Collection and Development Of Actionable Reclamation Data Using Aerial Remote Sensing

Contract No. G-037-73

Final Report

January 15, 2018

Prepared For:

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 E. Boulevard Ave.
Bismarck ND, 58505-0310

Prepared by:

Mark Jackson
Hell Creek Environmental LLC
15399 Cranes Mill Rd.
Canyon Lake, TX 78133

January 15, 2018

Collection and Development of Actionable Reclamation Data Using Aerial Remote Sensing

Mark Jackson, Project Lead & Principal Investigator
Ahmed Fahsi, Senior Analyst, Ph.D.
Kevin McGlaughlin, Hess Project Lead

This page intentionally left blank

Table of Contents

List of Figures

List of Tables

List of Abbreviations

2D	Two Dimensional
3D	Three Dimensional
µm	Micrometer ($1x10^{-6}$)
AGI	Analytic Graphics Inc.
BBMU	Blue Buttes Madison Unit
BLDU	Beaver Lodge Devonian Unit
CCD	Charged Coupled Device
CIR	Color Infrared
CMOS	Complementary Metal Oxide Semiconductor
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EO	Electro Optical
ESRI	Environmental Systems Research Institute
GIS	Geographic/Geospatial Information Systems
GSD	Ground Sampling Distance
HCE	Hell Creek Environmental
HD	High Definition
HDEO	High Definition Electro Optical
IR	Infrared
ITR	Intent to Reclaim
LIDAR	Light Detection and Ranging
MLC	Maximum Likelihood Classifier
ND	North Dakota
NDAC	North Dakota Administrative Code
NDIC	North Dakota Industrial Commission
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NRGB/RGBN	Near Infrared band, Red band, Green band, Blue band
RGB	Red Green Blue
TA	Temporarily Abandoned
TMU	Tioga Madison Unit

Executive Summary

This study was conducted as a joint endeavor between the North Dakota Industrial Commission (NDIC) and a leading member of the Oil and Gas Industry (Hess) to determine the efficacy and effectiveness of remote sensing technology for the evaluation of reclamation progress. The intent was to validate the use of high resolution imagery to conduct desktop inspections and evaluations and capture the basic requirements for an enduring program to accomplish the stated objectives. This was accomplished through two manned aerial flights utilizing a high definition electro-optical (HD-EO) camera from multiple elevations to capture three/four band imagery in the visible/infrared spectrum. The imagery was then processed, compiled, analyzed and displayed in the Cesium[1] as a "product" for NDIC Inspection Personnel and well operators. This analysis and display of the remote imaging was successful in projecting reclamation "results" relative to the North Dakota Administrative Code criteria, namely: removal of infrastructure, remediation of and reestablishment of the original land contours, and re-establishment of native vegetation.[2] The project results demonstrated that commercial off the shelf imagers[3] and processing[4] are capable of four band[5] imaging and were very capable of providing the products for the computation and display necessary to achieve the project goals. The research team found the processing of 3 cm RGB imaging to create and display orthomosaics, point clouds, digital terrain and surface models provided the user unambiguous clarity to accomplish visual recognition of the removal of infrastructure; reestablishment of land contours and the effectiveness of seeding/regrowth efforts. Production of the Normalized Difference Vegetation Index and Color Infrared from captured NIR imaging allowed for calculation and display of strikingly clear vegetation growth and provided an unexpected benefit of additional anomaly detection in and around the reclamation area. In addition to the sensors and processing, additional factors were determined necessary to provide the desired reclamation insights. These included: limiting planned imaging to sun angles approximately 40° above the horizon or higher; accomplishing vegetation analysis of sites in context to surrounding undisturbed ecologies by capturing an approximate 35-acre reference area for each pad area; and calculation of land cover types within specific reference boundaries. These requirements when evaluated and produced by an experienced imagery analyst provided all the tools necessary to produce displays in Cesium which could be made easily understandable to regulators, operators and landowners. The project fully realized its goals of determining basic requirements for remote imaging capture and processing and display. The enclosed report also provides addition insights future study areas, programmatics and the policy evolution which will need to be addressed to bring this technology and methodology to an operational capability.

---

[1] Cesium is a web based service offered by Analytical Graphics Inc. (AGI) and is a developing application that allows users to visualize processed imagery and terrain models in both two and three dimensions (2D, 3D).
[2] Found in the North Dakota Administrative Code Section 43-02-03-34.1.
[3] Such as the Leica RCD30
[4] Such as Harris' ENVI or Erdas Imagine
[5] Red, Greed, Blue (RGB) images in the visual spectral and Near Infrared (NIR) in the infrared spectrum

Introduction

Due to technological advances in oil and gas development in western North Dakota and economic opportunity has increased significantly. The State had roughly 4,500 producing wells in 2009[6] and 13,000 in 2015[7], and the industry is projecting a potential for nearly 40,000 new wells by 2035[8]. The state's oil production grew over tenfold during the past decade with an annual production total of 35.68 million barrels produced in 2005 and over 432.29 million barrels produced in 2015[9].

North Dakota's oil and gas rapid development has brought a mix of responsible and longstanding industry partners and inevitably other companies that look for short term returns and leave their lease acreage out of compliance with State land requirements which in general negatively impacted ecological and environmental condition. Restoring the land to its original state after production ceases is a necessary step in the life cycle of production in the energy sector, particularly in North Dakota, where reclamation is law[10]. Reclamation is defined as restoring the land as closely as practicable to the original conditions. In North Dakota, oil well abandonment must meet certain specifications in accordance with North Dakota Administrative Code (NDAC) regulations[11]. This usually involves infrastructure removal, re-contouring, topsoil replacement, and re-vegetation. North Dakota (ND) law (NDAC §43-02-03-34.1) requires a well site, access road, and associated lands to be reclaimed as closely as practicable within a reasonable time[12]. North Dakota law also requires the stockpiled topsoil to be distributed evenly over the disturbed area and the site be revegetated with native species, or according to reasonable specifications of an appropriate government land manager or surface owner. However, North Dakota law authorizes state government, with the consent of the appropriate government land manager or surface owner, to waive the reclamation requirement after a well is plugged and an affidavit is filed with the NDIC. A generalized well life cycle and NDIC well status progression is shown in **appendix B**.

Oil and gas production (therefore, abandonment) in North Dakota has been on rise, and as production increases, ground based inspection during field visits strain public resources and

---

[6] 2009 Monthly Statistical Update. Industrial Commission of North Dakota, Oil & Gas Division. Updated August 14, 2013

[7] 2015 Monthly Statistical Update. Industrial Commission of North Dakota, Oil & Gas Division. 2015

[8] Director's Cut, North Dakota Producing Counties Update. North Dakota Industrial Commission, Department of Mineral Resources. September 18, 2014; Saskatchewan Oil Report. 2014. Oil-well reclamation processes across the Bakken.

[9] North Dakota Annual Oil Production Report. 2015. North Dakota Industrial Commission. ND Drilling and Production Statistics. Historical Annual Oil Production Totals. https://www.dmr.nd.gov/oilgas/stats/annualprod.pdf

[10] Dickinson Press. 2013. When drilling for oil in North Dakota, land reclamation a must. http://www.thedickinsonpress.com/content/when-drilling-oil-north-dakota-land-reclamation-must

[11] Chapter 43-02-03, Oil and Gas conservation

[12] Sedivec, K. and Saxowsky, D. 2015. Reclamation of Oil and Gas Industry-impacted Land. A Guide and Checklist. North Dakota State University, Fargo. USDA

aremay no longer be feasible to adequatlye and to sustain a regular and accuratacccurately e assess ment of site reclamation activity. There is no standard or definition as to what a finished and acceptable reclaims look like. The diversity across North Dakota landscapes and ecologies inhibits standardization of the process and very different interpretation and conclusions may exist between different evaluators, industry and regulators respectively.

Currently, field notes, lists, photographs, and spreadsheets are used to track and communicate reclamation progress. The subjective nature of these tracking methods is a concern to both regulators and industry and has led to iterative field visits draining limited budgets inadvertently. Lack of time, expertise, and program support to gauge what is actually deficient, timely, or feasible also contributes to the evaluation problem. Many of the sites on the reclamation schedule are in remote locations, where roads may have been removed or are in a degraded state. Site inspections routinely require significant time, personnel, and resources which will not be feasible or sustainable in the long term as production cycles mature and more wellsite's need to be plugged and abandoned. Therefore, a viable procedure to safely, efficiently, and cost-effectively evaluate the reclamation process is warranted. A moren automated and more effective monitoring strategy is possible through advancement in remote sensing technology and maybe necessary as a requirement to keep up with this increasing activity.

Remote sensing technology has proven effective in many applications, ranging from environmental studies, agriculture, forestry, and wildlife, to archaeology, social studies, and military operations. Remote sensing is especially important for temporal change assessment. As such, current commercial off the shelf aerial remote sensing technology has the potential to effectively and efficiently assess the eligibility of well sites for their satisfaction with NDIC and other agency requirements for post-closure reclamation while providing the standardized, transparent review the industry, regulators, and landowners need to ensure effective and timely completion.

There is also the potential that imagery based assessment, inspection, and record keeping programs can provide efficiency across multiple business groups and stakeholders, including pipeline, construction, and facility inspections, making a value proposition for the overall program to be more cost effective. As sensors, analytical software, and data management improves data collected today will provide additional analytical capabilities and insights as the industry progresses in to the future. Imagery based data and record keeping is the standard for many industries today and the oil and gas sector will need to incorporate this capability as the need for business intelligence increases due to constraints on operating budgets and as the long-term energy sector evolves.

Objective

The objective of the research is to collaborate between industry and regulators to apply current state of the art remote sensing technologies and spatial data[13] analytics software to evaluate reclamation activity without having to spend the resources or incur the risks associated with well sites being inspected in the field. This research is intended to build the execution framework for a capability driving toward a wellsite inspection program based on data and processed imagery rather than field inspections, effectively making business decisions from the desktop.

The current reclamation process is inefficient, time consuming, costly, and varies from area to area and site to site. The subjectivity involved with the current process leaves room for unresolved disputes between regulators and industries. Geospatial data (i.e. remote sensing data) provides a scientific data set in the visible and non-visible spectrum which can be used to perform qualitative and quantitative analysis of earth objects. These techniques may provide more timely and accurate information regarding the condition and state of ecologies and terrain at lower cost. Accurate assessment leads to adequate determination of the eligibility of well sites for their satisfaction with NDIC and other agency requirements for post-closure reclamation. The long-term goal is that this initiative transitions from research to a viable capability to be utilized by both regulators and Industry.

Data Visualization Intro

Cesium

The data from all 10 sites was uploaded to a virtual platform called Cesium. Cesium is a web based service offered by Analytical Graphics Inc. (AGI) and is a developing application that allows users to visualize processed imagery and terrain models in both two and three dimensions (2D, 3D). This platform provides the ability to conduct inspection and analysis of all three-reclamation evaluation and inspection criteria in a virtual environment.

This application is an "operational prototype" generating a simple viewer application available to all authorized parties. When completed, the prototype will allow the user to view the data, navigate in 2D and 3D, and be able to visually discern the differences between imagery multiple seasons. The dataset hosted in the Cesium terrain platform includes the HD photographs, RGB imagery mosaics, as well as high-resolution 3D digital elevation models (DEM). The AGI's

[13] Spatial data, also known as geospatial data, is information about a physical object that can be represented by numerical values in a geographic coordinate system. http://searchsqlserver.techtarget.com/definition/spatial-data

Cesium Team processed the source data into a streamable web format and into a web based 3D visualization application. AGI's Team has made this data and application available for demonstration purposes for one year upon completion of the research. Evaluation of the full extent of the utility the application provides inspectors is unique in the sense that the development of the platform is ongoing with the research. Requests for additional capabilities are conveyed from the research team to the Cesium team. The initial feedback from analysts is very exciting and may drive toward an expansion of this component of the research.

Initial specifications of the Cesium-based application as it applied to this project include the following:

- A web application that lives on the Internet that NDIC and Hess Corporation stakeholders can view from anywhere online.
- The application must have authentication so it's not available to the general public.
- There is no need to download or export any of the data for offline use.
- The application will be read only viewing by any non-research team members.

Cesium generates a 360-degree perspective of each location from any elevation between the collection elevation and the ground surface. This this "bird's eye" viewing enhances the ability of the analyst to view and compare each sites data (features) in context to the surrounding vegetation and landscape. Because one of the three primary evaluation criterial is the re-contouring of the surface, it was critical to find a platform which would allow for the analysis of the actual land surface (3D) in the context of the surrounding lands, similar to the vegetation analysis.

The Common Operating Picture

file number	Well Name	Field Name	Year Plugged	Status	Phase of reclamation	Notes
213	TMU J-132	TIOGA	2014	need site visit	Phase 1	Lots of scoria,everything else removed
233	TMU J-136	TIOGA	2004	work	Phase 2	site visit in 9/14. cattle guard still in place. either remove or get an affidavit
431	TMU J-146	TIOGA	2005	work	Phase 2	work-site visit 9/14, need work, weeds, lots of fox tail grass
135	TMU K-131	TIOGA	2004	Follow up with NDIC	Phase 4	Take out cattle guard, and sign. Need affidavit for other cattle guard left in.-found affidavit dated 6/2012, sent to NDIC 12/2012-agreement to take out cattle guard fill in the hole, plant grass, the fence can stay in-site visit in 9/14-cattle guard was removed, can be released-wait for letter from NDIC-rec'd letter dated 11/5/2014-released from bond
371	TMU K-147HR	TIOGA	2014	need site visit	Phase 1	some equipment on site, lots of scoria
340	TMU K-149	TIOGA	2006	work	Phase 2	lease road still in and sign, big rock pile, may need affidavit for the road, Please retain this road for access to our Hunt LP 8" pig receiver, but there is a big pile of debris at the end of the road that we should not take responsibility for future clean up reasons. The road does not extend all the way to the gas plant equipment and we should look at getting more right away to give us all weather access.-site visit in 9/14, need affidavit for road, gas plant needs road for access to pig receiver-see note before-once road issues resolved, will be released
419	TMU G-125	TIOGA	2006	need site visit	Phase 4	some bare spots, poor growth, soil sample-site visit 9/14 with Tom, released-need to wait for letter from NDIC-rec'd letter dated 11/5/2014-released from bond

Figure 1: Inspection Results – This spreadsheet represents the current practice of communication between site inspectors and industry

Images, unlike lists, provide situational awareness which can flow from regulators to industry and industry to regulators. This shared and common picture can be used to discuss the specific of site attributes. Annotations and geographically precise markers made on the imagery create a more effective way of conveying details which could not be captured on a list or in a spreadsheet. Imagery also establishes a base line reference for the site as operations are under way and changes take place. This common operating picture is as intuitive as the notion that a picture is worth a thousand words. Ultimately the common operating picture is intended to provide a more efficient way of conducting inspections through a more intuitive and streamlined communication process, better informed and defined requirements, and transparency between the industry and regulators. In this way the data and imagery becomes a "business intelligence" tool which makes processing decisions easier, more efficient, and timely.

