PROFESSIONAL ACHIEVEMENTS

RECENT ACCOMPLISHMENTS (<5 years)

Geoscientific Data Fusion and Knowledge Discovery

Background – According to the U.S. National Science Foundation, discovery of solutions to future challenges in geoscience will require the fusion and mining of mutual information from big data. The fusion of big data variables, however, is computationally challenging because they tend to be disparate, noisy, nonlinear, redundant, scale-dependent, sparse, spatially-limited, and uncertain. Research in devising and testing alternate data-fusion paradigms and uncertainty quantification techniques represents the state-of-the-art in computational geoscience.

Role- I established the scientific basis, extended theory, and developed and implemented relevant data-fusion and knowledge discovery schemes to solve previously unanswered research questions associated with six research themes: Climate and Land-use Change, Core Science Systems, Ecosystems, Energy and Minerals, Natural Hazards, and Water. My work aims to enhance mutual information for knowledge discovery with reduced uncertainty through fusion of big data sets using three computational paradigms: numerical joint-inversion (novel constraints and solvers), artificial adaptive systems (evolutive and machine-learning), and hybrid models (combination of the former and statistical models). I continued direction for these research efforts based on my own work.

Results – My research involving these data-fusion paradigms solved previously intractable problems as described for each of the following themes.

<u>Climate and Land-use Change</u>: (1) I identified scale-dependent telconnections among climate variables and El Niño-Southern Oscillation (ENSO) events (pres. 83, pub. 93). This study demonstrates that it is possible to integrate and simultaneously analyze relations of scale-dependent (local to global and modern to ancient time) climate variables. (2) I extended modern annual tropical Pacific land-air-sea temperature data to the millennial scale. This study provides a 2,000 year temperature and precipitation series at an annual frequency for trend analysis and future use in calibrating global circulation (numerical) models. The application of quantile regression to these data provides alternative interpretation in trends whose uncertainty can be quantified annually as empirical density functions. Quantile trends reveal that the ENSO phenomenon operates over a continuum of temporal and spatial scales. This finding suggests that any forcing influencing the frequency or intensity of climate change will increase the likelihood for drought hazards placing national and global security at risk. (3) I estimated the number of annual global ENSO events over the past 2,000 years. This study provides data used to quantify the persistence for annual warm season El Niño, Neutral, and La Niña events over the past two millennia, and identify delays in global teleconnections and distribution of cooling and warming periods. These findings have broad economic, political, and social implications with respect to developing water resource policies. (4) I identified that climate variables have a fractal and long-memory process and performed a 50-year climate forecast for southern and southwestern United States. This study demonstrates the self-similar nature of reconstructed climate variables. This finding of long-memory processes supports the forecasting of climate change in temperature and precipitation. Also, this study provides the first short-term (<50 years) forecast of annual precipitation and temperature at local and regional scales across southwestern US. This information can be used by water managers to formulate water-resource and security planning. This application can be extended from annual to monthly time scale and from local to global spatial scales. (5) I classified the likelihood of landscape soil and vegetation components in Brazil from space-borne satellite data. This study classifies landscape characteristics from hyperspectral satellite data without the use of traditional multiple linear regression equations beset by poor resolution. This approach is generalized for climate applications in collaboration with researchers at the Brazilian agricultural research institute (Empresa Brasileira de Pesquisa Agropecuária) and university research institute (Centro de Pesquisas Meteorológicas e Climáticas Aplicadas a Agricultura). (6) I downscaled climate models for generating alcohol production in Brazil. (7) I modeled tropical land-use and land-cover change in relation to sugar cane. (8) I integrated vegetation index time series and meteorological data to understand land use/land cover seasonality. (9) I evaluated influence of global volcanic processes on climate modulation in the southwestern US.

Core Science Systems: (1) I determined depth, orientation, weight, and type of buried munitions and explosives of concern. (2) I predicted the magnitude of earthquakes for a region of china (unpublished). (3) I estimated uncertainty in lithospheric boundaries determined using a joint seismic inversion. (4) I improved resolution of lithospheric boundaries using joint inversion of receiver function and surface wave dispersion and receiver function and surface wave dispersion and magnetotelluric measurements. (5) I co-developed a hybrid evolutionary-gradient solver for numerical inversions.

