**Basic Information**

* **Project No. and Title:** W3188: Soil, Water and Environmental Physics Across Scales
* **Period Covered:** 10/01/2015 to 09/01/2016
* **Date of Report:** 02/21/2017
* **Annual Meeting Dates:** 01/02-04/2016

**Participants**

Hoori Ajami, UC Riverside; Shahila Beegum, UC Riverside; Markus Berli, DRI Las Vegas; Maria Dragila, Oregon State University; Markus Flury, Washington State University; Sarah Helalia, UC Riverside; Bob Horton, Iowa State University; Yan Jin, University of Delaware; Scott Jones, Utah State University; Maziar Kandelous, UC Davis; Honeyeh Kazemi, University of Arizona; Thijs Kelleners, University of Wyoming; Jing Liang, UC Riverside; Steve Loring, New Mexico State University; Laura Rosales, Nevada State College; Javier Reyes, University of Kentucky; Hirotaka Saito, UC Riverside; Rose Shillito, DRI Las Vegas; Manoj Shukla, New Mexico State University; Jirka Simunek, UC Riverside; Ole Wendroth, University of Kentucky; Jing Yan, University of Delaware; Michael Young UT Austin; Cheng Yu, UC Riverside; Wei Zhang, Michigan State University; Xi Zhang, University of Kentucky.

**BRIEF SUMMARY OF MINUTES OF ANNUAL MEETING**

2016 Annual Meeting of the W-3188 Multi-State Research Project:
*Soil, Water, and Environmental Physics across Scales*

January 2-4, 2017, Desert Research Institute, Las Vegas, NV

Teamrat Ghezzehei (Chair) and Maria Dragila (Secretary).

**January 2 2017.** Chair brought the house to order at 1 PM.

*Markus Flury* (Washington State University) Discussed colloid fate and transport associated with the movement of air-water interfaces in contaminated unsaturated media; Fate of pollutants moving through engineered bio-retention systems focusing on nitrates, DOC, and organically complexed copper.

*Jirka Simunek* (UC Riverside) presented various updates and applications of the Hydrus family of codes, including new module for furrow irrigation, development of new recommendation drip irrigation associated with FAO-56Dual Approach, incorporation of the Richard’s equation to the DSSAT crop model; collaborated in two review papers on soil modeling and Hydrus applications. *Jing Liang* (Graduate Student under Jirka Simunek) discussed improved models for overland flow using Hydrus-1D for more accurate generation of predictive hydrographs associated with CAFO. *Sahila Beegum* (Graduate Student under Jirka Simunek) Discussed integration of solute transport in Hydrus to link to Modflow.

*Scott* Jones (Utah State University) Discussed improvements to the heat pulse probe, and the complexities of quantifying soil water content in a rock soil system.

*Steve Loring* (New Mexico State University) discussed the need to identify and emphasize the impact of our scientific activities.

Meeting closed for the day at 5:00 pm

**January 3 2017.** Chair brought the house to order at 8:30 AM.

*Markus Berli* (DRI, Las Vegas) Discussed their work to improve the hydrologic impact of solar panels in desert landscapes; use of remote sensing to improve characterization of desert tortoise habitat.

*Maziar Kandelous* (UC Davis) Discussed leaching of water and nitrate below the root zone using water balance, Darcy-Equation, and numerical modeling.

*Manoj Shukla* (New Mexico State University) discussed the impact of brackish water on the timing of flowering and on the yield of chile peppers, and how to manage brackish water application to reduce detrimental impact on soil properties; field studies using zeolites to support isolated plants in highly arid ecosystems.

*Maria Dragila* (Oregon State University) Presented work to determine the efficacy of soil solarization as soil disinfecting method for the Pacific Northwest; investigation on the transport dynamics within microfractures in the epikarst; continuing investigation on the impact of soil biology on soil water dynamics.

*Michael Young* (University of Texas, Austin) He used his time to encourage the broadening of the participation of the soil physics community in global and national cross-cutting communities, to avoid duplication of effort, determine where the gaps are in soil science research and drive a new generation of collaborations. He introduced the international GEWEX network for scientific collaboration, and encouraged soil physicists to participate in the formation of the new SoilWat Panel. Michael then introduced two documents released recently by the White House. The first is a “Fact Sheet of new Steps to Advance Soil Science.” It is a summary of on-going and upcoming federal initiatives to advance soil research. The list includes several institutes that are represented in our multi-state project. The second document is a draft “Framework for a Federal Strategic Plan for Soil Science” prepared by a 15-person working group drawn from federal agencies. Nancy Cavallaro, the NIFA representative of W3188 is one of them. Michael Young has had contacts with the group and he presented to the group in November. He suggested and agreed to collect comments until January 8th and send on behalf of this group.

*Business meeting (led by Teamrat Ghezzehei)*

1. The presentation by Michael Young triggered a substantive and animated discussion on the future research direction for soil physics to address the concerns listed in the draft Framework released by the White House, to increase the awareness of the relevancy of soil physics to other disciplines and to stimulate increased funding support for important advances in soil physics research. The discussion has continued via email. Topics brought out during the discussion included: Tying instrument development to questions rather than to physical properties; what frontiers should be pushed?; strengthen the continuum of discovery, development and delivery of knowledge; upscaling of function such as the relationship between soil biology and soil health; enhance collaboration between soil physics and biogeochemistry to advance understanding of carbon sequestration; soil physics feeds into agriculture, hydrology and all of environmental sciences - identify future contributions; find venues to highlight the expertize that resides at universities; increase the infrastructure of soil science research so departments are more effective.
2. Michael volunteered to collect the thoughts of the group and submit these to the working group responsible for the Draft Framework for a Federal Strategic Plan for Soil Science. Input to Michael should take the form of a short statement of how your research is related to the three categories of threats to soil resources identified in the framework: land-use/land-cover change, unsustainable land management practices, and climate and environmental change.
3. The members who were present unanimously selected Hoori Ajami to be the secretary of the project for 2017. Hoori recently joined UC Riverside as an Assistant Professor of Hydrology.
4. New members: Hoori Ajami (UC Riverside), Wei Zhang (Michigan State) and Maziar Kandelous (Oregon State). They are still not included in the mailing list, so please add them individually to any messages you send through the mailing list.
5. Consider joining the International Soil Modeling Consortium. The mission and activities of ISMC are relevant to most members of this project.
6. If you have not sent your reports yet, please do so ASAP. You will hear from Maria and Hoori about planning of next year’s meeting.
7. Group photograph was taken (Thank you Ole and Markus)

<https://www.dropbox.com/s/vzdd16j6zvhgwbb/DSC_0314.jpeg?dl=0>

1. Steven Loring (W-3188 Administrative Advisor, NMSU) addressed the group and answered questions regarding the future path for the group. Emphasized that attention needs to be paid to the impact of research ventures. Funding support for this research focus depends on the ability of researchers to clearly and accurately demonstrate the value of their work.

