Preface

Experimental hydrology: A bright future

1. Introduction

Experimentation and observation are central activities within the hydrologic sciences. Part of the scope of ADWR is the publication of experimental approaches that advance the basic understanding of water resources systems. Yet, the fundamental character of the journal is perceived by some that it excludes experimental work. To clearly demonstrate the contrary, we present a special issue dedicated to experimental approaches. The goal of this special issue is to illustrate the vibrancy of experimental hydrology broadly across the areas of subsurface and surface hydrology and hydrometeorology, as represented by 18 articles that present new scientific discoveries in hydrology.

There are many reasons that justify the need for hydrological measurements and experiments. First, we realize that observations and experimentation play a very important role in scientific discoveries. Thus, innovation and development of experimental approaches are crucial when exploring the scientific field. Second, the development and application of innovative instrumentation are key when testing theory, thereby helping us to improve the understanding of new and existing theories. Third, as hydrological models are developed that increasingly incorporate intricate temporal and spatial variations, they must be tested through comparison and analysis of experimental data. Experimental research is needed to develop measurement techniques that allow for model calibration and the estimation of scale-appropriate hydrological properties. For example, local scale measurements may not adequately reflect basin-scale hydrologic responses. Fourth, there is an increasing societal need for monitoring of hydrologic systems to monitor anthropogenic effects on water quantity and quality and for risk management purposes.

Experimentation is defined by the manipulation of system variable(s) or parameters of an experimental system with controlled boundary and initial conditions, to test a conceptual model. Because complete control is difficult in many natural hydrological systems, we use innovative surrogate settings such as soil columns, channel flumes and erosion/deposition facilities to answer fundamental questions in hydrologic science.

Alternatively, one may conduct *exploratory observations* based on statistical or process-based designs that are selected for their ability to reveal the key hydrological mechanisms. Ideally, testable quantitative hypotheses should be posed prior to measurement. Mathematical model calibration and testing is a form of exploratory observation, with measurements collected to constrain boundary and initial conditions, to estimate model parameters, and to compare model functionality with the measured hydrological dynamics. Stratified landscape comparison is another type of exploratory observation, dividing the study area into distinct hydrologic units using relevant criteria such as geology, soils, vegetation, and topography, and using measurements to contrast hydrological processes. The classic "paired basin" study represents a special case when two hydrologic areas are compared. Monitoring campaigns are a third form of exploratory observation in which the study area is monitored to characterize baseline hydrological functioning that can be compared with the hydrology of that same area, for example to study the hydrologic effects of extreme events or human impacts.

2. Overview

The papers in this special issue on experimental hydrology represent the development and application of innovative experimental techniques in the areas of surface hydrology, subsurface hydrology and hydrometeorology.

2.1. Surface hydrology

Thompson [1] conducted flume experiments to evaluate the control of different obstructions in streams and

associated turbulence intensity on scour of pools. Pool formations result in water depth variations that are believed to be critical to the presence of many aquatic species. The experimental study by Cozzetto et al. [2] on temperature regime in glacial meltwater streams was conducted to identify the dominant processes controlling water temperature in polar desert streams, with a focus on the role of hyporheic exchange. In addition to heat budget calculations, conservative tracer and snow-addition experiments were conducted to quantify hyporheic exchange mechanisms.

Three papers present different hydrological models for hydrograph and runoff analysis. The paper by Rupp and Selker [3] presents a new method for analysis of the recession limb of a hydrograph using a variable time-stepping procedure, using recession hydrograph data from two gauging stations in the coastal range of Chili with very different accuracies. The field research by Ocampo et al. [4] demonstrates the hydrologic functioning of two different landscape units along a hillslope. Using both hydrological and biogeochemical measurements, the researchers conclude that riparian zones control storm responses, while upland zones behave as storage units that control the base flow component of stream flow. Their experimental results show that the transition between riparian and upland zones is controlled by the space–time dynamics of the shallow water table. Lyon et al. [5] show a new application of indicator kriging to shallow water table measurements, predicting spatial distribution of runoff generation along a hillslope. They demonstrated that the inclusion of soft data, representing landscape features significantly increased prediction capabilities.

Using temperature measurements within the snow pack, the snowmelt process was simulated in a paper by Ohara and Kavvas [6]. Their measurements showed that the snow temperature of the active layer near the snow surface varies continuously, whereas the lower inactive snow layer is hardly affected by atmospheric temperature and varies little, while its thickness (or freezing depth) varies with time. Their data provided the necessary information for the development of a unique physically-based snowmelt model.

2.2. Subsurface hydrology

Two studies focus on interfacial properties of the capillary pressure–saturation relationship of non-aqueous phase liquids (NAPL). Improved characterization of interfacial properties is required to understand NAPL redistribution and dissolution. The first paper by Hwang et al. [7] reports on the application of various experimental techniques to better describe the effect of fractional wettability on the constitutive relationships. A pore-scale analysis of NAPL–water interfacial area

was conducted by Culligan et al. [8], using a synchrotron-based computed micro-tomography technique. High-resolution three-dimensional imaging demonstrated that differences in interfacial areas between fluid pairs could be explained by interfacial tension calculations.

