Remote Sensing Estimates of Evapotranspiration at a Southwestern Uranium Mill Tailings Site

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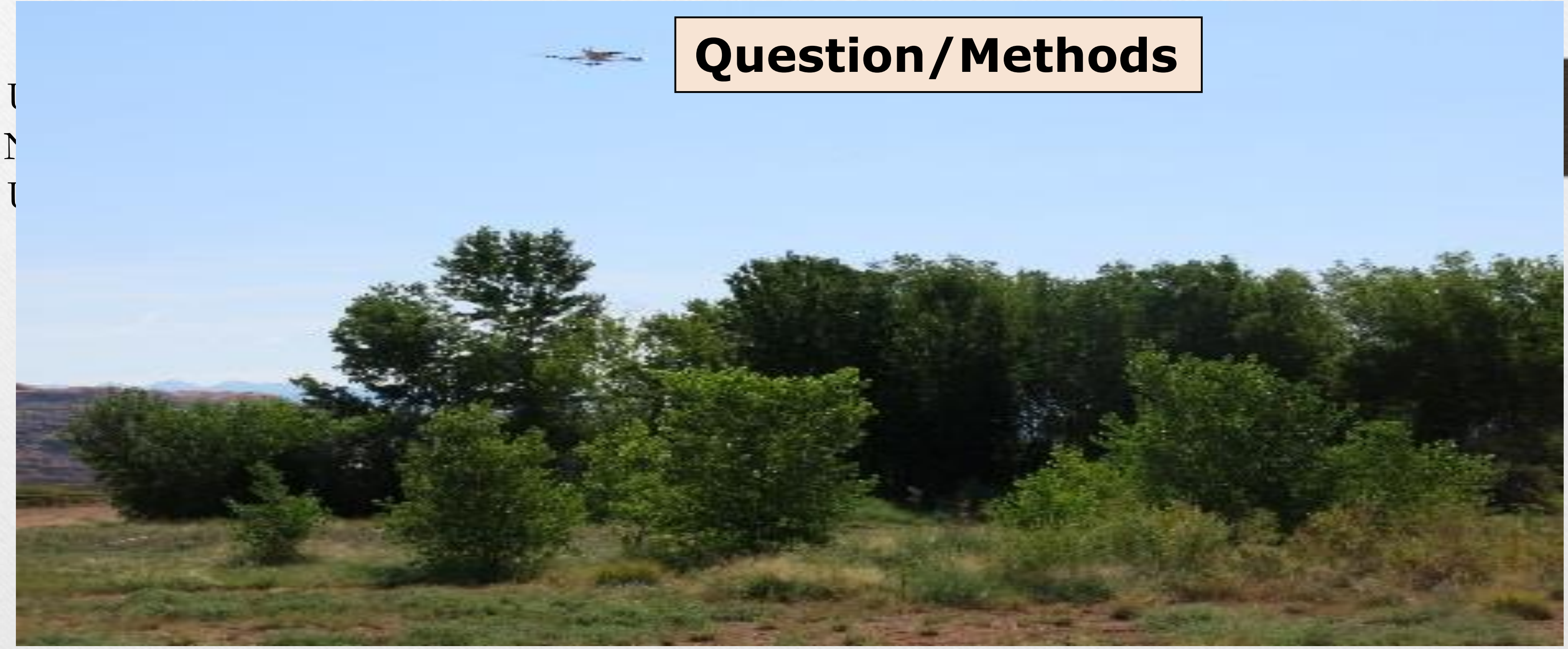


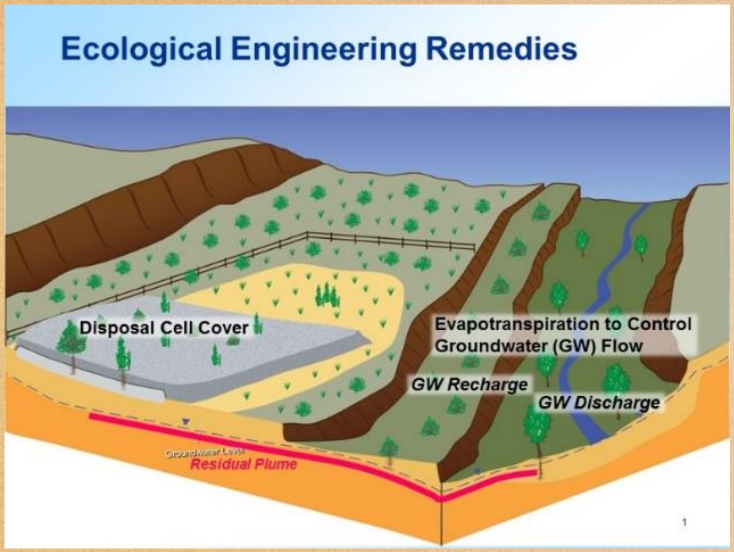
Rationale for our study

The U.S. Department of Energy (DOE) Office of Legacy Management (LM) uses mathematical models and monitoring well data to understand and predict groundwater (GW) flow at former uranium processing sites.

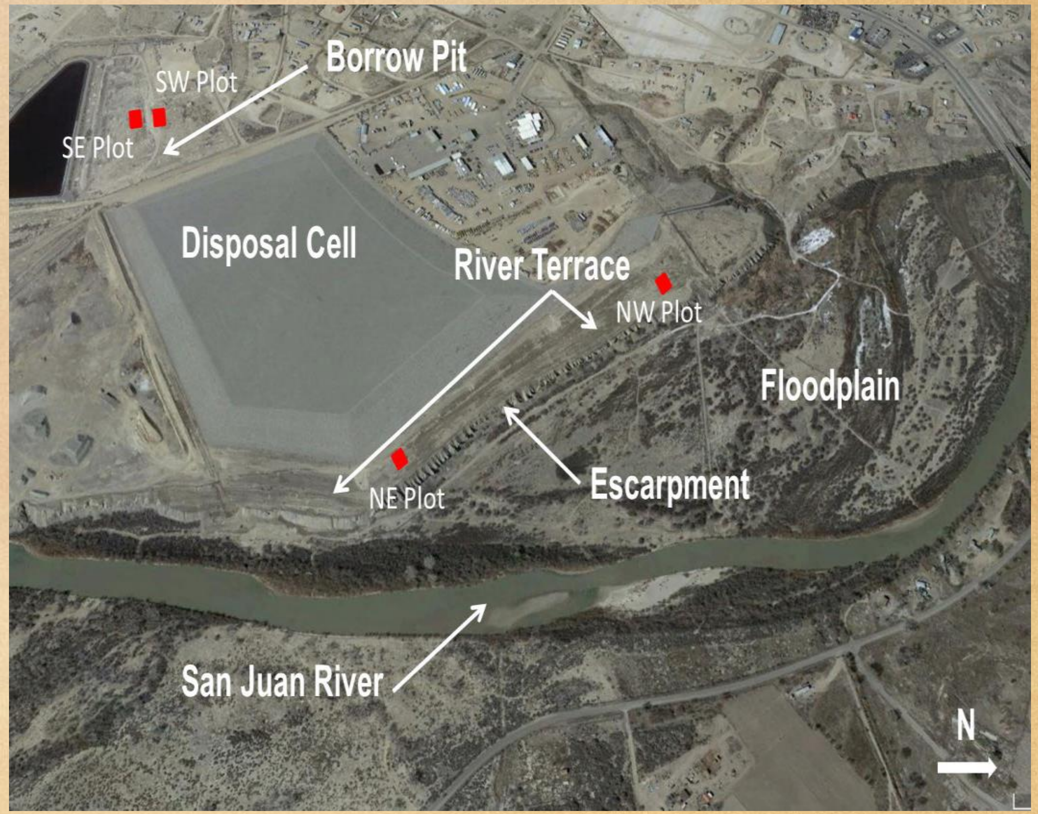



GW elevation varies seasonally and spatially where Tamarisk and other phreatophytes grow. Our hypothesis is that our high resolution maps will show how GW elevation and flow patterns respond to changes in tamarisk biocontrol and health. Results may improve modeling of GW flow and contaminant transport, leading to improvements in GW remediation.

