A Research Proposal to NOAA GEWEX-GAPP and PACS Program

VARIABILITY OF WARM SEASON FLOODS IN THE SOUTHWEST UNITED STATES: DIAGNOSIS, IMPACTS AND APPLICATIONS FOR WATER AND ADAPTIVE ENVIRONMENTAL MANAGEMENT

Proposal Number: GC04-053
Requested Starting Date: February 1, 2004
Total Support Requested: $242,010 (3 years)

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**BUDGET**

Institution: NOAA-CIRES Climate Diagnostics Center  
NOAA/OAR  
325 Broadway  
Boulder, CO 80305  
Title: Variability of Warm Season Floods in the Southwest United States  
Duration: February 1, 2004-January 31, 2007

### A. SALARIES AND WAGES

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Salaries and Wages: 19.25% and $368/mo  
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| **Total Salary, Wages, Benefits (A-B)** | 39289 | 41253 | 43316 | 123858 |

### C. PERMANENT EQUIPMENT

| | 0 | 0 | 0 | 0 |

### D. EXPENDABLE EQUIPMENT - Lap Top

| | 3000 | 0 | 0 | 3000 |

### E. TRAVEL

1. Domestic - four trips to the Grand Canyon  
| | 4800 | 5040 | 5292 | 15132 |
2. Domestic - Scientific Conference  
| | 3200 | 3360 | 3528 | 10068 |
| **Total Travel** | 8000 | 8400 | 8820 | 25220 |

### F. PUBLICATION (Page charges; $115 per page)

| | 0 | 1725 | 1811 | 3536 |

### G. OTHER COSTS

1. Computer Services/Maintenance  
| | 4626 | 4782 | 4946 | 14355 |
2. Materials and Supplies  
| | 982 | 1031 | 1082 | 3094 |
3. Communication/Duplication  
| | 200 | 210 | 221 | 631 |
4. DOI - Topping  
| | 9017 | 9324 | 9641 | 27981 |
| **Total Other Costs** | 14825 | 15346 | 15890 | 46061 |

**TOTAL DIRECT COSTS (A through G)**  
65113 | 66725 | 69837 | 201675 |

**INDIRECT COSTS (CIRES 20%)**  
13023 | 13345 | 13967 | 40335 |

**TOTAL COSTS**  
78136 | 80070 | 83804 | 242010 |
Variability of warm season floods in the southwestern United States: diagnosis, impacts and applications for water and adaptive environmental management

Shaleen Jain, Roger Pulwarty, Theodore Melis, David Topping and Rajgopalan Balaji

Abstract

In the semi-arid southwestern United States, intraseasonal to interannual variability in the May-October precipitation directly impacts the variations in the magnitude, timing, and statistical frequency of warm-season floods. As a result, an understanding of the spatial scales of flood variations and lead-information on flooding has the potential to benefit the water resources operations and planning objectives in the region. In the proposed work, the central thrust is a diagnosis and characterization of Southwest U.S. floods, and the application to water and adaptive environmental management for the Grand Canyon region. This work will diagnose the spatial and temporal structure of warm-season flood magnitude and timing in the Southwest, and develop a predictive framework. Furthermore, collaborative work with the Grand Canyon Monitoring and Research Center will focus on investigation of the value of climate-based flood prediction for sediment input into the Grand Canyon, and decision processes related to the Glen Canyon Adaptive Management Program. The multidisciplinary team (from NOAA-CDC, University of Colorado and the GCMRC) will investigate the multiple facets and challenges, ranging from climate diagnostics studies, hydroclimatic prediction, decision model-based simulations, stakeholder engagement, and knowledge dissemination for the Grand Canyon region. Lessons learned and synthesis from this work is expected to be relevant to developing dynamic water and adaptive management strategies across the Southwest.
RESULTS FROM PRIOR FUNDING
The co-PIs (Pulwarty and Melis) studied the “climate”-“water”-“decision-making” overlaps and linkages for Glen Canyon Dam during the course of their NOAA-OGP funded project, “The Role of Climate Variability and Forecasts in Adaptive Management of the Colorado River: Balancing the Resource Objectives of the Lower and Upper Basin at Glen Canyon Dam.” User studies, assessments of the decision-making processes led to a synthesis of the complex planning and decision process for water and adaptive environmental management. A hydroclimatic decision calendar exemplifies the time-scales and processes that are relevant to the planning and management process.

The study clearly illuminated the knowledge gaps, specifically with respect to the climate information, likely to benefit release scheduling, coordinated operations, and importantly, the sediment input assessment of forecasts during the warm season. A detailed description of the results and lessons learned from the research are documented in Pulwarty and Melis (2001). The proposed research is the next step in this research and learning process. We are focusing on the warm season precipitation and flood diagnosis and prediction, with special reference to the sediment input problem in the Grand Canyon. The multidisciplinary research team will investigate the multiple facets and challenges, ranging from climate diagnostics studies, hydroclimatic prediction, decision model-based simulations, and stakeholder engagement, and knowledge dissemination.
**Motivation**

