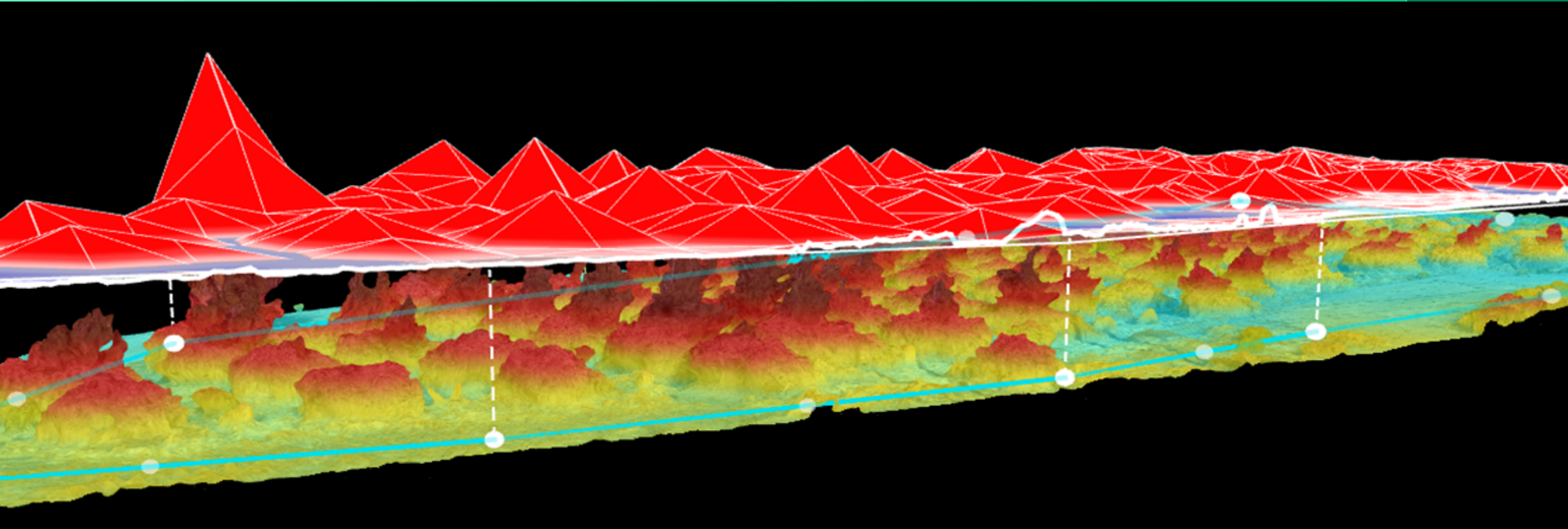


Drone Applications to Optimize Operational success of an Engineered Phytoremediation System

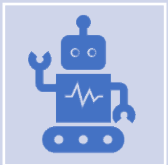


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AGENDA



Background: Drone Applications and Remediation Performance Optimization



Activities/Approach: Drone Applications Supporting Phyto-Remediation Performance Optimization



Lessons Learned: Adaptive Design and Operational Adjustments

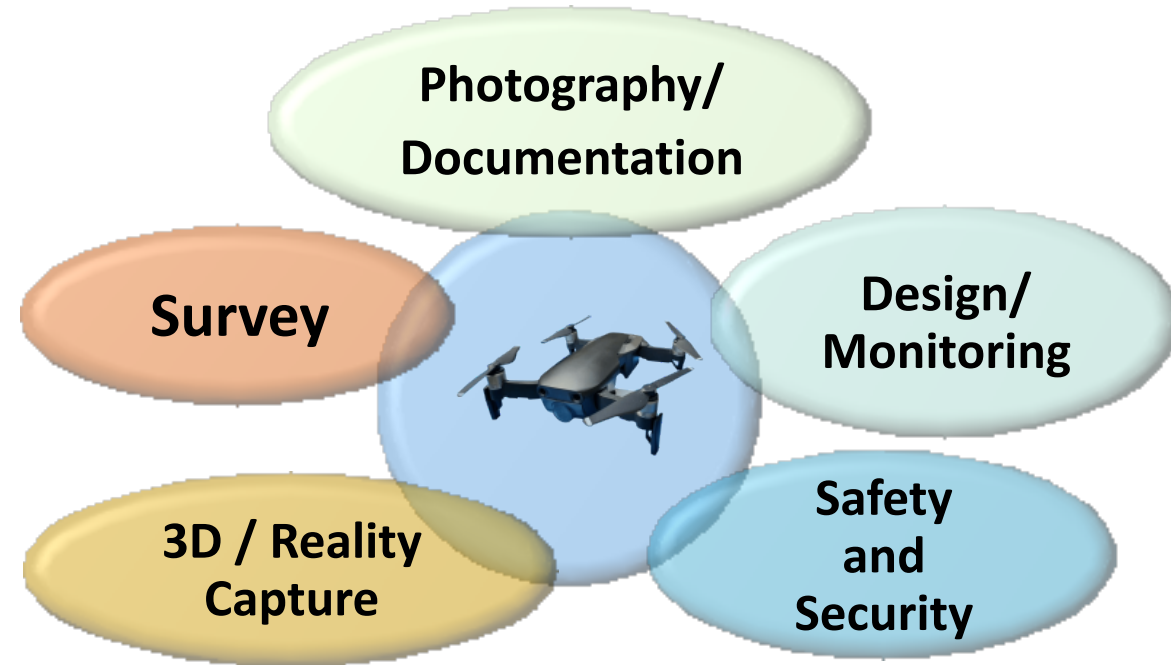


Project Background: Drone Applications and Remediation Performance Optimization



Why Use Drones?

- **Survey:** Capture topography, volumes, slopes, subsidence rates; multi-spectral capture/analysis for agriculture; orthorectified (overhead) imagery
- **3D:** Laser or photogrammetry: 3D terrain/elevation surfaces, contours, models, point clouds
- **Safety/Security:** Views from where a person can't safely go; perimeter patrols (+ thermal); one pilot vs. multiple staff on site
- **Design/Monitoring:** Accurate 3D models allow overlay of designs, surveys, monitor volume/topographic changes during construction
- **Photography/Documentation:** Stills, video, panoramas; not obtainable any other way; high-quality cameras (raw image capture)



How Drone Image Capture Works - Typical Deliverables and Workflow:

1. Photos/video/panoramas

- Single photos/videos
- Stitched panoramas
- 360° Panoramas

- Position drone
- Capture many images, video
- Process imagery
- Produce outputs



2. High resolution orthorectified imagery

- Corrected using ground control survey
- Measure accurate distances & areas

3. 3D Model and resulting derivatives

- 3D object model (.OBJ)
- Contours (CAD/DXF, GIS/shapefiles)
- DEM/DTM (GeoTIFF)

- Fly special patterns
- Integrate (stitch) images
- Export deliverables
- Conduct analysis to meet DQO's (data reduction/evaluation)
- **Actionable data**



