**Basic Information**

Project No. and Title: W3188: Soil, Water, and Environmental Physics Across Scales

Period Covered: 10/01/2018 to 09/30/2019

Date of Report: 06/03/2020

Annual Meeting Dates: 01/02/2020 to 01/03/2020

**Participants**

Majdi Abou Najm, UC Davis; Hoori Ajami, UC Riverside; Markus Tuller, University of Arizona; Brian Hill, Oregon State University; Joan Wu, Washington State University; Thomas Harter, UC Davis; Robert Heinse, University of Idaho; Jingyi Huang, University of Wisconsin Madison; Scott Jones, Utah State University; Thijs Kelleners, University of Wyoming; John Nieber, University of Minnesota; Hanna Ouaknin, UC Davis; Elia Scudiero, UC Riverside; Manoj Shukla, New Mexico State University; Jiri Simunek, UC Riverside; Ryan Stewart, Virginia Tech; Markus Tuller, University of Arizona; Ole Wendroth, University of Kentucky; Michael Young, University of Texas at Austin; Wei Zhang, Michigan State University.

**Brief Summary of Minutes of Annual Meeting**

2019 Annual Meeting of the W-3188 Multi-State Research Project:

Soil, Water, and Environmental Physics across Scales

January 02-03, 2020, University of California Riverside, Riverside, CA

Wei Zhang (Chair) and Ryan Stewart (Secretary)

January 02, 2020. Chair brought the house to order at 8:30 AM.

Ole Wendroth (University of Kentucky) discussed spatial variability of soil properties, including zone delineation mapping using soil sampling versus Veris electrical conductivity mapping. He performed a clustering analysis using clay + normalized differential vegetation index (NDVI) + topography. Future work will add variable rate irrigation to a center pivot. He also discussed testing the RZWQM2 model with measured versus generated parameters and developing pedotransfer functions (PTFs) that include spatial correlations.

Michael Young (University of Texas at Austin) discussed a study to characterize desert tortoise habitats. He is using remote sensing and other data products to examine uncharacterized basins and determine abiotic factors controlling shrub canopy characteristics. He found that aspect was more important than slope and shrub volume and spacing decreased as soils aged and pavements formed. Michael also talked about a new project looking at multi-sector modeling of natural/human interactions related to water, energy, ecosystems services, and urbanization in Texas. The project partially arose from considering Hurricane Harvey’s impacts on the state.

Joan Wu (Washington State University) discussed three ongoing projects: urban stormwater management, measuring river sediment from Landsat, and studying water erosion for inland areas of the Pacific Northwest. The latter used the WEPP model to examine water erosion processes, examining environmental factors such as climate, soil type, and slope, along with different tillage practices (intense, reduced, and no-till). The results showed that reduced tillage can produce more surface runoff than intense tillage, while no-till always had the least surface runoff. Shallow soils had less surface runoff but more erosion than deeper soils.

Jirka Simunek (UC Riverside) updated the group on activities related to training and usage of HYDRUS, including four short-courses taught in locations around the world. Research included hydrological applications (e.g., dry well simulations, neutron flux measurements of soil moisture, coupled water and solute transport in HYDRUS plus Modflow), fate and transport modeling (e.g., virus transport), and agricultural applications (e.g., ring-shaped irrigation emitters, salinization in olives, dynamic plant water uptake modeling). He is also serving as Editor-in-Chief for Journal of Hydrology.

The business meeting was called to order at 10:30 AM. Steve Loring (Administrative Advisor, New Mexico State University) joined the meeting through video conferencing.

1. The meeting started with introductions.
2. Steve provided a USDA NIFA update.
3. Group members were reminded to submit their REEport materials and materials for the annual report due to NIMSS (60 days after meeting). Members were encouraged to include strong impact statements that detail the differences that were or will be made by the project.
4. Steve recommended that W3188 be nominated for the excellence in research award, with a deadline of February 15th. A committee was formed to prepare the nomination materials, with committee members including Manoj Shukla, Michael Young, Majdi Abou Najm, Robert Heinse, and Ryan Stewart.
5. The group discussed the project fund and treasurer. Currently, Robert Heinse manages the funds for the annual meeting. After some talk about previous history of the fund management, Michael Young motioned for Robert to continue to serve as treasurer, which was seconded by Majdi Abou Najm. The motion carried with unanimous approval.
6. The group next discussed the need to acknowledge NIFA support in publications, including referencing collaborations made possible through W3188/W4188.
7. Nominations were solicited for the 2020 group secretary. Fred Zhang was nominated by Wei Zhang, and seconded by Ryan Stewart. Fred was elected with a unanimous vote.
8. The 2021 meeting will be held from January 3rd (noon start) until January 5th (noon end), 2021. The Desert Research Institute will again host the meeting.
9. A discussion ensued about possible corporate sponsorship for a social during the 2021 meeting. Pros, cons and expectations were mentioned. The conversation then shifted towards the possibility of bringing in an external speaker to help the group think about other challenges that may be addressed by soil physics. The group had support for that idea, and a subsequent session had people provide ideas for potential topics.

Sean Schaeffer (University of Tennessee) discussed microbial carbon utilization and aggregate stability response to precipitation and drought. The project goals were to analyze microbial resistance and resilience to perturbation, analyze long-term shifts in carbon utilization due to cyclical wetting and drying cycles, and evaluate effects of chronic versus acute stress. The results showed that wetting alters microbial enzymatic ratios of C:N, C:P, and N:P, and soil organic matter can be destabilized with more frequent wetting.

Ray Anderson (USDA ARS) discussed persistent effects of brackish groundwater use on almonds. He and collaborators used eddy covariance methods to partition evaporation, transpiration, and gross primary production, and found that high salinity resulted in higher mortality and lower gross primary production. Under low salinity conditions evaporation was constant from 15 to 30 degrees C, then all treatments have less evaporation when air temperatures exceed 30 degrees C.

Toby Ewing (Climate Corp) discussed the possibilities and potential pitfalls of digital agriculture, placing different technologies on the “innovation hype curve”. Soil physics has a role to play as agriculture becomes increasingly data-driven.

Gabrielle Boisrane, Yuan Luo, and Rose Shillito presented updates from the Desert Research Institute. Gabrielle showed results comparing soil moisture measurements in different lysimeters; Yuan talked about moisture dynamics of near-surface desert soil; and Rose presented her measurements and models regarding infiltration dynamics into water repellent soils.

John Nieber (University of Minnesota) discussed several ongoing projects, including stormwater management in highway swales, characterization of moisture retention and hydraulic properties for oil-contaminated soils, mapping water content storage in Minnesota, evaluating nitrogen reducing BMPs, modeling soil piping processes, and using machine learning to model hydrological processes.

Markus Tuller (University of Arizona) presented results from the TERRA-REF project, which included physicochemical characterization of soil properties. He presented data from a beta-test of the Campbell Scientific SoilVUE sensor, and showed issues with compaction around the installation borehole when installed under saturated conditions versus preferential flow along the instrument in other situations.

Fred Zhang (PNNL) discussed modeling approaches to characterize performance of surface barriers to prevent migration of radioactive materials in subsurface storage units. He considered pore-size specific flows, and showed that drainage and solute transport velocities differed.

Thijs Kelleners (University of Wyoming) presented results from a student on subsurface structure and flow regime for Rocky Mountain hillslopes with different geologies. He used time-lapse ERT, seismic refraction, and hydrological monitoring and modeling. His techniques could identify water- versus air-filled soil and water- versus air-filled rock, and he then discussed some efforts to inverse solve for porosity profiles.

Meeting closed for the day at 5:30 PM.

January 3, 2020. Chair brought the house to order at 8:30 AM.

Ryan Stewart (Virginia Tech) described projects to better quantify soil health, measure aggregate stability, soil respiration and soil organic carbon dynamics, and studies to quantify antibiotic transport and urban hydrology.

Jack Brookshire (Montana State University) discussed nutrient cycling dynamics in tropical forests and the northern Great Plains. The northern Great Plains are becoming greener, due to a 30% increase in water-use efficiency since 1970 (likely due to CO2 ferilization). Nitrogen availability is decreasing, meaning that a bottleneck will likely form. The tropics are likely to be nitrogen saturated, which may explain why they export 10x as much DIN as temperate forests.

Thomas Harter and Hanna Ouaknin (UC Davis) discussed basin-scale groundwater sustainability and non-point pollution in irrigated agriculture, focusing on nitrate transport. The groundwater modeling was compiled into a decision-making tool that can help growers in their practices.

Elia Scudiero (USDA ARS and UC Riverside) discussed efforts to use digital agronomy to map and monitor turfgrass cooling effects, forecast orchard yields, and manage irrigation and field salinity. One result presented showed an inverse relationship between distance from irrigation drip source and electrical conductivity (ECe).

Salini Sasidharah (UC Riverside) presented water recharge management strategies, focusing on drywells. She used HYDRUS-2D with various modifications to examine recharge, effect of soil heterogeneity, and pore-scale virus removal in the vadose zone.

Hoori Ajami (UC Riverside) examined global groundwater recharge, then focused on mountain recharge systems and water partitioning. Using Parflow CLM, she found that potential recharge varied by elevation and that 85% of groundwater recovers within 10 years following drought, but recovery time increases with drought severity. Topography was important for lag times in shallow groundwater systems while precipitation was more important in deeper systems.

Robert Heinse (University of Idaho) studied hydraulic properties and spacing/orientation of terrasettes, which are natural soil terraces that likely form from ungulate traffic and freeze thaw. He also discussed work on a farm-to-table collaboration and studying freshwater dynamics in low-lying islands that are experiencing vegetation changes.

Scott Jones (Utah State University) discussed work on an SBIR project to commercialize a thermoTDR sensor. So far, the team has put all circuitry onto a single PCB and is now trying to thermally isolate the rods to improve performance.

Manoj Shukla (New Mexico State University) discussed efforts in teaching soil physics, using machine learning to understand water content dynamics, studying salt stress in tomatoes, and sustainable usage of brackish groundwater and RO concentrate.

Majdi Abou Najm (UC Davis) described efforts to lead a recent special issue in Vadose Zone Journal, and then presented research on studying pore structure using innovative methods such as liquid latex and non-Newtonian fluids. He concluded by discussing challenges and successes in teaching undergraduate soil physics.

Jingyi Huang (University of Wisconsin) discussed applications of proximal and remote sensing in soil management, including soil water mapping, identifying variations in texture and yield, and a case study to compare profile moisture sensors versus other types.

Brian Hill (Oregon State University) presented results from his M.S. project to evaluate and model the effects of solarization on weed suppression. He found that if the peak temperature was less than 48 degrees C there was little mortality and if temperature exceeded 53 deg C there would be 100% seed mortality in one day.

Wei Zhang (Michigan State University) discussed antibiotic resistance in soil, plant and water systems. He found that antibiotic exposure changed antibiotic resistant genes and soil microbes, and that soil type matters more than antibiotic concentration or exposure time.

Iael Raij-Hoffman (UC Davis) presented work studying salt, leaching, and nitrogen dynamics using both SWAT and HYDRUS. She also presented field measurements from an NRCS-funded project on conservation effects on nitrogen leaching in tomatoes.

Meeting adjourned at 5:00 PM.

**Accomplishments**

**Short-term Outcomes**

University of Arizona (Markus Tuller)

(1) Physically and hydrologically characterized the TERRAPHENOTYPING – REFERENCE (TERRA-REF) field site at 15-cm voxel resolution to establish a comprehensive database for the discovery and modeling of fundamental relationships between soil and plant reflectance, soil water status, and evapotranspiration.

(2) Evaluated the applicability of the ecoTech Tensiomark matric potential sensor for *in situ* determination of the soil water characteristic (SWC).

(3) Beta-tested the Campbell SoilVUE TDR soil moisture profiling probe for different soils and boundary conditions.

(4) Validated our OPtical TRApezoid Model (OPTRAM) with sub-cm resolution Vis-NIR and SWIR observations obtained with the TERRA-REF platform for potential precision agriculture applications in collaboration with the University of Minnesota and Utah State University.

(5) Collaborated with the University of Minnesota and Utah State University to expand our analytical model for estimation of land surface net water flux from near-surface soil moisture observations to the global scale.

(6) Developed new approach to determine soil specific surface area from Vis-NIR reflectance spectra and water vapor adsorption isotherms in collaboration with Aarhus University.

University of Arizona (Karletta Chief)

(1) Conducted experiments on lysimeter soil to determine water retention characteristics.

(2) Through a $3M NSF NRT Grant secured in 2017, 12 Graduate Students began their research in Indigenous Food, Energy, and Water Security and Sovereignty and were trained on how to work with Indigenous Communities on FEWS research topics. Through this grant, we worked extensively with Tribal Colleges and Universities particularly Dine’ College. We built an off-grid solar powered water treatment system that Navajo communities who do not have access to electricity or clean water and are vulnerable to contaminated waters, can use this system to access drinking water. We also worked with farming communities around Dine’ College to address food sovereignty and trained key community leaders in food production.

(3) Presented results of analysis of 850 environmental samples collected in Navajo Farming Communities within one year after the Gold King Mine Spill of 2015.

University of California-Riverside (Jirka Simunek)

We continue 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.

University of California-Riverside (Laosheng Wu)

(1) Developed numerical and data analysis methods for predicting gas, water and solute transport in porous media and in groundwater;

(2) Evaluated management practices to maximize salinity leaching and minimize nitrate leaching in irrigated croplands.

University of California (Thomas Harter)

(1) Developed improved fertigation practice in nut crops to reduce nitrate leaching.

(2) Continued intensive monitoring of water and nitrogen fluxes, including groundwater recharge and nitrate leaching in a commercial-scale nut orchard.

(3) Continued development of a nonpoint source groundwater nitrate effects assessment tool.

(4) Worked to better understand the Role of Agricultural Managed Aquifer Recharge in Sustainable Groundwater Management.

University of Delaware (Yan Jin)

(1) Demonstrated that natural nanoparticles (NNP, 2.3-100 nm) and fine colloids (100-450 nm), which are conventionally considered as part of the dissolved fraction (< 450 nm), are quantitatively significant in depressional wetlands.

(2) Continued progress on characterizing both organic and inorganic elements among NNP, fine colloid, and particulate fractions (450-1000 nm) using inductively coupled plasma mass spectrometry (ICP-MS).

(3) Successful progress on examining microbial and oxygen dynamics along preferential flow paths has led to further examination of microbial community structure at these locations for deeper insight into carbon dynamics.

(4) Continued progress on examining the effects of rhizobacteria on soil physical and hydraulic properties using novel experimental technique and on elucidating possible mechanisms for these changes using various mutant strains.

(5) Studied the role of air-water interface and contact line (in the form of micro- and nano-bubbles) in colloid detachment on rough surfaces.

(6) Continued collaborations with former students/postdocs: Dengjun Wang (EPA), Chongyang Shen (China Agricultural University), and Jae-Soo Chang (Korean Maritime and Ocean University).

Iowa State University (Robert Horton) and North Carolina State University (Joshua Heitman)

(1) We showed that bulk density changes following disturbance (tillage and traffic) create substantial changes in soil porosity, thermal properties and hydraulic properties.

(2) We developed measurement methods using both fabricated and commercial sensors to determine in situ changes in soil density and porosity.

(3) We developed and tested models that account for dynamic effects of water content, bulk density, soil hydraulic conductivity and soil thermal properties.

