Scaling of hydrologic and land-surface responses: Are the right processes represented at the right scale?

1 Introduction

Groundwater is declining across much of Washington State [Burns et al., 2012; Vaccaro et al., 2015] and there is a general consensus that climate change will place significantly more stress on existing resources [Pitz, 2016]. The Washington State Department of Ecology (Ecology) has called for establishing formal mechanisms to monitor and assess current and future groundwater depletion in the state’s aquifers [Pitz, 2016], which will require an exhaustive inventory of existing resources as well as dynamic models to infer future changes. This is problematic because there is a discrepancy between the scale of hydrologic measurements, often scattered points, and the scale of management decisions across the entirety of a region. Water level measurements in wells are still considered the best source of information about the state of groundwater reserves [Alley, 2006], however there are limits to their utility for monitoring and planning across a larger region. A single monitoring well is likely to be an accurate estimate of the piezometric heads within several meters of that well, but it is unreliable across longer distances. This sparsely available data is also limited in predictive and future planning applications because the lag time of the groundwater response to perturbations may not be immediately reflected in monitoring wells. Ecology is already experiencing these constraints in their efforts to differentiate the impact of recent droughts from longer-term trends in depletion [WA Ecology – Water Resources, 2015]. The core of this problem is the transfer of information across scales and how the observed response in one area depends on the inferred properties of the greater hydrologic system. A robust framework to monitor and sustainably manage groundwater systems is only achievable if it is built from physically-realistic multi-scale linkages of hydrologic processes that capture both system-wide responses and localized dynamics. Such an analysis does not presently exist for Washington.

Data interpolation and numerical modeling efforts are often combined to coarsen local measurements for regional applications but to do so confidently requires an understanding of how hydrologic and earth system processes interact across disparate scales. The average response of a fine resolution model for total water content, for example, may not match the result of a coarse resolution model even when they are calibrated to the same data [Hill and Tiedeman, 2007]. This nonlinear response reflects how different hydrologic interactions manifest at different scales for different variables, and how best to integrate multiple sources of data to reduce scaling error is an open research question [Fan et al., 2007; Wood, 2009; Wood et al., 2011]. Traditional hydrologic models did not consider process interactions (i.e. the coupled nature of groundwater and surface water) and this has led to countless discrepancies between observations and simulations. Integrated hydrologic models are designed specifically to investigate the interactions between traditionally incompatible domains that cross surface water, groundwater and ecologic processes [Mikkelsen et al., 2013]. These models are ideal tools for the exploration of how parameters and variables scale (spatially and temporally) and how representative a local or global averaged value may be for different variables [Wood, 2009]. Integrated models are often calibrated to point data such as piezometric heads or stream discharge and this can be very useful if the resolution of the model is fine enough, with cells on the order of several meters across. However, planning models often cover areas on the order of hundreds of square kilometers using model cells that are hundreds of meters across [e.g. Barnett...
et al., 2005; Palmer et al., 2008] and a single point measurement may not be sufficient to represent the actual distribution of a variable across these spatial scales. One way to address this issue is to create high-resolution, integrated models that represent each of the basic cell types within a planning model to understand how each behaves. The high-resolution model then provides the link back to the data and a description of the distribution of the property, bridging the gap between the scale of the measurement and the scale needed for planning. This is a powerful approach but it falls short of the requirement for a robust planning model: the nested approach only addresses the accuracy of a point observation in a larger model and does little to remedy the problem of data scarcity.

Recent advances in remote sensing, specifically with the Gravity Recovery and Climate Experiment (GRACE) satellite mission [Tapley et al., 2004], provide a novel opportunity to quantify large-scale hydrologic fluxes for calibration and validation of regional-scale models. GRACE observes integrated changes in terrestrial water storage as the sum of changes in surface water, snow water equivalent, soil moisture, and groundwater from both human and natural dynamics. GRACE observations are accurate to about ±1.5 centimeters of equivalent water height across spatial scales of 150,000 square kilometers ($km^2$) or greater [Swenson and Wahr, 2002]. The potential of GRACE to quantify anomalies and trends of hydrologic components that were previously immeasurable is vast [e.g. Syed et al., 2010; Richey et al., 2015]. However, its utility is limited by two main factors. First, the course spatial scale can provide a large-scale constraint on system dynamics but they are unable to resolve the local dynamics that drive management changes. Second, the use of GRACE to isolate specific components of the terrestrial water balance (e.g. groundwater) are only as good as the independent estimates of the remaining hydrologic components used to isolate the variable of interest from the total GRACE signal. Especially in data poor regions, researchers do not have in situ measurements available for this exercise and instead rely on output from land surface models. Combining the powerful, process level simulation capabilities of integrated models with observations of field conditions will likely improve the accuracy of GRACE observations to quantify large-scale groundwater storage changes. This could provide the necessary framework for long-term predictive modeling, but also give near real time monitoring of water resources and the response of the system to a management change. The remaining question is how to traverse these vast scales and translate point data into process understanding to inform remote sensing observations.