Methods and Materials

This effort involved collection of aerial data and imagery in conjunction with ground surveys to determine the effectiveness and accuracy of the data to characterize a former well site's compliance with North Dakota's post closure requirements. Qualitative and quantitative analysis of the high-resolution imagery was conducted using adequate image processing and GIS analysis tools and techniques. The study demonstrated the ability to properly identify compliant site conditions as well as non-compliant site conditions. The analysis included surface contouring, removal of industry infrastructure, and the discrimination between grasses and potential invasive vegetation, and also the comparison of the sites in context to the surrounding and adjacent lands. . The data analysis was conducted between spring and fall conditions and also spring to spring conditions, respectively.

Software used in the analysis included commercial off the shelf GIS platforms and one platform under development known as Cesium. Cesium was subcontracted to develop a North Dakota specific platform to host and visualize three dimensional terrain data, processed imagery and associated geospatial analytical products. Post flight processing of the data included;

- Comparison of the effects of solar angle between late season fall imagery and early spring imagery.
- Detection and interpretation differences between trained and untrained analyst using high resolution photographs at each of the three collection elevations and image resolutions.
- Contour evaluation in context of surrounding undisturbed terrain.
- Vegetation analysis and classification in context to surrounding undisturbed ecologies.
- Rendering of Infrared data (vegetation density and health).
- Construction of 3D digital terrain models.
- Initial programming to upload the geospatial data into a web based 3D visualization application.

The original intent and methodology was to use data from multiple elevations in conjunction with the most economical sensor and least amount of data (i.e. spectral bands) to determine what resolution and minimum technology suites were necessary to meet the research objectives. The conclusion after analyzing the spring 2016 imagery was that inspections success was not discernable at the 10 centimeter (cm) and 30 cm resolutions. A decision was made to collect data from only the 3 cm elevation and change to a sensor and camera capable of capturing and additional spectral band (Infrared) and utilize software assisted and automated analysis instead of just trained human analysis. After the fall 2016 and spring 2017 collections it was determined that the new sensor and software suite was able to meet the research objectives.

The development of the Cesium platform to host all the processed imagery met and exceeded the expectations of the research team. Results included a functioning capability to visualize very high resolution photographs and multiple processed spectral images draped over very high resolution 3D terrain models. The Cesium application was used and reviewed by the NDIC inspection personnel and determined that the combination of imagery was capable of comprehensive inspections from the desktop.

Geographic Information Systems and Software

This study used advanced remote sensing tools for image processing, post-processing analysis, and visualization. Each of these tools is available commercially.

- **Erdas IMAGINE** is world-class remote sensing software. It is the worlds most widely used raster-based remote sensing software package, which incorporates advanced image processing, and analysis, geospatial modeling, and GIS capabilities. The software allows the processing of geospatial and other imagery, including multispectral and hyperspectral data, as well as vector data and LIDAR from various sensors. As such, the software can be used to extract valuable information from satellite imagery, aerial photography, LiDAR, and other modalities. The multi-source, multi-format data can be examined quantitatively or qualitatively to characterize a reclamation site; including areas of disturbance, change in vegetation cover and types, and topographic structure. Change detection maps can also be produced to determine and quantify changes over time.
- **ArcGIS** is a product of the Environmental Systems Research Institute (ESRI), which is the world leading Geographical Information Systems (GIS) analysis software. ArcGIS consists of several integrated applications that allow, among others, geospatial data manipulation, analysis, display, and map production.
- **Cesium** is an Analytical Graphics Inc. (AGI) web-based tool used for globe and map visualization dynamic data. It is an open source JavaScript library for creating 3D geospatial visualizations and enables a web hosted multi-user/agency interface and cloud storage of data. This tool was selected for its potential to provide a "next generation" data organization, storage, access, and visualization capability, resulting in a major gain in efficiency to the regulatory agencies and regulated industries by establishing a "common operating picture" capability. A simplified process and data flow diagram for this project is shown in **appendix C**

Study Sites

A list of twenty candidate locations was generated in collaboration with the NDIC and Hess. Each site was evaluated during site visits and considered in terms of a selection matrix which included site specific attributes, stage of reclamation activity, ecological setting, land use, and previous inspections noted in the well file. Each of the candidate sites was inventoried during site visits in terms of the selection matrix to select 10 locations with varying attributes that would likely provide evolving research parameters over the course of the study. The 10 locations chosen from the pool to represent the study group included wells in the Tioga Madison Unit (TMU), Beaver Lodge Devonian Unit (BLDU) and Blue Buttes Madison Unit (BBMUThese ten sites are in the northwestern region of North Dakota (ND). The sites selected in the TMU field were the TMU E-143, TMU E-144, TMU N-130, and TMU N-152 and are within a 10-km radius. They are also about 25 km north of the site BLDU D-306 which was closest to the Missouri River (approximately 10.5 km north). The five selected in the BBMU were the BBMU E-331, BBMU F-220, BBMU F-429, BBMU G-316, and BBMU H-408. These were all south of the Missouri River, located slightly southeast of Keene and within 6 km radius of each other. The ten sites are primarily on privately owned land.

Land cover in these sites range from agricultural fields to mixed grass fields to range land and moderately wooded areas (Figure 2). The sites range from low relief to extreme slopes characterized by rolling upland terrain. The restoration stage of the ten sites ranges from nearly complete, adequate (e.g., E-143), and poor in terms of ecological condition and the state requirements (e.g., D-306). This variation in restoration stages will determine the ability of remote sensing and GIS technologies to objectively and consistently assess and differentiate among varying levels of site conditions.

The United State Department of Agriculture (USDA) soil survey data base was used to identify the landscape and ecological profile for each location. Relevant information included; slope, drainage, native vegetation type, abundance, and distribution. Multiple visits were made to each location to inventory and document site attributes including; residual infrastructure, vegetative and ecological state, erosional features, and any site specific attributes which impacted the reclamation process.

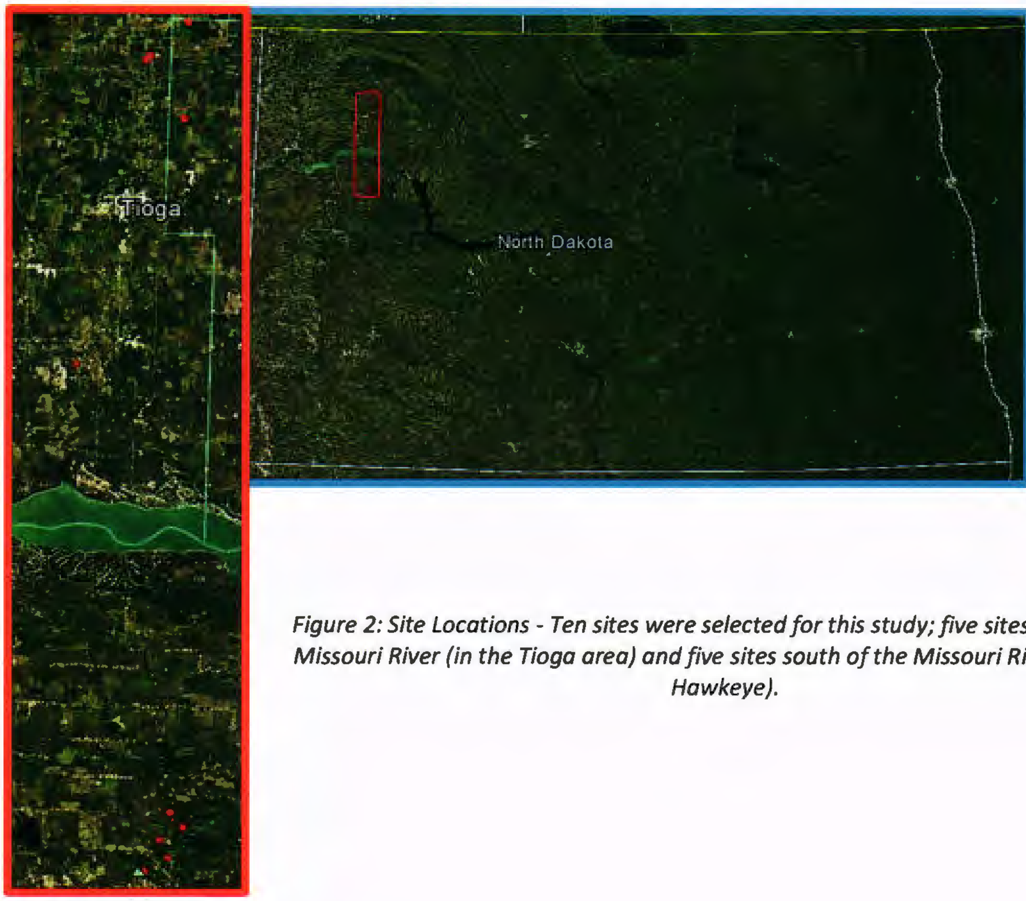


Figure 2: Site Locations - Ten sites were selected for this study; five sites north of the Missouri River (in the Tioga area) and five sites south of the Missouri River (south of Hawkeye).

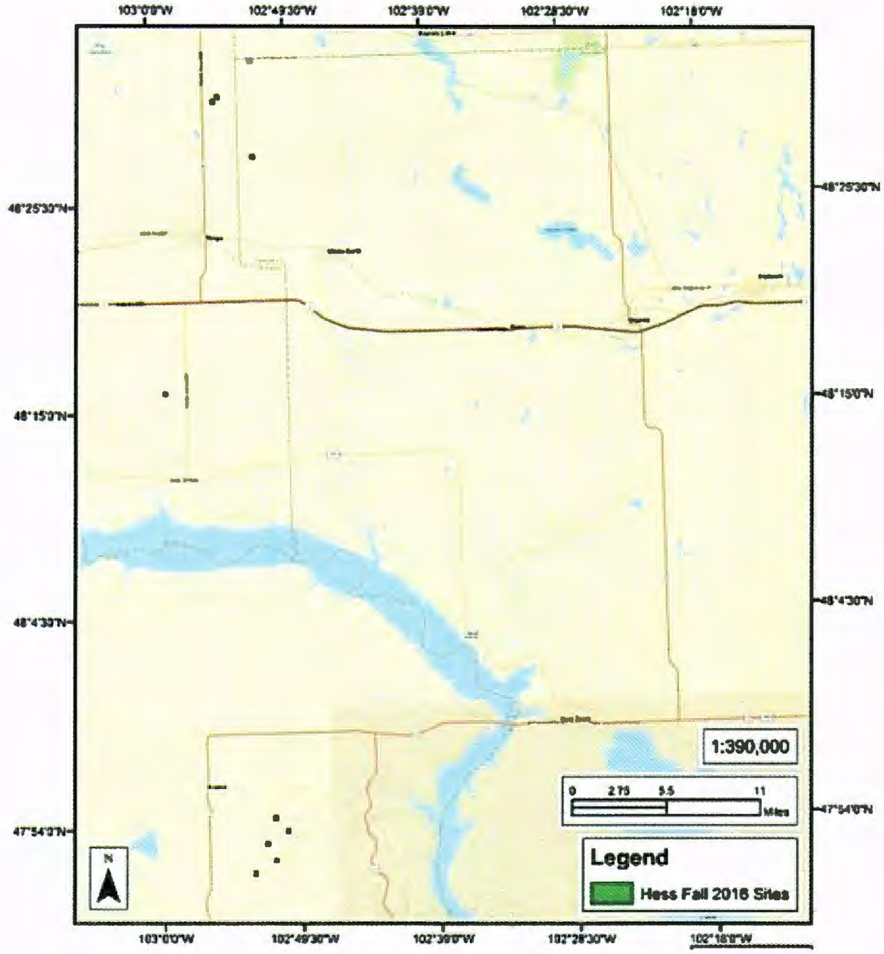


Figure 3: Reference locations - the ten study sites

Data collection

The project conducted aerial imagery collection in two seasons – spring and fall – at three altitudes, resulting in three spatial resolutions of 3-cm, 6-cm, and 10-cm. The project also conducted ground survey on each site before and one control site during and after the flight campaigns.

The ten reclamation sites were flown both in the spring and the fall of 2016, and again in the spring of 2017 with a manned aircraft. The spring of 2016 initial collection included a high-resolution RGB camera at low altitude, producing 3-cm, 6-cm, and 10-cm Ground Sampling Distance (GSD) resolution digital images. The purpose of the multiple flight altitudes was to determine the suitable resolution to accurately and adequately identify compliant/noncompliant site conditions as compared to flight time requirements and therefore cost of collection sorties.

