-atmospheric circulation, and how are the large modes translated into the regional patterns that actually control precipitation (e.g., Weaver 1962)? 2) Have circulation influences on the Bay-Delta region changed over time, including the possible interaction of ENSO and the PDO (Hoerling et al., 1997, Gershunov et al., 1999, McCabe and Dettinger 1999, see also Figure 6). 3) How have the north-south "seesaw" modes that dominate precipitation variability across North America (Dettinger et al. 1998) behaved over the past 500-years, especially with respect to the Bay-Delta region? 4) Does anomalous precipitation correlate with temperature over California and western North America at interannual to decadal scales? Temperature during precipitation events can strongly influence snow accumulation, and the nature and timing of streamflow (Roos 1991, Redmond and Koch 1991, Cayan 1996). This issue also bears on how well we might anticipate the impacts of anthropogenic climate change, since we will probably have to deal with both temperature and precipitation changes in the coming decades (Jeton et al. 1996).

**3f. Ancient Forest Mapping**

In developing the network of tree-ring chronologies we will randomly select 50 old-growth blue oak sites in order to map fine-scale spatial anomalies in reconstructed precipitation over the past five centuries, and to estimate and map how much ancient blue oak woodland still exists in California. This objective will be met by stratified random testing of an initial predictive model based only on the co-occurrence of two blue oak cover maps (Figure 1). We will then develop a refined predictive model/mapping of *ancient* blue oak cover based on statistical analyses of the environmental and tree-ring data collected at 50 old-growth study sites visited during field testing. This refined predictive model will then be randomly field-tested in year three to estimate the accuracy and precision of the derived *ancient* blue oak mapping in California (emphasizing high quality *ancient* forests as opposed to second growth woodlands more heavily affected by man).

We have already compiled an initial predictive model of "blue oak cover" (Figure 1) using a GIS and two digital hardwood cover data sets produced by the California Department of Forestry and Fire Protection (CDF; see Pillsbury et al. 1991, Pacific Meridian Resources 1994). The first data set includes a grid of 25m cells derived from supervised classification of Thematic Mapper (TM) satellite imagery from 1989-1991 (PMR 1994). Each cell is labeled as one of five hardwood cover types [including Blue Oak Woodland (BOW) and Blue Oak/Gray Pine (*Pinus sabiniana*) Woodland (BOP)], along with seven other land cover types (e.g., urban, grass, shrub, water). The second data set is based on an analysis of low-level 1981 aerial photographs, and is composed of polygons that show large areas (minimum 16ha) of the same five hardwood cover types as used for the TM grid data. Our initial predictive model is based only on those areas identified as BOW or BOP by both the satellite data and aerial photographs, and is illustrated in Figure 1. Our previous field research indicates that ancient blue oak is well represented in both pure blue oak and in blue oak/gray pine woodlands, and we have combined the two types to define “blue oak cover” and initiate our field sampling. The spatial extent of these combined cover types is 1,186,310ha (2.9 million acres, Figure 1).

The California GAP Project has also mapped blue oak cover in the state and it is reassuring to note that the blue oak cover data illustrated in Figure 1 are highly consistent with the GAP mapping of blue oak cover (>90% agreement). The differences between GAP and Figure 1 appear to be due to two factors: 1) the minimum mapping unit for GAP was 1km$^2$ (100ha) so other land cover types are included, and 2) the PMR classification did not use the California Wildlife Habitat Relationships System (WHR) employed by GAP so the classifications of the two systems are not always equivalent, particularly concerning the montane hardwood class (see PMR 1994 p.81, and Davis et al. 1998). The blue oak cover data in Figure 1 have a minimum mapping unit of $625 m^2$ (25x25m) and are more suited for the proposed analysis of ancient blue oak woodlands. Extensive preliminary field inspection of the data in Figure 1 indicates that this mapping of blue oak cover is quite accurate, and that indeed much of this cover type includes exceptionally old blue oak trees.

The preliminary ancient blue oak predictive model (Figure 1) will be field tested at 50 randomly sampled locations using standard size 50 x 400m transects (2ha each). The sampling will be stratified to ensure that the full elevation range of blue oak and the five drainage regions are represented (see section 3c). Land cover found within each sample transect will be measured and classified into one of three categories: ancient forest, second growth, or non-forest land. The key category is "ancient forest," and the primary criterion for classification of a stand into this category will be the presence of 150- to over 500-year old trees in a largely intact forest or woodland canopy. Old-growth blue oak can be easily recognized in the field (see Stahle 1997, Stahle and Chaney 1994, or Therrell and Stahle 1998 for a discussion of the external attributes of ancient oaks). The random samples of 40 trees ≥10cm DBH can also be used to define "ancient forest" quantitatively for the purposes of testing and refining our predictive model. "Ancient forest" will be identified when ≥10% of the 40 sample trees in each transect exceed 150 years in age. For comparison, 14% of a random sample of 620 post oak (*Q. stellata*) ≥10cm DBH were over 150 years old in 15 ancient Cross Timbers forests of eastern Oklahoma, a deciduous oak savannah not unlike the blue oak woodlands (Mangioni 2001).

Areas classified as "second-growth" forests will be dominated by young trees (i.e., <10% of sample trees >150-years old), and may have extensive evidence for human disturbance. "Non-forest land" will be shrubland or cleared land misidentified by the initial predictive model as wooded terrain, or woodlands that were cleared subsequent to the acquisition of the remote sensing data starting in 1989.

The predictive model will certainly not perform with complete accuracy. In cases where a randomly selected transect does not include ancient forest, we will randomly select another area of ancient blue oak within a 10 km radius of the test site to obtain the tree-ring collections and vegetation data (using the same 2ha transect design). If no ancient blue oak stands can be found within a 10km radius of the sample site we will continue to the next randomly selected transect. We will ensure that the *first* 50 randomly selected sites will be used to test the predictive model, and that a total of 50 ancient forests will be randomly sampled to acquire the tree-ring chronologies for hydroclimatic reconstruction and the environmental data needed to refine our predictive model. All sample transects will be accurately located using landscape orientation off of 7.5 minute USGS topographic maps and a global positioning system (GPS).

A random sample of cores from 40 trees and descriptive vegetation data will be obtained at each site using a modification of the point-quarter sampling method (Cottam and Curtis 1956). At ten points along the 400m transect we will record the species, distance from the sampling point, and diameter at breast height (DBH) of the nearest tree and sapling in each of the four quadrants (and within the 50 x 400m transect; breast height = 1.4m). These data will be analyzed to determine the species density, basal area, and composition of each stand. We will also determine sapling to tree density ratios for each species (trees = >10cm DBH; saplings = >1.4m height, but <10cm DBH). At each of the ten sample points in each transect, core specimens will be extracted non-destructively with a Swedish increment borer from one blue oak (>10cm DBH) in each of the four quadrants (40 trees per transect). However, we will also selectively core additional old trees and relic wood at each site in order to maximize the length of the derived tree-ring chronologies for paleoclimatic applications. These selected old trees will not be included in testing the accuracy of the predictive model.