*Hoori Ajami* (UC Riverside) discussed the application of integrated groundwater-land surface model for large scale catchment simulations in order to characterize feedback processes between the land surface and subsurface.

*Yan Jin* ( and group, University Delaware) discussed investigation of colloid attachment to the surface of food products associated with the disinfection of commercial fruits and vegetables; using turbidity measurements to quantify the concentration of colloid fraction < 45 microns.

**January 4 2016.** Chair brought the house to order at 8:30 AM.

*Bob Horton* (Iowa State University) presented an algorithm to correct for deviations of the tines in TDR thermal probes; an intriguing model for a capillary barrier; production of biochar with zero-valent-iron made from lignin and magnetite via slow pyrolysis process for the purpose of degrading TCE; transportation study on the effect of concrete slurry on vegetation.

*Dalia Kool* (Iowa State University) Presented investigation in vineyards to study partitioning of irrigation water to plants, soil and atmosphere, focusing on the goal to maximize the proportion of water to plants over soil and atmosphere.

*Ole Wendroth* (University of Kentucky) presented research results on the impact of stones on soil hydraulic properties, and showed that an existing model would allow converting the soil water retention behavior known for a stone-free soil into the water retention of a soil whose volume is occupied with stones by 40 %, while a conversion algorithm for hydraulic conductivity behavior does not exist yet and is the objective of current experiments. Xi Zhang (PhD Student of Ole Wendroth) commented on the capacity of models based on soil texture, such as Rosetta, to predict field Ksat, and demonstrated that it is not possible for such models to predict Ksat because Ksat is controlled by structure rather than texture. Javier Reyes (PhD Student of Ole Wendroth) Investigated the minimum number of valid landscape subdivisions necessary to optimize the success of precision irrigation practices.

**ACCOMPLISHMENTS**

**1. Short-term Outcomes**

1. **University of Arizona** **(Marcel Shaap)**: Developed initial (2D) version of pore-scale colloid code developed and tested for low and high ionic strengths; Wrote seven chapters of an 11-chapter textbook; Conducted first phase of comparison of drought indices and soil moisture simulations; Collaborated with Robson Armindo (Universidade Federal do Paraná) regarding development of pedotransfer functions for tropical soils; Improved hierarchical pedotransfer function to be distributed as Rosetta3 (python source-code). PTF-assisted inversion technique published.
2. **University of Arizona (Markus Tuller)**: Improvement of previously developed segmentation algorithms, and improved method for calculating interfacial/surface areas from X-Ray CT images; Developed a novel method to estimate the cation exchange capacity (CEC) of soils from water vapor sorption isotherms. Collaborative activities: improved method to determine the SWC from hyperspectral reflectance and to develop a new optical model (OPTRAM) for remote sensing of surface soil moisture; derived a new solution to Richards’ equation to improve NASA’s AirMOSS P-band radar root zone soil moisture retrieval algorithm; developed and tested a new TDR array for measurement of near-surface soil moisture in 5-mm depth increments.
3. **University of California-Riverside (Laoshen Wu)**: Developed new numerical methods to identify and apportion the source of heavy metal pollution in cropland; an adaptive Gaussian process-based method for efficient Bayesian experimental design in groundwater contaminant source identification problems; new methods for Data assimilation for unsaturated flow models with restart adaptive probabilistic collocation based Kalman filter; sequential ensemble-based optimal design for hydraulic model parameter estimation; and a mathematical model for the transfer of soil solutes to runoff under water scouring and raindrop impact.
4. **University of California-Riverside (Jirka Simunek):** Continued to expand the capabilities of the HYDRUS modeling environment by developing specialized modules for more complex applications that cannot be solved using its standard versions, including: furrow fertigation, drip irrigated gray and desalinated water, deficit irrigation; investigated accuracy of machine learning models, Hydrological applications included: recharge into layered loess, stony soil, green roofs, permeable pavements and preferential flow through glacial deposits; fate of carbon nanotube.
5. **University of Delaware (Yan Jin):** Developed method of using size-dependent turbidimetric correlations to quantify colloids in different size fractions, i.e. 0.1-0.45 and 0.45-1.0 µm; Quantified the role of colloids in organic carbon (OC) retention and mobilization in agricultural, forestry, wetland and estuary systems; Improved understanding of redox oscillation on mineral organic association (MOAs) and carried out molecular characterization of organic matter (OM) in different size fractions; Quantified the fate and transport of a promising phosphorus (P) nanofertilizer-hydroxyapatite nanoparticle (HANP) in the co-presence of iron oxide colloids (goethite and hematite) under environmentally relevant conditions; Demonstrated the usefulness of measuring phosphate oxygen isotope fractionation of engineered phosphate-based nanoparticles (NPs) in assessing their physical transport and chemical dissolution processes; Measured effects of plant-growth-promoting-rhizobacteria (PGPR) on water evaporation and retention in soils.
6. **Iowa State University (Robert Horton)**: Developed a heat pulse probe method to estimate water content and bulk density simultaneously; a new de Vries-based thermal conductivity model for unfrozen and frozen soils that provides accurate and consistent thermal conductivity estimates, and performs better than other de Vries-based models; an improved, automated algorithm for analyzing waveforms of short TDR probes; designed and tested a water vapor diode to accumulate water naturally in specific soil layers.
7. **University of Kentucky (Ole Wendroth)**: Established and improved a spatio-temporal wireless soil moisture monitoring network in a farmer’s field; Provided advice to farmer about site-specific irrigation rate; Provided advice to engineering company to avoid over-irrigation in Arkansas; introduce simple check-book method and FAO-Penman ET0; introduce soil-specific irrigation management scheme; and, EC-based clay mapping. In progress: Delineation of management zones; and improving soil physical parameter estimation for field soil water processes.
8. **North Dakota State University (Aaron Daigh)**: Improvement in brine spill site assessment methods and conservation equations to facilitate rapid and accurate assessment of brine spill sites; developed a new in situ remediation method to enable remediation specialist to remove 29 to 57% of brine salts from the soil surface within a few days; Evaluated salt and water transport properties in saline-sodic soil conditions for a range of soils prone to shrink-swell.
9. **New Mexico State University (Manoj Shukla)**: Demonstrated impact on chile pepper production and soil quality from irrigation with brackish groundwater, desalinated bracking groundwater and desalination concentrate, in support of national food security mission. Demonstrated use of zeolite to wick water from shallow groundwater to support natural native vegetation.
10. **University of Oklahoma (Tyson Ochsner)**: Advances in scientific knowledge on estimating drainage rates from the root zone using long-term in situ soil moisture data.
11. **Oregon State University (Maria Dragila)**: Developed conceptual model for the development and maintenance micro-aggregation on sandy soil, impacting irrigation methods; conceptual model for vapor sieve as a water reserve measure in semi-arid climates. In progress; experiments to quantify the partitioning of soil water into biological and capillary pools; hydro-geochemical evolution of karst microfractures; determination of feasibility of solarization for soil disinfection in Pacific Northwest.
12. **USDA-Bushland (Robert Schwartz and Steven Evett)**: Characterized capability of failure modes of a prototype down-hole NMR device used to measure soil water content; compared deep percolation losses of drip irrigation and optimized sprinkler irrigation; developed and evaluated a frequency domain through transmission probe for soil water content sensing in conjunction with a VNA.
13. **USDA-USSL (Todd Skaggs, Scott Bradford, Ray Anderson, Elia Scudiero)**: Developed new software to aid researchers investigating water and carbon fluxes in agroecosystems; new method for irrigation scheduling based on crop coefficients and eddy covariance flux partitioning; new findings concerning whether aerobic spores are a suitable surrogate for Cryptosporidium oocysts in groundwater; new overland flow and transport model.
14. **Utah State University (Scott Jones)**: Developed and tested a new TDR array that allows measurement of near-surface soil moisture in 5-mm depth increments in (collaboration with UAZ); Derived a new solution to Richards’ equation to improve NASA’s AirMOSS P-band radar root zone soil moisture retrieval algorithm (collaboration with UAZ, USC); develop a new optical model (OPTRAM) for remote sensing of surface soil moisture and vegetated soil profiles (Collaboration with UAZ); developed a new time efficient method to determine the SWC from hyperspectral reflectance via controlled laboratory experiments and inverse modeling (collaboration with UAZ).
15. **Washington State University (Markus Flury)**: Demonstrated that compost can leach excess nitrate, phosphorus, and copper from bioretention soil mixes; showed that moving air-water interfaces can translocate polyaromatic hydrocarbons from porous media; showed that biodegradable plastic mulches degrade under composting conditions; demonstrated that water activities in the driest localities on earth are sufficient to support microbial life; showed that nanoparticles behave differently than micrometer-sized colloids at the air-water interface; and provided new insights on transport of non-spherical colloids; dynamics and quantity of leaching nutrients and metals from bioretention systems (compost); as well as how surface coal mining impacts soil hydraulic properties and erosion.
16. **University of Wyoming (Thijs Kelleners)**: Completed a seismic survey at an experimental hillslope; A second snow lysimeter was installed at an experimental hillslope; The SNOWPACK model was calibrated to simulate snow pack dynamics at an experimental hillslope; An inverse modeling procedure was developed to estimate subsurface hydraulic parameters using time-lapse electrical resistivity tomography data; and the integrated watershed model GEOtop was tested in watersheds in Wyoming and Idaho.