Two fundamental questions must be addressed in order to integrate data and modeling tools across spatial scales for a robust groundwater monitoring and management system. First, how do process interactions and the hydrological response at small scales translate to larger, basin scales? Second, how well do remotely sensed observations of terrestrial water storage anomalies capture regional-scale dynamics and how are local drivers integrated into this larger signal? Resolving both questions is a long-term goal of the project team and the purpose of this application is to focus on the first question as a necessary stepping-stone toward fully bridging the scales in future work. Our primary research objective is to effectively translate the information from explicit, process-based hydrologic models at the data rich farm scale up to equivalent models at the basin scale. The approach will compare the response of high-resolution models calibrated to detailed data at a heavily instrumented site to several different coarser resolution models in a sequential upscaling approach. Each model will be calibrated to the data at each scale and the changes in the best-fit (calibrated) parameters at each scale are expected to define scaling laws [e.g. Kirchner et al., 2000; Kollet and Maxwell, 2008]. The scaling laws will
allow small-scale observations to be useful at larger scales, enabling meaningful basin-wide hydrologic simulations, without requiring the same high-resolution as our reference model. The proposed approach is necessary because coarse model grids (i.e. cells of hundreds to thousands of meters across) sacrifice detailed information in order to investigate larger scales but an ideal upscaled model is able to strip off excess information without significantly changing the model results, including reproduction of data observations. In other words, a properly upscaled model produces the same result as the spatial average of a detailed model, but the upscaled model is simpler and faster and these features make them ideal for basin-scale modeling.

The results of this project will be directly applicable to stakeholders at the local scale across eastern Washington, including municipalities and farmers, because it will link point scale measurements and variables (soil moisture, temperature, depth to water, etc…) to larger scales that can be used for planning. Equally important is the ability to take larger scale data and translate it back to the farm scale, which will also be possible since the detailed models explicitly simulate the distribution of properties, not just their area weighted mean. Over the long term, this project and its continuations are expected to lead to a dynamic modeling framework for the entire Columbia Plateau Regional Aquifer System (CPRAS) that will facilitate data informed, long-term sustainable management. The PI’s are committed to developing this framework and are preparing a full proposal to submit to the NSF Hydrologic Sciences program to address the remaining questions that will complete the link from point data to satellite observations for effective management. In addition to peer-reviewed journal publications, the results of this project will be disseminated to stakeholders at community meetings and presented at annual, international scientific meetings. These events will support our long-term goal by developing ties to local stakeholders and bringing international attention to proactive, sustainable groundwater management. The project will also increase the profile of the early career faculty PI’s, support graduate student research, and strengthen the position of Washington State University and the SWWRC as leaders in future water resource management.

1.1 Study site and Nested Domains

The Palouse Basin of eastern Washington and northwestern Idaho is an agriculturally dominated region; nearly all of 610km$^2$ of land within the basin are used for the seasonal production of wheat, barley, chickpeas, and lentils, which are rotated seasonally. The Palouse is part of the larger Columbia River Basin, both of which are complicated hydrologic systems where managers must balance municipal, industrial, agricultural, ecologic, and electrical power generation needs [Barnett et al., 2005; Beall et al., 2011]. Changes in the allocations of water in such a hydrologically complex region can have major impacts on small-scale processes, such as wildlife habitats, and realistic representations of process interactions are necessary for reliable decision making and forecasting. However, the scale, complexity, and scarcity of data prohibit ultrahigh-resolution (meter scale resolution) modeling of the Columbia River Basin and even the smaller Palouse Basin. Only a handful of simplified models have been constructed for the latter [Barker, 1979; Lum et al., 1990; Beall et al., 2011] and the modeling of the Columbia has generally been at much larger scales [Matheussen et al., 2000; Payne et al., 2004; Barnett et al., 2005]. Moderate scale (grid cells on the order of hundreds of meters) modeling of the entire Palouse Basin is possible using state-of-the-art computing technologies and models, but the variability of hydrologic properties and process interactions have not been quantified at that scale yet. For this reason, we will focus first on a small farm site located within the Palouse Basin to test the scaling of parameters at the farm-scale. Increasingly course resolution model runs will be
conducted across the Palouse Basin and future work enabled by this project will expand the approach to the Columbia Plateau Regional Aquifer System.