Oregon State University (Maria Dragila)

(1) Vadose Zone Aeration:

1. Completed three manuscripts associated with vadose zone aeration

(2) Soil Solarization:

1. Processed data from three field seasons
2. Developed model to assess solarization success during application
3. Graduated one MS student

Oregon State University (Carlos Ochoa)

(1) Installed two additional stations to monitor soil moisture, temperature, and conductivity fluctuations in juniper woodlands of central Oregon.

(2) Installed two stations to monitor soil moisture, temperature, and conductivity fluctuations in a sagesteppe rangeland location in eastern Oregon.

(3) Installed six stations to monitor soil moisture, temperature, and conductivity fluctuations in a riparian area, a meadow pasture, a non-irrigated pasture, and an irrigated pasture in western, Oregon.

(4) Performed data collection and analyses of soil physical properties from the three sites mentioned above.

U.S. ARS – Bushland, TX (Robert Schwartz and Steven Evett)

(1) Fourth year of beta-testing of irrigation scheduling supervisory control and data acquisition system was completed in four states, with associated testing of new soil water sensors and wireless infrared thermometers.

(2) New node and gateway system for SDI-12 sensor data collection and wireless transmission to field edge followed by upload over cellular telephone network to the Internet was developed by ARS partner and CRADA partner (Acclima), used in Jordan on two watersheds, sent to Uzbekistan, used at Bushland, and used by partner in four states.

(3) An app for downloading node and gateway data from Hologram was developed and deployed to multiple partners.

(4) The TDR-315 sensor was field tested against volumetric soil sampling in South Carolina to ascertain that inconsistencies between sensor reported water contents and supposed field capacity values was not due to sensor error but to soil water dynamics in layered soils that resulted in actual water contents consistently greater than laboratory determined field capacity values.

U.S. Salinity Lab (Todd Skaggs, Scott Bradford, Ray Anderson and Elia Scudiero)

(1) Improved flux variance similarity algorithm for partitioning ET and CO2 fluxes into their constitutive components.

(2) Improved methods for delineating management zones in precision ag operations.

(3) Improved understanding of Managed Aquifer Recharge.

Utah State University (Scott Jones)

(1) A prototype thermo-time domain reflectometry (T-TDR) sensor was developed from a USDA-SBIR grant received by Acclima Inc. and Utah State University.

(2) The Utah State-wide soil moisture mapping capability developed in 2018 is being extended in collaboration with the Utah Climate Center to provide forecasting of soil moisture and weather across the state.

(3) Morteza Sadeghi (now U Minnesota) developed a net water flux algorithm to employ SMAP estimates of near-surface soil moisture coupled with GRACE satellite estimates of ground water to determine monthly estimate of net water flux in collaboration with The University of Arizona (*Markus Tuller and Ebrahim Babaeian*).

(4) Kshitij Parajuli’s research regarding stony soil influence on hydraulic properties was extended to the Noah-MP Land Surface Model using single column simulations and compared to measured data at the Reynolds Creek Watershed.

Virginia Tech (Ryan Stewart)

(1) Tested a new mesh-based datalogger system that was developed from a DOE-SBIR grant received by IWT, Inc., Virginia Tech, and Pacific Northwest National Laboratories.

(2) Developed new low-cost and open-source methods using Arduino-based sensors to characterize soil microbial respiration and activity.

(3) Developed an analytical model to estimate infiltration and wetting in macroporous soils.

(4) Developed an analytical model that differentiates between overland flow mechanisms that is applicable to urban and reference soil profiles.

(5) Produced a web-based calculator that farmers and other producers can use to estimate soil health and crop productivity benefits based on cover crop usage.

Washington State University (Markus Flury and Joan Wu)

(1) We demonstrated that biodegradable mulch films macroscopically degradation in compost; however, micro- and nanoparticles, most likely carbon black, were released.

(2) We showed that biodegradable plastic mulches may be a viable alternative to polyethylene. However, evaluation under long-term studies is needed to better establish their effects on soil health.

(3) We assessed the colloidal stability of low and high temperature biochar colloids as a function of solution chemistry (ionic strength, humic acid concentrations).

(4) We developed a new method to determine the surface hydrophobicity of clay films.

**Outputs**

University of Arizona (Markus Tuller)

Research results were disseminated in collaboration with various involved groups through 9 peer-refereed international journal publications, 1 book chapter, and 16 conference contributions.

University of Arizona (Karletta Chief)

Research results and extension programs were disseminated through 2 referred article, 6 videos, 3 interviews, 3 newsletters, 6 seminars/webinars, 6 symposia presentations, 3 invited international talks, 6 submitted conference presentations, 4 guest lectures, 17 extension presentations, 2 society presentations, 5 tribal IRB presentations, and hosted 6 training workshops.

University of California-Riverside (Amir Haghverdi)

Multiple publications (in revision and published) focusing on measurement and estimation of soil hydraulic properties and field-level soil heterogeneity.

University of California-Riverside (Hoori Ajami)

Published 3 journal articles related to groundwater recharge processes, quantifying uncertainty of remotely sensed leaf area index (LAI) products in ecohydrologic models, and incorporating hillslope hydrology in Earth System models. Two journal articles are currently under review and 11 conference abstracts were published in 2019 (3 invited talks); co-chaired sessions at SSSA 2019 and AGU Fall meeting 2019. Gave 2 invited public presentations as part of the Cadiz Water project and California Agriculture summit at UC Riverside. Taught 2 upper division undergraduate course regarding principles of Groundwater science (4 units), and Spatial analysis and remote sensing for environmental sciences (4 units). Served on 1 MS thesis committee and 5 PhD qualifying exams, and served as an Associate Editor of California Agriculture and Hydrological Sciences Journals.

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 (see the publication section below). 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.

University of California-Riverside (Laosheng Wu)

Research results were disseminated through peer-refereed international journal publications, outreach presentations, and classroom teaching.

University of California-Davis (Majdi Abou Najm)

Research findings were disseminated via: 4 publications in peer-reviewed journals; 1 Editorial; Special Issue on nonuniform preferential flow in porous media was completed with 17 peer reviewed contributions published in Vadose Zone Journal; and 8 invited talks.

University of California-Davis (Thomas Harter)

Research results were disseminated through publications, white papers, and over 90 presentations, invited lectures, workshop presentation, public outreach event presentations and discussions, short course lectures, stakeholder meetings, grower meetings.

University of Delaware (Yan Jin)

Initiated collaboration with Dr. Kravchenko and publication in Vadose Zone Journal. Research results were presented at regional, national and international conference.

Iowa State University (Robert Horton) and North Carolina State University (Joshua Heitman)

Research results were disseminated in collaboration with various involved groups through peer-reviewed journals and presentations at regional, national, and international conferences.

University of Kentucky (Ole Wendroth)

Research results were disseminated in 8 scientific peer-reviewed journal articles (+3 accepted but not yet in press), during field days, and commodity group meetings, and to audiences at scientific meetings (Kentucky Water Resources Research Institute Meeting, Soil Science Society of America, and Tri-Society ASA-CSSA-SSSA meeting). One invited short courses on Spatial and Temporal Statistics was held at University of Lleida, Spain, 01/19/19 – 01/30/19. Three invited presentations, and nine conference presentations. Three Ph.D. dissertations (2 major advisor, 1 committee member) completed and defended; one M.S. thesis completed and defended (committee member). Handled 275 scientific manuscripts as journal chief editor (Soil & Tillage Research), and reviewed 19 manuscripts for various journals.

Michigan State University (Wei Zhang)

Studied environmental processes and impacts of engineered nanoparticles and antibiotic resistance in soil, water and plant systems. Published 10 peer-reviewed journal articles and gave 15 conference presentations that were relevant to this project.

University of Minnesota (John Nieber)

Research results were disseminated in three peer-reviewed journal articles, and to audiences at scientific meetings/seminars (Minnesota Water Resources Conference, American Geophysical Union, COMSOL Conference, and to the Water Resource Sciences Graduate Student seminar). Ten conference/seminar presentations. Four MSc. theses (3 major advisor, 1 committee member) completed and defended. Handled 95 scientific manuscripts as journal editor (Hydrological Processes Journal), and reviewed 20 manuscripts for various journals.

New Mexico State University (Manoj Shukla)

Research findings were disseminated via refereed journal publications, conference proceedings, and a number of presentations at national and international meetings (see the publication section below). A low-cost datalogger was developed for recording soil moisture and soil temperature data, and is currently in use in the experimental farm.

Oklahoma State University (Tyson Ochsher)

Published a paper describing a new approach for estimating deep drainage in Vadose Zone Journal (Zhang et al., 2019). Made available deep drainage estimates for the state of Oklahoma at <http://soilmoisture.okstate.edu/html/drainage-map.html>. Published an extension fact sheet on nutrient loss and water quality, as impacted by deep drainage (Wyatt et al., 2019).

Oregon State University (Maria Dragila)  
Published three journal articles. Gave five conference contributions.

Oregon State University (Carlos Ochoa)  
Presented findings related to soil moisture differences at different depth in under-canopy and inter-canopy locations in juniper dominated landscapes at conferences. Presented soil moisture monitoring in three long-term, watershed-scale, study sites being established in western, central, and eastern OR locations.

University of Texas at Austin (Michael Young)

Research was disseminated in 3 published manuscripts, 5 manuscripts submitted and in various stages of review, two lectures used for Continuing Education Credits by attendees, and through presentations made at various scholarly meetings (e.g., SSSA, GSA, AGU, etc.). Gave five invited presentations, and published invited op-ed.

Texas A&M (Binayak Mohanty)

Research findings were disseminated via refereed journal publications, conference proceedings, and a number of presentations at national and international meetings. Completed the development of the Texas Water Observatory on Brazos River Basin in Texas, a testbed for better understanding of coupled water, carbon, and energy cycle at different scales.

Texas Tech University (Sanjit Deb)

Research findings were disseminated via refereed journal publications, conference proceedings, and a number of presentations at national and international meetings (see the “Publications” section below). Different water management practices were evaluated to improve our understanding of different soil- and crop-based properties and processes that affect soil-crop water relations, water balance, crop abiotic stresses and phenological responses, water use efficiency, and water withdrawals for irrigation in groundwater-dependent cotton production or other land uses (e.g., pastures, golf courses) in the southern High Plains.

U.S. ARS – Bushland, TX (Robert Schwartz and Steven Evett)

CRADA partner Acclima introduced commercial version of ARS node and gateway system, which was deployed by ARS in five states and by ICARDA and an NGO in Jordan. The node and gateway hardware and firmware allow inexpensive, low-power (solar powered) collection of data from SDI-12 sensors (CS655, TDR-315L, TDR-310S, SapIP-IRT) and transmission from node to gateway using LoRa radio protocol across cropped fields and to the Internet via cellular telephony. CRADA partner Acclima introduced new TDR-315H and TDR-310H sensors with higher speed electronics and shorter pulse rise time. Published 9 peer reviewed journal articles in 2018 and 10 in 2019. Published 8 proceedings full papers. Made 3 invited and 5 volunteered presentations.

U.S. Salinity Lab (Todd Skaggs, Scott Bradford, Ray Anderson and Elia Scudiero)  
Research findings were disseminated via refereed journal publications, conference proceedings, and presentations at national and international meetings. Updated software for partitioning water and carbon fluxes measured with eddy covariance systems (<https://github.com/usda-ars-ussl/fluxpart>). Improved design of drywells to enhance recharge and avoid clogging.

Utah State University (Scott Jones)

Research results were disseminated in collaboration with colleagues in the US and China through 9 peer-refereed international journal publications, one professional magazine article and 12 conference oral/poster- or invited talk-contributions. practices

Virginia Tech (Ryan Stewart)

Research findings were disseminated via 10 publications in peer-reviewed journals and 21 conference abstracts and presentations (2 invited).

Washington State University (Markus Flury and Joan Wu)

Published research results in peer-reviewed journals and presented the research results in national and international conferences (Soil Science Society Annual Meeting; American Society of Agricultural and Biological Engineers; European Geoscience Union), and invited talks in China and Germany. Gave several interviews regarding the use of biodegradable plastics in agriculture to news outlets (BBC, scienceline.org). Served on an expert panel and testified before the USDA Organic National Standard Board on the use of biodegradable plastic mulch films. Published a review article on biodegradable plastic mulch films in agriculture.

University of Wisconsin Madison (Jingyi Huang)

Research results were disseminated in 6 scientific peer-reviewed journal articles, during the visits with stakeholders and to audiences at Soil Science Society of America Annual Meeting and Proximal Soil Sensing Workshop

University of Wyoming (Thijs Kelleners)

Two journal papers on cold region hydrology were published as part of the PhD dissertation research of Andrew Fullhart. One additional paper was published on soil reclamation as part of the MS thesis research of Samantha Day.

**Activities**

University of Arizona (Markus Tuller)

(1) Remote Sensing of Earth Surface Processes. In collaboration with the University of Minnesota and Utah State University we continued to extensively work on the development of novel measurement and remote sensing techniques for characterization of large-scale near surface processes and basic soil properties. Below are a few research highlights accomplished in 2019.

(2) Hydrologic and Physical Characterization of the TERRAPHENOTYPING – REFERENCE (TERRA-REF) field site (Ebrahim Babaeian, Juan R. Gonzalez Cena, Mohammad Gohardoust, Xiaobo Hou, Scott A. White, and Markus Tuller): We physically and hydrologically characterized the root zone (0-90 cm) of the TERRA-REF field site in Maricopa, AZ at 15-cm voxel resolution. We first applied Electromagnetic Induction (EMI) sounding to strategically select sampling locations with EASP-RSSD, a response surface sampling design software package for generation of the optimal sampling locations. Once the optimal locations were determined, 90-cm long and 3.2-cm diameter core samples were immediately extracted and split into 15-cm increments. The extracted samples were analyzed for water content, bulk density, porosity, OM, pH, EC, CaCO3 content, and texture (sand, silt, clay) and ordinary kriging was applied to generate the 3-D data volumes. In addition, we extracted a number of core samples across the field to determine the soil water characteristic (SWC) and hydraulic conductivity with a HYPROP instrument (METER Group, Inc., Pullman, WA, USA). We also measured the SWC in situ at several locations, pairing Acclima True-TDR moisture sensors (Acclima, Inc., Meridian, Idaho, USA) with ecoTech Tensiomark matric potential sensors (ecoTech Umwelt-Meßsysteme, Bonn, Germany). The data will be published in Earth System Science Data (ESSD) in 2020. Together with the sub-cm resolution TERRA-REF scanner data (i.e., Vis-NIR, SWIR, thermal, laser, etc.) to be published in Nature Scientific Data in 2020, this will provide an unprecedented dataset for the discovery of fundamental relationships between soil and plant reflectance, soil water status, and plant physiological responses, and allow the development of novel physical remote sensing top-of-canopy/root-zone models linking belowground processes to evapotranspiration, biomass production, and plant health.

