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EDITORIAL

Headwater regions — Physical, ecological, and social approaches to understand these areas: introduction to the special issue

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1 Introduction

Around the world human communities and natural ecosystems both rely on headwater regions for vital resources. Resources provided include groundwater storage (Flint et al., 2008; Clilverd et al., 2011; Cao et al., 2012) in addition to soil moisture and forest ecosystem dynamics (McNamara et al., 2005; Williams et al., 2009; Jencso and McGlynn, 2011; Smith et al., 2011; Harpold et al., 2015; Webb et al., 2015). Furthermore these regions are ecologically vital zones (Schlosser, 1995; Lowe and Likens, 2005) that impact downstream water quality (Peterson et al., 2001; Alexander et al., 2007). The dynamics of headwaters are quite variable and are projected to change in the future (Adam et al., 2009; Clow, 2010; Harpold et al., 2012; Fassnacht and Hultstrand, 2015; Fassnacht et al., 2016; Musselman et al., 2017), thus it is important to better understand the functioning of these systems for future planning and management of natural resources (Bales et al., 2006).

Much of the headwater research has focused on the physical nature of streams and rivers (Bishop et al., 2008), yet the definition of a stream varies (Nadeau and Rains, 2007; Doyle and Bernhardt, 2011). In the United States, legislation has set some of the definitions to establish federal jurisdiction, which is based partly on where the flowing and/or connected water is, and state regulations, which are based on where the water ends and the land begins (Doyle and Bernhardt, 2011). These distinctions were initially premised on the U.S. Army Corps of Engineers jurisdiction of navigable waters and their tributaries (Downing et al., 2003). The distinction between stream and landscape has been based on physical (flow and geomorphological), chemical (advection and dispersion), and biological (longitudinal connectivity, food-energy, dissolved oxygen and oxygen demand, and biotic community properties) components (Doyle and Bernhardt, 2011). This special issue focuses on aspects of all properties with the opening paper defining research needs for headwater streams (Wohl, 2017, this issue).

Headwater streams tend to be poorly defined (Bishop et al., 2008) due to a lack of information (Wohl, 2017, this issue), especially in wildland areas that are not easily accessible or due to uncertainty in definition. The latter is due in part to the complex interactions between the physical, chemical, biological, and social components, as well as the perennial, ephemeral, or intermittent nature of small streams. About 50% of the length of all headwater streams is perennial (Nadeau and Rains, 2007) and these streams are the focus of this special issue.

This special issue of Frontiers of Earth Science started as a Water and Environmental Sustainability symposium held at Tsinghua University in Beijing China on October 20th, 2015. The focus of this symposium was Headwater Regions. It highlighted that all rivers start at their critical headwaters within watersheds of any size. It illustrated that while research on such regions often takes a physically based or ecological approach, there has been limited emphasis on the social aspects of these regions. As such, the special issue solicited papers from symposium

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attendees and others whose research focuses on headwater regions in any part of the globe with a physical, ecological, or social science perspective, or any combination thereof. The goal of the special issue is to provide further insight into how we study headwater regions and the functioning of such regions. One invited paper (Wohl, 2017, this issue) and 12 regular papers appear in the issue.

2 Overview of special issue papers

Wohl (2017, this issue) provides an overview of the significance of small streams that here are defined as first and second order stream segments. The scientific understanding of headwater streams is incomplete. Research needs are outlined for headwater streams that include improving *mapping* especially in determining the location of first-order channels, understanding *resistance & resilience* especially in response to natural and human-induced disturbances, assessing impacts from *human alterations* to land use and climate, creating complete *species inventories* to understand biodiversity and the ecological resilience, improving techniques to measure the spatial and temporal extent of *surface flow* for ephemeral or intermittent streams, better understanding of hydraulics and sediment regimes with emphasis on the magnitude and episodicity of sediment inputs and downstream transfer, and an improved understanding of hydrologic connectivity (Wohl, 2017, this issue).