The farm site for the small-scale model will be the Cook Agronomy Farm (CAF) located near Pullman, WA which is managed by Washington State University (WSU) in collaboration with Pullman USDA/ARS scientists (http://css.wsu.edu/cook/). The CAF (Figure 1) is part of the Long-Term Agroecological Reserve (LTAR) network established by the U.S. Department of Agriculture and the site covers an area of roughly 0.57 km\(^2\), spanning an area several hundred meters across. The CAF is home to a large number of multi-disciplinary research projects focusing on agricultural efficiency and process-oriented applied research.

The soils, crops, and planting and harvesting practices at CAF are representative of the kinds of activities that take place at farm sites throughout the semi-arid Palouse Basin, as well as other dry land crop regions around the world; however, most farm sites do not have much, if any, data available, making CAF a unique location for investigating the coupled dynamics of hydrologic and land-surface processes in the region. Previous research projects administered through WSU have collected extensive data at the CAF that will be useful to the proposed study including land-surface elevation, soil moisture, solute concentrations, and estimates of evapotranspiration, to name a few [Moravec et al., 2010; Ibrahim and Huggins, 2011]. The observations and model results for the CAF can serve as estimates for other similar farm plots and the scaling behaviors are hypothesized to be similar throughout the Palouse and greater Columbia River Basins.

2  Research tasks

The proposed project will use a distributed parameter, integrated hydrologic model to simulate hydrologic and land-surface process interactions at the CAF study site. The simulations will then be analyzed at multiple scales to establish scaling laws. The final task will be a coarsened simulation of the greater Palouse region for future comparison to global and remote sensing datasets.

2.1  Hydrogeologic characterization

The first task is to construct a realistic conceptual model of the hydrogeologic and soil properties at the study site. This will primarily use existing, publically available, data collected from the CAF and maintained by the LTAR including saturation, soil samples, surveys, and the thickness of the soil. These data will resolve much of the structural and parametric uncertainty of the subsurface. The spatial variability of hydrologic properties at the study site will be quantified using 3-D ground penetrating radar, which may also give the first accurate picture of the depth to the bedrock of the Columbia flood basalts at the site [Douglas et al., 2007], estimated at no more than a few meters. GPR data is often not a direct analog for permeability [Neal, 2004] so the values of permeability for the model will be assigned by correlating the GPR response to borehole, outcrop, and core derived examples of permeability in
the region [Engdahl et al., 2010]. The PI is the caretaker of the Civil and Environmental Engineering department’s GPR system, which will be used for the project. Supplemental information about the composition of the interior of the soils can be inferred from exposed hill slopes, outcrops, and road cuts near the site, as well as from previous work in the region, including estimates of water content and some estimates of transmissivity [O’Geen et al., 2005; Keller et al., 2008]. Soil and vegetation types for the integrated model will be assigned using the freely available classification from NASA (http://data.giss.nasa.gov/landuse/) and field descriptions from the site. For each soil type, the classification includes values for the permeability, porosity, and wetting and drying curves, which are required data for the simulation of 3-D variably saturated flow. The surface topography will be specified using an existing digital terrain model for the CAF [Ibrahim and Huggins, 2011]. This data set will provide the surface slopes needed for computing any overland flow, and roughness coefficients for the surface will be assigned based on land-cover and vegetation type.