(3) A New Optical Remote Sensing Technique for High-Resolution Mapping of Soil Moisture (Ebrahim Babaeian, Paheding Sidike, Maria Newcomb, Maitiniyazi Maimaitijiang, Scott White, Jeffrey Demieville, Richard Ward, Morteza Sadeghi, David LeBauer, Scott Jones, Vasit Sagan, and Markus Tuller): The recently developed OPtical TRapezoid Model (OPTRAM) has been successfully applied for watershed scale soil moisture (SM) estimation based on remotely sensed shortwave infrared (SWIR) transformed reflectance (TRSWIR) and the normalized difference vegetation index (NDVI). We evaluated OPTRAM for field scale precision agriculture applications using ultrahigh spatial resolution optical observations obtained with one of the world’s largest field robotic phenotyping scanners located in Maricopa, Arizona. We replaced NDVI with the soil adjusted vegetation index (SAVI), which has been shown to be more accurate for cropped agricultural fields that transition from bare soil to dense vegetation cover. The OPTRAM was parameterized based on the trapezoidal geometry of the pixel distribution within the TRSWIR-SAVI space, from which wet- and dry-edge parameters were determined. The accuracy of the resultant SM estimates was evaluated based on a comparison with ground reference measurements obtained with Time Domain Reflectometry (TDR) sensors deployed to monitor surface, near-surface and root zone SM. The obtained results indicate an SM estimation error between 0.045 and 0.057 cm3 cm-3 for the near-surface and root zone, respectively. The high resolution SM maps clearly capture the spatial SM variability at the sensor locations. These findings and the presented framework can be applied in conjunction with Unmanned Aerial System (UAS) observations to assist with farm scale precision irrigation management to improve water use efficiency of cropping systems and conserve water in water-limited regions of the world.

(4) Global Estimates of Land Surface Water Fluxes from SMOS and SMAP Satellite Soil Moisture Data (Morteza Sadeghi, Ardeshir Ebtehaj, Wade Crow, Lun Gao, Adam Purdy, Joshua Fisher, Scott Jones, Ebrahim Babaeian, and Markus Tuller): In-depth knowledge about the global patterns and dynamics of land surface net water flux (NWF) is essential for quantification of depletion and recharge of groundwater resources. Net water flux cannot be directly measured and its estimates as a residual of individual surface flux components often suffer from mass conservation errors due to accumulated systematic biases of individual fluxes. Here, for the first time, we provide direct estimates of global NWF based on near-surface satellite soil moisture retrievals from the Soil Moisture Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP) satellites. We apply a recently developed analytical model derived via inversion of the linearized Richards’ equation. The model is parsimonious, yet yields unbiased estimates of long-term cumulative NWF that is generally well correlated with the terrestrial water storage anomaly from the Gravity Recovery and Climate Experiment (GRACE) satellite. In addition, in conjunction with precipitation and evapotranspiration retrievals, the resultant NWF estimates provide a new means for retrieving global infiltration and runoff from satellite observations. However, the efficacy of the proposed approach over densely vegetated regions is questionable, due to the uncertainty of the satellite soil moisture retrievals and the lack of explicit parameterization of transpiration by deeply rooted plants in the proposed model. Future research is needed to advance this modeling paradigm to explicitly account for plant transpiration.

(5) Combining visible near-infrared spectroscopy and water vapor sorption for soil specific surface area estimation (Maria Knadel, Lis de Jonge, Markus Tuller, Hafeez Rehman, Peter Jensen, Per Moldrup, Mogens Greve, and Emmanuel Arthur). The soil specific surface area (SSA) is a fundamental property that governs a wide range of soil processes and behaviors relevant for numerous engineering, environmental, and agricultural applications. Capitalizing on the excellent reproducibility and rapidity of spectroscopic and vapor sorption measurements, we developed a method for SSA determination based on a combination of visible near-infrared spectroscopy (vis–NIRS) and vapor sorption isotherm measurements. Two models for water vapor sorption isotherms (WSI) were used: The Tuller–Or (TO) model and the Guggenheim–Anderson–de Boer (GAB) model. They were parameterized with sorption isotherm measurements and applied for SSA estimation for a wide range of soil types (N=270) from 27 countries. The generated vis–NIRS models were further compared with models where the SSA was determined with the ethylene glycol monoethyl ether (EGME) method. Moreover, three types of regression techniques including machine-learning methods (partial least squares; PLS, support vector machines; SVM, and artificial neural networks; ANN) were tested and compared. The performance of all SSA models was mainly dependent on the range and variation in SSA values. However, an independent validation indicated very good and nearly identical estimation capabilities for SSATO, SSAGAB, and SSAEGME, with an average standardized root mean square error (SRMSE= RMSE/range) of 0.05, 0.06 and 0.05, respectively. In general, the machine-learning techniques (especially SVM) performed better than PLS regression. The results of this study indicate that the combination of vis–NIRS with the WSI as a reference technique for training vis–NIRS models can provide SSA estimations akin to the EGME method.

University of Arizona (Karletta Chief)

(1) Under the Superfund Research Program, I am working with tribal communities impacted by mining activities. The largest project is the Gold King Mine Dine’ Exposure Project where we have focused on disseminating results, gaining approval from the Navajo Nation to disseminate results, and writing up the results. Also, I have hosted 6 training workshops (listed below) and involve outreach and training in tribal communities as well as training on-campus scientists about environmental challenges facing Indigenous communities, learning about Indigenous Knowledge and how to work with Indigenous communities. Six videos were developed to summarize the research, partnership and outreach with the Navajo Nation in the aftermath of the Gold King Mine Spill.

(2) I am the PI of the NSF NRT Indigenous Food Energy and Water Security and Sovereignty. I have recruited 12 graduate students and developed a new PhD Minor entitled Indige FEWS. We developed a video to recruit and advertise our program at: NSF NRT "[Indigenous Food Energy and Water Security & Sovereignty or Indige-FEWSS](https://energy.arizona.edu/indigefewss)." During the summer 2019, we conducted a FEWS Training at Dine’ College for tribal college students and held a community outreach event where trained tribal college students presented on an off-grid mobile solar powered water treatment system. Two of the tribal college students came to the UA to conduct their research on FEWS. One student presented at the Society for the Advancement of Chicanos and Native Americans in Science National Conference and won an award for Exceptional Presentation in . His poster is entitled “Using Organic Photo-Voltaics to Regulate Photobioreactor Temperatures & Improve Algae Growth’.

(3) I have an NSF Workshop Grant called “Water in the Native World” in collaboration with Indigenous hydrology and water related professors including a professor from the Salish Kootenai Tribal College (SKC). SKC has the only tribal bachelors hydrology program in the United States. In 2018, I wrote an opinion piece during Native American Heritage Month in On the Prow “A Challenge to AGU to Include Indigenous Perspectives in Science. American Geophysical Union Blogosphere. From the Prow, November 26, 2018. <https://fromtheprow.agu.org/in-honor-of-native-american-heritage-month-a-challenge-to-agu-to-include-indigenous-perspectives-in-science/>. This piece stimulated more activities including the following. I presented at the GeoScience Alliance meeting by holding a session. We explored international collaboration with the Maori people of New Zealand in regards to water challenges their communities face. We attended an international conference and visited Maori communities. We also gained traction at AGU through an annual session on Native Science to Action session in Public Affairs that bridges western science with Indigenous knowledge and science. We also wrote an article in EOS.

(4) I am Co-PI on USDA grant “Native Waters on Arid Lands” and work with tribes on water challenges such as drought, water management, and climate change. We are looking at how Indigenous Knowledge plays a role in tribes’ adapting to climate change. Interviews were analyzed and preliminary results were written up.

(5) I received 2 national awards 2019 Friends of UCOWR Award, University Council on Water Resources (UCOWR) and 2019 Area/Regional Impact Award, National Indian Health Board.

(6) I have 9 active grants funding my tribal extension hydrology programs.

University of California-Riverside (Amir Haghverdi):

In 2019, undisturbed soil samples were collected from multiple irrigation fields in Southern and Central California. The samples were analyzed using state of the art HYPROP and WP4C instruments for high-resolution measurement of soil hydraulic properties including the soil water retention curve and the soil hydraulic conductivity.

University of California-Riverside (Hoori Ajami)

(1) Added new uncertainty quantification framework to SMART, in collaboration with Mojtaba Sadegh, Boise State University.

(2) Evaluated SMART model performance across Australian catchments, in collaboration with Ashish Sharma, University of New South Wales Australia.

(3) Quantified the combined impacts of woody plant encroachment and climate change on groundwater recharge processes.

(4) Improved mountain system recharge predictions in the Sierra Nevada.

(5) Performed multi-criteria assessment of integrated land surface-groundwater models for mountain system recharge prediction in Sierra Nevada.

(6) Assessed the impacts of droughts on groundwater response time.

University of California-Riverside (Jirka Simunek)

(1) In 2019, we offered three-day short courses on how to use HYDRUS models at a) Czech University of Life Sciences, Prague, Czech Republic, b) Colorado School of Mines, Golden, CO, c) Indian Institute of Technology (IIT) Mandi, Mandi, Himachal Pradesh, India, and d) the Sede Boker Campus of the Ben Gurion University, Israel. About 100 students participated in these short courses.

(2) Attended the following meetings:

* + 1. Annual Meeting of Soil Science Society of America, San Diego, California, 9-11, 2019.
    2. W-3188 Western Regional Soil Physics Group Meeting, U.S. Salinity Laboratory, Riverside, California, January 10-11, 2019.
    3. W-3128 Western Regional Soil Physics Group Meeting (Scaling Microirrigation Technologies to Address the Global Water Challenge), San Antonio, Texas, November 10, 201.
    4. Annual Meeting of Soil Science Society of America, San Antonio, Texas, November 10-13, 2019.

(3) Taught the following courses related to HYDRUS:

* + 1. A short course “Advanced modeling of water flow and contaminant transport in porous media using the HYDRUS software packages” organized by Czech University of Life Sciences, Prague, Faculty of Agrobiology, Food and Natural Resource, Prague, Czech Republic, March 25-27, 2019. Sole instructor (30 participants).
    2. A short course “Modeling Water Flow and Contaminant Transport in Soils and Groundwater Using the HYDRUS Computer Software Packages”, Colorado School of Mines, Golden, CO, June 10-12, 2019. Sole instructor (11 participants).
    3. A short course “International Workshop on Modeling Water Flow and Contaminant Transport in Soils and Groundwater Using the HYDRUS Computer Software Packages”, Indian Institute of Technology (IIT) Mandi, Mandi, Himachal Pradesh, India, September 9-11, 2019. Sole instructor (35 participants).
    4. A short course “Modeling Water Flow and Contaminant Transport in Soils and Groundwater Using the HYDRUS Computer Software Packages”, at the Sede Boker Campus of the Ben Gurion University, Israel, September 17-19, 2019. Other instructor: N. Lazarovitch (25 participants).

University of California-Riverside (Laosheng Wu)

Outreach: Organized a workshop on salinity management in Central California; Gave presentations to various academic and non-academic groups;

Research: Worked on the following on-going projects:

# (1) Worked on decision Support for Water Stressed FEW Nexus Decisions (DS-WSND). NSF INFEWS. Collaborator. 01/01/2018 to 12/30/2020.

# (2) Worked on Hispanic-Serving Institutions (HSI) Education Grants Program. USDA/NIFA. Co-PI. 10/01/2016 to 08/01/2020.

(3) Optimized 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.

(4) Enhanced site-specific turf irrigation management and developing turf deficit irrigation strategies using soil moisture sensors, smart ET-based irrigation controllers, and remote sensing. US Golf Association. Co-PI. 01/2018-12/31/2019.

University of California-Davis (Majdi Abou Najm)

(1) Developed a physically based model for extracting dual-permeability parameters using non-Newtonian fluids: a model was derived and validated with experimental sand columns and capillary tubes simulating a dual permeability soils, and showing that the new approach can be used for extracting dual permeability parameters of soils using physically based experimental approaches.

(2) Developed a validation method of previously developed model for characterization of the pore structure of porous media using non‐Newtonian fluids: the model was validated with synthetic soils (using combinations of different numbers of different capillary tube-sizes) and sand columns. The model provided good predictions of the number and sizes of the capillary tubes, as well as demonstrated good agreement with pore size distributions obtained from micro-CT scans of the sand columns, thus providing a validation to the newly developed method for pore structure characterization using non-Newtonian fluids.

(3) Developed educational tools for visualization of flow and transport processes in porous media using transparent soils: polyacrylamide beads were packed in transparent acrylic large column, generating a transparent porous medium, and infiltration and flow were demonstrated using dyed water. The effectiveness of this method was tested in SSC 107:Soil Physics course at UC Davis and students highly appreciated this addition. Next steps include further testing and development, followed by dissemination to the wide soil physics community.

(4) Incorporated UN Sustainability Development Goals (SDGs) into soil physics curriculum: several soil physics students expressed frustration in seeing a connect between the concepts they study in soil physics and what they foresee as “the real world”. I developed a one-week (three lectures) educational module that connects key soil physics elements into policy, and contemporary concepts including regional development, SDGs, and the water-energy-food nexus. One question from the take-home final was on the connections between soil and the SDGs which was highly appreciated by the students, and gave them a better perspective of how helpful soil physics can be at scales that they could not make the connection before.

(5) Served as lead guest editor in Vadose Zone Journal: Special Issue on nonuniform preferential flow in porous media was completed with 17 peer reviewed contributions published in Vadose Zone Journal.

University of California-Davis (Thomas Harter)

(1) For the second year, we managed a privately owned and operated 140-acre almond orchard, jointly with the grower, to reduce the nitrogen inputs to the orchard while maintaining yields. The grower is managing the orchard in 4 irrigation blocks, all of which utilize micro-irrigation. Prior to 2018, the grower fertigated the orchard in six split applications. Beginning in 2018, the orchard was fertigated in 14-16 split application. Pending leaf sampling, the fall application was omitted. In 2018, we achieved a 90% nutrient use efficiency. The improved grower practice has been demonstrated to over 200 growers in three on-site field days. We presented the management practices and harvest results in over ten conferences and workshops, reaching over 1000 growers. Publications in preparation.

(2) We used the same orchard to also evaluate various monitoring strategies to assess the loss of nitrate-nitrogen to groundwater at the orchard scale (>100 acres). Prior to the 2017 growing season, we installed three monitoring networks. The first two years of monitoring demonstrated that vadose zone water and nitrate concentrations follow closely the anticipated levels based on water and nitrogen fluxes into and out of the orchard at the land surface. Groundwater concentrations were consistent with management practices prior to 2018, which have resulted in recharge water quality to the exceed nitrate drinking water limit by a factor 2. The design of this study and results of the monitoring have been presented in three on-site field days to growers and state as well as federal regulatory agency personnel. Presentations given at over ten conferences and workshops have been reaching over 1000 growers. Publications in preparation.

(3) We continued our efforts to develop and validate a nonpoint source assessment tool, but also began to collaborate with interested parties that may ultimately be using this tool. Most of our efforts have focused on the validation of the tool and understanding the role of nonpoint source heterogeneity in recharge and nitrate loading, driven by the crop, soil, and agronomic management practice variability across the landscape, aquifer heterogeneity, and the mixing of waters in well screens and gaining stream sections. Henri and Harter (2019) assessed nitrate and salt transport under highly heterogeneous aquifer conditions typical of the alluvial basins in the southwestern United States and demonstrated the wide range of nitrate and salt travel times to production wells, as a function of pumping rates and well depth. They also quantified the difference in predicting nitrate concentration at wells using simple spreadsheet calculations versus complex model predictions that account for much of the natural aquifer variability.

Significant work was undertaken to better understand how further upscaling of spatio-temporal variability in nonpoint source loading to groundwater affects the ability to appropriately predict the dynamics and range of nitrate concentrations across an ensemble of wells (county, district, township). We are particularly interested in assessing the loss of accuracy when representing groundwater flow with a steady-state flow approximation of typically highly transient seasonal groundwater flow conditions. We use the steady-state flow assumption in our regional nonpoint source effects toolbox and understanding the degree to which predictive capacity is affected by such an assumption is a critical to further development of our toolbox. The steady-state assumption allows the tool to be built in a manner allowing for several orders of magnitude speedup in nonpoint source transport modeling. We will be building an online decision-support tool. We have presented the concept of the toolbox to agricultural stakeholder representatives in three halfday workshops and are in dialogue with agricultural coalitions representing nonpoint source dischargers to evaluate the possibility of using this tool in conjunction with coalitions tools to support their nonpoint source compliance efforts (Publications submitted).

