**Basic Information**

* **Project No. and Title:** W3188: Soil, Water and Environmental Physics Across Scales
* **Period Covered:** 10/01/2016 to 09/01/2017
* **Date of Report:** 02/04/2018
* **Annual Meeting Dates:** 01/02-04/2018

**Participants**

Hoori Ajami, UC Riverside; Markus Berli, DRI Las Vegas; Maria Dragila, Oregon State University; Sarah Helalia, UC Riverside; Bob Horton, Iowa State University; Yan Jin, University of Delaware; Scott Jones, Utah State University; Morteza Sadeghi, Utah State University ; Farnaz Malekjahani, Utah State University; Thijs Kelleners, University of Wyoming; Jing Liang, UC Riverside; Laura Rosales, Nevada State College; Javier Reyes, University of Kentucky; Rose Shillito, DRI Las Vegas; Jirka Simunek, UC Riverside; Jing Yan, UC Merced; Hongxing Li, UC Riverside; Wei Zhang, Michigan State University; Xi Zhang, University of Kentucky; Samuel Araya, UC Merced; Teamrat Ghezzehei, UC Merced; Yuan Luo, DRI Las Vegas; Tobi Ewing, The Climate Corporation; Thomas Harter, UC Davis; John L. Nieber, University of Minnesota; Joan Wu, Washington State University; Ahdee Zeidman, Nevada State College; Azadeh Gholoubi, Utah State University; Markus Tuller, University of Arizona; Ebrahim Babaeian, University of Arizona; Li Chen, DRI Las Vegas; Xiaojun Shen, UC Riverside; Ian Hopman, UC Davis; Jinghui Xu, Utah State University

**BRIEF SUMMARY OF MINUTES OF ANNUAL MEETING**

2017 Annual Meeting of the W-3188 Multi-State Research Project:   
*Soil, Water, and Environmental Physics across Scales*

January 2-4, 2018, Desert Research Institute, Las Vegas, NV

Maria Dragila (Chair) and Hoori Ajami (Secretary).

**January 2 2018.** Chair brought the house to order at 1:30 PM.

*Hoori Ajami* (UC Riverside) presented recent updates about the development and application of a new semi-distributed modeling framework (SMART) for catchment scale hydrologic modeling. Recent funding updates from the California Energy commission and NSF INFEWS were also discussed that focus on regional scale hydrologic model developments in California.

*Joan Wu* (Washington State University) discussed recent updates to the WEPP model by incorporating nonlinear reservoir algorithms to enhance baseflow estimation, and discussed application of the WEPP model to assess the impacts of forest treatment on water balance and sediment load. Recent updates regarding the urban projects are discussed that addressed optimizing green infrastructure in urban areas and assessing soil phosphorous levels as related to land use.

*Toby Ewing* (The Climate Corporation)discussed modeling activities at the climate corporation as well as scale dependency of van Genuchten parameters to core height.

*Thijs Kelleners* (University of Wyoming) discussed measurement and modeling of water flow at the plot, hillslope, and watershed scales using data from the NoName watershed in WY. Improved parameterization of snowmelt processes in hydrologic models and application of Time-lapse-Electrical Resistivity Tomography (ERT) data for watershed modeling are discussed.

*Jirka Simunek* (UC Riverside) presented various updates and applications of the HYDRUS family of codes for hydrological modeling, fate and transport modeling and agricultural applications. Discussed new updates regarding the improved models for overland flow estimation using HYDRUS-1D and 2D. Recent papers about the application of surrogate modeling, root growth modeling and Hydrus coupling to DSSAT are discussed.

Meeting closed for the day at 5:00 pm

**January 3 2018.** Chair brought the house to order at 8:30 AM.

*Bob Horton* (Iowa State University) presented recent updates about measuring transient bulk density using heat pulse and thermos-TDR, and illustrated the impact of bulk density on soil water modeling; discussed application of heat pulse sensors for quantifying sensible heat and water balance.

*Thomas Harter* (UC Davis)discussed the issue of high nitrate concentrations in groundwater in California and presented results of multiple modeling methods to characterize nitrate sources in California groundwater using long term data records.

*John Nieber* (University of Minnesota) presented research activities related to W3188 including watershed scale hydrologic modeling, modeling subsurface erosion and evaluation of BMPs for reducing agricultural chemical inputs to surface flow. Presented development of a simplified watershed model based on the storage-discharge functions.

*Steve Loring* (W-3188 Administrative Advisor, NMSU) joined via Skype and discussed the need to identify and emphasize the impact of our scientific activities as part of the W3188 project. In addition, requirements and the timeline for submitting a renewal proposal in 2019 were discussed. The 2019 proposal needs to be submitted by the end of January 2019.

*Business meeting (led by Maria Dragila)*

1. The chair discussed the group leadership and organization as well as expectations from the group members. Group members should submit their annual report to NIMSS as well as to the secretary (Hoori Ajami) to compile and submit a final report to Steve Loring by the end of January.

1. The members who were present unanimously selected Wei Zhang to be the secretary of the project for 2018. Wei joined the group last year and is an Assistant Professor at Michigan State University.
2. Location of the next year meeting is discussed and it was decided to hold the meeting in Riverside either before or after the SSSA meeting in San Diego. A Doodle poll was set-up by the Chair after the 2018 meeting to ask for the member preferences by January 15th regarding the dates for the next meeting. Based on the poll outcome, the next year’s meeting will be held in the USDA Salinity Lab in Riverside in January 10-11, 2019.
3. It was decided to invite NIFA representative to give a seminar in the next year W3188 meeting at Riverside.
4. Ideas for the next year proposal were discussed and groups of 4-5 members were formed to discuss emergent issues in soil science including application of remote sensing technology in soil physics, current issues related to food security and incorporating biophysical processes. A team of 6 members led by John Nieber will work on the proposal with the help of following group members: Wei Zhang (Michigan State University), Scott Jones (Utah State University), Markus Tuller (University of Arizona), Jie (Joe) Zhuang (University of Tennessee) and Ian Hopman (UC Davis).
5. Group photograph was taken

<https://www.dropbox.com/s/gbdcg6dftj30awm/IMG_7726.JPG?dl=0>

*Jie (Joe) Zhuang* (University of Tennessee) discussed the impact of soil organic matter on pore system including pore size, porosity and connectivity. Quantitative approaches for SOM-water relation were discussed.

*Markus Berli* (Desert Research Institute) presented soil moisture and flux data measurements from the SEPHAS weighting lysimeters and compared the measurements with numerical simulation results from HYDRUS-1D. The results of this work is published in a Special issue of Vadose Zone Journal, Lysimeters in Vadose Zone Research.

*Rose Shillito* (Desert Research Institute) presented a new physically based approach for quantifying the impact of water repellency on infiltration by developing a new sorptivity equation. This method will improve understanding and prediction of post-fire runoff and erosion.

*Yan Jin* (University Delaware) discussed quantification and characterization of colloid and colloidal organic carbon concentrations. In addition, the role of plant growth promoting rhizobacteria in increasing water retention were presented.

*Markus Tuller* (University of Arizona)presented the use of variety of remote sensing products for soil moisture estimation including development of a novel approach using Sentinel and landsat observations to estimate soil moisture; utilizing data from the Maricopa TERRA-REF phenotyping scanner to quantify evapotranspiration; estimating soil properties from water vapor sorption isotherms; and modifying the ParSWMS model to accommodate nonlinear solute adsorption and to support multi-species solute simulations.

*Morteza Sadeghi* (Utah State University) presented the impact of particle size on surface reflectance and discussed development of a new analytical solution for quantifying surface reflectance and comparing the results with experimental data. In addition, brief overview of other publications related to soil moisture estimation was discussed.

*Ebrahim Babeian* (Postdoc- University of Arizona) from Markus Tuller group discussed the use of cosmic ray soil moisture observing system for validating a new remotely sensed soil moisture product using optical remote sensing data.