Ecosystems*:* (1) I predicted mineral-resource effects on aquatic ecosystems (pres. 89, pub. X);

Climate-change effects on ecosystem services. (2) I determined connectivity among mining-aquatic ecosystem variables. (3) I developed an aquatic-mining ecosystem model. (4) I developed and used an artificial adaptive system to select input for ecosystem modeling. (5) I modeled the combined effects of natural and anthropogenic stressors on aquatic ecosystems. (6) I demonstrated the usefulness of artificial adaptive system to select optimal information for unbiased predictions with reduced uncertainty. (7) I provided various applications of artificial adaptive systems in environmental science.

Energy and Minerals: (1) I identified multivariate relations among global deposit and mining characteristics. (2) I identified heterogeneity in various grade and tonnage models. (3) I imputed missing data in grade and tonnage models. (4) I estimated true values of zeros in grade and tonnage models. (5) I estimated the density of various types of porphyry copper deposits. (6) I determined the economic feasibility of mining undiscovered porphyry copper deposits in British Columbia-Yukon territories. (7) I predicted background and mine-related acidity and metals in river basins. (8) I predicted the probable location of economic phosphate deposits. (9) I performed hydrogeophysical modeling of geothermal field data.

Natural Hazards: (1) I forecasted climate-change effects on the hydrology and geomorphology across post-fire landscapes in western U.S. (2) I provided a set of nonlinear debris-flow equations and quantified their uncertainty. (3) I modeled hydrometeorological hazards for coastal cities of São Paulo, Brazil. (4) I evaluated the role of large earthquakes on aquifer dynamics.

Water: (1) I estimated soil physical properties and quantified correlation structure across the Pocos de caldes basin Brazil. (2) I estimated hydrogeologic properties and characterized hydrostratigraphy across the transboundary South American Serra Geral-Guarani aquifer system. (3) I predicted the hillslope chemical weathering processes across Paraná state, Brazil. (4) I forecasted climate-change effects on ground-water recharge, (5) I predicted well yield in the semi-arid climate and fractured crystalline rocks of northeastern Brazil (6) I estimated starting parameter values and geostatistical constraints for applications to spatially-limited numerical inverse problems. (7) I performed near-real time airborne imaging of a heterogeneous surficial aquifer. (8) I computed continuous hydrostratigraphy for conceptual groundwater models by integrating geophysical-hydrogeologic data-integration scheme. (9) I devised scaling equations for ground-water recharge measurements. (10) I predicted climate-change effects on ground water recharge in the Midwestern United States. (11) I evaluated significance of climate and hydrology in the formation of natural acid-rock drainage. (12) I upscaled rainfall-recharge for groundwater modeling. (13) I estimated missing groundwater-surface water hydrochemistry values in a sparse data set. (14) I evaluated lithologic controls on GW/SW interaction.

Impact – The application of data-fusion and knowledge discovery is new to the USGS and most other earth science organizations. This body of work demonstrates efficacy of intelligent data fusion and analysis that transcends USGS research themes. This approach is significant because it provides alternative modeling paradigms to solve previously unanswered big data challenges that plague traditional methods. My shift in thinking toward these paradigms resulted in invitations for me to give an invited lecture to US Army Corps of Engineers, co-convene and give a Keynote address at NATO advanced research workshops (Climate Change and its Effect on Water Resources – Issues of National and Global Security, 2011; edit a NATO sponsored climate-change book, serve as an associate editor of the new Journal of Water and Energy Security (http://journalofwatersecurity.com/), convene an AGU Union Session on Computational Intelligence in Earth and Space Systems, and mentor a visiting USGS scientists and two Fulbright Scholars (Drs. Iwashita and Moreira;. Outside the USGS, I had requests by Brazilian agencies (Agricultural Institute, Climate and Meteorological Institute, Dept. Environment and Society, and Geological Survey) for research collaboration, technical assistance, and teaching of university courses (University of Campinas, and University of Brasilia), and participate in a 2013 State Department sponsored US-Italy scientific exchange between Center for Computational and Mathematical Biology (http://ccmb.ucdenver.edu/), University of Colorado, Denver, CO and Semeion Research Center of Sciences of Communication (http://www.semeion.it/), Rome, Italy. Ongoing computational intelligence research collaboration with Brazil scientists involves climate-change applications to agriculture (http://www.cpa.unicamp.br/alcscens/) and natural hazards.

