RESUME

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EDUCATION

Doctor of Philosophy in Civil and Environmental Engineering
Utah State University, Logan, Utah (2001)
Master of Technology in Civil Engineering
Indian Institute of Technology, Madras, India (1992)
Bachelor of Engineering in Civil Engineering
Regional Engineering College, Durgapur, India (1990)

JOB EXPERIENCE

Scientist, Surface Water Hydrology, Hydrology Group
Pacific Northwest National Laboratory, Richland, Washington (September 2004 onwards)

Postdoctoral Research Associate, Hydrology Group
Pacific Northwest National Laboratory, Richland, Washington (February 2002 – August 2004)

Postmasters Research Associate, Hydrology Group
Pacific Northwest National Laboratory, Richland, Washington (October 2001 – January 2002)

Postdoctoral Research Associate, Associated Western Universities, Richland, Washington (August 2000 – September 2001)

Graduate Research Assistant, Water Division, Utah Water Research Laboratory, Utah State University, Logan, Utah (September 1993 – August 2000)

AWARDS AND HONORS

Outstanding Performance Award, Pacific Northwest National Laboratory (2005)
Dean's Merit List, Utah State University (1994)
Graduate Student Scholar, Indian Institute of Technology, Madras, India (1990-1992)

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Gold Medalist, Civil Engineering, University of Burdwan, India (1990)
Merit Scholarship, Regional Engineering College, Durgapur, India (1986-1990)

RESEARCH INTERESTS

Distributed hydrologic modeling
Scaling in hydrology
Multi-scale modeling of hydrologic systems
Ensemble streamflow forecasting
Climate change diagnosis
Impacts of climate change on water resources systems
Integrated operations of water and energy systems
Evaluation of flooding hazards at nuclear power plant sites
Evaluation of tsunami hazards at nuclear power plant sites
Evaluation of storm surge hazards at nuclear power plant sites
Environmental impact assessment for water use and water quality

AFFILIATIONS

Member, American Geophysical Union
Member, American Water Resources Association

PROFESSIONAL EXPERIENCE

Early Site Permit and Combined License reviews (safety and environmental issues) for the U.S. Nuclear Regulatory Commission

Since 2003, I have helped carry out four concurrent **early site permit (ESP) reviews** at Dominion's North Anna, Exelon's Clinton, System Energy Resources' Grand Gulf, and Southern Nuclear's Vogtle sites for safety as well as environmental reviews for the U.S. Nuclear Regulatory Commission (USNRC). These reviews are being carried for the first time under new USNRC regulations as described in Title 10 of Code of Federal Regulations. This work involved hydrologic site assessment including hazards from external flooding events such as probable maximum precipitation (PMP), local intense precipitation, dam failures including cascading dam failures, storm surges, tsunami, and icing. Water availability was evaluated under current and post-plant conditions to determine water-use impacts including natural variability, plant-induced water use, channel migration, and blockages due to icing. I contributed to the environmental reviews leading to preparation of environmental impact statements (EIS) at these sites.

I have helped establish critical technical expertise at PNNL to support ESP and Combined Operating License (COL) reviews for the USNRC. The insights gained during this work have led to the recognition that some of the existing USNRC regulatory guidance needs revision to reflect state-of-the-science. I have worked on hydrologic engineering (safety) reviews for South Texas Project, Levy County, William States Lee, and Calvert Cliffs combined license (COL) applications. I also worked on the reviews for South Texas and Levy County EISs. These efforts include reviews of applicant's analyses as well as performing independent analyses conforming to USNRC guidelines to verify the conclusions presented by the applicants in the respective applications.

Updating Standard Review Plans for the U.S. Nuclear Regulatory Commission

There is renewed concern in the public regarding tsunamis and recognition at the USNRC that guidelines related to assessment of flooding hazard due to tsunamis at nuclear power plant sites located at or near a coastline are outdated. I presented the current technical approach for site assessment for flooding hazard at nuclear power plant sites in the United States at an International Atomic Energy Agency (IAEA) workshop. This workshop was organized by the IAEA in the aftermath of the December 26, 2004 Indian Ocean earthquake and subsequent tsunami that devastated coastlines in southeastern Asia. Under a contract from USNRC, I led the updates to the hydrologic engineering sections of the Standard Review Plan (SRP), Sections 2.4.1-2.4.14. The updated SRP Sections were published by the USNRC in March, 2007.

