Digital Soil Boundary Identification Using Quantitative Hydrologic Remote Sensing

Emily M. Engle
J. Bruce J. Harrison
Jan M.H. Hendrickx
Brian Borchers
New Mexico Tech

Introduction

- **Project Motivation**
  - Current soil mapping techniques are time consuming and expensive
    - Problem: area that are not economically important do not get fully characterized
  - Areas such as rangelands often mapped broadly
    - Problem: combine single soil units into associations and complexes
- **Project Goals**
  - Test new digital soil mapping methodology
    - Reproduce existing soil boundaries
    - Improve on existing soil maps?
  - Quantify and classify soil boundaries

Introduction

- **Background**
  - Remotely sensed data has been used to map landuse, land cover and certain types of soils
  - Previous studies use landsat images from a single day
    - Potential problem #1: some boundaries may appear only under certain environmental conditions
    - Potential problem #2: penetration depth is ~10 cm
  - Here we used data from the Surface Energy Balance Algorithm for Land (SEBAL) model
    - Root zone soil moisture can penetrate up to 500 cm

	Penetration Depth (cm)
Landsat Bands 1-5 & 7	0.1
Landsat Band 6	10
Root zone soil moisture	Up to 500 for trees

Landsat 5 and 7 images

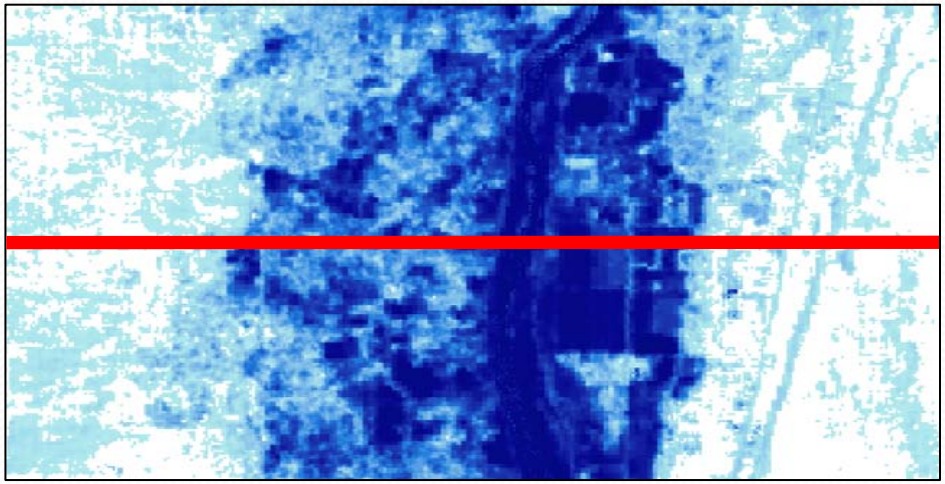
- In all, 20 images used in this study
  - Only 14 cover the Sevilleta
- Both satellites sense data in seven bands, covering visible, near infrared, mid-infrared and thermal channels
- Orbit of 16 days, swath width of 185 km

Landsat coverage information

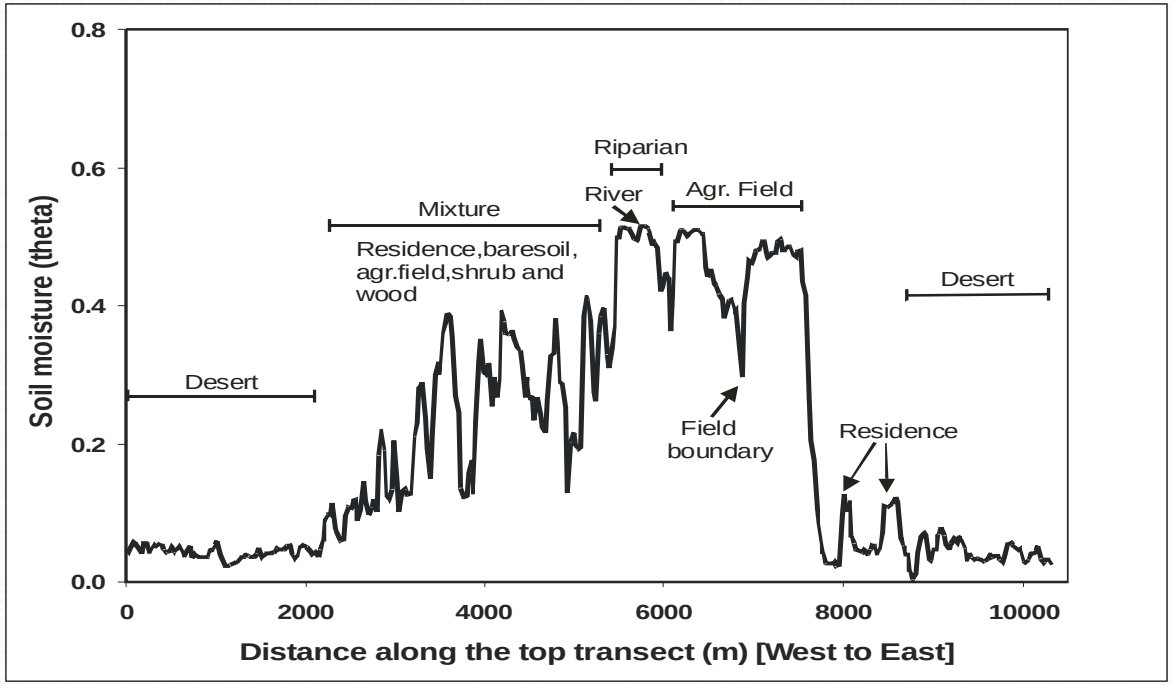
Date	Start Time	Path Number	Row Number	Satellite	Study Area
4/7/2000	2000:098:17:31:05.1178404	33	36	Landsat 7	Hilton, Sevilleta
5/6/2002	2002:126:17:33:41.1955229	34	36	Landsat 7	Hilton, Sevilleta
5/9/2000	2000:130:17:30:47.1290071	33	36	Landsat 7	Hilton, Sevilleta
5/12/2004	2004:133:17:19:09.02194	33	36	Landsat 5	Hilton
5/22/2005	2005:142:17:32:11.82375	34	36	Landsat 7	Hilton, Sevilleta
5/28/2004	2004:149:17:19:35.41369	33	36	Landsat 5	Hilton
5/31/2002	2002:151:17:27:40.7146875	33	37	Landsat 7	Hilton, Sevilleta
6/4/2001	2001:155:17:34:30.9953451	34	36	Landsat 7	Hilton, Sevilleta
6/13/2004	2004:165:17:20:03.30106	33	36	Landsat 5	Hilton
6/16/2002	2002:167:17:27:10.5069375	33	36	Landsat 7	Hilton, Sevilleta
7/2/2005	2005:183:17:26:17.49113	33	36	Landsat 5	Hilton
7/6/2004	2004:188:17:26:55.63275	34	36	Landsat 5	Hilton, Sevilleta
7/28/2000	2000:210:17:29:51.5247857	33	36	Landsat 7	Hilton, Sevilleta
7/31/2004	2004:213:17:21:20.99275	33	36	Landsat 5	Hilton
8/3/2005	2005:215:17:26:37.89150	33	36	Landsat 5	Hilton, Sevilleta
8/19/2002	2002:231:17:26:48.3184374	33	36	Landsat 7	Hilton, Sevilleta
9/14/2000	2000:258:17:29:16.2793605	33	36	Landsat 7	Hilton, Sevilleta
9/17/2004	2004:261:17:22:33.85738	33	36	Landsat 5	Hilton
9/30/2000	2000:274:17:29:06.6599898	33	36	Landsat 7	Hilton, Sevilleta
10/14/1999	1999:287:17:31:39.2421053	33	36	Landsat 7	Hilton, Sevilleta

SEBAL Root Zone Soil Moisture Detection

- Surface Energy Algorithm for Land (SEBAL) validated for use in New Mexico for mapping root zone soil moisture
- Uses Landsat images as input



Source: Fleming et al., 2005



Split Moving Window Technique

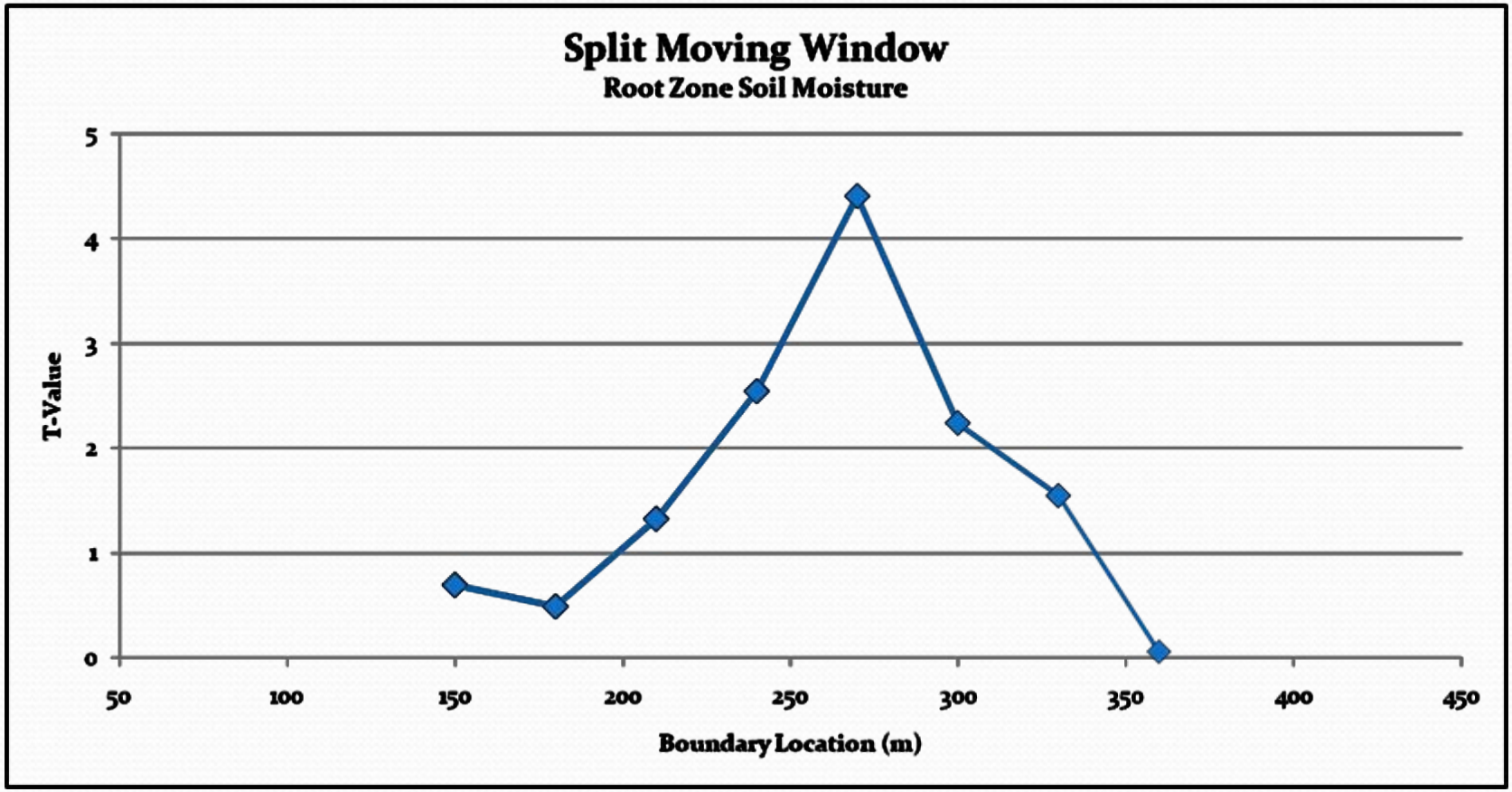
- Uses t-test to determine if values in adjacent windows are statistically different
- Where maximum t-value occurs, assume that boundary exists
- Test different critical t-values of 6, 8, 10 and 12