In 2014, I was hired by GNS Science, New Zealand to develop and apply data fusion, knowledge discovery and related algorithms as part of the geophysics, remote sensing, and tracer validation tasks of the Smart Aquifer Characterization program funded by the New Zealand Ministry of Business (MBIE), Innovation and Employment. Since arriving to GNS, I received requests and began collaboration with principal scientists from other departments/divisions to evaluate these methods for application to Earthquake hydrology funded by the Royal Society of New Zealand, Influence of regional groundwater flow on geothermal system funded by MBIE, Effects of climate change induced sea-level rise on coastal aquifers funded by GNS Strategic Development Fund, and Real-time satellite mapping of gold and geothermal deposits funded by GNS Strategic Development Fund. Various international requests for assistance in devising computational-intelligent solutions include: the Director of Strategic Directions in Hydrogeology, Geoscience Australia, Australia to help with real-time mapping of surficial aquifer structure and properties in southwest Pacific; a Professor of Geophysics, Geoscience Department, Federal University of Natal, Brazil to map cratonic basins for locating offshore oil & gas; a professor of environmental sciences at Sun Yat-sen University and Chinese Academy of Sciences, China to collaborate on a proposal for groundwater as a climate adaption funded by MBIE as part of the strategic NZ-China alliance; the Director of Geophysics, Tblisi State University, Georgia to evaluate relations and devise model accounting for hydrology and earthquake parameters; a professor at University of Brasilia to develop hybrid solver (software) for joint geophysical and joint hydrogeophysical inverse solutions; the Director of Semeion Institute, Italy to develop software for selecting optimal subsets of variables and estimate missing data in sparse matrices; a research Fellow, University of Florence to map soil age in satellite imagery; a PhD candidate, Earth and Environmental Sciences, Victoria University, NZ to quantify likelihood for unconventional on-shore shale-gas prospects in NZ; a PhD candidate, Institute of Environmental Assessment and Water Research, Spain to quantify groundwater recharge in a semi-arid environment.

Future Directions The field of Geoscientific data fusion and knowledge discovery is in its infancy. Future directions for my research will continue to focus on methods development and applications involving the numerical joint inversion, artificial adaptive systems and hybrid modeling paradigms. Examples of methods development for numerical joint inversion will include: (1) extending an evolutionary (global)-gradient (local) solver to accommodate n-joint solutions, (2) testing and integration of reduced order methods to speed the global solution and optimal subset selection, (3) evaluating Bayesian regression trees to quantify uncertainty, and (4) evaluating model worth using a measure theoretic approach. Some methods development for artificial adaptive systems will include: (1) the parallelizing of a modified self-organizing map technique for real-time classification and estimation and estimation of nonlinear uncertainty limits by stochastic cross-validation, (2) reduced-order methods for optimal information selection and uncertainty reduction, and (3) symbolic regression for evolutive spatiotemporal scaling equations. Examples of some methods development for hybrid modeling include: evaluating novel algorithms that combine numerical, artificial adaptive systems, and multivariate statistical approaches with recurrent training schemes to address data sparseness, enhance mutual information, and reduce uncertainty.

