TEREN
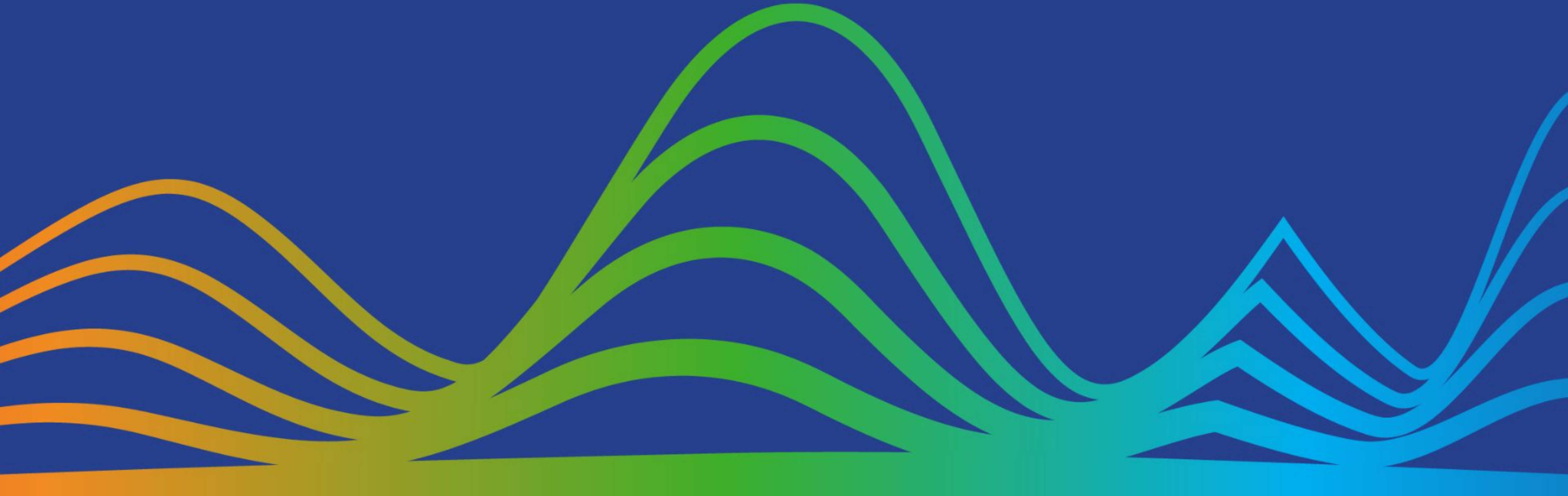
Actionable Earth Observation Insights
for a Changing World

The Project

Remote Measurement of Reclamation Success

Develop a suite of automated analytics that bring remote reclamation assessment technology to operational capacity for industry, agencies, and the interested public.

Reclamation Analytics Suite

```
Broad Scale          Vegetation          Contouring          Infrastructure          Hydrology          Volumetrics Tool          Reclamation
Assessment    →      Assessment    →     Assessment    →     Assessment       →      Assessment    →                      →      Success
                                                                                                                                  Assessment
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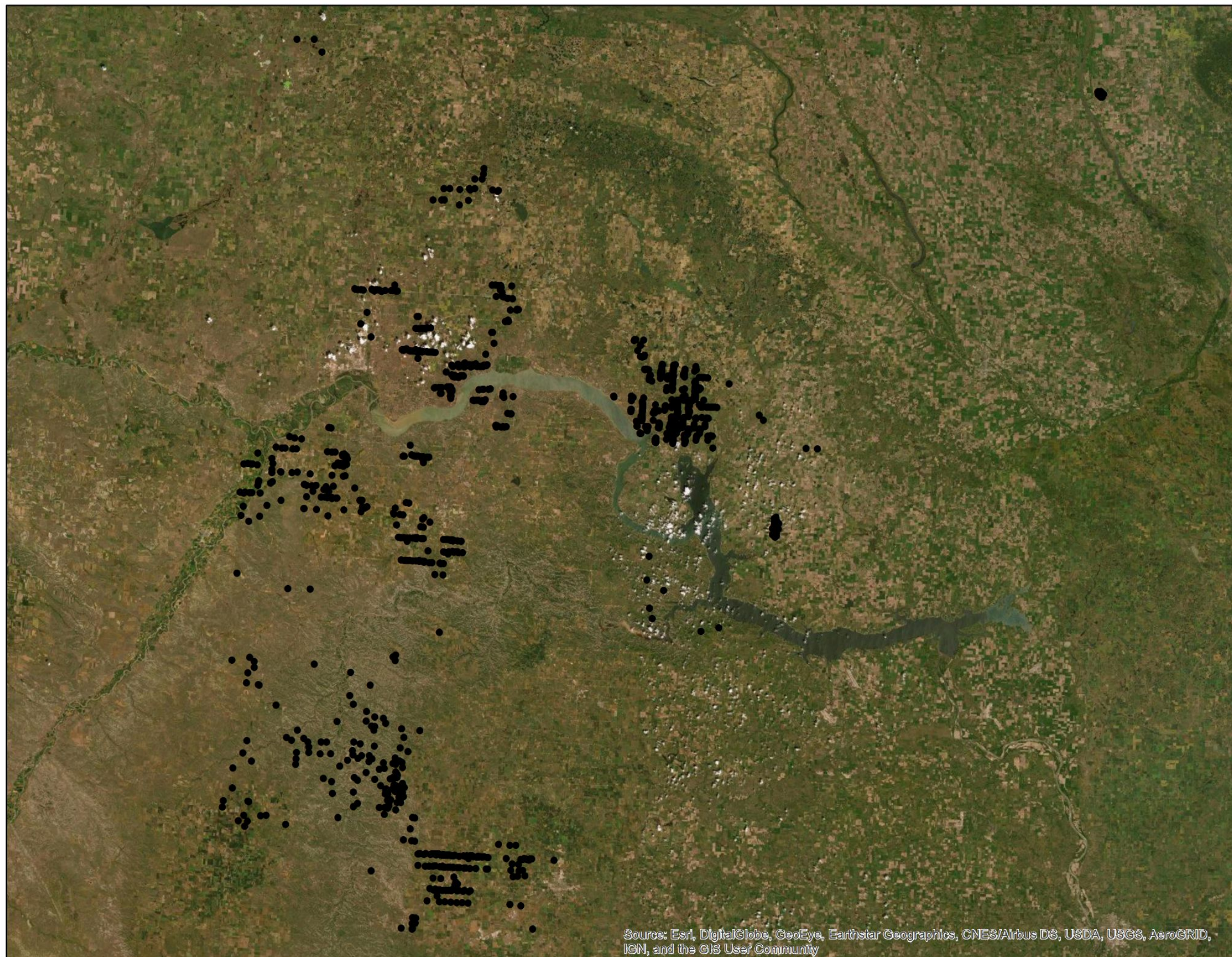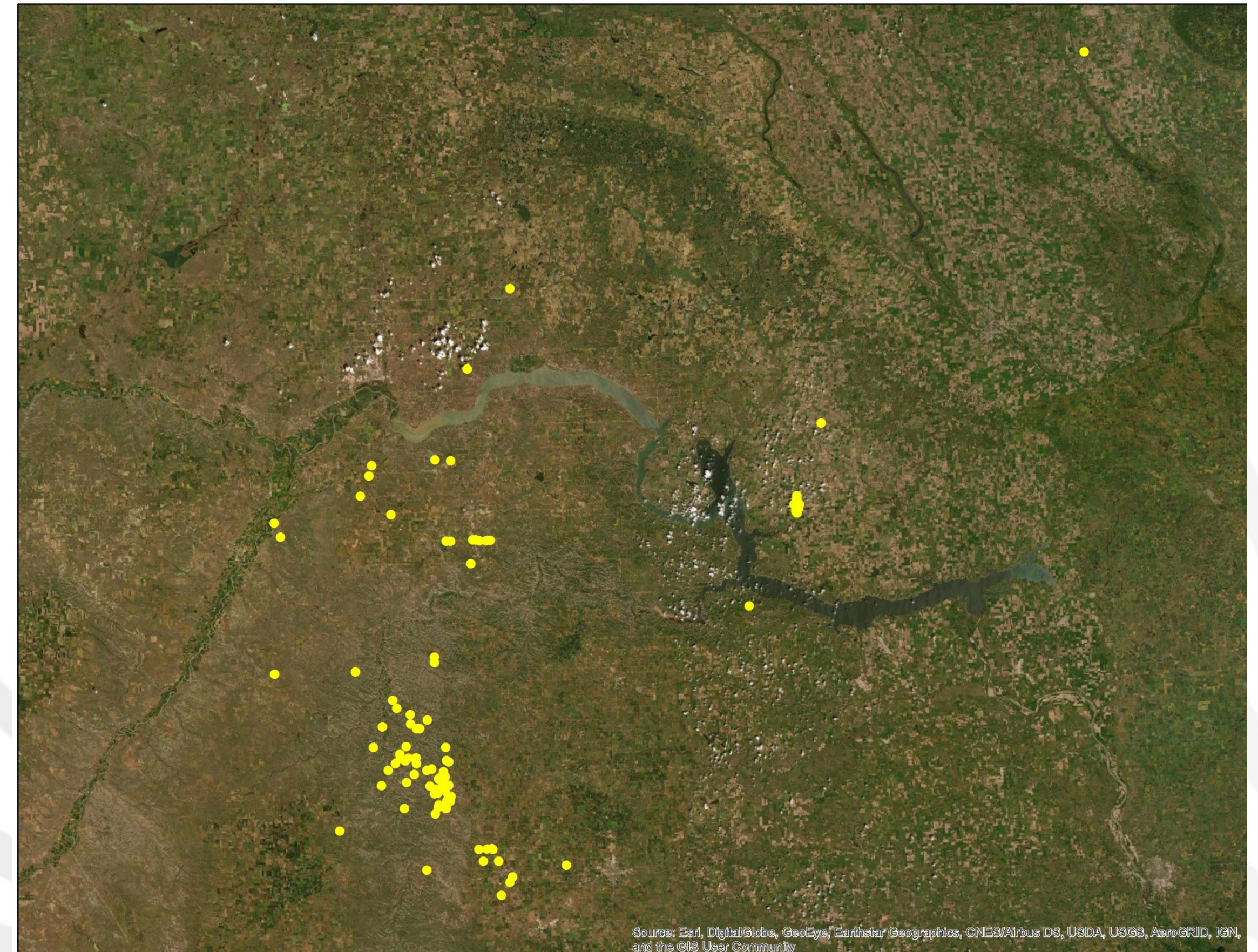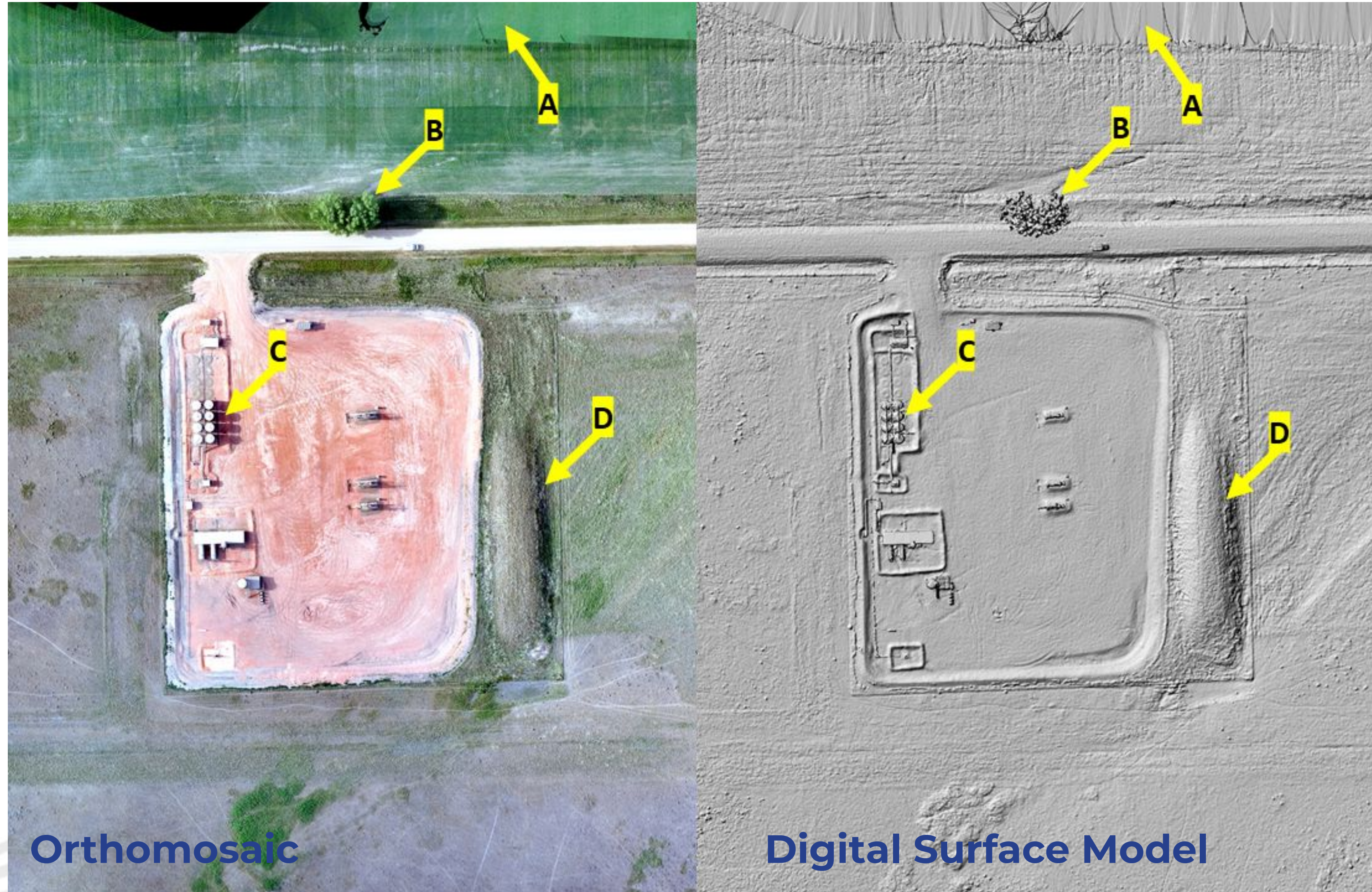
Well Pad Site Selection

Whiting pads summer 2020 (n = 1,139)

Whiting Pads selected for detailed analysis (n = 101)

Remotely Sensed Earth Surfaces

Orthomosaic

Digital Surface Model

Highlighted Features:

A. Interpolated noise
B. Tree
C. Storage tanks
D. Soil stockpile
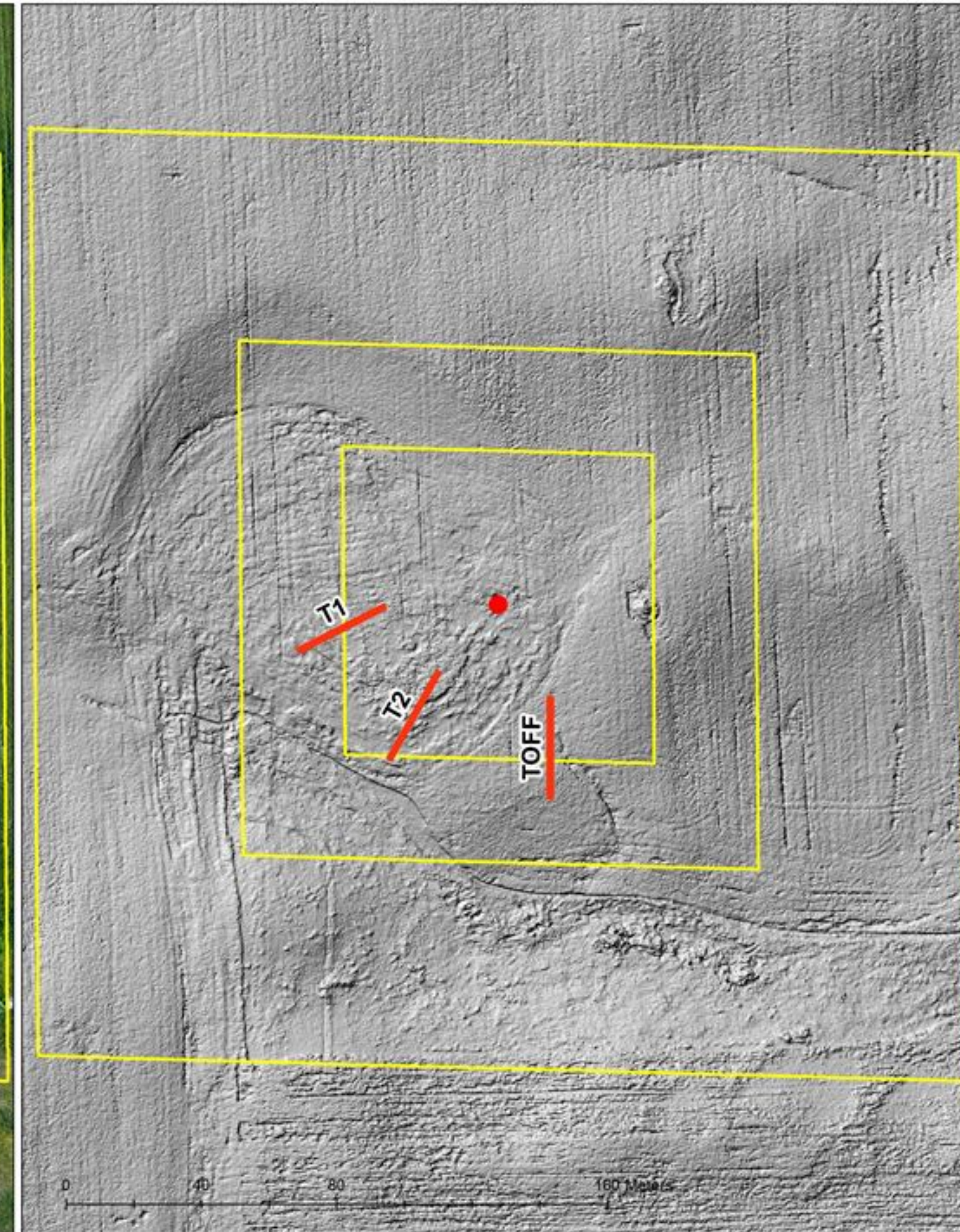
Field Sampling & Assessment

Duraroot surveyed 29 well pads for field validation.
- 19 in final reclamation
- 10 in partial reclamation

Two to three transects per well pad quantified soil cover, including vegetation, litter, rocks, and biotic crusts.

Field Sampling & Assessment