Venable (2017, this issue) provides a new approach to examining hydroclimatological data across Headwaters Regions through the use of boundary objects. Applied to the Khangai Mountains of Mongolia, this approach enables scientists to discuss a variety of datasets across multiple disciplines using a common theme. The concept of boundary objects was developed in the social sciences and is applied here to spatial and/or temporal hydrologic and climatologic datasets.

In higher latitudes and elevation, headwater regions are seasonally snow covered. Two papers focus on fine resolution spatial variability of snowpack properties. Using manual snow depth measurements from three field campaigns, including one of their own, Tedesche et al. (2017, this issue) investigated the scales of snow depth variability over a high elevation rangeland. Results show temporal stability of snow depth during the accumulation period due to the nature of vegetation and ground topography. These factors provide insights towards sampling protocol of snow depth in rangeland environments for improved snow water equivalent (SWE) estimates of similar headwater landscapes. Webb (2017, this issue) illustrated the variability of snow water equivalent within an evergreen-deciduous headwaters forest using Ground Penetrating Radar (GPR). A non-uniform melting of snow was determined through the use of GPR at peak accumulation and twice during the melt season. This new application of GPR can provide fine scale estimates of snowpack melting that are useful when evaluating point estimates from meteorological stations.

Three papers examined snowmelt at larger scales. Using stable isotopes of water, Wehner and Stednick (2017, this issue) examined the how the degree of tree mortality due to mountain pine beetle infestation modified the relative contributions of rain, snow, and groundwater to streamflow in 25 headwater catchments of the Colorado Rocky Mountains. Their study found that the relative contribution of groundwater increased with increasing area of beetle kill and the relative contributions from snow and rain were negatively correlated with beetle kill area. This suggests that downstream water yield will not be affected by the mountain pine beetle epidemic.

From more than 20 years of operational station measurements of daily SWE and temperature, the spatio-temporal variability in snowmelt rates was assessed for the Southern Rocky Mountains, USA (Fassnacht et al., 2017, this issue). The timing of melt explains much of the variance in melt factors in addition to elevation, longitude, slope and aspect, and land cover type. These results display the importance of high-quality monitoring of headwater regions to provide information towards how water stored in snow is transformed into streamflow. Sanmiguel-Vallelado et al. (2017, this issue) showed how snowmelt influences the flow regimes of mountain rivers. Using examples from the Spanish Pyrenees Mountains, streamflow data are assessed with observed SWE, precipitation and temperature data, together with simulated snowmelt quantities to determine that snow processes alone do not explain inter-annual variability in river regimes. Some of the variations were also attributed to longitude and elevation gradients.

Rets et al. (2017, this issue) used stable isotopes to determine the relative contributions of different source waters to two alpine rivers: one located in the North Caucasus and one located in the Central Tien Shan. They were able to show the contributions of rain, firn and ice meltwaters from glaciers and surface and subsurface flow to stream hydrographs.

Three papers examined water quality aspects of headwater basins, including coliform levels, macroinvertebrates, and sediment transport. Coliform is potentially pathogenic that is often a result of waste water treatment, and its presence in headwater streams is a substantial contaminant. The variation in instream coliform was examined along the Holtemme River, a river that starts in the Harz Mountains of Northern Germany (Karthe et al., 2017, this issue). The total and fecal coliform concentrations at some locations along this river were quite high, but there are no coliform water quality standards for headwater rivers not at drinking water intakes or for bathing.

Zhao et al. (2017, this issue) provides valuable research in the Ruoergai Wetland, an important headwater ecosystem of the Yellow River. Their study found the macroinvertebrate diversity within the basin to be highly diverse and a strong indicator of ecological status for the wetland. The primary factor of bio-community variance was hydrological connectivity in this headwater system.

Chalov et al. (2017, this issue) examined sediment transport in headwaters of a volcanic catchment in the Kamchatka Peninsula. Discharge and sediment transport in three sub-catchments with differing channel types were monitored. Their measurements showed that the catchment was characterized by large diurnal fluctuations of stream discharge and sediment loading as a result of snowmelt patterns and groundwater contributions due to high infiltration rates. In addition, the authors used an empirical soil erosion and sediment yield model to get a first order estimate of the spatial distribution of eroded volcanic substrates. Their study is important for understanding the relationship between hydrology and sediment transport in headwater volcanic catchments to improve downstream risk management.