Ancient blue oak forests are super-abundant in California, but the "blue oak cover" identified by remote sensing in Figure 1 is not synonymous with "*ancient* blue oak cover." Much of this forested landscape has been recently impacted by vineyards, home construction, livestock grazing, and fuelwood harvesting, and will not meet our criteria for ancient forest. Therefore, the tree-ring and environmental data gathered during the fieldwork will be used to develop a refined predictive model, based on the geographic variables found to be important to the survival of the 50 old-growth remnants located during fieldwork. Previous studies have found that variables such as degree of slope, exposure, infertile soil, rock outcrop, and remote terrain are associated with old growth forest remnants in heavily developed regions of the eastern woodlands (Stahle and Chaney 1994, Stahle 1997, Therrell and Stahle 1998). These variables, and others, are certain to be important in locating the least disturbed blue oak sites in California because they help define the non-commercial status of these woodlands.

Our final task will be to field test the refined predictive model in year three. This final field test will be based on measurement of the same three cover types (ancient blue oak woodland, second growth, and non-forest) in 50 2ha transects randomly selected from the polygons of our refined model. This tested predictive model will be an outstanding tool for the identification and conservation of high quality ancient blue oak woodlands in critical watersheds of California.

## 4. FEASIBILITY

Preliminary analyses (Stahle et al. 2001, Redmond et al. 2001) indicate an excellent opportunity to develop the vital historical and modern climate context for the CALFED ERP. We have developed a tightly organized research design that will be executed by an expert team of dendrochronologists, climatologists, and hydrologists, each with specific responsibilities. However, the tree-ring chronologies must be developed before the hydroclimatic reconstructions and analyses can proceed. For this reason, the fieldwork will proceed on a regional basis and we will complete subsets of about 10 chronologies per area (e.g., the San Joaquin basin) before initiating fieldwork in other subregions. This design will ensure that all collaborators will begin work in year 1, and continue research throughout the three-year project.

The proposed tree-ring sampling is non-destructive (5mm cores are extracted without harming the tree), but we will obtain written permission for fieldwork from all property owners. Therefore, our first task will be to randomly sample the blue oak cover data, determine the property owners of each potential sample site, and then request written permission to conduct field research. The UAF TRL has over 20 years of experience with this very problem. We have already obtained written permits for blue oak sampling on properties managed by the California Department of Parks and Recreation, California Department of Fish and Game, the National Park Service, the USDA Forest Service, the US Bureau of Land Management, and many individual landowners. However, we will reapply for all Federal, State, and private permits needed for the proposed research.

Many outstanding tree-ring chronologies have already been developed in California, including the famous Methuselah Walk bristlecone pine record from the White Mountains which is one of the longest tree-ring chronologies ever developed (Schulman 1958). Several excellent dendroclimatic reconstructions have also been published for subregions of California (e.g., Meko et al. 1980, Hughes and Brown 1992, Haston and Michaelsen 1994). However, the extraordinarily strong precipitation signal in ancient blue oak trees that are very widely distributed in California present an unprecedented opportunity to accurately and systematically document precipitation variability across the drainage basin of San Francisco Bay for the past three to five centuries. These unique trees will also permit development of improved reconstructions of streamflow, Delta inflow, X2, and estuarine salinity. Such detailed hydroclimatic reconstructions, including wet and dry extremes, have rarely been attempted because of the stringent sampling requirements and the heavy effort involved in the development of 50 massively replicated tree-ring chronologies. But because old, moisture sensitive blue oak are so widespread, we believe that the proposed network of 50 long blue oak chronologies can indeed be developed.

### 5. Performance Measures (see Table 2)

### 6. Data Handling and Storage

The UAF TRL is an official repository of the University of Arkansas Museum. All core collections will be accessioned and permanently curated in the Museum, where the wood itself will be available for further research by the scientific community. The digital ring width, chronology, and reconstruction data will be distributed on CD. They will also be contributed to the National Geophysical Data Center, operated by NOAA in Boulder, CO, where they will be available via anonymous ftp. The WRC is a NOAA-sponsored archive. All climate records and reconstructions will also be available from the WRC. The final mapping of ancient blue oak cover will also be written to CD, posted on the UAF TRL website, and distributed to interested agencies and individuals.

### 7. Expected Outcomes/Products

The research team will present project results each year at national, regional, and CALFED meetings. We will also publish the results extensively in the refereed scientific literature, in the popular press, and via the Web. The data will be made widely available in digital format. The four institutions involved share a strong mandate to reach a wide audience, and have extensive experience in the education, research, and public arenas. The web pages of the WRC (www.wrcc.dri.edu) receive about 35,000 accesses per day, and will serve this project as an outlet for the proposed data and results.

### 8. Work Schedule (see Table 3)

## B. APPLICABILITY TO CALFED ERP GOALS

The impact of natural climatic and hydrological variability on ecosystem dynamics and water management is a major uncertainty that underlies many of the priorities and goals of the CALFED ERP. The major contributions of the proposed research to the CALFED mission will be to: 1) substantially improve our understanding of the system-wide natural hydrodynamic regimes which CALFED is designed to re-establish and maintain (Strategic Goals 1 and 2), and 2) to inventory, map, and thereby help conserve a major native biotic community in the Bay-Delta watershed (i.e., blue oak woodlands, Strategic Goals 1 and 4). The ERP is focused on habitats in the riparian zone and adjacent floodplain, but the CVPIA authorizes projects that contribute to protection and restoration of associated habitats in the Central Valley, including the valley-foothill hardwood habitat that includes vast areas of ancient blue oak (CALFED ERP, Draft Stage 1 Implementation Plan, 2001, p.17).

The proposed research is multiregional and will provide accurate long-term data on the natural hydrodynamics of the Sacramento, San Joaquin, Delta/Eastside Tributaries, and Bay regions of CALFED. This project is specifically relevant to the MR-4 priority concerning climate and hydrologic variability. We will provide information that currently does not exist on the interannual to decadal variability of precipitation and streamflow across the entire CALFED region. We will also produce empirical data on extreme low-flow conditions in various streams over the past several centuries which we believe will assist the development of conceptual models of community dynamics for salmonids or other at-risk species (MR-6).

The proposed research is relevant to the following regional priorities:

SR-3, SJ-6, DR-8: We will provide long-term data needed to define precipitation variability and natural flow regimes, and will identify human modifications to natural flow (see Stahle et al., 2001 for the use of blue oak data to discriminate between natural and human-altered salinity in San Francisco Bay).

SR-7: The proposed data will be useful for developing interdisciplinary conceptual models of fish population levels. Extreme low-flow conditions reduce freshwater habitat area and stress fish populations. Tree-ring data have been linked to fish growth indices in other ecosystems (e.g., Guyette and Rabeni 1995), and potential applications in the CALFED regions will be explored.