Updating the review methodology for tsunami hazard assessment at U.S. nuclear power plant site

Under a contract from the USNRC, I led the effort to put together a technical team to revise review criteria and guidance related to hazards due to tsunamis. PNNL teamed with the Pacific Marine Environmental Laboratory (PMEL) to produce two documents for the USNRC. The PNNL authored document focused on the review aspects of the tsunami hazards at nuclear power plant sites, primarily to assist the USNRC staff in updating their SRP. The second document was authored by PMEL and describes the data collection, theory, and modeling aspects of tsunami. The SRP section that describes tsunami hazards was updated and published in March, 2007. The PNNL-authored report, NUREG/CR-6966, was published in April, 2009.

Updating the design-basis flood estimation methods for the USNRC

Under a contract with the USNRC, I worked to update the guidance and methodology for estimation of design-basis flood at nuclear power plant sites in the United States. The methods and recommendations were published in NUREG/CR-7046 in November 2011. The NUREG/CR will be used by the USNRC to update its Regulatory Guide 1.59.

Experience working with the International Atomic Energy Agency (IAEA)

I participated in an international workshop organized by the IAEA, the Atomic Energy Regulatory Board of India, and the Nuclear Power Corporation of India

Ltd. in Kalpakkam, India during August 29 – September 2, 2005. I presented a review and a summary of the experiences gained during the NRC ESP reviews related to site characterization for flooding. In May 2006, I was invited by the IAEA to participate in a follow-up meeting in Trieste, Italy to review IAEA Safety Guide NS-G-3.5 for possible updates. I participated in another IAEA sponsored workshop in Trieste, Italy in May 2007 and presented an overview of the tsunami guidance development that I led at PNNL. The resulting report from the effort, NUREG/CR-6966 was published in April, 2007. The IAEA is currently updating its Safety Guide NS-G-3.5.

Water-Energy Nexus

Although there is abundant hydroelectric power available in the Pacific Northwest, the energy system and the water resources system have traditionally been optimized decoupled from each other. I am a co-Principal Investigator on a Laboratory Directed Research and Development (LDRD) funded project that will demonstrate the advantages of water and energy integrated resources systems optimization approach. This project will leverage **ensemble streamflow forecasting** techniques and **multi-scale modeling** approaches that I helped develop at PNNL to implement a water resources module for the Integrated Energy Operations Center (IEOC). The IEOC is envisioned as a central control and operations center for system-wide information gathering, processing, optimization, and scheduling. The water resources module will be integrated into the IEOC framework to provide simultaneous optimization of the water resources and the energy systems for more efficient use of hydropower resources while meeting the aquatic and instream flow demands.

Ensemble streamflow forecasting

Ensemble streamflow forecasting capability was developed over the last two years. The **PNNL Streamflow Ensemble Generation System (PNNL-SEGS)** is a control program that drives the PNNL Watershed Model (PWM) to generate a set of possible future streamflow scenarios starting from a common initial condition but corresponding to alternate meteorologies. The alternate meteorologies may be specified from historical observations where a sequence of meteorological conditions over a given time period during all available water years on record are considered equally probable. Another approach may involve specifying alternate meteorologies under changed climate scenarios generated from regional climate models such as MM5. Each alternate meteorology produces a single streamflow trace or hydrograph. The complete set of these streamflow traces represents the streamflow ensemble, with explicit characterization of uncertainty in streamflow forecasts. This streamflow ensemble can then be used for optimal operation of the water resources system.

DHSVM-MASS2 linkage

An example of multi-scale modeling is the linkage between Distributed Hydrology Soil-Vegetation Model (DHSVM) and Modular Aquatic Simulation System 2D (MASS2) model. DHSVM is a watershed hydrologic model that simulates physical hydrological processes including solar radiation, interception of precipitation by canopy, throughfall, snow accumulation and melt, infiltration of water into a soil column, and surface and subsurface runoff on a regular rectangular grid. MASS2 is a depth-averaged hydrodynamic and water quality model that operates at the stream reach scale using detailed hydrographic representation of the stream channel profile. The Bonneville Power Administration research project targeting the Grays River watershed in southern Washington is aimed at learning how Chum Salmon spawning habitat has been affected due to logging in the watershed and what remedial actions may be required. DHSVM-predicted runoff under several land cover scenarios at several points on the channel network were provided to MASS2 to specify inflow, outflow, and lateral inflow boundary conditions for steady-state simulation of discharges corresponding to several percentiles during the spawning season for Chum Salmon. These simulations are expected to help in evaluation of impacts of changes at the watershed scale to habitat conditions at the "fish" scale.