*Azadeh Gholoubi* (PhD student - Utah State University) discussed development of a new proximal sensing index for quantifying soil aggregate stability.

*Scott* Jones (Utah State University) discussed the use of TDR array for near-surface soil moisture monitoring; presented recent updates about soil heat flux density sensor, and recent efforts for soil moisture monitoring and forecasting for water resource management in Utah

**January 4 2018.** Chair brought the house to order at 8:30 AM.

*Javier Reyes* (PhD student -University of Kentucky) from *Ole Wendroth* group presented the use of cluster analysis to incorporate spatial and temporal variability of soil and crop processes for delineating the irrigation management zones.

*Xi Zhang* (PhD student - University of Kentucky) from *Ole Wendroth* group discussed characterization of the spatial pattern of wet-range hydraulic conductivity at field scale by co-regionalization analysis. Results showed that including the electrical conductivity data in the cokriging analysis can improve prediction of spatial variability of hydraulic conductivity at a field scale.

*Jing Yan* (Post-doc UC Merced) from Teamrat Ghezzehei group discussed his recent experimental set-up to explore the impacts of spatial and temporal variability of water and nutrients on plant water uptake. Results indicated that plants are able to utilize resources from spatially segregated zones.

*Samuel Araya* (PhD student - UC Merced) from Teamrat Ghezzehei group discussed the use of machine learning methods to identify the most important soil structural variables for predicting saturated hydraulic conductivity. The new pedo-transfer function has improved hydraulic conductivity predictions compared to the ROSETTA3 model.

*Laura Rosales-Lagarde* (Nevada State College) performed analysis of sensors measuring soil temperature and volumetric water content in the SEPHAS lysimeters to identify redundant sensors and use these data for student training.

*Wei Zhang* (Michigan State University) discussed the issue of antibiotic resistance and pathways of pharmaceuticals into vegetables; discussed the upcoming special section in the Vadose Zone Journal for advancing soil physics for securing food, water, soil and ecosystem services.

Meeting closed at 12:00 pm

**ACCOMPLISHMENTS**

**1. Short-term Outcomes**

1. **University of Arizona (Markus Tuller)**: Modified the ParSWMS parallelized code for solving 3-D water and solute transport in order to accommodate nonlinear solute adsorption and to support multi-species solute simulations for optimization of soilless greenhouse substrates; Developed a method for semi-automated multiphase segmentation of 4-D Micro-Computed Tomography (CT) data of porous media and refined a physical framework for generation of artificial porous materials with precisely known phase distributions to test and improve segmentation algorithms; Initiated field experiments with a one-of-a-kind robotic phenotyping scanner to develop physical relationships between SWIR reflectance and actual evapotranspiration in collaboration with Utah State University (Morteza Sadeghi and Scott Jones); Refined predictive capabilities for soil specific surface area based on the Guggenheim–Anderson–Boer sorption model in collaboration with Aarhus University (Emmanuel Arthur); Collaborated with Utah State University (Morteza Sadeghi and Scott Jones) to develop a new analytical radiative transfer model to explain effects of particle size on SWIR soil surface reflectance; Collaborated with Utah State University (Morteza Sadeghi, Azadeh Gholoubi, and Scott Jones) to develop new methods to measure soil aggregate stability with SWIR imaging.
2. **University of California-Davis (Thomas Harter):** Collaborated with California Department of Water Resources to initiate a project that reviews research knowledge and gaps on the performance of well seals in the unsaturated zone; Began collaboration with the California State Water Board to assess modeling tools for evaluation of the assimilative capacity in groundwater basins with respect to salts and nitrate; Continued work with California North Coast Regional Water Board and Siskiyou County to develop modeling tool that will support local farming community. The modeling tool is designed to develop future groundwater management tools that address important threats to groundwater dependent ecosystems; Began collaboration with the California Almond Board and a grower-cooperator to establish a long-term nutrient, soil, and groundwater monitoring site to evaluate nitrogen fluxes in an almond orchard and their response to improved irrigation and nutrient management. Almonds are now one of the dominant crops in California and have high nitrogen input requirements; Met with key stakeholder groups in the San Joaquin Valley to develop future scenarios for agriculture and urban area groundwater management and landuse under new groundwater regulations.
3. **University of California-Riverside (Hoori Ajami):** Extended the functionality of the semi-distributed hydrologic model (SMART) to the catchment scale; Implementing and evaluating SMART catchment scale simulations across catchments in USA and Australia in collaboration with University of New South Wales (Ashish Sharma); Developed a new approach for mapping sub-basin scale soil moisture to fine resolution using statistical methods; Developed a new ecohydrologic catchment classification framework; Developed new approaches for quantifying uncertainty in conceptual ecohydrologic models in collaboration with University of New South Wales (Lucy Marshall).
4. **University of California-Riverside (Jirka Simunek):** Continued to expand the capabilities of the HYDRUS modeling environment by developing specialized modules for more complex applications that cannot be solved using its standard versions, including: developing robust and appropriately-scaled methods of irrigation scheduling using one or more soil-, plant- or weather-based approaches; Developing microirrigation designs and management practices that can be appropriately scaled to site-specific characteristics and end-user capabilities. A range of applications published in 2017 include *Hydrological Applications*, *Fate and Transport of Various Substances (Carbon Nanotubes, Viruses, Explosives)*, and the *Use of Hydrus Models to Evaluate Various Irrigation and Fertigation Problems - Agricultural Applications.*
5. **University of California-Riverside (Laoshen Wu)**: Applied synchrotron-based X-ray microcomputed tomography and high-performance pore-scale simulations to evaluate hydraulic properties of biocharamended soil aggregates; Developed efficient evaluation of small failure probability in high-dimensional groundwater contaminant transport modeling via a two-stage Monte Carlo method; Implemented a probabilistic collocation based iterative Kalman filter for landfill data assimilation; Implemented an ANOVA-based transformed probabilistic collocation method for Bayesian data-worth analysis.
6. **University of Delaware (Yan Jin):** Measured effects of plant-growth-promoting-rhizobacteria (PGPR) on water evaporation and retention in soils; Demonstrated the competition for retention sites when two viruses co-existed, resulting in increased transport of both viruses; Examined how the concentration of attached colloids (denoted as CAC) affect additional colloid attachment and subsequent detachment from collector surfaces; Generated data on the behavior of graphene oxide nanomaterials (GONMs), which have novel properties useful for medial and environmental applications, and in porous media under various environmentally-relevant conditions.
7. **Iowa State University (Robert Horton)**: Determined that a heat pulse sensor can accurately measure surface and subsurface soil heat fluxes; Developed a heat pulse probe method to estimate water content and bulk density simultaneously; Developed a method that can use a measured water retention curve (WRC) at one bulk density to estimate WRCs at other bulk density values; Developed a thermos-TDR method for estimating soil ice contents; Confirmed that soil heat pulse sensors can accurately measure daily soil water evaporation.
8. **University of Kentucky (Ole Wendroth)**: Developed EC-based clay mapping based on 1 soil sample per 2 ha and EC map taken in spring; Provided advice to farmers about site-specific irrigation rate; Delineated management zones in the field; Evaluated the existing pedo-transfer functions for site-specific parameter estimation, management applications and model input; Improving soil physical parameter estimation for field soil water processes is in progress.
9. **New Mexico State University (Manoj Shukla)**: Demonstrated that irrigation with brackish groundwater and desalinated concentrate decrease chile pepper yields; Demonstrated that desalinated brackish groundwater and RO concentrate can be used to grow halophytes; Demonstrated that RO irrigation will increase soil salinity, and RO irrigation should only be applied until vegetation establishment and in non-agriculture areas; Demonstrated that zeolite can be used to wick water from shallow groundwater table located within 3 m from soil surface to support natural native vegetation especially those with rooting depth of about 60 cm or more; Disseminated research results to stakeholders.
10. **University of Oklahoma (Tyson Ochsner)**: Made progress in advancing scientific knowledge for estimating drainage rates from the root zone using long-term in situ soil moisture data.
11. **Oregon State University (Maria Dragila)**: Obtained grower consent and finalized location selection for installation of soil moisture instrumentation in agricultural fields to assess irrigation efficiency; Commenced scientific examination of field data associated with irrigation efficiency; Began discussions with potential co-PIs for a project on deep drainage nitrate transport from sandy-soil agricultural fields; Completion of data collection for experiments on geochemical erosion of carbonate rock.
12. **Oregon State University (Carlos Ochoa)**: Installed instrumentation to monitor soil moisture, temperature, and conductivity fluctuations in under-canopy and inter-canopy locations in juniper woodlands of central Oregon; Installed instrumentation to monitor soil moisture, temperature, and conductivity fluctuations in an irrigated pasture field in Corvallis, Oregon; Continuing data collection and analyses of soil physical properties from the two sites mentioned above.
13. **Nevada, Desert Research Institute (Markus Berli)**: Developed a model to describe the relationship between soil hydrophobicity and infiltration; developed a model to describe water redistribution in an arid soil.
14. **Utah State University (Scott Jones and Morteza Sadeghi)**: Initiated work on development of a Utah state-wide soil moisture-mapping and forecasting capability through a Utah Agricultural Experiment Station Seed Grant; Morteza Sadeghi developed a new analytical radiative transfer model to explain effects of particle size on SWIR soil surface reflectance in collaboration with The University of Arizona (Markus Tuller and Ebrahim Babaeian); Wenyi Sheng (Postdoc) developed and field-tested the TDR Array at the TERRA-REF in Maricopa, AZ in collaboration with The University of Arizona (Markus Tuller and Ebrahim Babaeian). The TDR Array supports remote sensing of soil moisture through measurement of near-surface soil moisture in the top 8 cm at 1-cm depth increments; Azadeh Gholoubi (visiting Ph.D. student) developed a novel means for assessing soil aggregate stability using shortwave infrared reflectance of pre-and post-wetted soil aggregates in collaboration with The University of Arizona (Markus Tuller and Ebrahim Babaeian).
15. **Washington State University (Markus Flury and Joan Wu)**: Showed that biodegradable plastic mulches degrade under composting conditions; Demonstrated that water activities in the driest localities on earth are sufficient to support microbial life; Demonstrated that nanoparticles behave differently than micrometer-sized colloids at the air-water interface;