Warm season (July to October) precipitation and flood variations in the southwestern United States provide significant water supply (~40-60% of the average annual volumes) and sediment input into river reaches. The precipitation regime exhibits high spatial and temporal variability, and some known sensitivity to the low-frequency ocean and atmospheric state [e.g., Carleton and Carpenter, 1990; Higgins et al., 1998; Dettinger and Diaz, 2000; Higgins and Shi, 2000] and land boundary conditions [Gutzler 2000; Lo and Clark 2002]. The intraseasonal to interannual variability in the July-October precipitation directly impacts the variations in the magnitude, timing, and statistical frequency of warm-season floods. As a result, an understanding of the spatial scales of flood variations and lead-information on flooding has the potential to benefit the water resources operations and planning objectives in the region–hydropower generation, flood control, irrigation, reservoir operations, sediment yield, and stream habitat maintenance. The complexity of competing economic and environmental objectives to be met and the ever-increasing demand serve to: (a) constantly challenge the adequacy of the existing operating and management plans and (b) highlight the need for dynamic water resources operations and management at intraseasonal to interannual time scales. Consequently, an improved understanding of the spatial scales of warm-season flood variability, and identification of climate precursors constitutes an important source of hydroclimatic information that can directly feed into the water resources decision-making and adaptive environmental management process.

In the proposed work, the central thrust is a diagnosis and characterization of Southwest U.S. floods, and the application to water and adaptive environmental management for the Grand Canyon region. A key concern in this regard is the sediment input into the Grand Canyon, which directly affects the multiobjective reservoir operations of Glen Canyon Dam, as well as has important implications for river ecology. Remnants of late summer Eastern Pacific storms are known to travel into the upper U.S. Southwest creating large sediment flow events through ungaged streams. Late-summer, early fall precipitation events transport about 3 million tons of sediment down the Paria and Lower Colorado River into the Grand Canyon. As part of the Adaptive Management
Program the timing of operations at Glen Canyon Dam has to be scheduled to take advantage of this inflow for ecosystem management and sediment storage within the Grand Canyon. The Adaptive Management Program is managed under an agreement by the seven basin states, the Federal Government, the Western Area Power Administration, Native Tribes and recreation interests. One of the co-PIs (Melis) represents the major provider of scientific information (the Grand Canyon Monitoring and Research Center) into the planning process for adaptive management in the Grand Canyon. Thus the pathway to use of the outputs of this study is very clear and direct. The proposed research has two major objectives:

I. To diagnose the spatial and temporal structure of warm-season flood magnitude and timing in the Southwest. Using a comprehensive set of climate, daily historical precipitation and streamflow data and empirical-statistical diagnosis, we will identify: (a) the intraseasonal variations in regional floods, (b) year-to-year changes in the spatial scales of flooding, and at-site nonstationarities, (c) relevant metrics of precipitation and floods (n-day flow totals, peaks over select flow thresholds) that are most relevant for operations (such as, sediment yield) and (d) to what extent the indices of ocean-atmospheric processes and land boundary conditions impart structure and predictability to warm-season floods in the Southwest.

II. Develop a statistical flood prediction framework for applications to estimate the sediment transport from Paria and Lower Colorado River into the Grand Canyon, and investigate the implications for decision-making (planning, operations, and management) in the Glen Canyon Adaptive Management Program (AMP). The timing of the sediment input coupled with Glen Canyon Dam releases have been identified as a key knowledge gap in the co-PIs previous work. This work will involve a collaborative research component with the Grand Canyon Monitoring and Research Center. The GCMRC has a physical model (http://www.gcmrc.gov/CM/CM.htm), Grand Canyon Ecosystem Model in-place to assess the sensitivity of improved sediment and flow (and flood) inputs to operation schedule, adaptive management strategies, and planning. This work will constitute a central component of the joint studies to assess the usefulness of flood information of
various time leads (intraseasonal to interannual). Bi-annual meetings with the AMP research and management team and use of historical and current field sediment and flow data is planned for focused joint studies on use of climate and hydrologic information for dynamic water resources management and AMP.

**BACKGROUND**

The warm season precipitation variations in the Southwest result in flood peaks that deliver water supply and sediment to reservoirs and river reaches. Climate variations from intraseasonal to interannual and longer time scales determine the intensity, timing, and spatial scales of precipitation regimes and floods in this region. A detailed synopsis of the climatic factors and open climate science issues for this region are documented in the NAME program plans ([http://www.ofps.ucar.edu/name/](http://www.ofps.ucar.edu/name/)) and a number of recent studies [e.g., Adams and Comrie, 1997; Barlow et al., 1998]. Large-scale climate features (ENSO and PDO) modulate the atmospheric circulation through their teleconnections—thereby impacting the warm season precipitation [Carleton and Carpenter, 1990; Harrington et al., 1992; Higgins and Shi, 2000] and streamflow regimes. Recent studies [Gutzler and Preston, 1997; Gutzler, 2000; Lo and Clark 2002] have identified an inverse relationship between winter precipitation and subsequent summer precipitation in different parts of Southwestern US.