Shiprock, NM Uranium Mill Site



Contaminated groundwater at the Shiprock site occurs in a terrace and a floodplain of the San Juan River that are separated by an escarpment. A disposal cell for mill tailings is located on the terrace.



Shiprock, New Mexico

GOAL: to document long-term trends and relationships of ET and GW elevation at Cold War legacy waste sites (Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). We focused our research on the Shiprock, NM UMTRCA site.

Because contaminant transport appeared to vary seasonally & annually in response to changes in riparian ecosystems dominated by tamarisk at these Cold War legacy waste sites, the effect of tamarisk green-up and defoliation due to the leaf beetle, *Diorhabda*, are particularly relevant. These sites are adjacent to major western rivers.

We are now developing an empirical approach for estimating the effects of changes in tamarisk populations on water resources at these uranium mill tailings sites.

Research Goal

Understanding how much available water is used in various ecosystems can aid natural resource managers and decision makers.

LM office of DOE is responsible for remediation and monitoring of GW contaminated by uranium milling during the Cold War. We collaborated to acquire multiple levels of remotely sensed imagery over the Shiprock NM uranium tailings site to assess landscape-scale changes in ET, the effect of ET on GW recharge and discharge, and effect of ET on phytoremediation. We studied effects of changes in riparian plant communities dominated by tamarisk (*Tamarix* spp.) and measured the impact of the northern beetle, *Diorhabda carinulata*, on water resources.

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February 2018

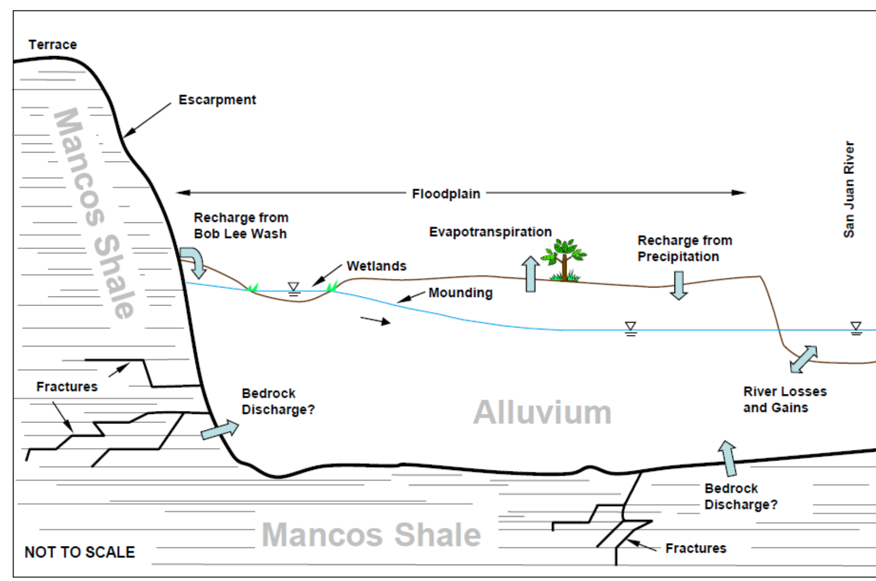

Figure 13. Cross-Section View of the Groundwater Conceptual Model for Baseline (nonpumping) Conditions

Flow Processes in the Floodplain Alluvial Aquifer, Shiprock, New Mexico
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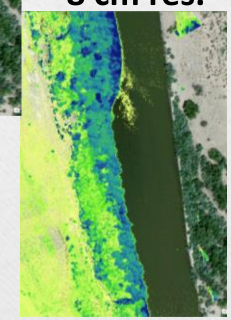
Methods

We used a drone flown by USGS in conjunction with DOE to acquire the high resolution spectral data (8 cm pixels) needed to estimate spatial and temporal variability in ET at the Shiprock site in NM adjacent to the San Juan River. The UAV (drone) imagery allowed us to map species composition and scale to Sentinal, Landsat and MODIS imagery so that we could monitor changes in tamarisk phenology, fractional greenness and ET.

400 ft AGL
~ 8 cm res.



Uranium mill tailings site

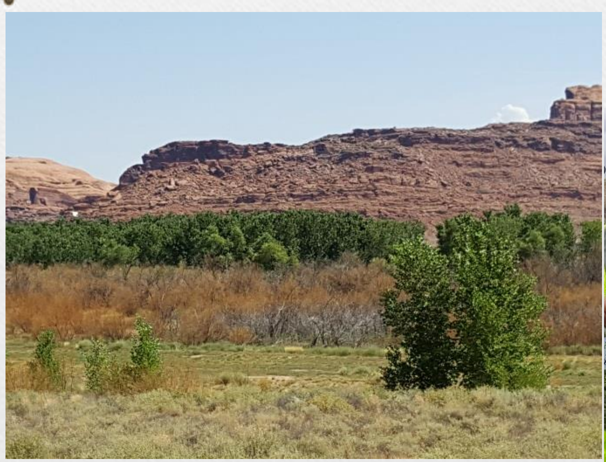
***Tamarix* in summer:**
impact of the *Diorhabda* beetle

UAS assembly
and imagery

Methods

Ground-based measurements focused on characterizing plant composition, including endangered plant species and invasive plant species. We measured leaf area index (LAI) and sampled biomass on tamarisk, cottonwood (*Populus* spp.), and willow (*Salix* spp.) and over a dozen other species within the UAS acquisition areas to scale leaf area to LAI of whole trees.

UAS cameras included a Sony Alpha A5100 for species-level vegetation mapping and a MicaSense Red Edge five-band multispectral camera to map NDVI and EVI. The VIs were used in an algorithm to predict reach-level ET.



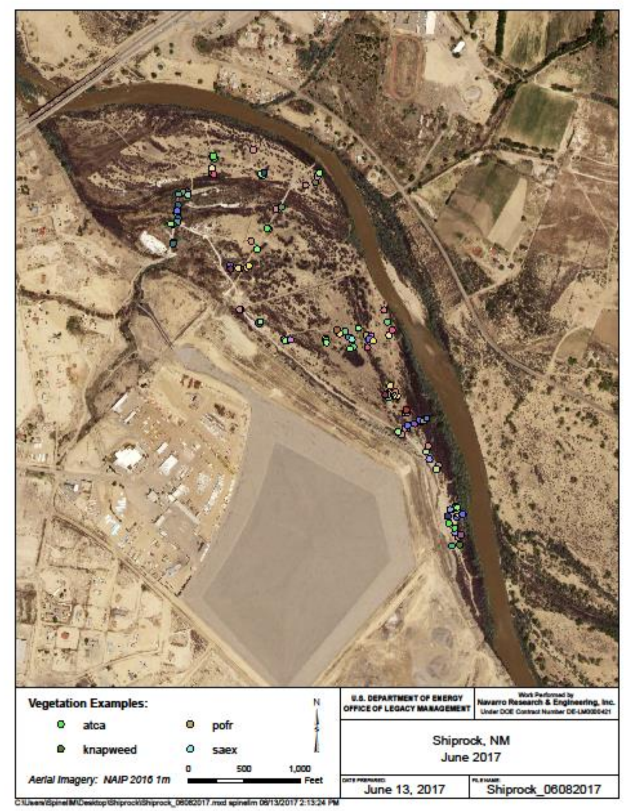
Methods

Allometric measurements of plant leaf area or LAI measurements for specific plant species were acquired. In order to estimate water used and ET rates for plant associations and vegetation map units, we characterized and mapped vegetation zones by:

1. **(1) identifying plant species within the entire region of interest (ROI),**
2. **(2) estimating changes in the abundance,**
3. **(3) defining separate plant associations, and**
4. **(4) delineating boundaries between plant associations.**

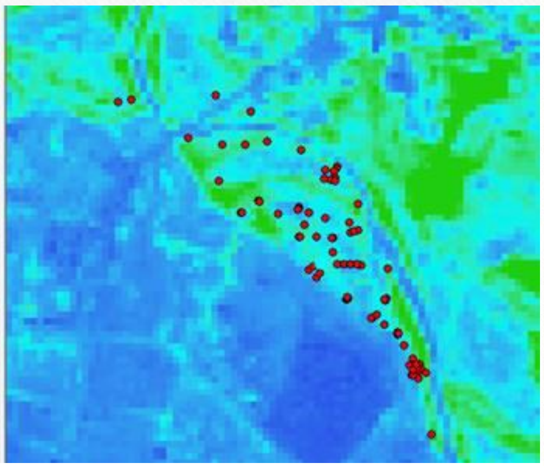
A map of discrete vegetation/ET zones can be created by interpreting and field-checking boundaries between plant associations on high resolution UAV imagery.

GPS points are shown for ground-truth of the dominant species for vegetation mapping.



Methods

Well locations have been monitored. We are still assessing the relationships between depth to GW and ET and other factors such as distance to river and soil texture and salinity.



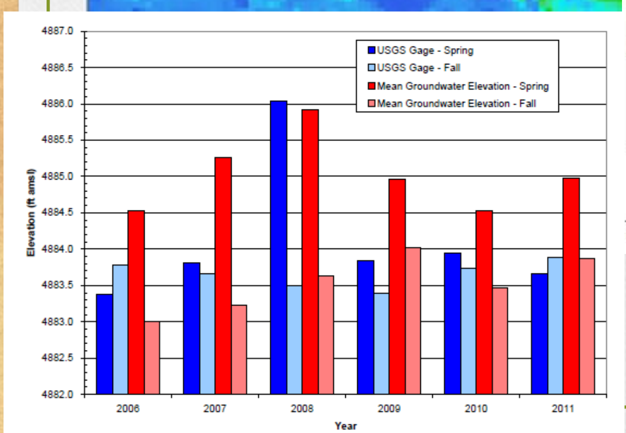


Figure 29. Mean River (USGS gage) and Groundwater Elevations During Semiannual Monitoring Events

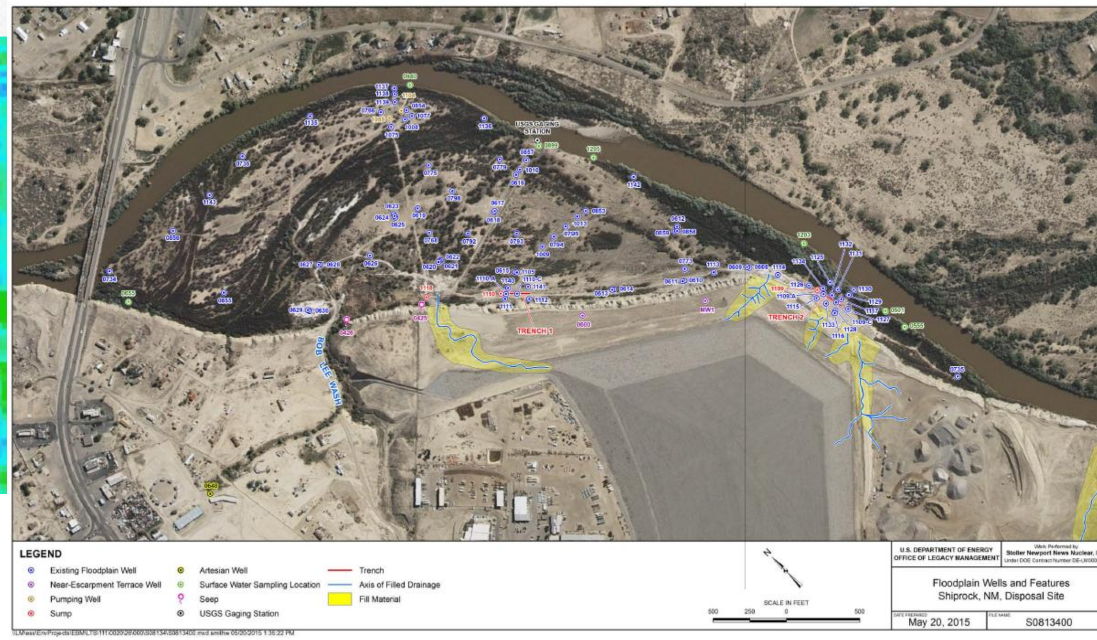


Figure 5. Monitoring Locations Used in This Study

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Flow Processes in the Floodplain Alluvial Aquifer, Shiprock, New Mexico
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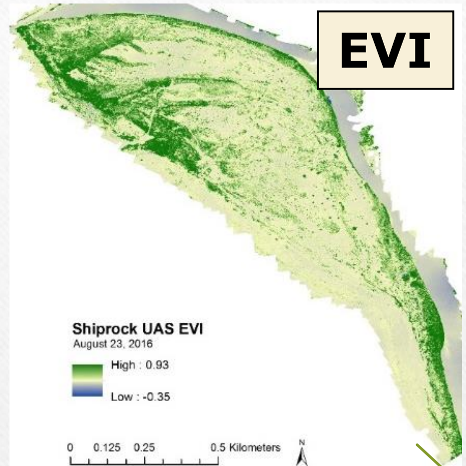
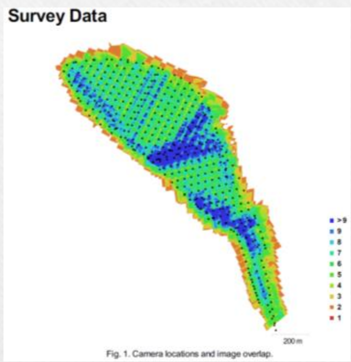
Acquisition of UAV data

UAV imagery over the Shiprock ROI

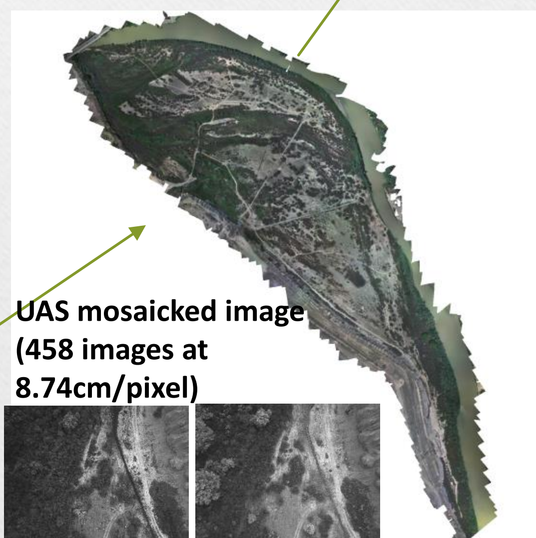
EVI



For these UAS images, we used *Groeneveld et al. (2007)* to calculate ET: NDVI* x ETo from UAS pixels and weather stations using Blaney-Criddle ETo (4.33 mm/d) and mean T_A (16.9 C) for Shiprock (NOAA Sta.298284).