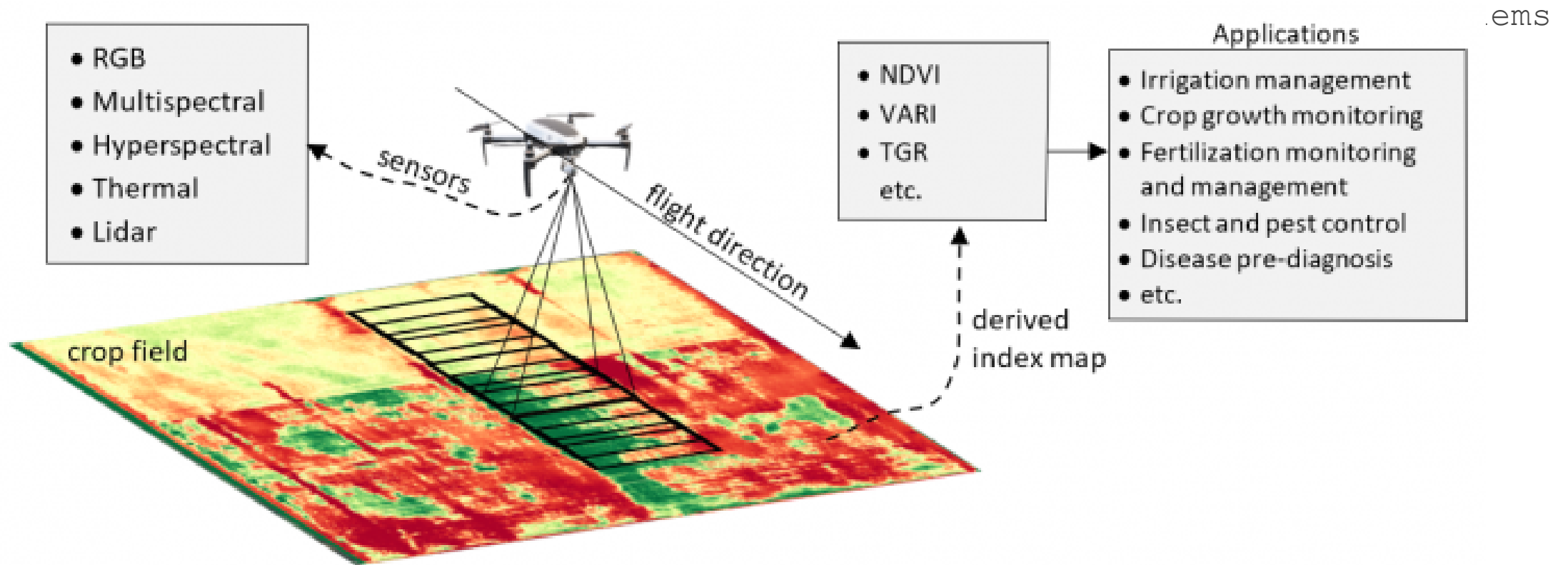
3D Drone Landscape Model derived from captured images



- Zoom in/view assess canopy areas that can't be seen from ground
- Keeps workers out of thick vegetation and "out of

Adapting the “Smart Agriculture” Use Case

- Drones fulfill a critical role in “Smart Agriculture,” which requires accurate and advanced data acquisition, modelling and management
- Promotes efficient use of fertilizer, water and pesticides to optimize crop yield—down to the row and plant
- Advanced warning of plant stress from drought, harmful insect invasion, disease, etc.



Drone Applications Supporting Phyto-Remediation Performance Optimization



Design Objectives of Phyto-Remediation System

- Phytoremediation System (PRS) designed to protect surface waters
- 1-acre Target Treatment Zone identified where maximum contaminant flux is located
- Focus on Hydraulic Control (Flatten hydraulic gradient/reduce mass flux)
- Design objective:
 - 9-12 gallons per planting/day target water consumption to sufficiently flatten gradient
- Three Phases of PRS
 - Pilot study
 - Initial Planting and grow-in period
 - Plant maturity and full-scale sustainable operations (focus of this presentation)
- Meet performance objectives

PRS Operational Features

- Grow-in Period (~ First 5 years):
 - Fast growth, intensive monitoring (Water levels, leaf tissue analysis, soil nutrient analysis, biomass, plant mortality , etc.)
 - For vegetation assessment, field crews conduct systematic random sampling (10%) throughout the PRS.
 - Labor intensive vegetation assessment, manually collecting data on plant growth, condition (vigor), biomass
 - Some re-planting conducted
 - Full Scale Operations (Recent 5 years):
 - Slower growth,
 - Aggressive re-planting required
 - Monitoring program conducted at relaxed frequency but still critical to PRS success
 - Plant mix/population composition shifts to adapt to site conditions
-

Operational Challenges

- As plants mature, density increases, access to plants becomes restricted, more labor intensive
- Thicker undergrowth and dry branches multiply worker hazards
- Harsh growing conditions, pines did poorly (high mortality) in high seasonal groundwater.
- Plant maturity delayed due to site conditions, limited fertilization, and lack of permanent irrigation.
- Drone-based assessment proposed to replace conventional ground-based



Approach/Activities Summary

- PRS drone imagery outcome tested in parallel vs. traditional manual methods.
- Good agreement, incorporated drones into operational and performance evaluations.
- Entire population of plants on site were assessed (as opposed to manual methods using random samples from representative locations).
- Commercial drone used with visible spectra (RBG) and VARI health index
- Overhead (~ 25 ft altitude) and oblique imagery enabled inspection of various 3-D features (broken limbs, mortality, insect damage, etc.) that can't be seen from the ground
- Drone technology offers excellent consistency and detail, safer operations and lower costs

Phytoremediation Grow-in Phase- Initial Planting and Grow-in 2013-2018



Initial 2013 Planting:

- 271 Afghan pines (~4 ft)
- 542 saltbushes
- Native Plant species selected for high salt and pH tolerance, adaptable to drought conditions

5 ft.

April 2016 Typical Pine
Rapid Grow-in



Aerial Circa



By 2023-

- Grow-in phase complete in some areas, nearly complete in others
- However, higher density creates obstacles to entry, inspection and

