INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources

Project Information

1. **Proposal Title:**

   INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources

2. **Proposal applicants:**

   Konstantine Georgakakos, Hydrologic Research Center
   Nicholas Graham, Hydrologic Research Center
   Aris Georgakakos, Georgia Water Resources Institute

3. **Corresponding Contact Person:**

   Konstantine Georgakakos
   Hydrologic Research Center
   12780 High Bluff Drive, Suite 250 San Diego, CA 92130, USA
   858 794-2726
   KGeorgakakos@HRC-LAB.ORG

4. **Project Keywords:**

   Climate Change
   Hydrology
   Reservoirs, Management and Modeling

5. **Type of project:**

   Implementation_Pilot

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

   No

7. **Topic Area**:

   At-Risk Species Assessments

8. **Type of applicant:**

   Private non-profit

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.

Study area is the Northern California reservoir system (Folsom, Oroville, Shasta, Trinity), their catchments and the downstream reaches of the Sacramento River.

10. **Location - Ecozone:**

    Code 15: Landscape

11. **Location - County:**

    Butte, Colusa, El Dorado, Glenn, Lassen, Nevada, Placer, Plumas, Sacramento, Shasta, Sierra, Sutter, Tehama, Trinity, Yolo, Yuba

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    No

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    3,4,5,51

15. **Location:**

    California State Senate District Number: 1,4

    California Assembly District Number: 2,3,4

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

    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: 57.8

Total Requested Funds: 600,000.00

b) Do you have cost share partners already identified?

Yes

If yes, list partners and amount contributed by each:

NOAA Office of Global Programs 40,000.00

c) Do you have potential cost share partners?

Yes

If yes, list partners and amount contributed by each:

NOAA Office of Global Programs 450,000.00

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

Yes

If yes, list total non-federal funds requested:

600,000.00

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)

Dr. Robert Hartman	**NOAA/NWS California Nevada River Forecast Center**	**916-979-3056**	**Robert.Hartman@noaa.gov**
Dr. Claudia Nierenberg	**NOAA/ Office of Global Programs**	**301-427-2089 x151**	**nierenberg@ogp.noaa.gov**
Mr. William Pennington	**USBR**	**916-978-5237**	**wpennington@mp.usbr.gov**
Mr. Maurice Roos	**DWR**	**916-574-2625**	**mroos@water.ca.gov**

21. **Comments:**

The INFORM initiative has had several multi-agency meetings during the last two years in Sacramento and in San Diego. Representatives from the US Bureau of Reclamation (incuding engineers from Central Valley Operations), Department of Water Resources, USA Corps of Engineers and NOAA/National Weather Service, the Hydrologic Research Center and the Georgia Water Resources Institute have attended these meetings. The suggested reviewers (agency representatives) have attended these information exchange meetings and they are familiar with the goals of the proposed project.

Environmental Compliance Checklist

<u>INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources</u>

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.

      The project is a numerical simulation project.

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
   Xnone

   NEPA
   -Categorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   Xnone

   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?

      None

   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

STATE PERMITS AND APPROVALS

Scientific Collecting Permit

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

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land.
Agency Name:

Permission to access state land.
Agency Name:

Permission to access federal land.
Agency Name:

Permission to access private land.
Landowner Name:

6. **Comments.**

The study consists of simulated real time experiments for specific historical events and potential future events. as such none of the sections in Form III apply.

Land Use Checklist

INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources

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?**

   No

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).

   Simulated real time numerical experiments for historical events and for potential future events to examine what-if scenarios of reservoir management.

4. **Comments.**

Conflict of Interest Checklist

<u>INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources</u>

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):

Konstantine Georgakakos, Hydrologic Research Center
Nicholas Graham, Hydrologic Research Center
Aris Georgakakos, Georgia Water Resources Institute

Subcontractor(s):

Are specific subcontractors identified in this proposal? Yes

If yes, please list the name(s) and organization(s):

Aris Georgakakos   Georgia Water Resources Institute

Helped with proposal development:

Are there persons who helped with proposal development?

No

Comments:

Staff from several Federal and State Agencies attended informational meetings on INFORM during the last two years (perhaps as many as 30-40 scientists and engineers). Discussions with such persons have been very beneficial and have contributed to the final form of the INFORM proposal. INFORM advocates close collaboration with Staff from operational forecast and management agencies for successful pilot implementation.

Budget Summary

INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources

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**
1.1,1.4, 2.1,2.4, 3.1.1-3.1.8	As in Main Text Tasks	3033.31	89,116	24,061	11,240	100	150,000	0	0	274517.0	71,274	345791.00
		3033	89116.00	24061.00	11240.00	100.00	150000.00	0.00	0.00	274517.00	71274.00	345791.00

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**
1.2,1.4,2.2,2.4,3.2.1-3.2.8	As in Proposal main text	2946.65	91115	24601	11,240	100	150000	0	0	277056.0	72727	349783.00
		2946	91115.00	24601.00	11240.00	100.00	150000.00	0.00	0.00	277056.00	72727.00	349783.00

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**
1.3,1.4,2.3, 2.4, 3.3.1-3.3.5	As in main proposal text	2708.32	89776	24240	11240	100	150000	0	0	275356.0	72612	347968.00
		2708	89776.00	24240.00	11240.00	100.00	150000.00	0.00	0.00	275356.00	72612.00	347968.00

Grand Total=<u>1043542.00</u>

Comments.
The INFORM project is a five year project with a total budget of $1,746,334.00. Identical proposals have been submitted to NOAA OGP (five years budget) and CALFED ERP (three years budget). The budget shown above represents the total funding requested for the first three years of the project. A total of $200,000 per year for three years is requested from CALFED ERP.

Budget Justification

INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources

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

YEAR 1 YEAR 2 YEAR 3 K.P. GEORGAKAKOS(Lead PI) 174 174 87 N.E. GRAHAM (Co-PI) 520 520 347 A.P. GEORGAKAKOS (Co-PI) 221 221 221 (Through subcontract to GWRI) T.M. CARPENTER (Hydro. Eng.) 1214 1214 1560 Graduate Student 1040 954 628 H. YAO (Water Resources Eng.) 1560 1560 1560 (Through subcontract to GWRI)

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

Rate of compensation: US$/HOUR YEAR 1 YEAR 2 YEAR 3 K.P. GEORGAKAKOS (Lead PI) 29.34 30.81 32.35 N.E. GRAHAM (Co-PI) 28.85 30.29 31.80 A.P. GEORGAKAKOS (Co-PI) 142.90 142.90 142.90 (Through subcontract to GWRI) T.M. CARPENTER(Hydro. Eng.) 31.65 33.23 34.90 Graduate Student 27.00 28.35 29.77 H. YAO (Water Resources Eng.) 75.91 75.91 75.91 (Through subcontract to GWRI)

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

For Hydrologic Research Center fringe benefit rate is: 27% of Salaries For Georgia Water Resources Institute (the subcontractor) the fringe benefits rate is: 24.1% of Salaries

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

For each of the five years of the INFORM Project: Travel for two Workshops and four meetings in Sacramento with collaborating agencies is budgeted. The purpose of the workshops is described in Tasks 1.1, 1.4, 2.4, 3.1.1, 3.1.8, 3.2.1, 3.2.8, 3.3.1, 3.3.5, 3.4.5, 5.4.1 in the main text of the proposal. Two trips Atlanta-Sacramento, 5days each, 1 person: $4,620 Two trips San Diego-Sacramento, 5days each, 2persons:$5,300 Four trips San Diego-Sacramento, 1 day each, 1person:$1,320 (Costs are per year)

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

Suplies are CD ROMs for the transfer of data. A total of $100 of supplies is budgeted for each of the years of the project.

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.

The Staff of the Georgia Institute of Technology (subcontractor to HRC) will be compensated based on the hours and rates shown under the Direct Labor Costs section above. HRC will not charge indirect cost for this subcontract.

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.

A total of 87 hours each for years 1, 2 and 3 of the Lead PIs time is charged on this project for Project Management. The rate of compensation for the lead PI is shown in the Direct Labor section of the budget justification form. This time is charged for project coordination and supervision and for informational presentations and meetings with Agency representatives in Sacramento. Travel for these activities is included in the travel justification section above.

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.

NOAA is the Oversight Agency for the Hydrologic Research Center (HRC). NOAA has approved a 57.8% fixed rate with carry forward provisions for HRC on 28 March 2001. HRC rate charged for the present proposal is 57.2% to conform to the proposal figures submitted to NOAA Office of Global Programs, who is expected to be the second source of funding for INFORM. HRC will not charge indirect cost rate on the GWRI subcontract for this project. GWRI fixed indirect cost rate is 49.7% and it is approved according to the policies of the Georgia Institute of Technology in Atlanta, Georgia.