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_{X_1 X_2} \cdot \sqrt{\frac{2}{n}}}$$

$$S_{X_1 X_2} = \sqrt{\frac{S_{X_1}^2 + S_{X_2}^2}{2}}$$

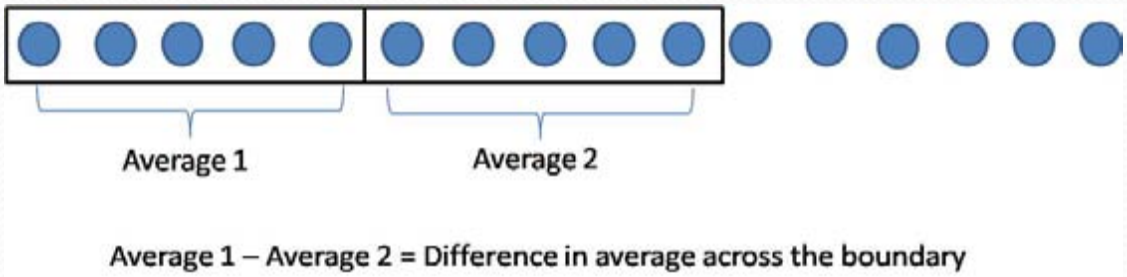
Split Moving Window Technique

0.029 0.041 0.040 0.024 0.028 0.038 0.035 0.032 0.028 0.045 0.044 0.054 0.052 0.040 0.037 0.038



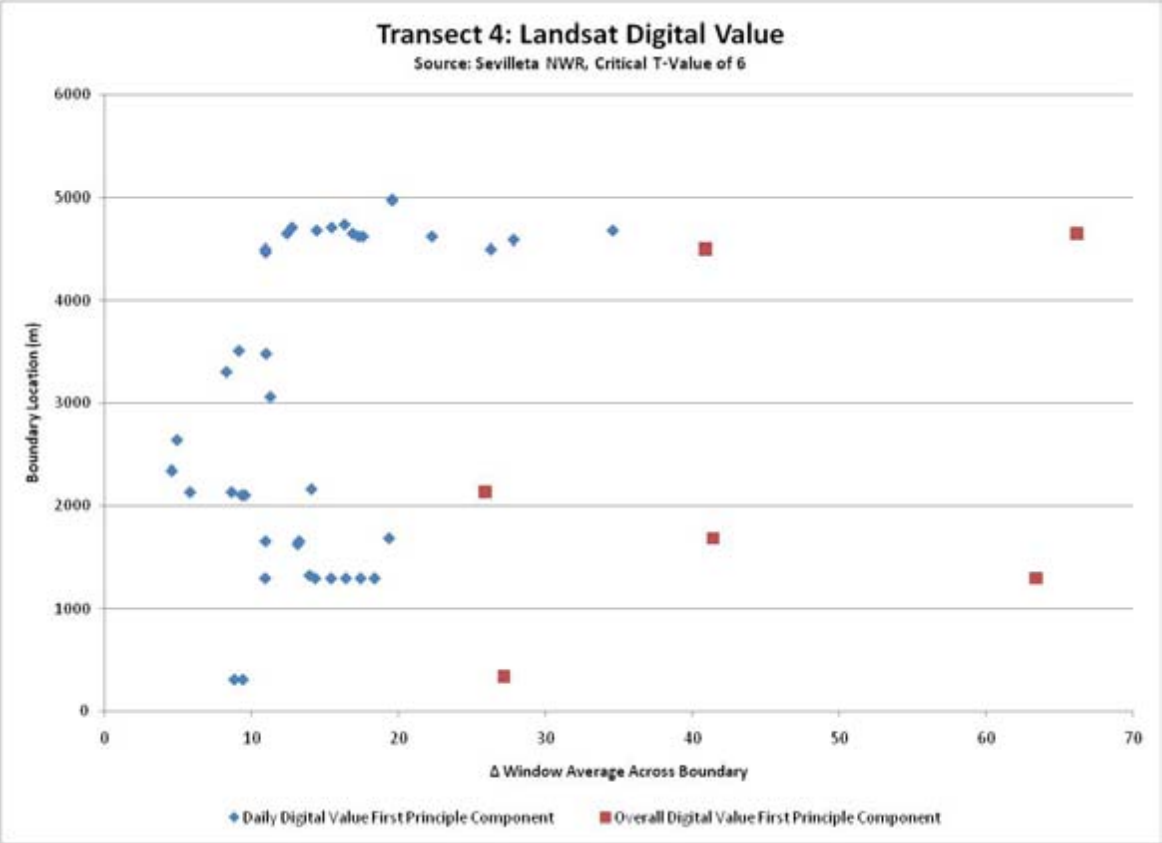
Split Moving Window Technique

- When t-value peak occurs (boundary), we marked location, t-value and difference in average across the boundary



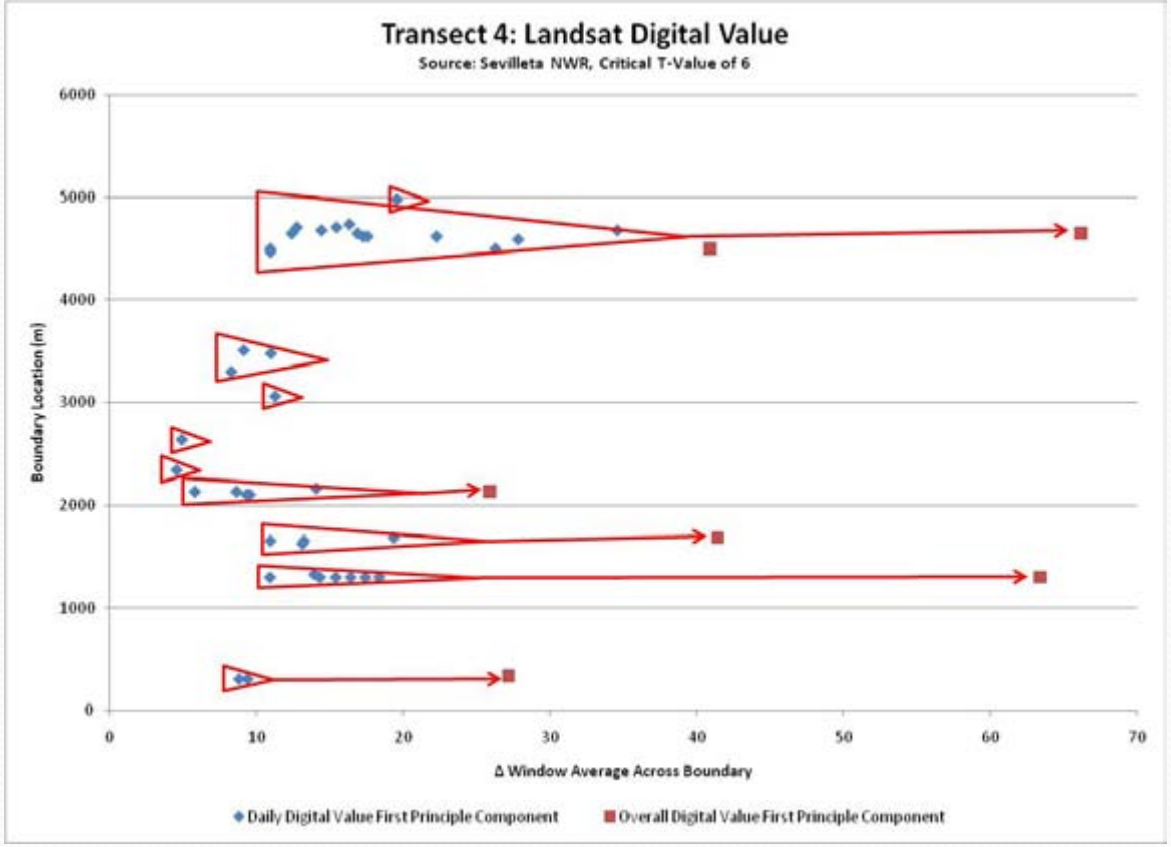
Split Moving Window Technique

- When t-value peak occurs (boundary), we marked location, t-value and difference in average across the boundary
- Plotted tabulated data from all days, two plots for each transect



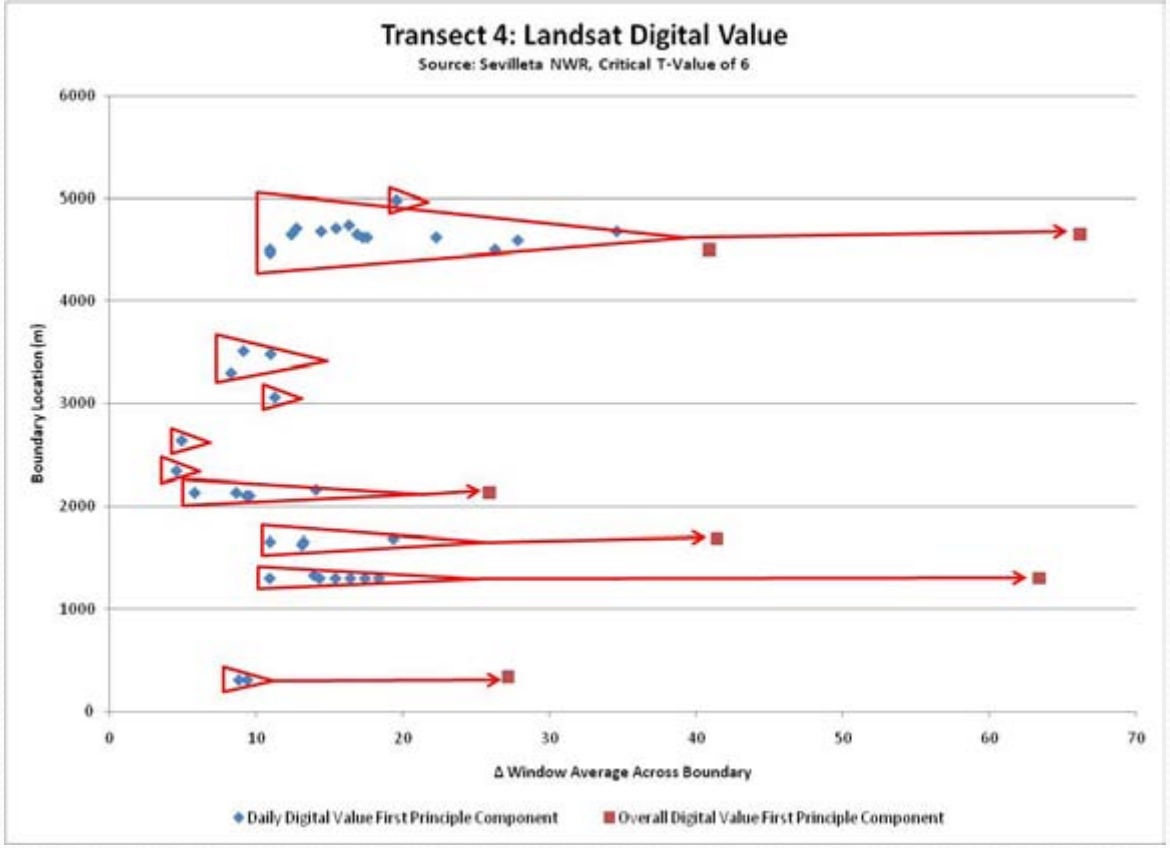
Split Moving Window Technique

- When t-value peak occurs (boundary), we marked location, t-value and difference in average across the boundary
- Plotted tabulated data from all days, two plots for each transect
- Based on clusters, data was grouped into separate boundaries



Split Moving Window Technique

- Each boundary transferred to second table with range and percentage of days the boundary appears in



