Title: Increasing water yield and quality through redcedar removal and establishment of herbaceous biofuel feedstock production systems: Effect of vegetation on groundwater recharge in upland ecosystems

Start Date: 03/01/2014

End Date: 08/30/2015

Congressional District: OK-3

Focus Category: Groundwater, invasive species, drought

Descriptors: Groundwater, redcedar, biofuel

Students:

Student Status	Number	Disciplines
Undergraduate		
M.S.		
Ph.D.	1	Natural resource ecology and management
Post Doc		
Total		

Principal Investigators: Chris Zou, Associate Professor, NREM, Oklahoma State University chris.zou@okstate.edu

Publications:

Peer reviewed articles

Zou CB, Caterina GL, Will RE, Stebler E, Turton D. 2015. Canopy interception for a tallgrass prairie under juniper encroachment. PLOS One. doi:10.1371/journal.pone.0141422.

Zou CB, Turton DJ, Will RE, Engle DM, Fuhlendorf SD (2014). Alteration of hydrological processes and streamflow with juniper (Juniperus virginiana) encroachment in a mesic grassland catchment. Hydrological Processes, 28(26), 6173-6182.

Presentations and abstracts

Acharya BS, Halihan T, Zou CB. 2015. Temporal variability in water level in a tallgrass prairie and juniper woodland indicate vegetation controls on deep drainage. NSF EPSCoR Annual State Conference, Norman, OK, USA, December 3, 2015.

Acharya BS, Halihan T, Zou CB, Fox G, Will RE. 2015. Hydrogeophysical evaluation of vadose zone moisture, subsurface flow and deep drainage in grassland, woodlands and oak forest, Oklahoma, USA. Oklahoma Governors Water Conference and Research Symposium, Norman, OK, USA, December 1-2, 2015.

Acharya BS, Halihan T, Zou CB, Will RE, Fox G. 2015. Detection of vadose zone moisture in a Oak forest using Electrical Resistivity. The 2015 workshop at MOISST: The dawn of the soil moisture information age? Stillwater, OK, USA, June 2-3, 2015.

Acharya BS, Halihan T, Zou CB, Will RE, Fox G. 2015. Time-lapse Electrical Resistivity Imaging (ERI) for spatio-temporal monitoring of vadose zone moisture. 24th Annual Clean Lakes and Watershed Association Confrence, Stillwater, OK, USA, April 8-9, 2015.

Acharya BS, Zou CB, Will RE, Fox G, Halihan T. 2014. Application of Electrical ResistivityImaging (ERI) in detecting vadose zone soil moisture dynamics. 3rd Annual Student Water Confrence (SWC), Stillwater, OK, USA, April 10-11, 2014.

Problem and Research Objectives:

Changes in land use and vegetation cover can directly alter groundwater recharge processes, especially in water limited semi-arid and subhumid regions. Vegetation reduces groundwater recharge by either extracting groundwater from the saturated zone or reducing rainfall reaching the groundwater table. Research so far has focused mainly on the riparian zone where connectivity between the surface and the alluvial aquifer is intuitive and the interaction can be rapid. However, over 90% of land surface is upland, and the effect on groundwater of changes in upland vegetation cover such as conversion from redcedar woodland to herbaceous biofuel feedstock production is poorly understood.

Objective 1: Quantify soil moisture for the rooting zone under three contrasting vegetation types – grassland, post oak forest and redcedar woodland with the same precipitation input.

Objective 2: Directly evaluate the water table and interflow under different vegetation types and its seasonable variation.

Objective 3: Directly assess long-term water efflux out of rooting zone using chloride mass balance - proximity for recharge potential.

Methodology:

We estimated soil moisture for the entire rooting zone and below up to a depth of 9 m using transient multi-electrode surface resistivity. For each vegetation cover type, we installed a permanent latitudinal transect of 42 m oriented along the contour lines and another permanent orthogonal transect of 21 m which run through the center of the latitudinal line. A total of 56 and 28 electrodes were permanently deployed on the surface across latitudinal and orthogonal transect, respectively with 0.75 m inter-electrode spacing. Electrode is 19.2 inch in length made up of copper coated steel lightning rods and was permanently installed to soil at a depth of 6 to 12 inch in June 2014. Apparent resistivity data was collected using SuperSting 8-channel resistivity instrument in an automated mode following OSU proprietary method (the Halihan-Fenstemaker method). A total of 277 apparent resistivity data were collected from an orthogonal transect and 1194 apparent resistivity from a latitudinal transect during one ERI data acquisition. A base station was established in both sites near ERI lines, and a rover and a TOPCON Hyperlite Plus Global Positioning System was set to record latitude, longitude and elevation for each electrode with 1 cm of accuracy. Data from Topcon GPS was downloaded to a computer and base data was sent to Online Positioning User Service (OPUS). The easting, northing and elevation of base station obtained from OPUS were used to correct location data of each electrode. Apparent resistivity data collected in field were inverted and images were developed using EarthImager 2D Software 1.6.8 (Advanced Geosciences, Inc., 2004), AestusRPT under a range of precipitation and soil moisture conditions and presented with consistent color scheme. Two groundwater observation wells were installed in the experimental site; one in grassland and the other in redcedar encroached site. The depth of the wells is 3 meter, which is the maximum depth we were able to reach using solid-stem auger mounted in Geoprobe 6300. EC-5 soil moisture sensor (Decagon Devices, Utah, USA) were also installed at 3 meter and 1.5-meter depth. Bentonite clay was packed around the well bore about 1 meter to guarantee that water and solutes are not traveling laterally through the topsoil and then vertically down the well hole. Prepacked wells were installed to limit clogging due to fine-grained aquifer sediments. Each observation well was instrumented with CTD-10 sensor (Decagon Devices, Inc., Pullman WA) to automatically monitor water level (*accuracy* ± 0.05%), electrical conductivity (accuracy ± 0.01 dS/m) and temperature (accuracy ±1°C) at 15-minute intervals.

In April 2015, we cored and collected soil samples at 25-cm interval and the maximum soil depth ranging from 125-cm to 275-cm using auger manually. Six locations in grassland and 6 locations in encroached site were randomly selected for sampling. A total of 90 samples were analyzed for chloride concentration. Chloride anion in the soil was determined by Lachat QuikChem 8500 flow injection analyzer by mercury thiocynate method. Cl content in the pore water was estimated by dividing soil Cl by gravimetric water. Deep drainage was estimated by using a steady-state equation which assumes that Cl deposited by rainfall is largely removed by drainage from the unsaturated zone and can be used as a surrogate for deep drainage or recharge

$$PCl_p = RCl_s$$

Where, P is the average annual precipitation (mm/yr), Cl_p is the average Cl input from all sources (mg/L); National atmospheric deposition program data was used to get Cl deposition (http://nadp.sws.uiuc.edu/), Cl_s is the average Cl concentration of pore water below root zone (mg/L), and R is the average annual deep drainage rate (mm/yr). Wet deposition of chloride was obtained from National Atmospheric Deposition Program (NADP) as weighted mean concentration in precipitation from Kessler Farm Field Laboratory, OK during 1983 -2014. Mean chloride concentration in precipitation was doubled to account for dry deposition.

Principal Findings and Significance:

We collected and archived a range of time-lapse electrical resistivity images (ERI) to track moisture change to a depth of 9 m in grassland and juniper (*Juniperus virginiana*, eastern redcedar) encroached, and oak forest catchments under different precipitation and soil moisture conditions. Analysis based on those images showed a two-layer moisture migration profile: non-wetted and wetted in grassland, juniper-encroached catchments, and oak forest after rainfall event. Percent change in conductivity was lower in the top 3-m and higher below 3-m depth in the electrical resistivity data across vegetation. However, the eastern redcedar-encroached catchment showed higher spatial-temporal variability in the root zone electrical conductivity and reduced deep drainage and recharge potential compared with grassland catchment (Fig. 1).