(4) The work of Ghasemizade et al. (2019) and Kourakos et al. (2019) considered the benefits of agricultural managed aquifer recharge (AgMAR) as a tool to enhance groundwater supplies in stressed aquifer systems. The approach takes advantage of winter flood flows and reservoir reoperation to increase the amount of groundwater recharge with surface water available during the wettest portion of the winter. Our work considers various temporal and spatial arrangements for AgMAR operations, considering soil suitability, recharge rates, and density of AgMAR sites across a region. The analysis further considers the benefits to groundwater storage, land subsidence, future availability of water resources, and long-term improvements in baseflow.

(5) Bastani and Harter (2019) considered several alternative best management practices to evaluate the dynamics and magnitude of groundwater quality improvements that may be achieved when targeting these practices specifically in the source area of public supply wells. The work focused on public supply wells in economically disadvantaged communities, which are often hardest hit by agricultural nitrate pollution, given their geographic locations. We evaluated three practices: agricultural managed aquifer recharge (AgMAR, winter recharge in orchards and fields), improved nutrient management / crop change, and the combination of both.

(6) The work by Owen et al. (2019) analyzed policy challenges faced by groundwater sustainability agencies attempting to bridge conflicting objectives between federal and state laws operating at the interface between surface water management, groundwater management and ecosystem protection. Through a series of workshops we solicited a broad range of perspectives, which we further classified and structured from legal and hydrological perspectives to outline potential approaches to meeting these challenges and guidance to groundwater management agencies.

University of Delaware (Yan Jin)

(1) We successfully completed 2-year long filed sampling form a freshwater Delmarva Bay depressional wetland. Pore-water samples were collected from 50, 100, and 200 cm depths below the soil surface along the transects delineated as upland, transition, and lowland to determine the effects of wetland hydrology on the dynamics of colloids and associated colloidal organic carbon. We measured changes in different environmental parameters (pH, Ec, Eh, water table depth, precipitation), stable δ13C and δ15N isotope signatures, and elemental composition of size-fractionated particles.

(2) Conducted laboratory experiments using 2D chambers to further demonstrate that preferential flow paths are biological hotspots and evaluate the changes in microbial community structure upon carbon addition.

(3) Conducted neutron and X-ray tomography imaging of pure sand samples with or without the presence of rhizobacteria to exam the difference of water distribution affected by rhizobacteria.

(4) Conducted infiltration and evaporation experiments to quantify the patterns of rhizobacteria's influence on water retention. To understand the mechanisms involved, we measured pellicle formation, contact angles, and surface tension profile of both the wild type and its mutant strains.

Iowa State University (Robert Horton) and North Carolina State University (Joshua Heitman)

(1) We tested approaches for combining remote and in-field measurements for determining evapotranspiration, water stress, and energy balance in vineyards.

(2) We evaluated changes to soil porosity, pore size distribution, water retention, hydraulic conductivity, and thermal properties following tillage and field traffic.

(3) We examined relationships between intrinsic soil properties, agronomic management, and soil health metrics.

(4) We developed and tested new measurement approaches for soil ice content, heat flux, water content, bulk density, porosity, and sap flow.

(5) We examined theoretical and empirical relationships between basic soil properties (density, texture, organic matter content) and thermal and hydraulic properties.

(6) We measured the environmental impacts and changes to soil properties associated with the application of concrete grinding residue.

(7) We compared the effects of tillage system, planting date, and irrigation on the growth and productivity of cotton.

University of Kentucky (Ole Wendroth)

(1) Performed mapping Zone delineation: Manuscript submitted and accepted (part of dissertation Javier Reyes).

(2) Submitted FFAR pre-proposal for on-farm site-specific N management; rejected.

(3) Submitted NIFA proposal letter of intent on water balance and soil structure in hemp.

(4) Continued to use RZWQM2 to simulate crop growth of different crops, nitrogen management (part of dissertation Saadi Shahadha).

(5) Completed a four-state research project on irrigation management between Kentucky, Georgia, Alabama, and Tennessee.

(6) Worked on two research projects, funded by Kentucky Small Grain Growers’ Association: “On-Farm Characterization of Soil Spatial Variability for Model-Based Site-Specific Management” and “Field-scale Characterization of Soil Structure and Hydraulic Properties for Variable-Rate Irrigation”.

(7) Taught PLS 575 Soil Physics, PLS 576 Soil Physics Lab, and PLS 486G (50%) of Soil Use and Management.

(8) Acted as faculty mentor for four Assistant Professors in our department.

Michigan State University (Wei Zhang)

We primarily focused on understanding the fate and transport of emerging contaminants as influenced by soil physical, chemical and biological factors. In addressing Objective 1, we investigated the internalization of silver nanoparticles through plant leaf stomata and the uptake of silver nanoparticles by radish in soils with and without biochar amendment (0%, 0.1% and 1% biochar by weight). Using high throughput qPCR and 16S rRNA amplicon sequencing techniques, we examined the level and type of ARGs and bacterial communities in soil, lettuce root, and shoot samples under soil-surface and overhead irrigations. Lettuce shoots under soil-surface irrigation had lower abundance and diversity of ARGs and bacteria than those under overhead irrigation, probably suggesting lower risks of producing fresh produce with high

abundance of ARGs by soil-surface irrigation. We were also studying the Salmonella survival, bacterial microbiome and antibiotic resistance genes on lettuce shoots under soil surface irrigation with antibiotics-contaminated water using culture-dependent isolation method, metagenomics and high throughput qPCR. We developed an effective and quick method to characterize organic carbon released from biochars. We studied the photocatalytic degradation of cephalexin by ZnO nanowires. Finally, we participated in MSU Multicultural Apprenticeship Program and trained two high school students on laboratory research.

University of Minnesota (John Nieber)

(1) Conducted analysis of the relation between lake volume and lake surface area and land slope in a buffer area surrounding the lake (MSc. Thesis research for Chelsea Delaney).

(2) Conducted analysis for estimation of mean travel time in the groundwater of seventeen HUC-8 watersheds located in the Upper Mississippi River Basin in central Minnesota; analysis was used to estimate the change in storage of water in groundwater within the watersheds based on the use of baseflow recession data (MSc. Thesis research for Xiang Li).

(3) Conducted assessment of the impact of implemented stream and riparian area BMPs on the water quality (nitrate, phosphorus, sediment) of Minnehaha Creek, a stream within the urbanized Twin Cities Metro Area. Analysis based partly on the use of the USGS EGRET model (MSc. Thesis for Jack Distel).

(4) Applied the SWAT model to assess the impact of nitrogen BMPs on water quality for streams in the South Branch of the Root River, Southeast Minnesota (MSc. Thesis for Mark Greve; thesis still in revision).

(5) Developed a model of turbulent flow through a full-flowing soil pipe, and the erosion of the pipe walls and transport of eroded sediment out of the pipe.

(6) Conducted infiltration measurements for highway swales at two highway locations using three methods, and analysis of data provided to us related to infiltration measurements conducted at other locations around the U.S.

(7) Conducted analysis of watershed water storage (for seventeen HUC-8 watersheds) using three methods; GRACE satellite, water balance model, and integration of pointwise water storage estimates.

(8) Initiated a new project (funded by the Legislative-Citizen Committee for Minnesota Resources) for modeling the transport of nitrate through karst dominated watersheds in southeastern Minnesota. The project will involve groundwater age-dating, groundwater modeling, and development of a model for nitrate transport using a simplified travel-time model.

(9) Initiated a new project (funded by the National Science Foundation) coupling physically-based models with machine learning algorithms for prediction of hydrologic and water quality outcomes in watersheds.

(10) Co-taught five courses, three fall semester and two spring semester.

(11) Served as President of the American Institute of Hydrology.

(12) Served as Director of Graduate Studies, Water Resource Sciences Graduate program.

New Mexico State University (Shukla Manoj)

In 2019, field and laboratory experiments were designed for using brackish groundwater and reverse osmosis concentrate for irrigating glycophytes and halophytes. These experiments provided new and further insight in to the ion uptake patterns, physiology, salt tolerance, and potential for use in arid saline environment.

Meetings attended:

* + 1. Annual Meeting of Soil Science Society of America, San Diego, California, 9-11, 2019.
    2. W-3188 Western Regional Soil Physics Group Meeting, U.S. Salinity Laboratory, Riverside, California, January 10-11, 2019.
    3. W-3128 Western Regional Soil Physics Group Meeting (Scaling Microirrigation Technologies to Address the Global Water Challenge), San Antonio, Texas, November 10, 201.
    4. Annual Meeting of Soil Science Society of America, San Antonio, Texas, November 10-13, 2019.
    5. 2nd annual WIN workshop, BGNDRF, Alamogordo, Oct. 28-29.
    6. Two Nation One Water Conference, WRRI, Las Cruces
    7. EBID workshop with growers, Las Cruces

Oklahoma State University (Tyson Ochsner)

*Objective 2:*

During this project period, we have analyzed, interpreted, and published new findings on the effectiveness of coupling deep soil moisture measurements and Hydrus 1D simulations to estimate deep drainage.

Oregon State University (Maria Dragila)

*Objective 1:*

(1) Analysis of soil temperature data to investigate the relationship between short weather patterns and soil heat storage which could impact solarization effectiveness.

(2) Development of a model to more accurately determine the minimum time necessary for plastic application during solarization in the Pacific Northwest.

(3) Analysis of data associated with limestone erosion during water infiltration.

Oregon State University (Carlos Ochoa)

*Objective 1:*

(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)].

(2) Field and laboratory work related with soil physical properties and water transport through the unsaturated zone.

(3) 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)].

(4) Automated field data collection at multiple locations in one watershed with juniper and one where juniper was removed 13 years ago.

University of Texas at Austin (Michael Young)

(1) Mentored undergraduate research scholar toward completion of manuscript on assessing basin scale canopy structure in the Mojave Desert.

(2) Directed research group of ~50 researchers, staff and students in environmental geosciences.

(3) Mentored three MS students, main advisor for one MS student.

(4) Member of proposal writing team for W-4188 renewal.

(5) Conducted regional scale analysis of landscape impacts from energy development, including oil and gas, wind and solar. Project initiated in 2019 and includes nearly 10 different organizations and substantial stakeholder engagement and input.

(6) Continued fundraising efforts to local foundations for the support of the Texas Soil Observation Network, which consists of ~100 monitoring stations across central and west Texas, and activities related to the NASA SMAP mission.

(7) Lead organizer of UT campus-wide initiative known as “Planet Texas 2050” that aims to build resiliency to urban and natural systems, especially those related to land and water resources. Program led to several proposals to NSF and local foundations. Received several foundation gifts to enhance community engagement and improve resiliency to hydrologic extremes.

(8) Published one computer program that uses machine learning to classify permafrost soil and a dataset on soil water content in Texas from the TxSON monitoring network.

Texas A&M University (Binayak Mohanty)

In 2019, field monitoring and laboratory experiments were designed at Texas Water Observatory sites under different land use land covers for improved understanding of soil moisture, temperature, and carbon dynamics and soil hydraulics variation from local scale to regional scale. Using ground monitoring stations, Eddy Covariance towers, and satellite observations and improved process modeling concepts, we developed a number of new soil moisture and ET retrieval, scaling, fusion, gap-filling, and forecasting techniques at multiple space-time scales.

Meetings attended:

* + 1. Annual Meeting, Soil Science Society of America, San Antonio, Texas, November 10-13, 2019.
    2. American Geophysical Union Fall Meeting, San Francisco, California, December 8-13, 2019.

Texas Tech University (Sanjit Deb)

In 2019, field and laboratory experiments and numerical simulation (Hydrus 2D/3D) were carried out to evaluate rootzone soil water processes and efficient water use in drip-irrigated cotton, vegetable and forage crop production systems under both dryland conditions and deficit subsurface drip irrigation in west Texas. Field experiments and numerical simulation were also designed to evaluate interactive effects of rootzone soil water and thermal regime on early planting “cold-tolerant” cotton production. These experiments and simulation would provide an improved understanding of crop root water uptake patterns, crop abiotic stress patterns and crop phenological response patterns under semiarid water-limited environments, as well as would assist growers in making early season planting decisions without compromising cotton seedling germination and stand establishment. An comprehensive field sampling and laboratory analyses were also carried out to evaluate soil water retention and hydraulic and thermal properties, a range of empirical models, and spatial variability of these properties across different land uses such as crop fields, pastures and golf courses in west Texas. Results of above-mentioned field and laboratory and modeling studies have been presented at national and international conferences and published in peer-reviewed scientific journals, and three manuscripts have been submitted (under review/revision) to the journals.

Meetings attended:

1. Annual Meeting of Soil Science Society of America, November 10-13, 2019, San Antonio, Texas.
2. Annual Meeting of Soil Science Society of America, January 6-9, San Diego, California.
3. 2019 Texas State Support Committee Meeting, Lubbock, Texas, December 4-5, 2019.
4. 2018 International Aridlands Conference, Lubbock, Texas, August 13-14, 2018.

U.S. ARS – Bushland, TX (Robert Schwartz and Steven Evett)

(1) Due to personnel losses from the commercial partner, we discontinued work with commercial and university partners related to a Materials Transfer Research Agreement (MTRA) to develop and test an NMR based down-hole device for determining soil water content.

(2) We continued work with a Cooperative Research and Development Agreement partner to improve new, low-cost soil water and bulk electrical conductivity sensors based on miniaturized TDR circuitry that is directly coupled to the probe waveguide. The work also included field testing of new sensors (TDR-315H and TDR-310H) at Beltsville, Maryland; Bushland, Texas; Amman, Jordan; Florence, South Carolina; Portageville, Missouri. A new Cooperative Research and Development Agreement with Acclima, Inc. was initiated in 2019 to utilize acquired waveforms from the new TDR-315H sensor for the characterization of soil properties and to improve water content calibrations specific to a given soil.

(3) We continued cooperation with ARS Beltsville in their development of a low-cost, low-power node and gateway system to gather data from SDI-12 based sensors and transmit it wirelessly from nodes to a gateway at field’s edge using the LoRa radio transmission protocol. The system was improved by addition of a cellular modem in the gateway that allows transmission of data to the Internet. At the moment, Hologram is the Internet service provider for data upload and storage. A CRADA developed with Acclima, Inc., resulted in commercial production of beta test units that were deployed nationally and in two watersheds internationally. Beta test results guided improvements and refinements of the hardware and firmware and led to our developing an app for downloading the data from Hologram.

(4) Collaboration was initiated with the Centro Regional de Estudios de Agua (CREA) University of Castilla-La Mancha, Albacete, Spain to adapt and improve irrigation scheduling strategies that involve some degree of planned or unplanned water stress. The collaboration was supported through a fellowship funded by the Organization for Economic Cooperation and Development (OECD) and entitled “Crop Stress Response Calibrations for Improved Water Use Assessments under Deficit Irrigation”. Irrigation scheduling strategies and TDR-315 sensors were evaluated under deficit and full irrigation of purple garlic during the 2017 growing season.