Snowmelt modeling

Utah Energy Budget (UEB) model from Utah State University, which is an energy-budget based point snowmelt model, was used in a mountainous terrain (Reynolds Creek Experimental Watershed (RCEW) in Idaho), driven by spatially-distributed inputs to develop a simpler parameterization of snow drifting and snowmelt in a small catchment (Upper Sheep Creek (USC) within RCEW). The simpler model, called **Pseudo-Distributed Index-Based Model for Snowmelt (PDIMS)**, was developed along with a drift factor map calibrated for USC using measured SWE data on a 30-m grid. This approach to snow drift and snowmelt modeling assumes that all of the drift occurs during winter and most of the snowmelt occurs during spring.

Snowdrift modeling

Results from SnowTran-3D, a three-dimensional mass-transport model from Colorado State University that runs on a grid over complex terrain were used to help parameterize spatially-distributed snowmelt in mountainous terrain affected by wind-blown snowdrifts. This approach helped **estimate drift factors** for Tollgate a subwatershed within RCEW, where SWE measurements were not feasible due to its size. SnowTran-3D estimated drift factors were then used with PDIMS to estimates spatially distributed surface water input for Tollgate, a larger subwatershed within RCEW.

Hydrologic modeling

A lumped hydrologic model called **Dominant-Zone Hydrologic Model (DZHM)** was developed to capture the within-watershed variability of dynamics of hydrologic processes. The concept of dominant zones allows the model to remain simple, yet capture the major sources of variability in hydrologic response within the catchment. Dominant zones must be developed from the understanding of hydrology within a given catchment, for example, in RCEW most of the variability in hydrologic response can be attributed to highly spatially-variable surface water input. This variability can be parameterized in terms of drift factors in RCEW. The DZHM representation for USC and Tollgate used drift factor zones. The modeling results were compared using observed aggregated streamflow (point comparison) and observed snow cover maps (spatial pattern comparison).

I have helped test and improve Distributed Hydrology Soil-Vegetation Model (DHSVM) and PNNL Watershed Model (PWM) during my post-doctoral appointment. I have applied automated calibration techniques implemented in the open source statistical software R to both models. Modeling results from these endeavors were used in research projects funded by NASA, NOAA, and EPA, among other state and federal agencies.

Most of this work involves recognition of and accounting for the landscape properties, especially the spatial heterogeneity related impacts, in hydrologic modeling.

Hydrologic design

A criterion for inclusion of rain-on-snow events in **probable maximum flood (PMF)** estimation was developed using SNOTEL and snowcourse data in Utah. The "probable maximum rain-on-snow event" was conceptualized as an existing "high" snowpack that is subjected to a "high" precipitation event (not the PMP event), in presence of "relatively high" sequence of air temperatures. Statistical analysis of historical SNOTEL and snowcourse data was performed to determine "high" snowpacks likely to occur during spring. Statistical analysis of precipitation and temperature data was performed to prescribe a 72-hour high precipitation/high temperature sequence. US Army Corps of Engineers HEC-1 model was used to compute the event hydrograph from this "**probable maximum rain-on-snow event**". This inflow hydrograph was used further to analyze dam risk in terms of failure and overtopping to recommend appropriate action for risk mitigation.

Watershed characterization

I was involved in watershed characterization work for the Corps of Engineers' Seattle Office, Grays Harbor County, and Washington Department of Fish and Wildlife, and Washington Department of Ecology for the Chehalis watershed located in southwestern Washington. The goal of the project is to provide information for decision-making to improve flood control and restoration of degraded ecosystem functions. The watershed was delineated automatically from digital terrain data, and PWM was calibrated using historical meteorologic and streamflow datasets. Streamflow for all subbasins on a spatial resolution approximately equal to that of level 6 hydrologic unit codes (HUC) were modeled. A sediment generation model, the Hillslope Erosion Model (HEM) was adapted to estimate steady state sediment delivery to the stream network from the subbasins. A simple stream temperature model was also developed to help predict stream temperature. Results from these models were used to estimate environmental indicators based on the Ecosystem Diagnosis and Treatment (EDT) approach. These indicators are expected to help characterize habitat suitability for fish in these watersheds under undisturbed and current conditions for restoration.