**Floods and Climate**

The space-time structure of flood variability in the Southwest is less well studied and understood. Webb and Betancourt (1992) documented the sensitivity of Santa Cruz River (Arizona) flood to storm types, highlighting the importance of appropriately recognizing the causal atmospheric state for flood estimation. Graf et al. (1991) analyzed the Paria River flood record and found secular trends, and also documented the three key storm types that drive the precipitation and flood regimes. Furthermore, they also documented the ENSO influence on floods and the empirical relationships between floods and sediment input [also see Webb et al. 2000]. More recently, Milhous (2003) examined the warm season flood and sediment relationship on a broader scale, including Rio Puerco River (NM), Sevier River (UT), Little Colorado River (AZ), and Paria River (AZ).
Milhous (2003) report regime-like changes in the flood and sediment record. Hereford et al. (2002) corroborate this multidecadal regime-like behavior in the Colorado Plateau warm season precipitation record for the 20th century. Given this perspective from the available research on the range of temporal scales, ranging from intraseasonal storm types to decadal shifts in flood potential, the need for incorporating climate information into flood and sediment estimation framework is evident. Indeed, recent research that develops integrative climate-floods diagnostics and modeling approaches have shown promise [Hirschboeck 1987; Bradley, 1998; Jain and Lall, 2000, 2001; Jain, 2001; Jain, Lall, and Rajagopalan, 2003b], and an ability to accommodate climate-related slow variations and non-stationarities in the flood process.

**Grand Canyon: Climate, Water and Sediment**

Grand Canyon region is a unique natural laboratory where climatic, geomorphologic, and hydrologic processes shape and constrain the river flows, sediment and debris transport [Webb and Melis, 1996]. As a result, the river and riparian ecosystems are quite sensitive to the variations in water and sediment supply that results from natural variability and decision-making for the management of the extensive water resources infrastructure. For the past four decades, the engineered perturbation of this riverine corridor has resulted in modified sediment input regimes. Since completion of Glen Canyon Dam in March 1963, most fine sediment (i.e., sand, silt and clay) crucial to the riparian and aquatic environments of the Colorado River ecosystem in Grand Canyon National Park (GCNP) is derived from the Paria and Little Colorado Rivers. These tributaries deliver large quantities of fine sediment to the Colorado River during short-duration, high-magnitude
floods. Advance notice of tributary flooding may allow better coordination of the timing of managed high releases from Glen Canyon Dam to improve sediment conservation throughout the Colorado River ecosystem in GCNP. Recent monitoring of sediment input to the Colorado River during Paria River floods in September 1997, suggests that, under normal powerplant releases from Glen Canyon Dam, the residence time of the finest sediment (i.e., very fine sand and finer-sized material) in the Colorado River is relatively short. Because effective management of the Colorado River ecosystem in GCNP requires that the dam be operated to retain as much of the tributary-supplied fine sediment in GCNP for as long as possible, it is desirable to not only know the magnitude of tributary sediment-supplying events (as they occur) but also to have a deeper understanding of the spatial and temporal scales of floods, so as to harvest the predictive components of climatic variations—through tailored monitoring, retrospective diagnostics, and predictive framework that integrate the understanding of climate and regional hydrologic cycle—thus allowing an adequate and focused inclusion of climate information into sediment transport and river ecological processes in the Grand Canyon.

An understanding of the warm season precipitation regimes that initiate and trigger flood and sediment input into Grand Canyon is a critical starting point to understand the complex interplay of physical and biological processes. Hereford (2002) report significant interannual and longer-term variations in the 1900-2000 record of warm season precipitation in this region. Figure 2. shows the correlation between July-October precipitation in the Grand Canyon and the entire West for the 1948-2001 period. Coherent spatial scales are quite evident, suggesting synchronous flooding and sediment transport episodes that may have relatively large spatial scales. Furthermore, water and sediment input into the Glen Canyon and downstream reaches is likely quite
sensitive to the spatial scales of precipitation. The key precipitation metrics: 1-, 3-, 5-day warm season maximum precipitation totals show high pairwise correlation, as well as correlate well with the seasonal precipitation totals. This coherence from episodic-to-seasonal time scales is reminiscent of the identified linkages between storm types and seasonal climatic state. Precipitation on multiple time scales directly impacts the reservoir operations and sediment inputs into the Grand Canyon.

On interannual time scales, connections of seasonal precipitation to oceanic and atmospheric state show limited tropical Pacific linkages in our preliminary analysis. Figure 3(right) show the composite July-October SST anomaly for five wettest (top) and driest (bottom) years in the post-1948 period for the Grand Canyon region. Modest tropical Pacific covariances are revealed. From the standpoint of flood estimation, changing flood potential conditioned on large-scale climate state can be particularly useful in deriving likelihood estimates or “restricted set of hydrologic states” that are consistent with the large-scale climate.

Floods variability on Paria River also shows substantial multidecadal and secular variations. Graf et al. (1991) note that the decreasing trend in Paria River floods are also shows consistent with decreasing trends in the three storm types commonly associated with floods. Since some of the sediment estimation relationships use flood return periods, it is clear that sediment input volumes likely respond to the changing flood potential at multidecadal time scales. Figure 4 (right) show
the 1916-1999 historical record for the Paria River floods (top), and a 30-year moving window estimate of the 2-, 5-, and 10-year return period floods (bottom). The flood estimates are plotted at the last year of the 30-year moving window.

The hydroclimatic variations in the Southwest and the information needs based on the annual decision calendar for the Glen Canyon Adaptive Management Program motivate a number of questions to investigate and understand the nature of flood variability, sediment inputs, and the usefulness to the reservoir and adaptive environmental management in the region. Next, we articulate the key questions that will drive this research effort, and also provide some rationale based on the understanding gained from prior research effort (Pulwarty and Melis) and the results summarized above.