BR-3, BR-5, BR-7: The proposed Delta inflow, X2, and estuarine salinity reconstructions will provide a long term perspective on hydrologic regimes that may be related to the success of some at-risk species, and may be linked in part to the invasion of non-native species.

## C. QUALIFICATIONS

The members of the research team are recognized experts in their fields. Dr. David Stahle is the Director of the UAF TRL, Dr. David Meko is a Principal Research Scientist in the UAZ Laboratory of Tree-Ring Research, Dr. Daniel Cayan is the Director of the Climate Research Division at the SIO, Dr. Michael Dettinger is a Research Hydrologist with the U.S. Geological Survey and SIO, and Dr. Kelly Redmond is the Deputy Director/Regional Climatologist at the

Western Regional Climate Center in Reno, NV. Each investigator has published extensively on the type of data and analyses proposed for this project (a selection of key citations are listed below, also see the literature cited).

Cayan, D.R., K.T. Redmond, and L.G. Riddle, 1999: ENSO and hydrologic extremes in the Western United States. *J. of Clim.*, **12**(9), 2881-2893.

Cayan, D.R., Dettinger, M.D., Diaz, H.F., and Graham, N., 1998, Decadal variability of precipitation over western North America: *J. Clim.*, 11:3148-66.

Dettinger, M.D., and Cayan, D.R., 1995, Large-scale atmospheric forcing of recent trends toward early snowmelt in California: *J. Clim.* 8(3), 606-623.

Dettinger, M.D., Ghil, M., Strong, C.M., Weibel, W., and Yiou, P., 1995, Software expedites singular-spectrum analysis of noisy time series: *Eos, Transactions of American Geophysical Union* 76(2), pp. 12, 14, 21.

Dettinger, M.D., Cayan, D.R., Diaz, H.F., and Meko, D., 1998, North-south precipitation patterns in western North America on interannual-to-decadal time scales: *J. Clim.*, 11, 3095-3111.

Meko, D.M., Stockton, C.W., and Blasing, T.J., 1985, Periodicity in tree rings from the corn belt: *Science*, v. 229, p. 381-384.

Meko, D.M., 1997, Dendroclimatic reconstruction with time varying subsets of tree indices: *J. Clim.*, v. 10, p. 687-696.

Meko, D.M., Therrell, M.D., Baisan, C.H., and Hughes, M.K., 2001, Sacramento River flow reconstructed to A.D. 869 from tree rings: *J. of the American Water Resources Association*, v. 37, no. 4, p. 1029-1040.

Redmond, K.T., 2000. Integrated climate monitoring for drought detection. In: *Drought: A Global Assessment.* Volume I, Ed. D.A. Wilhite, pp. 145-158, Hazards and Disasters Series, Routledge, London and New York.

Stahle, D.W., M.K. Cleaveland, D.B. Blanton, M.D. Therrell, and D.A. Gay, 1998. The Lost Colony and Jamestown Droughts. *Science* 280, 564-567.

Stahle, D.W., et al., 2000. Tree-ring data document 16th century megadrought over North America, *Eos* 81(12):212, 125.

Stahle, D.W., M.D. Therrell, M.K. Cleaveland, D.R. Cayan, M.D. Dettinger, and N. Knowles, 2001. Ancient blue oak reveal human impact on San Francisco Bay salinity. *Eos* 82 (12) 141, 144-145.

Therrell, M.D., and D.W. Stahle, 1998. A predictive model to locate ancient forests in the Cross Timbers of Osage County, Oklahoma. *J. Biogeography* 25:847-854.

**D2 COST SHARING** (none)

**E. LOCAL INVOLVEMENT** (none yet developed, but many presentations are planned to help raise public awareness of the abundance, scientific value, and conservation potential for ancient blue oak woodlands.)

**F. COMPLIANCE WITH STANDARD TERMS AND CONDITIONS**
(see letter from the University of Arkansas faxed with signed cover page)

**G. LITERATURE CITED**


Cayan, D.R., 1996. *Journal of Climate* 9:928-948.

Cook, E.R., 1985. *A Time Series Approach to Tree-Ring Standardization.* Ph.D. dissertation, University of Arizona, Tucson.

Cook, E.R. and L. Kairiukstis (eds.), 1990. *Methods of Tree-ring analysis: applications in the Environmental Sciences.* Kluwer Academic Publishers, Dordrecht.

Cottam G., and J.T. Curtis, 1956. *Ecology* **37**:451-460.

Davis, F.W., D.M. Stoms, A.D. Hollander et al., 1998. *The California GAP Analysis Project—Final Report.* University of California, Santa Barbara, CA. [http://www.biogeog.ucsb.edu/projects/gap/gap_rep.html]

Dettinger, M.D., D.R. Cayan, H.F. Diaz, and D.M. Meko, 1998. *Journal of Climate* 11(12):3095-3111.

Douglass, A.E., 1941. *Journal of Forestry* **39**:825-831.

*Fremontia*, 1990. Year of the Oak. *Fremontia*, 18(3)1-112.

Fritts, H.C., 1976. *Tree Rings and Climate*. Academic Press, New York.

Gershunov, A., T.P. Barnett, D.R. Cayan, 1999. *Eos* 80(3):25-30.

Guyette, R.P., and C.F. Rabeni, 1995. *Oecologia* 104:272-279.

Haston, L., and J. Michaelsen, 1994. *Journal of Climate* **7**:1373-1387.

Hoerling, M.P., A. Kumar, M. Zhong, 1997. *Journal of Climate* 10:1769-86.

Holmes, R.L., 1983. *Tree-Ring Bulletin* **43**:69-78.

Hughes, M.K., and P.M. Brown, 1992. *Climate Dynamics* **6**:161-167.

Jeton, A.E., M.D. Dettinger, and J.L. Smith, 1996. *USGS Water Resources Investigations Report* 95-4260, 44pp.

Jones, P.D., and M. Hulme, 1996. *Int. J. of Climatology* 16:361-377.

Mangioni, M., 2001. MA Thesis, University of Arkansas (in preparation).

Mardia, K., Kent, J., and Bibby, J., 1979, *Multivariate Analysis*: Academic, 518.

McCabe, G.J. and M.D. Dettinger, 1999. *Int. J. of Climatology* 19:1399-1410.

McClaran, M.P. and J.W. Bartolome, 1990 *J. Range Management* **43**(1):61-63.

Meko, D.M., C.W. Stockton, and W.R. Boggess, 1980. *Water Resources Bulletin* **16**:594-600.

Meko, D.M., and Baisan, C.H., 2001. *Int. J. of Climatology* 21:697-708.

Meko, D.M., M.D. Therrell, C.H. Baisan, and M.K. Hughes, 2001. *Journal of the American Water Resources Association* (in press).