**2. Outputs**

1. **University of Arizona (Marcel Shaap)**: We published 3 journal articles and 2 abstracts. Schaap also wrote 7 chapters in a forthcoming “Topics in Environmental Physics.” Draft versions of these chapters are already used in the ENVS420/520 course “Environmental Physics.”
2. **University of Arizona (Markus Tuller)**:Research results were disseminated in collaboration with various involved groups through 6 peer-refereed international journal publications and 14 conference contributions.
3. **University of California-Riverside (Jirka Simunek)**: Research findings were disseminated via 20 refereed journal publications, 22 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.
4. **University of California-Riverside (Laosheng Wu)**: Research results were disseminated through 10 peer-refereed international journal publications, 2 MS theses, 2 abstracts, presentations and classroom teaching.
5. **University of Delaware (Yan Jin)**:Research results were disseminated in collaboration with various involved groups through 6 peer-refereed international journal publications, 1 Ph.D. dissertation, and 6 conference contributions.
6. **Iowa State University (Robert Horton)**: Research results were disseminated in collaboration with various involved groups through at least 12 peer-refereed publications.
7. **University of Kentucky (Ole Wendroth)**: Research findings were disseminated through journal publications, Thesis, conference proceedings, presentations at national and international conferences, field days, and coordination of a 4-state research project and development of a smart-phone app for irrigation control.
8. **New Mexico State University (Manoj Shukla)**: Eight peer-reviewed manuscripts were published; three invited talks in China, and presentations at national meeting.
9. **North Dakota State University (Aaron Daigh)**: 6 publications in peer-reviewed journals, 18 conference abstracts and 1 thesis.
10. **University of Oklahoma (Tyson Ochsher)**: Maps of annual and long-term average drainage rates across the state of Oklahoma available online at <http://soilmoisture.okstate.edu/html/drainage-map.html>. Manuscript under review describing and evaluating the new method for estimating drainage from in situ soil moisture data.
11. **Oregon State University (Maria Dragila)**: Peer-reviewed manuscript that quantified gas fluxes across soil surface; conference contribution presenting proof for the existence of films on smooth surfaces of glass beads during drainage, specifically films of thickness that are below the current resolution threshold of CT scan images.
12. **USDA-Bushland (Robert Schwartz; Steven Evett)**: CRADA partner introduced two new soil water sensors based on true, directly connected TDR, the model TDR-315L (low power, CMOS circuitry) and the model TDR-310S (round with should to fit into PVC pipe for installation into bore holes of indeterminate length, vertically, horizontally or at an angle); 1 Patent: O’Shaughnessy, S.A., S.R. Evett, M.A. Hebel and P.D. Colaizzi. Multi-Band Photodiode Sensor. US Patent No. 9,451,745 B1. Issued Sept. 27, 2016. 11 peer reviewed journals, 2 proceedings full papers, 1 MS thesis, 14 invited and volunteered presentations.
13. **USDA-USSL (Todd Skaggs, Scott Bradford, Ray Anderson, Elia Scudiero)**: Research findings disseminated via refereed journal publications, conference proceedings, and presentations at national and international meetings. Collaborative research is ongoing with researchers in Australia, Austria, Korea, Germany, Iraq, Sweden, and Taiwan.
14. **Utah State University (Scott Jones)**: Research results were disseminated in collaboration with colleagues in the US and China through 5 peer-refereed international journal publications and 17 conference or invited talk contributions
15. **Washington State University (Markus Flury)**: Published 10 peer-reviewed manuscripts and presented the research results in national and international conferences (Soil Science Society Annual Meeting, Phoenix, AZ; European Geoscience Union, Vienna, Austria), and invited talks in China and Germany.
16. **University of Wyoming (Thijs Kelleners)**: 5 peer-reviewed manuscripts and 4 conference abstracts, 4 courses were taught: Soil physics lecture (3 credits), Soil physics laboratory (2 credits), Agroecology capstone (1.5 credits), and Modeling flow and transport (4 credits).