Applications of these developments will benefit seven research themes: Climate and Land-use Change; Core Science Systems; Ecosystems; Energy and Minerals; Natural Hazards; Water; and Energy, food, water security nexus. <u>Climate and Land-use Change</u>: Reconstruction and forecasting of climate-change variables on a monthly time scale at local, regional, and global spatial scales (Global Change, GNS, NZ; University of Campinas, BR); spatiotemporal downscaling of climate variables and large scale surface fluxes (Hydrogeology, GNS NZ; NIWA, NZ); real-time satellite remote mapping of landscape components (Minerals and Geothermal, GNS, NZ; Satellite Monitoring, EMBRAPA, BR); and spatiotemporal scaling of hyperspectral sensor footprints for agricultural and earth science (Massey University, NZ). <u>Core science systems</u>: Earth structural and geological

mapping of the USA by joint-inversion of national magnetotelluric and seismic data (University of Brasilia, BR). Ecosystems: Modeling effects natural and anthropogenic stresses on aquatic ecosystems (Semeion Institute, IT).
Energy and Minerals: Unconventional shale-gas prospecting in NZ (Victoria University, NZ); unconventional off-shore oil-gas prospecting in BR (University of Natal, BR). Natural hazards: effects of climate change impacts on coastal environments (University of Campinas, BR); role of large earthquakes on aquifer dynamics (GNS, NZ; Victoria University, NZ; Tblisi State University, GA). Water: Airborne aquifer characterization and mapping of hydrostratigraphy (Smart Aquifer Characterization, GNS; Strategic Directions, Geoscience Australia, International Program, USGS); groundwater as an adaption (Sun-yet Sen University, CN); effect of sea-level rise on coastal groundwater supplies (Global Change, GNS; Hawkes Bay Regional Council); water footprint for regions of New Zealand (Gannan Normal University, CN); effects of urban ecosystem on the climate system (National Research Program, USGS); transport of atrazine and dicamba through silt and loam soils (National Research Program, USGS). Energy, food, water security: Evaluating the role and interdependencies of energy, food, and water on risk to national and global security (National Research Program, USGS). I am currently supervising a visiting scientist and two PhD candidates.

OTHER ACCOMPLISHMENTS (>5 years)

Modeling Hydrologic Response to Extreme Climate Events

Background- Monsoon storms and hurricanes are associated with extreme rainfall events that result in natural hazards, such as flooding, debris flows, and landslides. In developing countries, the response to extreme events is more catastrophic because river basins are sparsely or completely ungauged with no rainfall information.
Role- I formulated and established the scientific basis, extended theory, and developed and implemented relevant models and inverse solutions. I continued direction for these research efforts based on my own work.
Results- I developed and applied new inverse methods to solve problems involving extreme rainfall events in gauged and ungauged basins. In *gauged* basins of Midwestern U.S., the application of soft prior information in the form of spatial dissimilarity equations during inverse modeling demonstrated that: (1) the structure of an overly parameterized model could be estimated without a-priori simplifications; (2) the influence of calibration-constraint measurement information could be evaluated by estimating and evaluating the nonlinear limits of prediction uncertainty; and (3) sufficient model complexity guaranteed prediction within the limits of uncertainty, but reduced prediction uncertainty at the expense of model complexity could lead to prediction bias. By extending the regularization strategy to multiple models, it was possible to form an implicit simultaneous inversion for solving otherwise intractable problems in *ungauged* basins. For example, in ungauged mountain basins of El Salvador and Western US, it was possible to: (1) estimate coastal unconfined flood-flow depths in response to monsoon rains, (2) estimate hurricane-induced basin rainfall amounts; and (3) estimate wild-fire induced debris-flow discharge amounts and depths.
Impact – By using the alternate modeling paradigm, it was possible to formulate new regionalization procedures for predicting probable flooding, rainfall amounts, and wildfire-induced debris flow amounts in-ungauged basins. This new paradigm shifted thinking away from the traditional principle of parsimony, split-sample model validation, and perceived need for gauged basin measurements. It demonstrated the need and how to compute limits of nonlinear prediction uncertainty; and need to strike a balance between an acceptable level of model complexity, predictive uncertainty, and model bias. Since this work, multiple special sessions related to these findings have, and continue to be, convened as topics at the American Geophysical Union and European Geosciences Union (EGU) conferences. For example, some of the 2009 EGU special sessions directly related to my published research: Adapting model complexity to available data – alternative paradigm to conventional model parsimony, Catchment similarity for regional predictions in ungauged basins, Diagnostic evaluation of hydrological models, Hydrological processes and extreme events in mountain areas, Hydrological

mapping and regionalization, Floodplain mapping and flood prevention techniques in the 21st century.