Showed that the improved Water Erosion Prediction Project (WEPP) model can be applied to forested, mountainous watersheds where groundwater baseflow is important.

1. **University of Wyoming (Thijs Kelleners)**: Obtained above and below canopy eddy covariance data from collaborators to validate the calculated canopy and energy balances of plot and watershed-scale numerical models; Progress was made towards determining hillslope subsurface hydraulic parameters using time-lapse electrical resistivity tomography data; Applied the integrated watershed model GEOtop to determine the annual water balances for snow-dominated mountainous catchments in Idaho and Wyoming.
2. **Michigan State University (Wei Zhang):** Investigated the effect of irrigation methods (i.e., overhead vs soil surface irrigation) on pharmaceutical residues and changes of bacterial community and antibiotic resistance genes (ARGs) in greenhouse lettuce leaves, roots, and soils upon exposure to pharmaceuticals in irrigation water. Results showed that the level of pharmaceutical residues in lettuce shoots was greater under overhead irrigation than under soil surface irrigation. One manuscript summarizing the results is currently under review. In addition, results illustrated that pharmaceutical exposure changed the bacterial community and ARG profile. A manuscript on this result is under preparation. Characterized the amount and properties of dissolved organic carbon (DOC) in 46 biochars, and developed a UV-vis spectrophotometry method to predict the DOC concentrations in biochars. The release of DOC from biochars will likely change the sequestration of contaminants by biochars, and is thus very important to development of soil biochar amendment technique. The manuscript on this study is currently under review.
3. **University of Minnesota (John Nieber):** Quantified the fraction of runoff that will be infiltrated into roadside swale sideslopes based on sideslope hydraulic characteristics and input runoff intensity; Developed modeling methods and sensitivity charts to assess sideslope infiltration potential based on sideslope characteristics (hydraulic conductivity, slope, slope length, and runoff input); Monitored the leaching of nitrate, phosphorus, chloride, a suite of heavy metals, and total petroleum hydrocarbon beneath stormwater infiltration facilities in the Twin Cities Metro Area; Used the HSPF model calibrated for a 9 ha forested watershed in northern Minnesota to assess the impact of potential climate change scenarios on water yield and groundwater recharge; Developed, calibrated and tested a simple dynamic hydrologic model to simulate the nonlinear behavior of groundwater contributions to streamflow for a watershed in eastern California.

**2. Outputs**

1. **University of Arizona (Markus Tuller)**:Research results were disseminated in collaboration with various involved groups through 7 peer-refereed international journal publications, 1 peer-reviewed article in conference proceedings, and 15 conference contributions.
2. **University of California-Davis (Thomas Harter):** [Video library](https://www.youtube.com/channel/UCS-mQDuWhJEw7as2XEVhK3A/featured) of over 100 twenty-minute videos that cover a wide range of agricultural groundwater supply and agricultural groundwater quality topics in California, North-America, and five other continents, filmed at the International Conference “Toward Sustainable Groundwater in Agriculture, San Francisco, California, June 28-30, 2016”; [Presentation library](http://ag-groundwater.org/Conference_Presentations_2016/) of over 160 scientific, technical, and policy presentation given at the International Conference “Toward Sustainable Groundwater in Agriculture, San Francisco, California, June 28-30, 2016”; Sustainable agricultural groundwater banking index (SAGBI) developed for California and available as an online app, <https://casoilresource.lawr.ucdavis.edu/sagbi/> ; Published 10 peer-reviewed journal articles, 2 theses and dissertations, and 31 technical and extension publications that are available online (2016 and 2017); Over the two year period 7/1/2015 – 6/30/2017, gave over 160 presentations in conferences, short courses, and in meetings involving government agencies, a diversity of stakeholder, the general public, and professionals.
3. **University of California-Riverside (Hoori Ajami):** Published 5 peer-reviewed journal articles related to groundwater recharge processes and ecohydrology; 1 journal article is currently under review and 3 conference abstracts were published in 2017; Presented the SMART modeling framework in one of the CUAHSI webinars on incorporating hillslope processes into earth system models; Developed and taught 1 upper division undergraduate course regarding principles of groundwater science (4 units).
4. **University of California-Riverside (Jirka Simunek)**: Research findings were disseminated via refereed journal publications, conference proceedings, and a number of presentations at national and international meetings. HYDRUS models have been updated with several new capabilities and options that have been developed for various research projects, which in turn have been published in peer-reviewed journals.
5. **University of California-Riverside (Laosheng Wu)**: Research results were disseminated through 8 peer-refereed international journal publications, 4 presentations and classroom teaching.
6. **University of Delaware (Yan Jin)**:Research results were disseminated in collaboration with various involved groups through 6 peer-refereed international journal publications and 9 conference contributions.
7. **Iowa State University (Robert Horton)**: Research results were disseminated in collaboration with various involved groups through 20 peer-refereed publications.
8. **University of Kentucky (Ole Wendroth)**: Research findings were disseminated through 4 journal publications, and presentations.
9. **New Mexico State University (Manoj Shukla)**: Published 7 peer-reviewed manuscripts; mentored 2 MS and 5 PhD students as chair and 5 other as committee member; Graduated 1 MS student
10. **University of Oklahoma (Tyson Ochsher)**: Maps of annual and long-term average drainage rates across the state of Oklahoma available online at <http://soilmoisture.okstate.edu/html/drainage-map.html>; Published 1 journal paper; Presented 6 invited talks.