**KEY QUESTIONS AND RATIONALE**

The proposed research is driven by the needs of water resources and adaptive environmental management in the US southwest, with special emphasis on the *identified set of knowledge gaps in hydroclimatic information for the Glen Canyon Adaptive Management Program*. In the AMP, decision-making on weekly-to-interannual time horizons seeks to balance multiple, often competing objectives, such as, water supply, hydropower generation, low flow maintenance, maximizing the tributary supplied sediment, biological opinion, and flood control. In this context, the proposed work seeks to diagnose and predict the warm season floods at point-to-regional scales, and multiple time scales. Diagnostic studies are planned so as to arrive at a detailed scale-by-scale (episodic to seasonal and longer) picture of the southwest flood variations, and the covarying large-scale ocean and atmospheric state. A predictive framework that: (a) exploits the coherent scales of flood and atmospheric and oceanic processes, and (b) generates conditional flood prediction, based on the evolving state of the large-scale climate precursors is one end point of this research. A parallel and overlapping applications effort, will investigate the expected value of lead-information on floods for the sediment input, water supply and AMP decisions through: (a) a direct assessment of the usefulness of flood diagnosis and prediction, through Grand Canyon Ecosystems
model simulations, and (b) a continuing involvement and assessment of the planning, deliberations and decision-making within AMP at GCMRC. To this end, the key research questions are as follows:

1. What are the spatial scales of coherent warm season floods and precipitation in the Southwest, and are there concurrent or precursory large-scale atmosphere and oceanic states associated with them?

Changes in the frequency, duration, and magnitude of floods directly influence the water supply and sediment input into the river reaches and reservoirs. In the warm season floods context, the characterization of spatio-temporal floods may likely be sensitive to: (a) within-season precipitation statistics, (b) pre-storm antecedent state (precipitation total and storm duration may be reasonable surrogates), (c) and the relative frequency of storm types, for example, monsoonal, frontal, or remnants of tropical storms. Furthermore, the incidence, frequency, and intensity of the storm types (embedded within the seasonal large-scale climatic state) is also a key determiner of flood potential. A systematic data-driven diagnostics studies will identify the relate role played by the above listed factors to arrive at a climate-driven likelihood classification of storm and flood risk.

2. Does an improved understanding of the intraseasonal and longer climate states and associated flood variations (magnitude and spatial scales) improve the planning and operations processes related to water resources and adaptive environmental management?

Climate forcing on seasonal-to-interannual, and longer time scales results in changing flood potential, and renders analysis and planning based on limited length flood records sub-optimal. Dynamic management approaches that adequately connect the climatic-related sensitivity of floods are better suited to respond, adapt, and be resilient to “climate and weather surprises,” and better
balance the multiple decisions and objectives to minimize risk and negative impacts. On longer time scales (decadal and beyond) climate-related variations in floods manifest as nonstationarities, and limit the validity of empirical flood-sediment relationships that are inherently dynamic.

3. With special reference to the Glen Canyon Dam, what role can a climate-related flood framework play in improving sediment input estimation, reservoir operations and planning, and adaptive environmental management at seasonal, interannual, decadal and longer time scales?

Lead information on spatial scales of floods has the potential to directly improve estimates of the sediment input from ungaged basins. Current approaches use regional regressions to arrive at sediment estimates, and thereby have no explicit consideration of the changing spatial scales of floods. On intraseasonal time scales, the sediment transport estimates determine the extent to which sand input into the channel and sandbars can facilitate fish spawning, survival and success. Furthermore, reservoir releases can be timed so as to maximize sediment transport and residence time in the Canyon. On interannual time scales, flood potential (and estimates of sediment transport) provides lead information to the Adaptive Management Workgroup and Annual Operating Plan to schedule releases so as to meet the flow targets for multiple objectives. Furthermore, potentially a biological opinion can be articulated as soon as the lead information on floods is available. Floods variations on decadal and longer time scales reflect the slowly varying regime-like nature of coupled climate and hydrologic systems. While in the short-term, much of the long time scale variability may get masked by the higher frequency variations, however, limited length hydroclimatic records may not represent the full-range of variations, and thus lead to design and planning estimates that are not robust. Empirical sediment input estimates are based on computed flood magnitudes with 2-, 5-, and 10-year return periods. As these return-period estimates vary on decadal scales (see Figure 4), one can expect under/overestimates in sediment volumes. Given the availability of near century-
long hydroclimatic records for the Grand Canyon region, ecosystem and reservoir operation model simulations are planned to understand whether observed decadal-scale variations and trends have significant impacts on planning and operations. A related question is that of determining the “benign” range of variability for the existing infrastructure and management plans.

DATA

Long precipitation (station and gridded) and climate datasets are available at Climate Diagnostics Center. Regional streamflow data for the 20th century (and updated regularly) is available through the U.S. Geological Survey, as well through the PI’s ongoing research on hydrologic information systems (http://www.cdc.noaa.gov/~sjain/waterpulse/).