The spring 2016 imagery was collected with a sensor pod and integrated high definition electro-optical (HDEO) aerial camera, which collects light in the visible region of the electromagnetic spectrum i.e., blue, green, and red bands – also known as RGB which represents the spectrum associated with visible light (0.4-0.7 µm). The fall 2016 and spring 2017 imagery was collected with the Leica RCD30 medium format camera system. The Leica RCD30 is an 80-megapixel camera, capable of acquiring co-registered multispectral imagery in the visible (RGB) and Near-Infrared (NIR) regions of the electromagnetic spectrum. The camera employs two 60MP charge coupled device (CCD[14]) imagers. The first CCD records the RGB image with a Bayer pattern and peak quantum efficiencies of blue 470nm, green 530nm and red 590nm, respectively. The second CCD records the NIR image of the incoming light across 780 – 900nm simultaneously and across the same area as the RGB sensor. This, combined with highly accurate camera calibration, allows the creation of co-registered, perfectly fitting 4-band imagery in both RGB and NIR. The fall camera generated three additional image types;

- Near Infrared (NIR)/Color-Infrared (CIR)
- Normalized Difference Vegetation Index (NDVI)
- Near Infrared band, Red band, Green band, Blue band (NRGB)

Near Infrared is the invisible part of the spectrum beyond visible light but shorter than microwaves (0.75-1.4 µm) and is used to render Color Infrared (CIR) imagery which is good at penetrating atmospheric haze and determining the health of vegetation. Normalized Difference Vegetation Index uses the near-Infrared band and the Red band and is used as a graphical indicator to assess whether the target being observed contains live green vegetation. Two different methods were used for processing the imagery during the progression of the research, one in the spring of 2016 then another for the fall 2016 and spring 2017. The change in processing was made to facilitate research into the possibility of additional spectral data improving and augmenting our analysis beyond the capability of just photographic imagery and the human eye. The two methods are a Remote Sensing processing algorithm and an Aerial Picture algorithm. The Remote Sensing algorithm data is scientific quality imagery, which means that the pixel values represent scientific measurements of the light as it entered the camera. Aerial Picture algorithms and output data add gain and color balancing to create natural looking photos, which are more "realistic" pictures but lose the original spectral characteristics that make it analyzable. The spring 2016 collection data was processed with the Aerial Picture algorithm. This is apparent from the color quality of the imagery displayed in Cesium. The fall 2016 and spring 2017 images were processed with the Remote Sensing algorithm which resulted in a "darker" and less natural color pallet but retained the ability to be analyzed by automated software. Also, other factors affected the imagery for the fall 2016 collection; specifically, the date of that survey was conducted on 8-9 October 2016. This was very late in the year for aerial photography in North Dakota because of the lack of sunlight i.e. low solar angle. The lower frame rates induce a lot of motion blur, high shadows and poor light quality also made it difficult to visually discern site attributes.

---

[14] Generally speaking, charged coupled device or CCD imagers are bettered suited for this application than current CMOS (complementary metal oxide semiconductor) imagers commonly found in many consumer applications due to their better Near IR sensitivity.

Spring 2016	3cm				6cm				10cm				
Site	CIR	NDVI	NGRB	RGB	CIR	NDVI	NGRB	RGB	CIR	NDVI	NGRB	RGB	DTED
UNIT E-331				x				x				x	x
UNIT F-429				x				x				x	x
UNIT F-220				x				x				x	x
UNIT G-316				x				x				x	x
UNIT H-408				x				x				x	x
UNIT D-306				x				x				x	x
UNIT N-130				x				x				x	x
UNIT E-143				x				x				x	x
UNIT F-144				x				x				x	x
UNIT N-152				x				x				x	x

Fall 2016	3cm				6cm				10cm				
Site	CIR	NDVI	NGRB	RGB	CIR	NDVI	NGRB	RGB	CIR	NDVI	NGRB	RGB	DTED
UNIT E-331	x	x	x	x	x	x	x	x					x
UNIT F-429	x	x	x	x									x
UNIT F-220	x	x	x	x									x
UNIT G-316	x	x	x	x	x	x	x	x					x
UNIT H-408	x	x	x	x	x	x	x	x	x	x	x	x	x
UNIT D-306	x	x	x	x	x	x	x	x					x
UNIT N-130	x	x	x	x									x
UNIT E-143	x	x	x	x									x
UNIT F-144	x	x	x	x					x	x	x	x	x
UNIT N-152	x	x	x	x	x	x	x	x	x	x	x	x	x

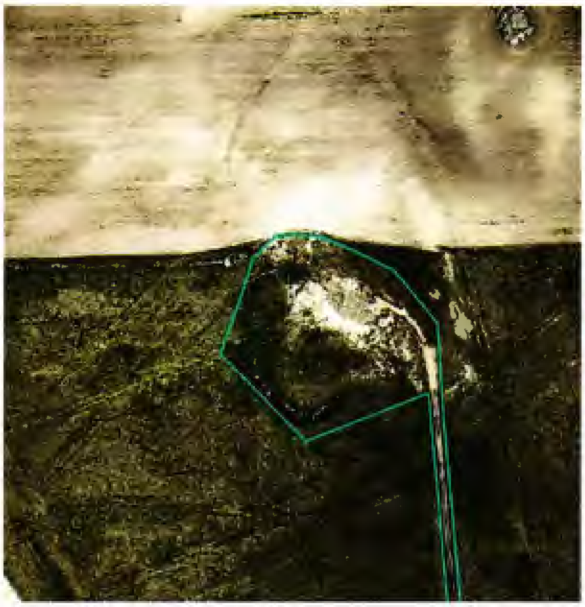
Spring 2017	3cm				6cm				10cm				
Site	CIR	NDVI	NGRB	RGB	CIR	NDVI	NGRB	RGB	CIR	NDVI	NGRB	RGB	DTED
UNIT E-331	x	x	x	x									x
UNIT F-429	x	x	x	x									x
UNIT F-220	x	x	x	x									x
UNIT G-316	x	x	x	x									x
UNIT H-408	x	x	x	x									x
UNIT D-306	x	x	x	x									x
UNIT N-130	x	x	x	x									x
UNIT E-143	x	x	x	x									x
UNIT F-144	x	x	x	x									x
UNIT N-152	x	x	x	x									x

Table 1 - Progression of data collected throughout the research by well site and collection date.

Collection Area

Imagery was collected over a larger area than the pad boundaries to allow for analysis inside the pad area and its surroundings (Figure 4). In addition to use for spectral characterization of land cover types, the imagery was also collected stereoscopically, with high-end lap (i.e., overlap between successive image frames along flight lines) and side lap (i.e., overlap between flight lines), to generate digital elevation models (digital surface models – DSM and/or digital terrain models – DTM). The purpose of the DSM and DTM data was to assess the topographical characteristics of the ground surface (i.e., re-contouring and drainage conditions).

Figure 4: Aerial coverage – the following series of images shows the study sites with variable land cover characteristics (from dominantly grass area, such as Site N-152 to highly wooded area, such as Site G-316) and restoration condition stages. Approximations of Pad boundaries and lease roads are represented in magenta.



Site D-306 (340m x 347m)

Site E-143 (400m x 400m)

Site E-331 (325m x 400m)

Site F-144 (361m x 400m)

Site F-220 (360m x 382m)

Site F-429 (324m x 358m)

Site G-316 (368m x 402m)

Site H-408 (400m x 400m)

Site N-130 (400m x 400m)

Site N-152 (400m x 400m)

Solar Angle

The effects of the low solar angle on the imagery were compared between the fall and spring imagery by a trained analyst. The implications of low sun angle on imagery are multifold: lowered signal-to-noise ratio and increased shadows. Depending on the imaging system there is generally less contrast, meaning decreased quality of the light during low sun angles. Comparison between the two seasons revealed that spring imagery was more informative for detecting infrastructure and discerning vegetative differences due to more space between features and vegetation. The imagery captured vegetation in a state where phenological differences highlighted different plant communities, and where the low vegetation height aided the detection of infrastructure and surface contouring.

In contrast, fall season imagery captured vegetative conditions when the growth cycle was complete and plants had fully matured, making it difficult to discriminate among vegetation types or to detect the small infrastructure with just HD photographs even at 3-cm resolution. Fall vegetation, in terms of spectral data and imagery, often appeared in the same state (senesced or dead) because the chlorophyll and associated spectral discrimination was greatly diminished. Generally, we learned that early-season imagery is more informative for detecting infrastructure and discerning vegetative differences.

This seasonal comparison, via visual examination and preliminary image processing was valuable as it provided insightful information and guidance as to what period of the year is suitable for imagery collection, but also what image resolution was adequate for multipurpose analysis (i.e., vegetation type discrimination, infrastructure detection, and contouring and drainage analysis).

After the 2016 investigations and limits in analytical methods, and due to some data partiality, the ten sites were flown a third time in the spring of 2017. The spring 2017 imagery was collected at 3-cm spatial resolution (GSD) using the same Leica system as the fall 2016 collection. This imagery was primarily used to generate DTM and DSM layers, allowing a comparison between the two.

The images of the wellsite's in Figure 4 are the results of mosaicking multiple frames from several flight lines. The images were also color calibrated to normalize/homogenize the color differences across multiple frames.

Ground survey/Ground truth data collection

To "anchor" remotely sensed measurements, we need to compare them to known measurements, called "ground truth." Ground truth is usually done on site, performing surface observations and measurements of various attributes and features of a site which is then compared to the remotely sensed imagery and classifications provided by the image processing software. It is best practice to conduct ground truthing at the same date and time of the remote data acquisition, or at least within a time frame which the environmental condition does not change in relative terms.

To adequately characterize and evaluate the primary evaluation criteria of the NDIC approval process for reclamation activity, a team including Hell Creek Environmental (HCE) personnel conduct ground surveys of each of the locations pre-flight and again during each flight series (spring and fall). Field activities included the demarcation and photo cataloging of infrastructure and vegetation, which served as ground truthing for the analysts. The team demarcated areas with different vegetation species, including native vegetation and invasive vegetation areas by physically laying down multiple 3m by 3m plots delineating different types and density of vegetation cover (Figure 5a and 5b). Infrastructure and other features were also identified and annotated on the imagery.

Figure 5(a): shows control plots delineating forbs from grasses before aerial survey. 5(b): shows infrastructure which was included in the sites inventory during ground truthing.

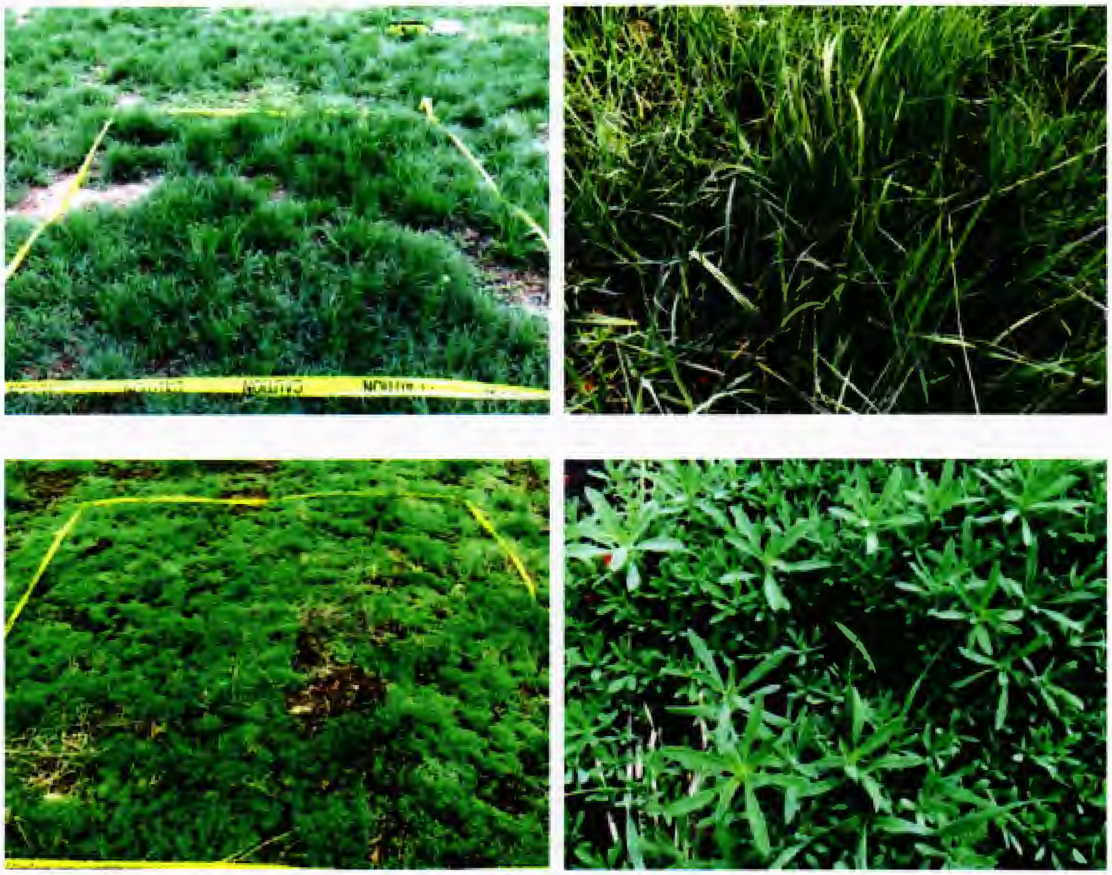


Figure 6: Needle and Wheatgrass dominated plot (top) and Kochia fireweed dominated plot (bottom).

Weed control is essential for reclamation success. Annual broadleaf and grass weeds will be common during the year of implementation and second year after seeding. These annual weeds should not be a concern during the first growing season; however, mowing or chemical treatment (depending on seed mixture) to control seed development may be necessary during the second growing season. If the seed mixture contains broadleaf, legume or shrub plants, chemical control would not be recommended because the chemical will also damage the seeded plants (Sedlvec, et al., 2014).

Study Sites

An inventory of specific site attributes was generated before the flights, which included photographs, demarcation, GPS locations, plant specimens, and relevant measurements were compiled and referenced in comparison with each site's well file and NDIC inspection notes.

Beaver Lodge-Devonian Unit D-306

Name	Beaver Lodge Devonian Unit D-306
File #	2005
Well Status	Plugged and Abandoned
Insp. Date	Comments:
9/24/2014	Without Reclamation. Eliminate Junk.
10/25/2016	Two piles of gravel, wood and metal junk needs removed, sereval large bare spots.
Ecological Site	Loamy (100%)
USDA Description*	Appendix A-1

*Description of major map unit (by percent area)

Figure 7: Persisting bare ground areas and debris refuse piles. Operational infrastructure was also inventoried at the D-306 Site for comparison with the aerial imagery.