2.2 Model design and spin-up
The study area will be laterally discretized into 2 meter (m) square grid cells in the numerical model. At this scale, the spatial distributions of soil and hydrologic parameters should be well described by local averages. The preliminary design for the model grid will use 450 by 350 cells in the x- and y-directions, respectively. This will produce a model with roughly 160 thousand nodes per layer. Six layers will be used for the model grid that will have variable thickness and will follow the slope of the terrain [Maxwell, 2013]. Layers near the surface will be thinner (from 10cm to 2m) and the bottom of the model will be a thick layer representing the bedrock (~100m). This design allows the effects of topography and lateral flow to be included and finely resolves the cells near the surface (i.e. root zone) where there are likely to be more rapid changes. The total number of nodes in the model will be just under 1 million and such a model can be efficiently run on a workstation class computer or one of the compute clusters managed by WSU. Depending on model performance and runtime, the grid could be increased in resolution to 1m and this will be explored to maximize the detail in this “reference model.”

The numerical simulations will be conducted using ParFlow [Ashby and Falgout, 1996; Jones and Woodward, 2001], which solves the 3-D variably saturated Richard’s equation and a kinematic wave approximation of overland flow in a fully coupled framework. This allows lateral and vertical flow in the subsurface and a 2-D sheet flow approximation of overland flow; the system is fully mass conservative and both domains are solved simultaneously [Kollet and Maxwell, 2006]. The model domain will be “spun-up” to a steady state using the annual average values of precipitation minus evaporation as the input. The spin-up stage allows the early fluctuations of the model to stabilize, and filters out any lingering artifacts from the observation-based initial conditions. The model used for spin-up will only focus on the hydrology to improve the speed of the models, but this is only an intermediate step in the modeling process and not the final simulation.

2.3 Transient integrated modeling
ParFlow has also been coupled to the Common Land Model (CLM), which simulates land-surface and root zone processes [Ferguson and Maxwell, 2010, 2011]. CLM simulates a large number of variables including snowpack depth, leaf area index, evaporation, root uptake, and soil temperatures, which are typically omitted from hydrologic management models. The execution of the model is fully coupled and both systems of equations are solved at each time
step, with all flows simulated by ParFlow. The land-use and vegetative cover classifications will be used to define the additional parameters required by CLM.

The steady-state model will provide the initial condition for the transient model, which will simulate at least a typical year, with extended periods to be investigated if time allows. All of the inputs for the transient model runs will be specified using the observed atmospheric data for the study site, which are available through NASA’s Land Data Assimilation System (http://ldas.gsfc.nasa.gov/nldas/) and include wind speed and direction, precipitation, and solar radiation. The model will use a constant time step of 60 minutes to maintain high temporal resolution of sub-daily dynamics. The model results will be compared to the available point observations of water levels, soil moisture, temperature, outflow from an artificial drain, and existing estimates of evapotranspiration at the CAF. If a significant mismatch is observed between the simulated and observed values, the model parameters will be calibrated to provide a more reliable fit to the observations.

2.4 Multi-scaling analysis

The results of the numerical modeling will be regularly spaced, gridded values of the model variables (saturation, pressure, latent heat flux, etc...) output at each time step, all of which will be averaged to coarser/larger scales. Formally, upscaling, as defined by Wood [2009], contains two parts: 1) averaging of values, 2) adjusting the conceptual model to the revised scale. Here our “upsampling” will focus on the former and even this can be conducted in two ways that we will loosely refer to as 1) parametric upscaling, and 2) variable upscaling. Parametric upscaling averages the values of the parameters and inputs used in the numerical model and the numerical model is then re-run using those revised values at a coarser spatial scale. Variable upscaling refers to averaging the output values of the different variables in the simulation.

Our method for upscaling will first compute spatial average values of the model variables at several different resolutions that are coarser than the model grid; this will be done separately for each layer. Local clusters of grid cells and moving average type means will be compared and the changes in the global distributions of the values will be investigated, with particular emphasis on identifying changes in the shapes (i.e. skewness, kurtosis, etc...) of the distributions. Cross-correlations between the variables will be investigated as well as correlations with the spatially distributed input variables and the available data collected from the field site. Formally, this approach evaluates what, if any, information is redundant that can be removed from the upscaling process for future modeling efforts at larger scales [Wood, 2009]. The results will be averaged at grid resolutions of 4m, 10m, 20m, and 50m, plus a single domain wide average.

The second, parametric component of upscaling will be to coarsen the model grids described in section 2.2, average the small-scale parameters, and re-run the simulations. The same range of grid sizes used for variable averaging will be simulated, using the same input forcing (precipitation, solar radiation, etc…) as the high-resolution model, and the results of these simulations will be compared to the variable upscaling. We expect the agreement of the two methods to degrade as the grid is coarsened and the last step in this process will calibrate the coarsened models to the data observations. This step will determine the “correct” parameters for each scale and the changes in each parameter as resolution is decreased are the scaling laws, which we expect to be power-law functions. The determination of these scaling laws and the parameter distributions associated with each property at each scale are the primary objectives of
this project that will enable the efficient translation of information across scales for future basin-scale planning models.