October 24, 2023

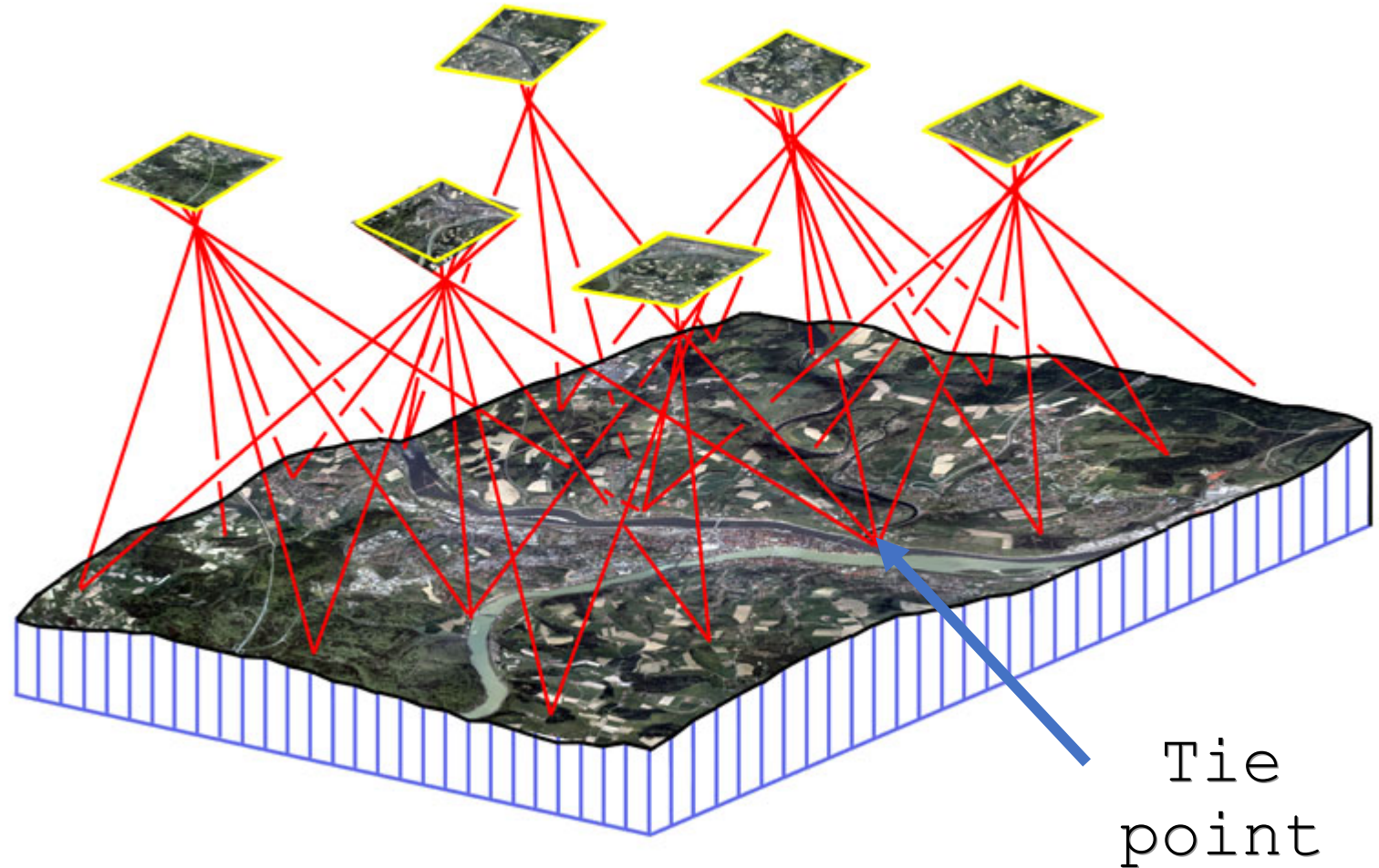
data collection



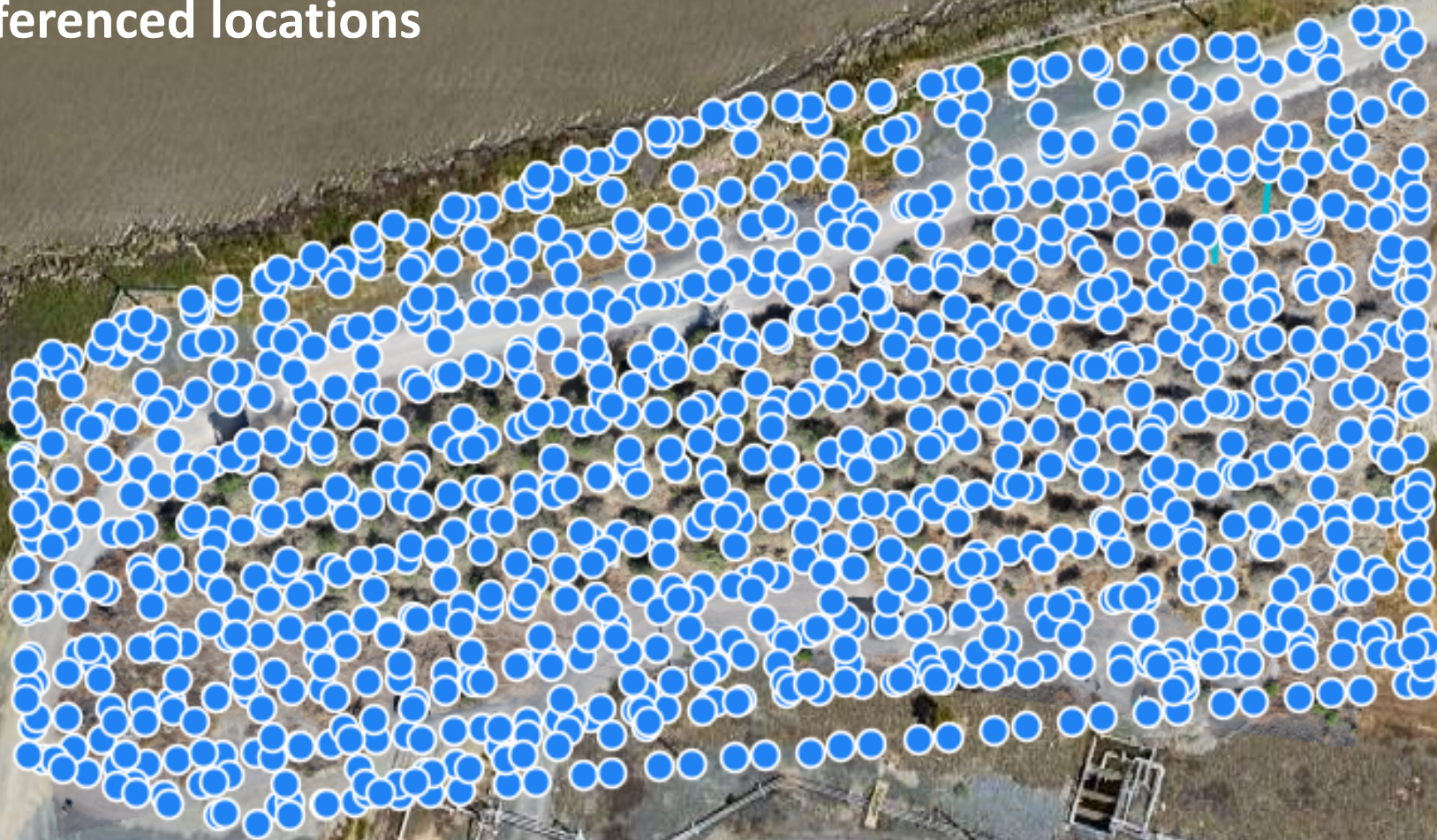
Two person field crew attempting to enter thick undergrowth to manually obtain measurements

Drone-based Vegetation Assessment Solutions

- Photogrammetry employed to create 2D & 3D products from raw drone imagery
- **Aerotriangulation** uses overlapping photos and allows scaled accurate measurements