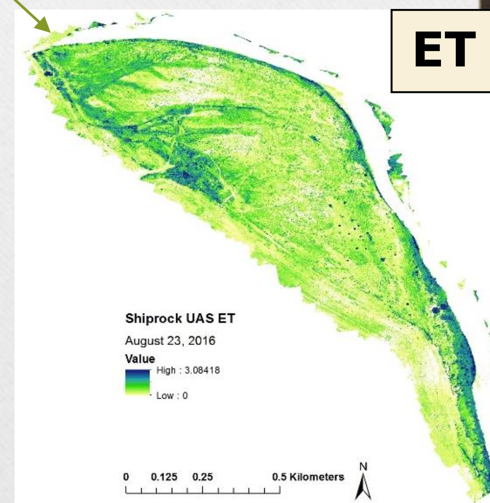


MicaSense Imagery from 400 feet AGL Aug. 23, 2016



UAS mosaicked image (458 images at 8.74cm/pixel)

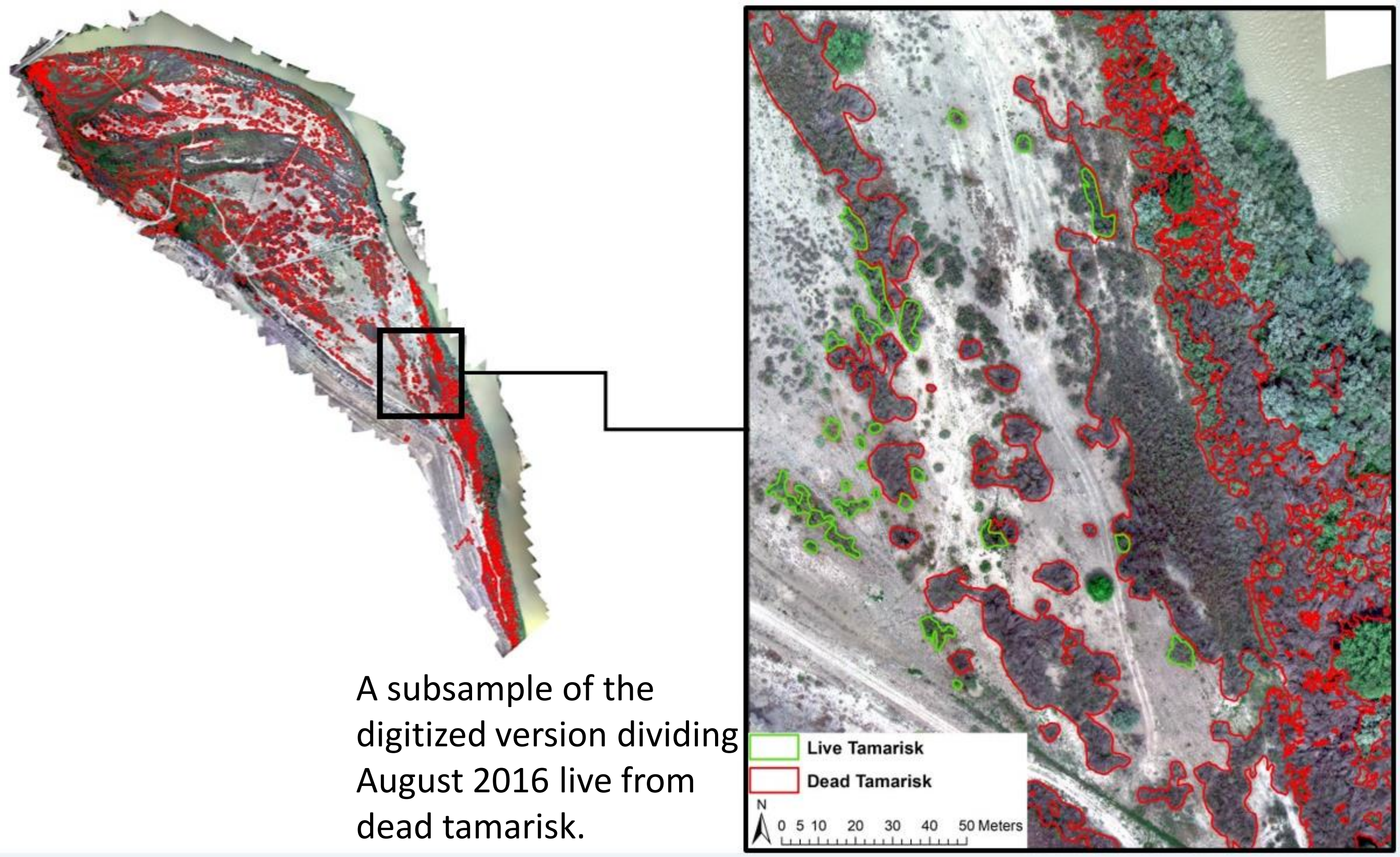
ET



Band 1 Band 2 Band 3 Band 4 Band 5

Methods

We compared hand-digitized regions to classification methods



A subsample of the digitized version dividing August 2016 live from dead tamarisk.

Methods

We teamed up with faculty and students at Diné College to measure LAI of phreatophytes growing on the floodplains. They measured LAI indirectly for tree species and directly for smaller shrubs.

The indirect method used a LAI-2000 instrument with a fish-eye optical sensor that detects light penetrating a tree canopy at different angles, and a mathematical model of light interception and transfer in tree canopies.

For the direct method, we harvested leaves overlying a standard ground surface area, and measured leaf area using an electronic planimeter.