2.5 Basin-scale comparative simulations

The full comparison to satellite observations cannot be completed in this study because it will require the construction of models like the high-resolution CAF model for the different kinds of major agriculture across the State of Washington. However, we can make a comparison of the hydrologic response across the Palouse Basin to larger-scale estimates of water table depths. Only one distributed groundwater model has even been constructed for the entire Palouse Basin and this is described by Lum et al. [1990]. The dated model is in need of updating so it can be used for planning and the proposed project provides a way to begin that process, while helping to evaluate the proposed scaling laws.

This task will construct a new, 2-D model domain of the 610km² Palouse Basin with a grid resolution of approximately 50m; this is thought to be sufficient to resolve lateral and topographic flows and will create a model with approximately 250,000 cells. The hydraulic parameters for the new model will use data observations of permeability in the wells used by Lum et al. [1990] and recent geologic data provided from cores, which will be extrapolated to the 50m grid resolution using the scaling laws developed from the CAF model. The mean annual recharge will be used to simulate steady-state groundwater flow at high resolution. Simulated and observed heads will be compared, as will the geostatistical properties of the distribution of water levels in the new and old models [Goovaerts, 1997]. Normally, such a model would also be calibrated to observations but this is a time consuming process and we do not anticipate being able to do so during this project; however, the calibration will be included in future work.

The results of the new model will be compared to the Lum et al. model but also to the nationwide dataset of water table depth developed by Fan et al. [2007]. This dataset is based on a relatively high-resolution 2-D flow model for the United States at 1.25 km x 1.25 km spatial resolution. Their flow model was very simple and used uniform parameters everywhere, which the authors acknowledge as a limitation, but a comparison to over 500,000 wells showed reasonably good agreement. Our new model of the Palouse will be averaged to match the resolution of the Fan et al. dataset for a direct comparison of the values and spatial correlations of the two datasets. We also expect to simulate a 1.25km resolution, upscaled version of the new Palouse model, using the scaling laws to determine the hydraulic parameters. The upscaled simulation will be compared directly to the Fan et al. results, local observations of water levels, and the spatially averaged results of the finer scale Palouse model. This will give a thorough comparison of the performance of all the models against the available data and evaluate the reliability of the scaling laws at a larger-scale than is possible using only the CAF site.

2.6 Anticipated results

The primary result of this work will be an analysis of how hydrologic and land-surface variables scale from the meter- to the farm- to the basin-scale. The simulation framework is physically based and the integrated modeling adds a level of realism not previously applied in the region that includes lateral, vertical, and overland flow as well as root zone processes and the energy budget. The simulations will evaluate the spatial distributions and mean values of the different variables based on a model that has been validated and/or calibrated to the available data, which is crucial for confident upscaling. The purpose of this analysis is to identify the relationships between the variables at different scales, with emphasis on identifying changes in
those relationships. This information will be valuable for improving our understanding of the variability of hydrologic properties at farm sites across the Palouse Basin. The results are compared to the large-scale datasets available in the region, and this will help inform the validity of those datasets in other regions around the world. Better integration of multiple data types into models will inform remote sensing observations and improve the tools for monitoring and managing groundwater in Eastern Washington, the full CPRAS and other data-sparse regions globally.

3 Project timeline and dissemination plan

The only portion of the project requiring data collection is the GPR survey of the site, which will take place during the summer/fall of 2017. Model construction can begin without this data and it can easily be incorporated later. Preliminary model construction tasks like terrain modeling and soil classification will be completed early during the summer of 2017 and it is expected that the transient modeling will be completed within 1-semester (4-months) of the completion of the hydrogeologic model. The results of the model and the scaling study will be published as part of the graduate student thesis associated with this project and also as two or more peer reviewed journal articles, the first of which is expected to be submitted to peer-review by late 2017. The intermediate progress of the modeling efforts will also be presented at the annual Palouse Basin Water Summit, the Pacific Northwest Water Research Symposium, and the American Geophysical Union annual meeting. A final report will also be given at the 2018 annual Palouse Basin Water Summit, which directly engages the local community.