1. **Oregon State University (Maria Dragila)**: Published a paper on the structure of micro-aggregation in sandy soil and their hydrologic impact; Submitted for publication mathematical model describing the fraction of soil water held in the form of liquid films; Submitted for publication a manuscript describing film formation and drainage in two-phase saturated porous media.
2. **Oregon State University (Carlos Ochoa)**: Presented preliminary findings related to soil moisture differences at different depths in under-canopy and inter-canopy locations in juniper dominated landscapes at a conference.
3. **Nevada, Desert Research Institute (Markus Berli)**: Published a paper that focused on model development to describe the water dynamics of desert soils.
4. **Utah State University (Scott Jones and Morteza Sadeghi)**: Research results were disseminated in collaboration with colleagues in the US and China through 7 peer-refereed international journal publications and 22 conference or invited talk contributions.
5. **Washington State University (Markus Flury and Joan Wu)**: Published research results in peer-reviewed journals and presented the results in national and international conferences (Soil Science Society Annual Meeting, Tampa, FL; European Geoscience Union, Vienna, Austria), and invited talks in China and Germany.
6. **University of Wyoming (Thijs Kelleners)**: Published 1 journal article and 1 conference abstract in 2017; Taught 4 courses: Soil physics lecture (3 credits), Soil physics laboratory (2 credits), Agroecology capstone (1.5 credits), and Forest and range soils (3 credits)
7. **Michigan State University (Wei Zhang):** Published 5 journal articles and presented the results in a number of national and international conferences.
8. **University of Minnesota (John Nieber):** Published 7 refereed journal articles based on the outcomes of the project activities. Seven conference/outreach presentations (oral or poster) were made.