Split Moving Window Technique

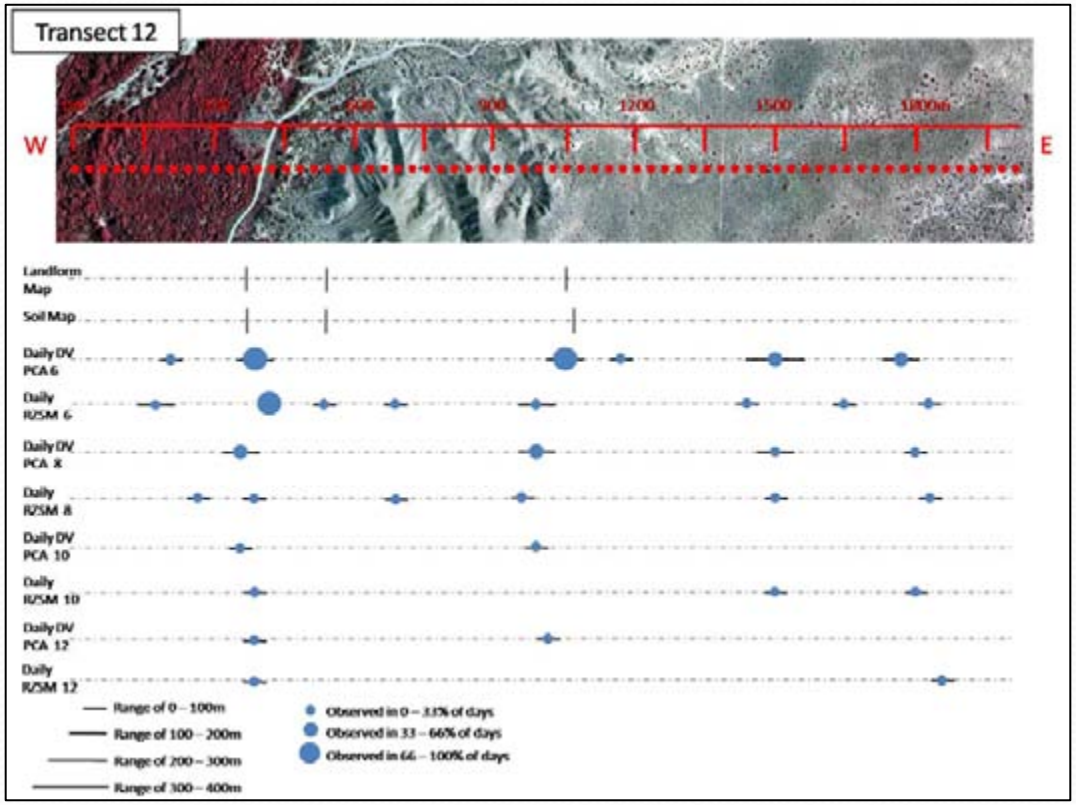
- Each boundary transferred to second table with range and percentage of days the boundary appears in

B4

Landform Map Soil Map	Boundary Location (m)													
	540		1380		1860		2490							
Daily DV PCA 6	300		1290	1650		2100	2340	2640	3060	3400			4600	4980
percentage of days	14.29		50	28.5714		35.7143	7.14286	7.14286	7.14286	21.4286			100	7.14286
range (m)	0		30	60		60	0	0	0	210			270	0
Overall DV PCA 6	300		1290	1680		2130						4500	4650	
T-Value	6		7.1	9.1		9.1						7.7	7.1	
Daily RZSM 6		700	1300	1700		2050		2800	3100	3550	3990	4500		5040
percentage of days		14.2857	42.8571	35.7143		21.4286		28.5714	21.4286	35.7143	7.14286	92.8571		7.14286
range (m)		150	90	180		330		210	180	270	0	540		0
Overall RZSM PCA 6			1290			2100				3270		4500	4680	
T-Value			7.4			7.3				7.1		8	7.2	
Daily DV PCA 8			1290	1650		2130							4700	
percentage of days			7.14286	14.2857		21.4286							21.4286	
range (m)			0	30		30							60	
Overall DV PCA 8				1680		2130								
T-Value				9.1		8.9								
Daily RZSM 8		810	1350	1750				2880	3270	3690		4550		
percentage of days		7.14286	7.14286	21.4286				7.14286	7.14286	7.14286		28.5714		
range (m)		0	0	180				0	0	0		390		
Overall RZSM PCA 8												4500		
T-Value												8		
Daily DV PCA 10				1650										
percentage of days				7.14286										
range (m)				0										
Overall DV PCA 10														
T-Value														
Daily RZSM 10				1770					3270					
percentage of days				7.14286					7.14286					
range (m)				0					0					
Overall RZSM PCA 10														
T-Value														
Daily DV PCA 12														
percentage of days														
range (m)														
Overall DV PCA 12														
T-Value														
Daily RZSM 12														
percentage of days														
range (m)														
Overall RZSM PCA 12														
T-Value														

Split Moving Window Technique

- Each boundary transferred to second table with range and percentage of days the boundary appears in
- Created graphical representations of boundary data with an aerial photo of transect



Terminology

- Boundary Classification

Precentage of days	Boundary strength	Range	Boundary type
0 - 30%	Weak	0 - 100 m	Stable
30 - 60%	Intermediate	100 - 200 m	Intermediate/Stable
60 - 100%	Strong	200 - 300 m	Intermediate/Transitional
		300 - 400 m	Transitional

- Efficiency of detecting preexisting boundaries

$$\text{Efficiency} = \frac{\text{Total number of boundaries detected}}{\text{Total number of preexisting boundaries}} \times 100$$

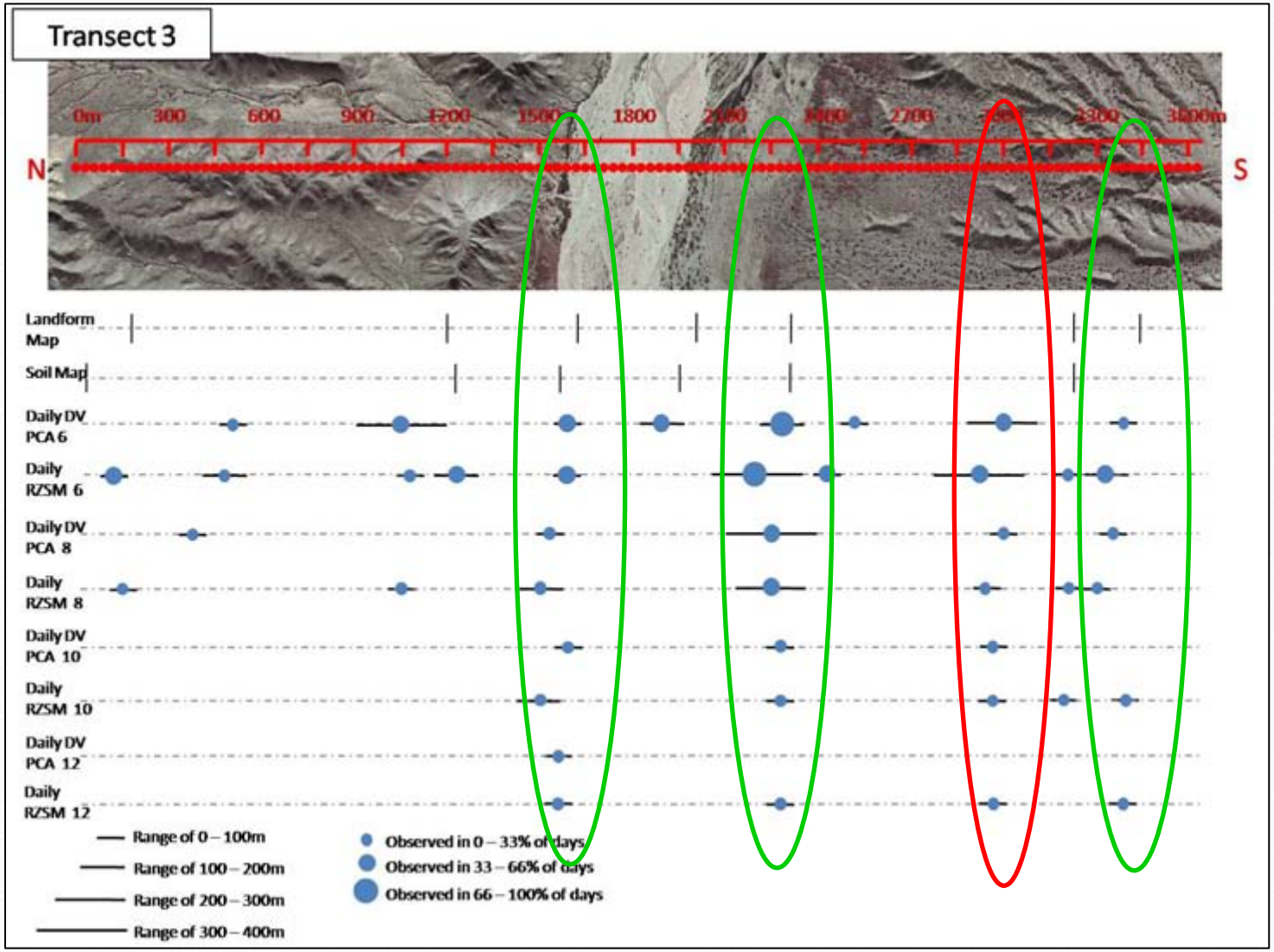
- Failure rate

$$\text{Failure} = 100 - \text{Efficiency}$$

Fix equation

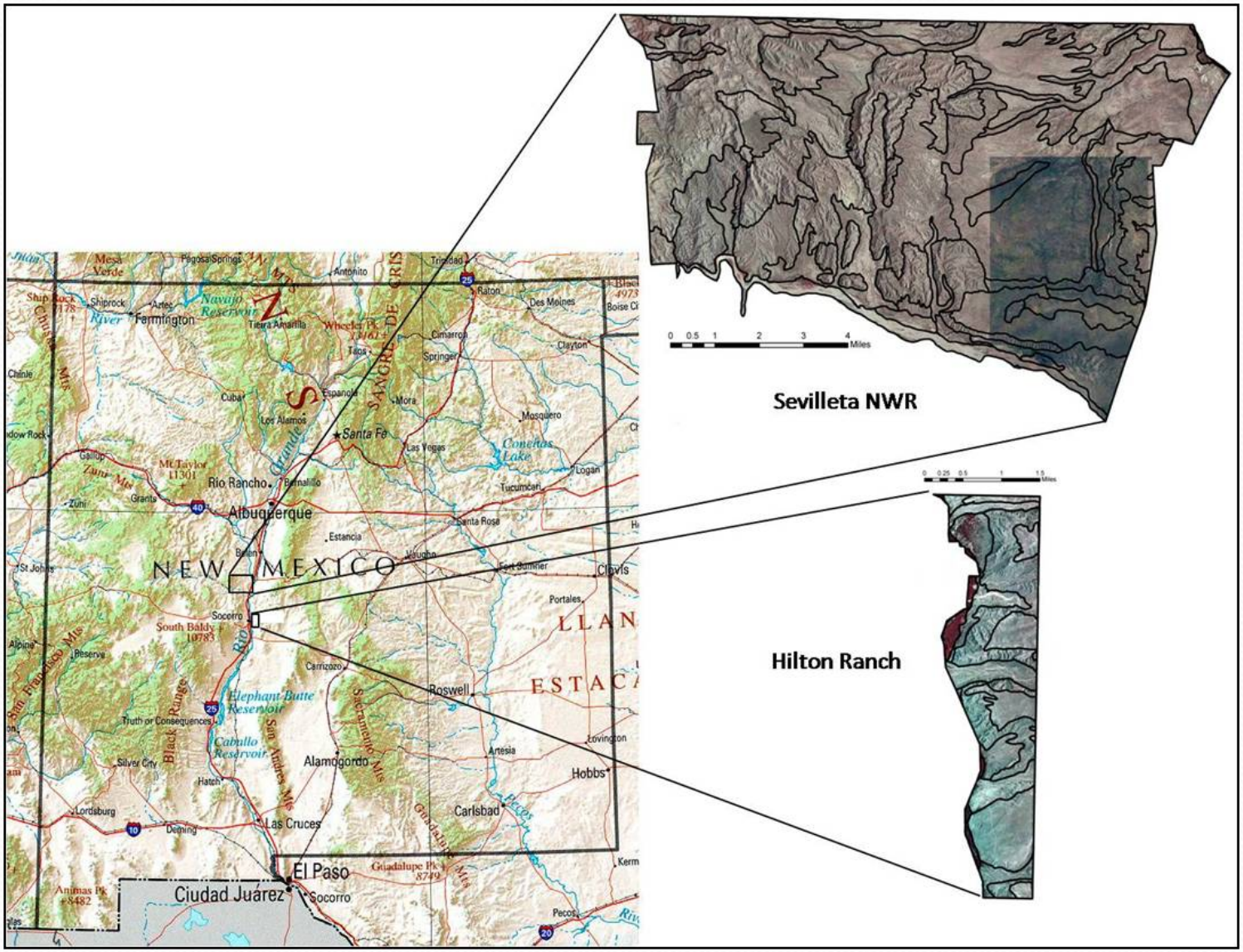
Results

- Transect 3



Any Questions?