Comprehensive flow and sediment data archives for the Grand Canyon region are archived and available through the Grand Canyon Monitoring and Research Center. The co-PIs will also make available updated datasets for streamflow and sediment load that have been recently collected and are not available in the public domain.

METHODOLOGY

1. Diagnostics studies for the warm season hydroclimate in the Southwest will systematically analyze spatial and temporal scales of covariations between precipitation (and some derived statistics) and streamflow. Furthermore, sediment data will also be examined to empirically identify the spatial scales and thresholds that initiate and trigger sediment transport episodes. Multivariate statistical methods will be employed for the preliminary analysis. A final set of analysis will employ quantile regression methodologies in the univariate and multivariate setting. The methodology will also provide a explicit characterization and assessment of nonstationarities in data, non-normal distributions, and outlier detection. These methodologies are being used in investigators’ ongoing and recently completed work [Jain, 2001; Jain et al. 2003a,b,c]. Parallel analysis of atmospheric circulation and sea surface temperature data will aim at identifying predictors that influence the warm season hydroclimate in the Southwest. Synthesis on the role of climate on intraseasonal to decadal scales will be
provided through analysis of long climate datasets, as well as case studies examining key historical episodes on watershed scales. Statistical analysis of storm frequency and their relationships to the background climate state is also a key task for this research. Preliminary analysis reveals three key moisture delivery modes for the Southwest, that were also identified in a previous study [Graf et al. 1991]; we intend to extend this work to regional scales and provide a detailed assessment of the characteristic spatial scales and storm intensity based on historical record.

2. Sediment transport processes are critical for the health of river ecosystems. Currently used methodologies, developed largely through the long-term effort at co-PIs center and Department of Interior, use empirical flood-sediment load relationships. The co-PIs (Melis and Topping) have extensive experience investigating the hydrologic and geomorphologic processes in the Grand Canyon region [for example, Melis, 1997; Topping, 1997; Webb et al. 2000], and will actively contribute to reassess the current state of science in this arena, in light of the results from [1]. The assumptions are that of stationary (time-invariant) flood processes and no inclusion of intraseasonal and longer climate information. Furthermore, there is limited understanding of the characteristic spatial scales of floods, especially in the context of sediment estimates for ungaged watersheds. Jain will work with Topping and Melis to investigate the sensitivity of sediment estimates, conditioned on intraseasonal-to-seasonal climate information and derived flood potential.

3. Analysis of the sensitivity of operations and decision will be pursued by using predicted flood risk for the Grand Canyon region, and generating model simulations for reservoir and ecosystems assessment. Jain will work with Balaji and GCMRC to develop retrospective and current year scenarios based on RIVERWARE system. RIVERWARE is a comprehensive multiobjective decision support system reservoir operations and management. Also, Grand Canyon Ecosystem Model (GCM) will be used with climate-conditioned sediment input and flood scenarios to ascertain the value of flood predictions for adaptive
management. These results will be actively communicated and discussed with the Adaptive Management Workgroup. Melis, as the Physical Science Program Manager is a key participant in AMP deliberations and planning. Pulwarty will coordinate effort with GCMRC to understand and synthesize the qualitative and quantitative results from decision analysis and decision making processes.

IMPLEMENTATION PLAN

The project is developed with a view that research effort, applications, and decision-making co-evolve and be integrated, so as to ensure an ongoing dialog and feedback between physical science and stakeholder and decision-making (Adaptive Management Program, in this case). Furthermore, the regional scope of our assessment is driven by the fact that there are different drivers and stresses on local-to-regional spatial scales and time scales, and lessons learned from case studies be synthesized in a broader light, so that the insights for the transferability are clearer.

With this as the premise, the following plan to broadly envisioned:

Year 1

- Diagnostics studies relating hydrologic and climate variations on point to regional scales, and intraseasonal to decadal and longer time scales. Detailed analysis of warm season atmospheric circulation and potential role of the tropical and North Pacific ocean (including ENSO and PDO influences). Jain, Pulwarty, and Balaji will be involved in this work. Results will be actively discussed and shared with the GCMRC group.

- Diagnostics studies to examine the flood and sediment variations in the Southwest. Jain will work with Topping to assess the hydrologic and geomorphologic processes that operate on watershed to regional scales.

- Example case study to examine the translation of seasonal climate variations to floods and sediment transport. For a historical year (1997 or 1999), the research team will pursue a phenomenological case study, and research the role of intraseasonal-to-interannual climate and hydrological variations, and the decision processes that were in-place. This is seen as an important step to understand the complex kernel of physical processes, ecosystems, and decision overlaps and
linkages. Monthly teleconferences and bi-annual meetings are planned at GCMRC to continually discuss results and ensure effective implementation.

Year 2

- A predictive framework for floods will be developed and tested. Retrospective case studies and cross-validated performance measures will be developed and assessed. Jain and Balaji will lead this effort.
- Jain will work with Topping to extend the flood predictions to sediment estimation. They will assess the usefulness of flood prediction framework for sediment input estimation.
- RIVERWARE and GCM studies will be initiated. This will involve an active collaboration between the groups at CDC, GCMRC, and the University of Colorado.
- Preliminary results will be shared with the Adaptive Management Workgroup and the research group GCMRC. This will done through presentations, briefings, and electronically. Melis and Pulwarty will coordinate this effort.