Executive Summary

INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources

Even though reservoir-based water resources management systems are a natural choice for the effective application of climate forecasts for improved operations, in most cases there is no direct use of forecasts in reservoir operations. Partially supported by various NOAA Office of Global Programs and by User Agencies (US Bureau of Reclamation) over the last four years, the Co-PIs have shown that the benefits to reservoir management are substantial in California. The proposed project builds on this past work to establish a pilot demonstration site in Northern California for assessing the utility of climate information for the operational management of regional water resources. Environmental concerns, flood control, water conservation, water supply for various uses, and hydroelectric power production are the main operational management objectives of the Northern California system. A virtual system of the reservoir forecast and management process will be built in close collaboration with the US National Weather Service California Nevada River Forecast Center, the US Bureau of Reclamation Central Valley Operations and Planning Division, and the California Department of Water Resources to simulate current operations. This decision support system will be built over a period of five years with the first two years devoted to individual reservoirs and the last three years devoted to the interacting four-reservoir system of Folsom, Oroville, Shasta, and Trinity reservoirs. Once the system is in place and the objectives of reservoir management have been defined in collaboration with participating agencies, we will produce an enhanced version of the virtual system that uses an integrated forecast-management approach, developed by the proposers, that is driven by ensemble climate forecasts. We will then use real time database data for selected periods during the five-year project duration to intercompare various configurations of the built decision support system (including that corresponding to present operations) during periods of different climate regimes (e.g., ENSO, etc.) The analysis will be complemented with retrospective studies using historical data. Economic assessments will be performed by a team of physical scientists and economists from the proposing organizations and Federal Agencies. Throughout the project period, a sustained mutual technology transfer process will be effected to assure sustainability of new systems and to facilitate reliable interpretation of the integrated system results. The project is proposed jointly by the Hydrologic Research Center, with climate and hydrologic forecast expertise, and the Georgia Water Resources Institute, with water resources systems planning and management expertise. It is proposed as a five year program to NOAA Office of Global Programs with a three-year contribution from the CALFED Ecosystem Restoration Program. It effectively addresses objectives of the NOAA Office of Global Programs Climate and Societal Interactions program, and restoration priorities for multi-regional Bay-Delta areas of the CALFED Ecosystem Restoration Program. Specifically with respect to the latter the most relevant priority is Item MR 4: Ensure restoration and water management action through all regions can be sustained under future climatic conditions. Support of participating federal, state and local agencies is expressed through letters of support. Total Cost for 5-years: $1,746,334.00. CALFED Ecosystem Restoration Share proposed: $600,000 for first three years of the project.

Proposal

Hydrologic Research Center

INFORM - Integrated Forecast and Reservoir Management Demonstration for Northern California Water Resources

Konstantine Georgakakos, Hydrologic Research Center
Nicholas Graham, Hydrologic Research Center
Aris Georgakakos, Georgia Water Resources Institute

Project Description

1. IDENTIFICATION OF THE PROBLEM

Managed water resources systems impact the regional economies and the environment significantly. In turn, they are greatly influenced by climate variability and trends, and a multitude of socioeconomic factors. The increasing demands on water at a low cost and the limiting water supply make imperative the increase of the efficiency of the use of water resources before other demand-based approaches are tried (*Frederick*, *1993*). Although there is considerable investment of resources for achieving improved climate information and water resources systems are a good candidate for showing benefits of improved climate forecasts, no focused program exists that has reliably quantified and demonstrated these benefits. The main reasons are: (a) there is substantial forecast uncertainty associated with present climate forecasts and their use in management requires advanced uncertainty modeling; (b) existing reservoir management systems are tuned to present information characteristics, and use of information of a different type (i.e., modern climate forecasts) requires nontrivial changes in the approach to water resources management; (c) usually, management applications cannot be generalized and each case must be treated individually; (d) there are institutional constraints that make changes in the management approach difficult; (e) performance criteria used in reservoir management of water resources are not easily linked to typical model-forecast performance criteria. As a result, few reservoir managers are willing to try new approaches and it is very likely that several systems, as presently operated, will not show benefit from the use of improved climate information.

2. SCIENTIFIC OBJECTIVES

In an effort to remedy the situation, the proposers have developed the basis for a research, technology transfer and demonstration program which aims at assessing the utility of climate information for water resources management. The fundamental components and scientific objectives of the approach taken are: (a) establishment of specific demonstration and assessment sites nationally and internationally, where there is history of collaborative work, existing technology transfer programs and supportive managers; (b) establishment of mutually-agreed-upon performance criteria with management input; (c) implementation of a baseline system reflecting present management practice and operational models, and an alternate system that includes climate forecasts and suitably modified models in an integrated forecast-control framework; (d) inter comparison of benefits as developed with management decisions for both systems using retrospective analysis of historical data and forecasts, or in real time for a given demonstration period; (e) participation of management staff in the demonstration activities and in user/modeler conferences for the mutual benefit of modelers, forecasters and managers. In this proposed project, our target application and demonstration system is the Northern California system of reservoirs, consisting of the Folsom, Oroville, Shasta, and Trinity reservoirs and associated water resources (Figure 1).

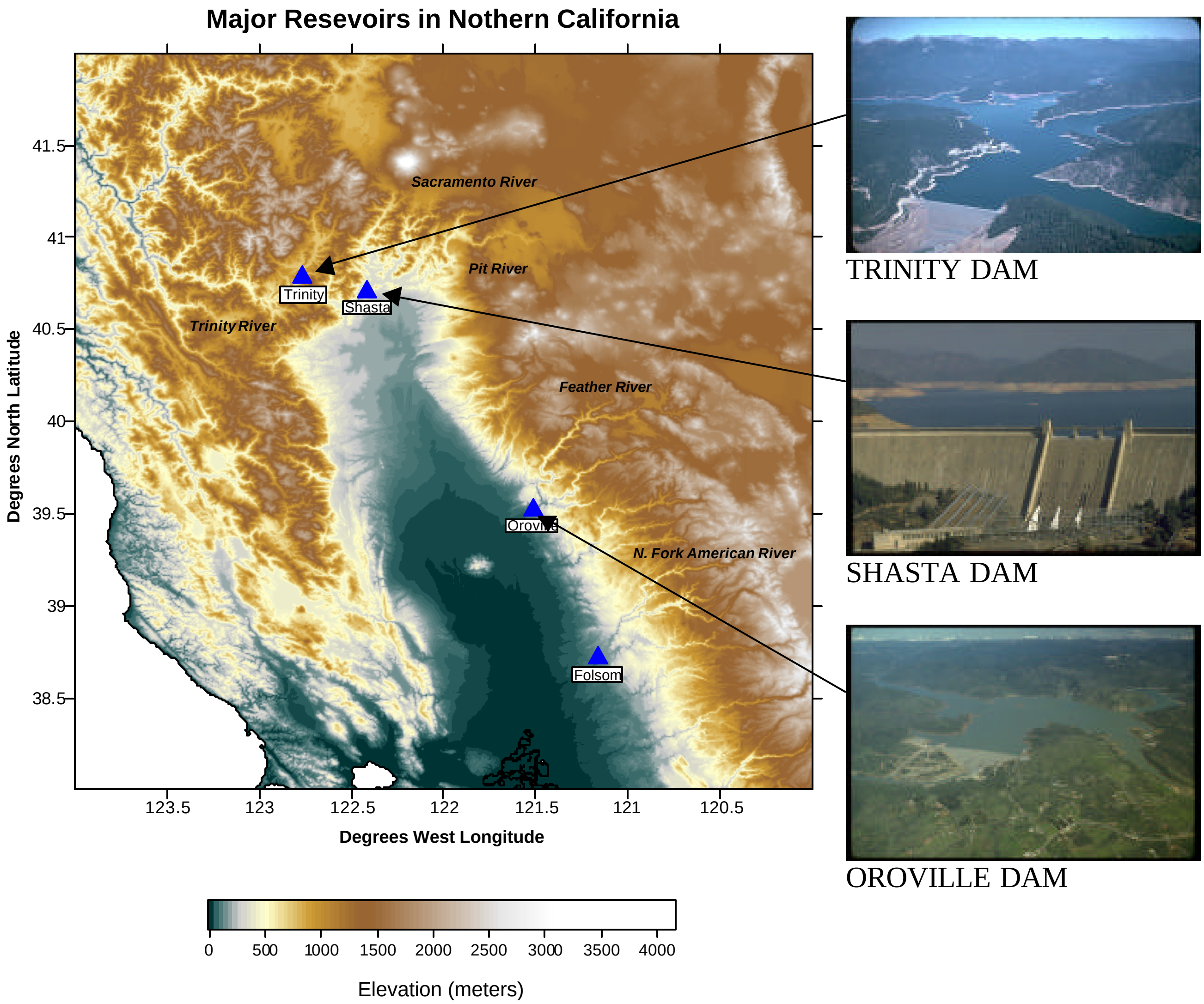

Figure 1. Study area in Northern California and major reservoirs used to manage water resources and to mitigate flood damage in the region. The southernmost Folsom Dam is shown in the lower right inset of Figure 3.

3. RELEVANCE TO THE GOALS OF ERP

This project is jointly proposed by the Hydrologic Research Center with climate and hydrologic forecast expertise and the Georgia Water Resources Institute with water resources systems expertise. It addresses the Climate and Societal Interactions (CSI) priority area of the NOAA Climate and Global Change Program and restoration priorities of the ERP Program, specifically MR4: Ensure restoration and water management action through all regions can be sustained under future climatic conditions. In particular, it is expected that the proposed research and demonstration project will define the basis of effective application of climate information for improved planning and management of large multi-objective water resources systems through application to real such systems. Through an application and demonstration process that involves close collaboration between forecasters and managers during the operation of actual systems and with mutually-accepted performance measures, for the first time, this proposed project will quantify the benefits of climate information to water resources planning and management for one of the most important (environmentally, socially, and economically) systems in the US. Lastly, and perhaps most importantly, the proposed project will begin and nourish a mutual learning process among modelers, forecasters and managers involved in the planning, modeling, forecasting and management of water resources systems through an institutional collaboration that would involve research centers, federal, state and local agencies.

4. BENEFITS TO THE PUBLIC

The target reservoir system provides the majority of water resources to the California Bay-Delta region, which provides two-thirds of the state's drinking water, irrigates 7 million acres of the world's most productive farmland, is home to 130 species of fish, 225 species of birds, 52 types of mammals, and 400 plant species (*Kaniewski, 1999*). In addition, the target reservoir system protects major California cities against flood disaster, affecting millions of people. The importance of the Northern California water resource system for the public is manifested by the fact that the US Congress has often in recent years held hearings on various aspects of this system (e.g., *First Session 106 Congress, Committee on Resources, 20 May 1999; Second Session 105 Congress, Subcommittee on Water and Power, Committee on Resources, 27 May 1998*). It has been also apparent by these hearings that improvements in cooperative water resources management and planning for this system are necessary to meet the increasing demands for water in the region. The proposed project will lead to a science-based information database for more informed decisions pertaining to reservoir management for improving water use efficiency for environmental restoration, water supply and other objectives, mitigating disaster, and for establishing the basis of cooperative water resource management based on commonly accepted measures of integrated system performance by a variety of stakeholders. The benefits to the scientific community stem from the interaction with users within this project context and from the establishment of scientific research goals motivated by the needs of the integrated system (rather than individual system components).