**Overflight – Approx. 1,000 overlapping photos-
as geo-referenced locations**

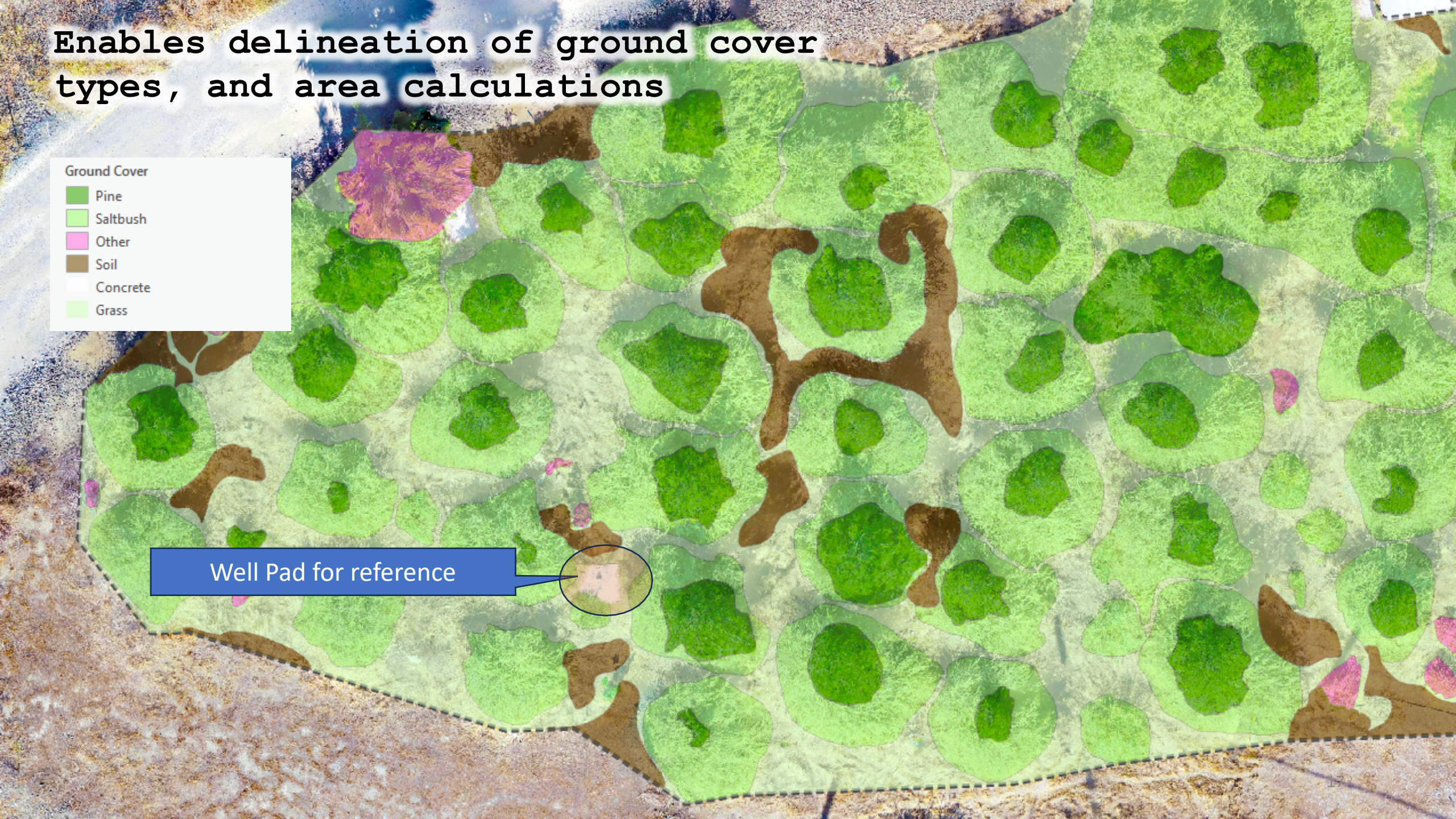


Enables delineation of ground cover types, and area calculations

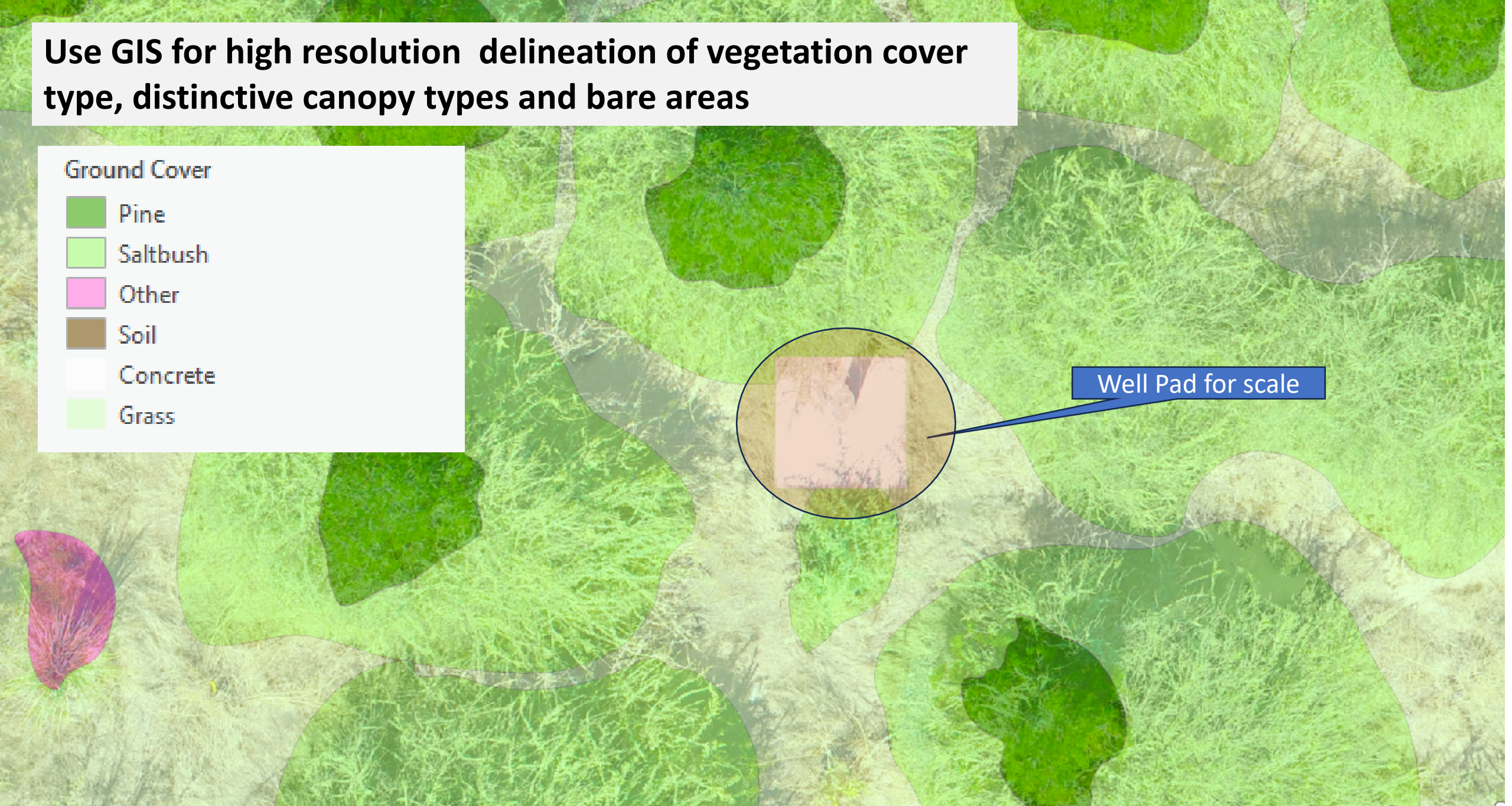
Ground Cover

- Pine
- Saltbush
- Other
- Soil
- Concrete
- Grass

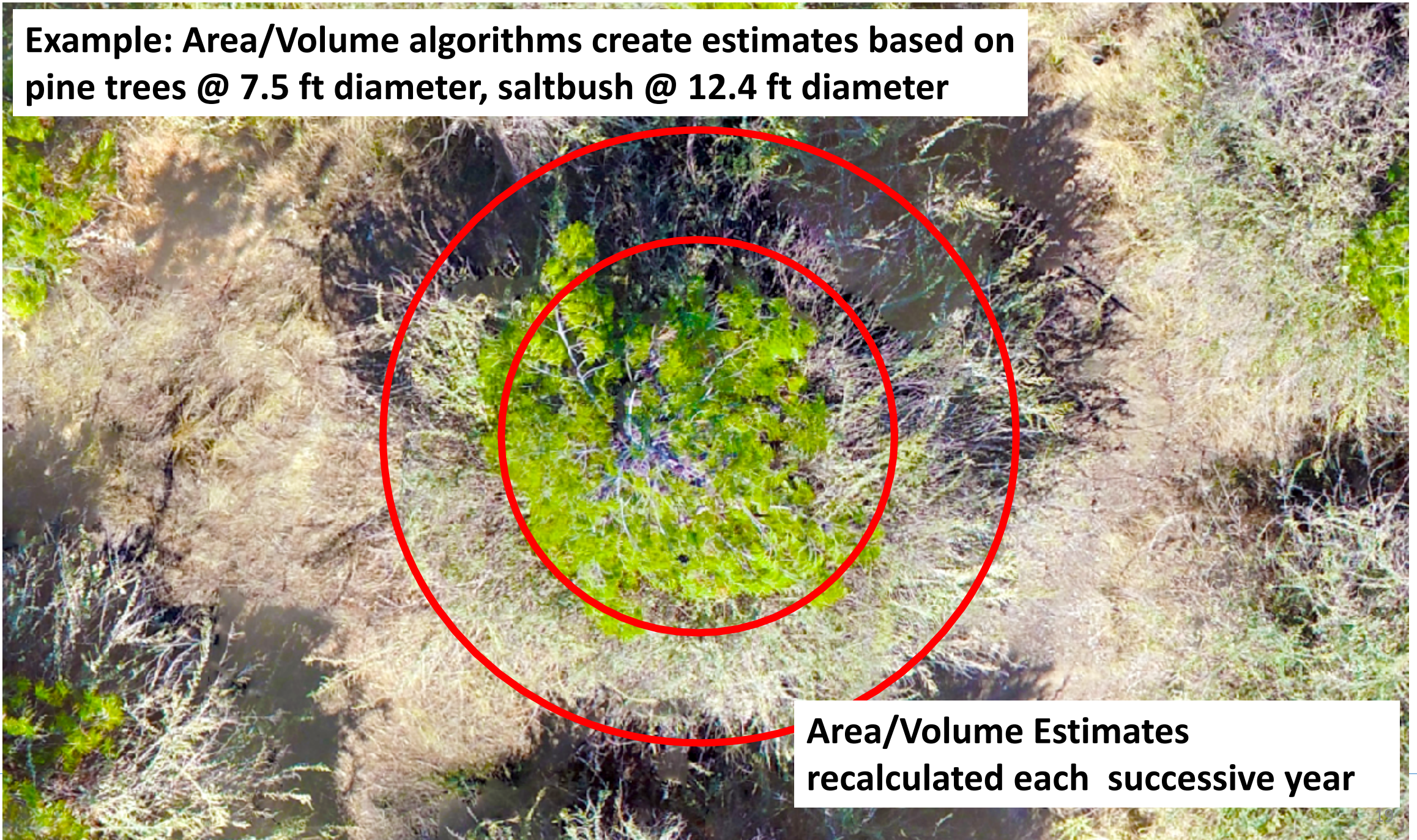
Well Pad for reference



Use GIS for high resolution delineation of vegetation cover type, distinctive canopy types and bare areas