(5) We continued development of sensors, sensing systems, software and hardware systems and systems integration for scheduling and control of variable rate irrigation systems. This involved laboratory prototyping, testing and calibration, and field testing of system components and the entire Irrigation Scheduling Supervisory Control and Data Acquisition (ISSCADA) system on two center pivots at Bushland, Texas; and one center pivot at each of Florence, South Carolina; Portageville, Missouri; and Stoneville, Mississippi. Test results indicated yields and water use efficiency at least as good as those obtained using alternative and more labor-intensive scientific irrigation scheduling methods based on soil water sensing alone and considerably better than county wide yields and water use efficiencies.

(6) We continued long-term work comparing ET by field soil water balance to ET by weighing lysimeter. The 2018 corn crop and 2019 soybean crop were successfully grown and harvested. This included work on characterizing the energy and water balances of irrigated cropping systems using weighing lysimeters and a host of radiative, sensible and latent heat flux sensing systems (eddy covariance and scintillometry).

(7) We concluded work on improved soil water sensing in salt-affected soils with participants in the IAEA Coordinated Research Project (CRP) on “Landscape Salinity and Water Management for Improving Agricultural Productivity” (D1.20.13).

(8) We continued work on assessment of climate change effects on watershed soil and water status and dynamics with participants in the IAEA Coordinated Research Project (CRP) D1.50.17 on “Nuclear Techniques for a Better Understanding of the Impact of Climate Change on Soil Erosion in Upland Agro-ecosystems”. This included work on the ICARDA Water & Livelihoods Initiative watershed outside Amman, Jordan. It also included our final year of work investigating the COSMOS system at Bushland.

(9) We continued work with ICARDA, USFS, and an NGO (WADI) in Jordan, including training on sensor and node and gateway telemetry systems at two watersheds in Jordan.

(10) We continued work with University partners (TAMU, KSU, TTU) to evaluate cultivar × environment response to soil water deficits in cotton and maize.

(11) We initiated work with Texas A&M AgriLife Research on field testing of the Campbell Scientific SoilVue soil water sensing system with six installations, two each, respectively, in corn fields irrigated at 50%, 75% and 100% of full irrigation to meet crop ET requirements. SoilVue sensors were installed 30 cm from neutron probe access tubes, and TDR-315L and TDR-315H sensors were installed between the access tube and SoilVue sensors at the center depths of SoilVue sensors.

U.S. Salinity Lab (Todd Skaggs, Scott Bradford, Ray Anderson and Elia Scudiero)

*Objective 1:*

Interaction Energies - An understanding of factors that influences interactions of microorganisms, nanoparticles, and other colloids with surfaces is needed for many industrial and environmental applications.  Approaches were developed to predict the interaction energy of colloids on natural or engineered surfaces with different amounts of roughness and surface charge variability and for hollow colloids.  Results reveal that roughness controlled the interaction between a colloid and solid surface.  Furthermore, the influence of roughness on colloid interactions was found to vary with the colloid size and the solution chemistry.  Roughness provided a viable alternative explanation for anomalous colloid retention and aggregation behavior that has previously been attributed to electrosteric repulsion in the literature.  Furthermore, hollow colloids were found to have weaker adhesive interactions than solid colloids.  This information will be of interest to scientists and engineers concerned with colloid interactions in diverse applications.  For example, Dr. Bradford is collaborating with a scientist at Hewlett Packard who is working on 3D Printer Technology that will use this information.

Horizontal Gene Transfer (HGT) - Batch experiments were conducted to examine the dynamics of bacterial conjugation with a multi-antibiotic and metal resistant plasmid in the presence and absence of antibiotics (Cefotaxime and Ampicillin) in growing (LB broth at 37oC) and non-growing (9.1 mM NaCl at 37oC) cultures of E. coli. Conjugation data exhibited a lag phase, rapid conjugation, a plateau phase in growing and non-growing cultures, and then a decay phase at later times under non-growing conditions due to bacterial die-off. Results indicated that there was a 2 to 4-hour window for conjugation after donor and recipient cells were mixed. Published models did not provide accurate descriptions of conjugation under non-growing conditions. A modified modeling approach was developed that accurately described the observed conjugation behavior. Presentations on this topic were given in Hong Kong (plenary talk) and to the USDA-ARS National Program 212 webinar series participants.

Managed Aquifer Recharge (MAR) – Drywells sites at the National Training Center in Fort Irwin, California were instrumented with water level and turbidity sensors to monitor their infiltration and clogging behavior over time. Analysis of collected particle size distributions during a new drywell installation and inverse simulations have been performed to determine temporal and spatial changes in soil hydraulic properties at this site. Numerical experiments have been conducted to quantify the influence of subsurface heterogeneity and soil type on the amount, timing, and extent of recharge from a drywell. This information is needed to assess the impact of drywells on groundwater quantity and quality. Numerical experiments have also been conducted to assess factors that influence the fate of viruses at an Aquifer Storage and Recovery (ASR) site in Australia, including virus retention and inactivation, storage time, and subsurface soil heterogeneity. An improved understanding of these factors can be used to optimize the performance of ASR to remove pathogens, minimize the risks to human health, and reduce the need for expensive pre- or post-treatments. Presentations on this topic were given at the SSSA annual meeting, to the EPA, and the CA State Water Board. This research was partially supported by an interagency agreement with the Environmental Protection Agency which supports a UCR postdoctoral researcher (Salini Sasidharan).

Managed Aquifer Recharge (MAR) – Field and numerical experiments were conducted, in conjunction with a project funded by the EPA, to improve our understanding and ability to characterize and design drywells for stormwater management and enhanced recharge. Mathematical models were also developed to simulate the influence of field-scale variations in water velocity on pathogen transport and fate at MAR sites. Results demonstrate that pathogen migration in soil is very sensitive to velocity variations, and that high velocity regions will control the ultimate transport potential of pathogens in soils and groundwater. Column transport and fate of viruses or bacteria were examined in experimental and modeling studies to better quantify the influence of solution and solid phase chemistry, temperature, and water velocity on pathogen removal during MAR conditions. Results indicated that virus removal in the soil occurred at a much higher rate than by death or inactivation, and this suggests that current MAR guidelines may be overly conservation. Bacteria retention parameters were found to be strong functions of water velocity due to changes in the adhesive interaction with time and due to differences in forces and torques that act on bacteria near solid surfaces. This information indicates that the mobility of bacteria in soils and groundwater will decrease under low velocity conditions, and that subsequent increases in velocity will have little impact on remobilizing retained bacteria.

Assessment of precipitation changes under future climate regimes. There is wide divergence in model forecasts of future precipitation under changing climate, particularly in the Western US where different climate model ensembles forecast either a significant decrease or significant increase in winter precipitation. Understanding future precipitation changes will be critical for managing water and soil resources, particularly as managed aquifer recharge becomes more critical for storing water for agricultural needs. Recent work in evaluating climate model ensembles has shown that models that better match large scale climatic variations (e.g. El Nino), show an overall increase in future precipitation compared to other models that show sustained drying. These same models also show that most increases in future precipitation come from increased extreme precipitation events, rather than from increased frequency of precipitation or lengthening of the wet season.

*Objective 2:*

Improved partitioning of measured ecosystem fluxes. The partitioning of water vapor and carbon dioxide (CO2) exchange between vegetation and the atmosphere remains a current research priority. A technique that has been proposed to simultaneously partition these fluxes, based on the correlation between their high-frequency concentration time series, has been the subject of recent empirical evaluations and theoretical advances. The method assumes that flux-variance similarity can be applied separately to stomatal exchange (transpiration for water vapor and net photosynthesis for CO2) and non-stomatal exchange (direct evaporation for water vapor and soil and stem respiration for CO2). Here, we present a mathematical simplification of this approach, from which the partitioned fluxes can be derived from routine eddy covariance measurements. The simplification arises from the fact that the transpiration and net photosynthesis fluxes are linearly related in solution space with respect to variable canopy water use efficiency, W. Conditions that are amenable to successful partitioning can now be determined a priori for a given averaging period. The simplified framework also has the benefit of providing a means for estimating W based on optimization theory. This allow for the estimation of W without any preconceptions of how the intercellular CO2 concentration, ci, varies as a function of ambient conditions. The simplified partitioning framework is applied to eddy covariance measurements collected over a mixed deciduous forests for three growing seasons. Aside from being more computationally efficient, the partitioned results exhibit less scatter compared with prior implementations.

Tests of percolation-based estimates of permeability. The saturated hydraulic conductivity of soil, Ks, is a critical parameter in hydrological models that remains notoriously difficult to predict. In this study, we test the capability of a model based on percolation theory and critical path analysis to estimate Ks measured on 95 undisturbed soil cores collected from contrasting soil types. One parameter (the pore geometry factor) was derived by model fitting, while the remaining two parameters (the critical pore diameter, dc, and the effective porosity) were derived from X-ray computed tomography measurements. The model gave a highly significant fit to the Ks measurements (p < 0.0001) although only ~47% of the variation was explained and the fitted pore geometry factor was approximately 1 to 2 orders of magnitude larger than various theoretical values obtained for idealized porous media and pore network models. Apart from assumptions in the model that might not hold in reality, this could also be attributed to experimental error induced by, for example, air entrapment and changes in the soil pore structure occurring during sample pre-saturation and the measurement of Ks. Variation in the critical pore diameter, dc, was the dominant source of variation in Ks, which suggests that dc is a suitable length scale for predicting soil permeability. Thus, from the point of view of pedotransfer functions, it could be worthwhile to direct future research toward exploring the correlations of dc with basic soil properties and site attributes.

*Objective 3:*

Hydro-economic modeling of Salton Sea inflows. As societies confront greater levels of water scarcity, conflict follows. Water transfers are increasing with irrigation water regularly considered in such discussions given it often comprises the bulk of water rights within a region, especially in water scarce environments. Here we analyze the impacts of three widely considered and implemented strategies to purchase water from irrigated agriculture—land fallowing, improvements in irrigation efficiency, and direct leasing. Our empirical application involves water transfers from Colorado River water rights holders to the Salton Sea, a critical ecological resource that has been in decline for many decades, with environmental damages estimated in the tens of billions of dollars. We develop a regional hydro-economic model that accounts for essential field-level agro-hydrologic processes related to crop production, irrigation, and salinity to evaluate the cost-effectiveness of these three programs. Results indicate that both fallow and direct water lease programs can generate significant environmental water flows with

relatively small decreases in agricultural production and no appreciable decrease in grower profits. Because these policies focus on a single input (applied water) rather than overall inflows to the Sea, the direct lease program—which is the most cost-effective approach for generating water conservation—may result in less inflows into the Sea than a land fallowing program.

Dynamic Management Zones. Soil-plant relationships often vary over time, decreasing the efficiency of static site-specific management units (SSMUs) for variable rate management in precision agriculture. In this research, we propose an analytical workflow for delineating dynamic management zones using spatial information on soil properties and in-season measurements of crop status. The procedure is two-fold: firstly, the spatial variability of plant-soil relationships is characterized; secondly spatial information on soil and its effect on crop status are used to delineate the management units through cluster analysis. Using data from a rainfed 21-ha maize (Zea mays L.) field from north-eastern Italy we show that texture and soil salinity influenced spatial variability of crop status in different ways in two growing seasons (2010 and 2011) characterized by contrasting meteorological conditions. We used maps of soil apparent electrical conductivity (ECa), as proxy for the target soil properties. The ECa maps were used as the explanatory variable in geographically weighted regressions (GWR) against in-season normalized vegetation index (NDVI) maps. The NDVI maps were obtained from WorldView-2 imagery obtained during the 2010 and 2011 maize kernel blister stages. Maps of local Pearson correlation coefficients r were generated from the GWRs and used, together with the ECa maps, for the SSMU delineation. The resulting SSMU were fairly — yet not completely — stable in time (overall consistency 65.3%). The changes in SSMUs membership over time reflected the spatiotemporal changes in plant-soil relationships. In-season dynamic SSMUs may be delineated at any point of the growing season when plants are the main contributors to reflectance measurements. We conclude by suggesting how to further improve dynamic in-season SSMUs for variable rate agricultural management.

Improved assessment of pesticide emissions from soils. Previously developed micrometeorological methods for assessing pesticide and fumigant emissions from the soil had wide variance, with one commonly used method, the aerodynamic gradient method (ADM), having considerably higher observed flux emission rates compared to other measurement and modeling approaches. New atmospheric transport parameterizations were developed and tested using two field observation campaigns with eddy covariance observations of energy and momentum fluxes. These newer parameterizations greatly reduced the differences between ADM and other observational and modeling approaches. Furthermore, these parameterizations were successfully applied to data from previous studies and showed the same corrective impacts.

Utah State University (Scott Jones)

*Objective 1:*

Thermal Properties of Granular Materials (Chihiro Naruke and Scott B. Jones): Thermal properties of a range of granular materials varying in particle and bulk densities were evaluated using two commercial sensors and the USU heat pulse sensor for comparison. A new calibration medium was evaluated as a standard and will be described in a future publication.

Application of Stony Soil Influence on Noah-MP Land Surface Model Simulations (Kshitij Parajuli, Morteza Sadeghi and Scott B. Jones): We extended our research on stony soil water retention to applications in the Noah-MP Land Surface Model estimation of actual evapotranspiration determination using measured changes in soil moisture coupled with numerical modeling. Estimates made using this method were compared to eddy covariance measurements of ET within the Reynolds Creek CZO showing improved correlations when the impacts of stone content on water retention are taken into account.

*Objective 2:*

A Prototype Thermo-TDR Probe was Developed in Collaboration with Acclima Inc. (Scott Anderson, David Anderson, Chihiro Naruke and Scott B. Jones): Thermo-TDR (T-TDR) was first introduced in 1996 but to date there are no commercial T-TDR on the market. Acclima Inc. and Utah State University have collaborated under a USDA-SBIR grant to develop an integrated printed circuit assembly where the 3-rods are shared by both the TDR and the heat pulse probe. The multi-functional sensor provides both travel-time analysis for permittivity determination as well as thermal property fitting, leading to water content and soil bulk density determination. Funding for a Phase-II project will be sought.

*Objective 3:*

A Utah Soil Moisture Monitoring and Forecast Network for Improved Water Resource Management and Risk Prediction. (Rob Gillies, Jon Meyer and Scott B. Jones). We are collaborating with the Utah Climate Center to develop resources in terms of a soil moisture mapping capability as well as to forecasting soil moisture into the future.

Virginia Tech (Ryan Stewart)

*Objective 1:*

(1) Quantified vapor sorption isotherms for different combinations of minerals and exchangeable cations, with the intent of developing a predictive models for mineralolgy.

(2) Analyzed physical and biological properties of 880 soil samples and 392 plant samples in an effort to better quantify soil health.

(3) Conducted two studies on transport of veterinary antibiotics through structured field soils.

(4) Conducted two studies on fate and transport of neonicotinoid pesticides, focusing on chemical uptake by different plant species and the role of organic matter in chemical retention.

*Objective 2:*

(1) Developed a simple analytical model to estimate overland flow generation mechanisms and amounts. The model was used to analyze overland flow characteristics of urban soils.

(2) Developed a new theoretical framework to analyze preferential flow based on simple analytical descriptions and only four parameters.

*Objective 3:*

(1) Created a web-based calculator to estimate potential benefits of using cover crops. This work has been submitted in a peer-reviewed article that will be published in 2020.

(2) Two Ph.D. dissertations were produced by Ayush Gyawali and Jesse Radolinski. One M.S. thesis was produced by Elizabeth Erwin.

(3) Served as guest editor in Vadose Zone Journal: Special Issue on nonuniform preferential flow in porous media was completed with 17 peer reviewed contributions published.