**3. Activities**

1. **University of Arizona (Markus Tuller)**: *(1) Optimization of Soilless Greenhouse Substrates by Adoption and Modification of ParSWMS (Mohammad Gohardoust, Horst Hardelauf, Asher Bar-Tal, and Markus Tuller):* Modified the ParSWMS (Hardelauf et al., 2007) code to accommodate nonlinear solute adsorption and to support multi-species solute simulations. *(2) Semi-Automated Multiphase Segmentation of 4-D Micro-Computed Tomography (µCT) Data of Porous Media (Ramaprasad Kulkarni, Jeffrey Rodriguez, and Markus Tuller):* Developed a new semi-automated multiphase segmentation algorithm by combining K-means (KM) clustering with a Markov random field (MRF) framework. A comparison of segmentation results with KM clustering shows that in the presence of noise inherent to X-ray CT data acquisition, KM-MRF yields fewer misclassification errors than sole KM clustering. *(3) Generation of Artificial Porous Materials with Precisely Known Phase Distributions (Ramaprasad Kulkarni, Jeffrey Rodriguez, Marcel Schaap, and Markus Tuller):* Because the exact phase (i.e., solid, liquid, and air) boundaries of an imaged porous medium are not known a priori, there is no reliable reference data for meaningful validation of porous media segmentation algorithms. To overcome this problem, a three-phase porous medium proxy with exactly known phase boundaries by using a discrete element method in conjunction with lattice Boltzmann fluid dynamics simulations were synthesized. This approach generates an artificial porous medium with known phase boundaries, comprising spherical particles along with liquid and air. *(4) Remote Sensing of Earth Surface Processes:* in collaboration with Utah State University (Morteza Sadeghi, Scott Jones, Wenyi Sheng, and Rong Zhou) novel measurement and remote sensing techniques for characterization of largescale near surface processes and basic soil properties are being developed including: *(4.1) High-Resolution Shortwave Infrared Imaging of Water Infiltration into Dry Soil (Morteza Sadeghi, Ebrahim Babaeian, Markus Tuller, Mahta Moghaddam, and Scott B. Jones):* Developed a novel proximal sensing framework for high-resolution soil water content profile retrieval under laboratory conditions. *(4.2.) Application of Satellite Remote Sensing for Mapping and Monitoring of Dust Emission Sources (Mohaddese Effati, Ebrahim Babaeian, Morteza Sadeghi, Scott B. Jones, and Markus Tuller):* Developed a framework to establish relationships between remotely sensed land surface properties such as soil moisture, soil texture, and vegetation cover and dust events to inform potential dust prevention measures and to establish thresholds for wind erosion susceptibility. *(4.3) A Novel Proximal Sensing Approach to Quantifying Soil Aggregate Stability (Azadeh Gholoubi, Morteza Sadeghi, Ebrahim Babaeian, Markus Tuller, Scott B. Jones):* Developeda framework for quantifying soil aggregate stability using wetting methods in conjunction with hyperspectral imaging. *(5) Estimation of Basic Soil Properties from Water Vapor Isotherms:* in collaboration with Aarhus and Aalborg Universities in Denmark (Emmanuel Arthur, Lis Wollesen de Jonge and Per Moldrup) further work on indirect estimation of basic soil properties from water vapor sorption isotherms were performed including application of the Guggenheim-Anderson-de Boer model to estimate soil specific surface area from water vapor sorption isotherms.
2. **University of California-Davis (Thomas Harter):** *(1) Innovative Approaches to Understanding and Managing Groundwater-Surface Water Interactions in Agricultural Basins:* developed and updated an integrated hydrologic model of the Scott Valley groundwater basin to study the relationship between crop water needs, groundwater pumping for irrigation, and streamflow. The tools have been used for water rights applications to perform winter recharge, and to comply with reporting requirements related to the adjudicated portion of the Scott Valley; *(2) Managed Aquifer Recharge in Agricultural Basins:* partnered with several colleagues at the Center for Watershed Sciences, UC Water, and with the Public Policy Institute of California to implement cutting edge research that will significantly support sound future decision making by water management districts, reservoir operators, state agencies (including water rights division) to increase the amount of managed aquifer recharge using California’s large agricultural landscape as a venue; *(3) Nitrate in Groundwater*: With funding from CDFA and SWRCB, we have expanded the groundwater nitrate analysis to the entire Central Valley. This includes the assessment of the Central Valley’s nitrogen budget dynamics with field-scale spatial resolution and over a 60-year time-span, compilation of groundwater nitrate data, and extensive statistical and numerical modeling analyses to support our understanding of past and current impacts to groundwater, and to develop long-term solutions that will sustain groundwater quality in California’s agricultural basins.
3. **University of California-Riverside (Hoori Ajami):** Continued on the development of SMART model to extend its capabilities to catchment scale simulations; Added a new uncertainty quantification framework to SMART in collaboration with Boise State University (Mojtaba Sadegh); Establishing a new soil moisture monitoring network in Riverside in collaboration with Andy Gray (UC Riverside).
4. **University of California-Riverside (Jirka Simunek)**: In 2017, offered three-day short courses on how to use HYDRUS models at a) CSIRO Land & Water, Adelaide, South Australia, Australia, b) Czech University of Life Sciences, Prague, Czech Republic, c) Colorado School of Mines, Golden, CO, d) the Research Center for Eco-Environmental Sciences, Chinese Academy of Science, Beijing, Peoples Republic of China, and e) the Sede Boker Campus of the Ben Gurion University, Israel. Additionally, offered one-day short courses at a) the International Workshop of Soil Physics and the Nexus of Food, Energy and Water, Shenyang, China and b) North Carolina State University, Raleigh, NC. About 170 students participated in these short courses.
5. **University of California-Riverside (Laosheng Wu)**: Taught hydrology course; Presentations were made to various academic and non-academic groups. Working on the following on-going projects: Decision Support for Water Stressed FEW Nexus Decisions (DS-WSND). NSF INFEWS. Collaborator. 01/01/2018 to 12/30/2020; Reducing Nutrient and Sediment Loss from Ventura and Santa Barbara County Macro-tunnels. California Department of Food and Agriculture. Co-PI. 04/01/2016 to 03/31/2018; Hispanic-Serving Institutions (HSI) Education Grants Program. USDA/NIFA. Co-PI. 10/01/2016 to 08/01/2020; Optimizing Water Management Practices to Minimize Soil Salinity and Nitrate Leaching in California Irrigated Cropland. UC Division of Agri. & Natural Res. PI. 03/2017-02/2019.
6. **University of Delaware (Yan Jin)**: *(1) Advancing mechanistic understanding of plant growth promoting rhizobacteria (PGPR):* found that all PGPR-treated soils held more water and had reduced hydraulic conductivity and accumulative evaporation, compared to their corresponding controls; *(2) Quantified transport and retention behaviors of a human pathogenic virus (Adenovirus 41 or Ad-41) a model bacteriophage (**X174) through metal oxide-removed and goethite-coated sand under saturated flow conditions*. The results clearly demonstrated that caution must be taken when applying laboratory results, which are generally obtained from experiments employing a single virus species to predict the mobility and environmental risks in natural systems where multiple agents are present. *(3) Systematically investigated the influence of CAC and collector surface heterogeneity on the detachment of colloids by conducting saturated sand column experiments.* We observed that the fraction of attached colloids that were detached (i.e., reversibly attached colloids, denoted as FRA) due to reducing ionic strength (IS) changed with the CAC. Scanning electron microscope examinations reveal that the concave regions favored irreversible colloid attachment. Reversible attachment is likely due to immobilization on flat surfaces with charge heterogeneities, retention in stagnation point regions via secondary minimum association, ripening in the acid-treated sand, and capture of colloids by protruding asperities with charge heterogeneity in the untreated sand. Findings have important implications for predicting the fate and transport of colloids in subsurface environments and design of surfaces for manipulating colloid deposition and release in engineered processes; *(4) Graphene oxide nanomaterials (GONMs) have novel physicochemical properties thus a great potential to be used in medical, energy, and environmental applications:* Understanding the fate and transport of GONMs in the subsurface is necessary for their benign use as well as providing assessment of their environmental impacts and health risks. Our findings advance current knowledge to better predict NMs' fate and transport under various solution chemistries such as during rainfall events or in the mixing zones between sea water and fresh water where transient IS can change drastically; *(5) Continued collaboration with colleagues Dr. Jie Zhuang (Institute of Applied Ecology, Shengyang, of the Chinese Academy of Sciences and University of Tennessee) and Dr. Chongyang Shen (China Agricultural University, Beijing)* on fate and transport of colloids and viruses, and initiated new collaboration with Dr. Yan Xue of Nanjing University of Information Science & Technology on ecotoxicological studies of heavy metal cadmium.
7. **Iowa State University (Robert Horton)**: Introduced the heat pulse method for measuring surface soil heat flux with a multi-needle heat-pulse probe (HPP); Presented a heat pulse-based method for simultaneous determination of b and  from soil thermal properties; Extended the van Genuchten WRC model to account for ρb variations; Presented and evaluated a soil thermal conductivity (λ)-based approach to determine θi with thermo-TDR probes; Evaluated the accuracy and precision of the heat-pulse technique using direct, continuous, and nondestructive E measurements from a weighing lysimeter. Results showed that heat-pulse technique can provide continuous daily E measurements with good accuracy and precision.
8. **University of Kentucky (Ole Wendroth)**: Installed wireless sensor network for soil water content monitoring in a farmer's field; Performed functional soil mapping for management decision support; Further progress was made in linking remotely sensed field information to soil processes; Continued to use the Root Zone Water Quality Model (RZWQM) to simulate soil water dynamics, crop growth and greenhouse gas emissions; Almost completed the 3-year research project that is funded by the three main crop commodities in Kentucky; Over the next months, we will complete two Ph.D. dissertations; Worked on the decision support for irrigation water management, and at the same time coordinating group of scientists from three other states (Georgia, Tennessee, Alabama) and our 4-state research project is funded by the SSRP (Southern Soybean Research Program). Scientists involved in this project writing effort here at UK are: Chad Lee, Carrie Knott, Mike Sama, and Lloyd Murdock. A continuation of the proposal for year 3 has been submitted; Smart Phone App is being under development that will help farmers to control their irrigation system; Continued mentoring of graduate students, giving invited lectures overseas, and being active in a number of Extension and Outreach activities.