Three to five photographs per well pad captured ground cover for ocular verification.

Field Sampling & Assessment

Quantitative dataset produced by **Duraroot** field inspections and used for remote assessment validation.

	A	B	C	D	E	F	G	H	I
1	Hits per transect	20							
2	Number of transects	--							
4	Transect	Grass	Forb	Shrub	Bare Ground	Rock	Litter	Non-desirable	Total
5	T1	85%	5%	0%	5%	0%	95%	5%	190%
6	T2	70%	0%	0%	40%	0%	60%	0%	170%
7	TOFF	65%	10%	0%	0%	0%	0%	0%	75%
8	Sample #	0%	0%	0%	0%	0%	0%	0%	0%
9	Sample #	0%	0%	0%	0%	0%	0%	0%	0%

	K	L	M	N	O	P	Q	R	S	T
4	Transect	Grass	Forb	Shrub	Non-desirable	Vegetative Cover	% Grass	% Forb	% Shrub	%Non-desirable
5	T1	17	1	0	1	19	89%	5%	0%	5%
6	T2	14	0	0	0	14	100%	0%	0%	0%
7	TOFF	13	2	0	0	15	87%	13%	0%	0%
8	Sample #	0	0	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
9	Sample #	0	0	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

PERCENT COVER

Summary	T1	T2	TOFF	Sample #	Sample #
Vegetation	90%	70%	75%	0%	0%
Bare Ground	5%	40%	0%	0%	0%
Litter and Rock	95%	60%	0%	0%	0%
Non-desirable	5%	0%	0%	0%	0%
Total	190%	170%	75%	0%	0%
Total	185%	130%	75%	0%	0%

	T1	T2	TOFF	Sample #	Sample #	
Grasses	17	14	13	0	0	Autofill
Forbs	1	0	2	0	0	
Shrubs	0	0	0	0	0	
Non-desirable	1	0	0	0	0	

| Hits	T1	T2	TOFF	Sample #	Sample #	
Bare ground	1	8	0			Input "HITS"
Rock	0	0	0			
Litter	19	12	0			
Total B,R,L	20	20	0	0	0	
Veg Hits	18	14	15	0	0	
Non-desirable	1	0	0	0	0	
Total Hits	38	34	15	0	0	

Field Sampling & Assessment

Qualitative dataset produced by **NDIC** field inspections and used for remote assessment validation.