The development of new measurement techniques for analysis of water flow and chemical transport in unsaturated soils was introduced in two studies. The first study by Al-Jabri et al. [9] presents a rapid field-based dripper-TDR method to determine in situ hydraulic conductivity and chemical transport parameters at many locations simultaneously. Their method is of great value when soil surface heterogeneity is large. Data demonstrated the presence of non-equilibrium water and chemical movement, such as caused by immobile water and preferential flow. The laboratory study by Mortensen et al. [10] demonstrates the application of the multifunctional heat pulse probe (MFHPP) to simultaneously measure coupled water, heat, and solute transport in unsaturated porous media. The probe combines a heat pulse technique for estimating soil heat properties, water flux, and water content with a Wenner array measurement of bulk soil electrical conductivity. The MFHPP's ability to measure thermal, hydraulic, and solute properties simultaneously within the same sample volume provides for a new powerful tool for vadose zone monitoring and characterization.

The following three papers present field-based experimental research. The study by Ward et al. [11] introduces two new upscaling procedures for the prediction of field-scale infiltration and redistribution in unsaturated anisotropic soils, using effective hydraulic functions. The one approach uses the analogy the moisture-based Richards' equation with the convective–dispersive equation to derive the effective hydraulic conductivity by spatial moment analysis. The other method develops the so-called combined parameter scaling inverse technique whereby the heterogeneous soil is made up of a composition of multiple equivalent homogeneous media. The second paper in this category by Tompson et al. [12] describes the outcome of a radionuclide migration experiment through a 220 m thick vadose zone at the Nevada test site (NTS). Tritium migration was simulated over a 30-year period, resulting in a predicted travel time of about five years, after matching simulated with estimated infiltration rates. The experimental study by Tromp-van Meerveld and McDonnell [13] analyzed relationships between spatial patterns of topography, soil moisture, soil depth and tree transpiration rate along a 50 m hillslope. They concluded that even small variations in soil depth controls soil water storage, transpiration patterns and associated species distribution along the hillslope. Their results confirmed the notion that the spatial structure of soil

moisture and its changes with time are both a cause and a consequence of vegetation. As demonstrated by the other field studies of Ocampo et al. [4] and Lyon et al. [5], the hillslope scale can serve as an ideal hydrologic laboratory because of its relative uniformity in soil type and atmospheric conditions, and the hydrological control of the underlying bedrock.

2.3. Hydromicrometeorology

With the exception of the first paper in this section, all experimental studies focus on measurement and analysis of evapotranspiration (ET). The first paper by Krajewski et al [14] evaluated rainfall measurements with three different types of disdrometers. The paper discusses systematic and random differences of rainfall amount, drop size distribution properties and drop size–velocity relationships. Their main conclusion was that main differences between instruments were found, despite that all data were collected within the same 100 m² area.

Prediction of water vapor or CO_2 transport above plant canopies requires detailed parameterization of turbulent transport. The study by Poggi et al. [15] investigates the effect of the estimated mean turbulent kinetic energy dissipation rate on concentration using the Lagrangian dispersion modeling (LDM) approach. LDM results were compared with dye concentration and water flow measurements, using Laser induced florescence and Laser Doppler anemometry, respectively. Remote sensing (RS) is now widely used to estimate spatially-distributed land surface characteristics and ET. The final three experimental studies show different examples of RS. Kampf and Tyler [16] used remotely sensed data to estimate land surface energy budgets and the spatial distribution of soil surface evaporation across a 3000 km² playa in the Atacama Desert of northern Chili. Their uncertainty analysis results showed that including spatially-distributed land cover parameters yielded significant improved ground and sensible heat flux predictions. However, their approach was not successful in estimating area-averaged evaporation for this dry environment. In part, they attributed discrepancies to differences in scale between ground truth and RS measurements and high uncertainty of the latent heat flux, relative to its mean value. This scale issue associated with spatial variations in land cover was also investigated by Kustas et al. [17], where heat flux calculations from remotely sensed data from 5 km and 30 m resolutions were compared with flux tower measurements from the SGP97 experiment. They concluded that water vapor and sensible heat flux footprints can be very different under strong convective conditions. This study showed that water vapor flux fields mix much more readily than sensible heat fluxes, and that the sensible heat flux variability is much more controlled by

local land surface variations. The last paper by Eichinger et al. [18] demonstrates how Raman lidar can be used to make high resolution (25 m) and small footprint ET estimates across different plant canopies, through three-dimensional atmospheric measurements of water vapor content directly above the canopies. Their results showed that the effective spatial extent or footprint size was about 200 m, or approximately equal to the commonly accepted fetch requirement considering that vapor content measurements were made to about 5 m above the canopy.