5. METHODOLOGY

5.1 <u>Outline</u>

We exemplify the main elements of our methodology with a brief summary of past research and development work in the area of integrated forecast and management of water resources. We emphasize the encouraging results of retrospective studies obtained for the target area and the established collaborative relationship between the proposers and federal and regional agencies involved in managing Northern California water resources (*Carpenter and Georgakakos, 2000; Yao and Georgakakaos, 2000*). It is shown that in several cases the use of climate information from Global Climate Models (GCM) is beneficial for management. It is also found that significant changes in management practice must be made in order to realize these benefits. We then outline the main issues associated with the planning and management of the target system and discuss a five-year plan for realizing the application and demonstration program for Northern California. On-going collaboration with federal and regional management and forecast agencies is described, and a plan for collaborative research and mutual technology-transfer is outlined. Lastly, we outline the main research tasks to be carried out.

5.2 Previous Work of Proposers with Northern California Water Resources Systems

The proposed project will build on past research performed by the proposers for Folsom Lake on the American River, funded through a subcontract to HRC on a UCSD/Scripps Institution of Oceanography NOAA OGP Grant: the California Applications Project (CAP). The methods and main results are outlined next, as they will form the basis of the proposed work.

5.2.1 Methods and Data

The primary tool for quantifying management benefits is a numerical integrated forecast-control system. Figure 2 presents a schematic of the system elements.

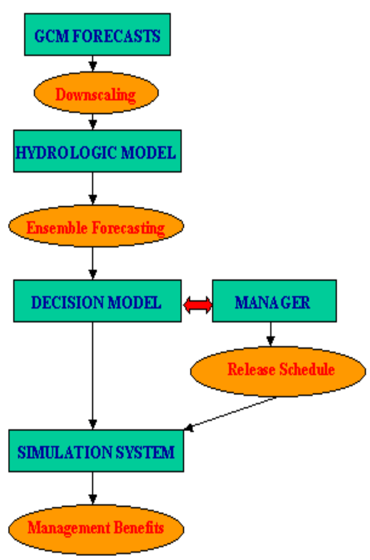

Figure 2. Schematic of integrated forecast-control system elements and links.

This design of the integrated forecast-control system shown in Figure 2 was first used by *Georgakakos et al. (1998)* successfully for the assessment of benefits of climate information for the management of Saylorville reservoir on the upper Des Moines River. Prior to that study, a system of the type in Figure 2 with fully coupled hydrologic-forecast and reservoir-control components but without GCM information processors was designed and was applied to the Des Moines River basin (*Georgakakos, et al. 1995; A. Georgakakos et al. 1998*). In that case, the performance of the system was superior to that of operational practices for all the objectives of management. The system of Figure 2 includes components for:

(a) adjusting GCM forecasts to account for known GCM simulation biases in specific regions, and for biases and random errors due to the difference between the spatial scale of the GCM and that of the reservoir contributing catchment (downscaling in Figure 1) (e.g., *Risbey and Stone, 1996; Mearns et al. 1990, Wolock et al. 1993; Murphy, 1999*);
(b) generating hydrologic forecasts and forecast uncertainty estimates through ensemble forecasting conditional on adjusted GCM information (hydrologic model and ensemble forecasting in Figure 1) (e.g*., Nibler and Anderson, 1993; Fread et al. 1999; Perica et al. 1999; Georgakakos, A., et al. 1998*);
(c) generating trade-off options among competing objectives (e.g., flood control versus hydroelectric energy production) with a given risk level for decision support of multi-objective reservoir operation (decision model in Figure 1) (*Georgakakos, A., and Yao, 1993, and Yao and A. Georgakakos, 1993*);
(d) interacting with management preferences to select among non-inferior competing trade-offs for the definition of operating release policy (manager/release schedule in Figure 1) (*Yao and A. Georgakakos, 2000*); and
(e) simulating system performance and quantifying benefits for a given reservoir release decision (simulation component in Figure 1) (*Yao and A.Georgakakos, 2000*).

In this context, ensemble forecasting refers to the production of a set of several forecasts of flow generated by a numerical model, forced with several likely scenarios of future precipitation, temperature and potential evapotranspiration. In producing these forecasts, the model always starts from the same initial conditions, representing the best estimate of the natural present system states.

Retrospective studies involving historical climate, hydrologic and reservoir-operation data together with a variety of scenarios of climate information and, to the extent feasible, operational models and forecast procedures were used in the assessment of benefits. *Carpenter and Georgakakos (2000)* and *Yao and A. Georgakakos (2000)* present the models and data used in the retrospective studies. Folsom Lake has plant objectives of flood control, hydroelectric power production, water supply and low-flow augmentation and it is operated by the US Bureau of Reclamation Central Valley Operations. Folsom Lake inflow forecasts are routinely issued by the NWS California Nevada River Forecast Center. These forecasts are based on the operational NWS snow accumulation and ablation model and the state-space Sacramento model developed by HRC Staff that includes a kinematic channel routing model. The models produce real time forecasts out to several days with 6-hourly resolution and with estimates of the non-stationary forecast uncertainty. For seasonal inflow guidance, the Bureau of Reclamation uses statistical models based on observed indices such as snow cover estimates and operational climate guidance for precipitation and temperature. For this work, probabilistic downscaling procedures were developed and used that conditioned the ensemble inflow forecasts to the ensemble forecasts from climate models, accounting for bias adjustment and scale differences between the climate models and the hydrologic models. The ensemble inflow forecasts account for both climate forecast uncertainty and hydrologic model uncertainty (*Carpenter and Georgakakos, 2000*).

The retrospective studies were concerned with the inter comparison of the benefits from Folsom Lake management for *(a)* a system approximating current operational practices, *(b)* the full integrated forecast-control system using GCM monthly estimates of precipitation and temperature from two climate models, and *(c)* a perfect-foresight scenario in which the observed flows were input to the decision component of the model as perfect forecasts. The two climate models used were: the Canadian Centre for Climate Modeling and Analysis coupled GCM and the Max Planck Institute for Meteorology ECHAM3 GCM. The historical study period starts on 10/1/1964 and extends through 12/31/1992. Forecasts of reservoir inflows were issued and management decisions for reservoir release schedules were made every 5 days through the record. The forecast and decision horizons are 60 days long with a daily resolution. Reservoir management performance was quantified in collaboration with Staff of the Bureau of Reclamation through annual spillage, annual flood damage, and annual energy value from hydroelectric power generation. Approximate dependence of costs and benefits on the reservoir levels and releases was specified, and decision preferences were set based on discussions with Folsom Lake Operations Staff. Figure 3 shows the study catchment, reservoir and region, together with the grid nodes of the climate models used in this work.

Key components for successful operation of the integrated forecast-control system are the uncertainty model and the decision support model. The former simulates the propagation and reduction of forecast uncertainty from the GCM forecasts to the reservoir inflow forecasts. The latter aims to develop operational policies that minimize the effect of inflow forecast uncertainty on the system outputs. This is accomplished through a hierarchy of nested models that address long-range, mid-range, and short-range system objectives and water uses such as water supply, drought management, energy generation, flood control, and short-term hydropower scheduling. The decision modules operate consistently across all time scales and fully utilize the reservoir inflow forecast ensembles. The decisions pertain to reservoir releases, power generation (turbine loads and operation hours), and spillage volumes and are updated adaptively as new inflow forecasts or other information on the condition of the system becomes available (Yao and Georgakakos, 2000).

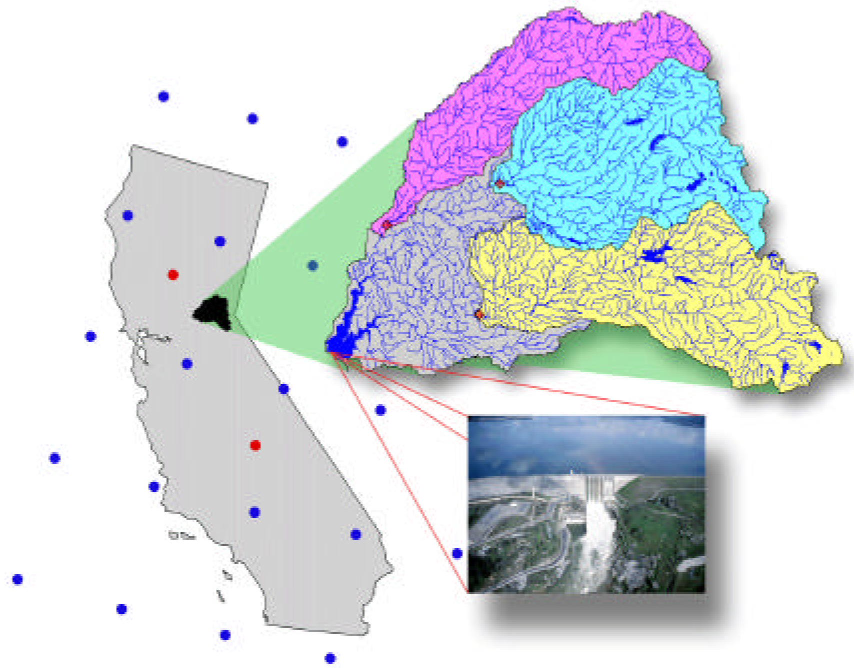

Figure 3. Folsom Lake reservoir at the outlet of the American River catchment in north-central California. The location of the catchment is shown together with the GCM computational grids for both the Canadian (red points) and ECHAM3 (blue points) GCMs used in this study. Operational models have been developed for all three Forks of the American River and the local Folsom Lake contributing area.