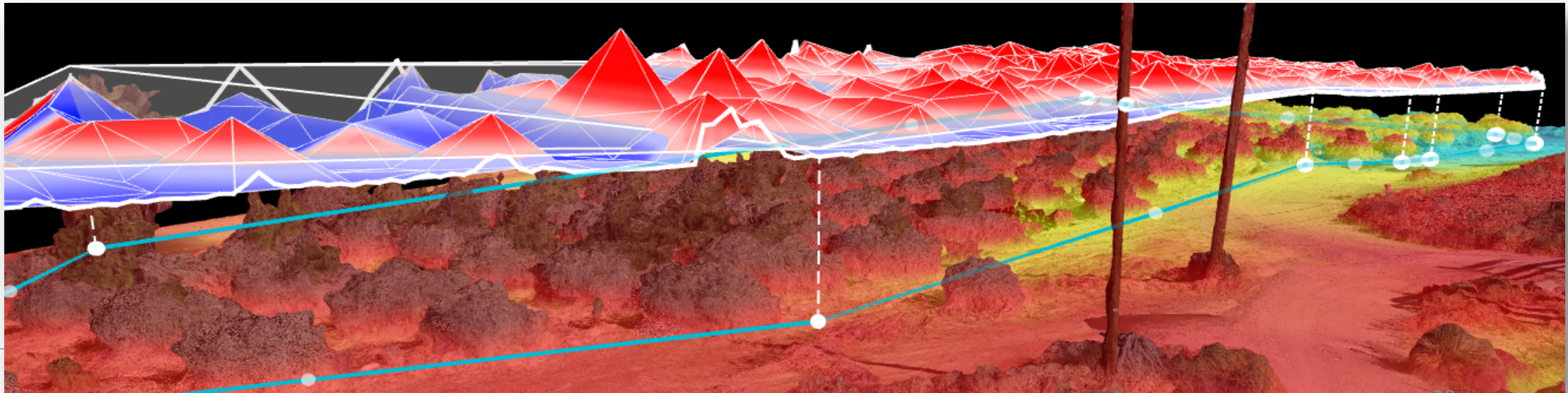
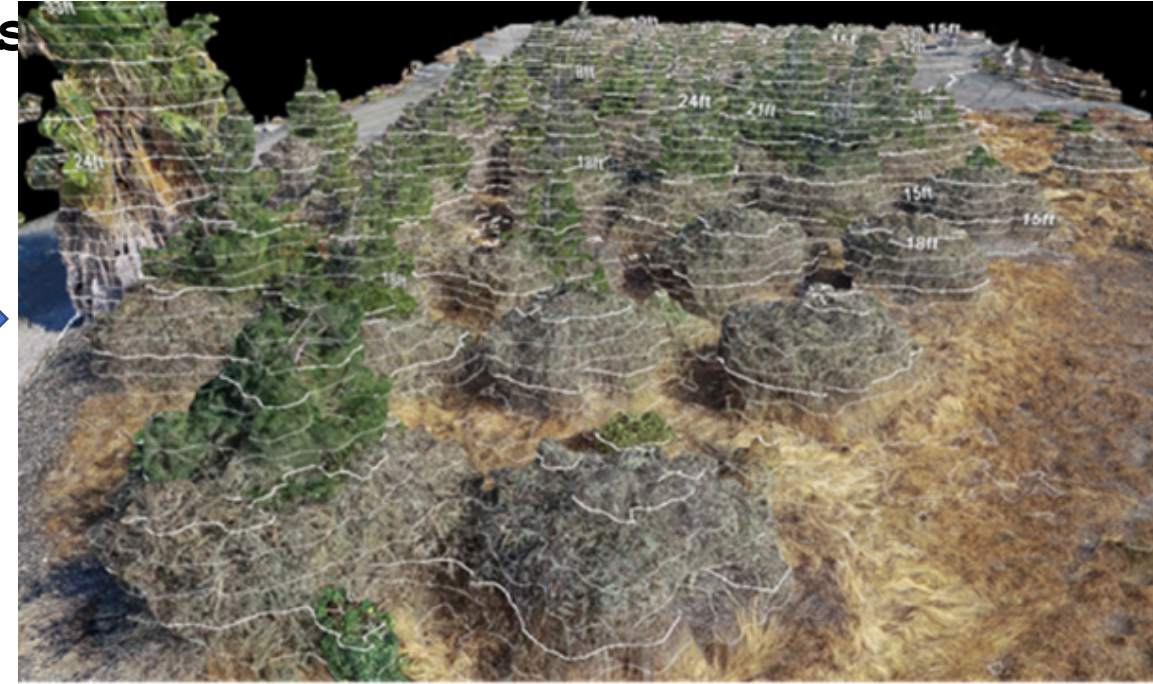
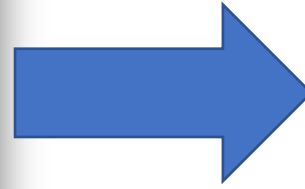
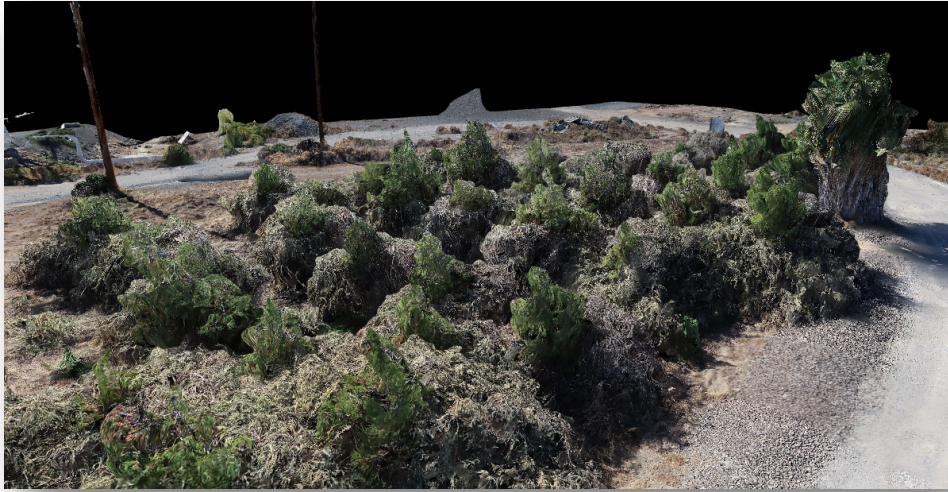