The D-306 site scored poor in each of the three site selection grading categories. The site visit conducted before the spring 2016 flights identified the "junk" and the degraded state of the ground cover which indicates the lack of any reclamation. Bare spots (A) were present throughout both the pad area inside and outside the site boundary. These areas contained scoria base cover and fine silts with a white hue. The debris pile (B/C) contained large stones, wood debris, a pallet, and a variety of sands and gravel. The pipeline riser (D) is active infrastructure but was inventoried to be used for an imagery inspection point of reference. The access road was still present and was likely being used to access the pipeline infrastructure.

Tioga-Madison Unit E-143

Name	Tioga Madison Unit E-143
File #	188
Well Status	Temporarily Abandoned (TA)
Insp. Date	Comments:
9/24/2014	N/A
9/13/2016	Site and road is completely overgrown with weeds and grass.
Ecological Site	Loamy (65.6%), Thin Loamy (24.7%), Shallow Marsh (9.7%)
USDA Description*	Appendix A-2

*Description of major map unit (by percent area)

The E-143 exists in a production field and is currently in use. This site is not in the reclamation cycle, however was chosen as a study site because the wellhead and above ground components which provided infrastructure of known dimensions. Ground truthing further identified other infrastructure such as the rig anchors and associated markers. Three of the four rig anchors were still installed at the site. Cones were placed at the three anchor and measurements were taken between each to ground truth the accuracy of the aerial imagery. The measurements between the actual distance and the distance measured in the geospatial platform were within three inches. The rig anchors and cable were 6 to 10 inches across and served as a reference for the actual 3 cm imagery and the ability to see sub 10 cm objects. The vegetation was well established but the actual base cover was greater than 30 percent residual scoria and gravel. This photo, taken during the site visit, shows these features as well as the vegetative state of the pad.

Figure 8: Wellhead and above grade infrastructure, including the cable, rig anchors, and postings.

During this site visit the land owner's representative who was farming the acreage around the site indicated that a near surface pipeline was identified previously in the immediate area of the wellhead but has since been lost. The area not in production was based on the risk associated with damage to equipment. Contouring looks very good when compared to the surrounding landscape. Because the well has Temporarily Abandoned (TA) status the road is not being considered in the inventory.

Blue Buttes-Madison Unit E-331

Name	Blue Buttes-Madison Unit E-331
File #	1647
Well Status	Plugged and Abandoned
Insp. Date	Comments:
8/21/2014	Still no reclamation work started. Still scoria.
7/19/2017	Still not affidavit for lease road. The gate is open and the east side of the fence was taken down. The stakes are sitting on location. Still a lot of scoria just past gate. Cattle have been in stomping around. Growth is pretty minimal in the center portion of site. The rest looks okay. The sloped west side seems to be holding well.
Ecological Site	Not Assigned (46.3%), Thin Loamy (51.9%), Shallow Sandy (1.8%)
USDA Description*	Appendix A-3

*Description of major map unit (by percent area)

Figure 9: Above grade pipe, erosion features, and invasive species persist at the E-331site.

The BBMU E331 also scored poorly in all three evaluation criteria and based on these site attributes was selected as the control site for the vegetation and infrastructure analysis as shown in figures 5 and 6 which is also discussed further in successive sections. Because the E-331 pad exists as a level area constructed on a steep slope by which the lack of erosion control is causing poor drainage and headward erosion which affects the landscape and ecologies both inside and outside of the pad boundary. Plant species better suited for these drainage conditions such as Kochia (fireweed) were well established and dominating much of the pad. Cattle and other range animals were exploiting the erosion features where a transition from rills to gullies was apparent.

The disturbed site may also be affected by runoff of surrounding lands causing an increase in cost to repair "But if your disturbed site is impacted from the surrounding landscape through runoff, other controls such as temporary berms, diversions or sediment fence diverting larger sheet flows from entering the site may be required. The area being protected may not be the only area impacting the erosion potential" (Sedlvec, et al., 2014).

(see next page)

Tioga-Madison Unit F-144

Name	Tioga Madison Unit F-144
File #	717
Well Status	Temporarily Abandoned (TA)
Insp. Date	Comments:
9/24/2014	N/A
10/18/2016	MIT Passed. No site, Overgrown road, No tubing
Ecological Site	Thin Loamy (57.7%), Loamy (40.3%), Shallow Marsh (2%)
USDA Description*	Appendix A-4

*Description of major map unit (by percent area)

Figure 10: TMU F-144 residual infrastructure ranging from the wellhead to rig anchors. Overall the site was in good vegetative state and surrounding land was being used for production.

The F-144 site is not in the reclamation cycle but rather has been designated as temporarily abandoned with the State. However, the site was chosen as a study location because the wellhead and above ground components (A) could be used to test the various resolutions. This site had established vegetation of mixed grasses, forbs, and shrubs. The base soil layer did not show residual scoria or gravel and the contour of the site matched the surrounding area within view from the pad. The remaining infrastructure included rig anchors and markers (B). This site is also set within a production field which is in use.

Similar to the E-143 the current land attendant had concerns over shallow underground pipes and damage to machinery as the reason why the pad area was as large as it is and not back into production.

Blue Buttes-Madison Unit F-220

Name	Blue Buttes-Madison Unit F-220
File #	1243
Well Status	Plugged and Abandoned
Insp. Date	Comments:
7/22/2014	Power pole still present, large propane tank setting on site.
7/18/2017	As before where the wellhead location was looks decent outside of some erosion issues on the slopeside. The tanks were located to the west of where the propane tank is sitting and growth is more poor there - a lot of kochia. Dead area was an evaporation pit. Took a sample to test chloride back. Maxed out chloride strip >645ppm. Confident this damage from evaporation pit usage.
Ecological Site	Thin Loamy (28.1%), Thin Claypan (20.9%), Loamy (25.9%), shallow Loamy (9.5%), Clayey (15.7%)
USDA Description*	Appendix A-5

*Description of major map unit (by percent area)

Figure 11: F-220 showing a washout feature and debris down-slope of the previous well pad.

The Blue Buttes-Madison F-220 well pad was not discernable from the surrounding terrain. A slope just off site exists but was not known if it was an engineered feature. A large washout area existed down slope to the west where vegetation was not able to be established. Debris was found in the washout of the slope indicating that there may have been a buried pit at one time which is now being exposed by erosion.

Blue Buttes-Madison Unit F-429

Name	Blue Buttes-Madison Unit F-429
File #	1498
Well Status	Plugged and Abandoned
Insp. Date	Comments:
4/11/2014	Carol (ph#) is upset that the road has not been reclaimed to satisfaction yet. Need to inspect and get more work done if needed.
7/18/2017	No work has been done to reclaim the portion of lease road left in place. Growth on hillside where the location is still looks good.
Ecological Site	Shallow Loamy (48.9%), Shallow Sandy (44.1%), Claypan (7%)
USDA Description*	Appendix A-6

*Description of major map unit (by percent area)

Figure 12: F-429 was considered a candidate for release from bond due to the recovery of the site in ecological terms. The remaining access road feature was the last consideration in terms of reclamation.

The F-429 site was a clear example of a successful reclaim. The pad was re-contoured to blend seamlessly into the extreme slope of the butte surrounding it. From ground level the vegetation had established itself with little erosional features even in such extreme sloping. It is anticipated that in time native plant and shrub communities will be reestablish over the site due to the stable state and appropriate context to the adjacent landscapes.

Blue Buttes-Madison Unit G-316

Name	Blue Buttes-Madison Unit G-316
File #	3176
Well Status	Plugged and Abandoned
Insp. Date	Comments:
8/22/2013	Site still scoria and dirt. North end bare and south end has some grass growth. Lease road is two track scoria, will need affidavit if road is ok.
10/25/2016	Two piles of gravel, wood and metal junk needs removed, sereval large bare spots.
Ecological Site	Thin Loamy (100%)
USDA Description*	Appendix A-7

*Description of major map unit (by percent area)

Figure 13: G-316 shows excavation features and residual scoria and gravel base. The slope was clearly altered and not returned to the native contouring.

The Blue Buttes-Madison G-316 site represents a common situation where reclamation activity has not been conducted but the surrounding ecology has encroached into the pad boundary over time. Reestablishment of vegetation is progressing on surface soils dominated by residual scoria and gravel pad and road base (Figure 13-C). The access road to the former pad location was very unstable, rutted due to running water, and degraded (Figure 13-D).

It was clear, based on the surrounding contours, that the former pad was once a crown of a hilltop which had been excavated to construct a level pad (Figure 13-A). North-west of the former pad there is a slope which looks as if material was plowed down the ravine during the excavation. This feature was dominated by headward erosion and looked very different from the adjacent slopes. A topsoil pile was also identified but was over grown with vegetation (Figure 13-B). The work and cost associated with re-contouring the site to a native state would most likely be prohibitive.

(see next page)

Blue Buttes-Madison Unit H-408

Name	Blue Buttes-Madison Unit H-408
File #	1301
Well Status	Plugged and Abandoned
Insp. Date	Comments:
7/22/2014	Location bare of vegetation. Need to start reclamation.
7/18/2017	No change from before. Scoria remains in place and erosion happening off north side.
Ecological Site	Thin Loamy (73.1%), Thin Claypan (26.9%)
USDA Description*	Appendix A-8

*Description of major map unit (by percent area)

Figure 14: The H-408 is essentially without reclamation with the original scoria pad remaining.

The H-408 site was plugged and abandoned but the scoria pad and contouring still remain. The level pad is causing pooling on the site and eventual spill-over and runoff is eroding the northeastern edge of the pad. This site is a good example of how if an operating pad or a bare spot left after a pipeline is installed can have erosion that incises the landscape and headward erosion moving up slope can eventually expose infrastructure to be left to the elements and or damage by cattle and range animals. This photo shows the erosion features as a preferential path for cattle migration due to the presence of excrement and hove marks traversing the rills.

Tioga-Madison Unit N-130

Name	Tioga Madison Unit N-130
File #	749
Well Status	Plugged and Abandoned
Insp. Date	Comments:
9/24/2014	N/A (TA Status at the time of this inspection date)
9/13/2016	No Form 4: ITR. No reclamation to date. Sign & flow line remain on site. Some good grass growth, but it is poor near the wellhead. Overall cover for the road & site looks pretty good. Need resolution for the approach. Wait on reclamation.
Ecological Site	Loamy (74.1%), Shallow Marsh (25.9%), Shallow Marsh (9.7%)
USDA Description*	Appendix A-9

*Description of major map unit (by percent area)

Figure 15: The N-130 with the existing well before being plugged and abandoned.

At the time of the ground truthing visit the N-130 was still in the TA process. Since the site visit and before the first aerial imagery collection the site was plugged and abandoned. The well vault (A/C), existing tubing and below grade features (B), and the rig anchors and markers are shown. Vegetation at the site was well established except around the well head itself. There was a pond just off location to the east and the data and imagery associated with that feature is addressed in successive sections of this report

Tioga-Madison Unit N-152

Name	Tioga Madison Unit E-152
File #	728
Well Status	Plugged and Abandoned
Insp. Date	Comments:
9/24/2014	Pile of rods and debris on site, without reclamation, no form 4- Intent to reclaim (ITR)
9/13/2016	Tubing still wracked. Anchors were pulled & left onsite. Wellhead cutoff & capped but not filled to surface. Anchor holes remain as well
Ecological Site	Thin Loamy (84.4%), Loamy (15.6%)
USDA Description*	Appendix A-10

*Description of major map unit (by percent area)

Figure 16: The N-152 showing residual infrastructure including the access road and debris piles. Vegetation was well established over most of the site and matched the ecology of the land adjacent to the former pad.

The Tioga-Madison Unit N-152 site includes the access road and old scoria/gravel base near the wellhead. Infrastructure includes multiple rig anchors which had been removed from the ground and are still laying onsite, pipe rack and pipe stands being stored on location, and the BOP and other valve tree components mingled in with debris pile. Vegetation has begun to recover but residual access road features are still present showing channeling of surface water runoff. Contouring work would need to be done to return the surface water runoff back to a native state.

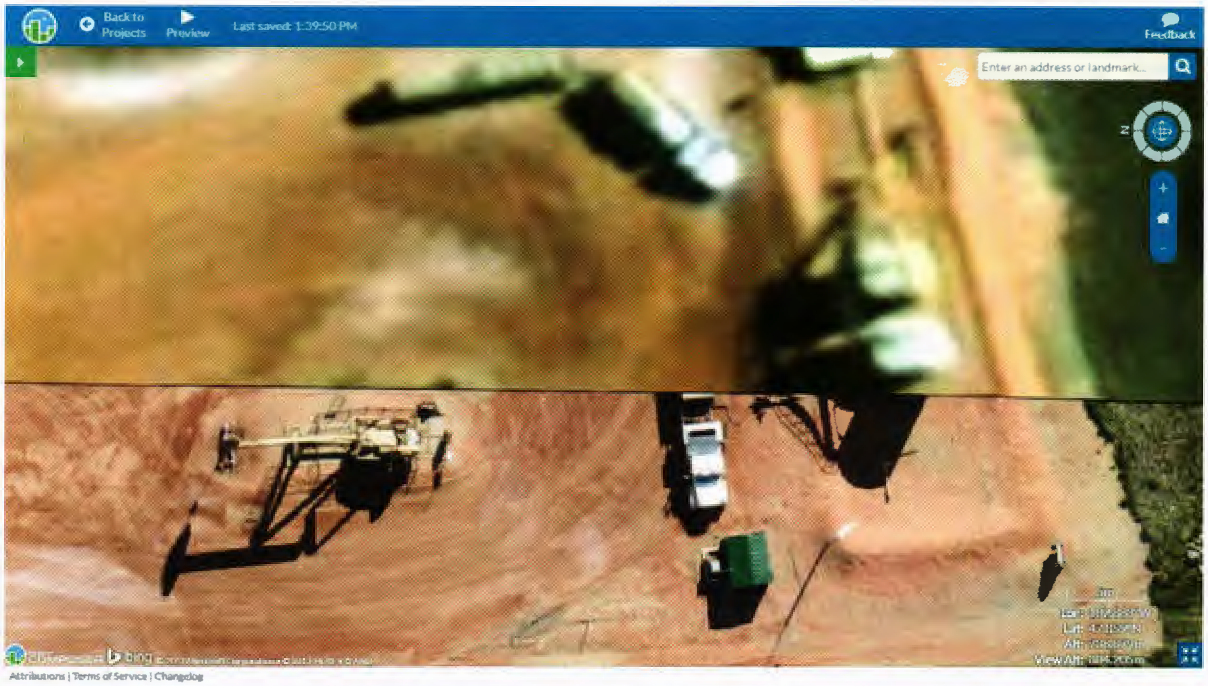


Figure 17: Comparison of 3-cm resolution (not at max zoom) to aerial imagery provided by Microsoft Bing Maps (at maximum zoom) hosted side by side in Cesium.