Pavlik, B.M., P.C. Muick, S. Johnson, and M. Popper, 1992. *Oaks of California*.. Cachuma Press, Los Olivos, CA.

Pillsbury, N., M. De Lasaux, R. Pryor and W. Bremer, 1991. *Mapping and GIS Database Development for California's Hardwood Resources*. California Department of Forestry and Fire Protection, Forest Rangeland Resources Assessment Program. Sacramento, CA.

Pacific Meridian Resources (PMR), 1994. *California Hardwood Rangeland Monitoring Final Report*. California Department of Forestry and Fire Protection, Sacramento, CA.

Raabe, R.D., 1990. *Fremontia* 18(3):64-67.

Redmond, K.T., D. Stahle, D. Cayan, M. Dettinger, and M. Therrell, 2001. 18th PACLIM Workshop, Asilomar, CA, March 18, 2001.

Redmond, K.T., and R.W. Koch, 1991. *Water Resources Research* 27:2381-99.

Roos, M., 1973, Drought probability study, Sacramento River Basin: Memorandum Report, California Department of Water Resources, 90 pp.

Roos, M., 1991. 59th Western Snow Conference, Juneau, AK.

S.F. Estuary Project, 2000. *State of the Estuary 2000.* Oakland, CA.

Schonher, T., and S.E. Nicholson, 1989. *Journal of Climate* 2:1258-1269.

Schulman, E., 1958. *National Geographic* 113:355-372.

Stahle, D.W., 1997. *Arnoldia* 56(4):2-10.

Stahle, D.W., and M.K. Cleaveland, 1992. *Bulletin of the American Meteorological Society* 73:1947-1961.

Stahle, D.W., and P.L. Chaney, 1994. *Natural Areas Journal* **14**:151-158.

Stahle, D.W., M.D. Therrell, M.K. Cleaveland, D.R. Cayan, M.D. Dettinger, and N. Knowles, 2001. *Eos* 82(12)141, 144-145.

Standiford, R.B., 1997. *USDA Forest Service Gen. Tech. Report*, PSW-GTR-160.

Therrell, M.D., and D.W. Stahle, 1998. *Journal of Biogeography* **25**:847-854.

Therrell, M.D., and D.W. Stahle, 2000. Am. Quaternary Association: *AMQUA ABSTRACTS*, Fayetteville, AR.

Weaver, R.L., 1962. *Meteorology of hydrologically critical events in California.* Hydrometeorological Report 37, U.S. Weather Bureau, Washington D.C.

Weisberg, S., 1985, *Applied Linear Regression*, 2nd ed., John Wiley, New York, 324 pp.

Woodhouse, C.A., 1999. *The Holocene* 9:521-529.

Zhang, Q.-B., Hebda, R.J., Zhang, Q.-J., and Alfaro, R.I., 1999. *Forest Science* 46:229-238.

Table 1. Regional precipitation reconstructions.

| Number | Region | Variable |
|---|---|---|
| 1 | northern Sacramento drainage | Total precipitation |
| 2 | northern Sacramento drainage | Low elevation precipitation |
| 3 | northern Sacramento drainage | High elevation precipitation |
| 4 | southern Sacramento drainage | Total precipitation |
| 5 | southern Sacramento drainage | Low elevation precipitation |
| 6 | southern Sacramento drainage | High elevation precipitation |
| 7 | San Joaquin drainage | Total precipitation |
| 8 | San Joaquin drainage | Low elevation precipitation |
| 9 | San Joaquin drainage | High elevation precipitation |
| 10 | Tulare Lake drainage | Total precipitation |
| 11 | Tulare Lake drainage | Low elevation precipitation |
| 12 | Tulare Lake drainage | High elevation precipitation |
| 13 | San Francisco Bay | Total precipitation |

Table 2. The proposed project can be evaluated on an incremental basis as specific research activities are completed each year (also see work schedule in Table 3).

| ACTIVITY | OUTPUT/OUTCOME | COMPLETION |
|---|---|---|
| | | |
| Sample predictive model | A random sample of >50 site locations with UTM coordinates (>50 needed because access will not always be permitted or possible) | Year 0.1 |
| Determine property owners | Associate name, address, telephone for owners of >50 random sample sites | Year 0.2 |
| Obtain written permission from property owners | Write letters with permission form to landowners. Compile file of permits. | Year 0.4 |
| Field test model, collect tree rings | Compile survey form for each random sample site. Complete form in field. Obtain 50-60 core samples from 20 sites in Year 1, 30 in Year 2. | Year 1 (40%)<br>Year 2 (60%) |
| Process tree ring samples | Dry, mount, prepare cores. Apply accession numbers. Archive samples. | Year 1 (40%)<br>Year 2 (60%) |
| Compile age/descriptive data | Prepare spreadsheet with site data. | Year 1 (40%)<br>Year 2 (60%) |
| Tree-ring dating | Crossdating of all cores. | 20 sites in Year 1, 25 in Year 2, 5 in year 3. |
| Tree-ring chronology development | Measure cores. Use COFECHA for quality control of dating and measurement. Compute chronologies with ARSTAN. | 20 sites in Year 1, 25 in Year 2, 5 in year 3. |
| Hydroclimatic data preparation | Compile and update station precipitation, FNF, Delta inflow, X2, and station salinity data. | |
| Station precipitation reconstructions | Interpolate station precipitation data to tree-ring site locations. Calibrate each chronology with interpolated precipitation data. Reconstruct | 20 sites in Year 1, 25 in Year 2, 5 in year 3. |

| | | |
|---|---|---|
| | precipitation at each site and verify. Digital estimates archived and shared. | |
| Regional precipitation reconstructions | Regionalize precipitation data. Calibrate, reconstruct, verify regional precipitation. Digital estimates archived and shared. | 2 regions in Year 1, 2 in Year 2, 1 in Year 3 |
| Full natural flow (FNF), Delta inflow, X2, and salinity reconstructions | Calibration, reconstruction, verification for each hydroclimatic variable summarized in Table format. Digital estimates archived and shared. | FNF in Years 1-3. All others in Year 3. |
| Field test refined predictive model/final mapping of ancient blue oak | Analyze environmental data linked with old-growth blue oak woodlands. Derive refined predictive model in GIS by buffering the blue oak cover in Fig. 1 with variables found to be important during initial fieldwork. Randomly sample revised model. Obtain written permission to visit 50 sites in Year 3 (no coring necessary). Visit 50 sites and measure percent cover in each transect. Compile digital map of probable ancient blue oak cover, estimate accuracy and precision of mapping. | Year 3 |
| Archive data and reconstructions | Write CD's, contribute to NGDC | As completed in Years 1-3. |
| Publication | Submitted manuscripts, published articles and reprints. | As completed in Years 2-3. |