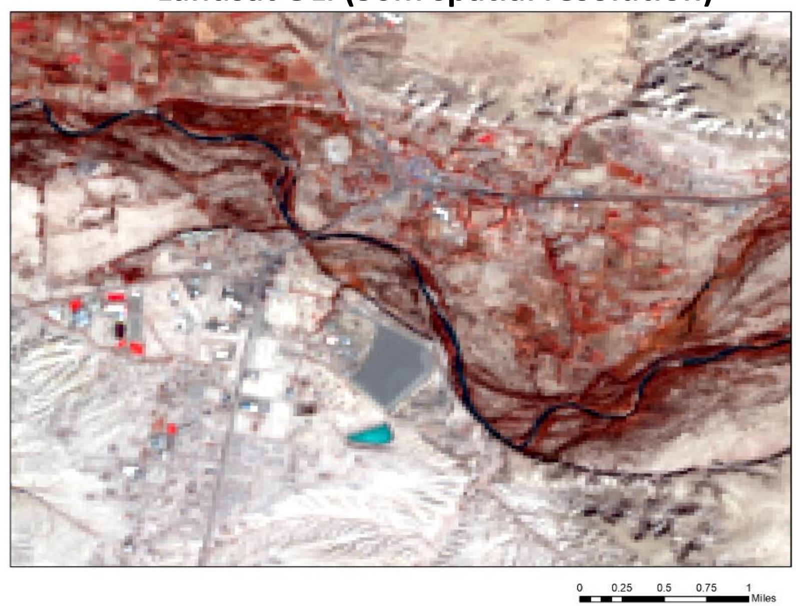
Shiprock Plant Species / Classes

Class	Common Name	Genus species	Acronym	Number Points
1 - grasses	indian ricegrass	Achnatherum hymenoides	achy	1
	purple threeawn	Aristida purpure	arpu	1
	saltgrass	Distichlis spicata	disp	3
	foxtail barley	Hordeum jubatum	hoju	1
2 – shrubs/forbs	Russian knapweed	Acroptilon repens	acre	3
	burning bush	Bassia scoparia	basc	3
	Russian thistle	Salsola tragus	satr	1
	rubber rabbitbrush	Ericameria nauseosa	erna	10
	broome snakeweed	Gutierrezia sarothrae	gusa	1
3 – phreatophyte shrubs	fourwing saltbush	Atriplex canescens	atca	8
	black greasewood	Sarcobatus vermiculatus	save	1
4 – Russian olive	Russian olive	Elaeagnus angustifolia	elan, elan-y	9
5 – Freemont cottonwood	Freemont cottonwood	Populus fremontii	pofr, pofr-y	2
6 – willow	willow	Salix species	salix	1
7 – wetland	hardstem bulrus	Schoenoplectus acutus	scac	3
	broadleaf cattail	Typha latifolia	tyla	1
8 – Siberian elm	Siberian elm	Ulmus pumila	ulpu	4
9 – dead tamarisk	dead tamarisk	Tamarix ramosisima	tara-d	18
10 – healthy/ regreening tamarisk	healthy tamarisk	Tamarix ramosisima	tara-h, tara-r	16(r), 4 (h)
11 – bare soil			Bare	5

Satellite Imagery

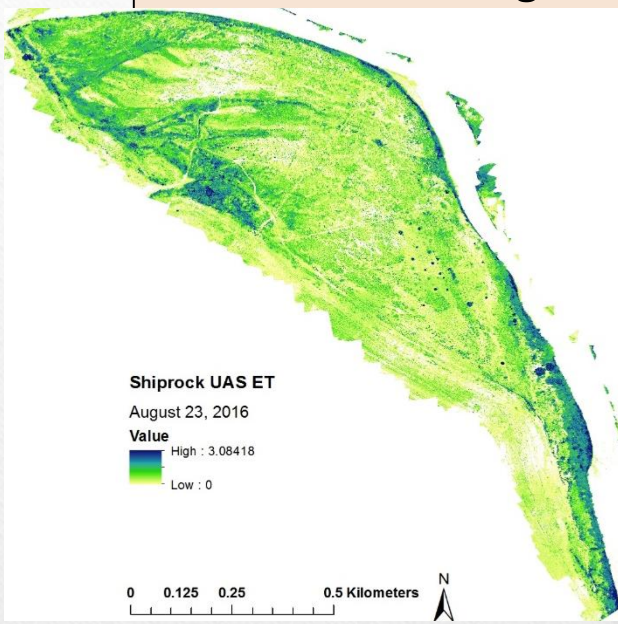
Sentinel-2 (10m spatial resolution)

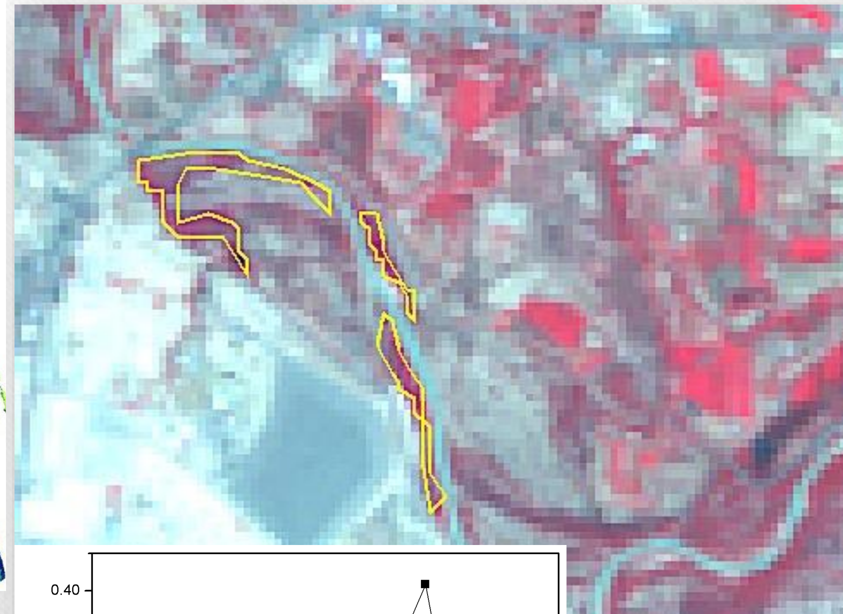
Landsat OLI (30m spatial resolution)

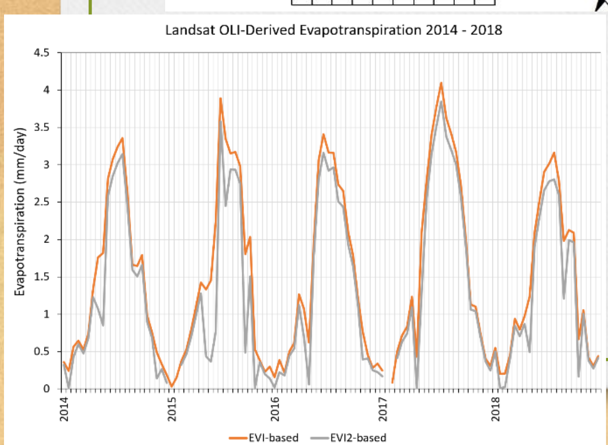


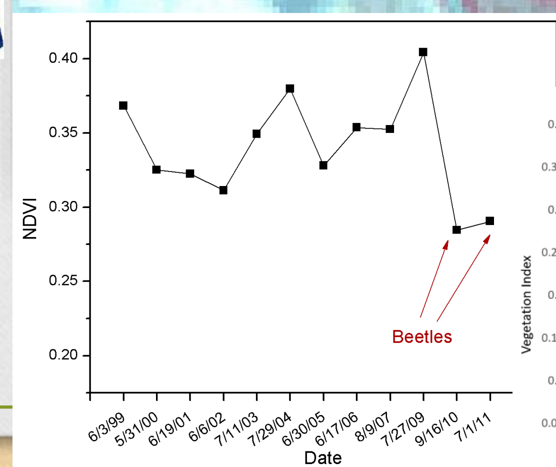
Results

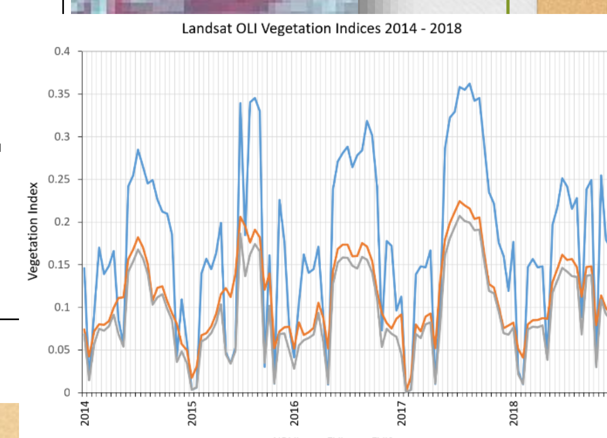
The UAV image showing riparian ET. Landsat satellite imagery shows ET from 2014-2018; Landsat from Aug. 2016 depicts areas of highest ET; we then acquired a few Landsat scenes to track changes in NDVI and then EVI and EVI2.