Ground Truthing and Imagery Analysts

A team of experienced and new analysts visually examined, identified, and annotated imagery for vegetation types, infrastructure, and terrain features (Figure 6). These features were digitized on 3-cm, 6-cm, and 10-cm resolution imagery if evident at the site. Ground truth data was re-examined after visual analysis to determine the accuracy of the manual interpretation approach. The results from experienced and new analysts were compared against one another to determine the discrepancies due to differing skill levels.

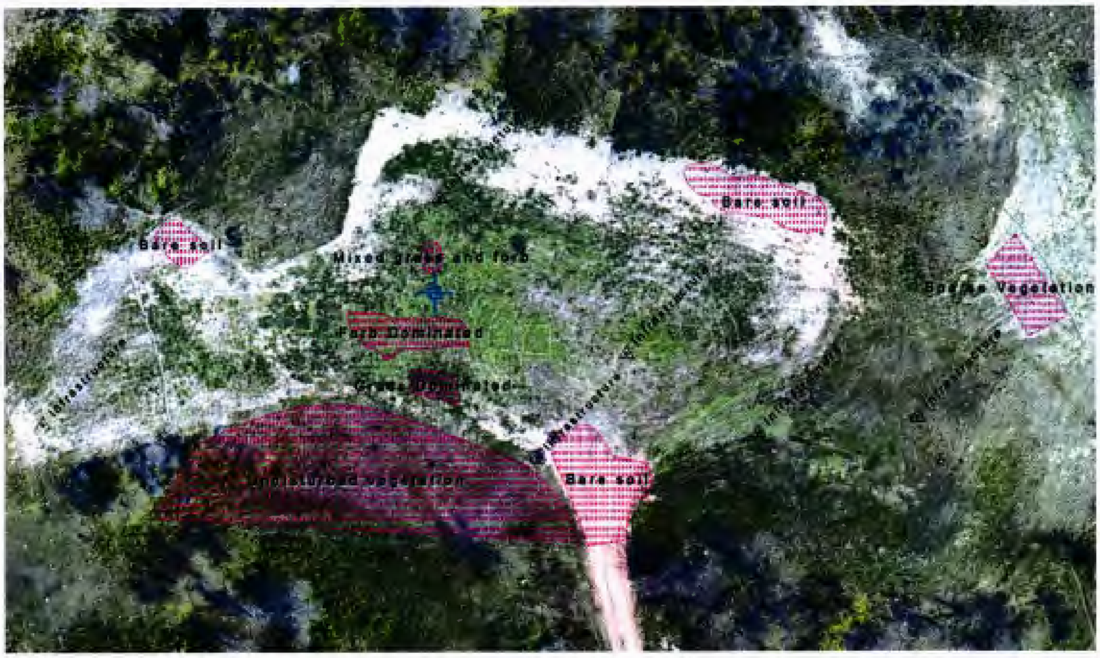


Figure 18: Manual image interpretation to identify vegetation types and infrastructure – Blue Buttes Madison Unit E-331.

The vegetation classes identified by separate analysts – with varying experience levels – were grasses, forbs, and bare ground. The BBMU E-331 site was examined on the ground and multiple examples of each vegetation type were identified and annotated on the three-different resolution imagery (3-cm, 6-cm, and 10-cm). Distribution and density of various grass and forb species were estimated and noted. Three plots were selected and demarcated in the active reclamation area based on relatively homogenous groups of grasses, forbs, and mixed distribution. A fourth plot was demarcated just off site capturing a sample set of the native forage group. Photographs and samples of the vegetation were cataloged in preparation of the collections and analysis. The plot representing the native forage group had over 15 different species, while the plots inside the active reclamation area had only 5 or fewer species. Each plot was used to identify and discriminate between grasses and forbs. Speciation was not expected to be possible using HD-EO data even at 3-cm resolution.

There was a considerable difference between analysts' results for vegetation type identification. Though, the less experienced analysts' results were much improved after reviewing the ground truth with more experienced analysts. This exercise highlighted the importance of training and experience in these types of experiments.

Similarly, infrastructure was identified using 3-cm, 6-cm and 10-cm resolution data. The specific features included pipes, posts, barrels, and trash. Unlike vegetation, infrastructure identification results among analysts were quite similar. Figure 7 below shows the results of infrastructure identification using 3-cm resolution imagery. As can be seen in Figure 7, most infrastructure features are accurately identified by both experienced and less experienced analysts; only a few locations are different.

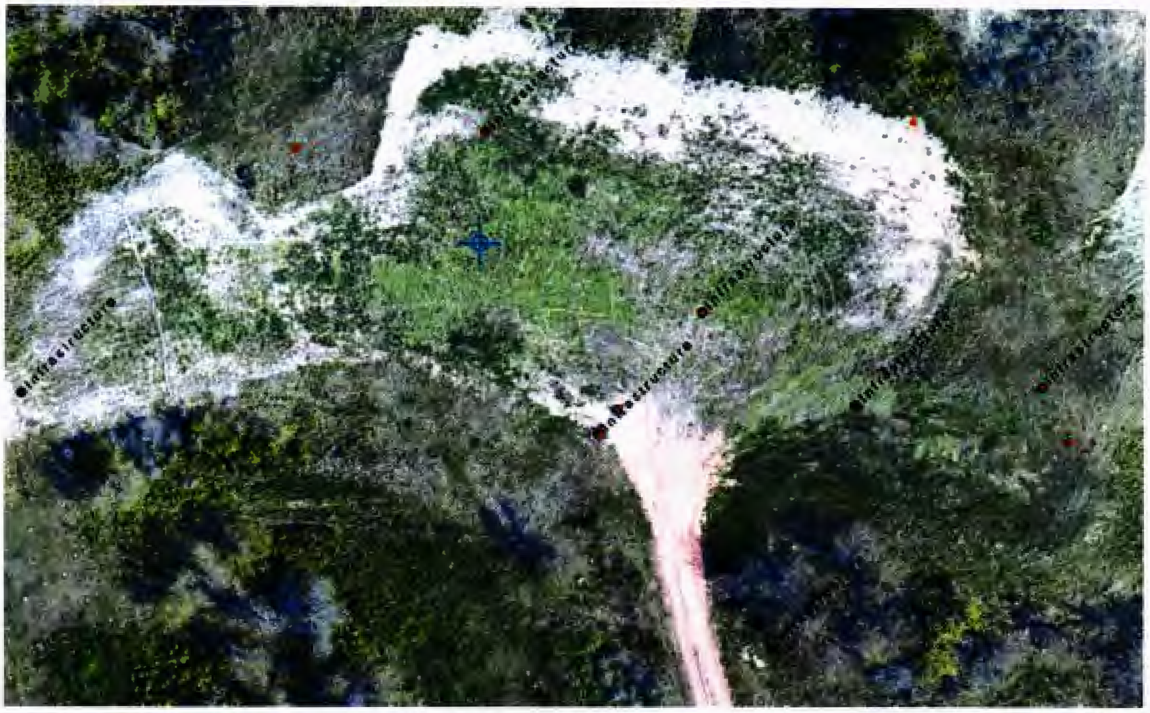


Figure 19 Comparison of results between analyst 1 (orange dots) and analyst 2 (black dots) at Blue Buttes Madison Unit E-331.

Though the identification of infrastructure is not significantly dissimilar among analysts with different levels of experience, as the resolution of the imagery changes, there is considerable difference in the number of infrastructure points identified at the sites. Table 1 shows a precipitous decline in the number of infrastructure items identified as the imagery resolution drops.

Table 2- Count of detected infrastructure points identified at varying resolutions.

Site	3-cm	6-cm	10-cm
Blue Buttes-Madison Unit D-306	6	4	2
Blue Buttes-Madison Unit E-331	17	8	3
Blue Buttes-Madison Unit G-316	2	1	1
Tioga-Madison Unit N-152 8 5 1	8	5	1
Total	33	18	7

The field team independently tested the analysts by leaving some of the infrastructure unmarked. Conversely some of the more difficult or obstructed infrastructure was marked with orange cones to increase the focus by the analysts and compare the level of detection between the various resolutions

When the identity and location of land cover types are known, for a sample of ground areas, through a combination of field work and personal experience, the information is then used to train the image processing software (i.e., signature development) using decision rules for classifying the rest of the image. These decision rules such as *Maximum Likelihood*

Classification, *Parallelepiped* Classification, and *Minimum Distance* Classification offer different techniques to classify an image. Additional ground truth allows the analyst to evaluate the accuracy of the automatic feature classification and identification algorithm. Evaluation usually includes qualitative and quantitative attributes. Conventional ground truthing usually involves collecting sufficient samples for signature derivation (classifier training) and for classification accuracy assessment. In the case of this study, ground truth was collected in one site only and was used to guide both signature derivation and classification accuracy assessment. Site E-331 was chosen for ground truth collection, as it comprised all the land cover classes of interest, contained evident infrastructure features, and was at its early restoration stage. Although the ground truth was limited, the high spatial resolution imagery (3-cm) was sufficient to visually identify the different ground features and assess their classification accuracy.

The third key element of NDIC approval for reclamation is site contouring. This element was analyzed for slope and drainage using manual techniques. Both DEMs and a slope map derived from DEM were used to visualize site terrain and compare it to the surrounding areas. As was the case for vegetation identification and infrastructure detection, results generated by experienced and new analysts were compared against one another and found no significant differences for contour analysis using these models due to the intuitive nature of the data and visualization tools.

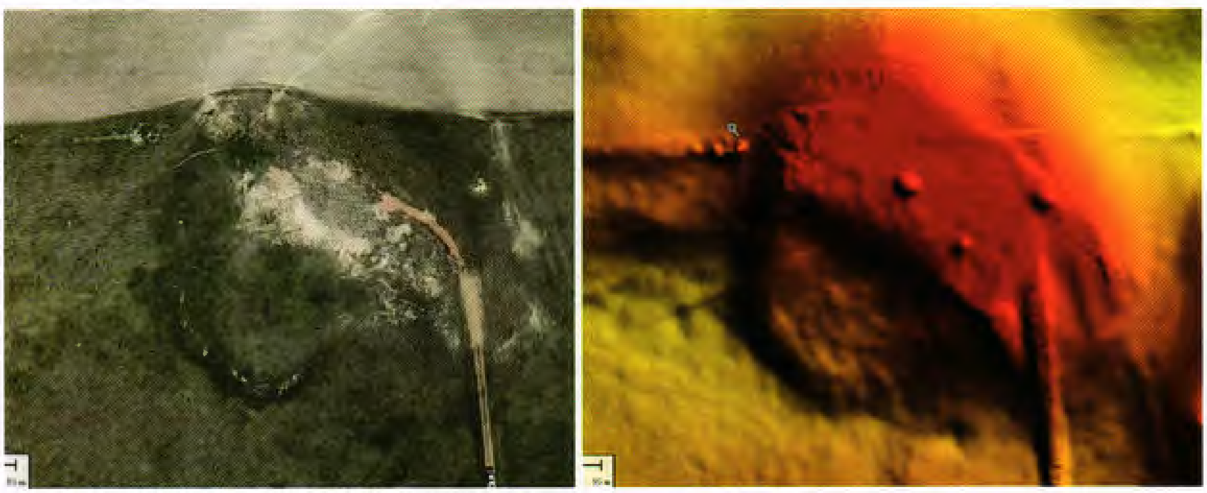


Figure 20: 3-cm image and slope analysis known as a Hillshade image. The slope image can be displayed in Cesium and rendered in 3-D

Data Processing

Two major categories of image classification techniques include **unsupervised** (calculated by software) and **supervised** (human-guided) classification. The choice of one technique over the other depends on the availability of truth data prior to image classification. In unsupervised classification, the software tool itself analyzes the image and groups pixels, based on their inherent spectral similarities, into a pre-determined number of spectral clusters without the user providing sample classes. The user intervenes only to assign the spectral classes to information classes of interest, by examining the image and comparing it to the clusters to determine the main land cover type of each cluster.

In supervised classification, the analyst first identifies the desired classes based on prior knowledge (i.e., ground truth) of the information to derive from the image or the ability (experience and expertise) of the analyst to extract the information by image interpretation techniques. This classification process encompasses two main steps: training the software and classifying the image. Training typically requires ground truth data (collected in the field) or surrogate ground truth data (interpreted by the analyst based on his/her expertise and ability to spectrally identify and discriminate among the different land cover types in the image) to create a *signature* for each feature to be extracted from the image. Classification is performed by applying the signatures to extract the corresponding features in the image, using a decision rule.

When performing classification, two types of classes need to be distinguished; *information classes* and *spectral classes*. Information classes are those ultimate categories the analyst desires to map, such as different forest types, different crops, water, etc. Spectral classes are clusters of pixels that are spectrally similar in the different spectral channels of the data. The objective is to match the spectral classes in the data to the information classes of interest. Rarely is there a simple one-to-one match between these two types of classes. An information class (e.g., forest) may contain multiple spectral classes (i.e., *sub-class*). In the forest example, each spectral class may simply be a spectral variation of the forest class under different conditions (e.g., age, species, density, shadowing, or variations in scene illumination). To assign spectral classes to information classes, the analyst usually examines the image and its classification to decide what spectral class corresponds to what information class. Supervised classification was the method we used in this study because of ground truth availability. Ground truth data used to carry out the classification was collected in one representative site (E-331) and was used as a guide to identify similar features and training sites in other sites. Where ground truth was not collected, spectral recognition of the different classes was based on the spectral appearance (color) of the class as compared to its appearance in the ground truth.

