Chapter 1

INFORM Vision, Objectives, Design and Feasibility

1.1 IDENTIFICATION OF THE PROBLEM AND INFORM VISION

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 in 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.

The Integrated Forecast and Reservoir Management (INFORM) Project was conceived to *demonstrate increased water-use efficiency in Northern California water resources operations* through *(a)* the innovative application of climate, hydrologic and decision science, and *(b)* reciprocal technology transfer activities between the INFORM developers and the staff of federal and state agencies with an operational forecast and management mandate in Northern California.

1.2 INFORM SPECIFIC OBJECTIVES

The fundamental premise of the INFORM project is that the current situation in the area of using short- and long-term operational forecasts in water resources management will improve through the establishment of demonstration and assessment sites under the following prerequisite conditions (all perceived as necessary):

(a) there exists a quantitative system that translates forecasts and their considerable uncertainty to useful trade-offs among competing reservoir management objectives;

(b) modelers, forecasters and managers have established a set of mutually-agreed-upon performance criteria by which they can measure the effectiveness of certain decision policies;

(c) a baseline quantitative system version is developed that reflects present management practice and operational models, together with an alternate system version that includes climate forecasts and suitably modified models in an integrated forecast-control framework;

(d) intercomparison of quantitative and other benefits is performed as developed by implementing management decisions for both systems using retrospective analysis of historical data and forecasts, or in real time for a given demonstration period; and

(e) there is continuing participation of management staff in the demonstration activities and in user/modeler conferences for the mutual benefit of modelers, forecasters and managers.

On this basis, the specific objectives of INFORM are:

(a) to implement a prototype integrated forecast-management system for primary Northern California reservoirs, individually and for the system of reservoirs; and

(b) to demonstrate the utility of climate and hydrologic forecasts for water resources management in Northern California through near-real-time tests of the integrated system with actual data and with management input, and by

comparing its economic and other benefits to those of existing water management systems for the same events.

In this proposed project, our target application and demonstration system is the Northern California system of large reservoirs, consisting of the Folsom, Oroville, Shasta, and Trinity reservoirs and associated water resources (Figure 1-1).

1.3 INFORM RELEVANCE

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 is expected that the INFORM demonstration project will advance substantially the state of the science in the area of forecast-decision interaction, and will define the basis of effective application of climate information for improved planning and management of large water resources systems through application to actual such systems. INFORM advocates an application and demonstration process that involves close collaboration between forecasters and managers during the operation of actual systems. With mutually-accepted performance measures, for the first time, INFORM is expected to 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 United States. Lastly, and perhaps most importantly, INFORM 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, and federal, state and local agencies.