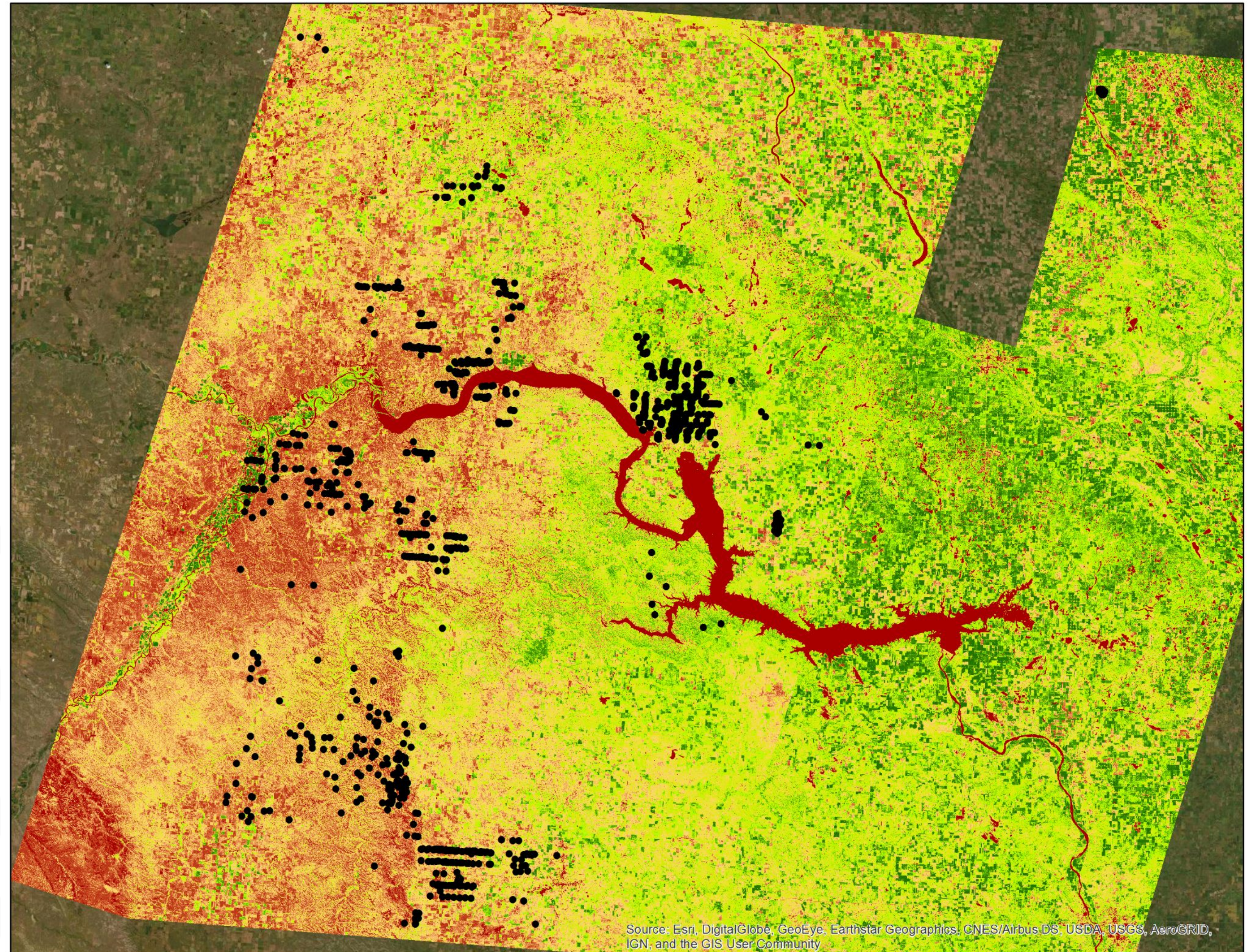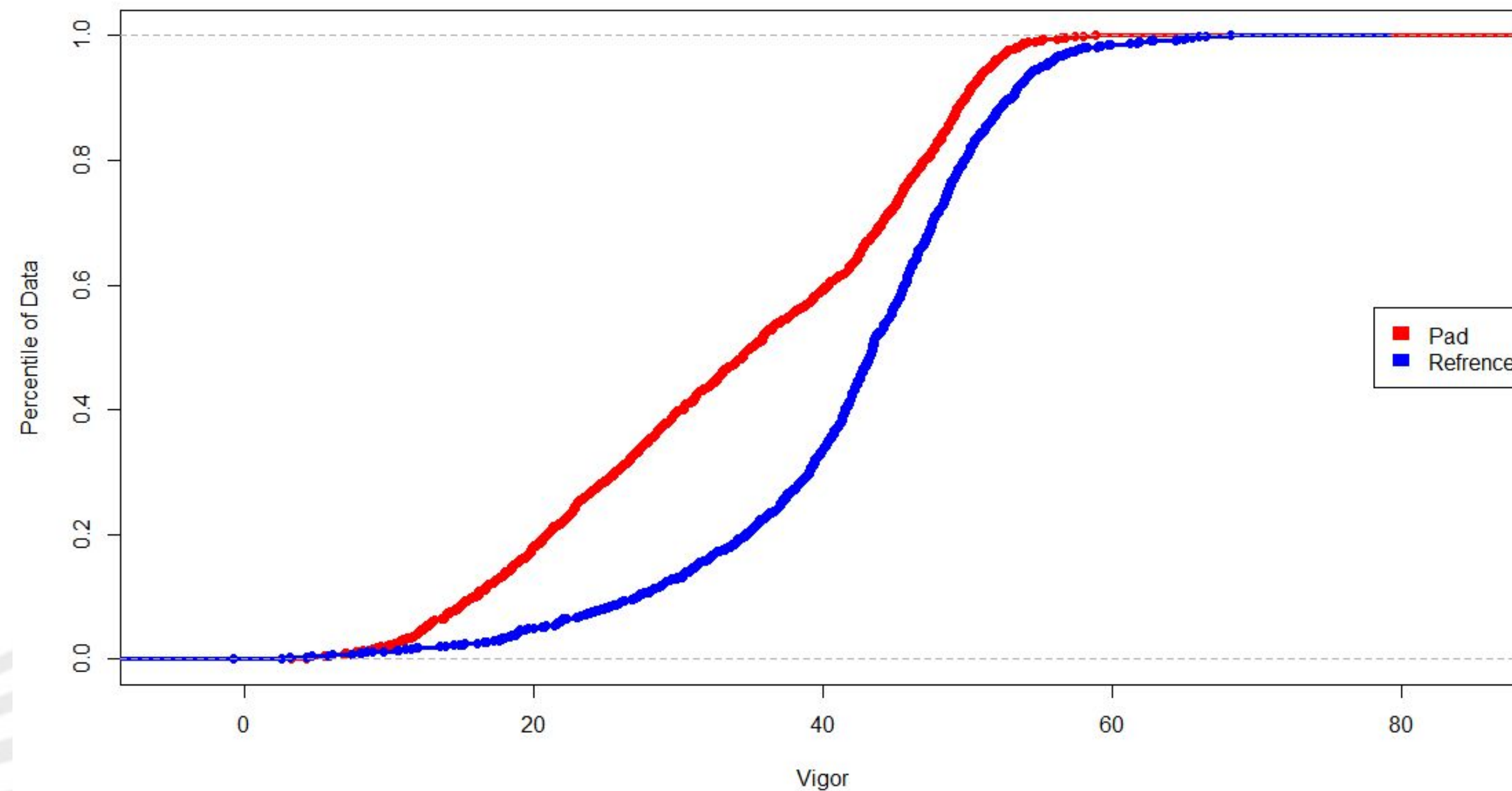| LInsp	Inspecto	Inspection Notes	SiteStatus	Well Name & Number
14-Apr-20	SLL	Farden has spread topsoil on the dead areas.	N	CLEVEN ET AL 1 44-27
18-Jun-19	NAE	Approach remains, road looks pretty good. Site is seeded in small grain, will have to look at after harvest. Looks like along east side might have some growth issues. Need waiver for approach. Cory said it's on the list, Ashley Schaper is new land dept.	N	ZASTOUPIL ET AL 8-08
07-Aug-19	MVB	Location and approach are fenced. Lease road slope looks much better this year. Bare areas have filled in slightly but still persist on west and north sides of location, with erosion channels on slope. Location is between scoria knobs so may be hard to ge	N	BIG STICK (MADISON) UNIT 2302
21-May-20	MVB	Growth looks very good, used for grazing. Check with USFS about if they have released	P	BIG STICK (MADISON) UNIT 0702
07-Aug-19	MVB	Significant bare areas remain on lease road on location, but soil seems poor. 4 years since location was reclaimed, may want to reseed or spread more soil	N	BIG STICK (MADISON) UNIT 0103
13-Jun-18	TMA	Growth on the lease road looks very good except right before the location where the erosion drainage cuts across it. Few other areas that are thinner as well on slopes. Location is still fenced. Growth still needs to fill in more on site. Pics taken with	P	BLACKTAIL FED. 1-20
11-Jan-21	RWH	No dirt work done.	N	H.A. MACKOFF FEE 23-17H
30-Aug-19	MVB	Growth on road needs more fill in, sparse areas along thelow areas of access road near the branch from remaining road. Location not fenced, grass filling in well. USFS	N	BIG STICK (MADISON) UNIT 1904
23-Apr-20	WJR	Growth on site is not great, some spots still bare, Main road to site still in place, and it bad condition, fence still around site.	N	USA 24-04
13-Jun-18	TMA	Growth on lease road is very good overall. Location still fenced. Overall site isn't bad but still a few large bare areas and some areas with only old vegetation from last year. WOG. USFS. Original road looped around to the east before coming in on the fa	N	BLACKTAIL FEDERAL 3-19
		Location is fenced and growth looks good, however there are utility boxes present that need to be accounted for. Lease road is not fenced and needs more time to fill in, lots of bare areas. Dirt pile		

Broad-Scale Vegetation Assessment
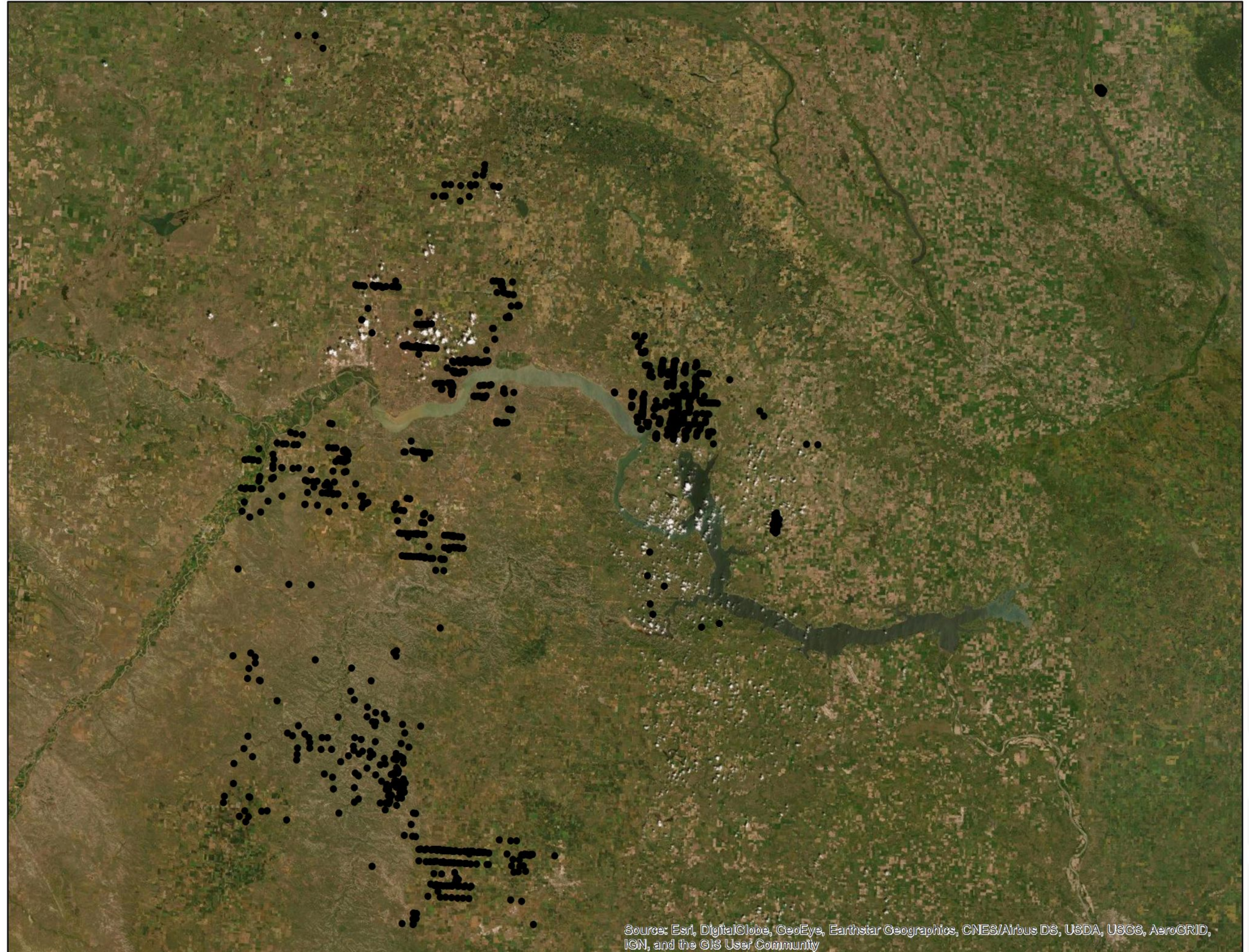
Teren performed a broad-scale assessment of vegetation vigor and classification on 2,313 well pads operated by Whiting using 0.6-meter NAIP data.