Figure 21: The E-331 Site control vegetation plots (red arrows identifying yellow plot boxes).

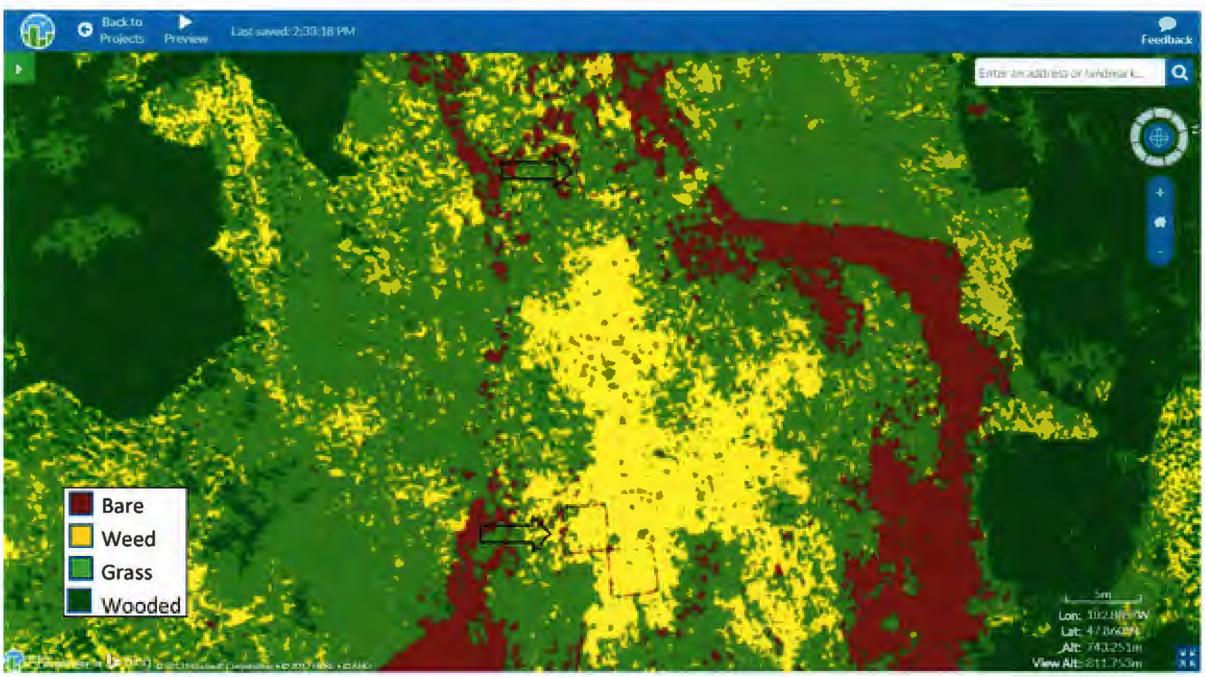


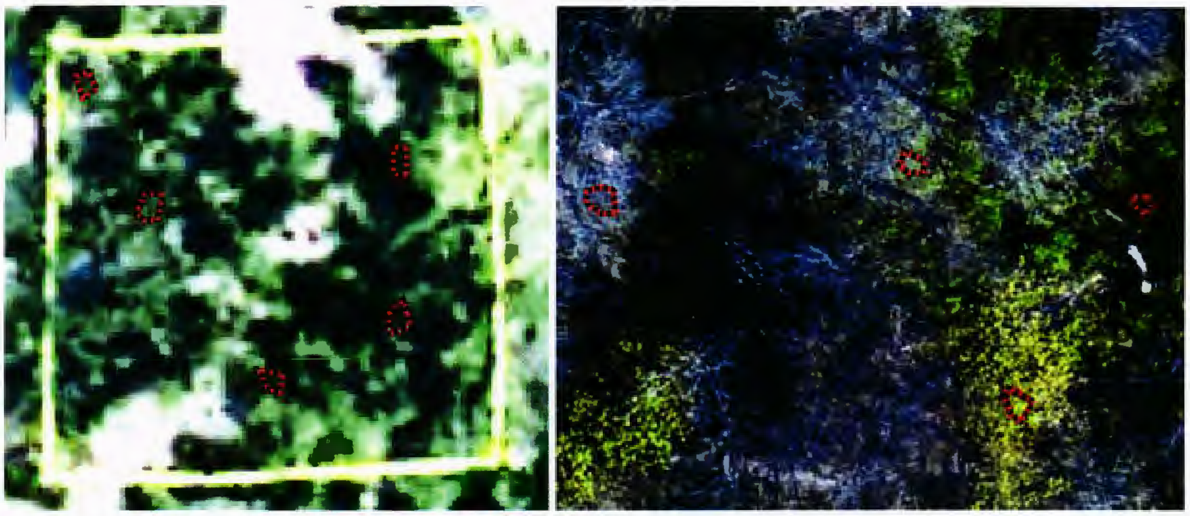
Figure 22: The same data from the E-331 Site displaying the spectral recognition of vegetation classes inside of the reference plots

By visually analyzing the land cover in the ten sites using the high-resolution imagery, we identified four broad information classes: **Bare soil, Weed** (invasive vegetation), **Grass** (mixed native vegetation), and **Wooded** (trees and bushes). Except for the Weed class, each information class contained multiple spectral classes, which required multiple training sites. Spectral variations in bare soil were due to soil types, moisture content, oil/gas contamination, and scoria content. The Grass class was characterized by a variety of grass types, densities, oil/gas contamination, and growth conditions. Wooded class was the most diverse category due to varied tree and bush species, texture, density, and shadowing (see Figure 8). Weed class was the most spectrally homogeneous land cover due to its broad leaf plant structure and uniform ground coverage (see Figure 8), resulting in fairly distinct spectral characteristics.

Erdas IMAGINE was the software we used to conduct our supervised classification on the high-resolution RGB imagery. To extract all the four land cover types accurately, it was important to choose training sites that covered the full range of variability within each land cover type to allow the software to accurately classify the rest of the image accurately. The image classification software uses these training sites to identify spectral classes for each land cover in the entire image. In other words, the classifier uses pixels of known classes to identify pixels of unknown classes.

Because training samples are critical in creating feature signatures, our selection of training samples was carried out by carefully selecting small, homogenous clusters of pixels that correctly represent the feature of interest without including pixels from other features (Figure 8). Inclusion of mixed pixels in the training sample results in confusion of the feature of interest with other features in the image. To capture the spectral variation of a land cover class, due to factors mentioned earlier, we selected training samples for each class from multiple locations in the image. In some cases, examination of training sample spectral diversity, signature scatter plots, or classification results led to iterative training samples to refine feature signatures, which produced better results.

(a) (b)



(c) (d)

Figure 23: Example of training set selection for Bare Soil (a), Weed (b), Grass (c), and Wooded areas (d). The training sets must be representative samples for each land cover class in the image. Notice the high spectral variability in the wooded (forest) class.

Once the process of training samples was finalized, class *signatures* were derived using the *Signature* tool in Erdas IMAGINE. Each signature is a statistical characterization of the reflectance for each information class. The signatures were analyzed and refined to ensure each information class was well represented without being confused with other information classes. Unlike conventional signature derivation, where one signature file contains all the signatures representing the different information class in the image, a signature file was created separately for each information class so each class is extracted and refined separately. This allowed the team to examine the performance of each signature and optimize its performance independently using a threshold technique to obtain the optimum results for each information class. Once satisfied with the signatures, they were applied to the entire image to extract the four information classes of interest.

The common supervised classification algorithms are *maximum likelihood*, *Parallelepiped*, and *minimum-distance* classification. In our supervised classification process, we used the *Maximum Likelihood* classifier (decision rule). The Maximum Likelihood Classifier (MLC) assumes that the members of each class are normally distributed in feature space. MLC is a pixel-based method and is more accurate than the *minimum distance* or the *parallelepiped* decision rules. It is the most accurate of the classifiers in the ERDAS IMAGINE system because it takes the most variables into consideration. It assigns each pixel to one of the different classes based on the means and variances of the class signatures.

Using the feature class signatures derived from the training samples as described above, we applied the MLC to each image of the ten sites to create a thematic layer for each information class in the image. Each thematic output, for each information class, was thereafter examined for accuracy and refined, if necessary. The four thematic layers, one for each information class (Bare, Weed, Grass, and Wooded), were then merged into one thematic layer. Pixels that remained unclassified (i.e., did not get assigned to any of the four classes) were re-examined and carefully re-classified into one of the four classes they most likely fit. The resulting classified image is a mosaic of pixels, each of which belong to a particular theme, and is essentially a thematic "map" of the original image.

Post classification

Classified data often manifests a 'salt-and-pepper' appearance due to the inherent spectral variability encountered by a classification when applied on a pixel-by pixel basis. It is often desirable to "smooth" the classified output to show only the dominant (presumably correct) classification. Post-classification processing is the process of removing the noise and improving the quality of the classified output.

One technique of classification filtering is the application of a majority filter. When a majority filter is applied, a moving window (defined by the analyst: 3x3, 5x5, or 7x7) passes through the classified layer and the majority class within the window is determined. If the center pixel in the window is not the majority class, its identity is changed to the majority class. If there is no majority class in the window, the identity of the center pixel is not changed. This process may be applied more than once if the data requires additional filtering. Filtering may also involve a user-specified minimum area for any given land cover type that will be maintained in the smooth output.

Majority filtering was the process we applied to our output classification layers to eliminate noise and clean the data. The results of this operation are illustrated in Figure 24. It should be noted that smoothing an image does not necessarily make it more accurate because some small features may wrongly be eliminated in the process. However, more often than not, smoothing is advantageous to reduce the noise in an image and make classes more realistic. This is especially true when detail is not important.

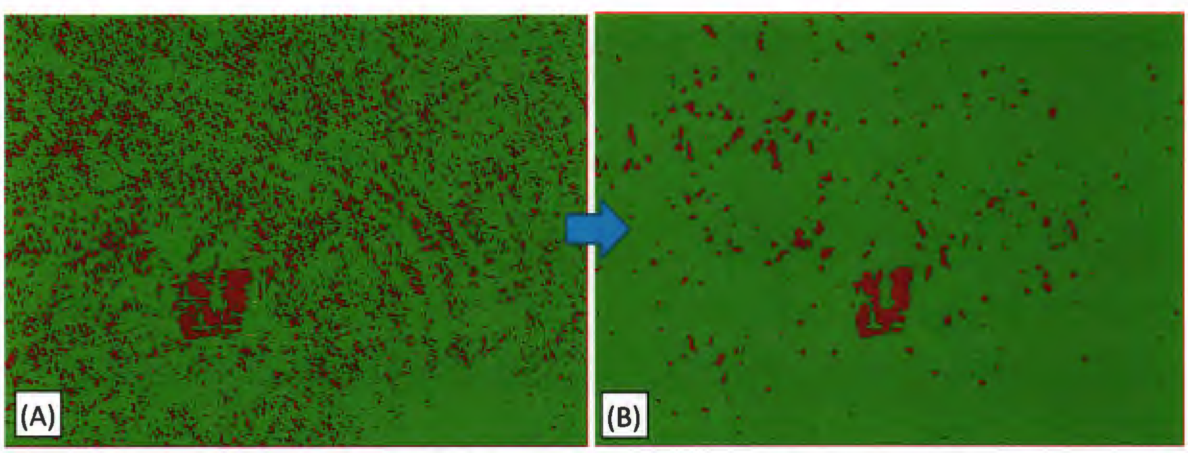


Figure 24: Effect of Majority filter; noise pixels in the unfiltered image (A) are removed and the resulting image (B) is smoother

Classification accuracy assessment

Classification accuracy assessment involves the comparison of classified map to the ground truth data to determine the accuracy of the classification process. Usually, the assumed true data is derived from ground truth (i.e., field data collection), but 'surrogate' truth data (e.g., data interpreted by experienced analysts from high-resolution imagery) may be used in lieu of actual field data. For low-resolution imagery, however, image interpretation is difficult and not reliable. In this case, ground truth is usually required to avoid any confusion. It is usually not practical to ground truth or otherwise test every pixel of a classified image. Therefore, a sample set of reference pixels is usually used. In addition, the evaluation process may combine qualitative and quantitative analysis to determine the quality and accuracy of the classification. With high resolution imagery, as was the case in this study, "surrogate truth data" may be derived visually because information classes are fairly easily identified in 3-cm spatial resolution imagery.

In this study, land cover classification accuracy was first evaluated by visually comparing the output classes from the classification process to the corresponding land cover types in the 3-cm imagery. Figure 25, for example, clearly shows good agreement between the classified image and the original image. Aside from ground truth, by simply examining the different land cover fields in the image and their classification in the thematic image, one can clearly establish a strong correlation. Wooded areas (trees and bushes) and bare soil are the most noticeable due to their natural appearance to the naked eye. The two classes that may need ground truth to confirm their classification accuracy are grass and weed, due to their spectral (color) similarities.

To validate the accuracy of our land cover classification, we overlaid the polygons of truth data (data collected in the field) on top of the image and the classified thematic layer (Figures 26 & 27). By analyzing each ground truth polygon individually, both in the image and the classification layer, it can visibly be determined that a strong agreement exists between the two images. The most obvious agreement can easily be identified for wooded and bare soil areas, sometimes down to individual trees or small patches of bare soil. For the more challenging land cover classes; i.e., weed and grass, a closer look at the ground truth polygons also displays good agreement. For example, polygons labeled as "Forb dominance" and "Grass dominance" is clearly classified as dominantly Forb and Grass, respectively. Likewise, polygons labeled "mixed grasses" and "sparse vegetation" are accurately classified accordingly. Finally, areas labeled "Undisturbed vegetation" are correctly classified as a mix of bare soil weed, grass, and wooded.