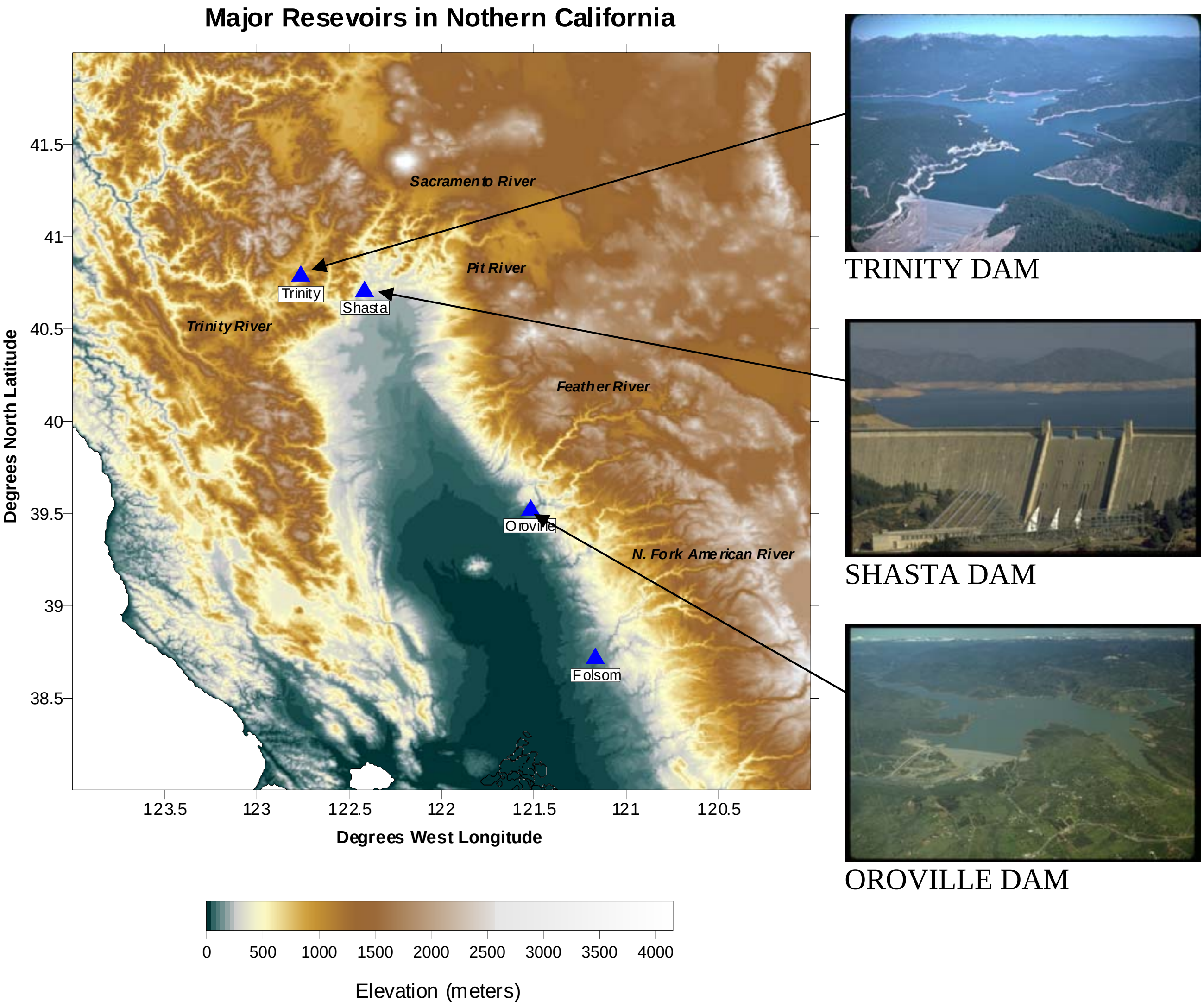

Figure 1-1: Study area in Northern California and major reservoirs used to manage water resources and to mitigate flood damage in the region. The southernmost Folsom Dam is shown in the lower right inset of Figure 1-4.

1.4 BENEFITS TO THE GENERAL PUBLIC AND THE SCIENTIFIC COMMUNITY

The target reservoir system (Folsom, Shasta, Oroville and Trinity) provides the majority of water resources to the California Bay-Delta region, which has supported the trillion dollar economy of California farms and cities for the last 50 years. It 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. 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.

INFORM is designed to generate a science-based information database for more informed decisions pertaining to reservoir management for improving water use efficiency for several management objectives. These include energy production, 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. It will also motivate and establish the beginnings of researcher-forecaster-user institutional cooperatives for the sustainability and improvement of the integrated water resources system performance. 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).

1.5 ELEMENTS OF INFORM DEMONSTRATION PROJECT DESIGN

The Northern California system is a complex system of interconnected channels and reservoir releases with a complex set of constraints for downstream environmental, 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 with the participation of various federal, state and local agencies with the purpose to define a manageable INFORM project plan. The plan allows the inclusion of important system components and functions, it can 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. Several guidelines were developed with the primary ones 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 interaction among reservoirs, because affected cities are directly downstream in the corresponding tributaries but before major confluences in each case.

(c) It is important to include components that allow 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 increasing agricultural and municipal water supply without adversely affecting flood control functions.

(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 between 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.)