Year 3

- Flood prediction, reservoir operations, and ecosystem model results will be run for the 2006-2007 year. The results will be available and communicated to Adaptive Management Workgroup. The research team will monitor and assess the usefulness of information through oral and written feedback from the group. Furthermore, a detailed synthesis of the reservoir operations results and sediment input model results is planned.
- The results from the project will be communicated through peer reviewed journal, at AGU/AMS meetings, and to stakeholders (through the co-PIs (Melis) direct involvement in the regional water issues)

**Budget Discussion**

Jain will lead the project implementation and completion. He will contribute to be project at 4 months/year. Topping will contribute at 1 month/year. Melis and Pulwarty will contribute at 1 month/year, and Balaji at 0.5 month/year. Funding is requested to cover the salary for Jain and Topping. Melis, Pulwarty, and Balaji have requested no salary funds.
Equipment: Support is sought for a laptop computer for the project-related computations, travel and meeting at GCMRC, and briefings to AMP. Support is also requested for licensing fees for RiverWare at CADSWES.

Publications: We anticipate 5 peer-reviewed publications from the project. Paper and electronic briefings will be generated for the AMP Workgroup and stakeholders in the region, and also made available on the project website. Publication costs are requested for year 2 and 3 of the project.

Travel: Travel support includes funds for travel to bi-annual meetings at GCMRC. Also, two of the PI’s will make presentations at national meetings (AGU, AMS).

LINKAGES AND READINESS
The collaborative component of the planned work is in-built stemming from the GCMRC collaboration (Melis and Topping). We plan to work closely with the scientists and managers involved in the Glen Canyon reservoir operations, AMP, as well as the USGS scientists working on sediment issues. Prior research funded through the NOAA/OGP has laid the foundation for this work and we have established contacts with various stakeholder groups in AMP (Pulwarty and Melis).

Our proposed research links very well with the applied research funded as part of the NOAA Regional Integrated Sciences and Assessments (RISA) Program at the University of Colorado and NOAA/CDC (Jain, Balaji, and Pulwarty are members of the Science Team). There are also linkages to other GAPP proposals, with Balaji as lead PI (Understanding the Spatio-Temporal Variability of the North American Monsoon).

FACILITIES
Research tasks will be done using existing computing facilities at NOAA CDC, GCMRC, and CADSWES, at University of Colorado, Boulder, CO. CADSWES will provide their Decision Support Model, RIVERWARE (http://cadswes.colorado.edu/riverware/).

REFERENCES


Topping, D. J., 1997: Physics of flow, sediment transport, hydraulic geometry, and channel geomorphic adjustment during flash floods in an ephemeral river, the Paria River, Utah and Arizona, Ph.D. Dissertation, University of Washington, Seattle.


## SHALEEN JAIN

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<thead>
<tr>
<th>NOAA-CIRES Climate Diagnostics Center</th>
<th><a href="mailto:Shaleen.Jain@noaa.gov">Shaleen.Jain@noaa.gov</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>National Oceanic and Atmospheric Administration</td>
<td>303.497.6295 (voice)</td>
</tr>
<tr>
<td>325 Broadway, Boulder, CO 80305-3328</td>
<td>303.497.6449 (fax)</td>
</tr>
<tr>
<td><a href="http://www.cdc.noaa.gov/~sjain/">http://www.cdc.noaa.gov/~sjain/</a></td>
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</tbody>
</table>

### Research Interests

Hydroclimatology, Floods and Droughts, Integrative Hydrologic Science, Statistical Hydrology, Water Resources Engineering, Ensemble Weather and Climate Simulation and Diagnostics, Climate Information for Water Applications, Low–Frequency Climate Variability, Paleohydrology, Statistical Analysis and Visualization of Environmental Data, Nonlinear Dynamics

### Education

<table>
<thead>
<tr>
<th>Year</th>
<th>Degree</th>
<th>Institution</th>
<th>Location</th>
<th>Details</th>
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<tbody>
<tr>
<td>2001</td>
<td>PhD, Dept of Civil and Environmental Engineering</td>
<td>Utah State University, Logan</td>
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<tr>
<td></td>
<td>Emphasis: Hydrology and Water Resources</td>
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<tr>
<td></td>
<td>Dissertation: “Multiscale Low-Frequency Hydroclimatic Variability: Implications for Changes in Seasonality and Extremes;” Advisor: Prof. Upmanu Lall</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1998</td>
<td>MS, Dept of Civil and Environmental Engineering</td>
<td>Utah State University, Logan</td>
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<tr>
<td></td>
<td>Thesis: “Low-Frequency Climate Variability: Inferences from Simple Models;” Advisor: Prof. Upmanu Lall</td>
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<tr>
<td>1993</td>
<td>BTech, Dept of Civil Engineering</td>
<td>Indian Institute of Technology, Bombay</td>
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<tr>
<td></td>
<td>First Class with Honors</td>
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<tr>
<td></td>
<td>Thesis: “Wake and Jet Interaction with Regard to Dilution: An Experimental Study;” Advisor: Prof. B. S. Pani</td>
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### Experience