**Example: Area/Volume algorithms create estimates based on
pine trees @ 7.5 ft diameter, saltbush @ 12.4 ft diameter**

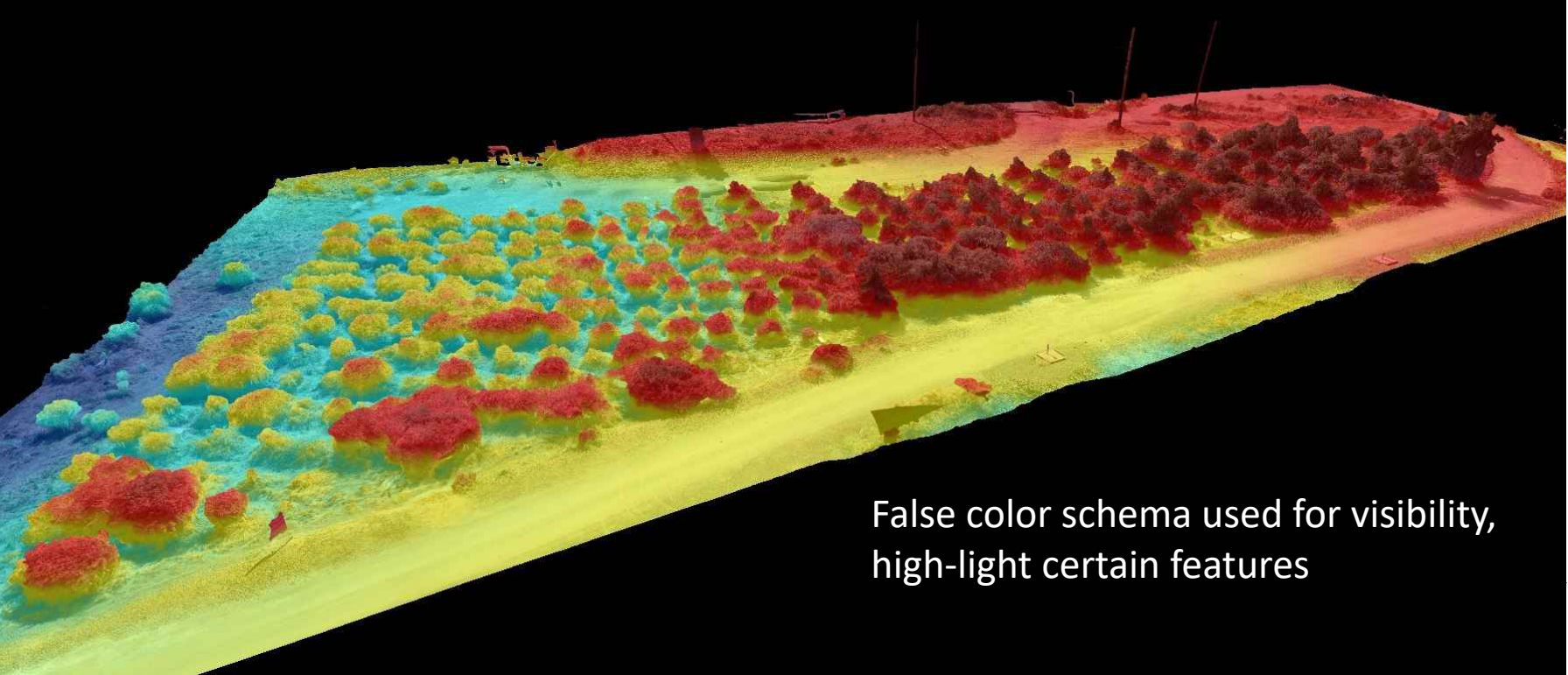
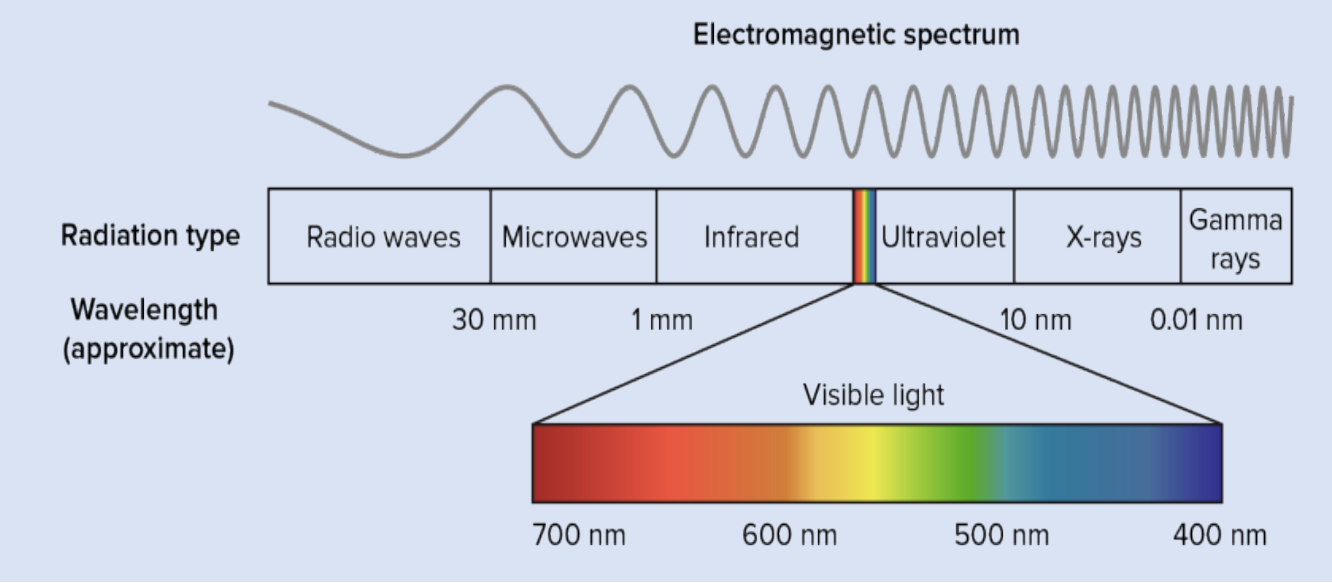


**Area/Volume Estimates
recalculated each successive year**

Generated 3D model to obtain accurate estimates of biomass contours, volume and vigor changes

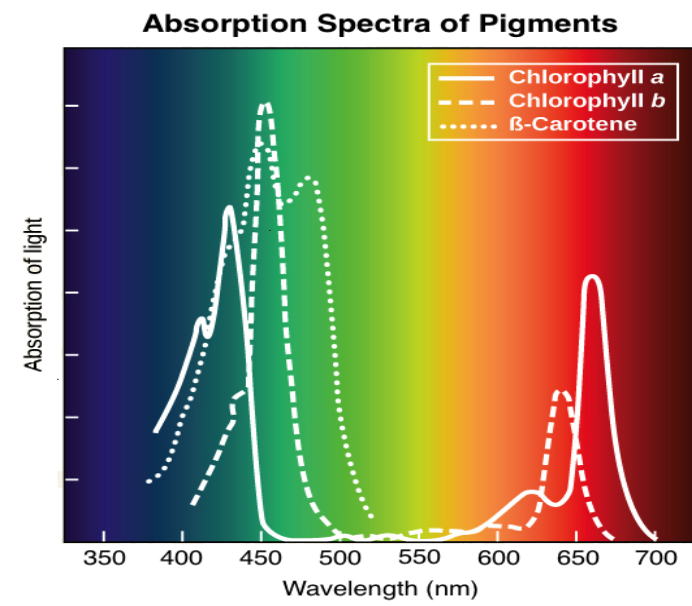


100% of vegetation sampled vs. random subsamples



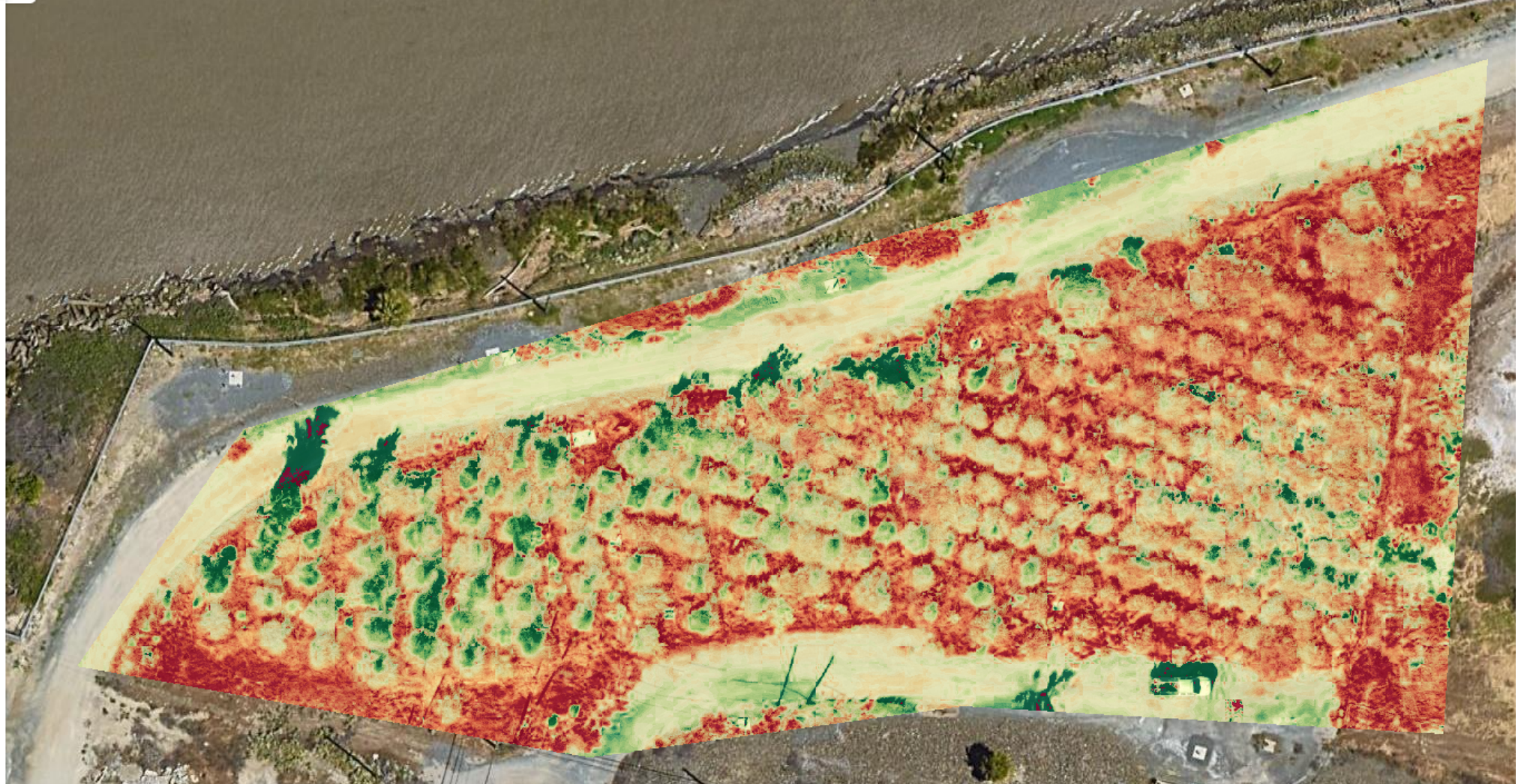
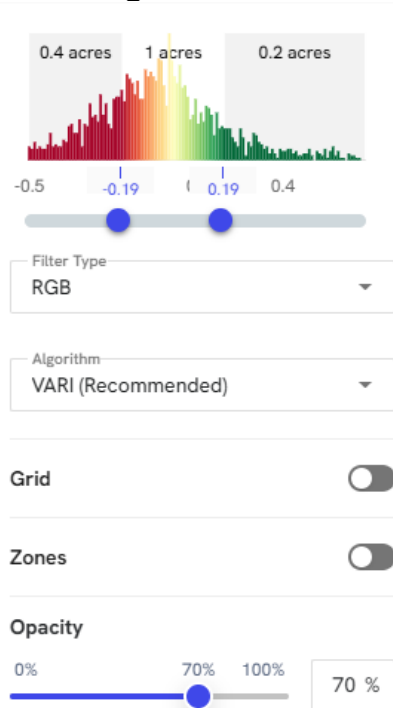
False color schema used for visibility, high-light certain features