Broad-Scale Vegetation Assessment

Teren performed a broad-scale assessment of vegetation vigor and classification on 2,313 well pads operated by Whiting using 0.6-meter NAIP data.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Broad-Scale Vegetation Assessment

Teren statistically compared the pad and off-pad reference areas to produce a **Continuity Index** of vegetation vigor and classification for each well pad.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Broad-Scale Vegetation Assessment

Teren ranked the 2,313 Whiting well pads based on their Continuity Index scores to reveal hot spots.

The results enable streamlined prioritization of field visits or aerial data collection.

Limitations:
- Temporal relevance
- Coarse resolution
- 2-dimensional
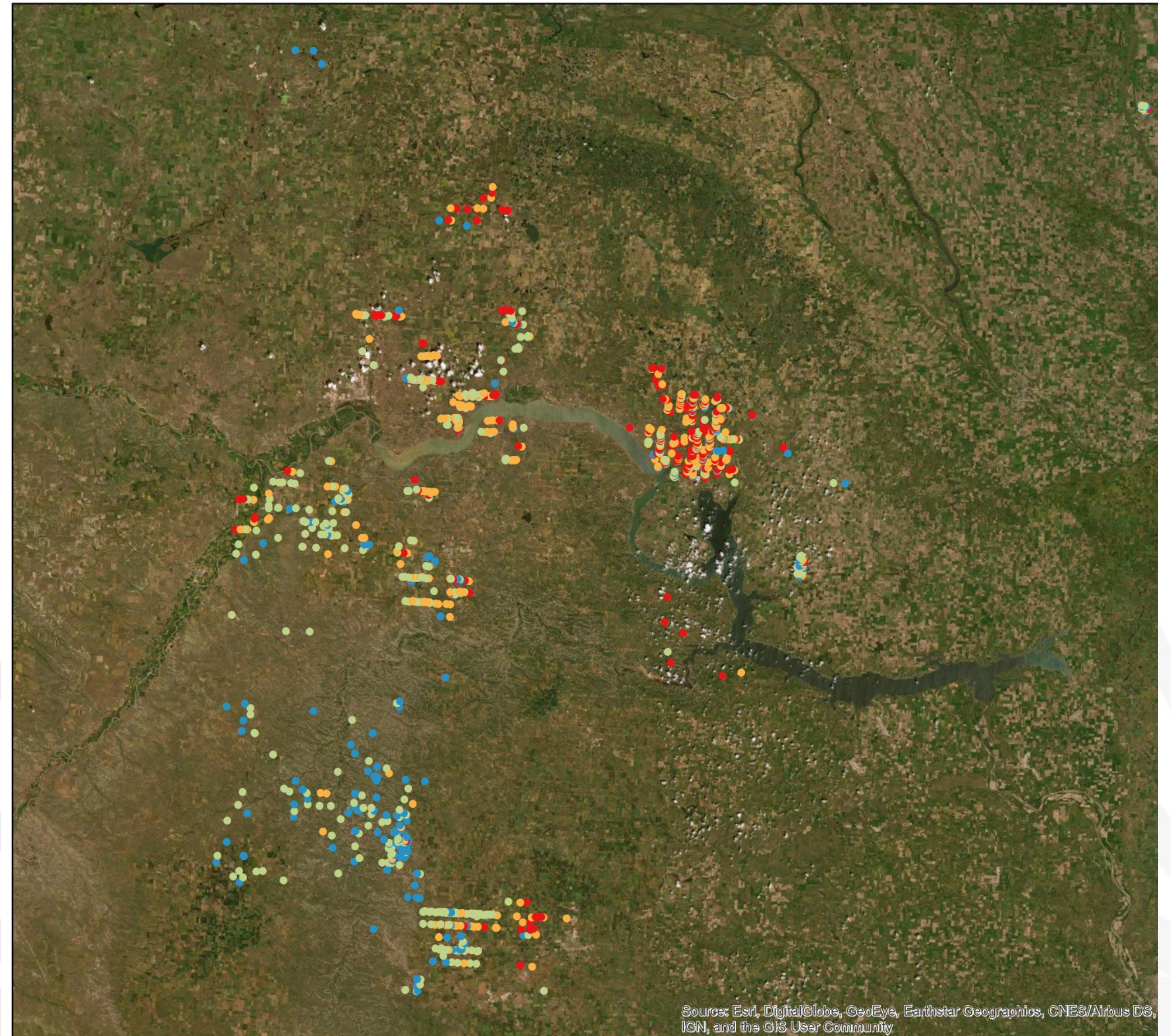
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, IGN, and the GIS User Community

Vegetation Assessment

- Orthomosaic-based vegetation analytic assesses regrowth with high temporal relevance and accuracy.
- Automatically discerns ground cover type and determines total area and percentage of each type.
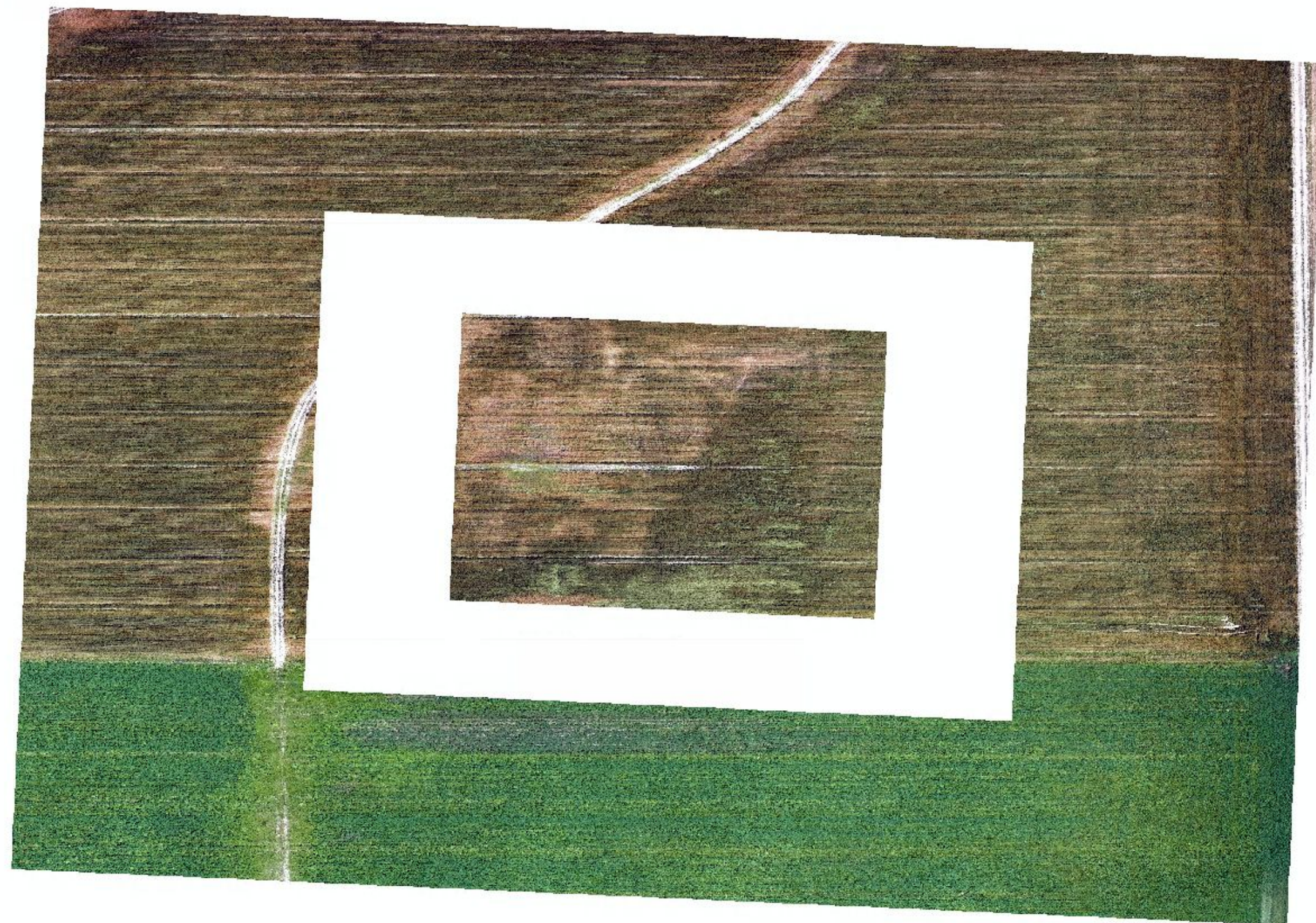
Unaltered orthomosaic
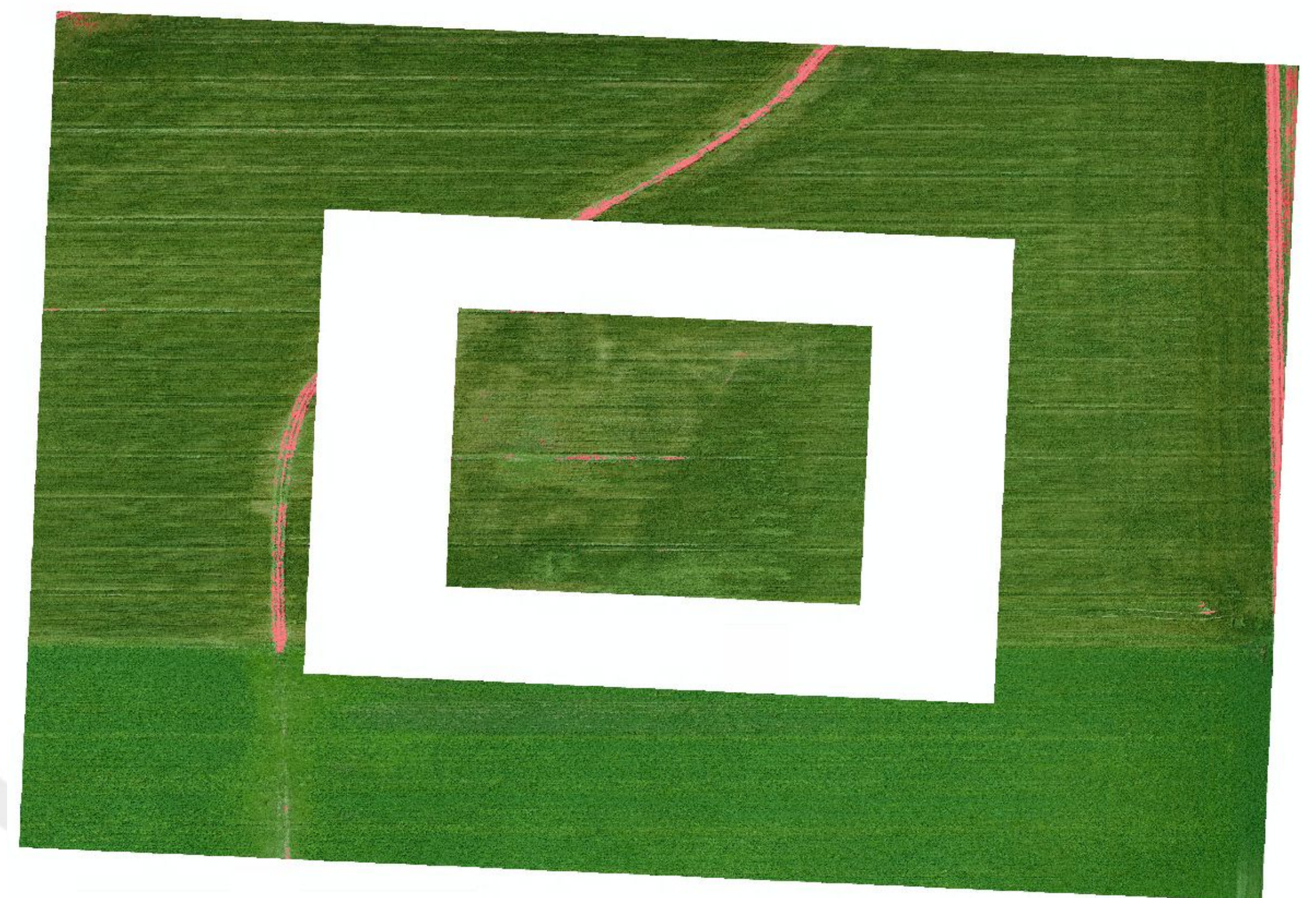
Model output with classified bare soil (red) and vegetation (green)

Vegetation Assessment

Vegetation vigor analysis on a well pad in interim reclamation.