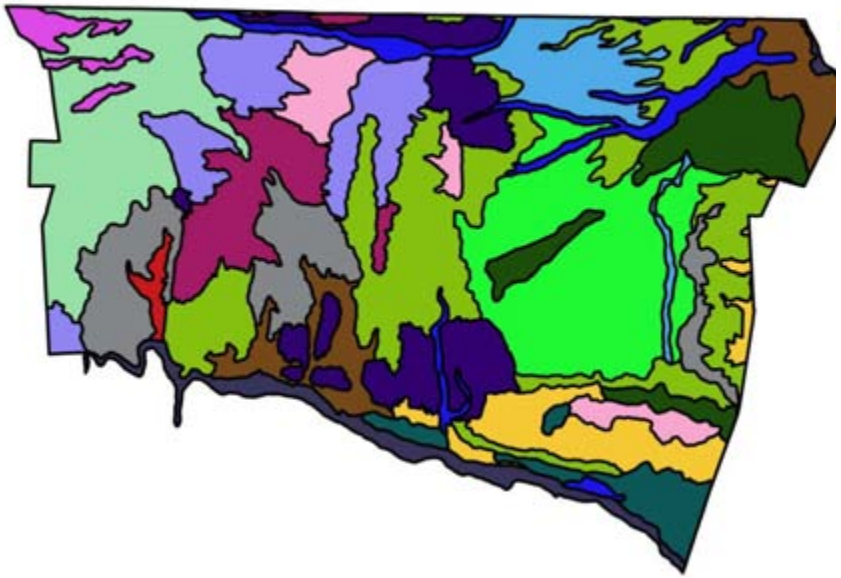
Study Areas

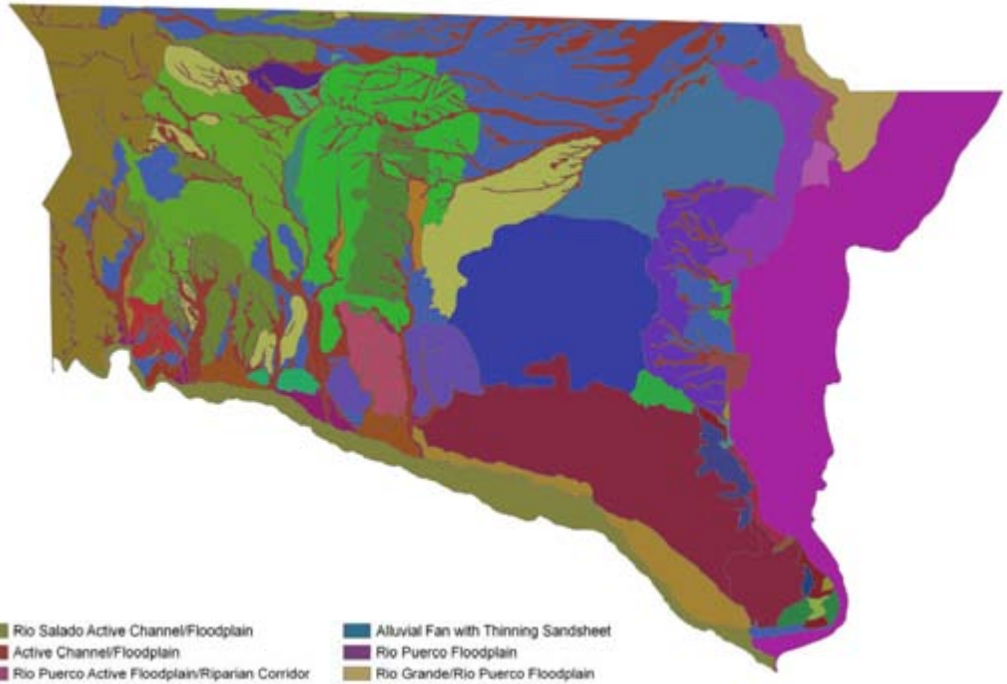

Sevilleta NWR
0 0.5 1 2 3 4 Miles
Hilton Ranch
NEW MEXICO
Albuquerque
Rio Rancho
Santa Fe
Las Cruces
El Paso
Ciudad Juárez
Roswell
Alamogordo
Carlsbad
Hobbs
Clovis
Farmington
Raton
Socorro

Sevilleta NWR

- Area approximately 1000 km^2
- Seventeen soil associations and complexes
  - Shallow rocky soils on the Sierra Ladrones
  - Soils up to 1.8 m deep in floodplains
- Landforms include alluvial fans, pediments and terraces of various ages, and active channels
- Receives about 2.24 cm of precipitation
  - ~45% falls during monsoon season
- Average air temperature is 14.4˚C
  - Daily fluctuation is 12.1 ˚C
- Average windspeed is 2.9 m/s
- Vegetation includes juniper, creosote, cholla, prickly pear and grasses

Sevilleta NWR





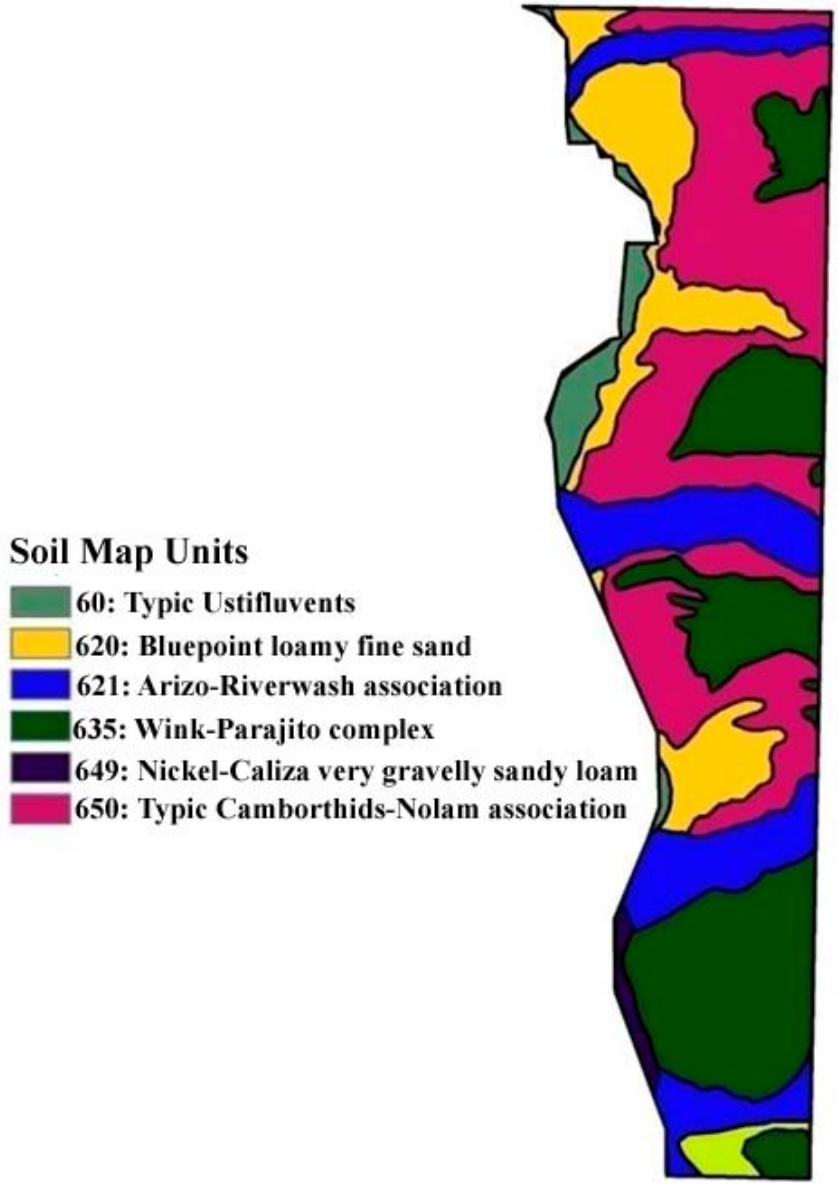
Soil Map Units

- 403: Puertecito-Rock outcrop complex
- 404: Motoqua-cool rock outcrop complex
- 421: Glenburg-Riverwash association
- 491: Riverwash
- 604: Turney loamy sand
- 620: Bluepoint loamy fine sand
- 621: Arizo-Riverwash complex
- 627: Berino-Dona Ana association
- 635: Wink-Parajito complex
- 641: Turney loam
- 648: Armijo-Glendale-Bluepoint association
- 649: Nickel-Caliza very gravelly sandy loam
- 650: Typic Camborthids-Nolam association
- 660: Dune land
- 689: Laborcita-Pilabo-Lemitar complex
- 690: Bluepoint-Caliza complex
- 786: Rock outcrop-Badland complex

- Rio Salado Active Channel/Floodplain
- Active Channel/Floodplain
- Rio Puerco Active Floodplain/Riparian Corridor
- Rio Grande Channel/Floodplain
- Alluvial Fan
- Rio Salado 1st Order Terrace
- Rio Salado 1st Order Terrace/Alluvial Fan Complex
- 1st Order Terrace
- Dissected Rio Grande Terrace
- Terrace Riser
- Rio Grande 1st Order Terrace
- Dissected Rio Grande Terrace/Sandsheet
- Terrace Riser/Dissected Sandsheet
- Alluvial Fans and Secondary 1st Order Terrace
- Rio Grande 1st Order Terrace/Fans
- Remnant Rio Grande Terrace
- Inactive Sandsheet/Sand-Covered Terrace
- Active Sandsheet/Terrace
- Dissected Sandsheet/Terrace
- Remnant Terrace
- Incised Alluvial Fan
- Remnant Fan with Sandsheet
- Alluvial Fan with Thinning Sandsheet
- Rio Puerco Floodplain
- Rio Grande/Rio Puerco Floodplain
- Alluvial Fan/Floodplain Deposits
- Rio Puerco Floodplain/Point Bar
- Floodplain
- Incised Terrace
- Incised Terrace/Fan Complex
- Incised Fan
- Remnant Alluvial Fan
- Remnant Surface
- Incising Remnant Alluvial Fan
- Highly Incised Alluvial Fan
- Alluvial Fan with Secondary Sandsheet
- Remnant Salado Terrace
- Remnant Fan with Incising Toe
- Remnant Fan/Pediment
- Alluvial Fan/Pediment
- Alluvial Fan with Undermap Scale Catchments
- Piedmont
- Incising Remnant fan with Bedrock Outcrops
- Incising Fan/Terrace Complex

Hilton Ranch

- Located east of Socorro
- Six soil complexes and associations
- Receives 2.6 cm of precipitation
- Range of temperature similar to that of the Sevilleta
- Vegetation includes juniper, creosote, mesquite, grasses, cottonwoods and salt cedar



Hypotheses

- Will remotely sensed root zone soil moisture obtained through SEBAL reveal subsurface trends and identify boundaries more accurately than raw Landsat digital values?

- By compiling multiple days of images, can we enhance spatial trends and reduce temporal effects to identify boundaries that can only be observed under certain environmental conditions?