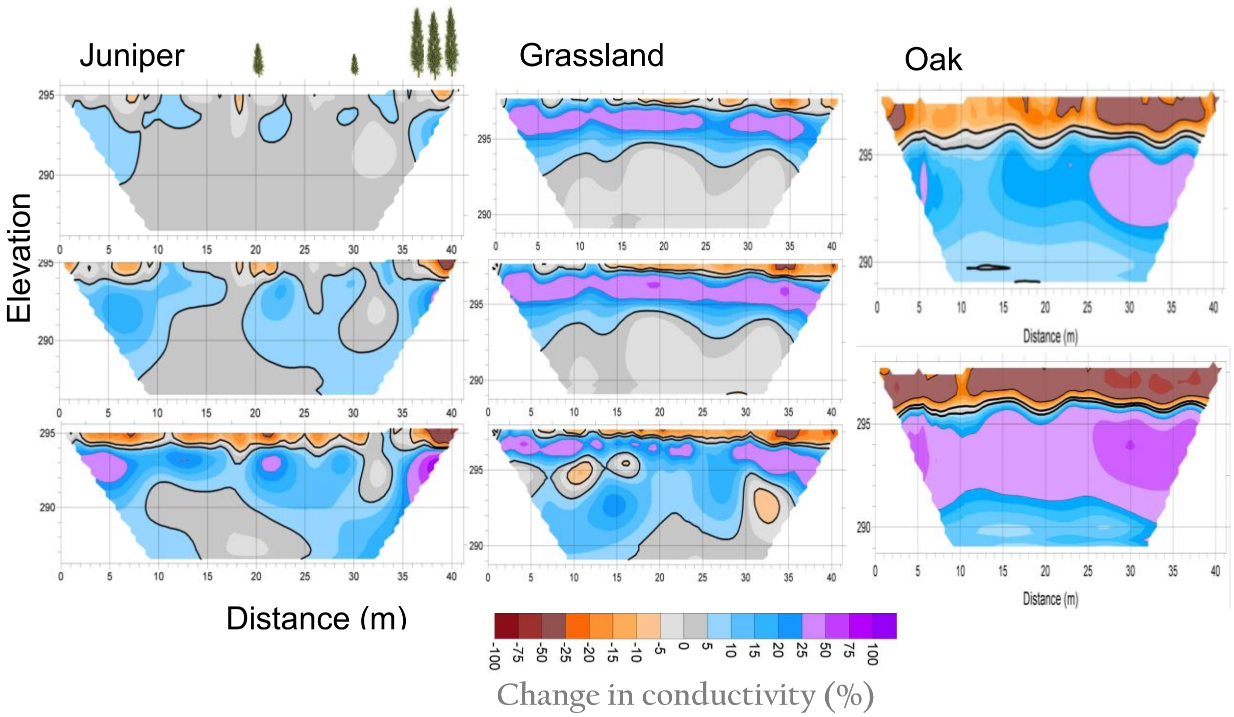

Fig. 1. Electrical resistivity images from the juniper-encroached (left panel) and grassland (middle panel) and oak forest (right panel) catchment. Images were taken during June-August, 2014 in juniper-encroached and grassland and during June-July, 2014 in oak forest from latitudinal transect deployed with 56 electrodes and are illustrated as pseudosections with percent change in conductivity to a depth of 9 m.

Direct observation of subsurface hydrologic flow pathways using point measurements is relatively difficult in soils underlying porous bedrock. Passive seasonal temporal ERI thus provided clues of lateral flow in tallgrass prairie. The flow was largely controlled by differences in lithologic properties with depth (Fig. 2).