Table 3. The proposed research schedule is organized by task and year of completion in this table (UAF = University of Arkansas; UAZ = University of Arizona; SIO = Scripps Institution of Oceanography; WRC = Western Regional Climate Center). The fieldwork, tree-ring chronology development, and single-station precipitation reconstruction components of the proposed research are inseparable, but the regional precipitation and hydrological reconstructions and analyses could be implemented in Year 2 or 3. The field testing of the refined predictive model in Year 3 could also be deferred.

| TASK | YEAR 1 | YEAR 2 | YEAR 3 |
|---|---|---|---|
| | | | |
| Project administration | UAF | UAF | UAF |
| Sample predictive model | UAF | UAF | UAF |
| Determine property owners | UAF | | |
| Obtain written permission from property owners | UAF | | |
| Field test model, collect tree rings | UAF,UAZ | UAF,UAZ | UAF |
| Process tree ring samples | UAF | UAF | UAF |
| Compile age/descriptive data | UAF | UAF | UAF |
| Tree-ring dating | UAF | UAF | UAF |
| Tree-ring chronology development | UAF | UAF | UAF |
| Hydroclimatic data preparation | SIO,WRC | SIO,WRC | SIO,WRC |
| Precipitation reconstructions | UAZ | UAZ | UAZ |

| | | | |
|---|---|---|---|
| Streamflow/Salinity reconstructions | UAF,UAZ,SIO, WRC | UAF,UAZ,SIO, WRC | UAF,UAZ,SIO, WRC |
| Analyses of reconstructions | UAF,UAZ,SIO, WRC | UAF,UAZ,SIO, WRC | UAF,UAZ,SIO, WRC |
| Field test refined predictive model/final mapping of ancient blue oak | | | UAF |
| Archive data and reconstructions | UAF,UAZ | UAF,UAZ | UAF,UAZ |
| Publication | | UAF,UAZ,SIO, WRC | UAF,UAZ,SIO, WRC |

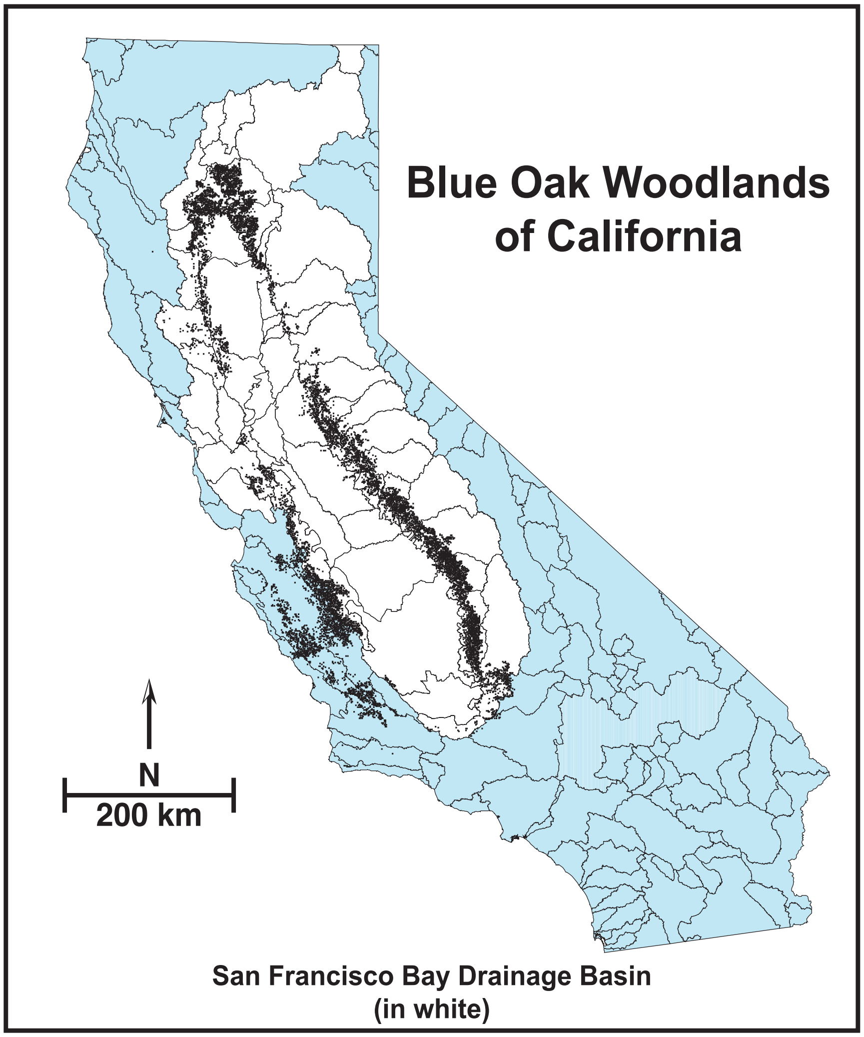



**Figure 1**. This map identifies 1.18 million hectares (2.9 million acres) of blue oak woodland in California based on the co-occurrence of blue oak cover data derived from satellite imagery and aerial photography (black shading; minimum mapping unit is 625m$^2$, after Pillsbury et al., 1991 and PMR 1994). This mapping does not discriminate relatively undisturbed old-growth blue oak forests from second- and third-growth stands that have been more heavily affected by human activites. Nevertheless, we hypothesize that a sizeable fraction (>25%) of these woodlands are, in fact, still dominated by a canopy that includes ancient blue oak in the 150- to 500-year age class. To test this hypothesis, and to acquire a well replicated sample of precipitation-sensitive blue oak chronologies, we will visit 50 ancient blue oak study sites randomly selected from the blue oak cover illustrated on this map (also see Figure 3). The data gathered at these 50 study sites will be used to develop a refined prediction (i.e., mapping) of where in the modern landscape of California *ancient* blue oak woodlands are likely to survive. The tree-ring data collected from the 50 ancient forest study sites will be used for high-quality reconstructions of precipitation, streamflow, X2, and San Francisco Bay salinity.

**Figure 2.** A 340-year old blue oak at Pacheco State Park in Merced County. These foothills oaks are highly sensitive to cool season precipitation totals and can explain 70 to 90% of the variance in instrumental precipitation, streamflow, and estuarine salinity data (Stahle et al., 2001).