- Will the compilation of the first principle component of the root zone soil moisture images (SEBAL) provide more information than the compilation of the first principle component of landsat digital values?

Methods

- Landsat 5 and 7 images
- Soil and landform maps
- SEBAL
- Principle component analysis
- Datasets
- Split moving window technique
- Terminology

Soil Map

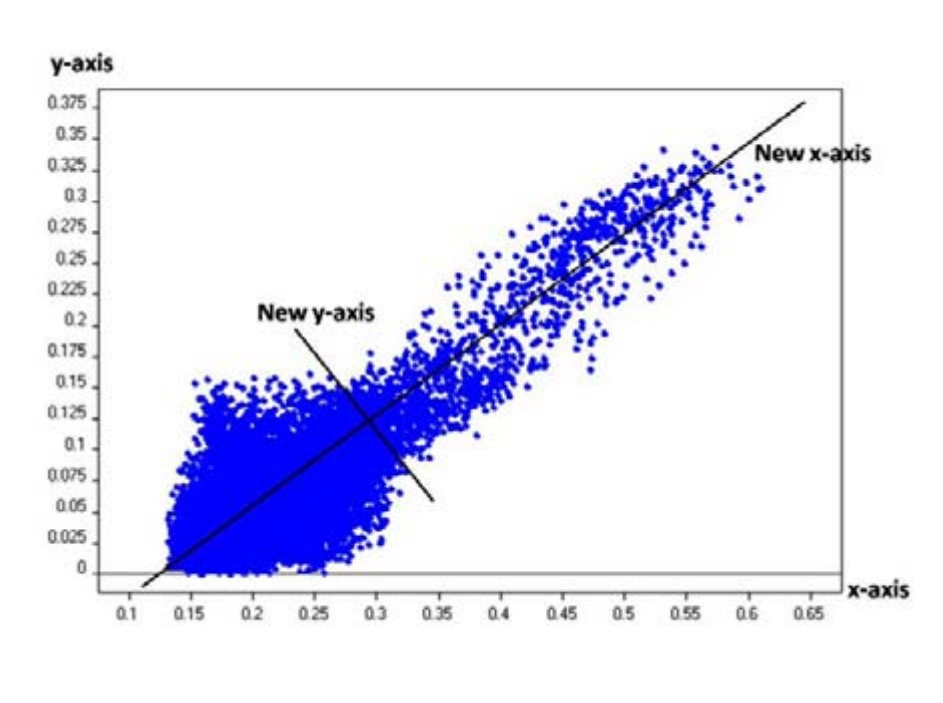
- Mapped by the Natural Resources Conservation Service (NRCS) at the 1:48,000 scale in 1984
- Converted into digital format
  - Errors in digitizing
    - Units that occur only in active channels extend up hillslopes
- Corrected using ArcGIS Spatial Adjustment

Landform Map

- Mapped by Alex Rinehart in 2008
- Identified geomorphic units using:
  - Orthophotos
  - 5 and 10 m contour maps
  - Quaternary fault map
  - Hillshade map
- Landform boundaries identified at 1:24,000 scale and plotted at 1:10,000 scale
- Proxy datasets:
  - topography, vegetation, surface color and soil texture

Principle Component Analysis (PCA)

- Used to reduce high volumes of data
  - Each Landsat image contains 7 bands
  - Shifts axes to correspond to maximum amount of variability
- Results in the same number of components as original image, each contains a percentage of total variability
  - Amount of variability decreases in each component
  - Used only first component, usually contained at least 70% of variability

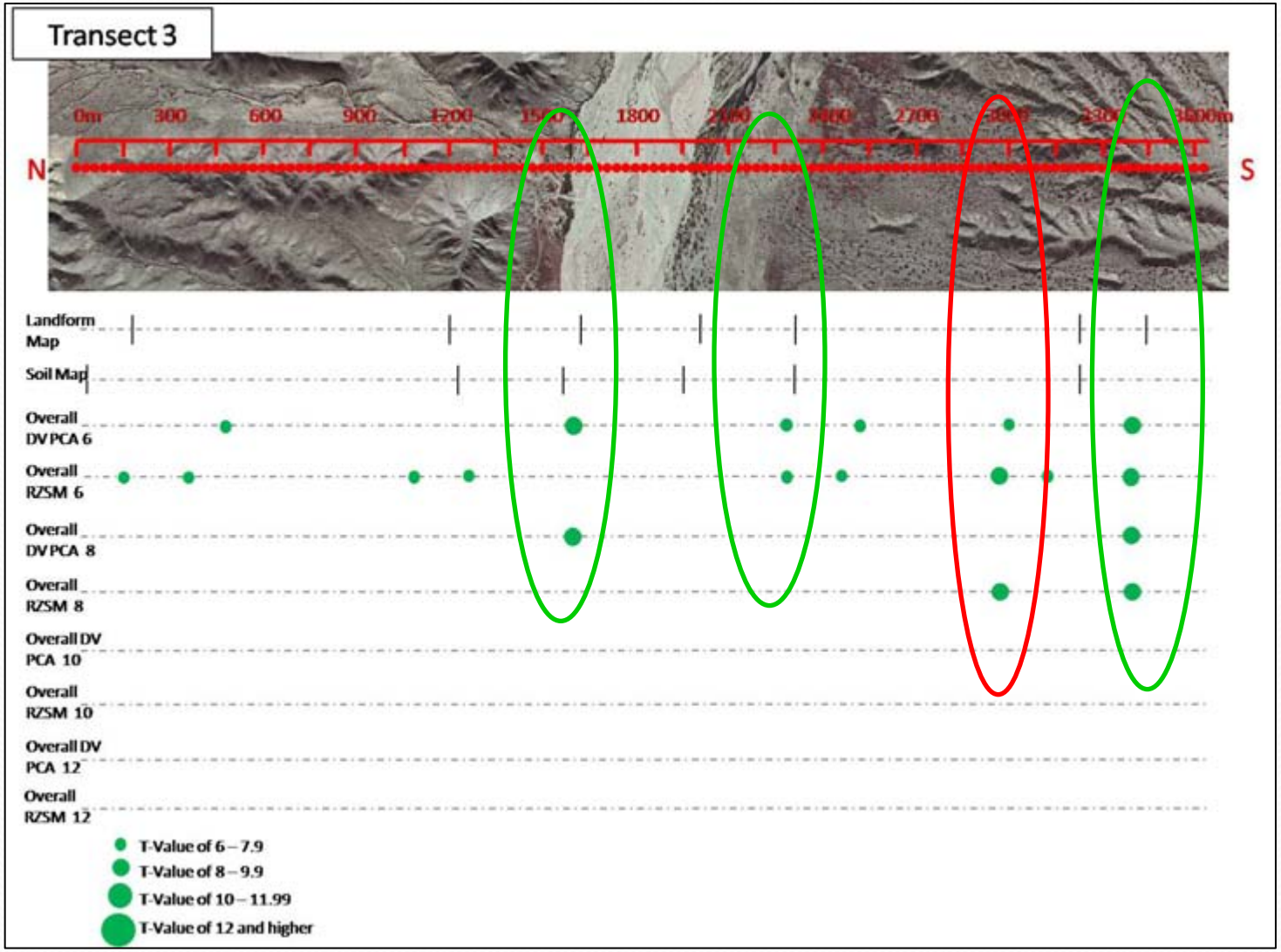


Datasets

- Using four datasets
  - Two daily datasets
    - Daily root zone soil moisture (daily RZSM)
    - PCA of daily Landsat digital values (daily DV PCA)
  - Two overall datasets
    - PCA of all root zone soil moisture (overall RZSM PCA)
    - PCA of all Landsat digital values (overall DV PCA)