Using Near Infrared Spectra (NIR) allows capture of key chlorophyll components



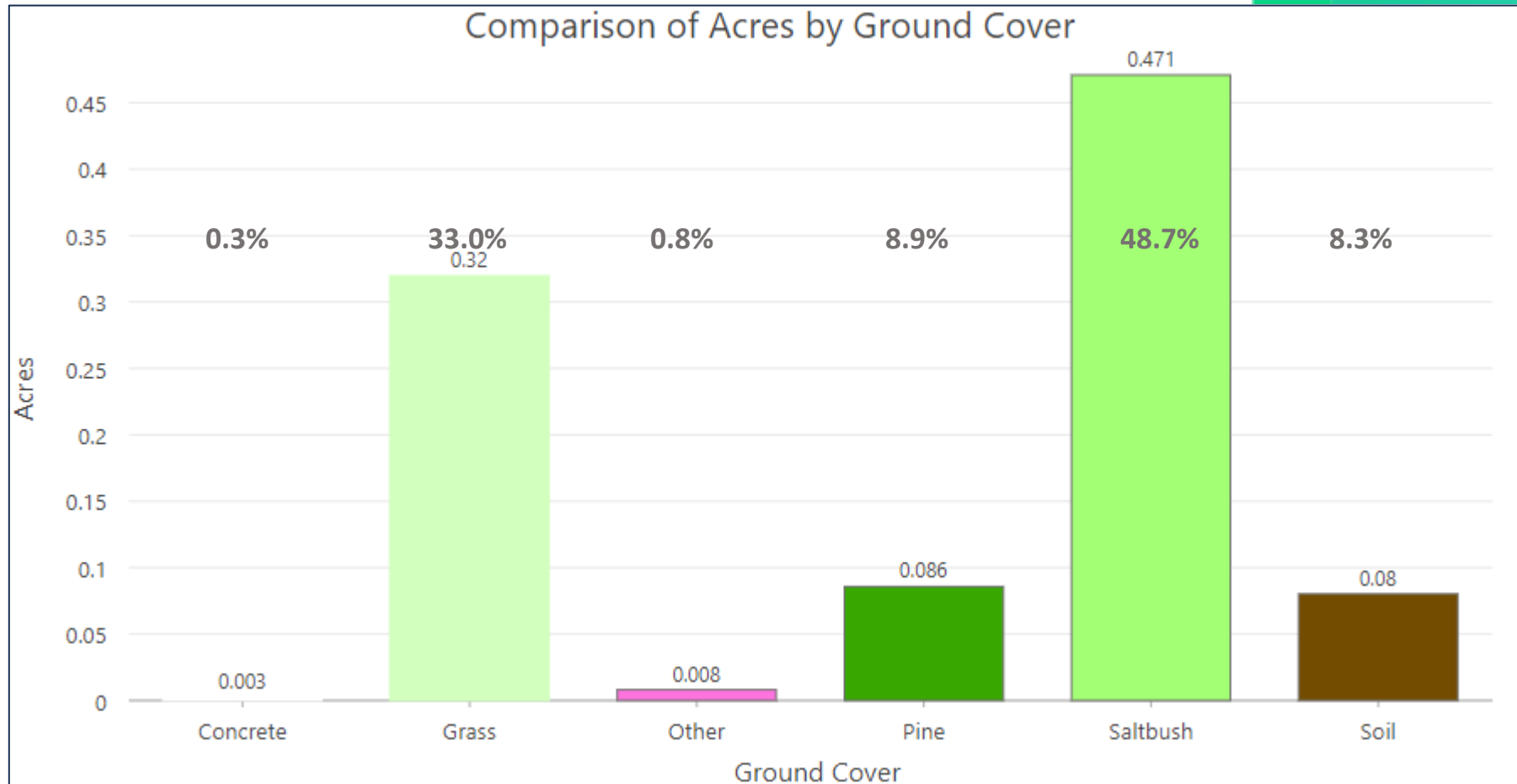
Vegetation Health Indices:

- Visible Atmospherically Resistant Index (VARI) – uses visible spectrum only (this study)
- Normalized Difference Vegetation Index (NDVI) – uses near infrared spectra (future study) to provide direct Chlorophyll index



Key Results:

- Saltbush most successful coverage/impactful on water balance
- PRS plant composition shifted away from pines to grasses



Key 5-year Observations:

- Pine vigor declined but stable, pines not viable in east area
- Saltbush vigor good, slight increase