5.2.2 Main Results

We present two types of results; the first to show that using GCM information has a beneficial impact on inflow forecast reliability, and the second to show that using GCM information in an integrated forecast-control framework increases management benefits. We also discuss planning studies performed using the integrated system.

To quantify the performance of the ensemble inflow forecasts to Folsom Lake, among other performance indices, reliability diagrams and a reliability score were computed based on each decile of the forecast ensemble distribution. This particular skill score shows the correspondence between the forecast that a certain event will occur with a probability in a given decile (tenth) range and the historical frequency distribution of the same event for the historical times that the forecast probability was in the given decile range. The reliability score compounds the results for all the probability decile ranges to provide a single skill score. It indicates perfect performance with a value of zero (e.g., for the perfect foresight scenario) and reflects decreasing skill as its value increases from zero. Events to be forecast may be the inflow volume over a given fixed-length period being in the upper or the lower tercile (third) of its distribution. Table 1 shows the value of this skill score for the retrospective experiments and for three cases: (a) a case when the hydrologic ensembles were not conditioned on the specific GCM information at each forecast time (climatological ensemble); (b) a case when the forecasts were conditioned on the Canadian GCM (one simulation of the GCM was used); and (c) a case when the forecasts were conditioned on the ECHAM3 GCM (ten simulations of the GCM were used). In all cases, the ensemble predictions included uncertainty due to expected errors in the parameters of the hydrologic model.

Table 1: Reliability Scores of Forecasting Folsom Lake Inflow Volumes
Event Forecast: Inflow Volume in Upper Third of its Distribution

Reliability Score: $\sum N_{f_i}(P_{f_i} - P_{o_i})^2 / \sum N_{f_i}$ (*)

Volume Accumulation Period (Days)	Climatological Ensemble	Ensemble Conditioned on Can GCM (1 Simulation)	Ensemble Conditioned on ECHAM3 (10 Simulations)
30	0.004	0.004	0.002
60	0.008	0.005	0.003
90	0.010	0.006	0.006
120	0.012	0.003	0.007

Table 1 cont'd: Event Forecast: Inflow Volume in Lower Third of its Distribution

Reliability Score

Volume Accumulation Period (Days)	Climatological Ensemble	Ensemble Conditioned on Can GCM (1 Simulation)	Ensemble Conditioned on ECHAM3 (10 Simulations)
30	0.011	0.014	0.006
60	0.015	0.012	0.005
90	0.016	0.011	0.007
120	0.015	0.011	0.008

(*) P_{o_i} and P_{f_i} are the observed and forecast frequencies for the ith decile of the event distribution, and N_{f_i} is the number of forecasts for the i^{th} decile.

The results in Table 1 show the reliability score for forecasts pertaining to the upper and the lower tercile of the distribution of volumes of a given duration as indicated in each panel. In all cases the same number of forecasts for the same situations were issued. It is clear that GCM information yields significantly more reliable inflow volume forecasts for Folsom Lake, especially for longer forecast lead times and longer-duration inflow volumes. Using GCM information in real time reduces the reliability score by half in several cases as compared to using ensemble forecasts that depend on climatology and parametric uncertainty (this is the traditional ESP methodology used by the NWS with added parametric uncertainty in the ensemble forecasts). In addition, it may be seen that the results conditioned on a single GCM forecast from a certain GCM may be significantly different from those conditioned on an ensemble of GCM forecasts from the same GCM, the latter results being more reliable. These scores are but one possible set of performance indices and for full measure of inflow forecast performance other scores may be necessary (e.g., *Wilks, 1995*). For reservoir management, however, a different set of performance measures are appropriate, as developed for this study in collaboration with Bureau of Reclamation staff and as shown in Table 2 below.

The increased reliability of the reservoir inflow forecasts when GCM information is taken into consideration in an appropriate manner can have a beneficial impact on the quantifiable benefits from the management of Folsom Lake. This is reflected on the results of Table 2. There is benefit to be had from GCM-conditioned inflow forecasts for all the objectives of reservoir management at Folsom, and especially for maximum flood damage reduction. Furthermore, these forecasts, when processed by a decision support system that simulates forecast uncertainty, yield management benefits that are near those obtained from a perfect-foresight scenario. Additional results, not shown, indicate that both (a) the use of GCM-conditioned forecasts with the operational rule-based management component and (b) the lack of uncertainty models for the integrated forecast-control system, reduce substantially management benefits.

Table 2: Simulated Management Benefits from the Operation of Folsom Lake

Scenario		*Performance Indices*	
	Energy Value (M$)	Spillage (BCF)	Maximum Flood Damage (M$)
Simulated Operational	56	11.5	840
Climatological Ensemble	58	7	220
Ensemble Conditional on Canadian GCM	58	6	100
Ensemble Conditional on ECHAM3 GCM	58.5	8	220
Perfect Foresight	60	5	0

Energy and Spillage are annual average values. BCF:Billion cubic feet

The integrated system may be used for planning studies to generate results from various “what if” scenarios. For Folsom Lake, we progressively increased the downstream-channel minimum flow constraint and examined the impact to water supply, hydroelectric energy production, and frequency of violation of minimum flow constraints for environmental concerns. We found that with the benefit of reliable forecasts, an increase of the minimum downstream flow constraint by 50% will not significantly impact other reservoir objectives while providing more water for downstream uses. Substantially greater increases of this constraint are likely to impact other management objectives significantly. This is of paramount importance for environmental restoration projects downstream.

5.2.3 Main Conclusions and Future Direction

The results obtained by applying our integrated methodology for the management of Folsom Lake are supporting further exploration and evaluation of the benefits of climate information for reservoir management. These results are based on simplifying assumptions agreed upon by the reservoir operators for the purposes of the retrospective feasibility study. The logical and feasible next step is to establish a demonstration site in Northern California using the interconnected regional reservoir system, for assessing in a more accurate way the benefits of using climate information for water resources management there. It is through such demonstration sites that both modelers and managers can be engaged in a mutual technology transfer process to study the complex multi-disciplinary issues involved. In addition, the quantitative results of such a demonstration study will provide the basis for any needed modification of existing institutional and other constraints imposed on water resources managers arising from the use of traditional methods and historical data in a changing climate. It is this next step we propose to take with this proposal.

5.3 Planning and Management Objectives and Plan for Realizing INFORM for Northern California

The Northern California system is a complex system of interconnected channels and reservoir releases with a complex set of constraints for downstream environmental, and agricultural, municipal and industrial water supply requirements. In addition, each of the system reservoirs has objectives of flood control and hydroelectric power generation. A number of meetings were held in Sacramento and in San Diego (see Table 3) with the participation of various federal, state and local agencies with the purpose to define a manageable project plan. Such a plan would allow the inclusion of important system components and functions and, at the same time, could be achieved within the time of the project and would produce results that would be acceptable as close approximations of the actual complex and, in some cases, ill-defined water resources system. Letters of support for the present INFORM proposal from such agencies are attached in the Appendix.

Table 3. Meetings on INFORM in 2000

Date	*Place*	*Agencies*
05/19	Sac	US Bureau of Reclamation (USBR) Planning Div. and Consultants, HRC
06/08	SD	NOAA OGP, USBR Planning Div., NWS CNRFC, HRC, GWRI
11/01	Sac	USBR Planning Div., USBR Central Valley Ops., California Dept. of Water Resources (DWR), HRC, GWRI
11/16	Sac	USBR Planning Div., USBR Central Valley Ops., DWR, NWS CNRFC, Sacramento Flood Warning Service, Sacramento Area Flood Control Agency (SAFCA), HRC

Although defining the actual approximation of the system will be part of the initial work under this proposed project, several guidelines were developed for this project. Those are listed below:

(a) Flood control, water supply for agriculture, municipalities and industry, environmental health, and hydroelectric power production are important objectives of the Northern California system to be studied.
(b) Flood control functions may be modeled without significant interactions among reservoirs, as affected cities are directly downstream in the corresponding tributaries and before major confluences in each case.
(c) It is important to include components for allowing planning questions to be answered using the integrated system. Important planning questions under current climatic variability pertain to the Trinity River diversion into the Sacramento River system, the water and temperature requirements of downstream river segments for improved anadromous fish habitat, and increased agricultural and

municipal water supply without adversely affecting flood control functions. Such questions may also be addressed using projected climate scenarios.

(d) It is important to use available operational models to the extent possible to allow focus on integrated system science and applications, as well as interaction of participating agencies and institutions.

(e) Hydroelectric power production is a multi-reservoir function with interacting components and should be modeled as such.

(f) Both retrospective studies and simulated real-time intercomparisons for specific periods should be used to establish performance of the various system options (e.g., system without the benefit of climate forecasts vs. system conditioned on climate forecasts of various kinds, system without uncertainty modeling versus system with components for quantifying forecast uncertainty , etc.)

Our project plan is based on these guidelines and on several discussions with participating agencies, and it is designed to allow useful results in each year, all along the path to the integrated Northern California system. We will start with the modeling and analysis of each of the four major reservoirs and their water resources systems, taken individually. Long-term average boundary conditions will be developed for each reservoir system as a simplified interaction with the other reservoir systems. This will be done in close collaboration with participating agencies to allow the production of useful results (such as those obtained for the Folsom Lake reservoir) even in this first phase of the project. Sensitivity to the set boundary conditions will be performed in each case, to develop an understanding of the range of performance or vulnerability of each reservoir system individually as affected by regional climate variability. It is expected that this first phase of the project will be of a two years duration and will use data of daily resolution for forecasts and decision support. Ensemble seasonal climate forecasts of 4-6 months duration from several GCMs will be utilized to generate ensemble reservoir inflow forecasts following *Carpenter and Georgakakos (2000*). Operational hydrologic models run at the NWS CNRFC would be used as much as possible.