Green indicates healthy vegetation with high levels of chlorophyll, and red indicates vegetation with low levels of chlorophyll.

Quantitative Outputs:
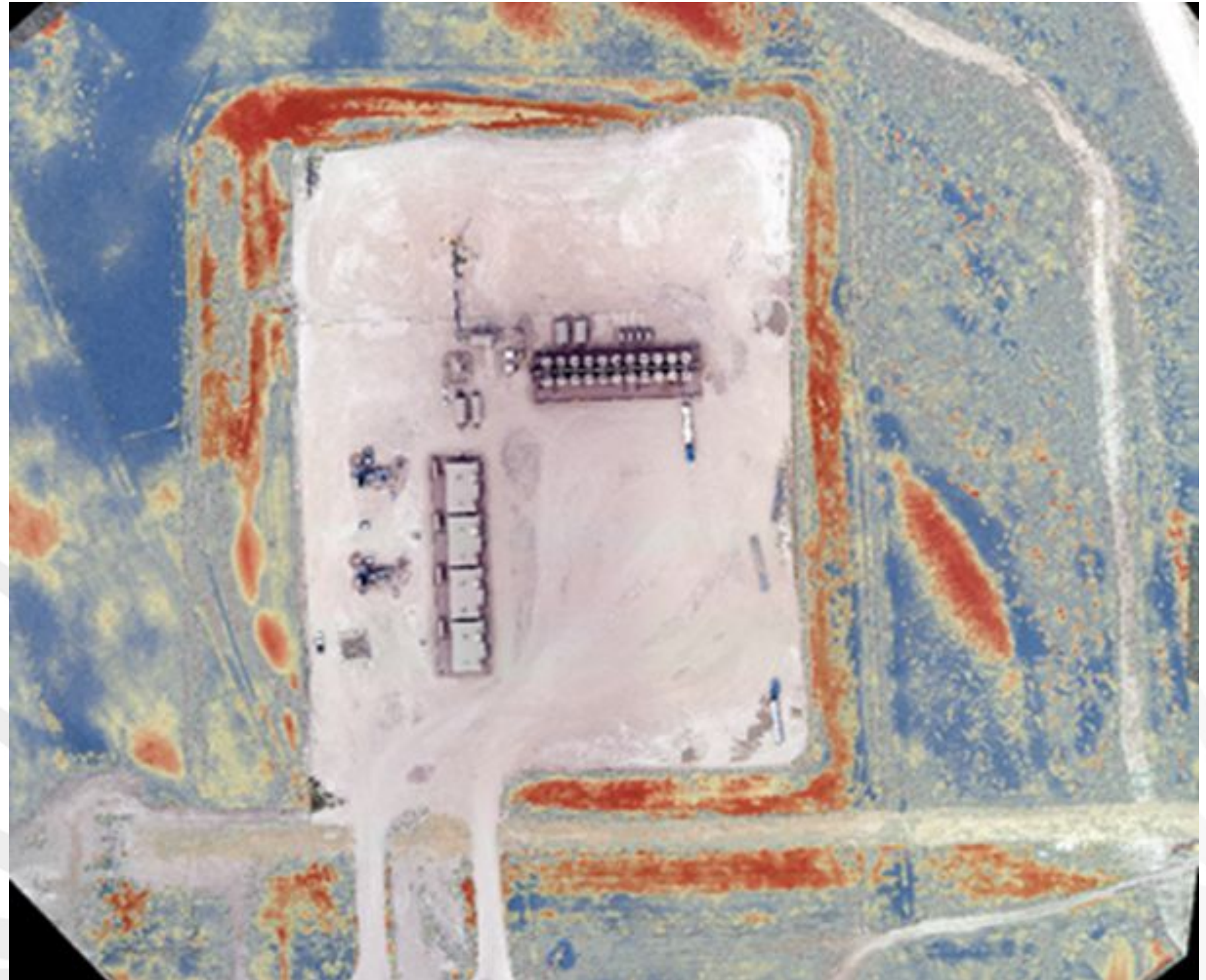- Average percent cover
- Standard deviation
- Continuity index

Vegetation Assessment

Vegetation structure analysis on a well pad in interim reclamation.

Red indicates taller woody vegetation, while blue indicates grass/forb vegetation.

Quantitative Outputs:
- Average vegetation structure
- Standard deviation
- Continuity index

Vegetation Assessment

Model validation compared model outputs against 2,000 sample points and 20 1-meter plots distributed across all 100 Whiting well pad sites.

Vegetation Assessment

Model Accuracy

		Model Classified		
		Bare Soil	Vegetation	Percent Model Accuracy
Human Classified	Bare Soil	273	35	88.6%
	Vegetation	374	673	64.3%
	Percent Model Accuracy	**42.2%**	**95.1%**	

Veg Positive	1047		Soil Positive	308
Veg Negative	308		Soil Negative	1047
Veg True Positive	673		Soil True Positive	273
Veg True Negative	308		Soil True Negative	35
Veg False Positive	35		Soil False Positive	374
Veg False Negative	374		Soil False Negative	35
Accuracy Veg	**72.40%**		**Accuracy Soil**	**77.27%**

Contouring Assessment
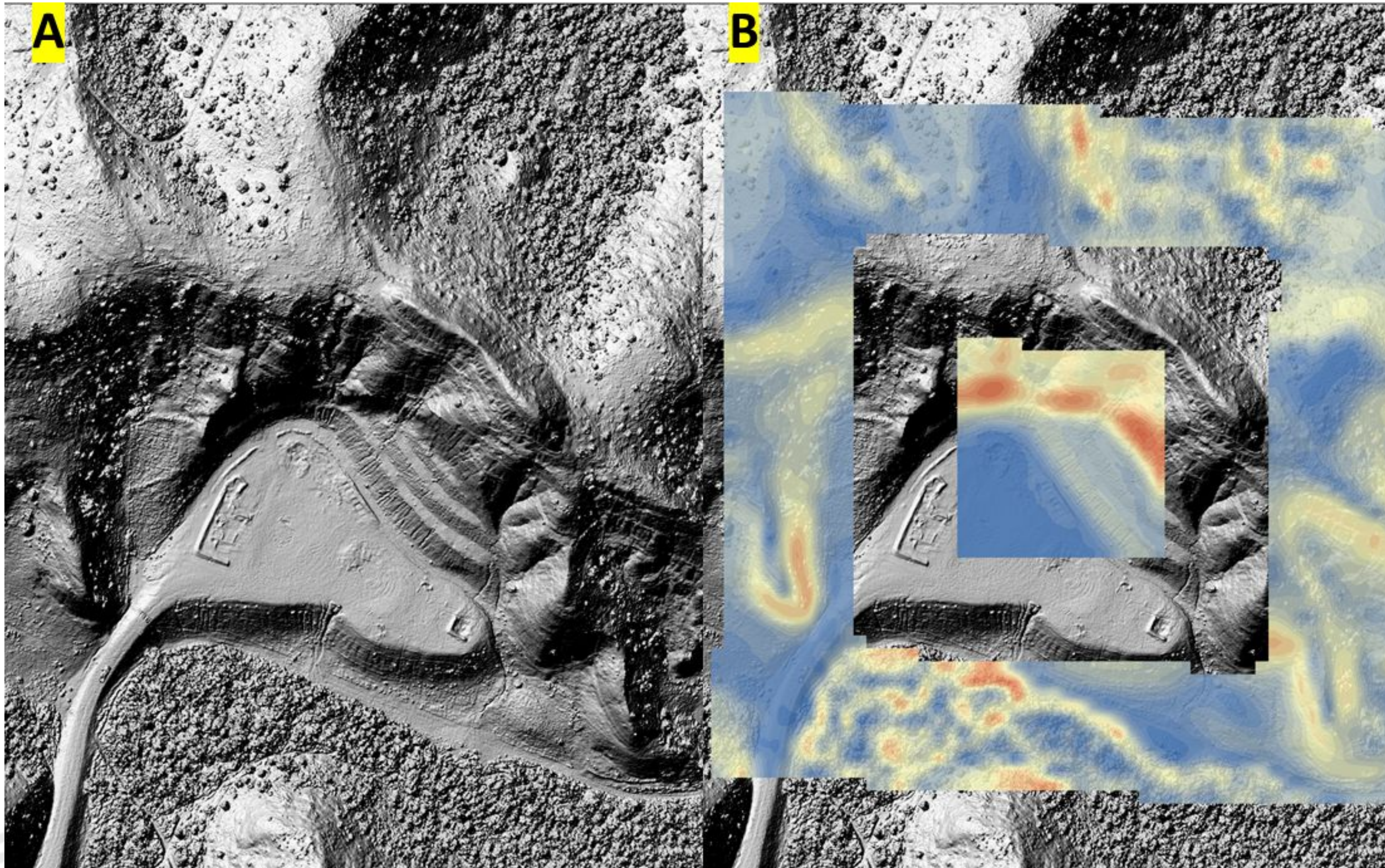
Digital surface model of well pad and reference area (A, left).