9. **New Mexico State University (Shukla Manoj)**: Taught soil physics, advanced soil physics and environmental soil science classes; Taught a class on Natural Resources in Northwest A&F University, China; Hosted one faculty members from University of Hebei, China, one faculty from Jiangxi Agriculture University of China, and one graduate student from China agriculture University; Organized field and greenhouse trips to collect soil and water samples, soil moisture content, soil temperature, and other meteorological data; Planned experiments on the use of brackish groundwater and RO concentrate for looking at the influence of irrigation water salinity on soil microbiological properties; Collected soil and plant samples from Pecan orchards from Hatch, NM to Fabens, Texas to evaluate salinity induced changes in pecan physiology; wrote multiple proposals; Evaluated Indaziflam movement through preferential flow channels and its impact on Pecan growth and gas exchange parameters, and soil properties; Started on developing a device to remotely collect soil moisture content data by commercially available sensors.
10. **University of Oklahoma (Tyson Ochsner)**: Published a peer-reviewed paper on demonstrating how useful drainage estimates can be obtained from a large-scale soil moisture monitoring network by applying the unit-gradient assumption; Distributed drainage maps to the public and to other researchers through the website listed previously; Presented results at multiple scientific meetings and conferences.
11. **Oregon State University (Maria Dragila)**: Investigating soil water relations in sandy agricultural soil to improve irrigation efficiency [Collaboration with M. Kleber and R. Qin (OSU)]; Continuing field and laboratory investigations associated with the evolutionary development of micro-aggregation in sandy soil; Investigating the biophysical mechanisms associated with the evolution of water repellency to uncover an effective remediation strategy [Collaboration with M. Kleber (OSU)]; Continuing laboratory investigations of water repellency development; Investigating the erosional evolution of microfractures in the epikarst; Completed experiments and initiation of final data analysis; Investigating the efficacy of using soil solarization for pest and weed disinfectation in the Pacific Northwest [Collaboration with J. Parke and C. Mallory-Smith (OSU) and S. Dollen (Grower)]; Completed second-year of field trials; Investigating how various mechanisms impact gas exchange across the interface between vadose zone and atmosphere [Collaboration with N. Weisbrod (Ben Gurion, IL)]; Investigation of film flow below the detection limit of CT scans [Collaboration with PI Dorthe Wildenschild]; Submitted one manuscript submitted, second manuscript is in progress.
12. **Oregon State University (Carlos Ochoa)**: *(1) Investigate soil water relations in irrigated pastures to assess water transport through the vadose zone and into the shallow aquifer [Collaboration with D. Godwin and S. Ates (OSU)]:* Field and laboratory work related with soil physical properties and water transport through the unsaturated zone; *(2) Investigate soil water relations in juniper-sage steppe landscapes to assess water transport through the vadose zone and into the shallow aquifer [Collaboration with T. Deboodt (OSU)]*: Automated field data collection at multiple locations in one watershed with juniper and one where juniper was removed 13 years ago.
13. **Nevada, Desert Research Institute (Markus Berli)**: Developed a physically-based model to describe the relationship between soil hydrophobicity (expressed as apparent contact angle) and infiltration; Worked on an improved understanding of water infiltration, redistribution and evaporation from arid soils; Evaluated a soil test kit to assess the health of desert soils
14. **Utah State University (Scott Jones and Morteza Sadeghi)**: *(1) Effects of Particle Size on Soil Reflectance (Morteza Sadeghi, Ebrahim Babaeian, Markus Tuller, and Scott B. Jones):* Developed a novel algorithm and tested it for estimation of soil particle size effects on surface reflectance in the optical domain (i.e., 400-2500 nm). *(2) Estimation of Actual Evapotranspiration in Stony Soils (Kshitij Parajuli, Morteza Sadeghi and Scott B. Jones):* Extended research on stony soil water retention for actual evapotranspiration determination using measured changes in soil moisture coupled with numerical modeling. *(3) A Novel Proximal Sensing Approach to Quantifying Soil Aggregate Stability (Azadeh Gholoubi, Morteza Sadeghi, Ebrahim Babaeian, Markus Tuller, Scott B. Jones):* Developed a proximal sensing (RS) technique for quantifying soil aggregate stability. *(3) A TDR Array Probe for Monitoring Near-surface Soil Moisture Distribution (Wenyi Sheng, Rong Zhou, Morteza Sadeghi, David A. Robinson, Markus Tuller, and Scott B. Jones):* The TDR array was fully described in a Vadose Zone Journal publication in 2017. The probe was designed to provide cm-resolution measurements of soil moisture content from the surface downward. *(4) High-Resolution Shortwave Infrared Imaging of Water Infiltration into Dry Soil (Morteza Sadeghi, Ebrahim Babaeian, Markus Tuller, Mahta Moghaddam, and Scott B. Jones):* Developed a novel proximal sensing framework for high-resolution soil water content profile retrieval under laboratory conditions and results were published in Vadose Zone Journal; *(5) Application of Satellite Remote Sensing for Mapping and Monitoring of Dust Emission Sources (Mohaddese Effati, Ebrahim Babaeian, Morteza Sadeghi, Scott B. Jones, and Markus Tuller):* Developed a framework to establish relationships between remotely sensed land surface properties such as soil moisture, soil texture, and vegetation cover and dust events to inform potential dust prevention measures and to establish thresholds for wind erosion susceptibility; *(6) Electromagnetic induction mapping at varied soil moisture reveals field-scale soil textural patterns and gravel lenses (H. Abdu, D. A. Robinson, J. L. Boettinger and S. B. Jones):* In a FASE publication, described an electromagnetic induction (EMI) mapping approach in low apparent electrical conductivity (ECa) soils under varying soil water contents to capture time invariant properties such as soil texture. Georeferenced ECa measurements were taken using a ground conductivity meter on six different days where volumetric water content (θv) varied from 0.11 to 0.23. Combined maps using temporal stability analysis gave the clearest image of the textural differences. These maps could be informative for modeling, experimental design, sensor placement and targeted zone management strategies in soil science, ecology, hydrology, and agricultural applications; *(7) A Utah Soil Moisture Monitoring and Forecast Network for Improved Water Resource Management and Risk Prediction. (Wenyi Sheng, Rong Zhou, Morteza Sadeghi, Rob Gillies, Markus Tuller and Scott B. Jones).* The Utah Agricultural Experiment Station funded a seed grant to develop a state-wide Utah Soil Moisture Map and Forecast. We are collaborating with the Utah Climate Center and the University of Arizona to develop external grant proposal in order to fully develop the capability of both mapping soil moisture as well as to forecast soil moisture into the future.
15. **Washington State University (Markus Flury and Joan Wu)**: Synthesizing work on colloid transport in unsaturated porous media; Co-edited a special section on “Lysimeters in Vadose Zone Research” in the Vadose Zone Journal; Organized symposium on “Nanoparticle Fate and Transport in Soil and Groundwater Systems” at the European Geoscience Union Annual meeting; Measured water potentials and sorption isotherms for soil samples from Atacama desert to determine the dry limit of life on Earth; Used numerical modeling to assess the effect of biodegradable plastic mulches on water dynamics in field soils; Performed field experiment to assess suitability of biodegradable plastic mulches for pumpkin production; Measured soil quality in field trials to check for adverse effects of biodegradable plastic mulches; Tested degradation of biodegradable plastic mulches under soil and compost conditions; Improved the Water Erosion Prediction Project (WEPP) model for groundwater baseflow, and applied the model to the Upper Cedar River Watershed in western Washington.
16. **University of Wyoming (Thijs Kelleners)**: Continue to maintain a state-wide soil moisture network for drought monitoring in rangelands (consisting of 17 sites); Continue to maintain 3 snow-soil monitoring stations, 6 soil moisture monitoring stations, and 2 snow lysimeters (measuring snowmelt rates) in a forested experimental watershed in southeastern Wyoming; Developed a novel bulk density optimization method to determine subsurface hydraulic properties for use in numerical plot, hillslope, and watershed-scale numerical models.
17. **Michigan State University (Wei Zhang):** Investigated the effect of irrigation methods (i.e., overhead vs soil surface irrigation) on pharmaceutical residues and changes of bacterial community and antibiotic resistance genes (ARGs) in greenhouse lettuce leaves, roots, and soils upon exposure to pharmaceuticals in irrigation water; Characterized the amount and properties of dissolved organic carbon (DOC) in 46 biochars, and developed a UV-vis spectrophotometry method to predict the DOC concentrations in biochars.
18. **University of Minnesota (John Nieber):** Conducted field experiments at highway swale sites to quantify the pattern of overland flow and the amount of infiltrated runoff on the highway swale surfaces; Developed a model for one-dimensional overland flow with vertical infiltration to simulate the infiltration of stormwater generated on highway surfaces, into the sideslopes of swales; Developed a model for infiltration from parallel strip sources to quantify the effect of strip width and strip spacing on the total infiltration over a surface, with reference to the infiltration that would occur for a condition of a completely wetted surface. The model was based on a 2-dimensional solution of the Richards equation and implemented in the COMSOL-MP software; Developed a model for turbulent flow, particle erosion, and suspended sediment transport inside of soil pipes using COMSOL-MP software. The model was for steady-state flow and for a fixed pipe geometry. The research is part of a continued collaboration with Dr. Glenn Wilson at the USDA-ARS sedimentation lab in Oxford, MS and Dr. Garey Fox at North Carolina State University; Conducted detailed laboratory studies on a large laboratory hillslope to investigate the infiltration of water where the water enters from the upper end of the flume and overland flow occurs down the slope; Monitored three stormwater infiltration practice sites in the Twin Cities Metro Area to determine the rate of mass transport for select heavy metals, nitrate, phosphorus, chloride, and Total Petroleum Hydrocarbon (TPH); Continued research on the characteristics of the vadose zone flow processes at a large area made water repellent by an oil pipeline spill that occurred in 1978; Developed the HSPF model of a 9 ha forested watershed in northcentral Minnesota. This modeling work is a collaboration with Dr. Stephen Sebestyen at the U.S. Forest Service office in Grand Rapids, MN; A calibrated GSFLOW model for the Sagehen Creek watershed (27 sq. km) located in Sierra Nevada Mountains) was used to synthetically generate baseflow recessions for a 16-year period. The generated baseflow recessions were examined to assess the effect of initial groundwater storage, groundwater recharge, and ET on recession characteristics; Using results of the Sagehen Creek watershed modeling study a simple dynamic model of watershed hydrology was developed to simulate groundwater contributions to streamflow. The developed model was calibrated for one single parameter for an 8-year period and then the calibrated model was validated using an independent 8-year record of streamflow.