## Blue Oak Woodlands

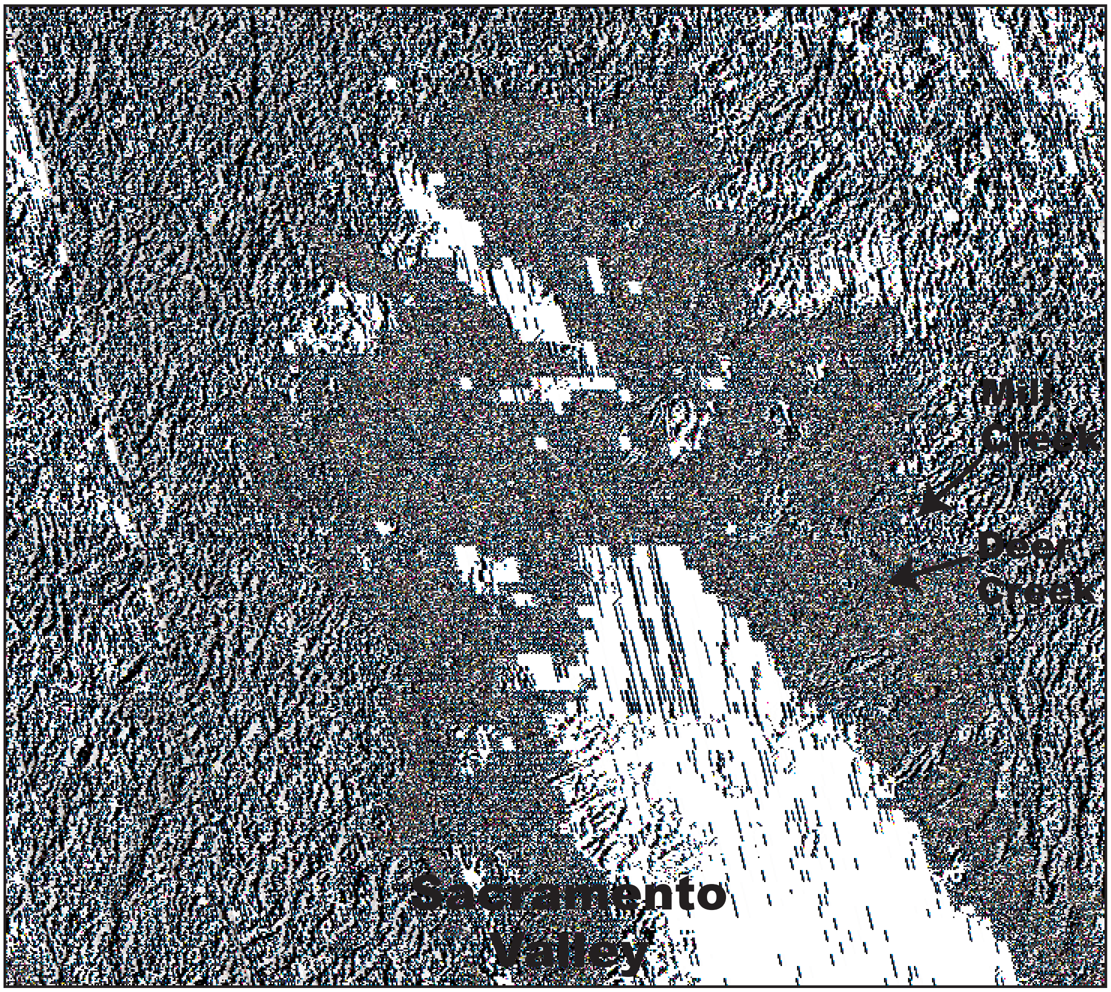
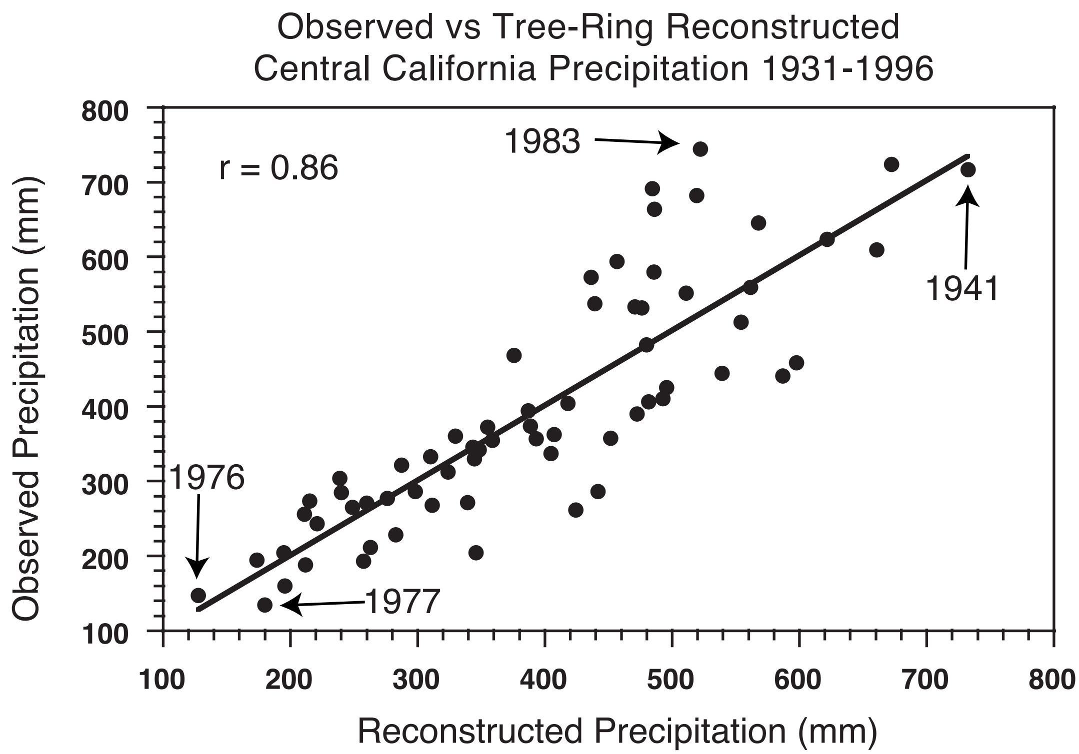



**Figure 3**. Deer and Mill Creeks contain some of the finest salmon habitat left in California (San Francisco Estuary Project 2000), and the lower drainage basins of these streams are dominated by ancient blue oak woodlands (initial mapping of blue oak cover shaded black, from Figure 1). Careful mapping of *ancient* blue oak remnants in these and other watersheds will help focus conservation and rehabilitation efforts on these high integrity ancient woodland cover types.