These findings are consistent with the results obtained in the feasibility study conducted prior to the spring and fall 2016 imagery collections. The research team who conducted the preliminary study was pleased at how well the results of the manual analysis correlated to the automated statistical analysis.

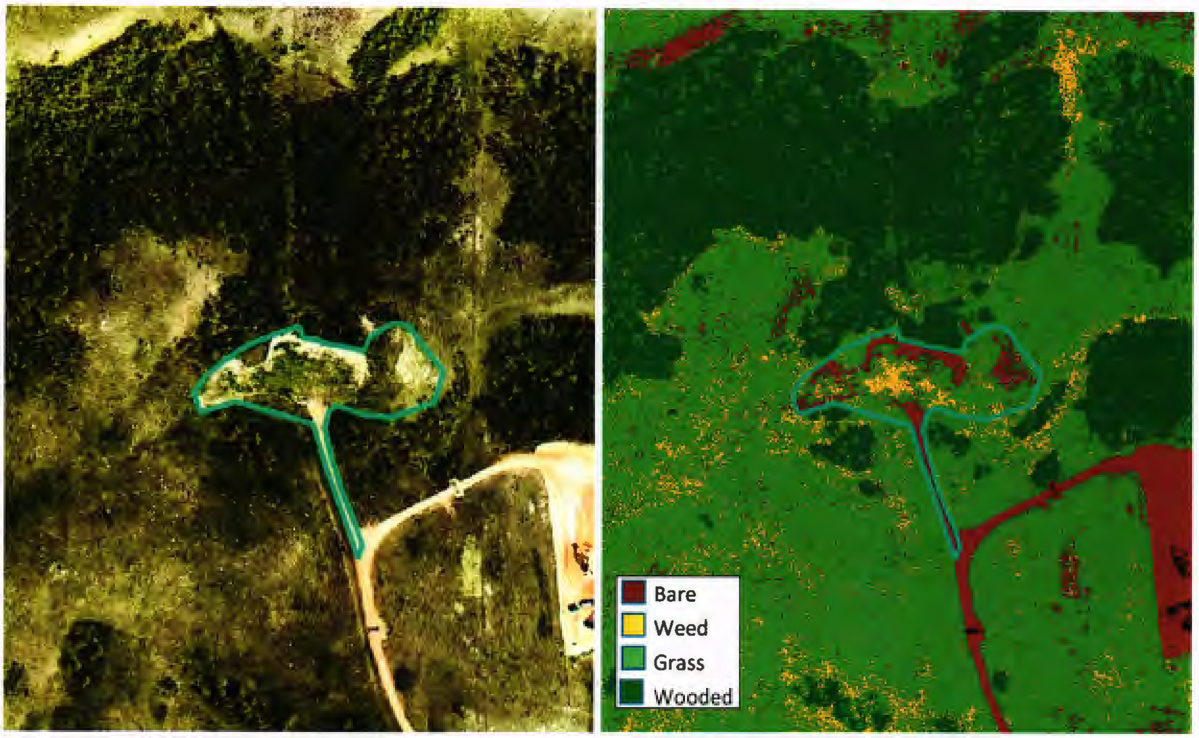


Figure 25: Comparison between land cover features in the image and its corresponding classification layer

From these results, it can be concluded that the classification process of the four land cover types has proven reliable and can confidently be used to automatically identify these features in other areas using high resolution remotely sensed imagery. Indeed, taking site E-331 ground truth as a reference for land cover identification, we applied the same processing and analysis methods to assess the land cover classification in the other nine sites. Though no ground truth was available in these sites, qualitative analysis did show similar results. The results for the 10 sites are presented in the following section – *Results and Analysis*.

Nevertheless, although visual qualitative assessment established enough confidence in the accuracy of the classification, it may not be sufficient to determine a site reclamation condition level. For this type of assessment, a more reliable validation of the accuracy of the classification may require ground truth samples collected across multiple sites. However, because emphasis was more on the accurate identification and mapping of weeds (invasive vegetation) and bare soil (damaged surfaces), visual analysis was appropriate to correctly identify these two categories without intensive collection of vegetation samples during the ground truth. The comparison between the vegetation analysis of the imagery (figure 26) and post processing classification of the same data (figure 27) showing the strong correlation between the two analysis types. However, it is important to quantitatively compare the distribution of the land cover composition and types inside the pad boundaries and in the surrounding areas to determine the status of a site as to its re-establishment to its native condition. This quantitative method of analysis is presented in the following section – *Results and Analysis*.

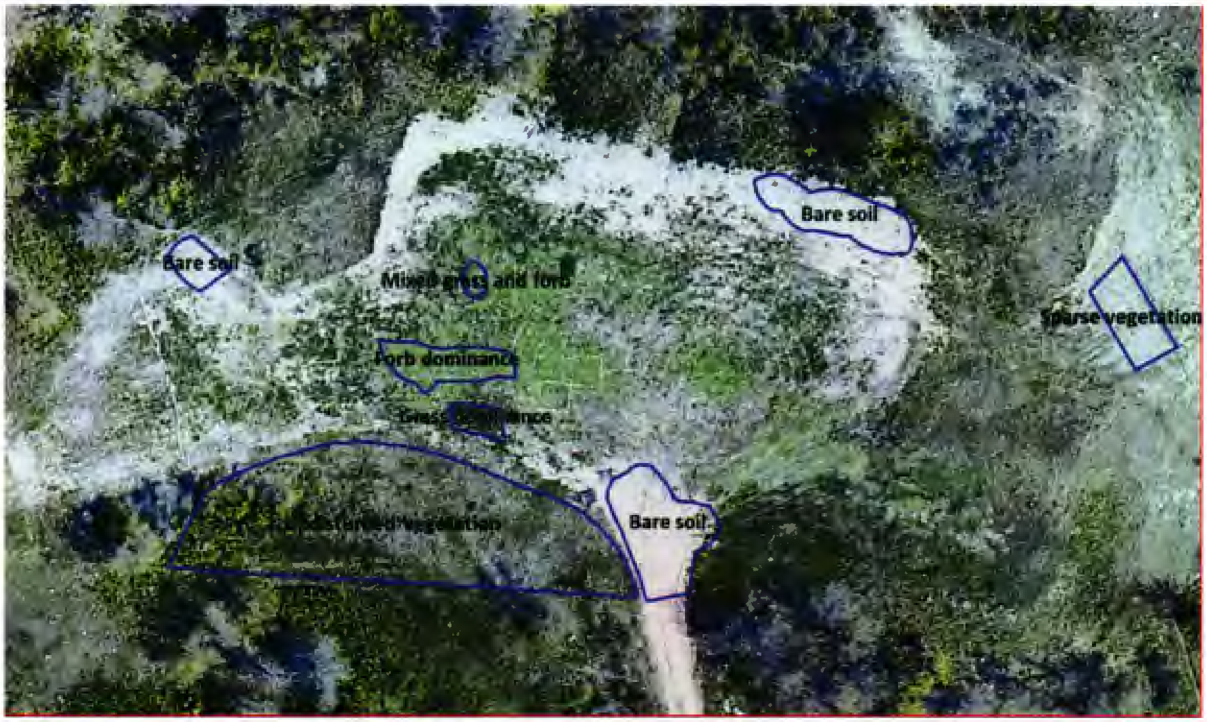


Figure 26: Ground truth analysis of RGB image at Site E-331

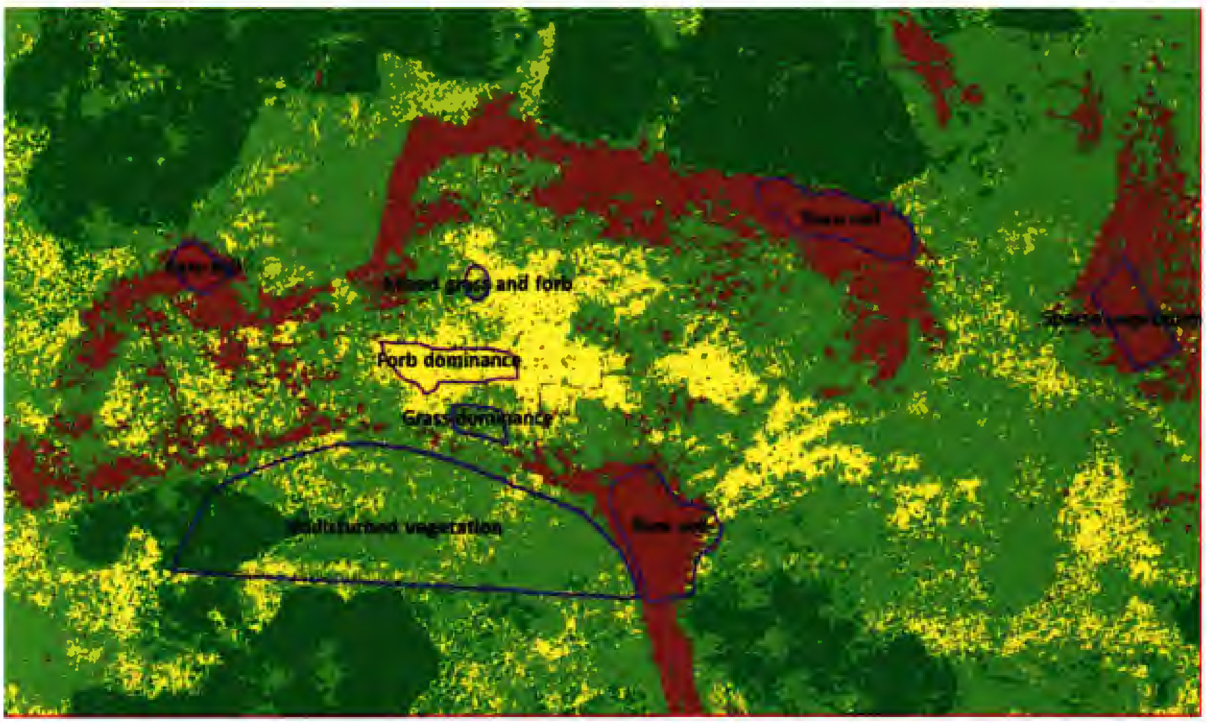


Figure 27: Comparison between ground truth and classified land cover features. Results show good agreement for all cover types

The accuracy assessment process was important as it established the credibility of our analysis when evaluating the site restoration conditions. In that regard, in term of land cover characterization, an adequate evaluation approach was to qualitatively and quantitatively compare the land cover composition inside and outside the pad boundaries to identify any inconsistencies. Successful reclamation must meet minimum requirements for land cover classes that are comparable to those on undisturbed lands adjacent to the lease[15]. If the distribution of land cover classes within the pad boundaries matches the distribution outside the site, it can be assumed the site has been re-established for those areas which are re-established to a like purpose. For example, a field site in pasture will be easily recovered to a like state and matched. For areas surrounded by conventional crop land however, additional substantive guidance from the regulatory agency/landowner may be required to firmly establish the requirement prior to the start of reclamation. In either case though, this aerial imaging capture and analysis can easily discern and display the effectiveness of the reclamation when the requirement is well understood.

Results and Analysis

This section focuses on two main issues; automatic land cover classification and characterization inside and outside the pad boundaries and infrastructure detection in HDEO imagery.

Land cover analysis

After establishing a processing methodology and demonstrating the reliability of the land cover classification process, we processed all the sites and conducted a thorough visual analysis to ensure the results were adequate and consistent across all sites. Robustness and repeatability of the methodology was important to establish the feasibility of remotely sensed imagery and automatic feature detection algorithms for this type of applications. The end target of this study is to determine if aerial imagery can be a reliable substitute for ground surveys to estimate the reclamation phases without having to perform onsite visits and measurements.

As the following results will show, HD-EO imagery and automatic image processing algorithms have demonstrated numerous advantages in many applications. Thanks to its ability to exhibit natural representation of the environment, remotely sensed imagery has become increasingly important to many researchers and decision makers. Important information may be extracted from RGB imagery, be it visually or automatically. As can be easily depicted in Figure 27, a quick look at the RGB imagery alone provides sufficient information regarding the land cover conditions across the entire extent of the image. A closer examination will reveal other features of interest, such as dirt and debris piles, infrastructure, surface degradation, etc.

An obvious advantage of aerial imagery is its ability to provide a synoptic view of the entire reclamation site and its surrounding areas. This allows the analyst clear visibility over a wider area than the field visits, allowing him/her to perform an instantaneous evaluation of the conditions inside and outside the site from his/her desktop, without having to visit the area. Classifying the RGB imagery alone can provide significant amount of information in a very short

[15] http://saskatchewanoilreport.com/oil-well-reclamation-processes-across-the-bakken/

time. From RGB imagery, an analyst can easily distinguish sites at different reclamation stages. In Figure 28, for example, it can clearly be seen that site D-306 is at an early stage of reclamation and site E-143 is at an intermediate stage.

Another advantage of synoptic view of remotely sensed imagery is its broad coverage, providing the ability to analyze and determine any issues or areas of interest beyond the immediate areas of the wellsite which may have linkage for the purposes of reclamation activity and may require further investigation. For example, by examining the image of Site D-306 (Figure 28), one can easily spot a noticeable feature at the upper-right corner of the image, potentially suggesting something of interest outside the permitted pad boundaries. However, on closer inspection it can easily be seen this is a farmer's rock pile consistent with standard farming practices. Although, this type of analysis may be outside the scope of this study, these potential anomalies will be addressed in a little more detail later in the results section.

Adjacent Reference LandS

The advantage of having an aerial image based inspection capability is that the recovering areas can be referenced against adjacent undisturbed lands to make an ecological evaluation. In many cases the adjacent lands to a reclamation site cannot be used as a comparison or represent a defined standard for reclamation activities due to markedly different land use[16].