Contouring assessment where blue indicates shallow slopes and red indicates steeper slopes (B, right).

Quantitative Outputs:
- Average slope
- Standard deviation
- Continuity index

Infrastructure Assessment

Infrastructure identification on an operating well pad's digital surface model (A, left) and orthomosaic (B, right).

Features exhibited:
  A. Stock tank
  B. Well head
  C. Truck
  D. Misclassification
  E. Pipe

Quantitative Outputs:
  • Number of structures

Infrastructure Assessment
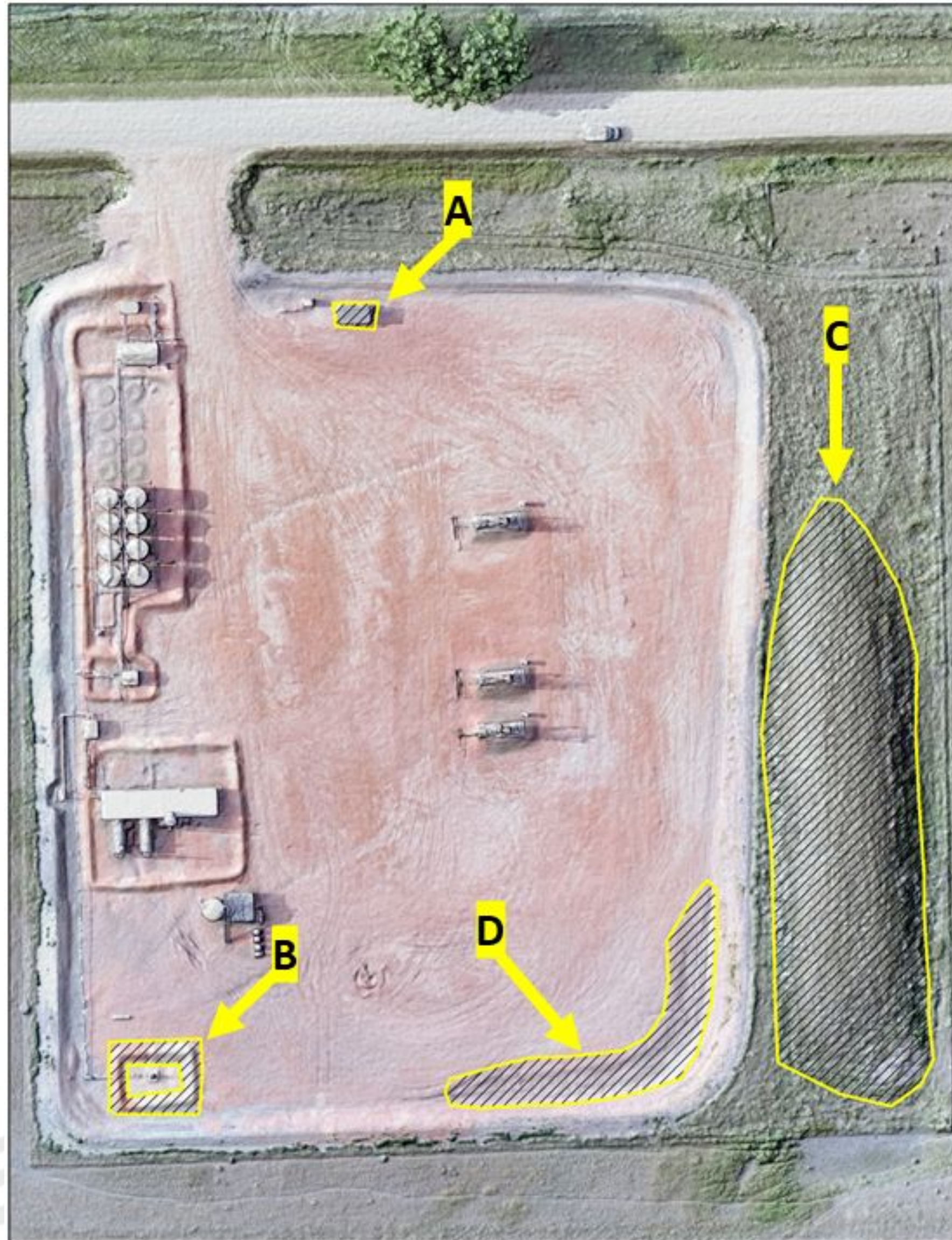
Surface Hydrology Assessment

Orthomosaic (A, left) and surface hydrology assessment (B, right) of an active well pad.

The surface hydrology assessment models ponding and stormwater hazards, with darker blue indicating deeper inundation.

Volumetrics Tool

The volumetrics tool enables the user to delineate the features of interest and calculates the volume in cubic yards for all of the delineated features.