**4. Milestones**

1. **University of Arizona (Markus Tuller)**:Modified ParSWMS parallelized code to include simulation capabilities for nonlinear solute adsorption and multi-species solute simulations for optimization of soilless greenhouse substrates; Developed a method for semi-automated multiphase segmentation of 4-D Micro-Computed Tomography (CT) data of porous media; Refined predictive capabilities for soil specific surface area based on the Guggenheim–Anderson–Boer sorption model; Developed a new analytical radiative transfer model to explain effects of particle size on SWIR soil surface reflectance; Developed new means to measure soil aggregate stability with SWIR imaging.
2. **University of California-Davis (Thomas Harter):** Held the International Conference “Toward Sustainable Groundwater in Agriculture”, June 28-30, 2016”, which was attended by over 350 participants from 6 continents.The conference was preceded by 2 half-day workshops on groundwater nitrogen management and on the implementation of the California Sustainable Groundwater Management Act. The conference brought together a unique diversity of speakers and attendees from water sciences, agricultural extension, agricultural organizations, NGOs, government organizations, and growers; Completed a multi-year assessment of the spatial and long-term temporal distribution of nitrogen losses to groundwater that threaten drinking water resources that most of the population in the Central Valley depends on. The assessment, for the first time, provides detailed mass balance at the one-acre scale across the 12 million acre Central Valley; Katherine Ransom completed her dissertation, a body of work that is complementary to the nitrogen mass balance analysis of the Central Valley (<https://californiawaterblog.com/2017/09/17/groundwater-nitrate-sources-and-contamination-in-the-central-valley/>); (4) Emily Edwards completed her MS thesis, a comprehensive assessment of dry wells as tool for urban stormwater recharge.
3. **University of California-Riverside (Hoori Ajami):** The SMART modeling framework was published online and is available to users; Worked on recharge estimation in the western US; Worked on ecohydrologic modeling applications
4. **University of California-Riverside (Jirka Simunek)**: Various novel applications of the models were implemented including: application of the machine learning method to estimate the main wetting branch of soil water retention curve based on its main drying branch; evaluation of the role of heterogeneous lithology; simulating overland flow processes, quantifying the long-term stream-aquifer exchange in a variably saturated heterogeneous environment; evaluating transport and fate of viruses under managed aquifer recharge (MAR); modifying HYDRUS-1D to consider particle dissolution to evaluate dissolution and transport of energetic constituents from the new insensitive munitions (IM) formulations IMX-101, a mixture of NTO, NQ, and DNAN, and IMX-104, a mixture of NTO, RDX, and DNAN. NTO and DNAN; Developing a root growth model, and publication of two review papers.
5. **University of California-Riverside (Laosheng Wu)**: Improve our fundamental understanding of vadose zone physical properties and processes, and how they interact with other environmental and biogeochemical processes across various spatial and temporal scales; Apply our knowledge of scale-appropriate methodologies to enhance the management of vadose zone resources that benefit agricultural systems, natural resources and environmental sustainability.
6. **University of Delaware (Yan Jin)**: Implemented novel experimental approaches and demonstrated that PGPR can increase soil water retention and reduce evaporation from soils; Demonstrated how co-presence of two viruses affected the retention and transport behavior of each (e.g., reduced retention hence increased transport due to competition for attachment sites); and Improved understanding of colloid behavior in porous media.
7. **Iowa State University (Robert Horton)**: Developed a heat pulse sensor method to measure surface and subsurface soil heat fluxes; Developed a heat pulse sensor method to determine soil water content and soil bulk density simultaneously; Developed a method to estimate soil water retention curves as a function of bulk density; Developed a thermo-TDR method to measure soil ice content.
8. **University of Kentucky (Ole Wendroth)**: Refining and troubleshooting a wireless sensor network for soil water content monitoring in a farmer’s field; Made substantial progress in mapping zone delineation for irrigation decision support; Made progress in linking remotely sensed field information to soil processes.
9. **New Mexico State University (Manoj Shukla)**: Quantified impacts of irrigation water salinity induced changes to evapotranspiration and yields of several chile pepper cultivars; Quantified impacts of irrigation water salinity induced changes to evapotranspiration and yields of several halophytes; Quantified increases in soil salinity and ion concentrations in soil with continued irrigation with brackish groundwater and RO concentrate; Showed Clinoptilolite zeolite can be used to wick water from groundwater tables to support native vegetation; Quantified dissipation rates and half-life of indaziflam herbicide; Quantified various airborne fungal spores along US-Mexico border; Calibrated three soil moisture sensors (Hydra probe, 5TE, and 5TM sensors); Started on developing a low cost data logger with wireless capability to collect data at a location and directly transmit to central storage; Quantified dissipation rates for indaziflam for management of Pecan orchards; Quantified ion accumulation in soil and plant for designing improved irrigation strategies
10. **University of Oklahoma (Tyson Ochsner)**: Explored the potential for expanding this drainage estimation method nationwide using existing soil moisture monitoring networks.
11. **Oregon State University (Maria Dragila)**: Continuing work on water motion within sandy soils has resulted in the development of a conceptual field-scale model for the role of biofilms on water storage within the upper-soil water cycle.
12. **Oregon State University (Carlos Ochoa)**: Established a soil moisture-monitoring network in one irrigated pasture field in the Oak Creek watershed in Corvallis, OR.;

Expanded a soil moisture-monitoring network in rangeland juniper-dominated systems in central Oregon.

1. **Nevada, Desert Research Institute (Markus Berli)**: Developed a model for water infiltration into hydrophobic soils; Developed a model to describe water redistribution in arid soils
2. **Utah State University (Scott Jones and Morteza Sadeghi)**: Developed a new analytical radiative transfer model to explain effects of particle size on SWIR soil surface reflectance; Developed new means to measure soil aggregate stability with SWIR imaging; Received private grant to modify the tri-needle heat pulse probe for reduced energy consumption and improved longevity of the sensor heater; Published a description and application of the TDR Array for measurement of near-surface soil moisture in cm depth increments; Published the Optical Trapezoiod Model (OPTRAM) paper for improved remote sensing of land surface moisture content using only optical satellite data; Initiated Utah state-wide soil moisture mapping and forecasting project using UAES seed grant.

1. **Washington State University (Markus Flury and Joan Wu)**: Developed mechanistic understanding of interactions of colloids with the air-water interface; Determined vapor sorption isotherms to evaluate the dry-limits of life; Developed a numerical model to analyze the effects of biodegradable plastic mulches on soil moisture; Completed a third of four field seasons to evaluate the effects of biodegradable plastic mulches on soil quality; Incorporated nonlinear algorithms into WEPP (v2012.8) for estimating baseflow.
2. **University of Wyoming (Thijs Kelleners)**: Soil Science MS student Mark Pleasants successfully defended his thesis entitled: Hydrologic flow paths for a snowmelt dominated, forested hillslope in southeastern Wyoming: Linking snow and subsurface hydrology. One paper was published from this work in Hydrological Processes. Mark is currently a hydrologist at the Ohio Geological Survey.
3. **Michigan State University (Wei Zhang):** This project provided training for one undergraduate student, four graduate students, and one post-doctorate research

Associate.

1. **University of Minnesota (John Nieber):** Stormwater runoff generated on highways was observed to occur in concentrated flow patterns over the surface of highway swale sideslopes, even in the absence of rills on the surface; Developed a prediction model that facilitates the calculation of the fraction of surface wetted with overland flow based on sideslope characteristics (mainly saturated hydraulic conductivity) and applied runoff intensity; Developed overland flow model was shown to match measured runoff amounts, without calibration, using only measured sideslope characteristics; The calibrated HSPF model applied to a headwater watershed in northern Minnesota showed that with projected changes in air temperature and rainfall the runoff from the headwater watershed will be reduced during the growing season, and groundwater recharge will also be reduced; The simple dynamic hydrologic model applied to the Sagehen Creek watershed was shown to match quite well (NSE > 0.85) the groundwater portion of streamflow for the creek. The model improves upon previous models by accounting for the nonlinear behavior of the storage-discharge relations in watersheds.