**3. Activities**

1. **University of Arizona (Marcel Schaap)**: (1) Developed new strategy for optimizing PTFs (pedo transfer functions) that demonstrated that while alpha-stable distributions provide a more consistent description of the estimated distributions than normal distributions, it is with modest improvement over normal distribution. The new PTFs (as well as those published by Schaap et al. 2001) will be distributed in the form of open-source python code. (2) Developed new strategy for low-parameter count PTF-assisted inversion of large heterogeneous 1D/2D/3D vadose zone domains. (3) Long-term (65 year) simulations of vadose zone moisture for drought-monitoring in the Desert-Southwest based on daily input of meteorological data for four characteristic locations with high-quality meteorological data (Tucson, El Paso, Albuquerque, and Winslow). (4) Development of lattice-Boltzmann computer code with physics-based colloid module., to establish a pore-scale model that can deal with a wide variety of colloid properties (size, charge, hydrophobicity). (5) Synthesis of Artificial Porous Media (see Tuller report). Schaap assisted the Tuller group in conducting very large-scale Lattice-Boltzmann simulations (100 million fluid voxels). (6) Currently writing a textbook for upper-level undergraduates and graduate students in the Earth and Environmental Sciences. The book is entitled “Topics in Environmental Physics” and contains several “threads” such as energy and water flow at global and local scales. Basic physical relations are presented in environmentally relevant contexts such as global change, critical zone science, drought, and pollution science.
2. **University of Arizona (Markus Tuller)**: (1) *X-Ray Computed Tomography (CT), Synthesis of artificial porous media:* Refined a physical framework to generate artificial porous materials with precisely known phase distributions to test and improve previously developed 3D multiphase segmentation algorithms for X-Ray CT data. Currently publishing results and are testing the newly developed codes to make them available to the research community. (2) *X-Ray Computed Tomography (CT), Surface Area Estimation from Segmented X-Ray CT Data*: Developed a new surface area estimator that is based on surface curvedness computed from principal curvatures. Currently publishing results and are validating the new approach for a number of CT datasets. (2) *Remote Sensing of Soil Moisture:* In collaboration with Utah State University we are developing novel measurement and remote sensing techniques for characterization of near surface soil moisture with the following outcomes. (a) *Advancing NASA’s AirMOSS P-Band Radar Root Zone Soil Moisture Retrieval Algorithm via Incorporation of Richards’ Equation*by deriving a more realistic, physically-based SMP model containing three free parameters based on a solution to Richards’ equation for unsaturated flow in soils. (b) *A Novel Approach to Remote Sensing of Soil Moisture Applied to Sentinel-2 and Landsat-8 Observations*that overcomes a number of restrictions of present models and provides equivalent accuracy. (c) *TDR Array Probe for Monitoring Near-surface Soil Moisture Distribution* in collaboration with Utah State University. See report from Utah State University. (d) *Soil Water content from Hyperspectral data*: Developing a new time efficient method to determine the Darcy-scale SWC from hyperspectral reflectance via controlled laboratory experiments and inverse modeling that will lead to high-resolution mapping of Darcy-scale surface moisture redistribution processes with the potential for rapid estimation of soil hydraulic properties. (3) *A New Method to Estimate CEC from Water Vapor Sorption Isotherms****:*** Based on measurements for more than 200 soils of various textures we developed a new approach to estimate CEC from water vapor isotherms considering hysteresis with superior results compared to models/methodologies based on other soil properties. Knowledge of soil cation exchange capacity (CEC) is crucial for soil fertility considerations, sorption and release of polar and non-polar compounds, engineering applications, and other biogeochemical processes.
3. **University of California-Riverside (Jirka Simunek)**: In 2016 we offered short (three-day) courses on how to use HYDRUS models at a) Colorado School of Mines, Golden, CO, b) Czech University of Life Sciences, Prague, Czech Republic, and c) the Research Center for Eco-Environmental Sciences, Chinese Academy of Science, Beijing, Peoples Republic of China. About 100 students participated in these short courses.
4. **University of California-Riverside (Laosheng Wu)**: Taught hydrology course. Presentations to various academic and non-academic groups. Converted the PCbased WatSuit, a steady-state model to assess irrigation water quality and soil response, to a web-based version. Developed a salinity management website. Received funds for three projects to support my research.
5. **University of Delaware (Yan Jin)**: (1) We developed a simple and reliable method for quantification of colloids using correlations between nephelometric turbidity and mass concentrations of colloids, that for the first time, permits quantification of < 1.0 µm colloids in different size fractions in environmental samples, especially colloids < 0.45 µm, which are traditionally considered as dissolved solutes and hence underestimated. (2) Investigated colloids and colloidal OC in different size fractions from samples collected from agricultural, forestry, wetland, and estuary systems. (3) Explored the biogeochemical role of colloids in redox dynamic systems (such as the wetlands). (4) Examined the cotransport and retention of HANPs and iron oxide colloids (goethite and hematite) in water-saturated sand columns under environmentally relevant transport conditions (pH, ionic strength, and natural OM type and concentration, and flow rate). Findings offer important insights into application of HANPs as P nanofertilizer and an *in situ* amendment for the remediation of contaminated sites where iron oxides are present ubiquitously. (5) Investigated how low-molecular-weight organic acids (LMWOAs) secreted by plants in agricultural soils mediate the dissolution of HANPs and release of dissolved PO43−. Our results provide useful insights into understanding the dissolution kinetics and oxygen isotopic evolution of phosphate-based NPs that are relevant to plant–soil systems particularly at the rhizosphere. (6) Water is a key resource limiting agricultural production; the limitations will further intensify as agricultural activities expand to less fertile areas in order to meet the world’s growing demands for food and fiber. In support of enhancing plant drought stress tolerance by plant growth promoting rhizobacteria (PGPR) we are investigating PGPR’s role in mediating physiochemical and hydrological changes in the rhizospheric soil that may impact plant drought stress tolerance. (7) We continued our collaboration with colleagues Dr. Jie Zhuang (Institute of Applied Ecology, Shengyang, of the Chinese Academy of Sciences and University of Tennessee) and Dr. Chongyang Shen (China Agricultural University, Beijing) on colloid fate and transport.
6. **Iowa State University (Robert Horton)**: (1) Developed a method to simultaneously determine soil bulk density and volumetric water content, b and  from soil thermal properties measured with a heat pulse sensor. (2) Developed a simplified de Vries-based model to estimate thermal conductivity of unfrozen and frozen soil. (3) Adaptive waveform interpretation with Gaussian filtering (AWIGF) and second order bounded mean oscillation operator $Z^{2}\left(u,t,r\right)$ are TDR analysis methods based on second order differentiation. We are theoretically and experimentally evaluating the performance of AWIGF and $Z^{2}\left(u,t,r\right)$ on both long and short probes. (4) Diurnal soil temperature fluctuations drive subsurface cyclic water vapor fluxes. We are investigating the concept of a water diode to maintain direction-controlled vapor fluxes, and water vapor diodes can be used to accumulate or remove water in particular soil layers.
7. **University of Kentucky (Ole Wendroth)**:Continue investigation of the spatial variability of soil hydraulic properties. Installed a wireless soil water monitoring network in farmer’s field. Determined that EC is a very effective auxiliary variable to estimate the spatial variability of soil clay content at the field scale. Submission of CAP grant in collaboration with 5 investigators and three farms. Begun to use the Root Zone Water Quality Model to simulate soil water dynamics, crop growth and greenhouse gas emissions. Working on decision support for irrigation water management. In collaboration with visiting international scientists, progress was made on the derivation of field capacity for Kentuckian soils (published in SSSAJ), impact of stones on hydraulic properties, new concepts on the derivation of soil quality based on soil physical measurements (SSSJA). Participation in College Strategic Team, mentoring of 5 graduate students, taught 2 courses: Spatial and Temporal Statistics, and Soil Use and Water Management. Active in a number of Extension and Outreach activities.