The following two years will be devoted to the modeling of the downstream river systems and requirements, and the integration of the reservoir management functions among all four of the reservoirs. In this phase, we will use available monthly and daily models to the extent possible (e.g., CALSIM of Dept of Water Resources, monthly reservoir and river temperature model of USBR, and others). Significant interaction with USBR and DWR Staff is envisioned during this phase as well, as we develop reasonable approximations to the complex actual downstream systems and requirements. The fifth year will be devoted to integrated system analysis under a variety of forecast scenarios for present and projected climate variability. Of particular importance would be the development of competing planning trade-offs given various socioeconomic assumptions regarding the demand for water in the region.

Throughout the project tenure, we intend to have modelers spend time in the operational centers associated with the target system (e.g., USBR CVO, NWS CNRFC, California DWR) and we would host several visits of operations Staff at HRC and GWRI during system development and analysis. Both proposing organizations have used this exchange policy in previous application projects in the US and abroad with mutual benefits and for assuring sustainability of developed prototype systems. An interagency oversight committee will be formed that includes funding agency representatives, operations managers, forecasters, and HRC and GWRI modelers. Bi-annual meetings for progress report and project direction alignment are envisioned. It is expected that participating agencies will fund their staff time for participating in these visits and meetings. Funds for this project are only requested for HRC and GWRI personnel.

5.4 Main Research Tasks

5.4.1 Climate Forecasts and Downscaling (Dr. Nicholas Graham, Tasks Lead Co-PI)

For the completion of these research tasks, considerable climate model and observational data is necessary. HRC has data from a number of AGCM simulations that will be used for initial work under this proposal. Some of these data has been used in the preliminary work that has been done to date. These data include:

(a) Simulations forced with observed sea surface temperatures (SSTs) – these will be referred to as OSST simulations. For the 3 ensemble OSST simulations below we have (at least) monthly precipitation, 2-meter temperature, and 500 hPa height.
ECHAM3 T42 (Max Planck) – Ensemble of 10, 1950-98
MRF9 T40 (NCEP) – Ensemble of 13, 1950-95
CCM3 T42 (NCAR) – Ensemble of 10, 1950-95

Note: Many other variables are available from 7 (approximately) of the ECHAM3 OSST simulations. There are now many more runs of CCM3. These data are on the mass store at NCAR and could be obtained. MRF9 has been, or will soon be, phased out of operational use by NCEP. Extended simulations with the replacement model (T63 resolution) will presumably be available.
Also available from ECHAM3 are 4-per-day history files from 7 simulations covering 1950-98 which can provide boundary conditions for downscaling models. These are available on the SDSCC mass store.
Also available are daily precipitation and temperature data from 7 ECHAM3 simulations for 1950-98 for the US.

(b) Retrospective forecasts forced with persisted SST anomalies. These simulations use the SST anomalies present in Month 0 as prescribed forcing for Months 1-3, and are for 4 seasons – December through February, March-May, June-August, and September-November. These will be referred to as PSST simulations.
ECHAM3 - Ensemble of 5, 1970-95

Note Daily precipitation and temperature data from 7 ECHAM3 simulations for 1950-98 for the US.

On the basis of the available data, the following research tasks will be performed.

Task 1.1: Establish baseline performance levels for simulating Central California rainfall with the OSST simulations. The goal is to provide reliable probabilistic estimates of observed rainfall categories.

- Define and remove any spatial biases in the GCM precipitation using American River MAPs or Colfax rainfall as a reference.

- Define reliability of each model for a variety of stratification (tercile, pentile). These results will be checked using the runoff model for flow volumes into Folsom Lake.
- Repeat the above two steps for Oroville, Shasta and Trinity (it is expected that skill levels will drop for Shasta and Trinity as the El Niño signal in California rainfall drops to the north.
- Choose a reasonably good method from above 1 and 2 – apply them to the PSST simulations as a test of expected operational performance using the runoff model.
- Test the point immediately above against forecast NINO3 or NINO3.4 SSTs.

Task 1.2: Develop a condition the runoff-snowmelt trace selection on the basis of AGCM H500 gradient (that is wind).

- Reanalysis data can be used to match up H500 gradient data – we can use speed / direction bins or use an EOF / CCA style technique to go from H500 field to Northern California rainfall.
- This will be done initially for Folsom – then the other sites if Folsom works
- Tests will be as in Task 1

Task 1.3: Test a downscaling approach using a potential flow model coupled to an orographic/convective cloud model as operationally implemented for the Panama Canal Authority (*Georgakakos et al. 1999*). Ensemble forecasts on small scales required by the hydrologic model, make this procedure most suitable for the task at hand.

- Develop and tune the model for California using reanalysis (RA) fields (available at CDC) and with selected years from ECHAM 4-per-day fields (note: off the HRC mass store).
- Describe the skill of the technique using reanalysis data and with ECHAM3 data to drive the model. ETA mesoscale model fields would also be used to intercompare the simplified model skill on scales of 22km.
- Investigate the potential for using monthly mean RA and ECHAM3 U, V, Q fields to drive the model – can the derived steady state rainfall be transformed to useful runoff traces?
- Test all above with runoff model for flow volume at Folsom
- If this works, extend to other reservoirs.

Task 1.4: Develop close collaborative efforts with California DWR, state meteorologist, CNRFS, USBR Central Valley Operations, CDC, and CPC

- For DWR and state meteorologist: supply AGCM data for California to them. Develop a list of research questions they have concerning forecast models and their ability to simulate the probabilities of intense precipitation episodes.
- With USBR operations: work with USBR CVO so that they understand the probabilistic nature of climate prediction and how in the long run this information might reduce costs.

- With CPC or the NCEP CMP (coupled model project) – establish a working relationship for the INFORM project to get data from the new AGCM after OSST validation runs are performed. Establish the performance level of this model as described in Task 1.
- Also for DWR-CNRFS-USBR: daily precipitation and temperature data from 7 ECHAM3 simulations for the US from the OSST and PSST runs. Do these contain any useful information concerning risks of extreme events?

5.4.2 Hydrologic Forecasts and Uncertainty (Dr. K.P. Georgakakos, Tasks Lead PI)

HRC has collaborated closely with the NWS CNRFC in refining the operational models used for flow prediction on the American River. HRC has developed and implemented within the NWS River Forecast System the operation SS-SAC, which complements the NWS operational hydrologic forecast model with a nonlinear state estimator for flow data assimilation and forecast uncertainty estimation (*Sperfslage and Georgakakos, 1994*). In addition to the 6-hourly real time operational data that HRC has stored in its mass stores during the last three years, daily observed data and simulated model forecast data have been stored for the three forks of the American River since the early sixties. Furthermore, HRC has the entire database of daily and hourly precipitation data and daily surface temperature, snowfall and snowcover data for Northern California in its historical data set of EARTH INFO disks.

Task 2.1: Available data will be used to refine hydrologic model calibrations for the upstream catchments of each reservoir and for the local contributing areas. Downstream catchments providing lateral flows to the Sacramento River system will also be modeled to the extent allowed by the available data.

- This process will be done in close collaboration with the NWS CNRFC to permit the use of the refined estimates in the operational models.
- An issue to be addressed is the adequacy of the available data for hydrologic and hydrometeorologic modeling. For Folsom, *Tsintikidis et al. (2000)* recently show that the existing operational network is likely to have significant biases in reproducing rainfall spatial variability and additional gauges were recommended for this mountainous area. Similar studies will be performed for the rest of the catchments involved to develop estimates of measurement uncertainty for the modeling and calibration tasks.
- Daily potential evapotranspiration estimates will be refined based on bulk formulas and daily surface meteorological data.
- Validation will be performed for the snow accumulation and ablation component of the NWS operational hydrologic model (*Anderson, 1973*), and the effect of the number of elevation zones used in the model will be assessed in each case.

Task 2.2: Development of the capability for ensemble hydrologic forecasting for reservoir inflows, allowing for short-term precipitation forecasts and parametric uncertainty.

- In collaboration with the NWS CNRFC we will apply the conditional approach of *Carpenter and Georgakakos (2000)* to generate ensemble inflow forecasts with maximum lead time of a few months and daily resolution, that account for both precipitation, temperature and potential evapotranspiration forecast uncertainty, and hydrologic model uncertainty.
- For short lead times, out to a few days, the use of operational precipitation and temperature forecasts may be beneficial in some cases. To account for this information in the ensemble forecasts, the state space form of the SS-SAC would be used to produce variance estimates of inflow forecasts for the short lead times, which may be converted to ensemble inflow forecasts assuming a near normal distribution of forecast errors (there is strong evidence for this as shown recently for the American River in *Carpenter and Georgakakos, 2000a*). For longer lead times, the *Carpenter and Georgakakos (2000)* GCM ensemble-conditioning approach would be used but for an ensemble of initial conditions as produced by SS-SAC for the short lead times. Other possibilities would also be evaluated.
- HRC Staff will assist the NWS CNRFC Staff in implementing the hydrologic forecast procedure in the current operational system for operational use and validation using reliability diagrams and rock curves (e.g., *Wilks, 1997*).
- The existing statistical procedures of the USBR CVO will also be used (as done with the Folsom Lake case study) to provide a baseline for comparison.

Task 2.3: Hydrologic-hydraulic models would be assembled and formulated as needed for the downstream portion of the Northern California River system to allow evaluation of impacts of release decisions at the reservoir sites.