The final two papers examined lakes and reservoirs fed by headwaters. Bai et al. (2017, this issue) provided multi-site calibration and evaluation of the Soil and Water Assessment Tool (SWAT) for the Miyun Reservoir watershed, China. This watershed provides a foundation for future simulations of further studies of pollutant transport in large basins. Results show the benefit of multi-site calibration for evaluating water resource and pollution concerns in large watersheds. Tangjiashan Lake is a reservoir located among steep canyons in Sichuan Province of Central China and prone to earthquake induced landslides, as occurred in 2008. Kidyaeva et al. (2017, this issue) used a modeling approach to examine the outburst potential and estimate the risk assessment in the downstream valley due to such events. Their work will inform local policy and management, plus provide a template for modeling risk assessment in such headwater regions.

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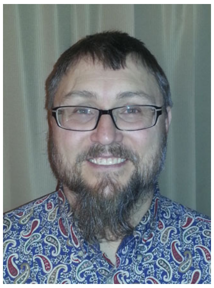
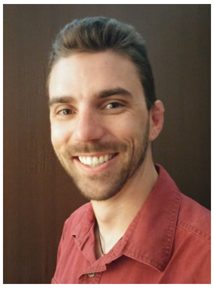
Guest Editors



Dr. Steven R. Fassnacht, Professor of Watershed Science, Department of Ecosystem and Sustainability, Colorado State University

He received his Ph.D. in Civil Engineering from the University of Waterloo, Canada in 2000 after receiving a B.A.Sc. (Civil Engineering-Water Resources) in 1992 and M.A.Sc. (Civil Engineering) in 1995 from the same institution. From 2000 to 2002 he was a Research Associate in the Hydrology and Water Resources Department at the University of Arizona. Since then he has been faculty at Colorado State University. He is currently a Research Fellow with the Cooperative Institute for Research in the Atmosphere, a Senior Research Scientist in the Natural Resources Ecology Laboratory and the Associate Director of the Vertically Integrated Projects Program at CSU and the Geospatial Centroid at CSU. Dr. Fassnacht's research interests include improving our understanding of snow and cold land hydrological processes into different type of models and the impacts of a changing climate on water resources. To better understand cold land processes, his work is examining the spatio-temporal complexity of snowpack properties and their measurement. To examine how a changing climate affects water resources, his work is integrating human observations of change with station and geospatial information.



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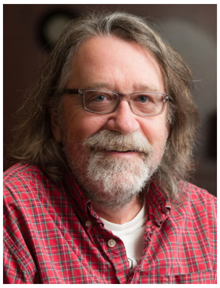
He received his Ph.D. from Colorado State University in the Department of Civil and Environmental Engineering focusing on hydrologic science and engineering. He received his MS degree in Civil Engineering in 2012 as well as his BS degree in Construction Engineering in 2010 from the University of New Mexico. Ryan has professional experiences that include testing and validating modifications of TOUGH2 code, designing hydraulic and concrete systems for reservoirs, calculating seepage and infiltration from earthen dams, and construction estimating. He has traveled to Central and South America with Engineers Without Borders to work on water resources issues in indigenous communities in addition to spending three months in Beijing, China to participate in the establishment of a collaborative institute between Tsinghua University and Colorado State University. Dr. Webb's research interests include representing the snow as a porous media, vadose zone hydrology, geophysical methods in snow measurements, hydrologic impacts of forest fires, and water resources in developing communities.



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He received his Ph.D. in Soil and Water Engineering and M.S. in Geophysics from Cornell University and a B.S. degree in Geology from Beloit College. He was also a Research Associate at Oak Ridge National Laboratory and a visiting scientist at CSIRO, Australia and Garyounis University in Bengahzi, Libya. Dr. Sanford's interests include use of isotopes and tracers in the study of groundwater and groundwater/surface water interactions, hydrogeophysics, transport of nanoparticles and flow and transport in fractured porous media. His research results provide information for the management and protection of water resources.