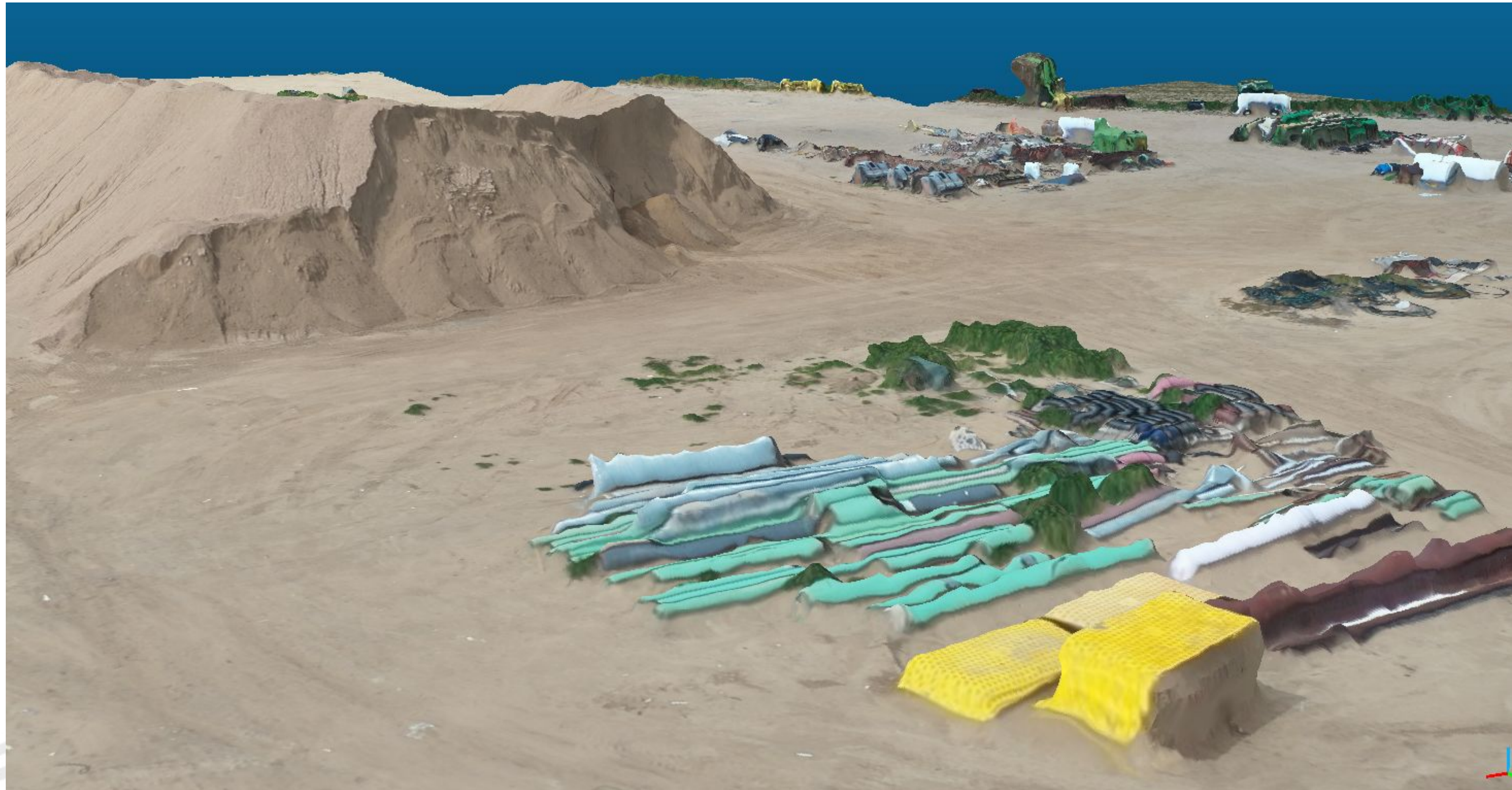
Features exhibited:
- A. Small building at 89.4 cubic yards
- B. Bermed area at 56.3 cubic yards
- C. Topsoil stockpile at 5,116 cubic yards
- D. Concave area that accumulates water at -175 cubic yards

Volumetrics Tool

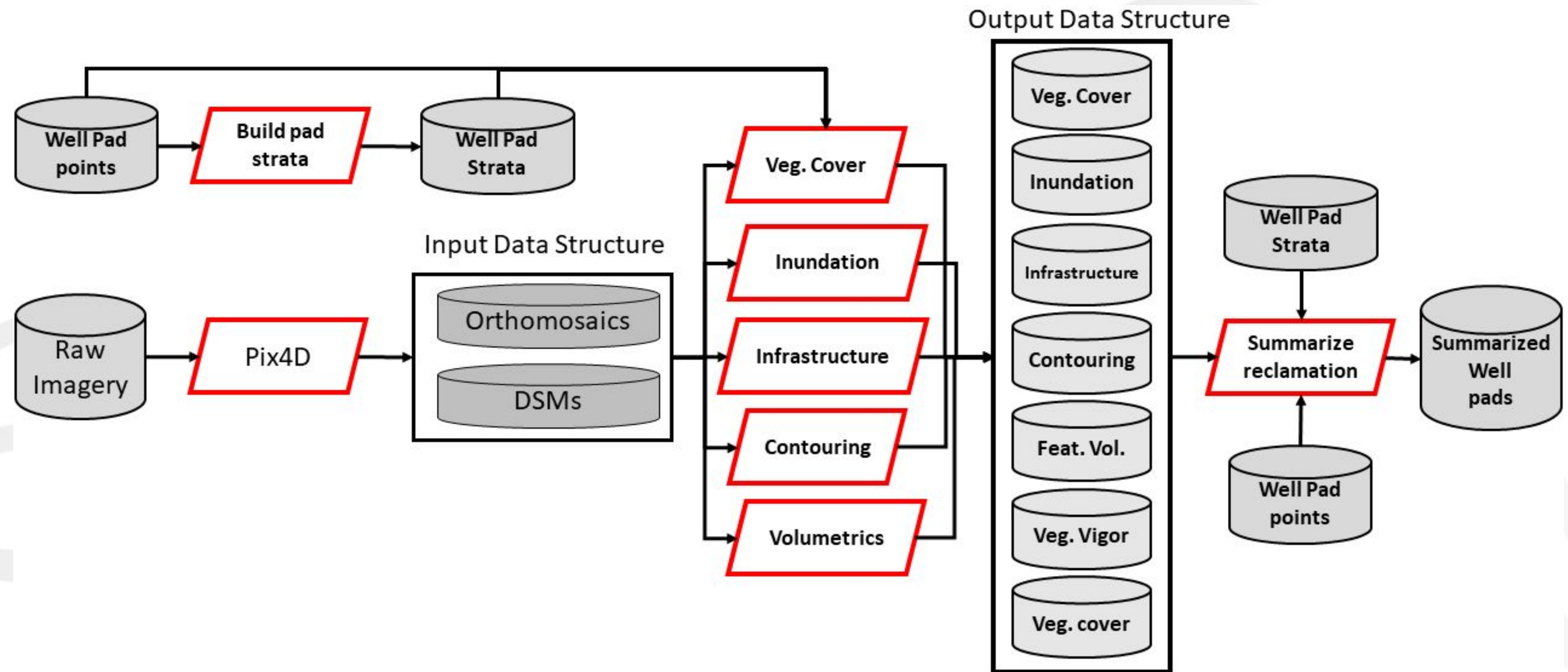3D perspective of an orthomosaic of a stockyard

Model Development & Automation

Automation of the **Reclamation Success Analytic Suite**

Case Study

Orthomosaic (left) and digital surface model (right) of the Christen 24-10 well pad, reference areas, and transects.

Christen 24-10 was in advanced stages of reclamation but had not yet received NDIC certification as of summer 2020.
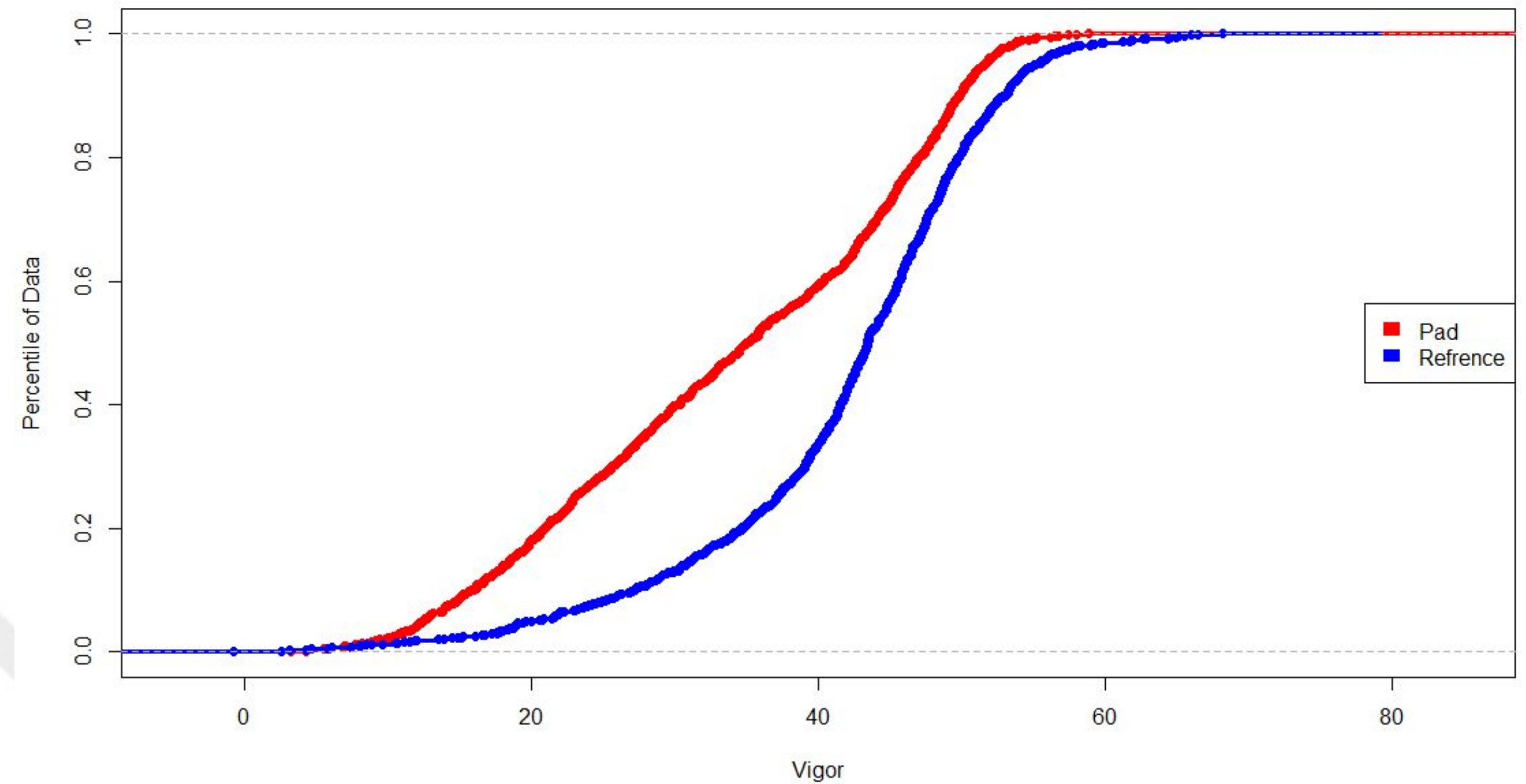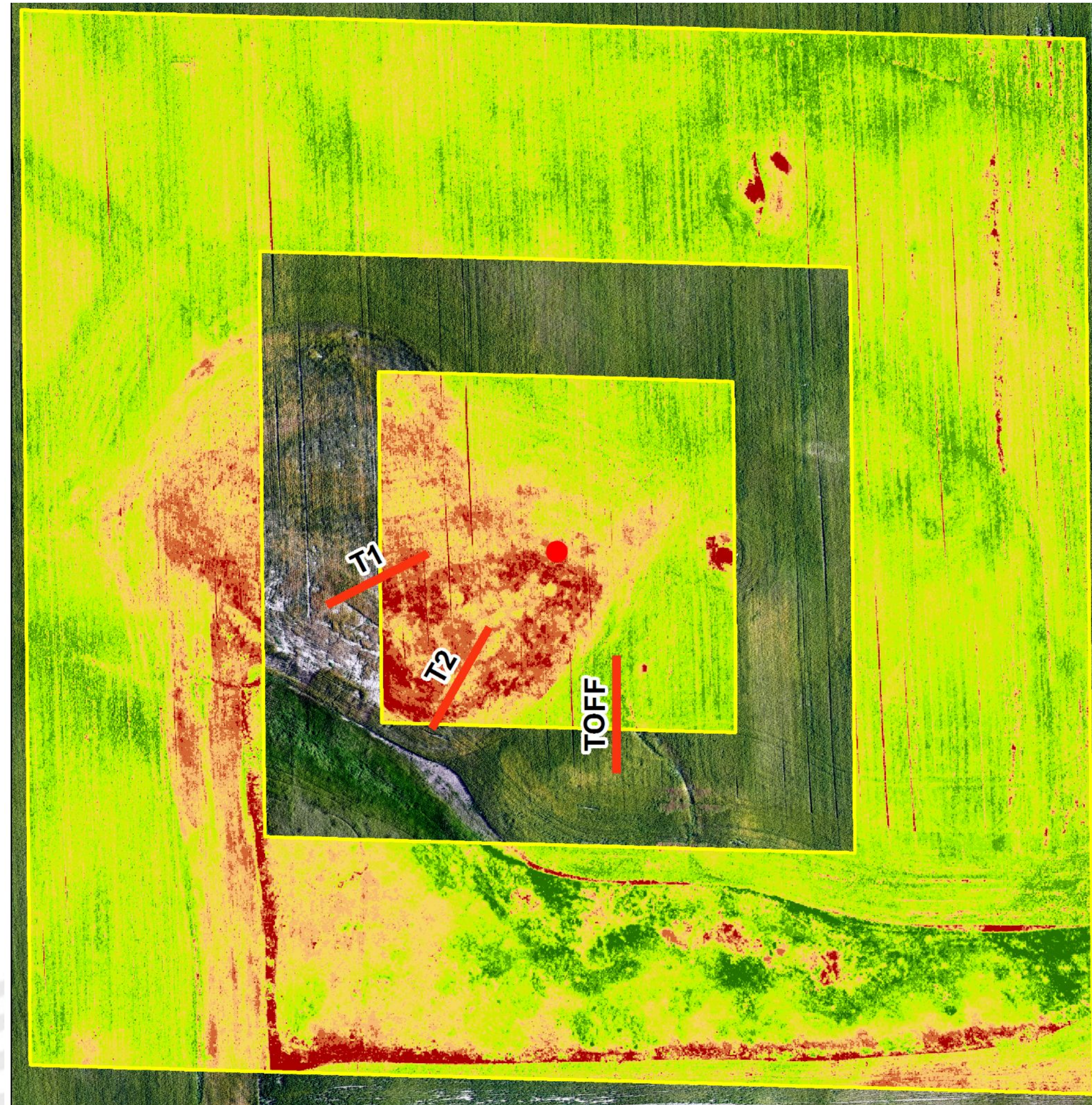
Case Study

Vegetation analytic output, with green indicating vegetation cover greater than 15% and brown indicating bare ground.