- CALSIM runs would be performed to develop necessary formulations. The feasibility of developing tables with CALSIM runs for evaluating impacts would be examined. Simplified models will also be examined as alternatives with monthly and daily time steps. These models would be compared against CALSIM simulations for fidelity in reproducing important system flows and components. These tasks would be done in close collaboration with DWR, USBR and NWS CNRFC.
- The current USBR operational river and reservoir monthly temperature model () would be used as well to establish downstream environmental impacts to anadromous fish during certain parts of the year.
- Downstream-model uncertainty and lateral inflow uncertainty would be analyzed through a Monte Carlo simulation framework, sampling from uniform distributions of selected parameters and boundary conditions (representing uninformative priors).
- After the analysis of uncertainty, the final downstream river and temperature models would be converted to a state space form to allow use by the decision models (discussed in section 4.5.4.3 below).

Task 2.4: Develop close collaboration with the State Hydrologist of DWR, the Hydrologist in Charge of the NWS CNRFC, the Staff of the USBR CVO and Planning Div. of USBR, and SAFCA representatives.

- With CNRFC, close interaction with the exchange of data and knowledge for the refinement of calibration of the operational models for the study catchments. Assist with improved operational forecasts by supplying improved parameters and assist in operational implementation of ensemble forecasting for the study catchments.
- For DWR, make available short- and long-range forecasts, the former conditioned on short-term precipitation and temperature forecasts and the latter conditioned on GCM forecasts. Collaborate in conducting meaningful CALSIM experiments and identifying simplified models for the purposes of the proposed work.
- For USBR, assist in the interpretation of the short- and long-range ensemble forecasts for use in reservoir operations.
- With SAFCA, collaborate in defining the important system components as pertain to flood control and setting validation criteria for developing a reasonable approximation to the actual system.

5.4.3 Decision Models (Professor A.P. Georgakakos, Tasks Lead Co-PI)

The Sacramento River decision support system (DSS) will be designed to support reservoir management decisions pertaining to multiple time scales. Specifically, the SRDSS will consist of (a) a long-range control model with a horizon of one year and monthly or weekly time steps, (b) a mid-range control model with a horizon of one month and daily time steps, and (c) a short-range control model with a horizon of one day and hourly time steps. The concept of this decision hierarchy for reservoir management has been discussed by *A.Georgakakos et al., 1997a,b,c*, and its operational implementation for actual reservoir systems are described by *Yao and A.Georgakakos, 2000*, and *A.Georgakakos and Yao, 2000*. In what follows, we only provide a summary discussion of the DSS elements.

Short Range Model

The purpose of the short range model is to determine the most efficient reservoir operation such that for a given daily total outflow (from all active turbines, spillways, and outlet conduits) all intra-day instream flow and power requirements are met. Daily reservoir levels and releases are determined by the higher decision levels and are inputs to this model. In addition to solving the turbine commitment and load dispatching problem, the model also generates a function that relates total power to reservoir level and total release, under best efficiency plant operation. This function is determined using dynamic programming (*A.Georgakakos et al., 1997a, Yao and A.Georgakakos, 2000*), and is used by the mid range decision model. Due to the short time horizon, this model will be developed for <u>individual</u> reservoirs and power facilities.

Mid Range Model

The mid range decision model will use the functions generated by the short range model to determine reservoir release and level sequences that address flood protection, hydropower generation, water supply, and fish and wild life requirements within a period of a month in daily time steps. Monthly or weekly release volumes will be provided by the long range model and will be an input to this model. Due to its monthly horizon, the mid-range model will be developed for each sub-basin of the Sacramento River including the Trinity, Shasta, Oroville, and Folsom sub-basins. In the mid range model, reservoirs and river reaches will be modeled through appropriate water balance and river routing equations, and future inflows will be forecasted through inflow forecast ensembles as described earlier. The second purpose of the mid range model will be to aggregate the response of each sub-basin from daily to monthly or weekly time scales. The aggregation functions will be used by the long range model.

The mid range management problem will be solved using the Extended Linear Quadratic Gaussian (ELQG) control method which was developed by *A.Georgakakos 1989, 1993, A.Georgakakos et al., 1997a,b,c,* and *A.Georgakakos et al., 1998a, Yao and A.Georgakakos, 2000*.

Long Range Model

The long-range model will use the sub-basin aggregation functions generated by the mid range model to address basin-wide issues such as drought management (i.e., water supply) and ecosystem protection. This model will simultaneously consider all sub-basins as one system, will have monthly or weekly time steps and a horizon of one year. Seasonal inflow forecasts will use climate and hydrologic information and their uncertainty will be explicitly considered in the derivation of decision policies. The long range management problem will be solved using the ELQG control method referenced earlier. ELQG is especially suited for uncertain multi-reservoir systems.

Decision Model Linkages

The three models of the decision system constitute a multilevel control hierarchy with an operational flow that follows two directions: The lower level models are activated first to generate information that is used by the upper levels regarding performance functions and bounds. In the course of this upward flow, the decision system simulates the reservoir and river response for various hydrologic and water use scenarios, selecting those that optimize system performance. Once the most desirable policies are identified, the control levels are activated in the reverse order to generate the best turbine hourly sequences and loads implementing these decisions consistently across all relevant time scales. The decision system is designed to operate sequentially, at the beginning of each day, continually updating its release policies in keeping with the most current inflow forecasts and operational conditions.

The Sacramento River DSS will be implemented within a user-friendly, PC-based interface and will be useful for planning as well as operational management purposes.

The research and development tasks by year pertaining to the decision models follow:

Year 1 Project Tasks

3.1.1 Extensive interaction/consultation with stakeholder agencies on the scope, design, and data requirements of the Folsom and Shasta short/mid range decision support systems;

3.1.2 Development of short range and mid range decision models for Folsom and Shasta reservoirs and corresponding sub-basins;

3.1.3 Linkage with hydrologic forecasting systems for Folsom and Shasta sub-basins;

3.1.4 Development of policy assessment model for Folsom and Shasta;

3.1.5 Development of a graphical user-model DSS interface;

3.1.6. Assessment of the Folsom and Shasta forecast-decision systems;

3.1.7 Technical report and user manual writing for the Folsom/Shasta DSS and investigations;

3.1.8 Technical workshops with the stakeholder agencies to demonstrate and implement (a beta version of) the Folsom and Shasta short/mid range DSS, provide training in model theory and use, and consider further enhancements and modifications.

Year 2 Project Tasks

3.2.1 Extensive interaction/consultation with stakeholder agencies on the scope, design, and data requirements of the Trinity and Oroville short/mid range decision support systems;

3.2.2 Development of short range and mid range decision models for Trinity and Oroville reservoirs and corresponding sub-basins;

3.2.3 Linkage with hydrologic forecasting systems for Trinity and Oroville sub-basins;

3.2.4 Development of policy assessment model for Trinity and Oroville;

3.2.5 Development of a graphical user-model DSS interface;

3.2.6. Assessment of the Trinity and Oroville forecast-decision systems;

3.2.7 Technical report and user manual writing for the Trinity/Oroville DSS and investigations;

3.2.8 Technical workshops with the stakeholder agencies to demonstrate and implement (a beta version of) the Trinity and Oroville short/mid range DSS, provide training in model theory and use, and consider possible enhancements and modifications.

Year 3 Project Tasks

3.3.1 Extensive interaction/consultation with stakeholder agencies on the scope, design, and data requirements for the Sacramento River long-range decision support system;

3.3.2 Development of the long range decision model for the Sacramento River basin;

3.3.3 Development of a graphical user-model DSS interface;

3.3.4 Technical report and user manual writing for the Sacramento DSS;

3.3.5 Technical workshops with the stakeholder agencies to demonstrate and implement a beta version of the Sacramento long range DSS, provide training in model theory and use, and consider further enhancements and modifications.

Year 4 Project Tasks

3.4.1 Long range DSS linkage with the climate and hydrologic forecasting systems for the Sacramento River basin;

3.4.2 Development of the long range policy assessment model for the Sacramento River;

3.4.3 Assessment investigations for the long range Sacramento forecast-decision system;

3.4.4 Technical report and user manual writing for the Sacramento DSS.

3.4.5 Technical workshops with stakeholder agencies to demonstrate and implement a beta version of the Sacramento long range DSS, provide training in model theory and use, and consider further enhancements and modifications.

5.4.4 Assessment Models and Analyses (All Co-PIs)

The last element of the Sacramento DSS is the policy assessment model. Its purpose is to quantify the system response for a specified inflow sequence, streamflow forecasting scheme, and operational policy. The assessment model replicates the sequential operation in which the decision system is designed to work in practice. Thus, at the beginning of each day in the assessment period, the inflow forecasting scheme is invoked first to generate a forecast ensemble for the upcoming inflows. Next, the decision system uses the forecast information to determine the most desirable reservoir release sequences over the forecast-control horizon as described in the previous sections.

The response of the reservoir is then simulated for the current month, week, or day, and the process is repeated at the beginning of the next simulation time step. At the completion of the forecast-decision-simulation process, the program generates sequences of all relevant system performance measures including reservoir levels, releases, energy generation, flood stages, instream flow conditions, and water supply deficits, if any. These sequences can be used to compare the benefits and consequences of various inflow scenarios, forecast-decision configurations, and operational policies. For example, Figure 4 shows the Folsom reservoir level and release sequences that would result over the 1965-1993 historical time period under (a) the “Operational Forecast” option and a decision rule derived from current management practices, and (b) the “Perfect Forecast” option and the Folsom DSS (*Yao and A.Georgakakos, 2000*). These different scenarios can be viewed as two extreme cases, with the former using heuristic forecasts and fixed decision rule curves and the latter using perfect forecasts and adaptive decision policies such as the ones proposed herein. The Figure shows that the heuristic management scenario keeps lower reservoir levels and avoids flooding, but it also causes minimum flow violations and generates about 18% less energy. By contrast, the adaptive scenario uses the forecasts to derive dynamic release policies drawing the reservoir down in anticipation of high floods and allowing it to refill as flood waves pass. As a result, flood damage is avoided, reservoir levels and energy generation are higher, and minimum flow requirements are met always. Perfect forecasts, however, are unattainable, and the adaptive scenario can only serve to define an upper performance limit. A practical question that the proposed project will address is “How close can the Sacramento River reservoirs get to this optimal performance using *realistic* forecast procedures and adaptive management schemes?”