3. Concluding remarks

More than ever, new opportunities have emerged in the past decade that increased our awareness of investing in experimental research. Increasingly, the societal relevance of hydrologic sciences demands investigations at large spatial scales and across scientific disciplines, requiring experimental innovations in data collection and analysis to solve increasingly complex problems. Future advances in hydrologic modeling will be constrained by the lack of independent experimental data. The ongoing rapid development of large-array telemetry systems will enable real-time monitoring of hydrologic variables with unprecedented detail, allowing real-time forecasting of such hydrologic variables as soil moisture, estuary currents, river flows, and groundwater recharge, through coupling of the data with hydrological models.

The papers presented in this special issue clearly show that experiments are crucial towards the characterization and understanding of hydrologic mechanisms. The urgency of expanding and prioritizing experimental hydrologic research is being acted on by the hydrologic community through the planning and establishment of hydrologic observatories across the US by the Consortium of Universities for the Advancement of Hydrological Sciences, Inc. or CUASHI. This NSF-funded nation-wide effort will undoubtedly unify hydrology and position us in an interdisciplinary partnership with related environmental sciences, to promote a more sustainable utilization of scarce water resources.

References

[1] Thompson DM. The role of vortex shedding in the scour of pools. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.03.015.

[2] Cozzetto K, McKnight D, Nylen T, Fountain A. Experimental investigations into processes controlling stream and hyporheic temperatures, Fryxell Basin, Antarctica. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.04.012.

[3] Rupp DE, Selker, JS. Information, artifacts and noise in dQ/dt recession analysis. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.03.019.

[4] Ocampo CJ, Sivapalan M, Oldham CE. Field exploration of coupled hydrological and biogeochemical catchment responses and a unifying perceptual model. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.02.014.

[5] Lyon SW, Lembo AJ, Watler MT, Steenhuis TS. Defining probability of saturation with indicator kriging on hard and soft data. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.02.012.

[6] Ohara N, Kavvas ML. Field observations and numerical model experiments of snowmelt processes. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.03.016.

[7] Hwang SH, Lee KP, Lee DS, Powers SE. Effects of fractional wettability on capillary pressure–saturation–relative permeability relations of two-fluid systems. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.03.020.

[8] Culligan KA, Wildenschild D, Christensen BSB, Gray WG, Rivers ML. Pore-scale characteristics of multiphase flow in porous media: a comparison of air–water and oil–water experiments. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.03.021.

[9] Al-Jabri SA, Lee J, Gaur A, Horton R. Jaynes DB. A dripper-TDR method for in situ determination of hydraulic conductivity and chemical transport properties of surface soils. Adv Water Resour, in press, doi:10.1016/j.advwatres.2004.12.016.

[10] Mortensen AP, Hopmans JW, Mori Y, Simunek J. Multifunctional heat pulse probe measurements of coupled vadose zone flow and transport. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.03.017.

[11] Ward AL, Zhang ZF, Gee GW. Upscaling unsaturated hydraulic parameters for flow through heterogeneous anisotropic sediments. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.02.013.

[12] Tompson AFB, Hudson GB, Smith DK, Hunt JR. Analysis of radionuclide migration through a 200-m vadose zone following a 16-year infiltration event. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.02.015.

[13] Tromp-van Meerveld HJ, McDonnell JJ. On the interrelations between topography, soil depth, soil moisture, transpiration rates and species distribution at the hillslope scale. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.02.016.

[14] Krajewski WF, Kruger A, Caracciolo C, Gole P, Barthes L, Creutin J-D, Delahaye J-Y, Nikolopoulos EI, Ogden F, Vinson J-P. DEVEX—disdrometer evaluation experiment: basic results and implications for hydrologic studies. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.03.018.

[15] Poggi D, Katul G, Albertson J. Scalar dispersion within a model canopy: measurements and three-dimensional Lagrangian models. Adv Water Resour, in press, doi:10.1016/j.advwatres.2004.12.017.

[16] Kampf SK, Tyler SW. Spatial characterization of lands surface energy fluxes and uncertainty estimation at the Salar de Atacama, northern Chili. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.02.017.

[17] Kustas WP, Anderson MC, French AN, Vickers D. Using a remote sensing field experiment to investigate flux–footprint relations and flux sampling distributions for tower and aircraft-based observations. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.05.003.

[18] Eichinger WE, Cooper DI, Hipps LE, Kustas WP, Neale CMU, Prueger, JH. Spatial and temporal variation in evapotranspiration using Raman lidar. Adv Water Resour, in press, doi:10.1016/j.advwatres.2005.03.023.

Jan W. Hopmans
Gregory Pasternack
Department of Land, Air and Water Resources/
Hydrology, Veihmeyer Hall, University of California
Davis, CA 95616, United States
Tel.: +1 530 752 3060; fax: +1 530 752 5262
E-mail addresses: jwhopmans@ucdavis.edu
(Jan W. Hopmans), gpast@ucdavis.edu
(Gregory Pasternack)

Available online 22 July 2005