A similar project was also carried out in the Snohomish watershed. Initial delineation of the watershed and setup of PWM is complete. PWM was modified during this phase to include a snow component. GIS data layers are being built in to help improve hydrologic characterization of the watershed.

Watershed delineation quality control

Watershed characterization for acid total maximum daily load (TMDL) work was also performed for more than 140 forest preserve lakes in New York as part of work for the EPA. The objective was to evaluate the levels of pH, aluminum, and acid neutralizing capacity in these lakes in response to atmospheric deposition. This work involved adapting terrain analysis and hydrologic algorithms implemented in ESRI Arc/Info geographic information system (GIS) software to help delineate watersheds that contribute surface and subsurface flow to these alpine lakes.

Special care was needed for developing these procedures because of two concerns: (1) limitations of digital terrain data even at the finest available resolution (10 m) because of the small size of these watersheds, and (2) presence of special cases like closed drainages (watersheds draining to lakes without an outlet), multiple outlet lakes (lakes that had more than one stream existing at different locations), and nested lakes. In addition to these issues with the automated delineation procedures, it was required that the delineated watersheds be accurate at 1:24,000 scale as per requirements of Federal Geographic Data Committee draft proposal that lays out standards for delineation of HUCs. This requirement translated into a ground accuracy of 12 m for all watershed and lake boundaries. In order to address this requirement, a protocol was developed that used manual checking of all boundaries on USGS digital raster graphs (DRG) of 1:24,000 and 1:25,000 scale topographic maps. The automatically generated watershed and lake boundaries were overlaid on the DRGs. Each boundary was manually checked to ensure that it was consistent with topographic contours.

Where needed, the points constituting the polygon representing the boundaries were moved to follow topographic ridges.

PROGRAMMING AND SOFTWARE DEVELOPMENT EXPERIENCE

Computing Languages

FORTRAN, C, C++, Perl, S, R, Java

Software Development

Most of my programming is carried out in C, C++, FORTRAN, R, and Perl in order to develop algorithms for data processing and hydrologic modeling. This includes data analysis including the USGS DEMs, streamflow, river reach files, HUCs, interpretation of results of GAP analysis, interpretation of STATSGO and SSURGO soils data for input to hydrologic models. I use terrain processing algorithms to automatically delineate subbasins and generate the corresponding stream network. Postprocessing of terrain analysis results is used to automatically set up watersheds for hydrologic modeling using DHSVM.

RESEARCH PUBLICATIONS

JOURNAL PAPERS

Prasad, R., D. G. Tarboton, G. E. Liston, C. H. Luce, and M. S. Seyfried, "Testing a blowing snow model against distributed snow measurements at Upper Sheep Creek, Idaho, United States of America," *Water Resour. Res.*, *37*(5), 1341-1356, 2001.

Chandler J., S. Jain, R. Prasad, and J. Eischeid, "Projected Hydroclimatic Change In Western North America: Adaptation Considerations For Water Resources Management," manuscript under preparation, 2009.

CONFERENCE PRESENTATIONS

Prasad, R., D. G. Tarboton, and C. H. Luce, "Application of a Spatially Distributed Hydrologic Model to Semi-Arid Mountainous Watersheds," 17th Annual AGU Hydrology Days, Fort Collins, Colorado, April 14-18, 1997.

Prasad, R., D. G. Tarboton, G. N. Flerchinger, K. R. Cooley, and C. H. Luce, "Understanding the hydrologic behavior of a small semi-arid mountainous watershed," *Eos Trans. AGU*, Fall Meet. Suppl., *80*(46), Abstract H21B-19, 1999.