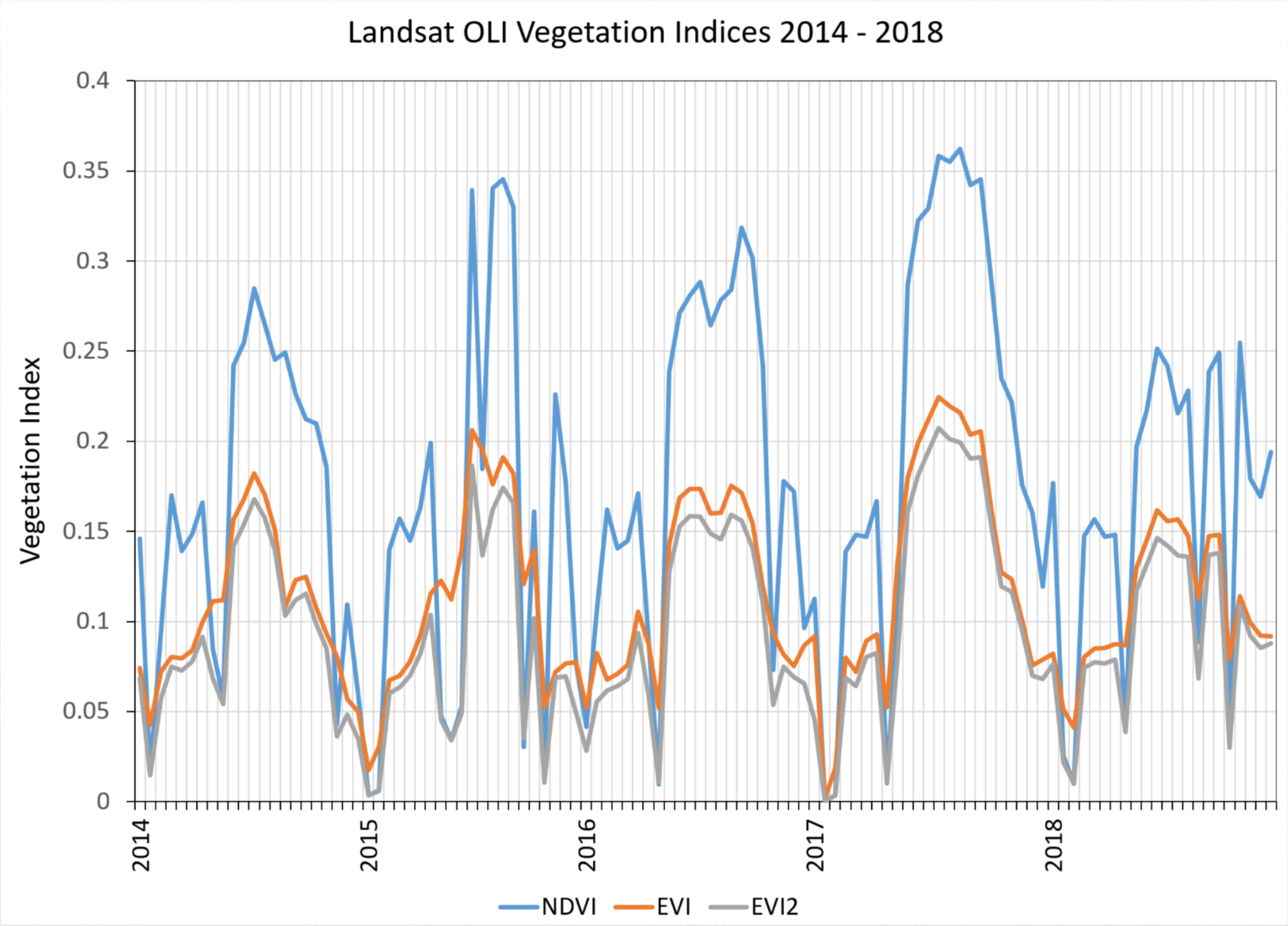






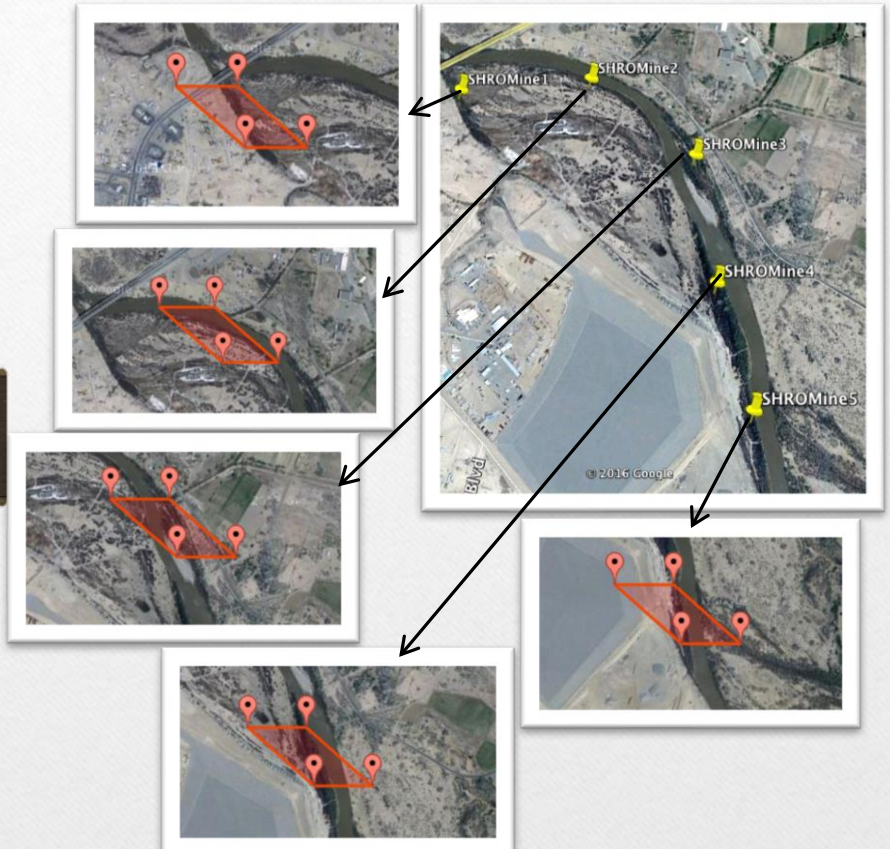


Vegetation Indices

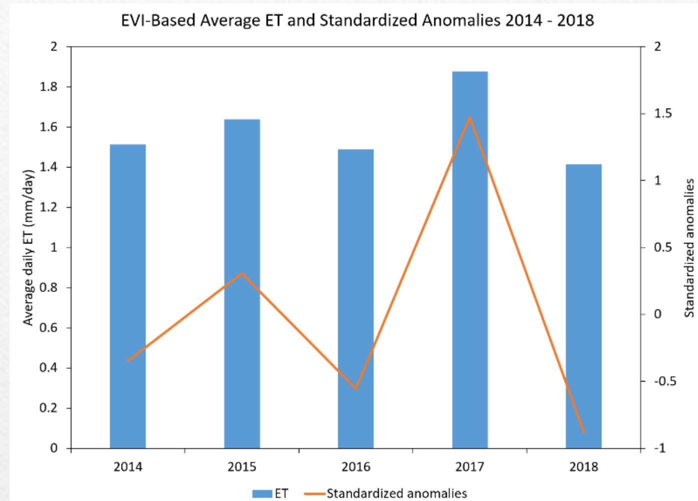


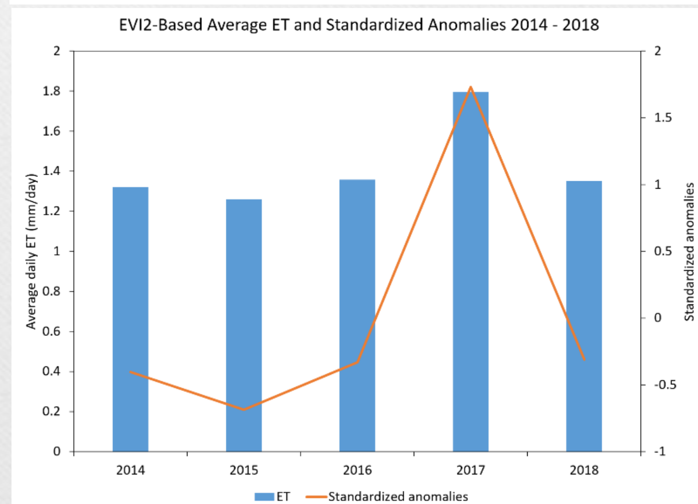
Results

MODIS and Landsat EVI data was used to estimate ET over the past five years; we are processing Imagery back to 2000 to track the impact of the beetle which arrived ca. 2007.