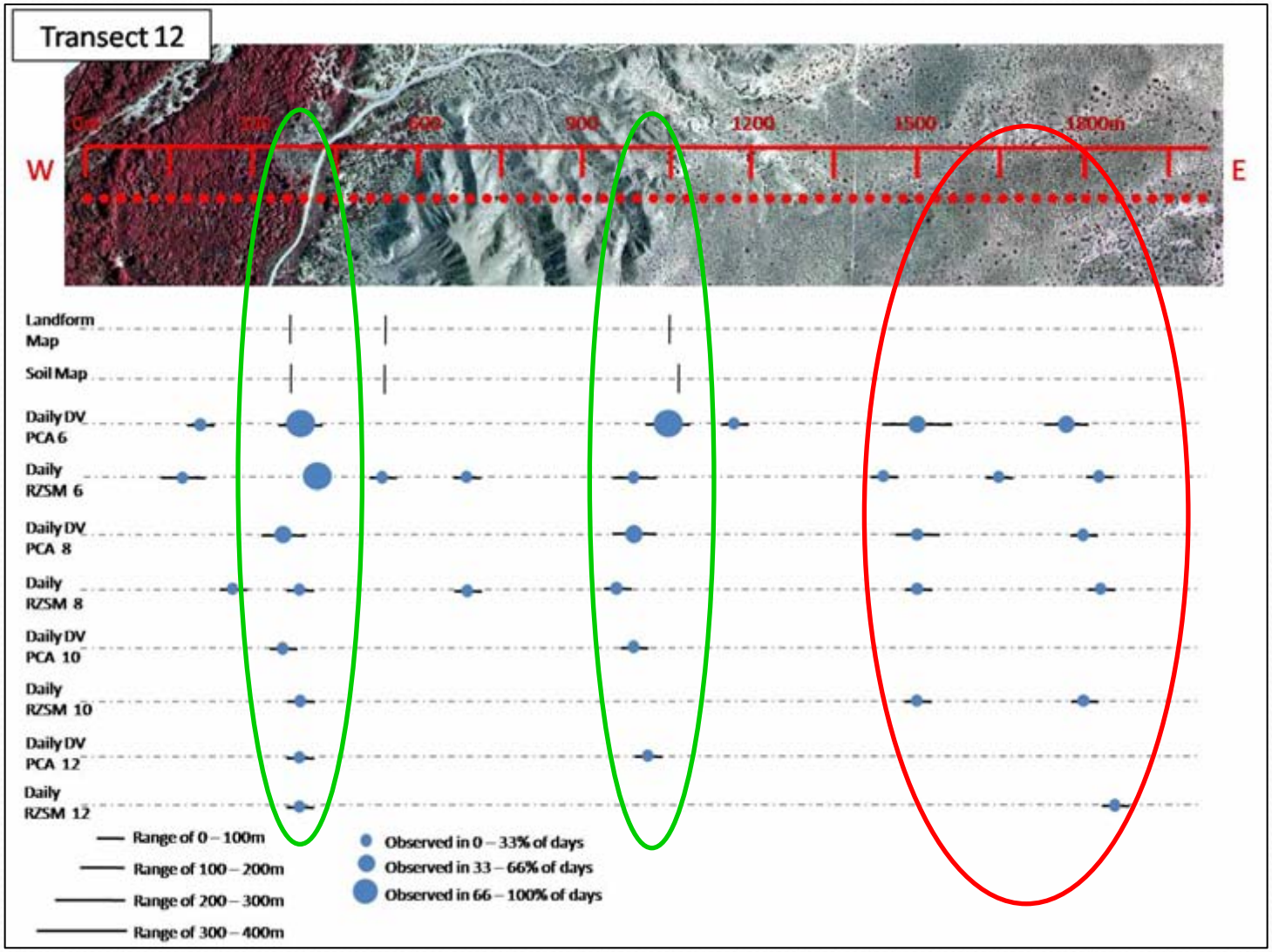
Results

- Transect 3



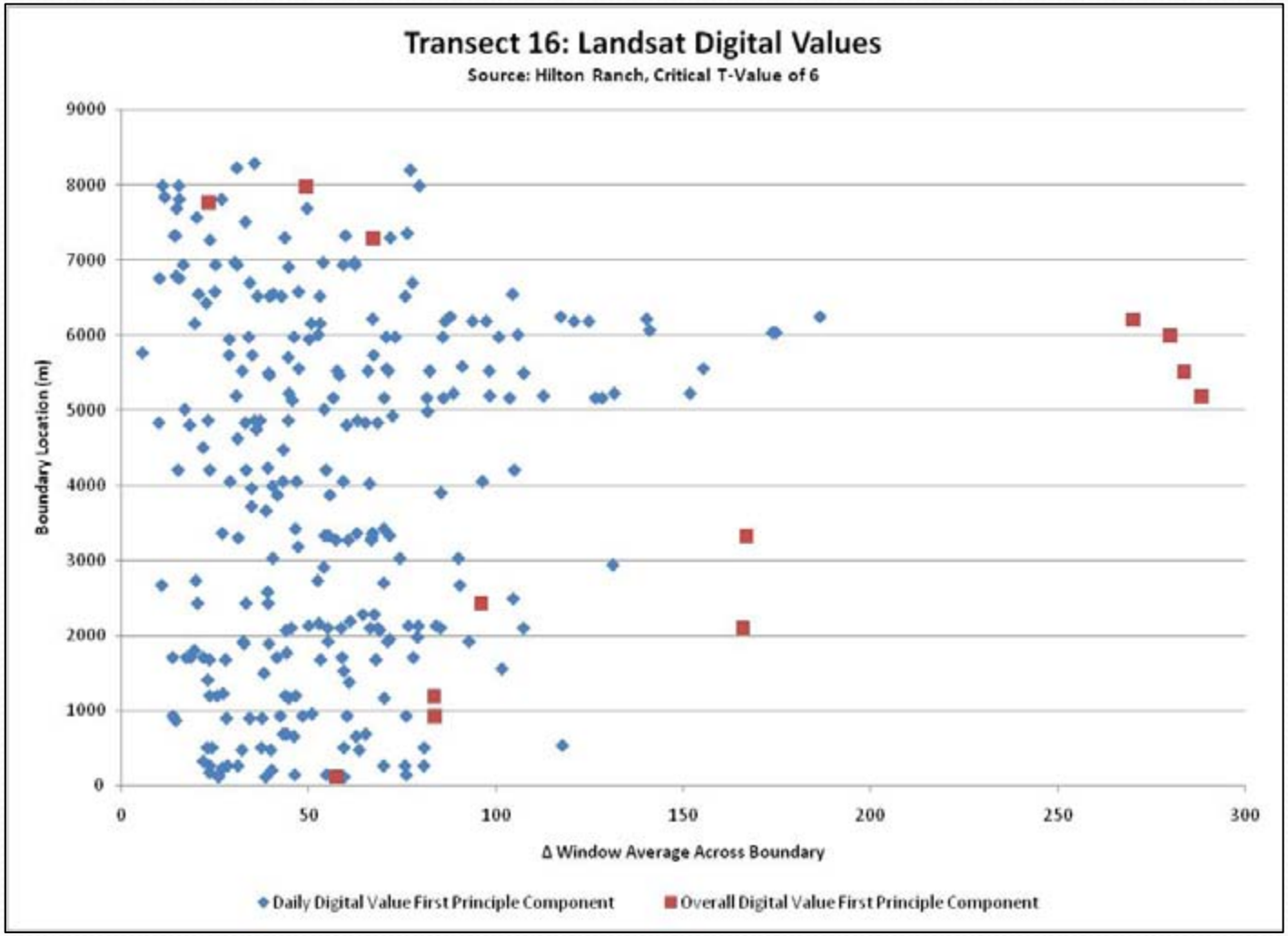
Results

- Transect 12



Results

- Transect 16

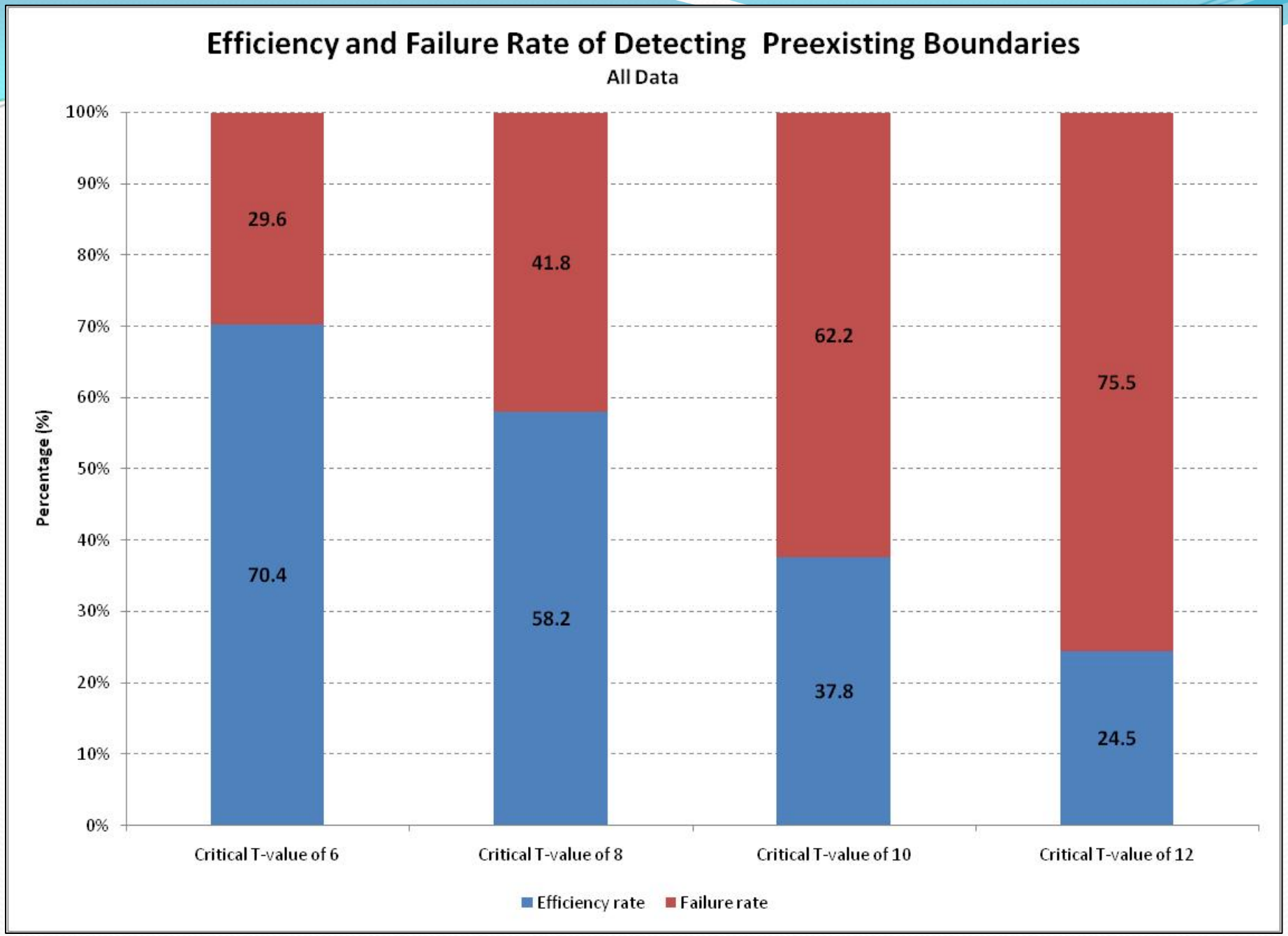


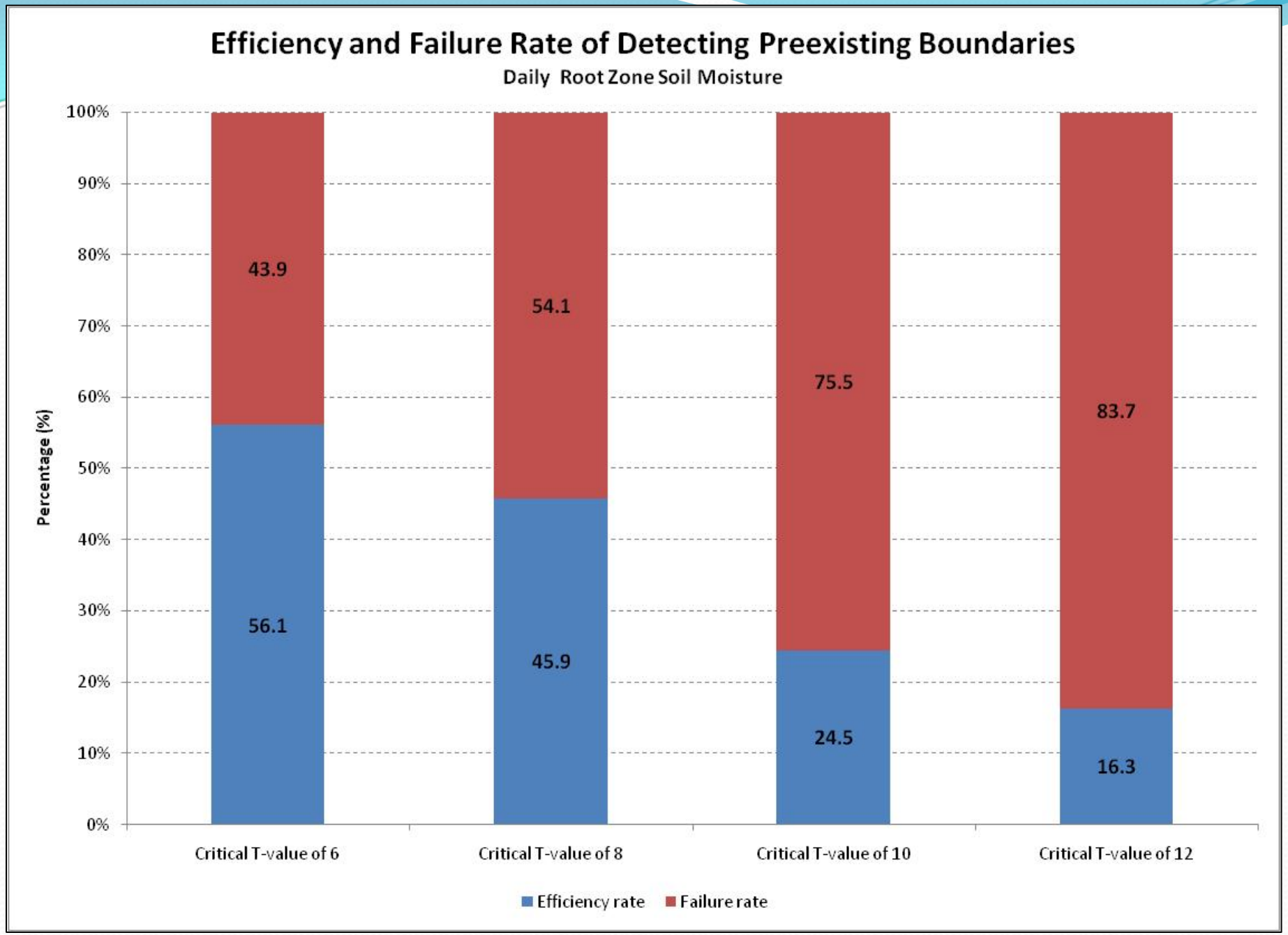
Discussion

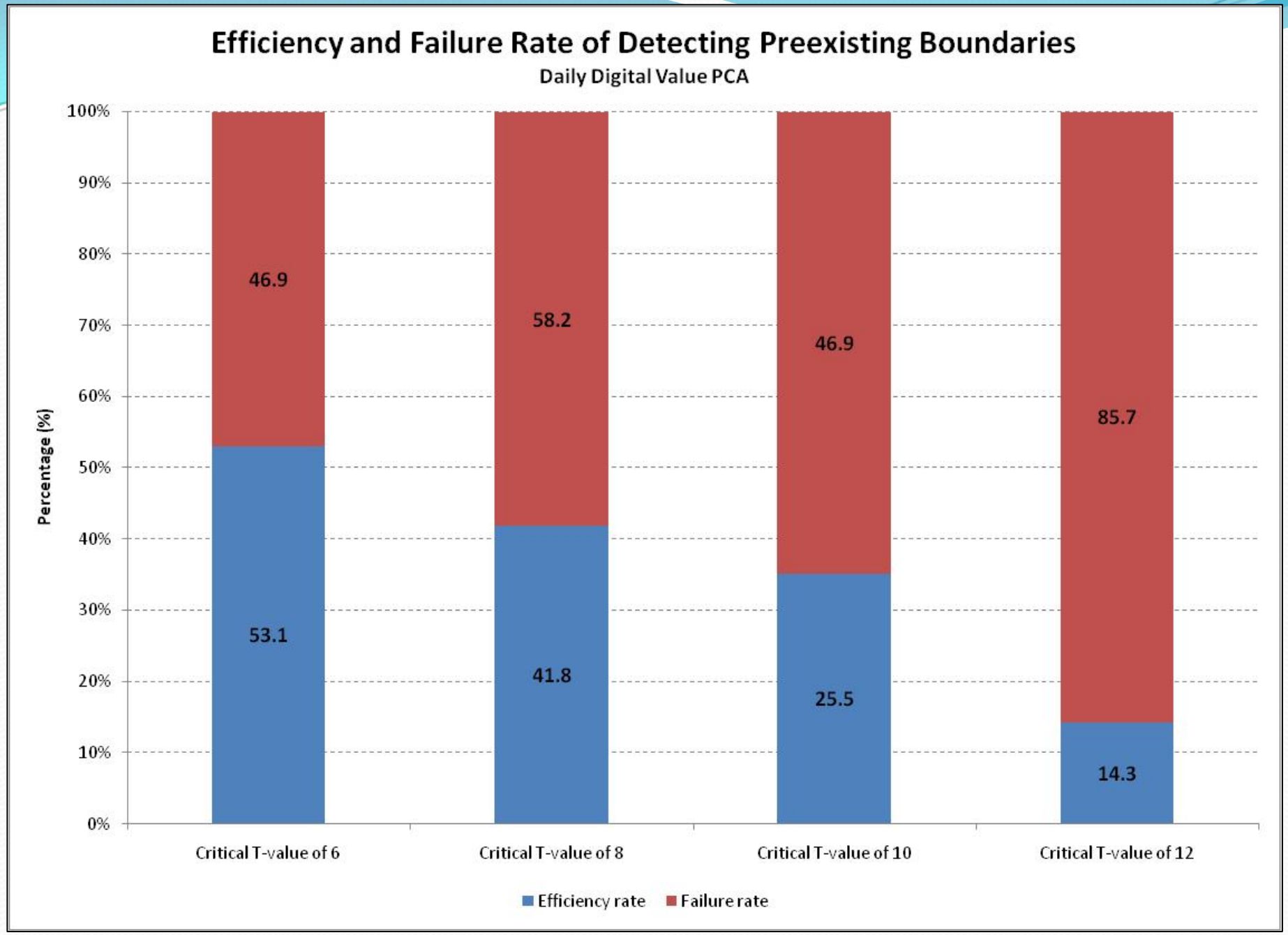
All Data, Critical T-Value 6

Transect	Total Number of Boundaries Detected	Total Number of Landform and Soil Boundaries	Total Landform and Soil Boundaries Detected	Number of Landform Boundaries	Number of Soil Boundaries	Detected Landform Boundaries	Detected Soil Boundaries	Detected Both Soil and Landform Boundaries	Extra Boundaries	Non-Detected Landform or Soil Boundaries
1	5	7	3	7	0	3	0	0	2	4
2	9	5	4	4	2	3	2	1	5	1
3	11	8	7	7	6	7	5	5	4	1
4	13	4	3	2	2	2	1	0	10	1
5	12	5	5	3	4	3	4	2	7	0
6	9	12	7	12	4	7	2	2	2	5
7	13	7	5	7	2	5	2	2	8	2
8	13	7	6	7	3	6	2	2	7	1
9	11	7	7	6	2	6	2	1	4	0
10	13	6	5	5	6	5	5	5	8	1
11	6	11	6	7	8	5	5	4	0	5
12	9	3	3	3	3	3	3	3	6	0
14	9	10	5	6	10	4	5	4	4	5
15	8	6	3	5	4	3	2	2	5	3
Totals	**141**	**98**	**69**	**81**	**56**	**62**	**40**	**33**	**72**	**29**

Efficiency Rate	**70.4**	Failure Rate	**29.6**


Efficiency and Failure Rate of Detecting Preexisting Boundaries
All Data
Percentage (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
29.6
70.4
41.8
58.2
62.2
37.8
75.5
24.5
Critical T-value of 6
Critical T-value of 8
Critical T-value of 10
Critical T-value of 12
Efficiency rate
Failure rate


Efficiency and Failure Rate of Detecting Preexisting Boundaries
Daily Root Zone Soil Moisture
Percentage (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
43.9
54.1
75.5
83.7
56.1
45.9
24.5
16.3
Critical T-value of 6
Critical T-value of 8
Critical T-value of 10
Critical T-value of 12
Efficiency rate
Failure rate


Efficiency and Failure Rate of Detecting Preexisting Boundaries
Daily Digital Value PCA