The INFORM project plan is based on these guidelines and on several discussions with participating agencies. It is designed to allow useful results in each year, all along the path to the integrated Northern California system. At first the modeling and analysis of each of the four major reservoirs and their water resources systems taken individually is performed. In a first phase INFORM focuses on Folsom and Oroville, while in a second phase it focuses on Shasta and Trinity. Long-term average boundary conditions are developed for each reservoir system as a simplified interaction with the other reservoir systems. This is done in close collaboration with participating agencies to allow the production of useful results even in these first phases of the project. Sensitivity to the set boundary conditions is 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. These two first phases of the project are approximately of a two-year duration and use data of 6-hourly to daily resolution for forecasts and decision support. Six to nine months of ensemble seasonal climate forecasts from the operational climate model are utilized together with ensembles from the Global Forecast System of NCEP with 6-hourly resolution and with maximum lead time of 16 days to generate ensemble reservoir inflow forecasts.

The third phase of the project is devoted to modeling downstream river systems and requirements, and the integration of the reservoir management functions among all four reservoirs. In this phase, available monthly and daily models are used to the extent possible (e.g., CALSIM of the California Department of Water Resources, monthly reservoir and river temperature model of USBR, and others). Significant interaction with management agency staff is envisioned during this phase as well to develop reasonable approximations to the actual complex downstream systems and requirements. In addition, during this third phase, integrated system analysis and intercomparison with the existing practices for forecast and management in the region is performed under a variety of forecast scenarios and for various selected events in near real time. Of particular importance for the integrated system analysis is the development of competing planning trade-offs given various socioeconomic assumptions regarding the demand for water in the region. Figure 1-2 presents the concept diagram for assessing the benefits of the demonstration project through the near-real-time intercomparison of the integrated forecast-management system (virtual system) with the existing practice of reservoir management (actual system). This comparison is for selected events using the same available information. The difference of the approach to management between the actual and virtual system is indicated: the former is based on more or less fixed operation rules, while the later is based on the development of flexible trade-offs.

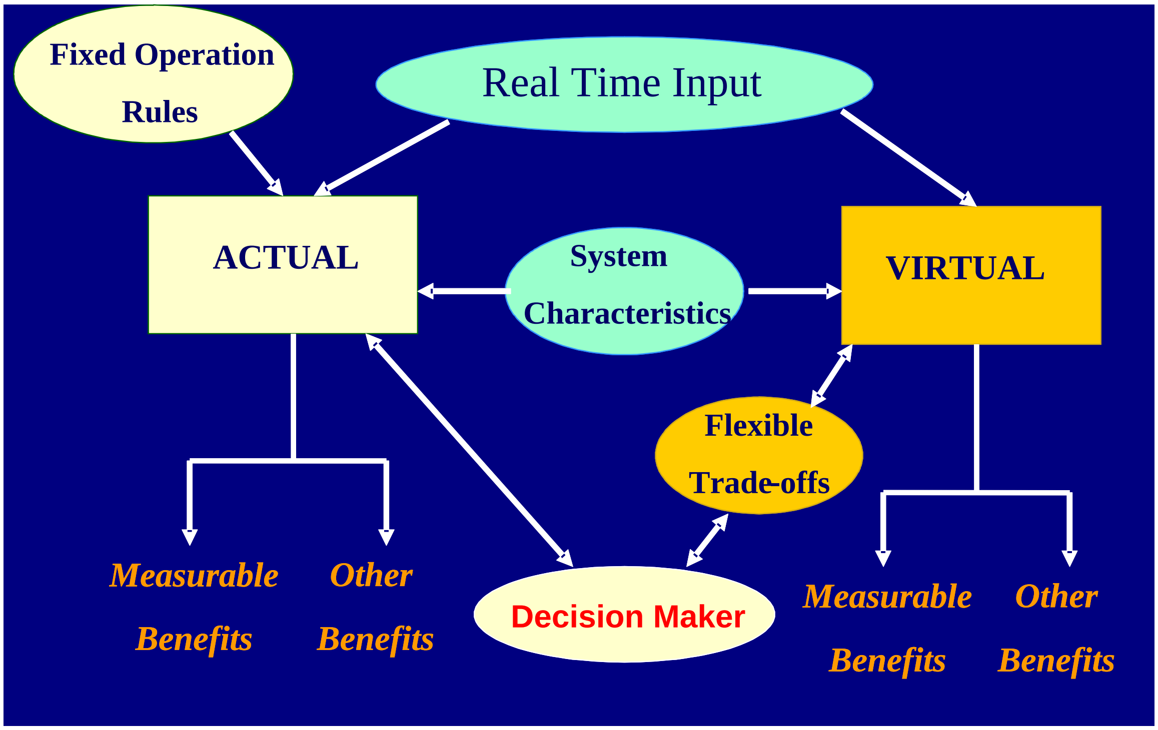

Figure 1-2: Demonstration project concept.