The practical impacts of this research span international, national, and local levels. *Internationally*, the El Salvadoran government received flood maps to locate a new seaport for enhanced competition in the global market. USAID provided funds for me to develop and provide related training to El Salvadoran hydrologists. Also, the governments of El Salvador and China provided funds and visiting professorships for me to teach, conduct research, and mentor faculty and students on new methods in ungauged hydrology, and participate as *keynote speaker* in the international conference on Methodologies in Hydrology. *Nationally*, these methods were adopted by the National Water Quality Assessment Program to quantify recurrent peak flows at ungauged sites in their Ecological Land-Use Gradient studies. The new wildfire-induced debris-flow approach and guidelines were adopted by the FEMA to reestablish insurance rates for the western United States. *Locally*, the FEMA funded another Colorado study with the results used by Douglas County, CO engineers and consultants in flood and debris flow designs for the Hayman basin. The Director of USGS sponsored a collaborative study between me and NMD scientists to test the efficacy of using satellite information to improve the Hayman debris flow model. Given on-going landscape and climate changes and recognizing that most basins are ungauged, these methods and guidelines have broad worldwide applicability in basin hydrology and other fields that use numerical models. Another new area of study that opened was the application of combined inversion in which lateral constraints as soft prior information extended the previously stitched 1D result to a 1.5D image. This affords the new possibility of incorporating the combined geophysical inversion into a joint geophysical-hydrogeological inversion to advance the new field of Hydrogeophysics.

Unsaturated Zone Modeling

*Background*_- Given the uncertainty in climate change and numerical complexities associated with simulating energy balance at the earth-atmosphere interface and subsurface fluxes, the development and application of appropriately coupled numerical models were limited, and calibration and prediction guidelines nonexistent.

*Role*_– I formulated and established the scientific basis, extended theory, and developed and implemented relevant numerical unsaturated zone models and inverse solutions. I continued direction for these research efforts based on my own work.

*Results*_- I completed development, verification, and documentation of several finite-element (numerical) models to simulate movement mass and energy in variably-saturated subsurface equivalent porous media: water flow, coupled water-heat transport, coupled water-heat-solute transport, and coupled water-heat-solute transport with freezing; and dual porous media: coupled water-solute transport (DUALPi; unpublished). This development constituted difficult research in which governing partial differential equations were derived and converted to a numerical form to facilitate explicit coupling and simultaneous solution of pressure, temperature, and concentration. This work resulted in invited presentations, participation on scientific committees, and USBM and USGS publications. My research *resulted in* development of the first USGS variably-saturated dual permeability flow and transport model, mentoring the task chief in application of this new model, and mentoring a graduate student in laboratory measurement and analysis of coupled and hysteretic phenomenon.

*Impact*_- These variably-saturated zone models have broad application to fields of study where climate-induced movement of mass and energy is important. Examples of special topics that have been studied using these models include arid zone hydrology, agricultural chemical movement, evapotranspiration, groundwater recharge, macropores, mine drainage, preferential flow and transport, nuclear waste isolation, seepage, and solute exclusion. Whereas other unsaturated-zone models exist, VARSAT2D is the only version that tracks hysteresis and has a stochastic component. SWHT was a precursor to several other models including VST2D. VST2D is the only USGS coupled variably-saturated water, heat, and solute transport model; two similar models were being developed concurrently by teams of researchers at national laboratories. At the time of development, this was the only model in which three dependent variables were explicitly coupled providing for future extension to a true reactive transport model. To date, DUALPi remains the only USGS model that couples variably-saturated water and solute transport with transfer of mass between two domains. Whereas all models are suitable for assessing atmospheric-subsurface interaction, this model is suitable for studying preferential flow and transport in macropores. Requests for my numerical models and reports have come from agencies and researchers throughout the world.