<table>
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<th>Start Date</th>
<th>End Date</th>
<th>Position</th>
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<tbody>
<tr>
<td>8/2001–present</td>
<td>Research Scientist</td>
<td>NOAA–CIRES Climate Diagnostics Center, Boulder</td>
<td></td>
</tr>
<tr>
<td>8/2000–present</td>
<td>Research Team Member</td>
<td>NOAA–CIRES Western Water Assessment</td>
<td></td>
</tr>
<tr>
<td>8/2000–7/2001</td>
<td>Visiting Fellow</td>
<td>Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder and NOAA–CIRES Climate Diagnostics Center</td>
<td></td>
</tr>
<tr>
<td>9/1993–7/2000</td>
<td>Graduate Research Assistant</td>
<td>Water Division, Utah Water Research Laboratory, Utah State University, Logan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Research Assistant on two NSF-funded projects on Hydroclimatology and Floods</td>
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<tr>
<td></td>
<td>Teaching Assistant, Engineering Risk and Reliability (Winter 1998)</td>
<td></td>
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</tr>
<tr>
<td>6/1992</td>
<td>Summer Undergraduate Trainee</td>
<td>Environmental Services Division, Engineers India Limited, New Delhi, India</td>
<td></td>
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**Honors and Awards**

<table>
<thead>
<tr>
<th>Year</th>
<th>Award Description</th>
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<tr>
<td>2002</td>
<td>Honorable Mention, Universities Council on Water Resources PhD Dissertation Award Competition</td>
</tr>
<tr>
<td>2000</td>
<td>CIERES Visiting Fellowship</td>
</tr>
<tr>
<td>1998</td>
<td>NSF Student Travel Award</td>
</tr>
<tr>
<td>1998</td>
<td>American Geophysical Union (AGU) Student Travel Award</td>
</tr>
</tbody>
</table>

**Publications**


**Papers in Review and Manuscripts**


**Collaborators**

- Martin Hoerling, NOAA-CDC
- Upmanu Lall, IRI and Columbia University
- Connie Woodhouse, NOAA-Paleoclimatology Program
- Henry Diaz, NOAA-CDC
- Brandon Whitcher, GlaxoSmithKline, UK
- Rajiv Prasad, Pacific Northwest National Laboratory
Curriculum Vita (Summary)
Roger S. Pulwarty
CIRES/Climate Diagnostics Center, University of Colorado, Boulder, Colorado 80309-0449

Education

BS Atmospheric Sciences (Hons. 1986). York University


Research experience and public service

08/94-09/98  RESEARCH SCIENTIST: NOAA/CIRES/CLIMATE DIAGNOSTICS CENTER UNIVERSITY OF COLORADO, BOULDER

10/98-05/02  Program Manager. Regional Integrated Sciences and Assessments Program Dept. of Commerce/National Oceanic and Atmospheric Administration-Silver Spring MD, 20910

06/02-PRESENT  RESEARCH SCIENTIST III: NOAA/CIRES/CLIMATE DIAGNOSTICS CENTER UNIVERSITY OF COLORADO, BOULDER

Professional Activities

Project Manager: Vulnerability Assessment Component: Mainstreaming Adaptation to Climate Change in the Caribbean GEF/World Bank (2003-2005)
National Research Council Committee on Climate Ecosystems, Infectious Diseases and Health (1999-2001)
NOAA Social Science Advisory Board (2001-2002)
U.S. Interagency Climate Council (1999-2001)
Co-chair U.S. Global Change Research Strategic Plan (2000-2001)
Inter-Agency Water Cycle Sciences Committee (1999-2002)
Chinese-American Frontiers of Science (National Academy of Sciences, 1999)
Editor (Human Dimensions): Climatic Research (International journal)
UCAR/IRI Post-doctoral Selection Committee (2001)
AMS Committee on Societal Impacts. Chair
AMS National Committee on Applied Climatology (1996-1999)

Recent Relevant Publications


Wilhite (ed). Drought and Water Crises: Science, Technology and Management in prep.)


Pulwarty, R., 2003: Climate and Water in the West: Science, Information and Decisionmaking. Water Resources Update 124, 4-12


Presentations: Over 40 invited presentations (excluding professional conferences) to international, national, interagency, and private sector audiences on climatic impacts, tropical climate and the use of scientific information for policy and applications in vulnerability assessments, water resources, agriculture, and ecosystem management
CURRICULUM VITAE

Name: David J. Topping  
Birth: October 6, 1966, Warwick, Rhode Island  

Education:  
B.S. in Earth, Atmospheric, and Planetary Sciences, 1988; Massachusetts Institute of Technology, Cambridge, Massachusetts  
M.S. in Geological Sciences, 1991; University of Washington, Seattle, Washington  
Ph.D. in Geological Sciences, 1997; University of Washington, Seattle, Washington;  
Title of dissertation: "Physics of flow, sediment transport, hydraulic geometry, and channel geomorphic adjustment during flash floods in an ephemeral river, the Paria River, Utah and Arizona"

Employment:  
Research Hydrologist: 3/01-present  
Research Hydrologist: 3/99-3/01  
Hydrologist, term appointment: 8/97-3/99  
Hydrologist, graduate student appointment: 7/92-9/93, 10/94-7/97  
University of Washington, Department of Geological Sciences, Seattle, Washington  
Teaching Assistant: 10/88-12/88, 4/89-6/89, 4/91-6/91

Professional Societies:  
American Geophysical Union  
Geological Society of America  
SEPM (Society for Sedimentary Geology)  
International Association of Sedimentologists

Awards:  
1989 National Science Foundation Graduate Fellowship  
1991 Geological Society of America Robert K. Fahnstock Memorial Research Award

Other:  
Co-organized and convened with John Pitlick of the Department of Geography, University of Colorado, Boulder, Colorado a special session entitled "Geomorphic research on the Colorado Plateau 125 years after John Wesley Powell" at the 1994 Fall Meeting of the American Geophysical Union, San Francisco, California.