8. **New Mexico State University (Shukla Manoj)**: Taught soil physics, advanced soil physics and environmental soil science classes. Hosted three faculty members from University of Hebei, China. Field and greenhouse trips were organized to collect soil and water samples, soil moisture content, soil temperature, and other meteorological data. Experiments were planned on use of brackish groundwater and RO concentrate for looking at influence of irrigation water salinity on soil microbiological properties. Soil and plant samples were collected from Pecan orchards from Hatch, NM up to Fabens, Texas to evaluate salinity induced changes in pecan physiology. Proposals were written and submitted to various Funding agencies. Indaziflam movement through preferential flow channels was evaluated and its impact on Pecan growth and gas exchange parameters, and soil properties were evaluated. Work was started on developing a device to remotely collect soil moisture content data by commercially available sensors.
9. **North Dakota State University (Aaron Daigh)**: (1) Continue development of a new method to harvest brine spill salts from the soil surface with no mechanical disturbance needed for brine spill remediation purposes. The use of a crystallization inhibitor was surface applied resulting in salt dendrites to form above the soil surface during evaporation. The method was field tested at three brine evaporation pits in northern North Dakota along wide traditional in-situ remediation methods. (2) Large soil leaching columns were constructed to monitor brine leachate over time. were constructed. (3) Ongoing field experiment monitoring soil temperature, water content and thermal properties to improve our understanding of soil heat and water processes across spatial scales leading to development of a suite of methodologies to design and execute a ‘soil weather’ forecasting system.
10. **University of Oklahoma (Tyson Ochsner)**: Evaluated a method for estimating drainage rates from the root zone using long-term in situ soil moisture data, and the relationship between those drainage estimates and long-term groundwater recharge rates. Calibrated a hydrologic model, Hydrus-1D, using measured meteorological data and soil moisture data from four Oklahoma Mesonet sites, and we used the calibrated model to provide independent estimates of drainage for comparison with our new method. We wrote and submitted a manuscript describing the results of this project.
11. **Oregon State University (Maria Dragila)**: Initiated investigation of soil water relations in sandy agricultural soil to improve irrigation efficiency and effectiveness. Continued field and laboratory investigations associated with the evolutionary development of micro-aggregation in sandy soil. Continue investigation of biophysical mechanisms associated with the evolution of water repellency to uncover a remediation strategy. Initiated laboratory experiments to investigate the erosional evolution of microfractures in the epikarst. Completed first year field trials to determine the efficacy of using soil solarization for pest and weed disinfection in the Pacific Northwest. Continue international collaboration to identify and quantify mechanisms that drive gas exchange across the interface between vadose zone and atmosphere. Collaboration to understand the role of thin films in the redistribution of oil-water flow in porous media. Manuscript development on a number of these projects. Cranberry growers traditionally use an established matric potential range to maximize productivity. Because of the strong hysteresis exhibited by cranberry sands, we are exploring soil moisture as a more accurate control to maximize productivity.
12. **USDA-Bushland (Robert Schwartz and Steven Evett)**: (1) We continued work with commercial and university partners related to a Materials Transfer Research Agreement 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 develop new, low-cost soil water and bulk electrical conductivity sensors based on miniaturized TDR circuitry that is directly coupled to the probe waveguide. (3) We continued work with US and Chinese partners on the Water Saving Technologies Flagship Project of the USDA-China Ministry of Science and Technology joint Science and Technology Agreement, which was renewed in 2016. (4) We continued development of sensors, sensing systems, software and hardware systems and systems integration for scheduling and control of variable rate irrigation systems. (5) We completed work with an M.S. student on comparison of deep percolation losses in cropped fields irrigated using mid elevation spray application sprinkler as compared with subsurface drip irrigation. (6) We continued long-term work comparing ET by field soil water balance to ET by weighing lysimeter. (7) We began work on relating soil available water fraction to water stress indices with the goal of developing a model to transform maps of crop water stress index (or another stress index) into maps of root zone available soil water.
13. **USDA-USSL (Todd Skaggs, Scott Bradford, Ray Anderson, Elia Scudiero)**: (1) Existing subsurface flow and transport models were modified to simulate these physically non-equilibrium processes by considering overland flow and transport in: (i) mobile and immobile regions; (ii) active and passive flow regions; and (iii) and active and passive flow regions with immobile water, as well as exchange between these regions.  The developed model improves our ability to describe non-equilibrium overland flow and transport processes, and improves our understanding of factors that cause this behavior. (2) Explored a new method to more rapidly determine crop coefficients for novel cultivars and cultivation practices. In this study, we partition eddy covariance ET observations into evaporation (E) and transpiration (T) components using correlation structure analysis of high frequency (10-20 Hz.) observations of carbon dioxide and water vapor (Scanlon and Sahu, 2008) at three irrigated agricultural sites. The results benefit irrigation managers, farmers, and hydrologists who rely on crop coefficients to accurately predict water demands, with a particular benefit to farmers and irrigators exploring new production systems to improve production and efficiency. (3) Investigation to compare the viability and utility of the two commonly used approaches for creating soil salinity maps. The approaches were tested using 22 fields (total 542 ha) located in California’s western San Joaquin Valley.
14. **Utah State University (Scott Jones)**: (1) Investigated the influence on soil water retention properties of stone content, which dominate forest soils. (2) Collaborated on development of a novel approach to remote sensing of soil moisture applied to Sentinel-2 and Landsat-8 observations that only requires a single universal parameterization for a given location, which is a significant advancement that opens a new avenue for remote sensing of soil moisture. (3) A TDR array was designed to provide cm-resolution measurements of soil moisture content from the surface downward. (4) During soil moisture redistribution experiments, we employed a benchtop hyperspectral line scan imaging system to generate high resolution surface reflectance maps of soil surface moisture from which, by inverse Hydrus-2D modeling, we determined the soil hydraulic function parameters during soil moisture redistribution experiments. Results demonstrate the potential for this method for rapid soil hydraulic properties determination. In addition, the experiments provide valuable basic knowledge that can be potentially applied for large scale airborne or satellite remote sensing of surface soil moisture. (5) We are collaborating on a project to advance NASA’s AirMOSS P-Band radar root zone soil moisture retrieval algorithm via incorporation of Richard’s equation. Evaluation of the new soil moisture profile model revealed that it exhibits greater flexibility for fitting measured and simulated SMPs than the currently applied polynomial
15. **Washington State University (Markus Flury)**: Work on review article on colloid transport in unsaturated porous media. Organized a special section on ``Lysimeters in Vadose Zone Research” in the Vadose Zone Journal. Organized symposium on “Nanoparticle Fate and Transport in Soil and Groundwater Systems” at the European Geoscience Union Annual meeting. Measured leaching of nitrate, phosphorus, and copper from compost-amended bioretention systems. Investigated transport mechanisms of polyaromatic hydrocarbons (fluorathene) in unsaturated porous media. Used numerical modeling to assess the effect of biodegradable plastic mulches on water dynamics in field soils. Performed field experiment to assess suitability of biodegradable plastic mulches for pumpkin production. Measured soil quality in field trials to check for adverse effects of biodegradable plastic mulches. Tested degradation of biodegradable plastic mulches under compost conditions. Conducted household-scale soil phosphorous (P) sampling and property owner surveys. Analyzed and obtained soil P data from 74 urban locations (511 samples) and seven agricultural locations (60 samples).
16. **University of Wyoming (Thijs Kelleners)**: We continue to maintain a state-wide soil moisture network consisting of 17 sites in rangelands. We continue to maintain 3 snow-soil stations, 6 soil moisture stations, and 2 snow lysimeters in NoName watershed, WY. A collaboration was initiated with Stefano Endrizzi (University of Zurich) to better understand and debug the integrated watershed model GEOtop.