Washington State University (Markus Flury and Joan Wu)

(1) We evaluated the degradation of biodegradable plastics during 18-week, full-scale composting, and determined whether additives from the plastics are released upon degradation. (2) We tested different types of biodegradable plastic mulches in field experiments and evaluated their degradation and effects on soil health.

(3) We tested sapling and measurement methods to determine degradation of biodegradable plastic much films under real field conditions.

(4) We studied diffusion of CO2 and O2 through typical agricultural mulches. We evaluated to what degree commonly used landscape mulches will affect carbon dioxide and oxygen concentrations in the root zone and gas exchange across the soil-atmosphere interface in a controlled greenhouse environment.

(5) We evaluated the effects of freezing-thawing and wetting-drying on heavy metals leaching from biosolids.

(6) We investigated the aggregation kinetics of wheat straw-derived biochar colloids pyrolyzed at two temperatures 300 and 600°C in monovalent and divalent electrolyte solutions in absence/presence of humic acid (HA).

(7) We investigated the coupled effects of chemical characteristics and surface topology in a simple model system of two lipids, DSPE (1,2-distearoyl-sn-glycero-3- phosphoethanolamine) and DOPE (1,2-dioleoyl-sn-glycero-3-phosphoethanolamine), and a clay substrate. These closely-related lipids allowed the study of how a small change in chemical structure influences the surface hydrophobicity.

(8) We applied the Water Erosion Prediction Project (WEPP) model to seven paired, nested watersheds within the Mica Creek Experimental Watershed in northern Idaho, USA. We evaluated the ability of WEPP to simulate the direct and cumulative effects of clear-cutting and partial-cutting on water and sediment yield.

(9) We organized a symposium on “Nanoparticle Fate and Transport in Soil and Groundwater Systems” at the European Geoscience Union Annual meeting.

University of Wisconsin Madison (Jingyi Huang)

(1) Worked on one research project funded by USDA Hatch: Mapping surface soil water dynamics at fine spatial and temporal resolutions across the U.S. Climate Reference Network using Sentinel-1 and ancillary data.

(2) Advised two Ph.D. students and served on the committee members of one Ph.D. student, two M.S. students.

(3) Taught Soil Science 622 Soil Physics and Soil Science 322 Physical Principles for Soil and Water Management.

(4) Reviewed 9 manuscripts for various journals.

University of Wyoming (Thijs Kelleners)

(1) Solute transport was added to an existing 1-D vertical coupled soil water flow and heat transport computer simulation model. A manuscript describing the testing of the new model on a seasonally frozen rangeland soil was accepted by Soil Science Society of America Journal.

(2) Two new PhD students, Mark Pleasants (Hydrology) and Felipe Neves (Geophysics) were hired as part of an NSF-funded research project with Andrew Parsekian (Department of Geology & Geophysics) on subsurface structure and flow regime for Rocky Mountain hillslopes with different geologies.

(3) Near-surface seismic surveys were conducted in five zero order watersheds in New Mexico, Wyoming, and Idaho in the summer of 2019.

(4) A new 2-D soil water and electrical current flow computer simulation model was developed to estimate distributed subsurface porosity from time-lapse electrical resistivity tomography data. Preliminary results of the model were presented at the W4188 annual meeting.

(5) An automated soil moisture monitoring network consisting of 17 sites in rangeland soils was maintained in collaboration with Ginger Paige (Department of Ecosystem Science & Management).

**Milestones**

University of Arizona (Markus Tuller)

(1) Developed a new optical remote sensing technique for high-resolution mapping of soil moisture for precision water management.

(2) Characterized the TERRA-REF field site to generate an unprecedented dataset for the discovery of fundamental relationships between soil and plant reflectance, soil water status, and plant physiological responses.

(3) Developed new approach to determine soil specific surface area from Vis-NIR reflectance spectra and water vapor adsorption isotherms.

(4) Developed new framework for globally estimating land surface water fluxes from remote satellite soil moisture observations.

University of California-Riverside (Amir Haghverdi)

*Objective 2:*

Developed and tested new instrumentation, methods and models to improve the mechanistic understanding of soil processes and the quality of soil information and knowledge.

A high-resolution data set containing nearly 10,000 measured water retention data pairs were organized via the extended evaporation method (the HYPROP system) and supplemental WP4C data covering the SWRC dry-end (available for some samples). The data set were used to develop and evaluate more than 4,000 regression-based parametric pedotransfer equations for a total of 16 soil water retention models.

University of California-Riverside (Hoori Ajami)

(1) Quantified mountain front recharge processes as a function of extreme rainfall events in dryland ecosystems.

(2) Developed new approaches for quantifying uncertainty of conceptual ecohydrologic models using remotely sensed vegetation products, in collaboration with Lucy Marshall University of New South Wales.

University of California-Riverside (Jirka Simunek)

*Objective 1:*

The standard versions of HYDRUS, as well as its specialized modules, have been used by myself, my students, and my collaborators in multiple applications described below.

1. Hydrological Applications
2. Beegum et al. (2019) first updated the HYDRUS package for MODFLOW (HPM) by developing a new methodology to eliminate the error in the determination of the recharge flux at the bottom of the HPM profile and then additionally also implemented solute transport into the HPM. She then successfully tested these two new developments against fully two- or three-dimensional simulations with HYDRUS (2D/3D).
3. Brunetti et al. (2019) assessed the information content of aboveground fast-neutron counts to estimate SHPs using both a synthetic modeling study and actual experimental data from the Rollesbroich catchment in Germany. For this, the forward neutron operator COSMIC was externally coupled with the hydrological model HYDRUS-1D.
4. Sasidharan et al. (2019) carried out numerical experiments using the HYDRUS (2D/3D) software to systematically study the influence of subsurface heterogeneity on drywell infiltration. Subsurface heterogeneity was described deterministically by defining soil layers or lenses, or by generating stochastic realizations of soil hydraulic properties with selected variance and horizontal and vertical correlation lengths.
5. Liang et al. (2019) developed physics-informed data-driven models to predict surface runoff water quantity and quality in agricultural fields.
6. Ponheiro et al. (2019) measured a full-range of soil hydraulic properties for the purpose of predicting crop water availability using gamma-ray attenuation and inverse modeling.
7. Hansson et al. (2019) studied the effects of soil compaction on root-zone hydrology and vegetation in boreal forest clearcuts.
8. Xie et al. (2019) evaluated experimentally and numerically the nitrate subsurface transport and losses in response to its initial distributions in sloped soils.
9. Torkzaban et al. (in press) modeled virus transport and removal during storage and recovery in heterogeneous aquifers.
10. Kacimov et al. (in press) developed analytical solutions for and then studied phreatic seepage flow through an earth dam with an impeding strip.
11. Ali et al. (in press) developed a pH based pedotransfer function for scaling saturated hydraulic conductivity reduction.

*Objective 3:*

1. The Use of Hydrus Models to Evaluate Various Irrigation and Fertigation Problems - Agricultural Applications
2. Saefuddin et al. (2019) evaluated a ring-shaped emitter made from a standard rubber hose that has been developed and introduced for subsurface irrigation in Indonesia. The main objectives of this study thus were 1) to experimentally investigate the water movement around a buried ring-shaped emitter and 2) to numerically evaluate the effect of modifying the design of the ring-shaped emitter on soil water dynamics around the emitter.
3. Phogat et al. (2019) used the HYDRUS-1D model to identify the future water and salinity risks to irrigated viticulture in the Murray-Darling Basin, South Australia. The modeling results indicate that soil salinity at the beginning of the vine season and the average seasonal salinity are crucial factors that may need special management to sustain the viticulture in this region.
4. Liu et al. (2019) developed a coupled model a numerical model simulating water flow and solute transport for a furrow irrigation system, in which surface water flow and solute transport are described using the zero-inertia equation and the average cross-sectional convection-dispersion equation, respectively, while the two-dimensional Richards equation and the convection-dispersion equation are used to simulate water flow and solute transport in soils, respectively.
5. Karandish and Šimůnek (2019) applied the HYDRUS (2D/3D) and SALTMED models to investigate the influence of various water-saving irrigation strategies on maize water footprints.
6. Ramos et al. (2019) evaluated current risks and possible trends in soil salinization in very high-density olive orchards grown in southern Portugal.
7. Ponheiro et al. (2019) carried out a process-based analysis of the role of soil hydraulic properties on crop water use efficiency for some Brazilian scenarios.
8. Kacimov et al. (2019) revisited the Ovsinsky’s smart mulching-tillage technology via Gardner-Warrick’s unsaturated analytical model and HYDRUS to mminimise evaporation by optimal layering of the topsoil.
9. Mokari et al. (2019) analyzed using numerical modeling the fate of nitrate in a flood-irrigated pecan orchard.
10. Yang et al. (2019) carried out a comprehensive assessment of salinity leaching efficiency in three soils using the HYDRUS-1D and -2D simulations.
11. Chen et al. (in press) evaluated the effects of biodegradable film mulching on soil water dynamics in a drip-irrigated field.
12. Brunetti et al. (in press) developed A Dynamic Plant Uptake module for the HYDRUS model for modeling the translocation and transformation of chemicals in the soil-plant continuum.
13. Phogat et al. (in press) carried out a comprehensive assessment of management of soil chemical changes associated with irrigation of protected crops.
14. Fate and Transport of Various Substances (Carbon Nanotubes, Viruses, Explosives)

With another member of the W3188 group, Scott Bradford we worked on three aspects of the transport of pathogens in the subsurface.

1. Liang et al. (2019) investigated the roles of graphene oxide (GO) particle geometry, GO surface orientation, surface roughness, and nanoscale chemical heterogeneity on interaction energies, aggregation, retention, and release of GO in porous media. Calculations revealed that these factors had a large influence on the predicted interaction energy parameters.
2. Zhang et al. (2019) evaluated a co-transport of multi-walled carbon nanotubes and sodium dodecylbenzenesulfonate in chemically heterogeneous porous media.
3. Adrian et al. (in press) studied the transport and retention of engineered silver nanoparticles in carbonate-rich sediments in the presence and absence of soil organic matter.
4. Liang et al. (in press) investigated the critical role of nanoscale surface roughness on the retention and release of silver nanoparticles in porous media.
5. Reviews
6. Vereecken et al. (2019) provided an overview and outlook for land surface modelling with respect to infiltration from the pedon to global grid scales.
7. Jia et al. (in press) developed a benchmark involving soil organic matter degradation under variably-saturated flow conditions for comparing reactive transport models.

University of California-Riverside (Laosheng Wu)

*Objective 1:*

(1) Effects of interactions between soil particles and electrolytes on saturated hydraulic conductivity. A model to predict soil saturated hydraulic conductivity based on interactions between soil particles was proposed. Firstly, a model of ion−soil particle interactions at the soil/water interface was established taking specific ion effects into account. Based on the ion–soil interaction model, the theoretical relationship between the sodium adsorption ratio and the surface potential was derived, and the surface potentials were calculated at different sodium adsorption ratios and electrolyte concentrations. Secondly, a theoretical expression of midpoint potential between two adjacent soil particles in a mixed 1:1 + 2:1 electrolyte solution (e.g., NaCl + CaCl2) was derived. Thirdly, the interaction pressure (repulsive pressure) between soil particles was quantified based on the obtained midpoint potential. Finally, an empirical model of the relationship between measured saturated hydraulic conductivity and maximum net repulsive pressure was proposed.

(2) Adaptive Multifidelity Data Assimilation for Nonlinear Subsurface Flow Problems. We proposed an adaptive multifidelity ensemble smoother for data assimilation, which takes advantage of both the accuracy of a high-fidelity (HF) model and the efficiency of a low-fidelity (LF) model. The efficiency of the proposed method is illustrated by a synthetic case and a real-world experiment. It is shown that even though the majority of model evaluations are implemented using the LF models in an adaptive multifidelity ensemble smoother, the accuracy is not sacrificed. The proposed multifidelity framework is with the general applicability since it can be equally combined with other ensemble-based data assimilation methods.

*Objective 3:*

# (3) Effect of Water Application Methods on Salinity Leaching Efficiency in Soils of Different Textures Based on both of Lab and Field Scales. The objective of this project was to test water application methods on salinity leaching efficiency in both lab- and field-scale. Three types of soil (clay, loam, and sandy soils) were collected from fields and packed the soil columns (10-cm dia. and 30-cm height), and then irrigated with three water application methods (continuous ponding, intermittent ponding, and unsaturated application), time intervals (5, 10, 20, 30 hrs.) and pressure head (-2, -5, -10, -20 cm). Results indicate that the breakthrough time of salinity (ECdw) is earlier in the sandy and loamy soils than in the clay soil, while more salts are leached out from the loamy and clay soils than from sandy soil. As the irrigation time interval decreased (every 7, 5, and 3 days), the cumulative drainage water decreased while cumulative root water uptake increased. Intermittent application has a higher leaching efficiency (>90%).

University of California-Davis (Majdi Abou Najm)

(1) Successfully developed an experimental approach capable of parameterizing dual permeability soils using water and one non-Newtonian fluid. To my knowledge, this is the only scalable experimental method that can be used to parameterize without the need for inversion.

(2) Successfully validate the method for characterizing the pore structure of soils using non-Newtonian fluids using synthetic soils and sands, opening doors for further validations with more complex soils, as well as in the field.

(3) Successfully implemented new educational tools for improving the teaching methods of soil physics in classrooms.

(4) Successfully implemented a new educational module for establishing a connection between soil-physics and policy.

University of California-Davis (Thomas Harter)

(1) A 2-day short course was conducted to provide an introduction to groundwater hydrology, to water law, and to California’s Sustainable Groundwater Management Act, and review of several case studies on a range of aspects in developing groundwater sustainability plans. 60 attendees: water managers, attorneys, teachers, growers, staff from local and state agricultural organizations, NGO staff, regulatory agency personnel

(2) A 3-day short course was held to introduce theory and basic concepts of applied groundwater flow and transport modeling with hands-on laboratory sessions and discussions to provide attendees with an intuitive understanding of basic concepts in groundwater modeling. 30 attendees: consultants, regulatory agency personnel.

(3) Workshops were held to educate water managers, growers, grower organizations, NGOs, local/regional/state representatives and decision/policy makers on the relationship between crop management practices and groundwater pollution based on nitrogen budgets, current and historic groundwater pollution, groundwater forensics to identify sources of nitrate (by specific crops), application of machine-learning algorithms to identify agriculture’s role in groundwater nitrate pollution, and on N balance; understanding the dynamics of future groundwater pollution improvements from current changes in management practices.

(4) Over a dozen consultation meetings were held with regulatory agencies, agricultural coalition representatives, and environmental NGOs on the technical merits of proposed policy solutions to regulating agricultural nitrate discharges to groundwater.

(5) Over a dozen workshops were held with local stakeholders, state and federal regulatory agencies, and regional grower representatives on sustainable management of groundwater.

(6) Two Ph.D. students and one M.S. student successfully completed their studies during the reporting period.

(7) The work by Hanak et al (2019) was developed through half a dozen stakeholder workshops with water managers, public policy makers, local/regional/state water managers, agricultural representatives, and environmental NGO staff with research and outreach developed by a large interdisciplinary science team. The final report provides a long-term blueprint for the San Joaquin Valley watershed to address future challenges from water supply shortages and water quality threats.

University of Delaware (Yan Jin)

(1) We demonstrated that colloidal organic carbon could play a significant role in terrestrial organic C (OC) cycling.

(2) We confirmed that commonly used operational definition of dissolved organic matter (DOM, <450 nm) significantly overestimates the dissolved phase C concentration by including the NNP and fine colloidal fractions, which contain mineral-associated C.