The assessments would be made on the basis of retrospective studies and on the basis of simulated real time intercomparisons for selected events. Particular emphasis will be given to the system performance and sensitivities during El Nino periods. The bulk of these assessments for the integrated Northern California system will be performed during the fifth year of the project.

Year 5 Project Tasks

5.1 Implementation of model enhancements and modifications for short, mid, and long range DSS and forecast model elements as agreed upon with the stakeholder agencies;

5.2 Assessment investigations using the final DSS version and in close collaboration with participating agencies;

5.3 Revisions of technical reports and user manuals;

5.4.1 Technical workshops with stakeholder agencies to demonstrate and implement the final version of the Sacramento DSS, and provide training in model use.

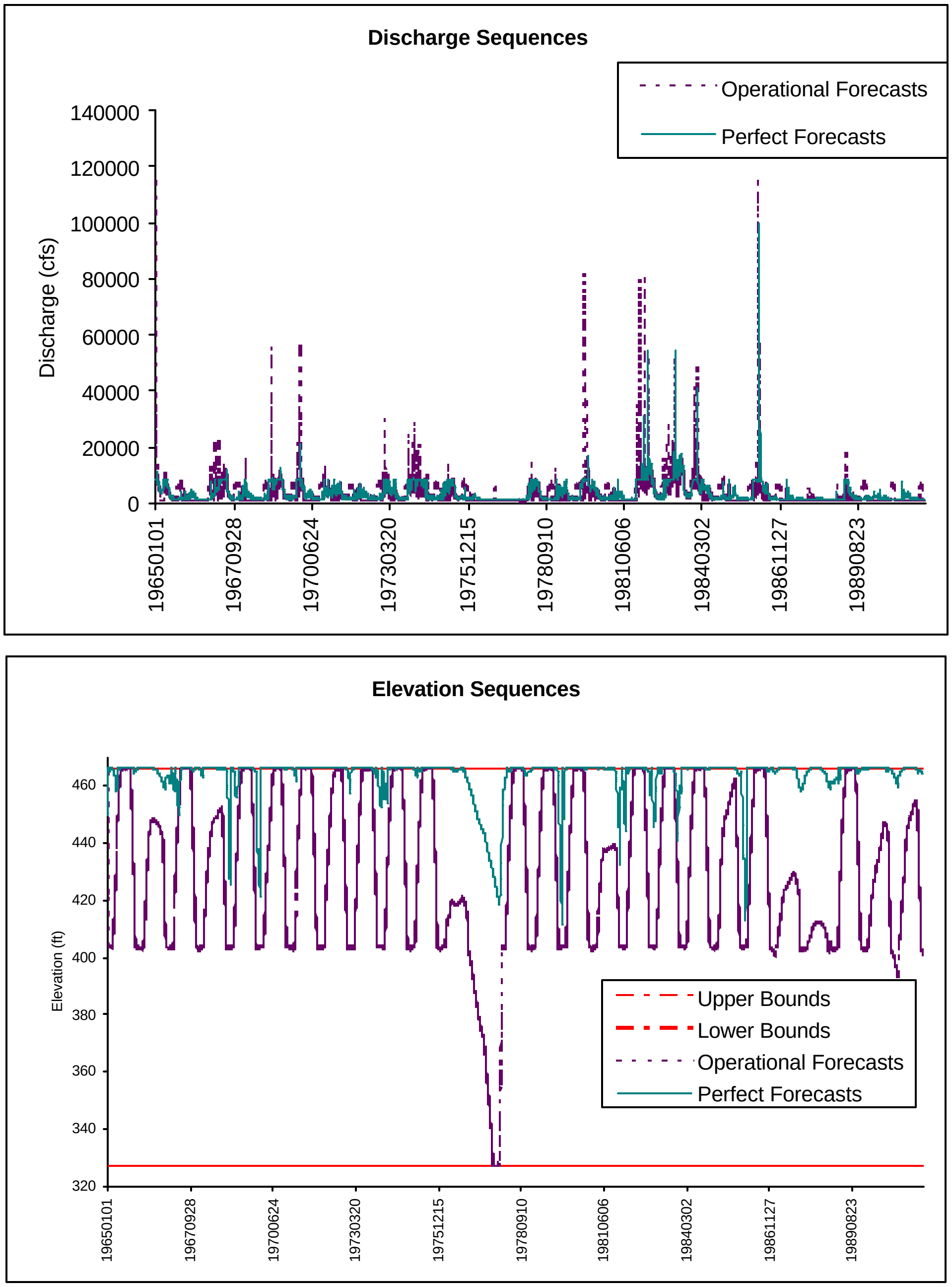

Figure 4. Example runs of the Folsom assessment model

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Qualifications

KONSTANTINE P. GEORGAKAKOS (Lead PI of Proposal)
Hydrologic Research Center, 12780 High Bluff Drive, Ste. 250, San Diego, CA 92130
Tel. 858-794-2726; Fax. 858-792-2519; Email: KGeorgakakos@hrc-lab.org
www.hrc-web.org

EDUCATION

Sc.D.	Hydrology & Water Resources, Civil Eng., MIT, 1982
M.S.	Hydrology & Water Resources, Civil Eng., MIT, 1980
Diploma	Civil Engineering, National Technical University of Athens, 1977

RECENT POSITIONS HELD

7/1993 - Pres	Founding Director, Hydrologic Research Center, San Diego, California
7/1997 - Pres	Full Research Scientist IV, Scripps Institution of Oceanography, University of California at San Diego, California
7/1994 - 6/1997	Full Research Scientist III, Scripps Institution of Oceanography, University of California, San Diego, CA
7/1995 - Pres	Adjunct Full Professor, Civil and Environmental Engineering (CEE), The University of Iowa, Iowa City, IA
1/1993 - 6/1994	Research Engineer, Iowa Institute of Hydraulic Research, and Adjunct Associate Professor, CEE, The University of Iowa
8/1989 - 12/1992	Associate Professor w/Tenure, CEE, The University of Iowa
1/1986 - 8/1989	Assistant Professor, CEE, The University of Iowa

SELECTED PROFESSIONAL ACTIVITIES

Advised to completion of their degree 7 PhD students and 9 MS students with Thesis at The University of Iowa (1986-1992), and UCSD (1996-2000).
Advised 6 Postdoctoral Associates at The University of Iowa, UCSD, and Hydrologic Research Center (1990-1997).
Served on NOAA Science Review Panel (1994-1995)
Served on the GEWEX Numerical Experimentation Committee (1993-1995)
Associate Editor for Journal of Hydrology and ASCE Journal of Hydrologic Engineering
Consultant to Food and Agriculture Organization of United Nations

SELECTED HONORS AND AWARDS

Appointed in the WMO Commission for Hydrology, Working Group on Applications as a US Expert in Hydrologic Modeling (1997-present)
National Science Foundation: Presidential Young Investigator Award (1987-1992)
The University of Iowa: University Faculty Scholar (1988-1991)
National Research Council - NOAA: Research Associate Award (1983-1985)
Listed in Who's Who in Science and Engineering

RELEVANT RECENT PUBLICATIONS

Dr. K.P. Georgakakos has more than 60 refereed-Journal publications and Book Chapters in the area of hydrology and hydroclimatology, with emphasis on operational hydrologic modeling and forecasting. Most relevant recent publications are reviewed in the main proposal text and are included in the Reference list above.

NICHOLAS E. GRAHAM (Proposal Co-PI)

Hydrologic Research Center, 12780 High Bluff Drive, Ste. 250, San Diego, CA 92130
Tel. 858-794-2726; Fax. 858-792-2519; Email: NGraham@hrc-lab.org
www.hrc-web.org

EDUCATION

Ph.D.	University of California, Santa Barbara	Geography	1986
M.S.	University of California, Santa Barbara	Geography	1982
B.A.	University of California, Santa Barbara	Geography	1970

RECENT POSITIONS HELD

2000-present	Research Climate Scientist and Climate Applications Coordinator Hydrologic Research Center, San Diego, CA
1994-present	Associate Research Meteorologist and Academic Coordinator Climate Research Division, Scripps Institution of Oceanography La Jolla, California
1992-present	Lecturer, Climate Research Division Scripps Institution of Oceanography, La Jolla, California
1988-1994	Assistant Research Meteorologist Climate Research Division, Scripps, Institution of Oceanography La Jolla, California
1987-1988	Postgraduate Research Meteorologist, Climate Research Division, Scripps Institution of Oceanography, La Jolla, California
1981-Present	Marine Meteorology Consultant, Pacific Weather Analysis, Santa Barbara, California (Certified Consulting Meteorologist)

SELECTED PROFESSIONAL ACTIVITIES

Served on NOAA Science Review Panels (last ten years)
Contributed to the IPCC Reports on Global Warming
Serves as an expert consultant to Peruvian Meteorological Service regarding seasonal climate prediction (since 2000)
Served as the Director of the International Research Institute Climate Forecast Division (1996-1999)

RELEVANT RECENT PUBLICATIONS

Dr. Graham has more than 40 refereed-Journal publications and Book Chapters in the area of climate science, with emphasis on climate variability, long-term climate change, and seasonal climate prediction. Most relevant recent publications are reviewed in the main text of the proposal and are listed in the Reference list above.