In addition to numerical studies of calibration and predictive analysis, the VST2D model has been used by USGS and university scientists, students and faculty for applied unsaturated- zone studies of agricultural transport, recharge estimation, and well bore leakage. The lack of calibration guidelines opened up an area of research for understanding the effects crossover between coupled dependent variables when used as calibration constraints. As a leading authority in numerical development of variably-saturated flow and transport models, I was invited to participate in a National Research Program, Water Resources Discipline, USGS, review and provide recommendations for development of true reactive unsaturated-zone transport model, and by Chief of the Agricultural Chemical Transport Team, National Water Quality Assessment, USGS, to assist in co-planning national studies of agricultural chemical transport in the unsaturated zone; requested to model the degradation of organic compounds in the unsaturated zone; requested to evaluate reactive transport in the unsaturated mining environment of Romania; requested to serve as reviewer for Vadose Zone Journal and member on the American Geophysical Union Unsaturated Zone committee. Most notably, I was funded by the Department of State to develop and teach a course on *Variably-saturated zone hydrology: experimental design, data collection, and modeling* to 18 scientists from 6 different ministries in the strife-ridden areas of the Middle East (Israel, Jordan, and Palestine). According to the State Department, this course was considered the most successful of all previous courses.

Geotomographic Imaging

Background - The extraction of ore underground often results in the redistribution of stresses that lead to catastrophic consequences and death. To improve miner safety, the mining industry wanted to understand the spatiotemporal dynamics of stressed mine structures.

Role - I formulated and established the scientific basis, extended theory, and developed and implemented relevant forward models and inverse solutions. The continuation of this research into other applications and USGS themes was based on my own work.

Results- Various forms of tomography provided the mining industry with the means to *see* into the earth and identify the distribution of base metals and hydraulic fractures; evaluate effects of blasting, movement of leach solutions or contaminants, rock quality, and changes in stress field; and locate abandoned mine openings; This work resulted in invited seminars, short courses, committee participation; presentations and publications.

Impact – Geotomography was adopted by mine operators throughout the world. Seismic tomography provides a cost-effective way to monitor extraction and solution mining processes, as well as mitigate various mining-related environmental and safety problems. Monitoring critically stressed regions facilitated targeted distressing to avoid otherwise unpredictable and catastrophic rockmass failures. Our research motivated U.S. and international scientists in other fields to use tomography for problem solving in civil engineering, nuclear waste, petroleum, and forensics. This work opened new areas of research including the integration of seismicity for enhanced imaging, inversion routines, and improved imaging through fusion of tomographic and hydrogeologic data in a recent field known as hydrogeophysics. After congress abolished the USBM, Western Mining Corp. offered me a position as chief geophysicist to oversee tomographic imaging of gold deposits worldwide. I still review at least one paper for various journals on tomographic applications each year.

Scientific Leadership

Leadership at project, team, program, and Bureau levels: At the *project* level, I promoted and prioritized work; coordinated and prepared the scope of work and financial plans with annual budgets to ~$2.0M; determined project staffing needs and hired scientists with specialized experience; determined assignments, awards, and promotions; reviewed and ensured timely completion and quality of technical proposals, work plans, presentations, and reports; and evaluated employee performance. As a leader, I motivated scientific teams toward common goals. Leading teams was challenging because they often included scientists and support staff from multiple disciplines, multiple states, and organizations. To facilitate implementation of core activities, I guided and participated in project designs, data collection, analyses, and interpretation; promoted team workshops on scientific field data collection and modeling applications; identified, planned, promoted, and coordinated multi-state activities with cooperating companies, State and Federal agencies, National Synthesis Teams, and other related studies; devised and promoted new scientific approaches; and developed, participated and chaired reviews at science center, headquarter, and stakeholder meetings. I was among the first chiefs to use web products in support of USGS Water Resource Discipline projects. Notable contributions included conceptualizing, funding, and directing the development of internal and external project management web pages for the Upper Illinois River Basin (UIRB) - National Water Quality Assessment (NAWQA) project. My direction and funding development of an internal web-based project management email/calendar and external web-based water quality data server were precursors to LOTUS notes and National Water Information System (NWIS). The programmers and software used in developing the UIRB web server were later used by headquarters in the NWIS development. One recent assignment was subtask chief for one of two large tasks funded by the Mineral Resources Program (MRP). This role emerged as a result of my direction and guidance in the reformulation of the project task. In addition to project leadership, I mentored visiting USGS scientists, and doctoral students at universities in the US and abroad.