**5.Impact Statements**

1. **University of Arizona (Markus Tuller)**: Our advanced X-Ray CT segmentation algorithms aided numerous other researchers with projects that utilize X-Ray CT for soil and porous media research. The NASA AirMOSS P-band radar algorithm was updated to improve root zone soil moisture retrievals based on our Richard’s equation based framework proposed in 2016.
2. **University of California-Davis (Thomas Harter):** (1) Through our research and extension program, I have been actively shaping the implementation of the California Sustainable Groundwater Management Act of 2014 (SGMA) as an expert in agricultural groundwater and groundwater management. My research group has provided significant technical and scientific feedback to the State of California on new regulations being written and implemented under SGMA. I have also provided extensive outreach programs to stakeholders in agricultural regions that, for the first time, are engaging in groundwater supply assessment and management. (2) I have been actively engaged in the emerging regulations for discharging nitrate and salts from the agricultural landscape to groundwater. I am providing a wide range of outreach and extension tools and events to educate growers, agricultural consultants, environmental NGOs, and regulatory agency personnel on nitrate and salt issues at the groundwater-agriculture interface. (3) Through a joint research project agricultural groundwater nitrate, we have been actively engaged with the USGS National Water Quality Assessment Program, which provides a national perspective to federal policy makers on groundwater pollution from agriculture and solution approaches.
3. **University of California-Riverside (Hoori Ajami):** This research provides a set of numerical model codes for understanding and quantifying surface water-groundwater exchange at large catchment scales. The numerical models will allow assessment of climate variability and management decisions on catchment water balance. This information will be valuable for sustainable water resource management in California and elsewhere.
4. **University of California-Riverside (Jirka Simunek):** The HYDRUS models are being constantly updated based on the basic research carried out by the W3188 group. The HYDRUS-1D model was downloaded more than 10000 times in 2017 and over 25000 HYDRUS users from all over the world registered at the HYDRUS website. New capabilities are added to rigorously consider processes in the soil to the very widely used modeling tools, such as MODFLOW and DSSAT. These two tools are used by thousands of users to simulate flow in the groundwater and the growth of multiple agricultural crops, respectively. Finally, in 2017, we have offered short courses on how to use HYDRUS models at a) CSIRO Land & Water, Adelaide, South Australia, Australia, b) Czech University of Life Sciences, Prague, Czech Republic, c) Colorado School of Mines, Golden, CO, d) the Research Center for Eco-Environmental Sciences, Chinese Academy of Science, Beijing, Peoples Republic of China, e) the Sede Boker Campus of the Ben Gurion University, Israel, f) the International Workshop of Soil Physics and the Nexus of Food, Energy and Water, Shenyang, China, and g) North Carolina State University, Raleigh, NC. About 165 students participated in these short courses.
5. **University of California-Riverside (Laoshen Wu)**: The new models allow to more accurately predict gas, water and solute transport in porous media; Assessment of best management practices improves water use efficiency and protects water quality.
6. **University of Delaware (Yan Jin)**: The long-term goal of the PGPR study is twofold: 1) to provide a more complete understanding of plant-soil-microbe interactions in the root zone and their influence on water retention and hydraulic properties, and 2) to explore the application potential of using PGPR as an alternative to plant genetic engineering and breeding for reducing plant drought stress tolerance and meeting the challenge of producing adequate food for the growing world population under the changing climate.

Although multiple viruses and other contaminants coexist in environmental samples, laboratory studies typically include only one agent, which do not provide accurate evaluation of contaminant behavior in natural environment. Caution needs to be taken when applying laboratory results obtained with single contaminant in modeling and risk assessment.

1. **Iowa State University (Robert Horton)**: The development of a new water retention curve model that accounts for soil bulk density will aid numerous modelers and experimentalists studying soil water, heat, and solute transport.
2. **University of Kentucky (Ole Wendroth)**: Based on our results, our recommendation to reduce irrigation intensity, helped to mitigate surface runoff and to keep irrigation water the root zone.
3. **New Mexico State University (Manoj Shukla)**: The availability of surface water for irrigation is not sufficient for sustaining agriculture in the southern New Mexico. Increasingly saline groundwater is used for irrigation, which can have severe consequences on the soil quality and sustainability of agriculture. My research on the use of brackish groundwater and RO concentrate for growing chile peppers and helophytes has identified the potential problems and opportunities, and has generated a lot of interest in the state and has been widely published by various Newspapers. Our strategy towards developing new irrigation scheduling protocols for safe and low cost disposal of RO concentrate can be a key for sustaining agriculture in water starved southern New Mexico as well as other similar arid areas. These efforts also be useful for safe reuse of RO concentrate (or waste) locally and could contribute to food security and desertification control.
4. **University of Oklahoma (Tyson Ochsner)**: The soil moisture-based drainage estimation method was presented in 6 invited talks in China; Published a peer-reviewed paper.
5. **Oregon State University (Maria Dragila)**: (1) Understanding bio-water-dynamics of sandy soil will provide the mechanistic foundation for improved irrigation methods that can reduce water usage and costs, reduce the transfer of contaminants to the water table, reduce water runoff and its associated erosion, and improve overall crop success in irrigated semi-arid land agriculture; (2) Understanding the erosional evolution of microfractures into larger conduit-carbonate-units provides a basis for the theoretical framework of Karst land evolution. Karst geological units extend across terrain associated with about 40% of the world’s aquifers. Where these lands are associated with agricultural activity or underlie populated areas, they present serious challenges for water quality management; (3) Determining the feasibility and practicality of solarization in the Pacific Northwest could offer growers a serious alternative for crop protection against weed and pest invasion where pesticides/herbicides are not available or allowed. Solarization also provides alternatives to chemical use by methods that are less harmful to the overall ecosystem.
6. **Oregon State University (Carlos Ochoa)**: Understanding the dynamics of soil water transport through the vadose zone and into the shallow aquifer in rangeland ecosystems provides critical information regarding the potential for shallow groundwater recharge in arid and semiarid landscapes of the Pacific North West; Understanding the dynamics of soil water transport through the vadose zone and into the shallow aquifer in agroecosystems connected to riparian areas helps understanding potential hydrologic flow paths that may affect water quality in the stream.
7. **Nevada, Desert Research Institute (Markus Berli)**: Improved our understanding of the water dynamics of desert soils; Developed a test kit to assess the health of desert soils; awarded 2 grants.
8. **Utah State University (Scott Jones and Morteza Sadeghi)**: The TDR Array is providing valuable information on soil moisture during seed germination of over 300 wheat varieties and for calibrating remote sensing estimates of soil moisture at the TERRA-REF Rapid Phenotyping complex in Maricopa, AZ. The NASA AirMOSS P-band radar algorithm was updated to improve root zone soil moisture retrievals based on our Richard’s equation based framework proposed in 2016.
9. **Washington State University (Markus Flury and Joan Wu)**: Demonstrated that the driest places on Earth is a transitory habitat for microbial life; The enhanced WEPP model can serve as a cost-effective tool for water yield assessment and forest watershed management.
10. **University of Wyoming (Thijs Kelleners)**: The fate and transport of snowmelt and rainfall was assessed for snow-dominated mountainous catchments in Idaho and Wyoming using hydrological measurements, geophysical surveys, and numerical modeling. Annual water balances were calculated showing that snow sublimation represented 3-10 % of incoming precipitation while streamflow represented 8-24 % of incoming precipitation.
11. **Michigan State University (Wei Zhang):** Knowledge gained will help improve process-based modeling of contaminant transport in surface and subsurface flows. Improved assessment of contaminant retention and transport in soil ecosystems will contribute to management strategies to mitigate the spread of emerging contaminants in the environment, thus protecting human and ecosystem health.
12. **University of Minnesota (John Nieber):** The results of the research are being implemented by the Minnesota Department of Transportation and the Minnesota Pollution Control Agency in assessing the credits that highway departments will get for controlling stormwater runoff in urban districts. The use of swale sideslopes are now viewed as being a resource that can help to reduce the need (or reduced size) for downstream holding ponds and raingardens. The improved model offers an opportunity to modelers to improve the features embedded in various conceptual watershed models (e.g., HSPF, SWAT, HEC-1) used by consultants and government agencies. Work remains with this model to include surface runoff, evapotranspiration, and snowmelt algorithms.

**PUBLICATIONS**

**Peer-reviewed Articles**

1. Abdu, Hiruy David A. Robinson, Janis Boettinger, Scott B. Jones. 2017. Electromagnetic induction mapping at varied soil moisture reveals field-scale soil textural patterns and gravel lenses. *Front. Agr. Sci. Eng.* 4(2): 135-145, doi: 10.15302/J-FASE-201714
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**Patents**

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