**4. Milestones**

1. **University of Arizona (Marcel Schaap)**:Improved hierarchical pedotransfer function to be distributed as Rosetta3 (python source-code). PTF-assisted inversion technique published. Initial (2D) version of pore-scale colloid code developed and tested for low and high ionic strengths. Wrote seven chapters of an 11-chapter textbook. Conducted first phase of comparison of drought indices and soil moisture simulations.
2. **University of Arizona (Markus Tuller)**:Developed a new hybrid method based on surface curvedness to determine interfacial/surface areas from segmented X-Ray CT observations of multiphase porous systems. Developed a novel method to estimate the cation exchange capacity (CEC) of soils from water vapor sorption isotherms. Developed a new time efficient method to determine the SWC from hyperspectral reflectance via controlled laboratory experiments and inverse modeling. Developed a new optical model (OPTRAM) for remote sensing of surface soil moisture. Derived a new solution to Richards’ equation to improve NASA’s AirMOSS P-band radar root zone soil moisture retrieval algorithm. Develop and tested a new TDR array that allows measurement of near-surface soil moisture in 5-mm depth increments. Refined a physical framework to generate artificial porous materials with precisely known phase distributions to test and improve previously developed 3D multiphase segmentation algorithms for X-Ray CT data.
3. **University of California-Riverside (Jirka Simunek)**: New options were added to Hydrus-2D modeling program: coupled movement of water, vapor and energy, surface energy balance to calculate potential evaporation, effect of slope and plant shading on solar irradiation, root growth and spatial distribution, and overland flow module. Various novel applications of the existing models were implemented; publication of two review papers.
4. **University of California-Riverside (Laosheng Wu)**: (1) Source identification and apportionment of soil cadmium in cropland, one of the most toxic heavy metals in the environment, is being performed in grower’s fields in China. (2) Development of an adaptive Gaussian process-based method for efficient Bayesian experimental design in groundwater contaminant source identification problems. (3) Motivated by recent developments in uncertainty quantification and ensemble Kalman filter (EnKF), we proposed and investigated a restart adaptive probabilistic collocation based Kalman filter (RAPCKF) for data assimilation in unsaturated flow problems. RAPCKF was demonstrated to be more efficient than EnKF with the same computational cost. (4) Investigated Sequential ensemble-based optimal design for parameter Estimation. (5) Developed a mathematical model to quantify the transfer of soil solutes to runoff under water scouring.
5. **University of Delaware (Yan Jin)**: (1) Turbidity-concentration correlations were developed from a large number of soils samples to be used as a quick and reliable method that allows quantification of colloids in different size fractions. The ability to quantify colloids in the < 0.45 µm fraction, which has traditionally been considered as part of the dissolved phase, in environmental samples provides the means to more accurately account for colloidal loads in natural and environmental systems. (2) We quantified the contributions of colloids and colloidal OC in various terrestrial or aquatic systems, which have important implications in differentiating OC in colloidal, nano-size and dissolved phase and thus accurately estimating the carbon inventory in different natural environments. (3) We observed that the nano size fraction (2.3-100 nm) contained the highest percentage and the most recalcitrant forms of OC compared to larger size fractions (e.g., 100-450 and 450-1000 nm) as well as had different mineral compositions. (4) We demonstrated, for the first time, that oxygen isotopic fractionation of manufactured phosphate-based NPs is insignificant during physical transport and chemical dissolution, which is useful for better understanding of the fate, transport, and transformation of engineered P-NPs in the environment. (5) We used novel experimental approaches and demonstrated that PGPR can increase soil water retention and reduce evaporation from soils.
6. **Iowa State University (Robert Horton)**: We developed a heat pulse probe method to determine soil water content and soil bulk density simultaneously. We developed simplified thermal conductivity models for unfrozen and frozen soils. We developed an automated algorithm for analyzing waveforms obtained from both short and long TDR probes. We used numerical analysis to show that water vapor diodes are effective at accumulating water naturally in specific soil layers.
7. **University of Kentucky (Ole Wendroth)**: Installed wireless sensor network for soil water content monitoring in a farmer’s field. Substantial progress in field-scale functional soil mapping for management decision support. Progress in linking remotely sensed field information to soil processes.
8. **New Mexico State University (Manoj Shukla)**: (Obj 1) Quantified impacts of irrigation water salinity induced changes to evapotranspiration and yields of several chile pepper variety. Threshold soil salinity range was determined beyond which yield reductions are observed in chile. Quantified impacts of irrigation water salinity induced changes to evapotranspiration and yields of several halophytes. Quantified increases in soil salinity and several cations and anions in soil with continued irrigation with brackish groundwater and RO concentrate. Showed Clinoptilolite zeolite can be used to wick water from groundwater tables within 3 m from surface to support native vegetation. Showed Clinoptilolite zeolite or soils amended with Clinoptilolite zeolite improve hydraulic properties of soils especially sand but increase nitrate leaching. Quantified dissipation rates and half-life of indaziflam herbicide. (Obj 2) Calibration equations developed for three soil moisture sensors (CS616, Hydra probe, and TM5 sensor). Work started on developing a sensor to collect data at a location and directly transmit to central storage. (Obj 3) Dissipation rates for indaziflam were quantified that would be useful for management of Pecan orchards. Ion accumulation in soil and plant was quantified that would be a helpful for designing improved irrigation strategies for using RO for agriculture
9. **North Dakota State University (Aaron Daigh)**: Developed a new method to harvest brine spill salts from the soil surface without mechanical disturbance. This method has great potential to increase brine spill remediation timelines and reduce risks to the environment. Improved our understanding of soil sodicity effects on soil pore size distributions in smectite dominated soils. Evaluated the evaporation method for determining soil water retention across a gradient of salinity, sodicity, and texture for soils containing smectite clays.