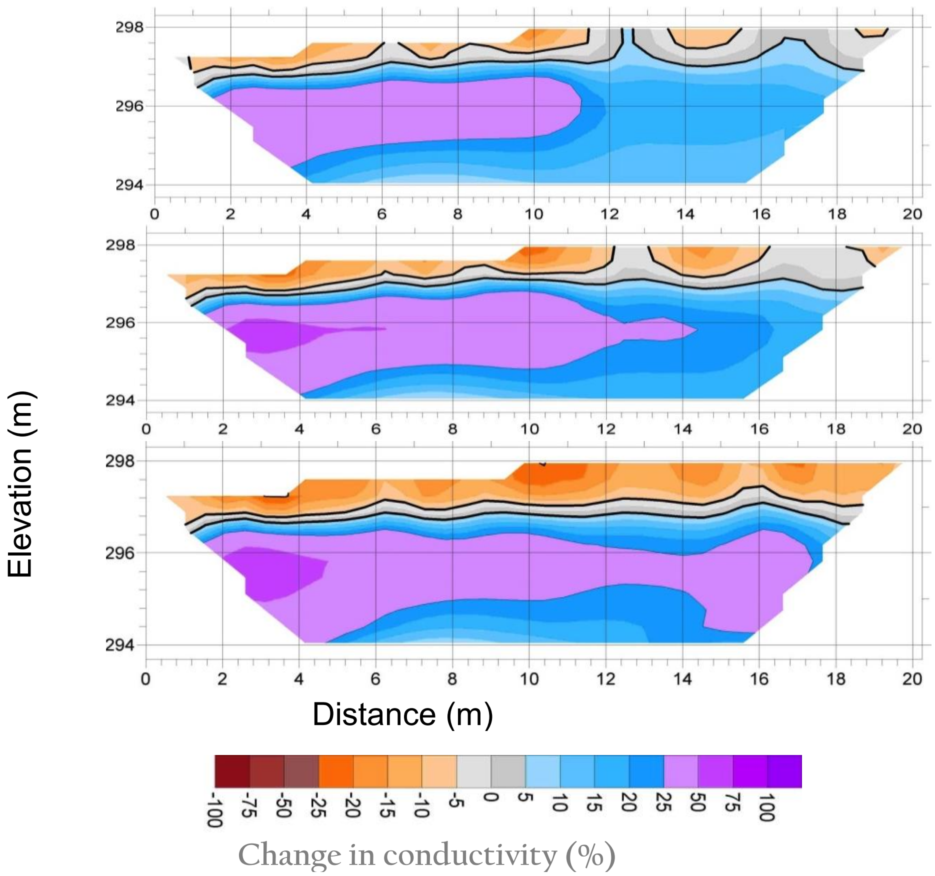

Fig. 2. Electrical resistivity images indicating lateral flow in the grassland catchment. Images were taken during June-August, 2014 from an orthogonal transect deployed with 28 electrodes, and are illustrated as pseudosections with percent change in conductivity to a depth of 4 m.

Based on drilling and ERI images, the groundwater table is deeper than 9 meters at the grassland, eastern redcedar encroached and oak woodland sites. This suggests that vegetation impact on groundwater at these upland sites is mainly through reducing net rainfall reaching the groundwater table. This limits our ability to quantify vegetation cover on groundwater through mentoring groundwater table fluctuation at these upland sites. This suggests that ERI method is a necessary approach to explore recharge process in order to further detect change in moisture content below different vegetation rooting zone in these heterogeneous sites.

Monitoring wells show temporal variability in water level in a tallgrass prairie and juniper catchment. Water level was higher under grassland than under juniper woodland for all times. Peak water level of 2485 mm was recorded during 16-May 2015 (Fig. 3). In contrast, the water level in woodland peaked up to 10 mm during 20-May 2015. Results indicate that vegetation can modulate deep drainage of water, and woody plants can decrease water level in a perched aquifer by a significant amount.

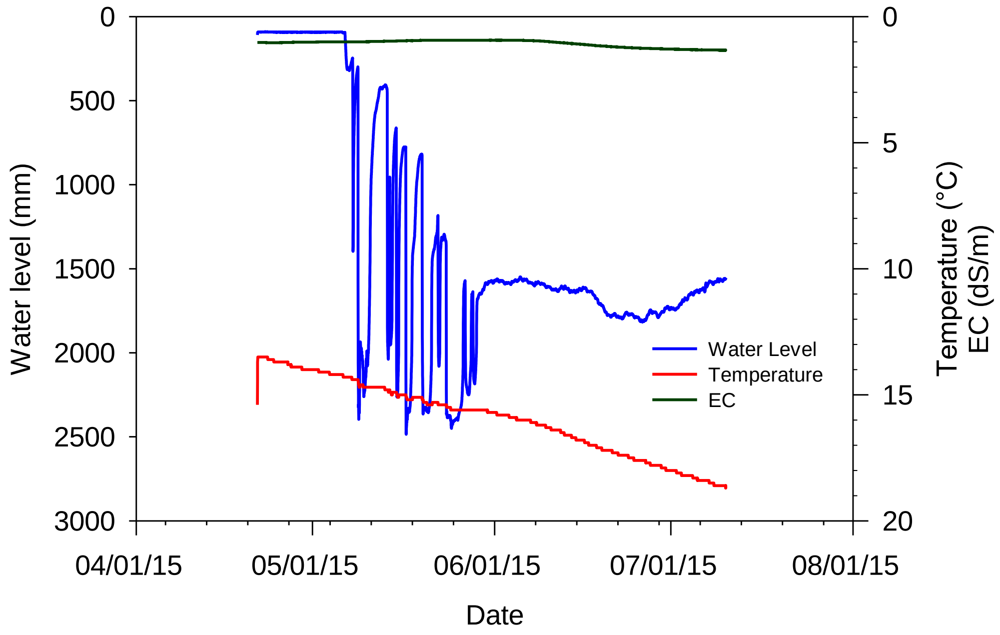

Fig. 3. Water level (mm), temperature (°C) and electrical conductivity (dS/m) recorded in a 3 m deep monitoring well in a grassland catchment at 15-minutes interval

Evaluation of soil chloride concentration indicates different chloride profiles under grassland catchment and redcedar encroached site. Soil chloride content varied between 5 to 162 mg/l in grassland (Fig. 4) and 88 to 612 mg/l in juniper encroached prairie (Fig. 5) across depths with greater Cl near the surface. Steady State flux indicates greater recharge potential in the grassland catchment. High soil chloride accumulation under redcedar indicates reduced percolation and potentially subsurface interflow flow and groundwater recharge potential associated with redcedar encroachment.