Publications:  


Rubin, D.M., and Topping, D.J., 2001, Quantifying the relative importance of flow regulation and grain-size regulation of suspended-sediment transport (α), and tracking changes in bed-sediment grain size (β): Water Resources Research, v. 37, p. 133-146.


RAJAGOPALAN BALAJI

A. PROFESSIONAL PREPARATION
Kurukshetra University, India, B. Tech. (with honors) in Civil Engineering, 1989
Utah State University, Logan, UT, USA, PhD in Civil Engineering (Stochastic Hydroclimatology), 1995

B. APPOINTMENTS
2000 (Aug) - present  Assistant Professor, Department of Civil, Environmental and Architectural Engineering, University of Colorado at Boulder.
2001 (June) – present  Fellow, Cooperative Institute for Research in Environmental Sciences (CIRA, University of Colorado, Boulder, CO.
2000 (Aug) – present  Adjunct Associate Research Scientist, International Research Institute (IRI), Lamont-Doherty Earth Observatory (LDEO), Columbia University, NY
1997 (July) – present  Research Assistant Professor, Utah Water Research Laboratory, Utah State University, Logan, UT
1999 (July) – 2000 (August)  Associate Research Scientist, International Research Institute (IRI), Lamont-Doherty Earth Observatory (LDEO), Columbia University, NY
1997 (July) – 1999 (June)  Associate Research Scientist, Lamont-Doherty Earth Observatory (LDEO), Columbia University, NY
1995 (April) – 1997(June)  Post-Doctoral Research Scientist, Lamont-Doherty Earth Observatory (LDEO), Columbia University, NY
1991 (Oct) – 1995 (April)  Graduate Research Assistant, Utah Water Research Laboratory, Utah State University, Logan, UT

C. HONORS AND AWARDS
Nominated for the 1996 Lorenz G. Straub award for the most meritorious thesis in hydraulics and hydrology and finished in the top three.
Young Researcher award: 2003. Department of Civil Environmental and Architectural, University of Colorado, Boulder, CO.

D. RESEARCH INTERESTS
Stochastic Hydrology and Hydroclimatology; Nonparametric functional estimation techniques (probability density Functions, regression, scenarios generation, forecasting); Understanding low frequency climate variability and its signatures on regional hydrology; Incorporating climate information in water resources/hydrologic decision making; Understanding spatio-temporal variability in Indian summer monsoon; Stochastic modeling of hurricane tracks; Nonlinear Dynamics - recovering dynamics from data; Bayesian techniques for optimal combination of information from multiple sources and decision making.

E. PUBLICATIONS
(i) Publications most closely related to the proposed project


(ii) Other significant publications

KrishnaKumar, K., B. Rajagopalan, and M.A. Cane, On the weakening relationship between the monsoon and ENSO, Science, 284, 2156-2159, 1999.


Tourre, Y., B. Rajagopalan, and Y. Kushnir, Dominant patterns of climate variability in the Atlantic ocean region during the last 136 years, Journal of Climate, 12, 2285-2289, 1999.


F. SYNERGISTIC ACTIVITIES

Member, The American Geophysical Union

Member, Precipitation Committee, AGU Hydrology section.


Organized a session titled Low frequency climate variability signatures on regional hydrometeorological variables - implications to hydrologic forecasting and planning at the Spring meeting of AGU, Boston, May, 1998.

Organized a session titled Incorporating climate variability information in water resources decision making”, at the Fall AGU, San Francisco, Dec 2002.

G. COLLABORATORS & OTHER AFFILIATIONS

(i) Collaborators

Clark, M., CIRES/Univ. of Colorado at Boulder; Kushnir, Y., Columbia Univ. at NYC; K. Krishna Kumar, Indian Institute of Tropical Meteorology, Pune, India; Lall U., Columbia Univ. at NYC; Ray, A., CDC-NOAA/Univ. of Colorado at Boulder; Strzepek, K., Univ. of Colorado at Boulder; Zagona, E., CADWES/Univ. of Colorado at Boulder; Zebiak, S., IRI/Columbia Univ. at NYC;

(ii) Graduate and Postdoctoral Advisors

Upmanu Lall, Columbia University, NY, Mark Cane, Columbia University, NY.

(iii) Theses Advised

David Newmann, CADSWES, University of Colorado, Boulder, CO, 2001
James Prairie, CADSWES, University of Colorado, Boulder, CO, 2002

(iv) Advisors for Research Associates

Theodore S. Melis
Physical Sciences Program Manager
Grand Canyon Monitoring and Research Center
2255 North Gemini Drive
MS-9394
Flagstaff, AZ
86001
United States
Fax: (928) 556-7092

Education
PhD (1997), University of Arizona

Research Program Description