4 Pathways to future work

Interdisciplinary research: The proposed numerical framework will create a detailed model of the hydrogeologic and land-surface processes for the CAF that can provide a common platform for interdisciplinary modeling work at the site. The physically based hydrologic model can also be used for direct simulation of solute transport, such as nitrogen, including root uptake. Biologic processes, microbial transport, and chemical reactions, amongst many others, can easily be added to the integrated model sequentially increasing the complexity and realism of the simulations, providing connections across a wide range of unique disciplinary interests.

Increased spatial-temporal extents: The proposed project is one step in a greater effort to characterize the integrated hydrologic response of the Columbia River Basin at a scale that can be useful for long-term planning to adapt to climate change. Our general approach is broadly referred to as “sequential upscaling” where the variability at smaller scales is quantified and used to inform the corresponding values at the next larger scale. This will eventually meet up with “downscaling” approaches where large-scale or satellite data over large areas are disaggregated, providing a framework to translate information from the soil scale to the satellite scale and vice versa. The long-term plan is to use the SWWRC seed grant to secure additional funding to model the Palouse Basin and eventually the entire CPRAS. All future models will be built using the same modeling framework described herein and may cover decadal time scales.

5 Contribution to SWWRC mission

The proposed project directly addresses the SWWRC priority topics of “climate change effects on water supply, demand, and quality” and “the food-energy-water nexus” because the coupled model is designed specifically to investigate the interactions of surface, groundwater, and agriculture and how those interactions propagate to larger scales. This proposed work
indirectly contributes to the application of remotely sensed data (priority topic 6) to farmlands on the Palouse since understanding the scaling behavior of hydrologic variables directly contributes to the interpretation of those data and a future NSF proposal will specifically make this connection. Future applications of the model framework can easily be adapted for investigating the transport of nutrients and emerging contaminants (priority topic 5). All of these support our long-term goal to develop a common modeling platform for groundwater in Washington State.

Training potential: All of the requested funds will be used solely to support thesis research by a graduate student, and this supports the educational goals of the SWWRC. The project will comprise roughly half of their thesis with the remainder coming from a comparative study in a heavily instrumented, mountainous watershed in Idaho funded as part of the PI’s startup funds.

6 References


Supporting documents included in the following pages:

1. Resume for PI-Engdahl
2. Resume for Co-PI Richey
3. Letter of non-concurrency
4. Official cost-share letter
Nicholas Bryan Engdahl
Assistant Professor
Department of Civil and Environmental Engineering
Washington State University
PO Box 642910, Pullman, WA, 99164-2910
Phone: (509) 335-9140
Email: nick.engdahl@wsu.edu

Education
University of California, Davis, PhD Hydrologic Sciences, December 2012.

Appointments
09/2014-present:  Assistant Professor, Department of Civil and Environmental
Engineering, Washington State University.
09/2009-12/2012: Graduate student researcher, Department or Land, Air and Water
Resources, University of California, Davis.
Albuquerque, NM.

Five selected publications
Engdahl, N.B., J.L. McCallum, and A. Massoudieh (2016) Transient age distributions in
subsurface hydrologic systems, Journal of Hydrology, in press, doi:
Leray, S., N. Engdahl, A. Massoudieh, E. Bresciani, and J. McCallum (2016) Residence time
distributions for hydrologic systems: Mechanistic foundations and steady-state
analytical solutions, Journal of Hydrology, in press, doi:
10.1016/j.jhydrol.2016.01.068
Engdahl, N.B. and R.M. Maxwell (2015) Quantifying changes in age distributions and the
hydrologic balance of a high-mountain watershed from climate induced variations
in recharge, Journal of Hydrology, 522, p.152-162, doi:
10.1016/j.jhydrol.2014.12.032
Water Resources Research, 48, W07508, doi:10.1029/2012WR012251
effects on river flow loss using a transition probability framework, Water Resources

Five additional publications
using simple streamtube models and multiple tracers, Advances in Water Resources,


**Synergistic Activities**
- Developer of the integrated model ParFlow and support/documentation
- Instructor at ParFlow short courses
- Scientific advisory committee, Modflow and More Conference
- Classes taught at WSU include:
  - CE 351 Water Resources Engineering
  - CE 450 Hydraulic Engineering Design
  - CE 562 Advanced subsurface flow and transport
  - CE 552 Numerical Methods
Alexandra (Sasha) Richey
Washington State University
Civil and Environmental Engineering
Pullman, WA 99164
Phone: (509) 335-1691
Email: sasha.richey@wsu.edu