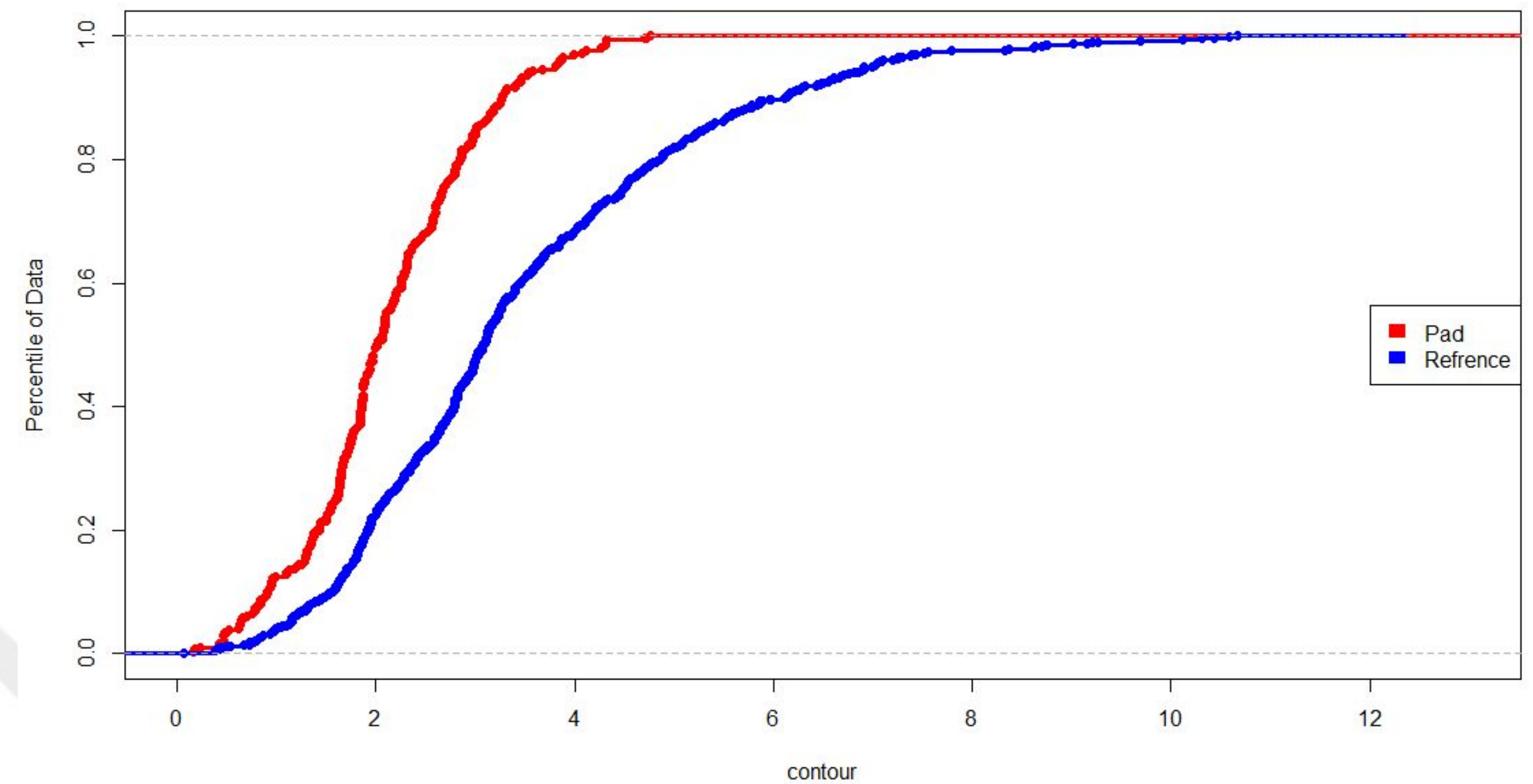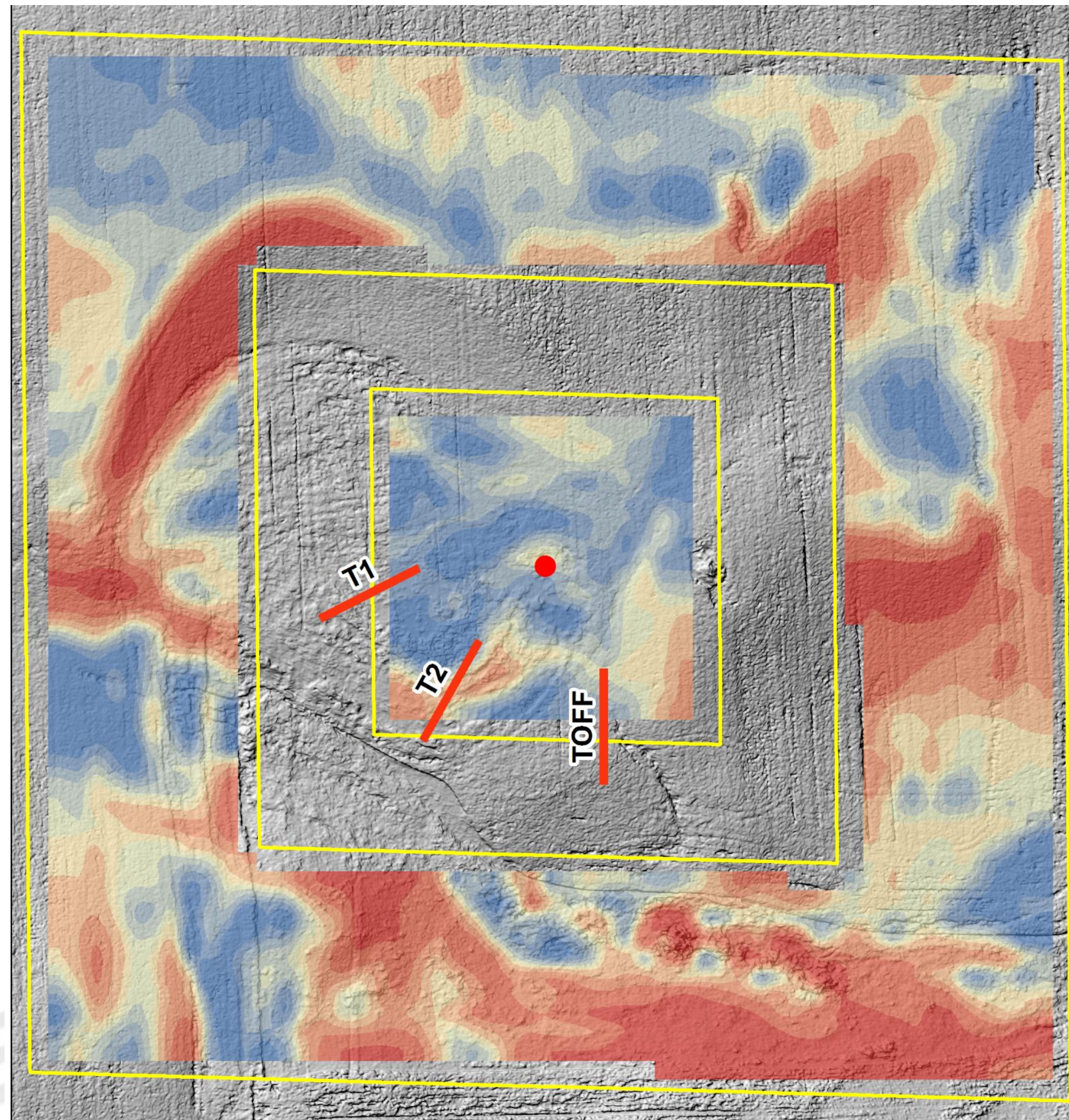
Case Study

Vegetation vigor analytic for the Christen 24-10 well pad and reference area with greener areas indicating high vegetation vigor and dark brown colors being bare soil or senescent vegetation.

Cumulative distribution function (CDF) comparing vegetation vigor between the well pad (red line) and the reference area (blue line).

Case Study

Contouring analytic for the Christen 24-10 well pad and reference area with blue indicating low-gradient slope and red indicating high-gradient slope.

Cumulative Distribution Function (CDF) comparing contouring metrics between the Christen 24-10 pad (red line) and reference area (blue line).

Case Study

Reclamation Success Assessment metrics for the Christen 24-10 well pad.

Pad Veg. Cover (%)	Ref. (Off-Pad) Veg. Cover (%)	Pad Contouring Avg/STD	Ref. (Off-Pad) Contouring Avg/STD	Inundation	Infrastructure	CI Veg. Vigor	CI Veg. Structure	CI Contouring
77.4	95.2	2.5/0.9	3.4/1.8	0	0	.29	.15	.26

Field-based vegetation transects performed by Duraroot for the Christen 24-10 well pad.

	Pad Transect 1	Pad Transect 2	Off-Pad Transect
Grass (%)	80	78	85
Forb (%)	2	3	5
Shrub (%)	0	0	0
Bare Ground (%)	18	19	10

Case Study

The automated **Reclamation Success Assessment** revealed these conditions for Christen 24-10 well pad:

- **Well pad vegetation cover has been returned to at least 80%** of the site's original conditions.

- **Well pad vegetation vigor differs by ~30%** from the site's original conditions.

- **Well pad vegetation structure differs by ~15%** from the site's original conditions.

- **Well pad contouring differs by ~25%** from the site's original conditions.

- The well pad has **no problematic inundation** zones.

- The well pad has **no remaining infrastructure**.

Cost Analysis

	Manual Field Inspection	UAV Data Collection & Processing	Manned Aircraft Data Collection & Processing	Reclamation Success Analytics
Cost Per Pad - Whiting	$142	$806	$217*	**$50**
Cost Per Pad - NDIC	$292			
Mobilization Rate	N/A	$20,000	$15,000	N/A

*Assumes flying 50 square miles with a density of 100 well pads at a cost of $435 per square mile, or $0.68 per acre.

Conclusions

- **Proven feasibility** of unbiased, accurate, automated, remote reclamation assessment.

- Reclamation Analytics Suite is **validated, automated, and fully operational**.

- Quantitative and geospatial data enable consistent analysis of well pad **change through time**.

- Outputs enable identification and prioritization of well pad conditions, optimizing site visits and **improving economic efficiencies for industry and agencies**.

- Cost-sharing of data capture across large geography would enable **economies of scale**.

- Implementation would benefit from a standard set of metrics and measurable objectives for **defining reclamation success**.

THANK YOU

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