Percentage (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
46.9
58.2
46.9
85.7
53.1
41.8
25.5
14.3
Critical T-value of 6
Critical T-value of 8
Critical T-value of 10
Critical T-value of 12
Efficiency rate
Failure rate

Efficiency and Failure Rates

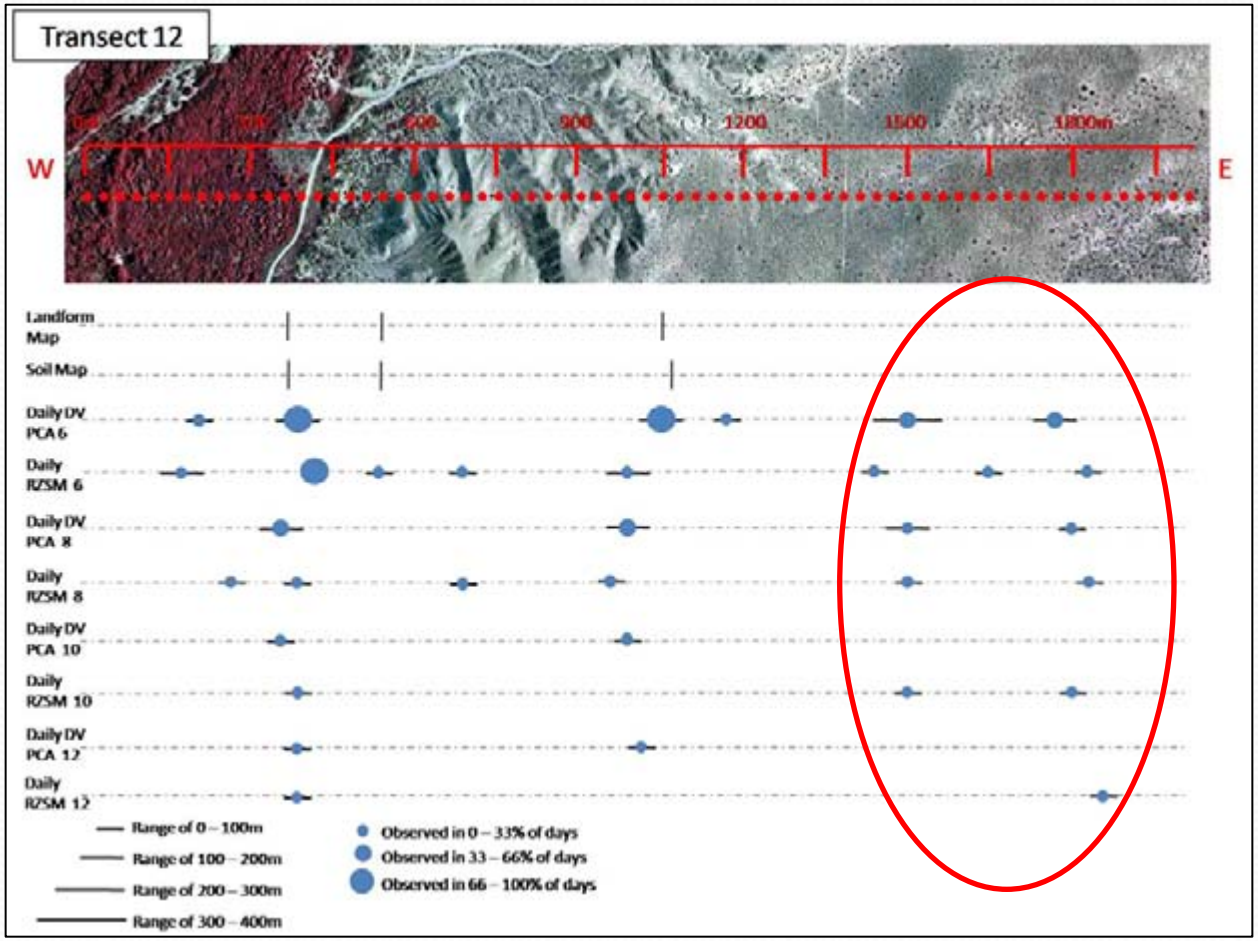
	All Data		**Daily Root Zone Soil Moisture**		**Daily Digital Values**		**Overall Digital Values**		**Overall Root Zone Soil Moisture**	
	Efficiency rate of detecting preexisting boundaries	Failure rate of detecting preexisting boundaries	Efficiency rate of detecting preexisting boundaries	Failure rate of detecting preexisting boundaries	Efficiency rate of detecting preexisting boundaries	Failure rate of detecting preexisting boundaries	Efficiency rate of detecting preexisting boundaries	Failure rate of detecting preexisting boundaries	Efficiency rate of detecting preexisting boundaries	Failure rate of detecting preexisting boundaries
Critical T-Value 6	70.4	29.6	56.1	43.9	53.1	46.9	43.9	56.1	36.7	63.3
Critical T-Value 8	58.2	41.8	45.9	54.1	41.8	58.2	16.3	83.7	13.3	86.7
Critical T-Value 10	37.8	62.2	24.5	75.5	25.5	46.9	4.1	94.9	0.0	100.0
Critical T-Value 12	24.5	75.5	16.3	83.7	14.3	85.7	1.0	99.0	0.0	100.0

Discussion

- When identifying soil map boundaries and landform map boundaries:
  - All data combined had highest efficiency rates
  - Daily root zone soil moisture and daily digital value PCA performed almost equally as well
  - Overall root zone soil moisture and overall digital value PCA also performed equally
- Method did not seem to be better at detecting one type of boundary than the other
  - Soil map often incorporate landform boundaries

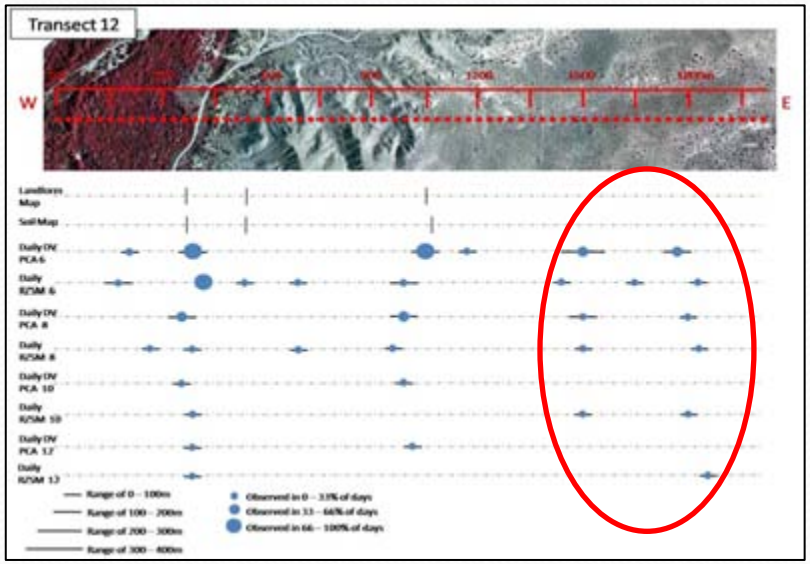
Conclusions

- Does root zone soil moisture reveal subsurface trends and identify boundaries more accurately than digital values?