1.6 INFORM FEASIBILITY

In this section, the feasibility of the INFORM project is established by reviewing the results of retrospective studies performed for the Folsom reservoir, one of the primary reservoirs of the INFORM Project. In addition, 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, 2001; Yao and Georgakakos, 2001*). 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.

To quantify management benefits, a numerical integrated forecast-control system has been formulated. Figure 1-3 presents a schematic of the system elements.

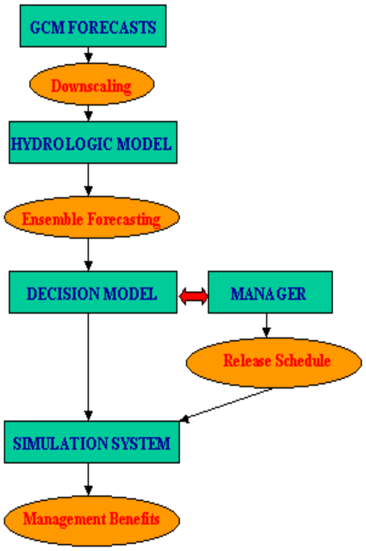

Figure 1-3: Schematic of integrated forecast-control system elements and links.

This design of the integrated forecast-control system shown in Figure 1-3 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 1-3 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; Georgakakos, A., 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 1-3 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 1-3) (e.g., *Risbey and Stone, 1996; Mearns et al. 1990; 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 1-3) (e.g*., 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 1-3) (*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 1-3) (*Yao and A. Georgakakos, 2001*); and

(e) simulating system performance and quantifying benefits for a given reservoir release decision (simulation component in Figure 1-3) (*Yao and A. Georgakakos, 2001*).

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 (2001)* and *Yao and A. Georgakakos (2001)* 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, 2001*).

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 1-4 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 A. Georgakakos, 2001*).

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

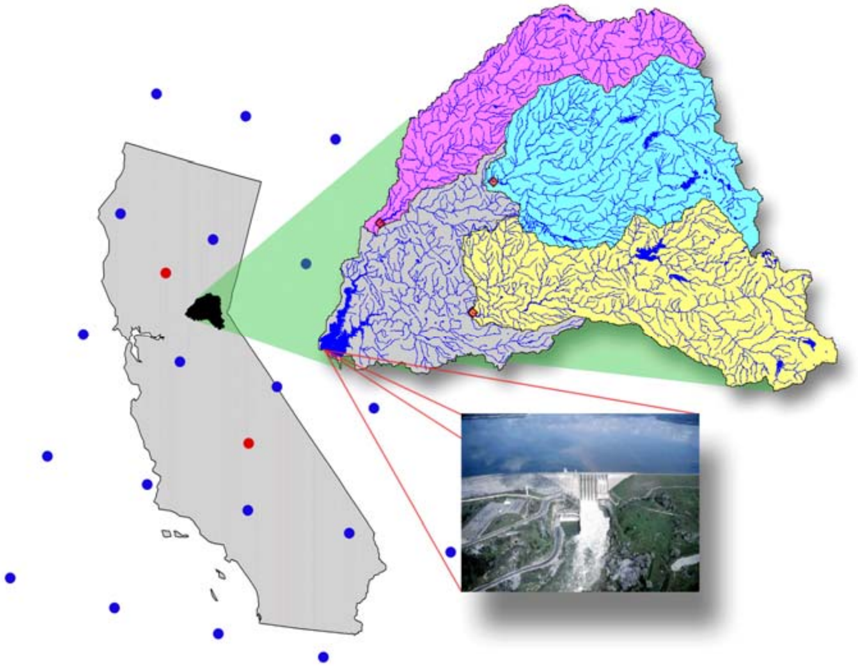

Figure 1-4: Folsom Lake reservoir at the outlet of the American River catchment in north-central California. The location of the catchment is shown together with the GCM computational grids for both the Canadian (red points) and ECHAM3 (blue points) GCMs used in this study. Operational models have been developed for all three Forks of the American River and the local Folsom Lake contributing area.