(a) Professional Preparation
Stanford University Civil Engineering BS, 2008
University of California, Irvine Civil Engineering MS, 2012
University of California, Irvine Civil Engineering PhD, 2014

(b) Appointments
2015 – present Postdoctoral Fellow, Washington State U., Civil & Environmental Engineering
2010 – 2014 Graduate Fellow, U. of California Center for Hydrologic Modeling
2009 – 2014 Graduate Student Researcher, U. of California, Irvine, Civil & Environmental Engineering
2009 Research Assistant, U. of Washington, Civil and Environmental Engineering

(c) Selected Publications


(d) Synergistic Activities
Service and Teaching
Mentored two undergraduate students
Interviewee for science outreach and education, 20+ newspapers and radio stations on publications (1) and (2) above, including the San Francisco Chronicle, Los Angeles Times, Desert Sun, and WBEZ Chicago (2015)

Board member and presenter, Climate Literacy Empowerment And iNquiry (CLEAN) Education, UC Irvine, Climate science outreach to K-12 students (2009-1014)

Teaching assistant, On Thin Ice: Earth’s Cryosphere, UC Irvine Department of Earth System Science (2014)

Lead organizer and participant, Hydro-diplomacy outreach to universities and water ministries in Israel, Jordan, and the West Bank, UC Center for Hydrologic Modeling (2012)

Lead organizer, “Groundwater and Climate Change in the Middle East: Next threat or chance for cooperation,” Outreach Event, UC Irvine (2012)

Member, Sustainability Science Team, UC Irvine Environment Institute (2010-2012)


Contributor, National Geographic Water Currents blog

Grants Received

“Validating a Glacier Melt Toolbox for High Mountain Asia using a remote-sensing-driven data integration framework”, 2016, Awarded, Submitted to National Aeronautics and Space Administration (Lead Institution: Univ. of Washington, PI A. Arendt, Amount: $1,052,041, WSU Sub-award: $197,337, Lead WSU PI)


Alaska Airlines Travel Grant Recipient for Food, Energy, Water Imagine Tomorrow category (2016)


NASA Earth and Space Science Graduate Fellowship, Graduate Awardee (2012-2014)

Journal Reviewer

November 21, 2016

Dr. Jonathan Yoder, Director
State of Washington Water Research Center
Washington State University
PO Box Number 643002
Pullman, WA 99164-3002

Dear Dr. Yoder,

This letter is regarding the proposal “Scaling of hydrologic and land-surface responses: Are the right processes represented at the right scale?” submitted by Alexandra Sasha Richey and myself to your State Water Resources Research Institute program section 104B call for proposals. As part of the required application, we wish to inform you that none of the proposed work is under consideration for funding from another agency. We do intend to submit an expanded scope of some of the key ideas described herein to the National Science Foundation, but these efforts will build on the proposed project.

Sincerely,

Nicholas B. Engdahl
Assistant Professor
Civil and Environmental Engineering
Washington State University
January 11, 2017

Dr. Jonathan Yoder, Director
State of Washington Water Research Center
Washington State University
PO Box 643002
Pullman, WA 99164-3002
Albrook Lab, Room 202B

RE: Commitment of Matching Funds for “Scaling of hydrologic and land-surface responses: Are the right processes represented at the right scale?”

Dear Dr. Yoder:

I am writing to document the commitment of matching funds from the Department of Civil and Environmental Engineering at Washington State University (WSU) for Dr. Nicholas Engdahl’s proposal, “Scaling of hydrologic and land-surface responses: Are the right processes represented at the right scale?” in the amount of $55,000 for the period of March 1, 2017 through February 28, 2018. This amount fulfills the 2:1 match requirement for the project.

Specifically, WSU will commit to the following as matching for the above referenced project:

- $29,367 in salary for 2.34 months of Dr. Engdahl’s time on the project and benefits at 29.3%
- $15,271 of indirect costs at our negotiated rate (52%) on the above expenses
- $10,362 of unclaimed indirect costs at our negotiated rate (52%) for graduate student salaries and benefits

Please let me know if you have any questions or require additional information.

Sincerely,

Dr. Balasingam Muhunthan
Professor and Chair