(3) We demonstrated preferential pathways can be biological hotspots and have begun to explore the impacts of what this may mean for overall soil functionality.

(4) We provided direct (visual) evidence of changes in soil water distribution with the presence of rhizobacteria and investigated possible mechanisms for the observed changes.

(5) We improved understanding of how rhizobacteria may affect soil water conductivity considering different interfaces of the soil system.

Iowa State University (Robert Horton) and North Carolina State University (Joshua Heitman)

*Objective 1:*

(1) We showed that the largest change in soil bulk density happened within the first few weeks after tillage and this reduced the thickness of the tilled layer by 25%. The increase in bulk density strongly affected water retention: at low density following tillage, water was retained at field capacity in only about one third of the pore volume, while at greater density following consolidation, the decrease in pore volume along with increased water retention resulted in water being retained in two thirds of the pore volume at field capacity. Saturated hydraulic conductivity decreased by an order of magnitude as bulk density increased from consolidation.

(2) Our measurements of radiation and Bowen ratio in a vineyard interrow, below the vine canopy, in combination with above canopy eddy covariance measurements showed that there are strong micro-climate effects on both radiation divergence and turbulent fluxes. In particular, the spatial and temporal variability in radiation strongly affects the magnitude of the energy fluxes across the vineyard interrow with soil moisture having a secondary level of influence.

*Objective 2:*

(1) We showed that the thermo-TDR method was effective for measuring in situ changes in soil porosity during compaction from field traffic. Our results indicated that the thermo-TDR technique reduces variability in measurement results compared to the core method and was accurate with RMSE of 0.11 m3 m−3.

(2) We introduced a commercial multi-sensor combination approach for estimating soil bulk density. Estimated values obtained from repacked and in situ soils had RMSEs of 0.08 to 0.16 Mg m−3, and about 0.12 Mg m−3, respectively, indicating that this approach can be a useful means for non-destructively determining bulk density.

(3) We extended the Mualem-van Genuchten unsaturated hydraulic conductivity model to account for soil bulk density using four empirical approaches with varying data input requirements. Our results show that it is possible to accurately estimate bulk density-related effects on unsaturated hydraulic conductivity from limited water retention and hydraulic conductivity data.

*Objective 3:*

(1) We demonstrated that conservation subsurface drip irrigation improved cotton productivity by >150% in seasons with periods of intermittent water stress and, on average, increased yields by >80% compared to typical non-irrigated NC production systems.

University of Kentucky (Ole Wendroth)

(1) Successfully linked remote sensing information and simply-observable soil state variables in a farmer’s field for functional soil mapping. The soil property maps are relevant for the next step in our work, i.e. decision support (dissertation Xi Zhang).

(2) Progress in developing pedo-transfer functions for computing soil hydraulic properties and their spatial variability at the field-scale in a farmer’s field. Current pedo-transfer functions tend to overestimate soil hydraulic conductivity and do not represent the spatial variability of soil hydraulic conductivity. Ongoing (dissertation Xi Zhang).

(3) Completed a 3-year research project on improving irrigation management in Kentucky.

Michigan State University (Wei Zhang)

We completed the investigation on the contribution of stomata to the internalization of silver nanoparticles into plant leaves. We published an article on the photodegradation of cephalexin by ZnO nanowires, an article on microbiomes and antibiotic resistance genes in soil, lettuce root and shoots under soil-surface and overhead irrigation using pharmaceuticals-contaminated water, and an article on microbiomes and antibiotic resistance genes in soils under varying land use and manure management. We also completed our research on plant pathogen filtration of recycled greenhouse irrigation water and published an article in HortTechnology.

University of Minnesota (John Nieber)

(1) Completed the development of the regression model relating lake volume to lake surface area and surrounding topography (MSc. Thesis for Ms. Chelsea Delaney).

(2) Found significant relation between watershed characteristics (geomorphic and groundwater physical) and the mean travel time for groundwater flow. Found good agreement between groundwater storage change and the storage change model using the mean travel time parameter (MSc. Thesis for Mr. Xiang Li).

(3) Determined that the data available for the Minnehaha Creek analysis was not sufficient to demonstrate significant water quality benefits of implemented BMPs. Recommendations are provided for future monitoring strategies to improve the ability to identify BMP impacts (MSc. Thesis for Jack Distel).

(4) Completed calibration of the SWAT model for runoff and nitrate transport for agriculturally dominated glacial till subwatershed in the South Branch of the Root River watershed. The calibrated model was applied to evaluate various recommended nitrogen BMPs for reduction of nitrate loads in streams. The SWAT model application to two karst dominated subwatersheds in the same watershed was not successful due to the karst dominated features in those subwatersheds (MSc. Thesis for Mark Greve; still in revision).

(5) Found good agreement between GRACE satellite measurements of water storage change and water storage change estimates derived from a lumped water balance model and pointwise measurements.

(6) Found good agreement between a model for turbulent flow and wall erosion in a soil pipe and experimental measures conducted at the USDA-ARS erosion lab (Oxford MS). Model was based on the assumption of pipe geometry dynamics being represented by a sequence of quasi-steady conditions.

New Mexico State University (Manoj Shukla)

*Objective 1:*

We continued to expand the work on use of brackish water and reverse osmosis concentrate on soil physical chemical, and microbiological properties, and gas exchange parameters of plant.

Mokari et al. (2019) quantified soil water and soil nitrate-nitrogen (NO3-N) (mg/l of soil) variations with depth, root NO3-N (kg/ha) uptake, and NO3-N (kg/ha) balance for the 100-cm soil profile during two growing seasons in a flood-irrigated pecan orchard. We also simulated water and NO3-N variations and root NO3-N uptake using HYDRUS-1D.

*Objective 3:*

(1) Kankarla et al (2019) investigated the effect of ion uptake from brackish groundwater and concentrate irrigation on the performance of two forage species, alfalfa (*Medicago sativa*) and triticale *(xTriticosecale)* in loamy sand soils in greenhouse conditions.

(2) Yang et al. (2019) evaluated the interactive effects of reduced irrigation and salt stress on leaf physiological parameters, biomass accumulation, and water use efficiency (WUE) of tomato plants at leaf and whole plant scales in a field experiment during 2016 and a greenhouse experiment during 2017.

(3) Yang et al. (2019) developed quantify the impacts of water deficit and salt stress individually and the interaction on tomato yield and quality, three pot experiments were conducted from spring 2016 to autumn 2017. The EPIC growth model was also used to simulate fruit growth process.

(4) Ghimere et al (2019) reviewed the literature on the effects of cover crops on soil organic carbon (SOC) and nitrogen (N) dynamics, soil water conservation, and crop yields in dryland cropping systems of the US Great Plains (GPs), and analyzed the opportunities and challenges for integrating cover crops into dryland crop-fallow systems of the SGP.

Oregon State University (Maria Dragila)

Completed model for solarization effectiveness.

Oregon State University (Carlos Ochoa)

(1) Expanded a soil moisture-monitoring network in riparian areas and pastures in the Oak Creek watershed in Corvallis, OR.

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

(3) Expanded a soil moisture-monitoring network in rangeland study site in eastern Oregon.

University of Texas at Austin (Michael Young)

*Objective 3:*

(1) Completed multi-year research project, based in northern Alaska, with the aim to understand landscape evolution and fate of soil carbon in permafrost soils undergoing rapid thaw. Research used local scale measurements as training set for regional (upscaled) landscape classification using machine learning. (Charles Abolt’s dissertation completed).

(2) Progress on using remote sensing for characterizing canopy structure across 35,000 ha desert area. Results led to identification of shrub type, size, and location of 62 million plants across the basin (James Gearon’s undergraduate project completed).

(3) Improved understanding of impacts to regional-scale ecosystems and soils in west Texas, as result of fossil and renewable energy development.

Texas A&M University (Binayak Mohanty)

*Objective 1:*

(1) Sviercoski et al . (2018) improved the prediction of simultaneous movement of liquid water, vapor, and heat in the shallow subsurface at multiple spatio-temporal scales. This work will allow a more accurate prediction of soil evaporation for various environmental applications.

(2) Yang et al. (2019) developed a set of new analytical models for prediction of relative air permeability from soil water retention function. This effort enhanced our capability for improved prediction of soil evaporation and improved water budget closure.

(3) Shin et al. (2018) developed new evolutionary algorithm for modeling multi-scale soil moisture using precipitation history. This is an useful technique when historcal precip and soil moisture data records are available for various applications.

(4) Gaur et al. (2019) developed a novel nomograph for multi-scale soil moisture downscaling using dominant geophysical hetereogeneity of soil, vegetation, and topographic features in different hydroclimates.

(5) Kathuria et al. (2019a,b) developed a new framework for soil moisture prediction and fusion with geophysical nonstationarity. This effort can fuse data from insitu and remote sensing platforms and provide soil moisture at multiple space-time scales for application purposes.

(6) Mao et al. (2019) provided a new two-step machine learning (ML) algorithm for gap-filling in soil moisture data collected by SMAP and Sentinel-1 satellites

(7) Neelam, et al. (2019) developed a new soil moisture retrieval algorithm for nested topographically complex landscape. This will enhance more accurate soil moisture using passive microwave remote sensing.

(8) Fan et al. (2019) provided a review and vision for including multi-scale near-surface soil hydrologic processes for next-generation Earth Systems Models.

*Objective 3:*

(1) Singh, et al (2019a,b) used our soil moisture spatio-temporal analysis tool and provided optimal sampling design and improved remotely sensed soil moisture products in tropical watershed of India.

Texas Tech University (Sanjit Deb)

*Objective 1:*

(1) Li et al. (2019) examined the effectiveness of cultivation practices combined with soil surfactant products to reduce soil salinity and enhance soil water retention properties without applying leaching fractions of water in semiarid golf courses with contrasting soil textures.

(2) Karnjanapiboonwong et al. (2018) provided a new insight into the effects of per- and polyfluoroalkyl substances (PFASs) such as perfluorobutanesulfonic acid (PFBS), perfluorohexanesulfonic acid (PFHxS), perfluorononanoic acid (PFNA), and perfluoroheptanoic acid (PFHpA) on earthworms (Eisenia fetida) in soils contaminated with these compounds.

*Objective 3:*

(1) Dhakal et al (2019a) evaluated the effects of various alfalfa cultivars and different agronomic options on soil water depletion, root water uptake, plant abiotic stresses and phenological responses, and water use efficiency (WUE) for improving forage productivity and quality in semiarid pastures under both dryland conditions and deficit subsurface drip irrigation.

(2) Dhakal et al. (2019b) calibrated and evaluated multi-depth capacitance water content sensors in semiarid pastures to provide reliable accuracy and precision for rootzone soil water measurement on a high-clay grassland soil.

(3) Dube et al. (2019) developed a rapid method of leaf area index (LAI) estimation, which is related to crop biomass, water use and yield, using point clouds (PCs) obtained with three-dimensional (3-D) structured light sensors and an open source image analysis software.

U.S. ARS – Bushland, TX (Robert Schwartz and Steven Evett)

(1) Fourth season of multi-location tests in semi-arid to humid climates of the integrated Irrigation Scheduling Supervisory Control and Data Acquisition (ISSCADA) system indicated positive outcomes for the system and system components. The ISSCADA patent was licensed by Valmont Industries, Inc. for use with their center pivot irrigation systems, including their variable rate irrigation systems.

(2) A commercial version of the node and gateway system for wireless transmission of SDI-12 sensor data from field to the Internet was introduced by Acclima, Inc., and was beta tested nationally and internationally.

U.S. Salinity Lab (Todd Skaggs, Scott Bradford, Ray Anderson and Elia Scudiero)

An update of the Fluxpart software was released (v. 0.2x). Fluxpart is a python module that processes data from eddy covariance instrumentation to partition measured evapotranspiration (ET) and CO2 fluxes into their constitutive parts: ET into evapotranspiration and transpiration, and CO2 in photosynthesis and respiration. The partitioning is based on a correlation analysis of measured fluxes and gas concentrations. The software update features improvements to the partitioning algorithm and other data processing enhancements.

Utah State University (Scott Jones)

(1) Developed a new optical remote sensing technique for high-resolution mapping of soil moisture for precision water management.

(2) Attended the European Geosciences Union Meeting with our Institute of Agrophysics collaborators (funded by Polish agency NAWA) to further our joint efforts to develop EM sensor standards for measurement of permittivity.

(3) Collaborated with the Utah Climate Center to expand the Utah State-Wide soil moisture map and forecast.

Virginia Tech (Ryan Stewart)

*Objective 1:*

(1) Gyawali and Stewart (2019) presented an improved method for quantifying aggregate stability that uses laser diffractometry measurements of aggregated versus dispersed samples.

(2) During a plot-scale experiment, Radolinski et al. (2019) determined that neonicotinoid pesticides moved from fields via surface runoff, shallow subsurface flow, with minimal losses to deep drainage.

*Objective 2:*

(1) Stewart (2019) showed that preferential infiltration in macroporous soils can be modeled using four physically based parameters.

(2) Gyawali et al. (2019) presented a new Arduino-based sensor to detect soil respiration in field and laboratory conditions. This instrument can be used to assess microbial activity and related measurements.

(3) Stewart et al. (2019) determined that non-urbanized soil profiles produced greater overland flow via infiltration excess mechanisms, while urbanized soil profiles tended to produce surface-excess overland flow during relatively low intensity storms. The results showed that urban soils produced more cumulative overland flow than did non-urban soils.

Washington State University (Markus Flury and Joan Wu)

*Objective 1:*

(1) Demonstrated that lower flow rates with longer residence time induced more metal leaching from land-applied biosolids compared with higher flow rate with shorter residence time. At each flow rate, flow-stop caused enhanced metal leaching. Higher drying temperature enhanced metal leaching. Water content or freezing-thawing had no significant effects on metal leaching from land-applied biosolids.

(2) Showed that the stability of biochar colloids decreased with increasing pyrolysis temperature and that humic acid greatly increased colloid stability of high-temperature biochar colloids. However, high concentration of humic acids increased biochar aggregation in CaCl2 solution by cation bridging.

(3) We found that surface hydrophobicity of clays is determined by not only surface chemistry but also by nanotopography and imbibition of liquids into the porous clay structure. The initial contact angle, quantitative variables extracted from the change in droplet shape over time correlated with the film topography or lipid distribution.

*Objective 2:*

(1) We developed an experimental system to measure diffusion coefficient for CO2 and O2 through agricultural mulches. Diffusion coefficients of CO2 through mulch materials were of the order of >10-3, 10-4, 10-5, and 10-6 cm2s-1 for wood chips, cardboard, landscape fabric, and polyethylene film, respectively. Despite the different diffusion coefficients of the different mulches, CO2 and O2 concentrations in the soil under the various mulches were not significantly different as compared to the control, except for the polyethylene treatment. The orders of magnitude differences in diffusion coefficients among the mulch materials, however, could negatively impact a diverse soil environment such as those found in biologically rich landscapes with higher oxygen demands.

*Objective 3:*

(1) We showed that biodegradable plastics hold promise, but the release of micro- and nanoparticles from biodegradable plastic upon degradation warrants additional investigation and calls for longer field testing to ensure that either complete biodegradation occurs or that no long-term harm to the environment is caused.

(2) We demonstrated that effects of different biodegradable plastics mulches on soil health were not consistent over time and site and no negative effects on soil health were detected. Biodegradable plastics mulches a promising alternative to polyethylene, but longer-term testing is needed.