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 1-1 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 1-1: 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

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 1-1 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 1-2 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 1-2. 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 1-2: 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. Increases of this constraint substantially greater than 50% are likely to impact other management objectives significantly.

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. INFORM is the logical and feasible next step, that 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 expected that the reservoir management benefits from the study of the Northern California region would prove higher than those estimated from the study of a single reservoir (Folsom Lake) because of (a) the added degrees of freedom in the decision process through the study of more than a single multi-objective reservoir; and (b) the fact that the scale of the problem becomes commensurate to the climate prediction scales afforded by present day GCMs. 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.

1.7 REFERENCES

Carpenter, T.M., and K.P. Georgakakos, 2001: Assessment of Folsom Lake Response to Historical and Potential Future Climate Scenarios: 1. Forecasting. *J. of Hydrology*, **249**, 148-175.

Fread, D.L., Ingram, J., Schaake, J., and D.T. Braatz, 1999: Recent experience with ensemble streamflow prediction in the Des Moines River basin. *Preprints 14th AMS Conf. on Hydrology,* American Meteorological Society, 4-7.

Frederic, K.D., 1992: Changing water resources institutions. In Sustaining our Water Resources, Water Science and Technology Board, National Research Council, National Academy Press, Washington, DC, 66-77.

Georgakakos, A.P., H. Yao, 1993: New control concepts for uncertain water resources systems, 1, Theory. *Water Resour. Res.,* **29**(6), 1505-1516.

Georgakakos, A.P., Mullusky, M.G., Yao, H., and K.P. Georgakakos, 1998: Impacts of climate variability on the operational forecast and management of the upper Des Moines River basin. *Water Resour. Res.*, 34(4), 799-821.

Georgakakos, K.P., Bae, D.-H., Mullusky, M.G., and A.P. Georgakakos, 1995: Chapter II-2, Hydrologic variability in Midwestern drainage basins; Diagnosis, prediction and control. In *Preparing for Global Change: A Midwestern Perspective*, Eds: G.R. Carmichael, G.E. Folk, and J.L. Schnoor. SPB Academic Publishing, Amsterdam, The Netherlands: 61-90.

Georgakakos, K.P., Georgakakos, A.P., and N.E. Graham, 1998a: Assessment of benefits of climate forecasts for reservoir management in the GCIP region. *GEWEX News*, **8**(3), 5-7.

Mearns, L.O., Gleick, P.H., and S.H. Schneider, 1990: Climate forecasting. In *Climate Change and U.S. Water Resources,* edited by P.E. Waggoner, John Wiley, New York, 41-73.

Murphy, J., 1999: An evaluation of statistical and dynamical techniques for downscaling local climate. *J. Climate,* **12**, 2256-2284.

Perica, S., Marcus, M., Schaake, J., and D.-J. Seo, 1999: Accounting for hydrologic model errors in ensemble streamflow prediction. *Preprints 14th AMS Conf. on Hydrology,* American Meteorological Society, 12-14.

Risbey, J.S. and P.H. Stone, 1996: A case study of the adequecy of GCM simulations for input to regional climate change assessments. *J. Climate,* **9**, 1441-1467.

Wilks, D.S., 1995: *Statistical Methods in the Atmospheric Sciences*. Academic Press, New York, 467 pp.

Yao, H., and A.P. Georgakakos, 1993: New control concepts for uncertain water resources systems, 2, Reservoir management. *Water Resour. Res.*, **29**(6), 1517-1526.

Yao, H., and A.P. Georgakakos, 2001: Assessment of Folsom Lake Response to Historical and Potential Future Climate Scenarios: 2. Reservoir Management. *J. of Hydrology,* **249**, 176-196.