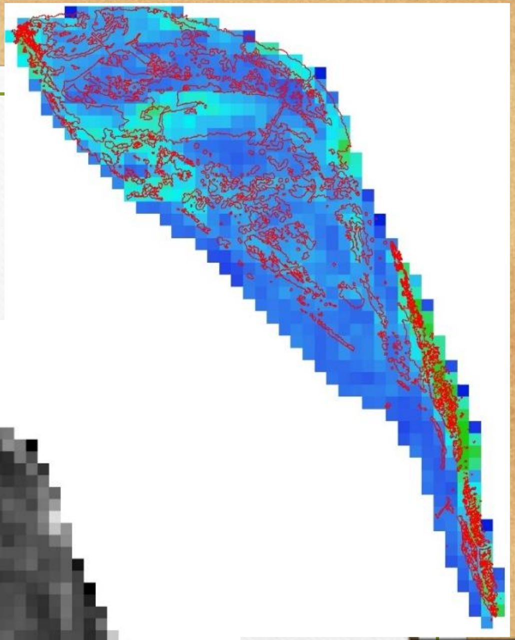
250m MODIS pixel of 5 sites

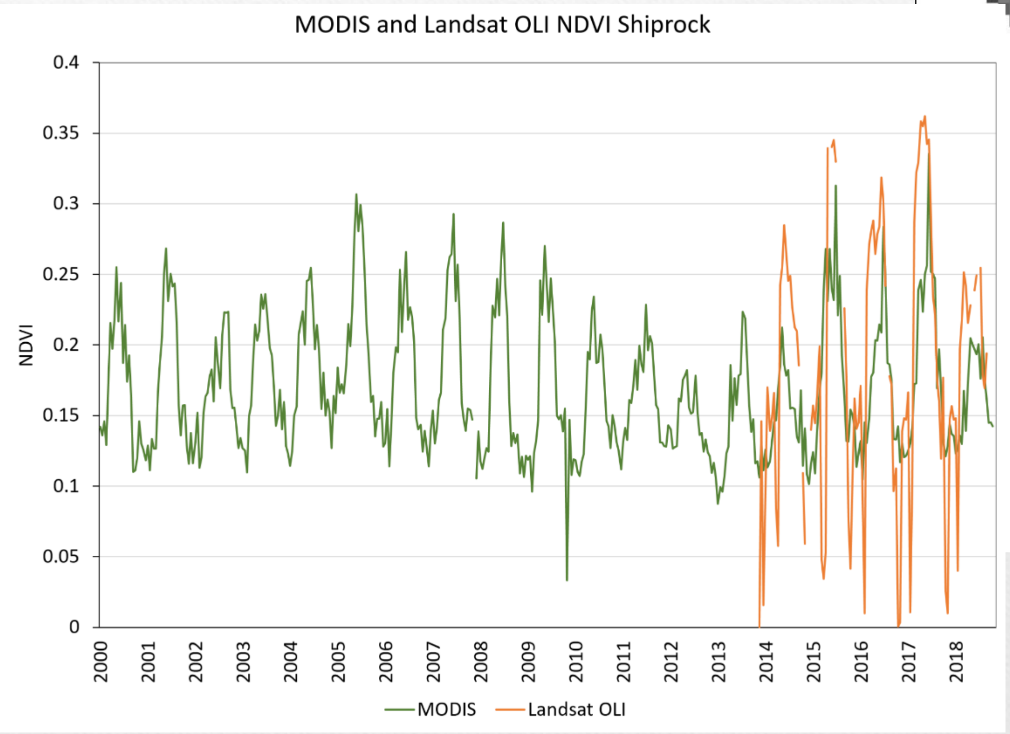


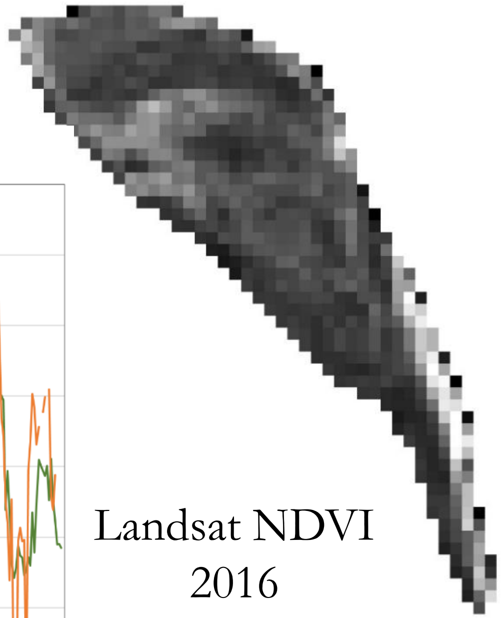


30m Landsat pixels

Vegetation Indices

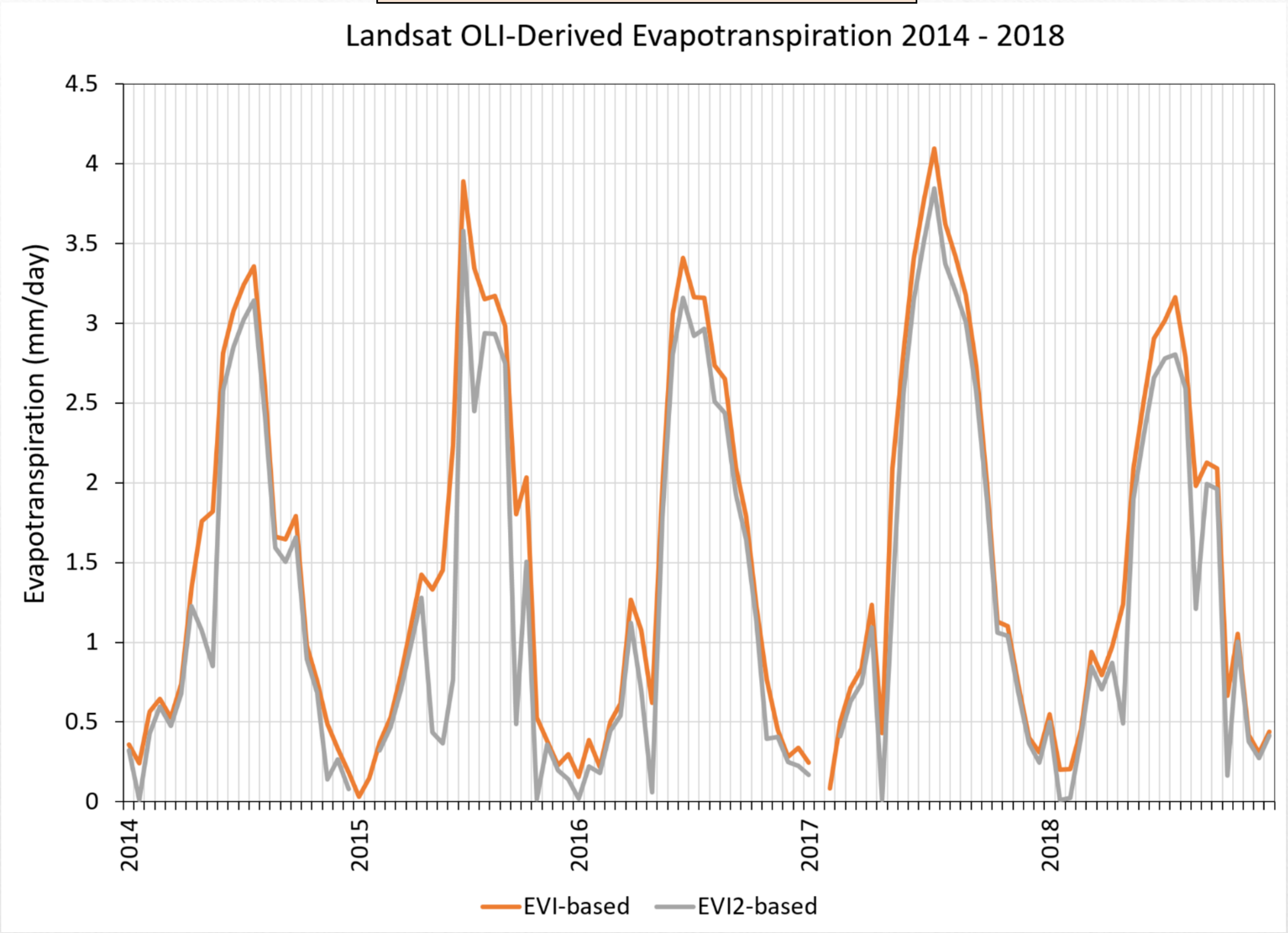






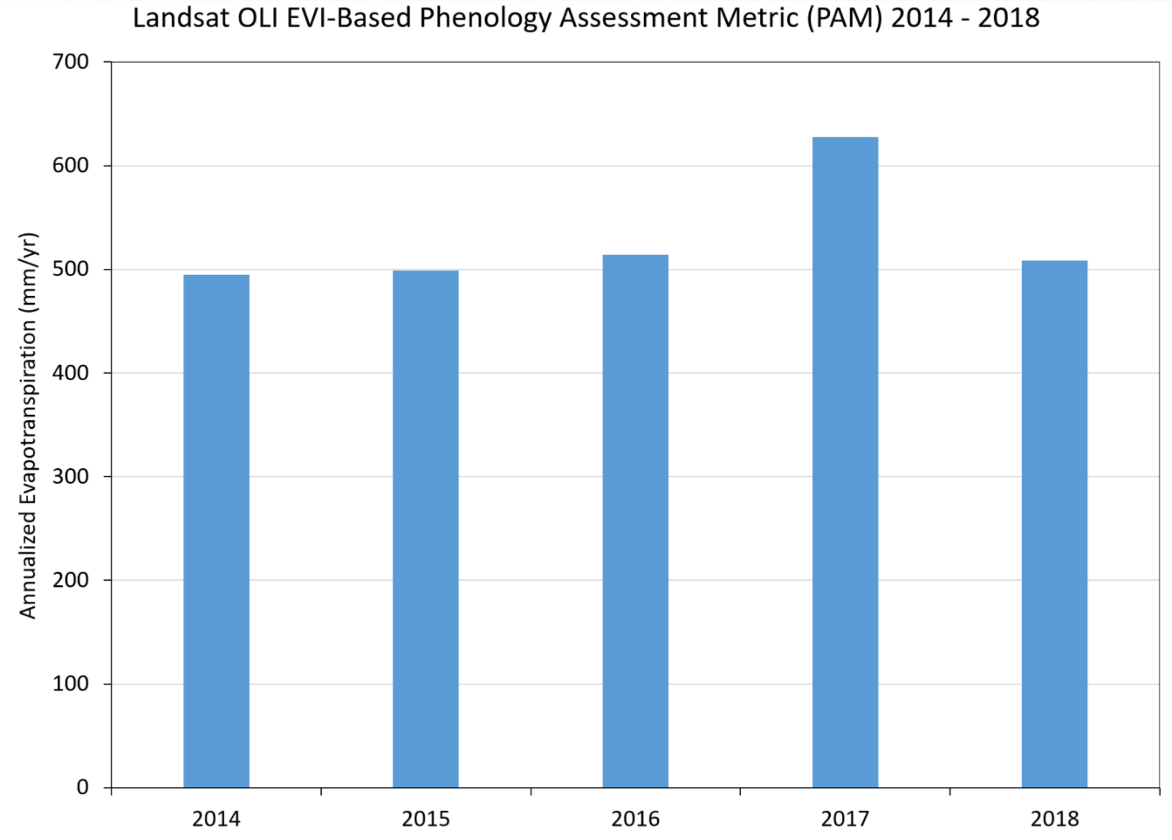
Landsat NDVI 2016

Evapotranspiration (Daily)



Results

For the first time, we applied an area assessment (Phenology Assessment Metric, PAM) to quantify changes annually in ET for the tamarisk dominated riparian areas.



Results

We acquired several sources of imagery for the Shiprock site:

- High resolution, 8cm, drone data
- Sentinal data at 10 m.
- Landsat 8 from Earth Explorer every 16 days. We transformed this imagery into an NDVI scene so that analysis of change from 2000 can be compared with MODIS EVI data.
- MODIS EVI. We then had both 250 m and 30 m pixels to document a time-series of landscape-level changes in vegetation.

Using baseline LAI, fractional cover and vegetation greenness, we will now be able to monitor changes in plants and their water use over time, with ET approximately 1.5 mm / day or 500 mm / yr.

We processed and analyzed the UAS imagery to acquire a high-resolution ET image. With the LAI data from Shiprock and Moab, we are refining the algorithm for estimating landscape-scale ET. LM and USGS will use the new algorithm to estimate spatial, seasonal, and annual variation in ET and GW discharge for tamarisk and other phreatophytes growing along river corridors at the Shiprock site.

Conclusions

Our results showed that remotely sensed monitoring of ET was improved using the drone imagery. We used greater vegetation detail provided by UAS in combination with satellite imagery to improve the ET algorithm for scaling up from ground measurements of plant health to larger areas in the landscape. More reliable ET estimates may improve GW flow modeling at this site.

For the uranium mill site, we demonstrated improved quantification of ET by

(1) using 4 resolutions of remotely sensed imagery at both sites and

(2) showing changes in the ecosystem vegetation cover, tamarisk phenology, fractional greenness, and water use over long periods (18 years).

We conclude that our methods to estimate the effects of changes in tamarisk cover on landscape-scale ET estimates improved our understanding of plant water use at this uranium processing site. These data may also improve GW flow modeling and evaluation of GW remediation strategies.

Acknowledgements

We would like to thank faculty from Diné College, a 4-year, tribally controlled community college serving the Navajo Nation.