ARIS P. GEORGAKAKOS (Proposal Co-PI)

Georgia Water Resources Institute, Georgia Institute of Technology, Atlanta, Georgia, 30332
Tel. 404-894-2240; Fax. 404-894-2677; Email: ageorgak@ce.gatech.edu
www.water.ce.gatech.edu

EDUCATION

Ph.D. (1984)	Massachusetts Institute of Technology, Dept. of Civ. Eng.
M.S. (1983)	Massachusetts Institute of Technology, Dept. of Civ. Eng.
B.S. (1980)	National Tech. Univ. of Athens, Greece, Dept. of Civ. Eng.

RECENT POSITIONS HELD

July 1997 - present;	Director, Georgia Water Resources Institute
Mar. 1996 - present;	Professor, Civ. and Env. Eng., Georgia Institute of Technology
Jan. 1994 - present;	Associate Chair for Research, Civ. and Env. Eng., Georgia Inst. of Tech.
Jan. 1994 - present;	Head, Environmental Hydraulics and Water Resources Civ. and Env. Eng., Georgia Institute of Technology
May '90 - Mar. '96;	Associate Professor; Civ. and Env. Eng., Georgia Institute of Technology
Sep. '84 - May '90;	Assistant Professor; Civ. and Env. Eng., Georgia Institute of Technology
Sep. '80 - Aug. '84	Graduate Research and Teaching Assistant Dept. of Civ. Eng., Massachusetts Institute of Technology

SELECTED PROFESSIONAL ACTIVITIES

Associate Editor, Water Resources Research, 1996-1999
Testimony before the U.S. House Subcommittee on Water and Power Resources on "The Water Resources Impacts of the 1997/1998 El Nino," 30 October 1997.
Chairman, ASCE Committee on Water Resources Operations Management
Citation for Excellence in Refereeing: Water Resources Res. (1992), HydroReview (1992)
Task Committee Excellence Award, Am. Soc. of Civ. Eng., Hydraulics Division (1991)
Research Funded from USGS, USCOE, USAID, FAO/UN, NOAA, Electrical Utility Industry
Technical Advisor: World Bank, Food and Agriculture Organization of the United Nations, Governments of Greece, Egypt, Uganda, Kenya, Tanzania
Appointed by the Georgia General Assembly as Member of the State Water Resources Planning Committee (since June 2001)

RELEVANT RECENT PUBLICATIONS

Dr. A.P. Georgakakos has more than 40 refereed-Journal publications and Book Chapters in the area of surface and groundwater water resources systems with emphasis in integrated decision support technologies. Most relevant recent publications are reviewed in the main proposal text and are included in the Reference list above.

Compliance with Standard Terms and Conditions

The Proposers will comply with the standard State and Federal contract terms described in Attachments D and E of the ERP 2002 Proposal Solicitation Package.

Cost Sharing

Identical proposals have been submitted to the NOAA Office of Global Programs and to the CALFED ERP. The proposed project is of a five-year duration with a total budget of $1,746,334.00. Of the total funds budgeted, the present request to the ERP is for a total of $600,000 for three years (approximately $200,000 per year), as a State funding contribution.

NOAA OGP has approved approximately $40,000 to facilitate meetings with State and Feederal Agencies for realizing the INFORM program in Northern California. Tentative approval of up to $150,000 per year in Federal funds for the first three years of the project has been received by the PI's of the proposed Project. The requested funding represents the balance of the required funds for executing the first three years of the INFORM Project.

Agency Letters of Support

United States Department of the Interior

BUREAU OF RECLAMATION
Mid-Pacific Regional Office
2800 Cottage Way
Sacramento, California 95825-1898

IN REPLY
REFER TO:
MP-700

NOV 29 2000

Dr. Konstantine Georgakakos
Director, Hydrologic Research Center
12780 High Bluff Drive, Suite 250
San Diego, CA 92130

Subject: INFORM (Integrated Forecasting and Reservoir Management) Project Proposal for Folsom Reservoir

Dear Dr. Georgakakos,

I understand that you are preparing a proposal to conduct an INFORM research demonstration project at Folsom Reservoir. The INFORM project will demonstrate the potential benefits of integrating Global Climate Models with reservoir management models. The resulting project system will also have key components including a decision module that will allow operators to make informed assessments of trade-offs among operational benefits. Reclamation is very interested in exploring means to improve forecasts and thereby improve the efficiency of reservoir operations to effectively meet Central Valley Project (CVP) purposes.

As you know, Reclamation operates its CVP reservoirs, including Folsom Reservoir, according to a lengthy variety of requirements and considerations. Operational constraints and requirements on the system include water supply deliveries, flood control, American River temperature requirements, Delta outflow and water quality requirements, fishery and environmental flow demands, and power generation commitments. Improvements which provide a greater ability to predict storm events or extended periods of wet or dry conditions could allow for more efficient reservoir operations, resulting in increased water supply conservation and improved flood protection. Reservoir operators and environmental flow managers could utilize more reliable and longer-term forecasts to prioritize operational considerations on a real-time basis.

Reclamation's Planning Division is responsible under the Central Valley Project Improvement Act to investigate means to increase the water supply and water supply reliability of the CVP. The INFORM program has significant potential to provide multipurpose benefits to the operation of Folsom Reservoir, and Reclamation supports your efforts to develop and demonstrate this integrated forecast-control system. Reclamation will continue to work with you to provide data and operational criteria for Folsom Reservoir and the American River. As an example of the complexity of American River operating criteria, Folsom is sometimes operated in coordination with other CVP and State Water Project reservoirs to meet San Francisco Bay/San Joaquin-Sacramento River Delta outflow or water quality criteria, particularly because of its proximity to the Bay-Delta. Therefore, Reclamation would ultimately like to see the INFORM project be expanded to include other key reservoirs in the Sacramento River basin, including Shasta and Oroville, as operations of these reservoirs are coordinated to provide maximum benefits to the Bay-Delta and to the Federal and State water projects.

My staff will continue to work with you to coordinate multi-agency workgroups and to provide necessary data and feedback as you develop the INFORM system models. Reclamation supports implementation of the INFORM program, and looks forward to participating in the development and demonstration of this significant reservoir management tool.

Sincerely,

Alan R Candlish

for Susan E. Hoffman
Regional Planning Officer

cc: Lowell Ploss, Deputy Regional Director (MP-115)
Chet Bowling, Acting Chief, Central Valley Operations Office (CVO-100)
Lloyd Peterson, Research Coordinator (MP-700)
John Davis, Resources Manager (MP-400)

SAFCA

Sacramento
Area Flood
Control
Agency

June 5, 2000

Kostantine P. Georgakakos, Ph.D.
Director, Hydrologic Research Center
12780 High Bluff Drive, Suite 250
San Diego, CA 92130

SUBJECT: INTEGRATED FORECASTING AND RESERVOIR MANAGEMENT (INFORM)

Dear Dr. Georgakakos:

Thank you for inviting me to the June 8, 2000 meeting on initiative INFORM being held in San Diego, California. I understand the purpose of the meeting is to plan the realization of Initiative INFORM for Northern California and in particular for Folsom Dam and Reservoir on the American River. SAFCA is the primary flood control agency coordinating local flood control efforts downstream of Folsom Dam on the American River. We are providing the local cost sharing for Federal projects in the Sacramento area. Our agency was formed following the 1986 flood when that event exposed the flood management deficiencies along the American River. Since that time FEMA has declared that Sacramento has less than 100-year level of protection and we have learned that nearly 400,000 people live in the flood plain below Folsom Dam. Over $200 million in federal projects are now under design and construction to improve Sacramento's flood protection to at least the 140-year level.

Although I will not be able to attend the meeting because of previous commitments, I want you to know that my Agency strongly supports Initiative INFORM.

We understand that there is tremendous potential to improve both water supply and flood control operations of multiple purpose reservoirs. The Federal government has invested well over a billion dollars in a water supply and flood control system of reservoirs and canals in California. Because of changes in population, rainfall amounts, and new environmental requirements, the system is not providing the water supply reliability or the flood protection for which it was designed. As a result major modifications to Folsom Dam have recently been authorized to improve its flood operations capability. Well over 300,000 people and the State Capitol are located in the flood plain below Folsom Dam and a very significant portion of the state's population relies on the water supply from the reservoir. The visionary Initiative INFORM provides the only ongoing research of which we are aware that provides hope of a more efficient and effective operation of the resource represented by reservoirs such as Folsom Reservoir.

Office 916-874-7606
FAX 916-874-8289

1007 - 7th Street, 5th Floor
Sacramento, CA 95814-3407

Through our partnership with the State and Federal governments, we are modifying Folsom Dam to be able to more efficiently and effectively operate the facility. Under the current operation plan, it is assumed that we have no skill in predicting rainfall amounts in the future. This causes the dam to miss opportunities for increased water supply and flood protection. The ability to classify the potential for storms for a period ranging from weeks to months in advance would greatly enhance our capability to provide both water supply and flood control improvements at Folsom Dam. The operation of the dam could be predicated on the characterization of the storm potential and modified as additional (newer) data was obtained. The reservoir would be dynamically operated based on scientific data instead of the current method of always assuming that the worst case for either flood control or water conservation is just about to begin.

We believe the ability to predict water conditions that are extreme (flood or drought) is better than the ability to forecast near average conditions. The continued development of this skill in even a small way provides the potential for significantly improving the operation of Folsom Dam. We also note that the Bureau of Reclamation and the NOAA have made significant investments in improving short-term flood forecasts and automated operation software for Folsom Dam. We expect the new forecasting and operating software to be available for utilization this fall. The additional operating capability that we believe is attainable from Initiative INFORM can be directly integrated into this new software and be implemented in a timely manner.

We strongly support the timely implementation of Initiative INFORM. Be assured that we will work with you to provide all of the information you may require making Initiative INFORM a success. The survival of our region depends on improving our ability to efficiently operate multiple purpose reservoirs such as Folsom.

Sincerely yours,

F.I. "Butch" Hodgkins
Executive Director