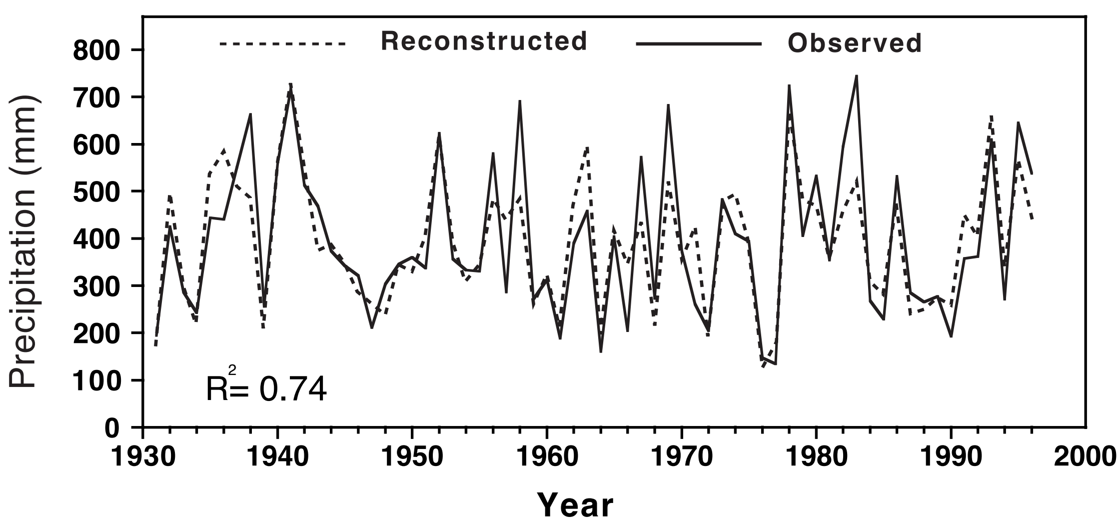




**Figure 4.** A regional tree-ring series based on four blue oak chronologies (Mt. Diablo, American River, Pacheco Pass, and Pinnacles National Monument) has been used to reconstruct central California precipitation (Dec.-April for climate divisions 4 and 5). Note the approximately linear relationship between tree growth and precipitation at these large regional scales (top), but also note the tendency for the tree-ring data to underestimate the very wettest years (top and bottom).

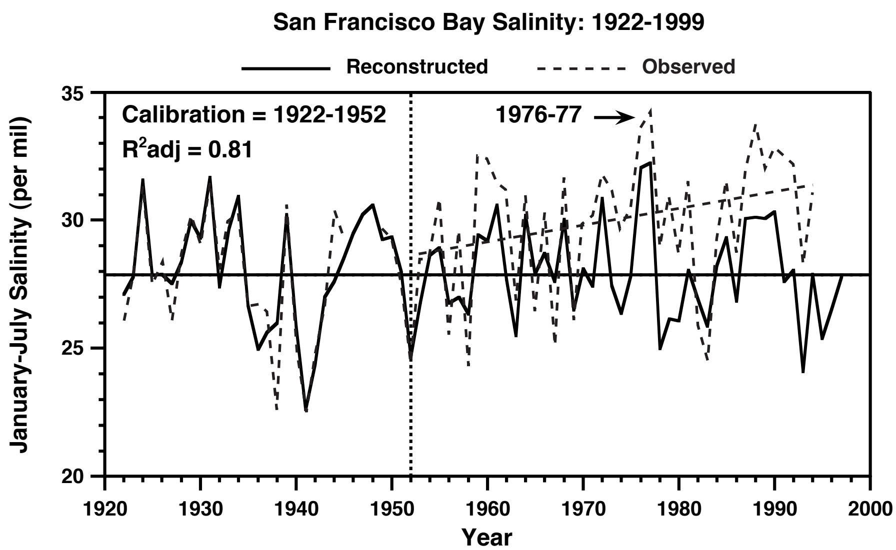



**Figure 5**. Observed and tree-ring reconstructed January-July surface salinity at Fort Point, 1922-1997 (Stahle et al. 2001). The reconstruction was calibrated with the salinity data from 1922-1952 (1946 and 1948 are missing, and 1947 is hidden). The horizontal line is the mean of the observed salinity for 1922-1952 (27.87‰). The rising trend line was fit to the instrumental salinity data for 1953-1994.

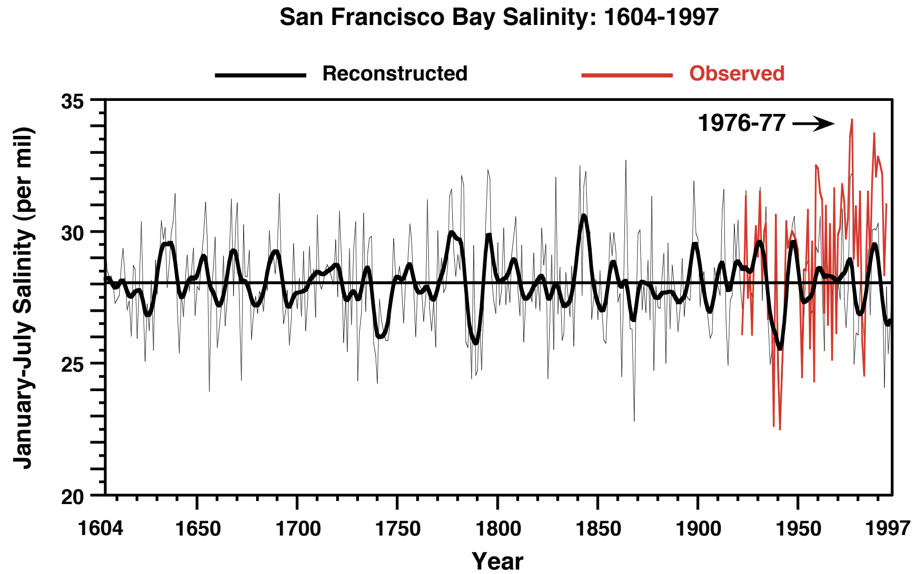



**Figure 6.** January-July surface salinity at Fort Point reconstructed from tree rings for 1604-1997 (light black time series, mean = 28.05‰, standard deviation = 1.79‰, and a smoothed version highlighting decadal variability [heavy black curve (Stahle et al. 2001)]. The observed salinity values measured at Fort Point from 1922-1994 are shown in red. Note the unprecedented trend and increased frequency of high salinity extremes during the period of heavy streamflow diversion after World War II. High salinity extremes occur during drought, and the extremes witnessed during the 1976, 1977, 1988, and 1990 droughts have not been matched over the past 400 years. Low salinity extremes occurred during certain very strong El Nino events (for example, 1789-1793, 1828, 1878, 1891, 1941, 1983, and 1998).