Prasad, R., D. G. Tarboton, G. E. Liston, C. H. Luce, and M. S. Seyfried, "Testing a Blowing Snow Model Against Distributed Snow Measurements at Upper Sheep Creek," *Eos Trans. AGU*, Fall Meet. Suppl., *80*(46), Abstract H11E-07, 1999.

Prasad, R. and M. S. Wigmosta, “Scalability issues in process-based hydrologic modeling,” *Eos Trans. AGU*, Fall Meet. Suppl., *82*(47), Abstract H12C-0312, 2001.

Jain, S., J. Eischeid, and R. Prasad, “Tailored hydroclimatic information for water resources management in the western United States,” Proceedings of the EWRI World Water and Environmental Resources Congress, Philadelphia, Pennsylvania, June 23-26, 2003.

Prasad, R., L. W. Vail, C. B. Cook, and G. Bagchi, “Establishment of Safety-Related Site Characteristics Based on Consideration of External Sources of Flooding at Nuclear Power Plant Sites in the United States of America,” in upcoming Proceedings of the International Workshop on External Flooding Hazards, August 29 – September 2, Kalpakkam, India, International Atomic Energy Agency, Vienna, Austria, 2005.

Bagchi, G., E. V. Imbro, K. Manoly, and R. Prasad, “U.S. Nuclear Regulatory Criteria on Nuclear Power Plant Protection against External Flooding,” in upcoming Proceedings of the International Workshop on External Flooding Hazards (tentative title), August 29 – September 2, Kalpakkam, India, International Atomic Energy Agency, Vienna, Austria, 2005.

Prasad, R., “Evaluation of External Flooding Hazard at Nuclear Power Plant Sites in the United States of America,” Presentation at the Topical Consultancy on Tsunamis and Other External Flooding Hazards at Nuclear Power Plant Sites jointly organized by International Center for Theoretical Physics and International Atomic Energy Agency, May 8 – 12, Trieste, Italy, 2006.

Prasad, R., “Guidance for Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America”, Presentation at the Workshop on the Physics Tsunami, Hazard Assessment Methods & Disaster Risk Management (Theories and Practices for Implementing Proactive Countermeasures), jointly organized by International Center for Theoretical Physics and International Atomic Energy Agency, May 14 – 18, Trieste, Italy, 2007.

REPORTS PRODUCED FOR THE USNRC

Prasad, R, “Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America,” NUREG/CR-6966, U.S. Nuclear Regulatory Commission, Office of New Reactors, Washington, D.C., 2009.

Prasad, R. and others, “Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America,” NUREG/CR-7046, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, D.C., 2011.

PNNL REPORTS

Vail, L. W., M. S. Wigmosta, and R. Prasad, "Impact of Climate on Aquatic Habitat in the Yakima River," PNNL-SA-35194, Pacific Northwest National Laboratory, Richland, WA, 2001.

Vail, L. W., M. S. Wigmosta, R. Prasad, and C. K. Knudson, "Accelerated Climate Prediction Initiative," PNNL-SA-36759, Pacific Northwest National Laboratory, Richland, WA, 2002.

Scott M. J., L. W. Vail, C. O. Stockle, A. Kemanian, K. M. Branch, R. Prasad, M. S. Wigmosta, and J. A. Jaksch. "Adapting Irrigated Agriculture to Climate Variability and Change," PNWD-SA-6848, Battelle—Pacific Northwest Division, Richland, WA, 2005.

Scott M. J., L. W. Vail, C. O. Stockle, A. Kemanian, K. M. Branch, R. Prasad, M. S. Wigmosta, and J. A. Jaksch. "Benefits and Costs of Options to Mitigate the Uncertain Effects of Climate Change on Irrigated Agriculture in the Yakima Basin. What Matters? What Doesn't?" PNWD-SA-6980, Battelle—Pacific Northwest Division, Richland, WA, 2005.

Scott M. J., L. W. Vail, and R. Prasad. "Managing Water for Irrigated Agriculture Under Extended Climate-Related Drought." Presented by Michael J. Scott (Invited Speaker) at American Water Reopurces Association 2005 Annual Conference, Seattle, WA on November 8, 2005.

BOOK CHAPTERS

Wigmosta, M. S. and R. Prasad, "Upscaling and Downscaling – Models," Contributed Chapter to upcoming Encyclopedia of Hydrological Sciences, John Wiley and Sons, 2004.