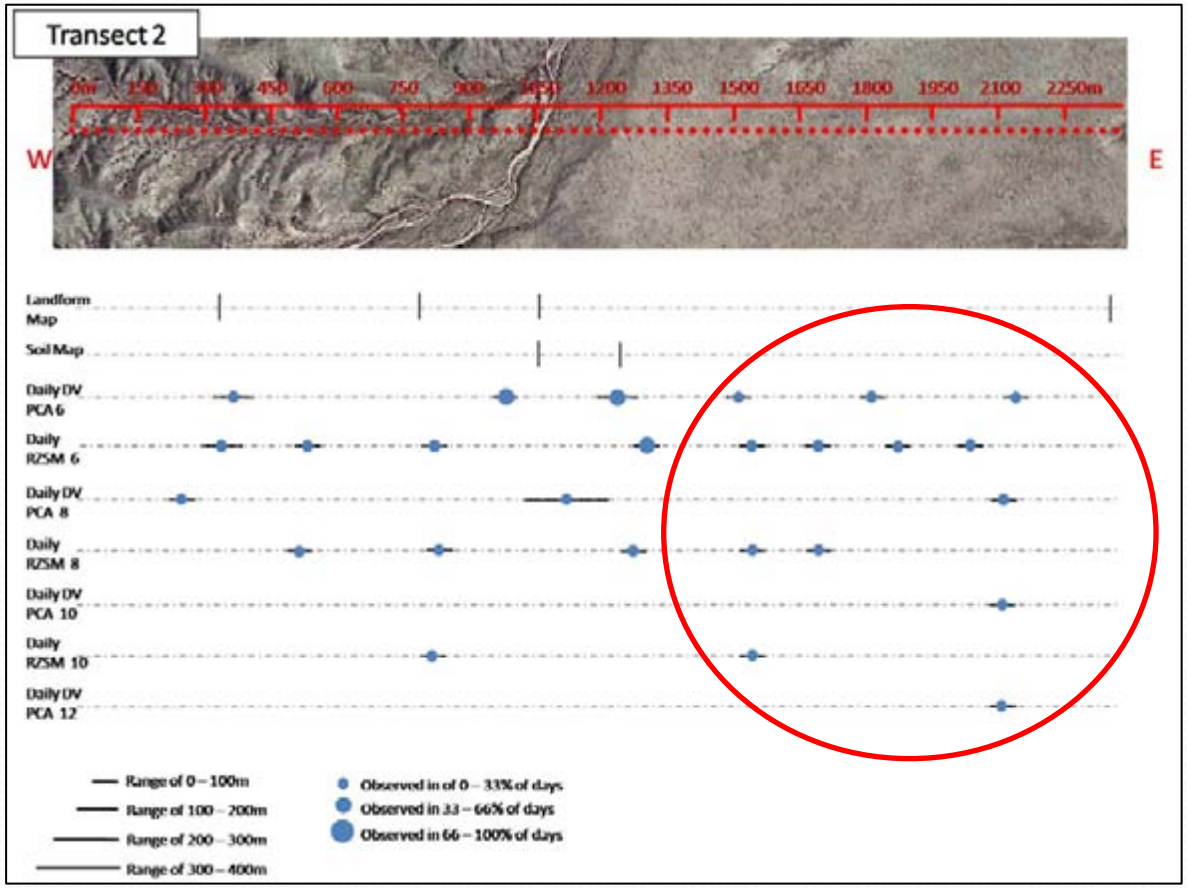
Conclusions

- Does root zone soil moisture reveal subsurface trends and identify boundaries more accurately than digital values?
  - Where sandsheet occurs, both daily root zone soil moisture and digital values reveal something going on in the subsurface and identify boundaries where none have previously detected



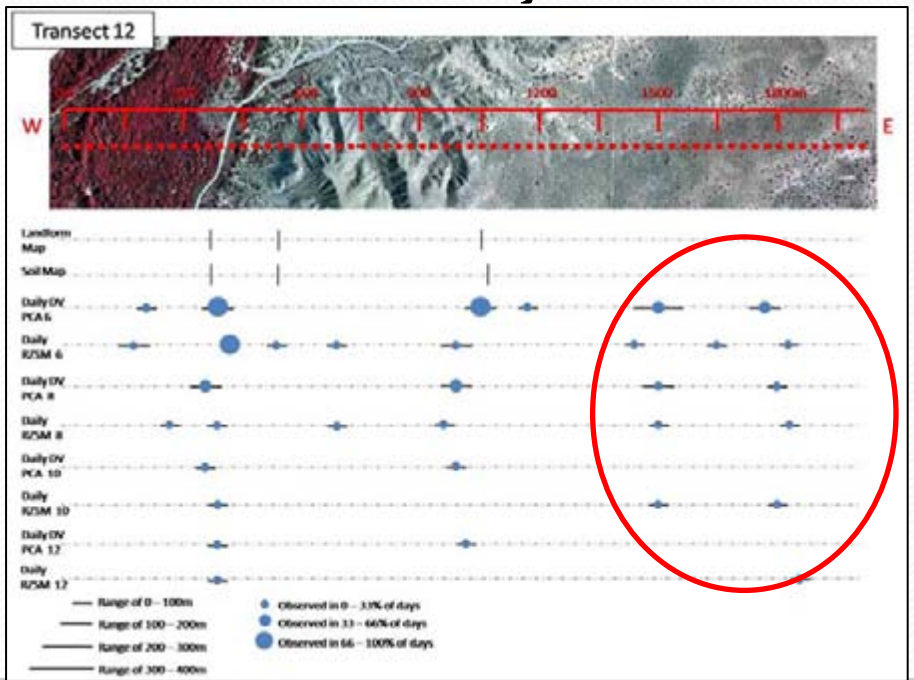
Conclusions

- By compiling multiple days, can we enhance spatial trends and reduce temporal effects to identify boundaries only be observed under certain conditions?



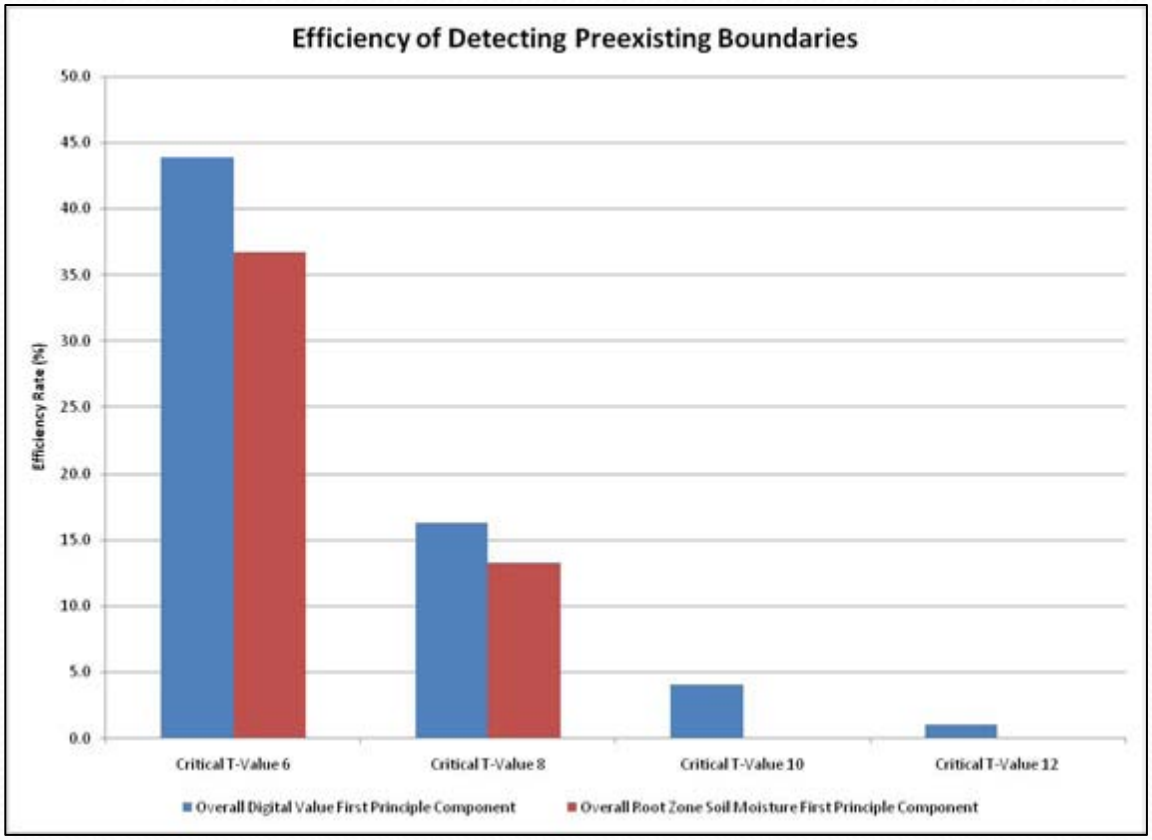
Conclusions

- By compiling multiple days, can we enhance spatial trends and reduce temporal effects to identify boundaries only be observed under certain conditions?
  - Boundaries only appear in 0 to 33% of days
  - If we use one of the other 66% of days, wouldn't see these boundaries



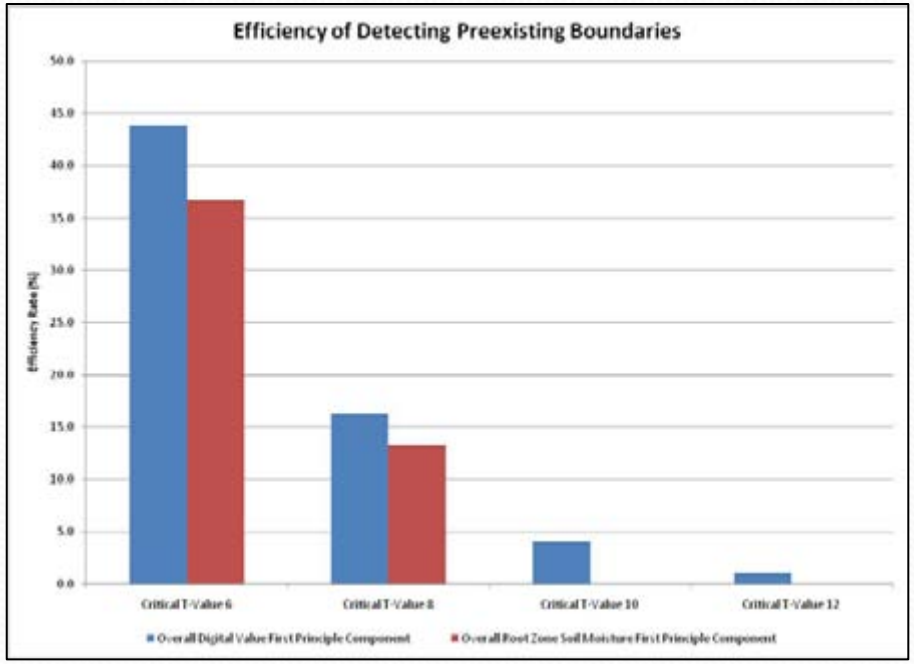
Conclusions

- Will the compilation of the first principle component of the root zone soil moisture images (SEBAL) provide more information than the compilation of the first principle component of landsat digital values?



Conclusions

- Will the compilation of the first principle component of the root zone soil moisture images (SEBAL) provide more information than the compilation of the first principle component of landsat digital values?
  - Overall digital value PCA performed slightly better than overall root zone soil moisture PCA



Conclusions and Future Work

- New methodology works well
  - Only few occasions when it does not, mostly due to changes over an area smaller than our window size and pixel size can measure
  - Is SEBAL really needed to produce good results?
    - Digital values work well when soil moisture is constant
    - SEBAL works well when soil moisture is variable
- Transects at the Hilton Ranch currently being validated by soils class
- Greatest contribution is not that have we reproduced existing maps but that we have identified boundaries that have not been previously identified