10. **University of Oklahoma (Tyson Ochsner)**: Manuscript describing the soil-moisture based method for estimating drainage was submitted for peer review.
11. **Oregon State University (Maria Dragila)**: Developed a cohesive conceptual framework for the development, evolution and amelioration of water repellency in coarse textured media. Quantified the governing physics responsible for film based drainage along non-textured oil-water systems. Completed laboratory installation and demonstrated that film flow instability leads to 3 distinct liquid flow regimes that coexist in natural micro-fractures. Developed dynamic (rather than static) hysteresis curves for cranberry sands.
12. **USDA-Bushland (Robert Schwartz and Steven Evett)**: First 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. M.S. thesis was completed by student on comparison of deep percolation losses in sprinkler irrigated versus subsurface drip irrigated fields.
13. **USDA-USSL (Todd Skaggs, Scott Bradford, Ray Anderson, Elia Scudiero)**: Concluded that aerobic spores can served as a conservative surrogate of the transport behavior of oocysts over a range of environmentally relevant conditions. Based on these findings, the US EPA is in the process of modifying regulations associated with groundwater surface water interactions to include aerobic spores. In collaboration with USDA-ARS we have developed new capabilities for regional-scale assessments of soil salinity, including: (i.) new satellite remote sensing techniques for mapping root zone salinity at regional-scales; and (ii.) new techniques for incorporating satellite-based estimates of evapotranspiration and groundwater storage changes into land surface models.
14. **Utah State University (Scott Jones)**: Developed and implemented enhanced SDI-12 commands for heat pulse sensor improvement including ambient temperature correction and in situ needle spacing calibration. Submitted 3 new proposals to advance sensor development at the state and federal levels. Developed and tested a new TDR array that allows measurement of near-surface soil moisture in 5-mm depth increments. Developed a new optical model (OPTRAM) for remote sensing of surface soil moisture. Derived a new solution to Richards’ equation to improve NASA’s AirMOSS P-band radar root zone soil moisture retrieval algorithm. Developed a new time efficient method to determine water content and water flux during imbibition from a Shortwave Infrared Camera measurement of reflectance via controlled laboratory experiments and inverse modeling.
15. **Washington State University (Markus Flury)**: (Obj. 1) Developed mechanistic understanding of interactions of colloids and hydrophobic compounds at the air-water interface. Showed that hydrophobic substances, i.e., PAHs, will preferentially partition to the air-water interface during transport through porous media. Showed that currently used bioretention soil mixes containing compost leach excess nitrate, phosphorus, and copper. We determined vapor sorption isotherms to evaluate the dry-limits of life. Preliminary data analysis showed a broad range of soil P concentrations in urban and suburban residential areas in the increasingly urbanized Puyallup Watershed, South Puget Sound. (Obj. 2) We applied a numerical modeling to analyze the effects of biodegradable plastic mulches on soil moisture. (Obj. 3) We completed a second of four field seasons to evaluate the effects of biodegradable plastic mulches on soil quality.
16. **University of Wyoming (Thijs Kelleners)**: PhD candidate Tegenu Engda successfully defended his dissertation entitled: Soil moisture-based drought monitoring in rangeland ecosystems. Three papers were published from this work. Tegenu is now employed as a postdoc at CU Boulder
17. **Impact Statements**
18. **University of Arizona (Marcel Shaap)**: The original Schaap et al. (2001) “Rosetta” paper for estimation of soil hydraulic parameters from soil texture continues to generate widespread interest (currently 770 citations). We expect that the new and improved models will likewise generate widespread interest. The new PTF-assisted inversion method is simple to implement with minimal (or no) modification to existing software. We expect that this method will facilitate inversions of large domains.
19. **University of Arizona (Markus Tuller)**: Our advanced X-Ray CT segmentation algorithms aided numerous other researchers with projects that utilize X-Ray CT for soil and porous media research. The new solution to Richards’ equation will be implemented in the NASA AirMOSS P-band radar algorithm to improve root zone soil moisture retrieval
20. **University of California-Riverside (Jirka Simunek):** Continue supporting a large number of HYDRUS users from 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. By 2016, over twenty five thousand HYDRUS users from all over the world registered at the HYDRUS website so that they could benefit from this activity, and HYDRUS-1D was downloaded more than ten thousand times. Additionally, in 2016 we have offered short (three- day) courses on how to use HYDRUS models at Colorado School of Mines, Golden, CO, Czech University of Life Sciences, Prague, Czech Republic, and the Research Center for Eco-Environmental Sciences, Chinese Academy of Science, Beijing, Peoples Republic of China. About 100 students participated in these short courses.
21. **University of California-Riverside (Laoshen Wu)**: The new models allow to more accurately predict water and nutrient transport in runoff. More reliable hydraulic parameter estimation improves model simulation by reducing prediction uncertainties. Identification and apportion of pollution sources improve the efficiency of water conservation efforts.
22. **University of Delaware (Yan Jin)**: The new turbidimetric method allows us to efficiently quantify 0.1-0.45, 0.45-1.0 µm colloids, which would enhance our capability to more accurately quantify the colloidal pools in natural systems, and thus provides more accurate assessment in the mobility of colloid-associated-constituent, such as nutrients, contaminants and trace elements. The findings of investigating colloids’ role in carbon mobilization fill the gap in the quantification of < 0.45 µm colloidal organic carbon and provide the basis for possibly considering colloidal organic carbon as a separate phase in carbon cycling and assessment of carbon inventory and budget in different natural environments. *In situ* characterization of different size fractions of MOAs enables more accurate assessment of the stability of terrestrial C under redox dynamic wetlands, thus improves understanding of C storage and cycling as influenced by colloid mobilization under changing climatic conditions. Compared to conventional P fertilizers, HANPs as a novel P nanofertilizer would have minimal eutrophication risks due to their limited mobility in natural soils, where positively charged iron oxides are present in many soils. Direct