At the *team* level, several new research projects were started under my direction with high national visibility and success. Some examples that were developed while I was chief of the UIRB NAWQA project included Nutrients and suspended solids in surface waters of the Upper Illinois River Basin; Influence of various water quality sampling strategies on load estimates for small streams; Ecological risk assessment in the Upper Illinois River Basin; and Urbanization influences on aquatic communities in northeastern Illinois streams. In addition to providing guidance on administrative and funding aspects of these projects, I provided scientific direction that helped make these projects successful. Findings from these research projects provided a basis and direction for modification of NAWQA program protocols that included strategies for frequency of surface water sampling and conducting urban land-use gradient (ULUG) studies. Findings from the ULUG study provided funding estimates and necessary protocols used in the program implementation of nine urban land-use gradient studies conducted across different metropolitan regions of the US. Another example of my team leadership included implementation of an alternative management paradigm for managing multi-state teams. This paradigm provided a means to manage cyclical NAWQA funding and reduce otherwise hardships in annual science center staffing. This strategy was adopted as a preferred means of managing teams in the NAWQA program. As a senior staff member of the Illinois and Colorado Water Science Centers, I provided technical program direction, long-range planning, and project reviews; and developed, coordinated, and promoted a WebEx seminar series.

At the *program* level, I worked across discipline barriers providing direction to various committees tasked with funding and planning scientific programs. This direction included the annual review and selection of technical proposals and long-range planning for the Health and Safety and Environmental Technology programs for the USBM. At the USGS, I provided input on long-range planning to the National Research Program for reactive unsaturated zone transport model development. Similarly, I provided input and direction on the development and long-range planning for a new NAWQA Agricultural Flow and Transport Synthesis Team. Other leadership examples included input on research grade evaluation panels for Ground Water Hydrology of the Water Resource Discipline, and Crustal Imaging and Characterization Team of the Geologic Discipline.

At the *bureau* level, I exercised intergovernmental leadership in the transfer of technical information and support of peace through science initiatives. In technical transfer, I provided information on findings of my research for which publications were new and guidelines otherwise nonexistent. This information transfer was in the form of committee involvement, seminars, workshops, and expert testimony that arose based on requests by management and scientists within the USBM, USGS, collaborating agencies, and industry personnel. For example, I provided technical direction on a special USBM committee charged with developing well-drilling guidelines to reduce Bureau liability for groundwater pollution. At the USGS, I provided technical seminars to management and scientists of the NAWQA Leadership and National Synthesis Teams, Office of Water Quality, and Office of

Surface Water on topics, such as model calibration framework for assessing effects of urbanization on water quality, model calibration and simulation of urbanization and its effects on ecological integrity, and a new approach to watershed model calibration and predictive analysis. The application of my regularized nonlinear inverse procedure was adopted as a standard for HSPF modeling in the USGS. I represented the Bureau as an expert witness on Colorado River water quality modeling in response to a Toughy request by Denver Water. An example of my interaction among bureaus included providing guidance to the Federal Emergency Management Agency on use of post-fire flood and debris flow modeling techniques which were used to reestablish new insurance rates. In other examples, I provided field training and model guidance to the US Department of Agriculture and National Institute of Occupational Safety and Health on how to evaluate solute leaching of agriculture chemicals in freezing (hydro-mechanical) ground and application of seismic tomography to mitigate rock bursts in deep metal mines. More recently, I provided updates and slides of my intergovernmental support to the International Program and Director of the USGS.