(3) We showed good agreements between (i) WEPP-simulated and observed streamflow with no calibration and (ii) WEPP-simulated and observed suspended sediment yield by calibrating a single channel critical shear stress parameter, for a 16-year (1992–2007) period.

University of Wisconsin Madison (Jingyi Huang)

Successfully retrieved soil water dynamics using Sentinel-1 and ancillary data at the U.S. Climate Reference Network (dissertation of Ph.D. student Sumanta Chatterjee).

University of Wyoming (Thijs Kelleners)

(1) Successfully modeled above and below canopy turbulent fluxes of water and heat in snow-dominated mountainous forest using the GEOtop model (dissertation Andrew Fullhart).

(2) Successfully used Hydra impedance sensor derived bulk soil electrical conductivity to validate numerical model predictions of solute transport in a seasonally frozen rangeland soil (Soil Science Society of America accepted manuscript).

**Impacts**

University of Arizona (Markus Tuller)

In 2019 our advanced X-Ray CT segmentation algorithms that we developed in past years have aided numerous other researchers with projects that utilize X-Ray CT for soil and porous media research. Also, the OPtical TRApezoid Model (OPTRAM) for estimation of soil moisture based on remotely sensed transformed SWIR surface reflectance that we developed in 2017 has been applied for numerous research projects in 2019.

University of Arizona (Karletta Chief)

One major accomplishment was publishing 5 peer-reviewed journal articles and 3 book chapters on climate change impacts on tribal water resources, which were non-existent prior to this program. This includes co-authoring the first tribal chapter in the Southwest Climate Assessment and two publications in a special issue in Climatic Change focusing on tribes. As part of this assessment, listening sessions were held across the country to ask tribal communities their perspectives and experiences with climate change. This effort developed nationwide interest and momentum at the educational, state, and congressional level to discuss and address how tribes and their homes and infrastructures are being impacted by climate change. However, tribes voiced a need for researchers to understand the sensitivities of incorporating traditional knowledge in climate initiatives. As a result, I joined a national working group where we developed a guide for university, federal and state researchers working with tribes on how to protect traditional ecological knowledge in climate initiatives. Also, I learned that decision tools can be too complex for practical use, so my approach was to develop decisions tools that tribal managers could understand and manipulate using a common platform like Microsoft Excel. For example, for PLPT, we developed a water balance for Pyramid Lake where tribal managers can manipulate climate parameters to discuss future scenarios and to consider tailoring water management and plan to address climate change impacts. Through the mining impacts extension program, 4 learning modules on mining were developed for tribal colleges and two Native American graduate students received their masters through the development of these modules. As part of the development of the learning modules, the modules were piloted at tribal colleges approximately 30 times (an average of 6 pilots per year for 5 years) as well as piloting it at Native American camps ranging from elementary to college students). Within a month of the Gold King Mine Spill, I led in authoring an 11-page factsheet that answered frequently asked questions from concerned Navajo farmers. Through the research and outreach, Navajo farmers are beginning to farm again. The first Tribal Leaders Climate Adaptation Summit, and wrote a report detailing the adaptation efforts and plans by tribes across the U.S. As part of this consortium, I participated in securing $561K to UA with $58K directly funding the water management and policy extension program. As a result of this extension program, there is increased knowledge and awareness of surface and groundwater hydrology, hydrologic modeling, and climate change impacts in efforts to change or create better water management practices and policies and create climate adaptation plans.

University of California-Riverside (Amir Haghverdi)

Our website (ucrwater.com) and twitter account (@ucrwater) were used as the clearinghouse to disseminate the findings of the projects in lay language for a diverse audience. The website had on average 835 unique visits and 2640 page views per month and the twitter account currently has 177 followers.

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.

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 ten thousand times in 2019 and over forty thousand HYDRUS users from all over the world registered at the HYDRUS website. We continue supporting all these HYDRUS users from USA and around the world at the HYDRUS website using various tools, such as Discussion forums, FAQ sections, and by continuously updating and expanding a library of HYDRUS projects. Additionally, we have added new capabilities to rigorously consider processes in the soil profiles with furrows (the Furrow module), to calculate cosmic ray neutron fluxes (the Cosmic module), and to simulate the translocation and transformation of chemicals in the soil-plant continuum (A Dynamic Plant Uptake module). Finally, in 2019 we have offered short courses on how to use HYDRUS models at a) Czech University of Life Sciences, Prague, Czech Republic, b) Colorado School of Mines, Golden, CO, c) c) Indian Institute of Technology (IIT) Mandi, Mandi, Himachal Pradesh, India, and d) the Sede Boker Campus of the Ben Gurion University, Israel. About 100 students participated in these short courses.

University of California-Riverside (Laosheng 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, soil salinity management, and protects water quality and environment.

University of California-Davis (Majdi Abou Najm)

We completed a successful Special Issue on nonuniform preferential flow in porous media with 17 peer reviewed contributions published in Vadose Zone Journal. We validated and developed experimental methods for pore structure characterization, as well as for the physical parameterization of dual permeability soils. Furthermore, a far-reaching impact was in the development of advanced educational modules for improved teaching and mentoring in soils physics that can impact a wide range of students and future soil physics scientists.

University of California-Davis (Thomas Harter)

Development of improved fertigation practice in nut crops to reduce nitrate leaching helped us achieve a 90% nutrient use efficiency in 2018. The improved grower practice has been demonstrated to over 200 growers in three on-site field days. We presented the management practices and harvest results in over ten conferences and workshops, reaching over 1000 growers. Using a groundwater model developed by Tolley et al. (2019) we have shown that current software tools are available capable of simulating highly complex relationship between agricultural water users, agricultural groundwater pumpers, and streamflow threatened by seasonal stream depletion through groundwater pumping. We have also supported the development of Clean Water Act Total Maximum Daily Load programs considering stream temperature and groundwater management, and the development of groundwater sustainability plans under new legislation in California. We have provided over a dozen workshops and over two dozen lectures on including modeling tools and AgMAR concepts in the development of groundwater sustainability plans.

University of Delaware (Yan Jin)

Understanding the mechanisms governing the dynamics of colloids and colloidal OC in subsurface systems is critical to predicting the stability of soil OC and transport of soil contaminants. Additionally, by examining microbial community structure along preferential flow paths we are able to further determine how these locations function biogeochemically as well as gain new ecological insight into the commonly ignored structure-function relationships in soil. The long-term goals of the rhizosphere study include: 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 learn the fundamentals of the important feedback among plants, microbes and soil; and 3) 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. Finally, coupled neutron and x-ray tomography investigation has the potential to yield high resolution, real-time images of multiphase systems thus a powerful tool for studying various multiphase flow problems in porous media.

Iowa State University (Robert Horton) and North Carolina State University (Joshua Heitman)

The development of new sensing methods to determine soil thermal and hydraulic properties will strengthen modeling and experimental studies of water, heat, gas, and solute transport across the soil-plant-atmosphere continuum.

University of Kentucky (Ole Wendroth)

Co-organisation of SSSA meeting within the Annual Tri-Society Meeting of ASA-CSSA-SSSA, San Antonio, Texas helped bring scientists and practitioners together and facilitated exchange of ideas and knowledge. We helped a farmer to irrigate more efficiently by lowering the irrigation rate and avoiding surface water runoff in parts of his field. Finally, we participated in four Congress Visit Days for science advocacy.

Michigan State University (Wei Zhang)

Our work have elucidated a critical mechanism responsible for foliar uptake of silver nanoparticle and the impact of crop irrigation and manure management on pharmaceutical residues, bacterial microbiomes and antibiotic resistances in crop production systems. This knowledge will help develop environmental-friendly agricultural nanotechnology, responsibly use reclaimed water for irrigation, protect soil quality, and ensure food safety.

University of Minnesota (John Nieber)

Infiltration measurement methods and recommendations developed are being applied by highway department planners and by urban landuse planners. Information on the SWAT assessment results for nitrogen BMP benefits in the glacial till dominated area of southeast Minnesota are being disseminated to producers in the region by the Minnesota Department of Agriculture. The lake volume estimation method developed is being applied to assess the dynamics of Dissolved Organic Carbon storage to lakes (greater than 6 ha size; about 9,600 lakes in total) across the state of Minnesota. The DOC concentration is estimated with satellite imagery and then the total DOC mass is computed using the estimated lake volume (manuscript in preparation).

New Mexico State University (Manoj Shukla)

Modeling soil water and solute fluxes provides an estimation of amount of water lost due to evaporation and deep percolation. A low cost datalogger was developed that can significantly decrease cost of collecting soil water content data. Model quantifies amount of nitrate loading to deeper soil layers and to the shallow groundwater. These estimates are helpful to schedule fertigation to prevent water and nutrient loss while maintaining productivity. We are working on creating a 2D/3D model ready for use by the growers with available soil water, and fertigation data, which can be beneficial for sustaining soil, plant, and groundwater quality.

Oklahoma State University (Tyson Ochsner)

One PhD student and one visiting scholar received training through this project.

Oregon State University (Maria Dragila)

Solarization provides a soil disinfection method that is an alternative to chemical applications, the project goal is transfer this technology to growers in the Pacific Northwest. Challenges in the PNW include low solar declination and short growing season. We have demonstrated that this technology is applicable in the PNW and have developed a method to track success and reduce duration of solarization application, to reduce impact on the agricultural production timeline. Additionally, the earth’s surface is a critical boundary for atmospheric gas exchange. We have shown that large boreholes (e.g. wells) that penetrate deep into the vadose zone drive gas exchange in the form pulses that are synchronized to the diurnal and seasonal temperature wave and to barometric pressure from storm fronts.

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.

University of Texas at Austin (Michael Young)

The research on Arctic permafrost soils has led, for the first time, to the creation of a high-resolution map of ice-wedge polygons at the cm-scale. The scale of the map is approximately 1,500 km2 in area with more than 1,000,000 polygons identified and classified as both high-centered and low-centered. The importance of these results rests on the potential for predicting whether carbon emissions are methane or CO2, vital for boundary conditions used in global climate models. These data will be available to the scientific community for future model calibration. Research on desert ecosystems and the classification and characterization of desert shrubs provides direct evidence of km2-scale influence of geomorphic surfaces and soil properties on species richness and density. These data will also be published and available to future researchers. Research being conducted on energy development (oil and gas, wind, and solar) is vital for long-term land conservation efforts in arid lands. Energy development is likely to be one of the largest sources of land alteration over the coming decades, more than urbanization or agriculture. Quantifying these potential impacts today could guide conservation planning tomorrow.

Texas A&M University (Binayak Mohanty)

Development of Texas Water Observatory (TWO; founding director, Mohanty) in the Brazos River corridor in Texas provides a network for real-time (ground, soil, surface, plant, and atmospheric water) data and improved multi-scale modeling skills for water, carbon, and energy cycle and its related societal applications such as prediction of drought, flood, agriculture, contaminant transport, ecosystem, water availability, weather, climate, health, biodiversity, and food-energy-water nexus. This provides triggers for many growth and discovery in water, nutrient, carbon, and energy related spatio-temporal science and evaluation of new ground and remote sensing technology.

Texas Tech University (Sanjit Deb)

In groundwater-dependent agricultural production of the southern Ogallala Aquifer Region, developing and evaluating water management strategies and technologies are major concerns for the economic viability of individual producers and the region. Different water management and conservation practices evaluated in drip-irrigated cotton production system or under other land uses (e.g., pastures, golf courses) provide an improved understanding of rootzone soil water properties and processes that affect soil-crop water relations, water balance, crop abiotic stresses and phenological responses, WUE and water withdrawals for irrigation in the southern High Plains. Soil water management practices under both dryland conditions and deficit subsurface drip irrigation in cotton or pastures or grasslands are also transferable to other crop production or other water-limiting areas. Our simulation modeling provides an additional tool for managing efficient water use in crop rootzone under dryland and water-limited scenarios while sustaining crop and soil productivity.

U.S. ARS – Bushland, TX (Robert Schwartz and Steven Evett)

The node and gateway system developed with Acclima, Inc., will be commercially available at end of first quarter 2020. The improved TDR soil water sensors were commercially available in 2019 (TDR-315H, TDR-310H). Regional, national and international requests to speak indicate considerable impact on soil water monitoring and irrigation management, including sensor-based irrigation management, subsurface drip irrigation and variable rate irrigation, and watershed management.

U.S. Salinity Lab (Todd Skaggs, Scott Bradford, Ray Anderson and Elia Scudiero)

Degradation of soil and water resources by agricultural contaminants (including salts, pesticides, pharmaceuticals, and pathogenic microorganisms) represents a serious threat to irrigated agriculture in arid and semi-arid regions. Advanced decision support tools and simulation models are needed to develop, test, and implement site-specific soil, water, and crop management practices that optimize crop production while minimizing soil and groundwater pollution. The activities discussed above provide new knowledge about the effects of root zone contaminants on crop growth and on soil and water quality which are needed to develop improved decision support and simulation tools.

Utah State University (Scott Jones)

The OPtical TRApezoid Model (OPTRAM) for estimation of soil moisture based on remotely sensed transformed SWIR surface reflectance that we developed in 2017 has been applied for numerous research projects in 2019.

Virginia Tech (Ryan Stewart)

Limited funding resources and critical deficiencies in environmental sensing necessitates the development of low-cost sensors capable of high-resolution measurements, so we created and validated a new methodology to analyze microbial respiration and activity in soils using a low-cost, Arduino-based infrared gas analyzer.

Research results were featured in a recent "Field, Lab, Earth" podcast: *What we mean by soil health*, disseminated by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Washington State University (Markus Flury and Joan Wu)

Agriculture is a major user of plastics, and plastic mulch films (mostly polyethylene) account for >40% of the total agricultural plastic usage. Plastic mulch films have to be removed and disposed of after use. Biodegradable plastic mulches have great potential to reduce plastic waste generated from the use of polyethylene. However, it has to be shown that biodegradable plastic degrades into products that do not harm the environment. We assessed degradation of two biodegradable plastic mulches, enclosed in nylon meshbags, in a compost pile. We found micro- and nanoparticles containing carbon black adhering to meshbag fibers after composting. While meshbags have slowed down the degradation process, the potential release of micro- and nanoparticles upon composting of biodegradable plastic is of environmental relevance. Also, intermittent irrigation or rainfall will enhance the risk of metals leaching from biosolids after land application. However, freezing of biosolids during winter will likely not cause an enhanced leaching of metals in spring when biosolids and soils thaw. Application of biosolids in fall should therefore not cause enhanced leaching of metals out of land-applied biosolids. Finally, WEPP stream sediment transport algorithms were evaluated on large watersheds for the first time. Its adequate performance demonstrates its potential as an effective modeling tool for forestland watershed management, particularly for estimating the effects of hydrograph modification on stream sediment transport.

University of Wisconsin Madison (Jingyi Huang)

Co-organizing an oral session (Session 81) of 2019 ASA-CSSA-SSSA Meeting, San Antonio, Texas led to exchange of scientific knowledge. Collaboration with Natural Resources Conservation Services on exploring geophysical instruments for mapping depth to bedrocks in Wisconsin generated new insight into sustainable soil and water management.

University of Wyoming (Thijs Kelleners)

Monitoring of snow, soil, groundwater, and streamflow conditions in mountain and basin ecosystems, combined with numerical (sub-)surface water flow modeling, is used to better understand storage and flux dynamics under current conditions and future scenarios. The resulting data and computer simulation models facilitate improved decision making to maintain ecosystem health and support human activities related to agriculture, industry, cities, and recreation.

**Publications**

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