application of HANPs in acidic soils is expected to provide bioavailable PO43− for crop growth in a timely fashion due to quick proton-promoted dissolution. The dissolution rate of HANPs could be much higher in the rhizosphere where LMWOAs are present due to both proton- and ligand-promoted dissolution. Because different sources of phosphate-based NPs may hold distinct oxygen isotopic signatures, and transport-related isotope fractionation is insignificant (≤ 1.3‰), isotope tracing could serve as a promising tool for identifying the sources and transport of phosphate-based NPs in complex subsurface environments. The long-term goal of the PGPR study is twofold: 1) to provide a more complete understanding of plant-soil-microbe interactions in the root zone and their influence on water retention and hydraulic properties and 2) to explore the application potential of using PGPR as an alternative (to plant genetic engineering and breeding) for reducing plant drought stress tolerance and meeting the challenge of producing adequate food for the growing world population under the changing climate.
23. **Iowa State University (Robert Horton)**: We developed a heat pulse probe method to determine soil water content and soil bulk density simultaneously. We developed simplified thermal conductivity models for unfrozen and frozen soils. We developed an automated algorithm for analyzing waveforms obtained from both short and long TDR probes. We used numerical analysis to show that water vapor diodes are effective at accumulating water naturally in specific soil layers.
24. **University of Kentucky (Ole Wendroth)**: Installed wireless sensor network for soil water content monitoring in a farmer’s field. Substantial progress in field-scale functional soil mapping for management decision support. Progress in linking remotely sensed field information to soil processes.
25. **New Mexico State University (Manoj Shukla)**: The availability of surface water for irrigation is not sufficient for sustaining agriculture in the southern New Mexico. Increasingly saline groundwater is used for irrigation, which can have severe consequences on the soil quality and sustainability of agriculture. My research group’s work on the use of brackish groundwater and RO concentrate for growing chile peppers and helophytes has identified the potential problems and opportunities. This has generated a lot of interest in the state and has been widely published by various Newspapers. Our strategy towards developing new irrigation scheduling protocols for safe and low cost disposal of RO concentrate can be a key for sustaining agriculture in water starved southern New Mexico as well as other similar arid areas. These efforts also may be useful for safe reuse of RO concentrate (or waste) locally and could contribute to food security and desertification control.
26. **North Dakota State University (Aaron Daigh)**: New methods to remediate brine spills and knowledge to understand salt, water, and heat transport in a range of soils prone to shrink-swell increase our ability to ameliorate and remove salts in sensitive or working landscapes
27. **University of Oklahoma (Tyson Ochsner)**: The soil moisture-based drainage estimation method was presented in an invited talk at the Third International Conference on Hydropedology in Beijing, China, in August 2016, reflecting the international interest in this new approach.
28. **Oregon State University (Maria Dragila)**: (1) Our work highlights that sustainable effective production in sandy soils needs to include co-management of a strong biologic component for water resource management. Our group aims to clarify this bio-water function for the purposes of improved food quality and more efficient resource use. (2) In support of improved water resource management, we are investigating the erosional evolution of karst units as conduits evolve from microfractures into larger features. This work will contribute to three very diverse fields of research, i.e., advance the theoretical framework of Karst land evolution; quantify the erosion rates caused by different liquid modes; and quantify hydrogeochemical fate of infiltrating water to karst aquifers. (3) Soil solarization, if proven effective for the Pacific Northwest, will provide a much needed ecologically friendly alternative to fumigation; and provide an economic option for organic agriculture
29. **USDA-Bushland (Robert Schwartz and Steven Evett)**: The directly coupled TDR sensors are commercially available and are being adopted widely in industry and by the research community. The thermal IR wireless sensor developed at Bushland is commercialized and is beginning to see adoption in irrigation management systems and by researchers. Regional and international requests to speak indicate considerable impact on soil water sensing and irrigation management, particularly variable rate irrigation.
30. **USDA-USSL (Todd Skaggs, Scott Bradford, Ray Anderson, 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.
31. **Utah State University (Scott Jones)**: Prototype Penta- and Tri-needle Heat Pulse Probes have been shared with research groups in China and the US, facilitating research data collection and real-time analysis using the only sensor of its kind with on-board computing and soil property output capability. The new solution to Richards’ equation will be implemented in the NASA AirMOSS P-band radar algorithm to improve root zone soil moisture retrieval in future flight opportunities.
32. **Washington State University (Markus Flury)**: Our findings of excess leaching of nutrients and Cu from compost have questioned current regulations on bioretention soil mixes and caused regulatory agencies to re-evaluate existing specifications for bioretention soil mixes.
33. **University of Wyoming (Thijs Kelleners)**: Automated sensor measurements are combined with numerical modeling to better understand water, heat, and carbon fluxes at the plot, hillslope, and watershed scales in cold regions.

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**Theses/Dissertations**:

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2. Klaustermeier, A. 2016. Brine-contaminated soils in western North Dakota: Site assessment methodology and a new in-situ remediation method. M.S. thesis North Dakota State Univ., Fargo.
3. Fenix, Ashley R. Field investigation of the variation of unsaturated flow under SDI and MESA irrigated cultivated fields. Submitted in Partial Fulfillment of the Requirements for the Degree Master of Science. Major Subject: Environmental Science. West Texas A&M University, Canyon, Texas, December 2016.

**Patents**

1. O’Shaughnessy, S.A., S.R. Evett, M.A. Hebel and P.D. Colaizzi. Multi-Band Photodiode Sensor. US Patent No. 9,451,745 B1. Issued Sept. 27, 2016.

**Multimedia**

Maps of annual and long-term average drainage rates across the state of Oklahoma available online at <http://soilmoisture.okstate.edu/html/drainage-map.html>.