Leadership in the external scientific community

My scientific leadership outside the federal government is reflected in frequently serving as a reviewer of manuscripts for in-house publications and outside books and journals, participating in or leading committees (American Geophysical Union technical committee on Unsaturated zone for hydrology, 2004-2011); annual chairing of symposia at scientific meetings (American Geophysical Union, and European Geosciences Union); serving as an editorial board member (Global Security Affairs and Analysis, Science publishers, 2007-2008; and The Open Civil Engineering Journal, Bentham Science publishers, 2007-present); and serving as an adjunct professor (Department of Geophysics, Colorado School of Mines: 2006-present; Department of Environmental Science, University of Colorado: 2004-2012; Department of Mathematics and Statistical Sciences, University of Colorado: 2012-present). As adjunct professor, I served on a number of graduate thesis committees and co-advised master and doctoral students.

In the past decade, my role has broadened to include various international assignments, such as a State Department-sponsored modeling course (Budapest, 2005) as part of the Middle East Peace Process (18 scientists from 6 different ministries in the strife-ridden areas of Israel, Jordan, and Palestine); NATO-sponsored Advanced Research Workshops (Urban Groundwater Management and Sustainability, Baku Azerbaijan, 2004; Groundwater and Ecosystems in Canakkale, Turkey, 2005; and Climate change Effect on Water Supplies – Issues of National and Global Security, Izmir, Turkey, 2011), Chinese-sponsored International Symposium on Methodology in Hydrology (Nanjing, China, 2005), and various governmental sponsorships as visiting scientist (Brazil and Finland) and visiting professor (Brazil, China, El Salvador, Finland). As part of the NATO-sponsored Advanced Research Workshops, Chinese-sponsored International Symposium, and Brazilian 44th Geological Congress, I gave keynote talks and presided as chairman over special advanced modeling sessions. In the case of the 2011 NATO-sponsored Advanced Research Workshop, I accepted the role of co-convener (36 scientists from 18 countries) and co-editor of a book on Climate Change and its Effect on Water Resources – Issues of National and Global Security (NATO Science for Peace and Security Science Series).

I provided technical assistance to scientists in the countries of Brazil, El Salvador, Finland, Haiti, Kyrgyzstan, Mauritania, Romania, and Turkey; and special European Union committees. My involvement in these international activities resulted in various requests for me to serve as visiting Scientist (Geological Survey of Finland, Kuopio, Brazil, 2007; Geological Survey of Brazil, Fortaleza, Brazil, 2008**),** visiting professor (Universidad Centroamericana, El Salvador: 2003, 2004, 2005, 2006; Nanjing University, Nanjing, China, 2005; Kuopio University, Kuopio, Finland, 2007; Universidade de Brasilia, Brasilia, Brazil, 2008; Universidade de Campinas, Campinas, Brazil, 2008, 2012), adjunct professor (Universidade de Campinas, Campinas, Brazil, 2008-present; Universidade de Brasilia, Brasilia, Brazil, 2008-present), and mentor visiting USGS scientists (Fabio Iwashita, University of Campinas, Brazil; Lucas Moreira (Fulbright Scholar), University of Brasilia, Brasilia, Brazil; and Can Ertekin, University of Çanakkale Onsekiz Mart University, Çanakkale, Turkey). As a visiting professor, I developed and taught advanced modeling courses on special topics related to my research published while working at the USGS. My role as an adjunct professor allowed me to participate and preside on a number of graduate thesis committees and serve as co-advisor for Ph.D. students in Brazil (University of Brasilia, and University of Campinas) and Turkey (University of Çanakkale Onsekiz Mart University). In these university rolls, I guided student projects to be consistent with USGS science program themes and goals, and provided guidance in development of manuscripts, and assisted in the development of a hydrogeology curriculum (University of Brasilia). While I served as adjunct professor in San Salvador, I provided guidance to a senate committee charged with developing country-wide groundwater protection plans for aquifers in El Salvador.