# 1978

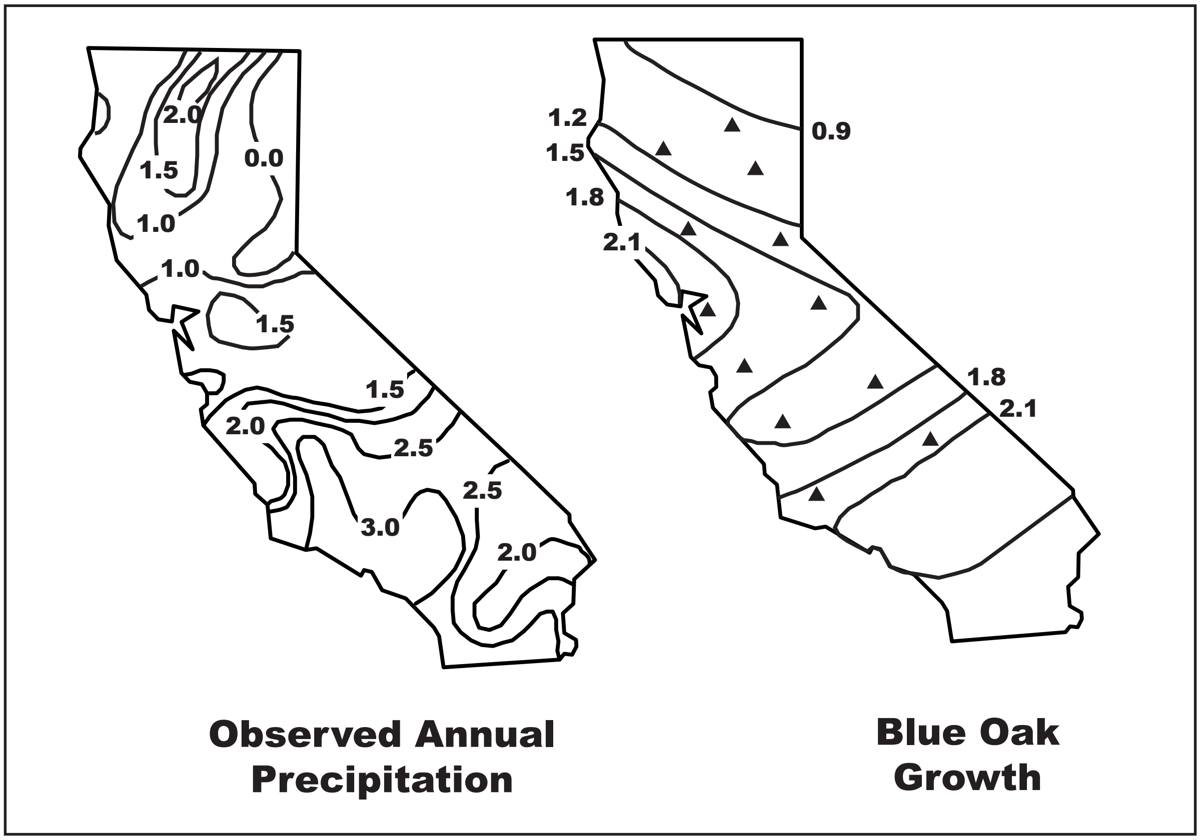



**Figure 7**. The spatial distribution of annual precipitation (Oct-Sept; left) and normalized tree growth (right) during the wet year of 1977-1978. The 12 available tree-ring chronologies (triangles) are not sufficient to represent the full spatial detail of precipitation across California.

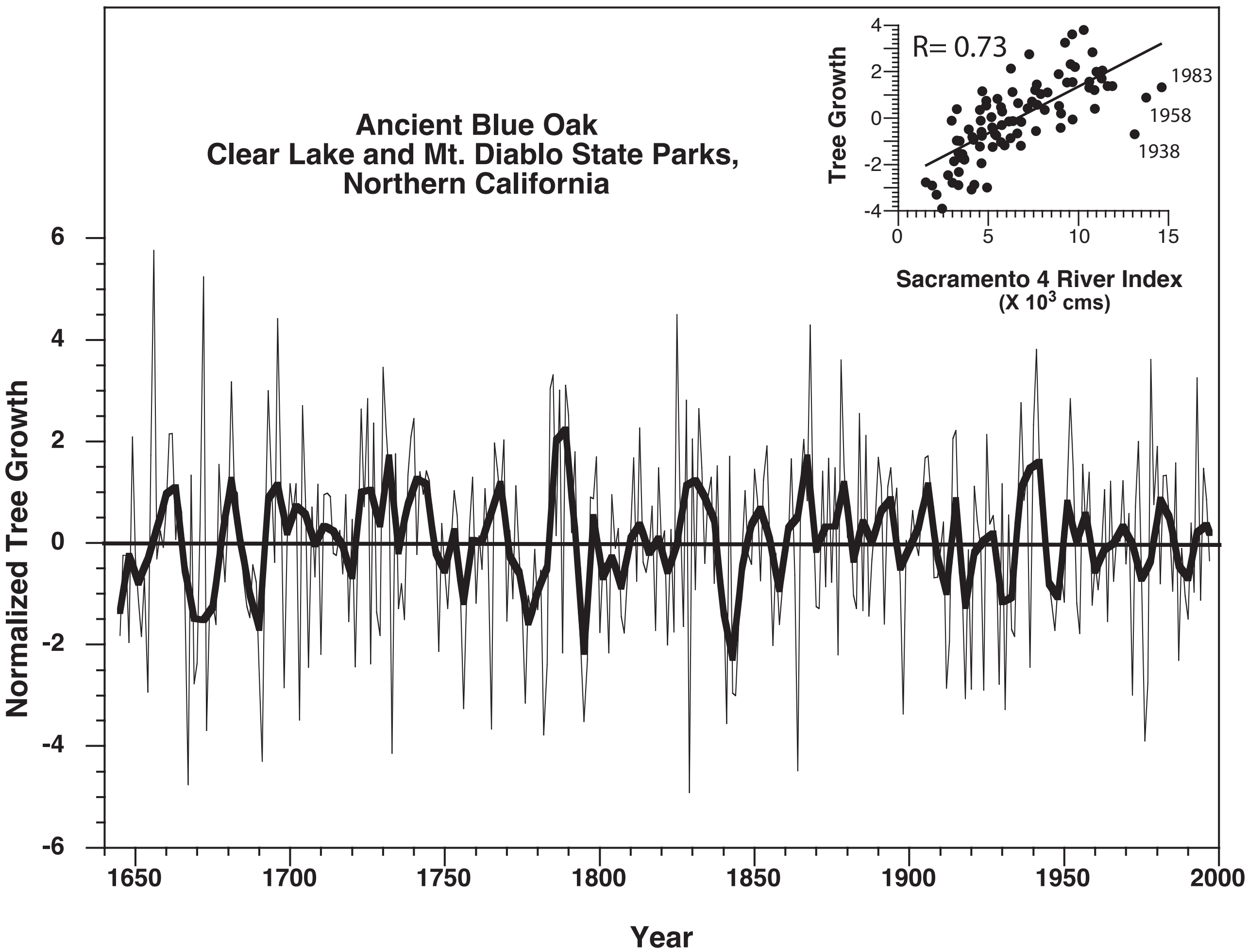



**Figure 8.** Precipitation-sensitive blue oak chronologies from northern California (the Clear Lake and Mt. Diablo average timeseries) demonstrate the potential application to Sacramento streamflow. The simple correlation between an average of just these two blue oak series and the Four Rivers Index is r = 0.73 (inset). These preliminary tree-ring data suggest that the severe and sustained droughts from 1929-1934 and 1987-1992 may have been equaled or exceeded by drought episodes in the 19th, 18th, and 17th centuries (time series plot). The highest flows during 1938, 1958, and 1983 are poorly represented by these two tree-ring series (inset), but this research is designed to improve the estimation of high flows using both field and analytical strategies.