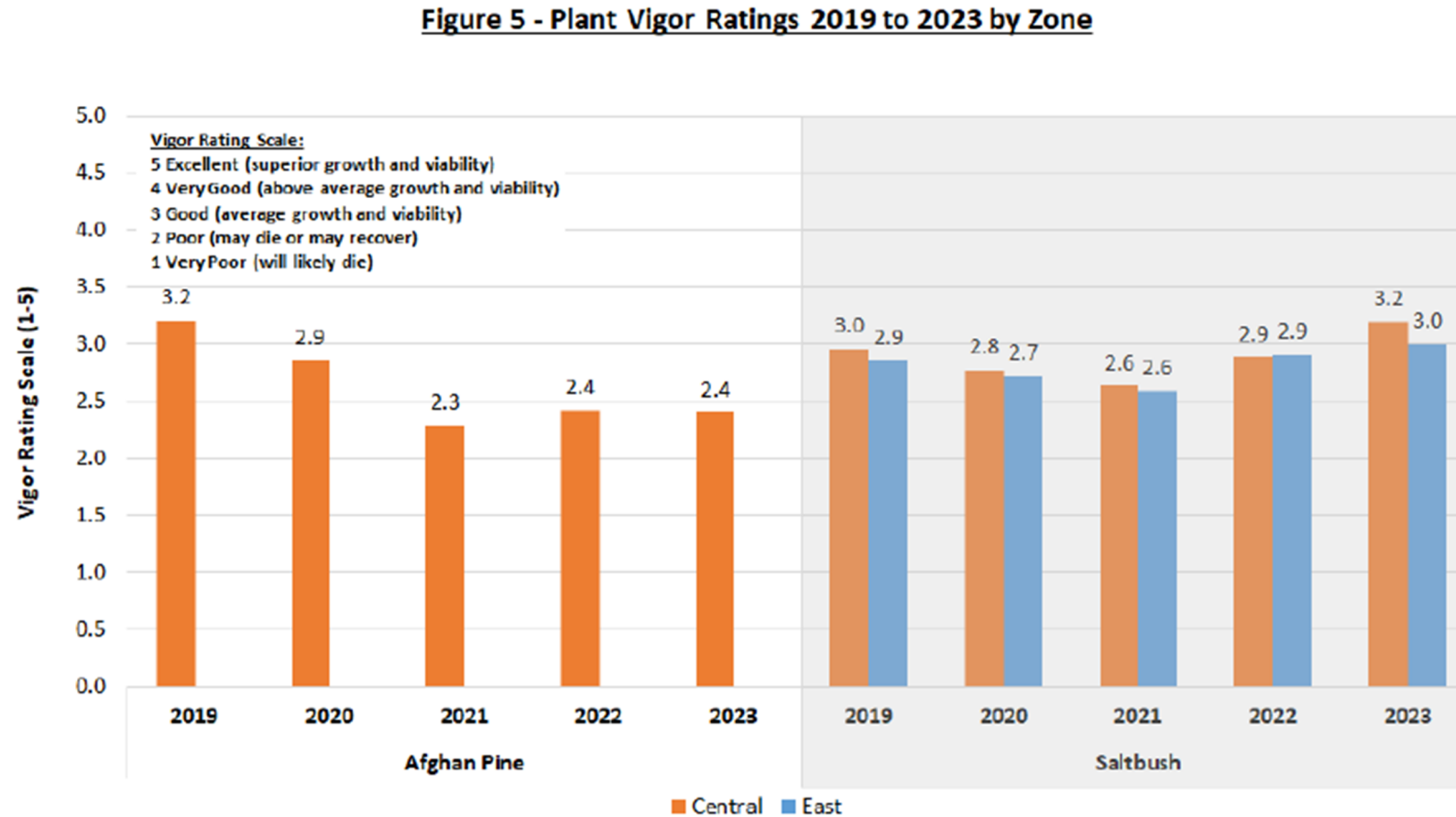
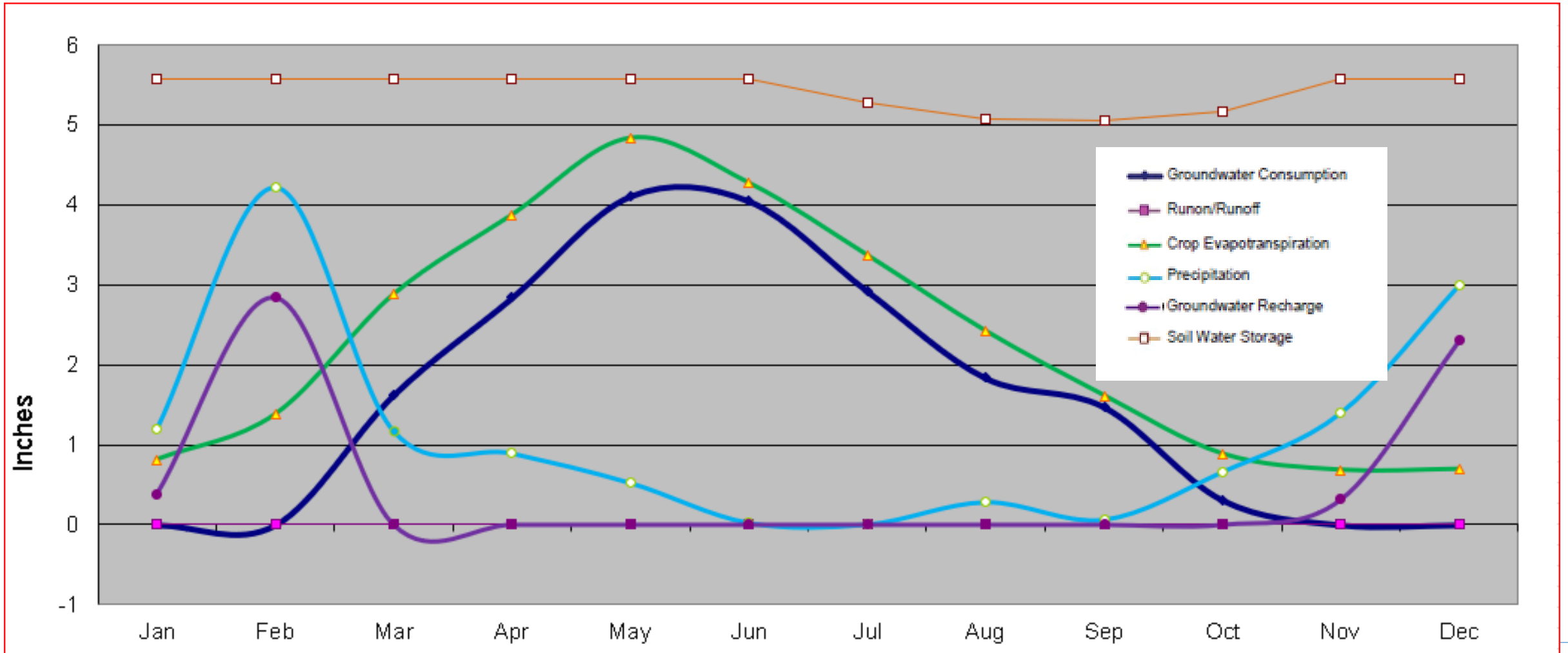


FIGURE 5
PLANT VIGOR RATINGS
2019 TO 2023 BY ZONE

- Water balance uses plant biomass and vigor to estimate plant water use
- Demonstrates influence on GW gradients based on drone data and plant health assessments



Drone Support for Monitoring Replanting Projects

- Drone Imagery able to pinpoint amount and location of plant mortality
- Vegetation color shifts may indicate drought impacts, faulty irrigation, pockets of disease or insect impacts.
- Actionable data for further investigation to minimize impacts, preventative measures
- Additional native species planted to increase plant diversity and plant density
- Fertilizer and permanent irrigation used to establish new plants, promote survival and more rapid biomass accrual in existing plants
- Increases the overall number and density of plants with an additional 225 plants (90 trees and 135 shrubs) composed of 7 new plant species
- Some plants are self-propagating -- ensuring the long-term sustainability of the phytoremediation cap
- Planning tests using near infra-red Advanced



Results/Lessons Learned: Adaptive Design and Operational Adjustments



Phytoremediation Monitoring with Drones Provides

Immediate Benefits:

- Safer, more accurate measurements, 100% sample size compared to traditional ground-based capture
- Lower costs to collect and process higher data density (pay less for more data)

Manual measurements

Increasing HSE risks; limited accuracy; small sample size; rough estimates of % cover,



Drone Measurements

Minimal risk; very accurate, 100% sample size; accurate % cover → more accurate biomass estimates



The Dark Side of Droning

- Must protect *Personally Identifiable Information* (PII) in all digital images that may “unequivocally identify a human being” ([NIST PII Guide](#))
- Operation with proper FAA Remote Pilot Certificate
- Operation within FAA requirements and state/local laws (line of sight, restricted air space, min/max altitude, privacy, etc.)
- Special insurance may be required by land-owner
- Only fly in safe operating conditions (weather, lights, no wildlife interference, etc.)



Results/Lessons Learned

- PRS are unique remediation systems, and specialized monitoring is required to ensure operating goals are met.
- Drone-based vegetation survey provides better accuracy, lower costs and improved safety compared to manual ground-based methods.
- During early “grow-in” phase (Years 0-5) manual assessment is workable
- However, as PRS plantings mature (Years 5-10), key observations include:
 - Biomass and canopy development must be optimized to achieve design/operational goals within a reasonable period
 - However, plant maturity greatly restricts interior access, O&M and inspection tasks
 - Shifts in plant dominance occur based on site conditions
 - Up to 20% mortality observed and must be replanted to ensure operational efficacy
- Use of drone-based assessment and inspection informs:
 - Changes in operations and maintenance practices to accelerate