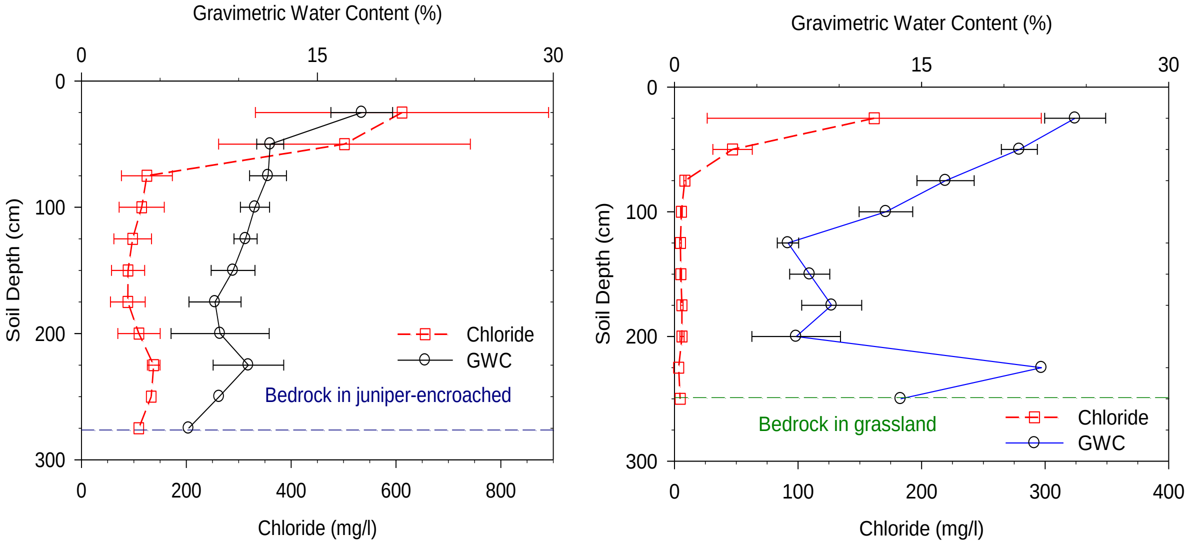

Fig. 4. Distribution of soil chloride (mg L^{-1}) and gravimetric water content (%) across different soil depth as measured in juniper-encroached and grassland catchments. Values are mean ± SE

In conclusion, different vegetation types control vadose zone soil moisture dynamics in the upland. ERI data confirms the existence of horizontal soil water migration (interflow) at the interface of soil and sandstone bedrock under grass cover, however, Juniper encroachment results in increased spatial and temporal variability of soil moisture in rooting zone, reducing both horizontal subsurface soil water movement (interflow) and vertical subsurface soil water movement (groundwater recharge). The results are consistent to the chloride data showing higher chloride concentration therefore less soil water percolation through the upper 100 cm soil profile for juniper encroached site in comparison with grassland.

Focus Categories

Category	Code
ACID DEPOSITION	ACD
AGRICULTURE	AG
CLIMATOLOGICAL PROCESSES	CP
CONSERVATION	COV
DROUGHT	DROU
ECOLOGY	ECL
ECONOMICS	ECON
EDUCATION	EDU
FLOODS	FL
GEOMORPHOLOGICAL PROCESSES	GEOMOR
GEOCHEMICAL PROCESSES	GEOCHE
GROUNDWATER	GW
HYDROGEOCHEMISTRY	HYDGEO
HYDROLOGY	HYDROL
INVASIVE SPECIES	INV
IRRIGATION	IG
LAW, INSTITUTIONS, & POLICY	LIP
MANAGEMENT & PLANNING	M&P
METHODS	MET
MODELS	MOD
NITRATE CONTAMINATION	NC
NONPOINT POLLUTION	NPP
NUTRIENTS	NU
RADIOACTIVE SUBSTANCES	RAD
RECREATION	REC
SEDIMENTS	SED
SOLUTE TRANSPORT	ST
SURFACE WATER	SW
TOXIC SUBSTANCES	TS
TREATMENT	TRT
WASTEWATER	WW
WATER QUALITY	WQL
WATER QUANTITY	WQN
WATER SUPPLY	WS
WATER USE	WU
WETLANDS	WL