Site Name	Ref. Area (acres)	Pad Area (acres)
D-306	29	3
E-331	32	1
F-220	34	4
F-429	29	3
G-316	36	1
H-408	39	2
E-143	39	1
F-144	36	1
N-130	39	2
N-152	39	0.4
AVERAGE*	35	2
*Does not include lease/access road area		

Table 3 – Approximate ratio of reference area and the pad area for each site

Another important aspect to the requirements of an imagery based inspection and evaluation was how much land around a site represents "enough" of a reference to make a proper evaluation. The cost of the collection sorties in terms of flight time, fuel, etc. and the processing time and data storage components were not defined. The ratio of the overall

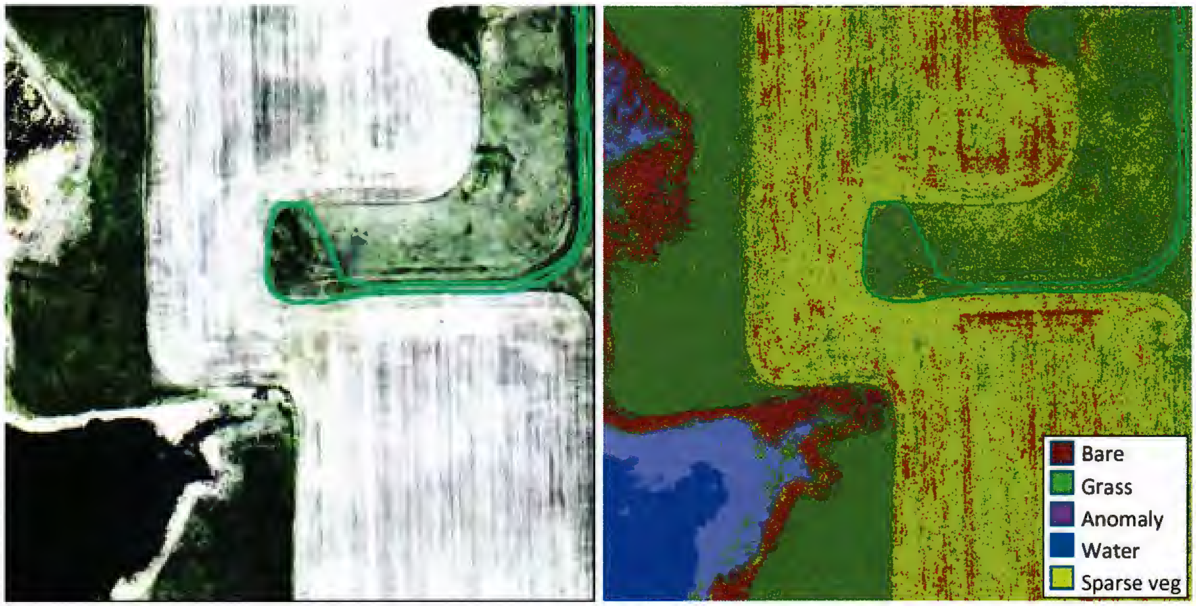
[16] For example, if the area surrounding a well site is cropland, the reclamation activity may be intended to recover this site to support that activity rather than pasture and a different reclamation effort would need to be planned appropriately. See site D-306, E-143 and F-144 for examples where cropland surrounds the well site and the landowner could prefer recovering the site directly to farmland rather than pasture.

collection area to pad area was randomly selected during this study. After the conclusion of this research discussions will need to take place between stakeholders to determine if the imagery ratio used for the research was sufficient or deficient and must also consider the cost benefit aspects.

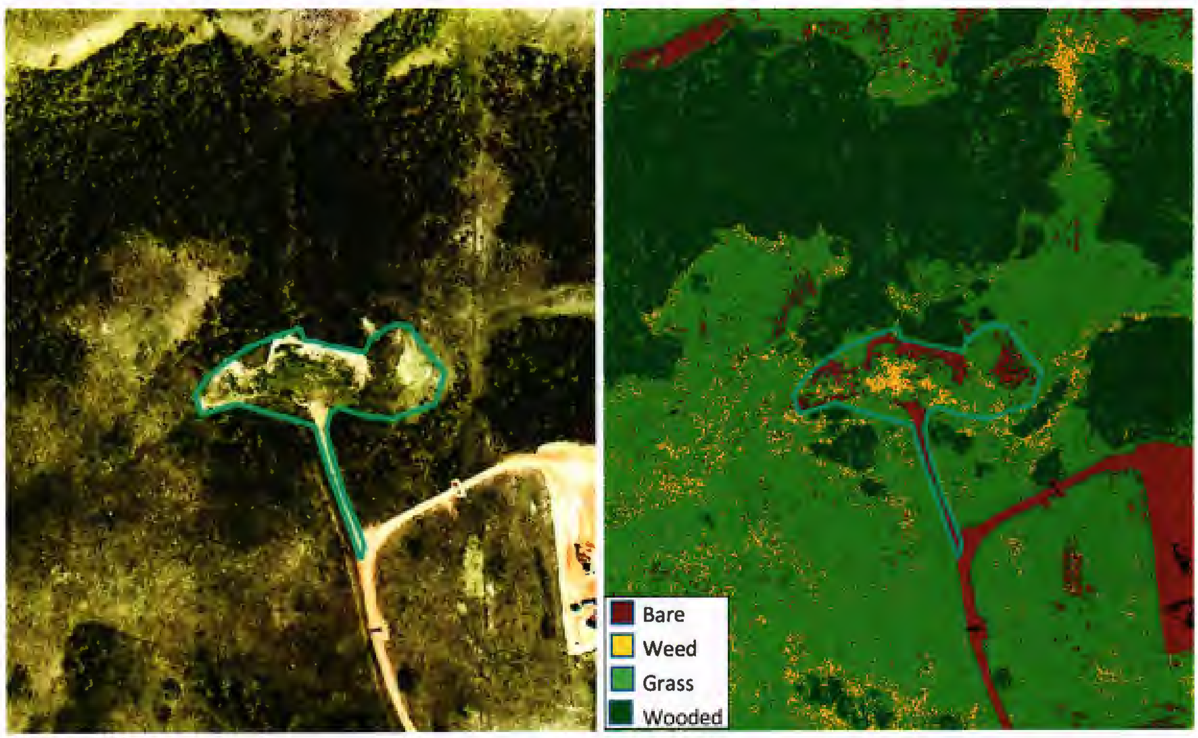
During pre-processing of the raw data the imagery was cropped into squares of roughly 160,000 m^2 or 39.5 acres. Table 3 shows the ratios of the approximate 39.5 acre reference area to the pad acreage for each site. The average reference acreage for all the sites was 35 acres and the pad area was 2 acres.

Figure 28: Image and classification comparison of in-pad to out of pad areas

(a) Site D-306 (b)

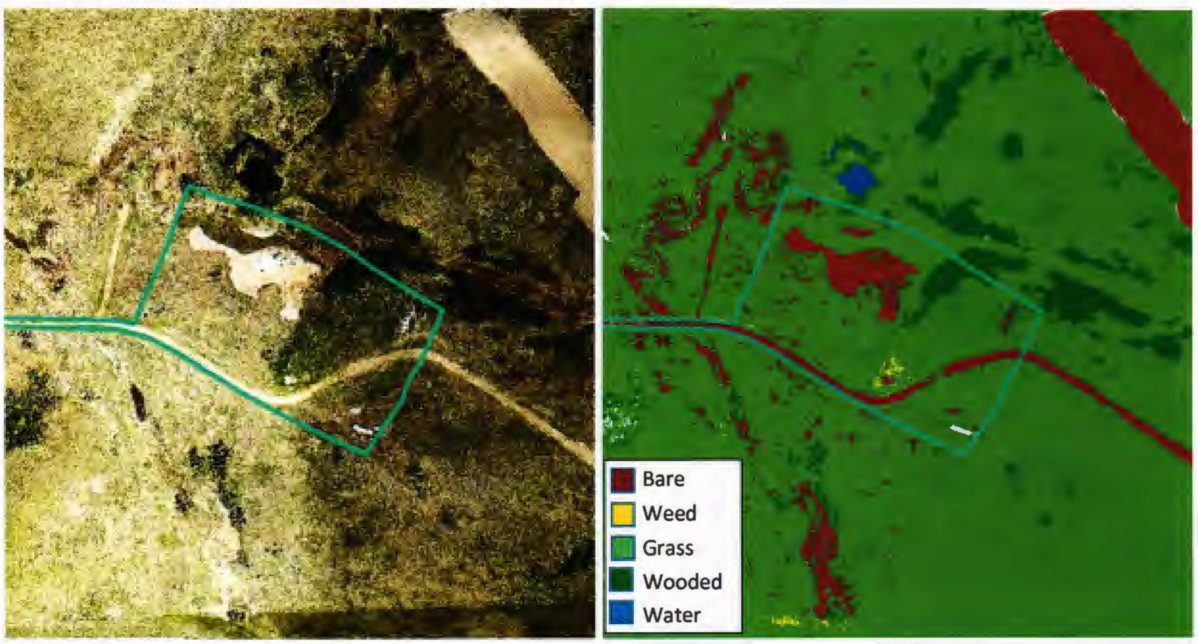


(a) Site E-143 (b)

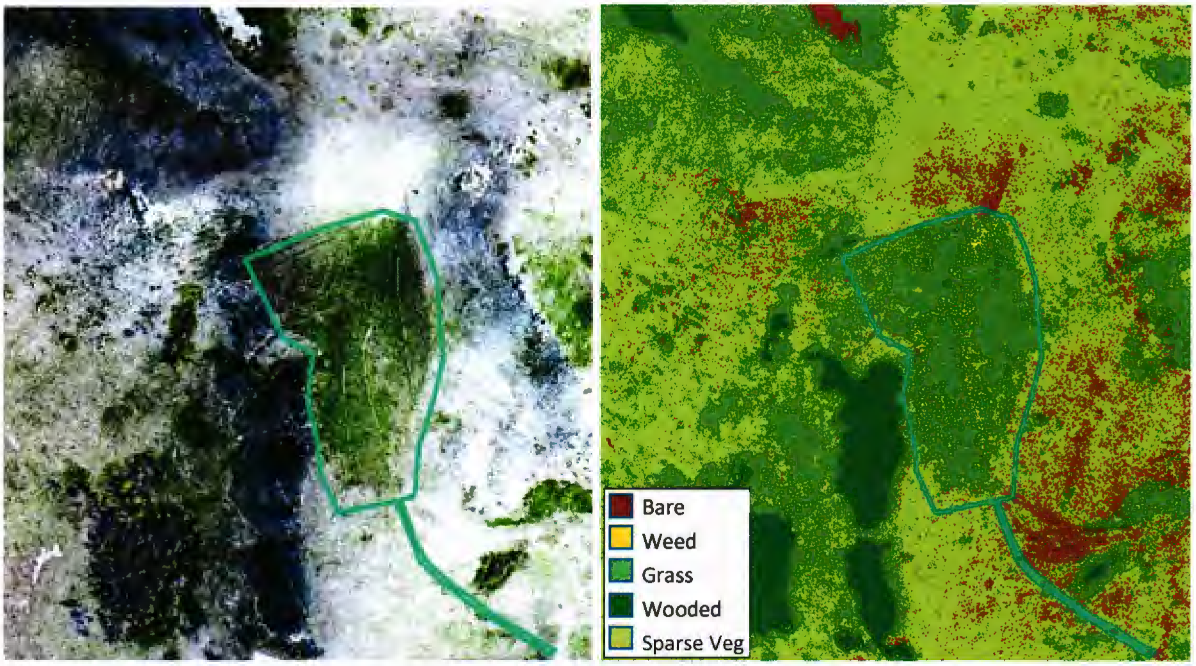


(a) Site E-331 (b)

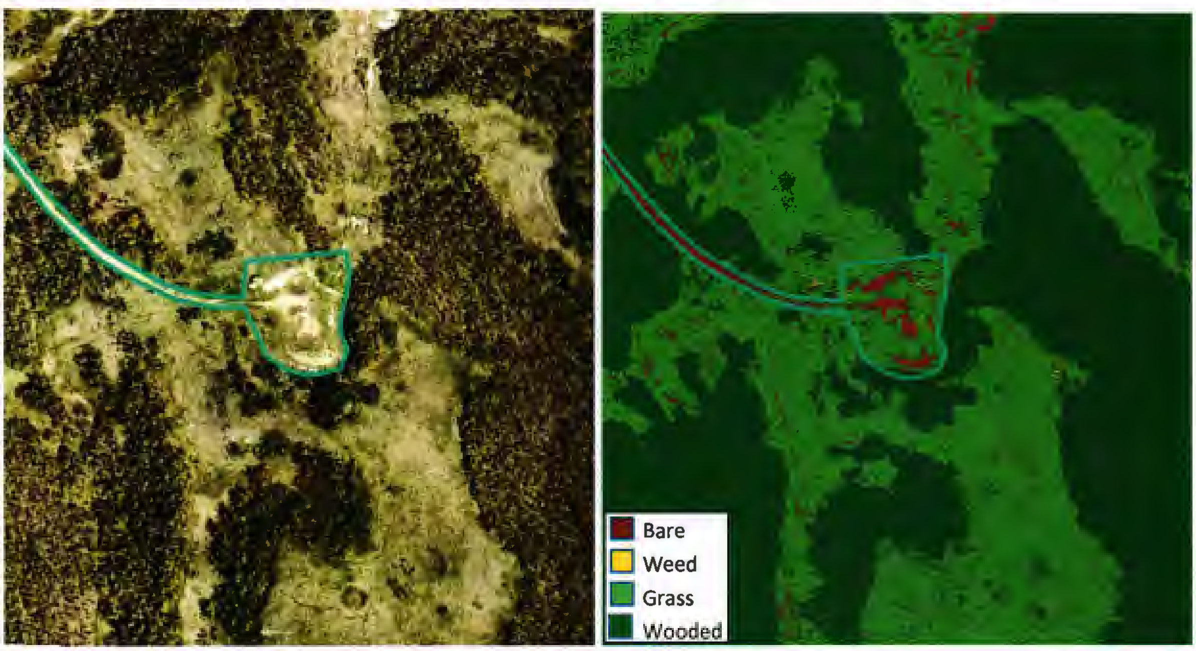
(a) Site F-144 (b)



(a) Site F-220 (b)

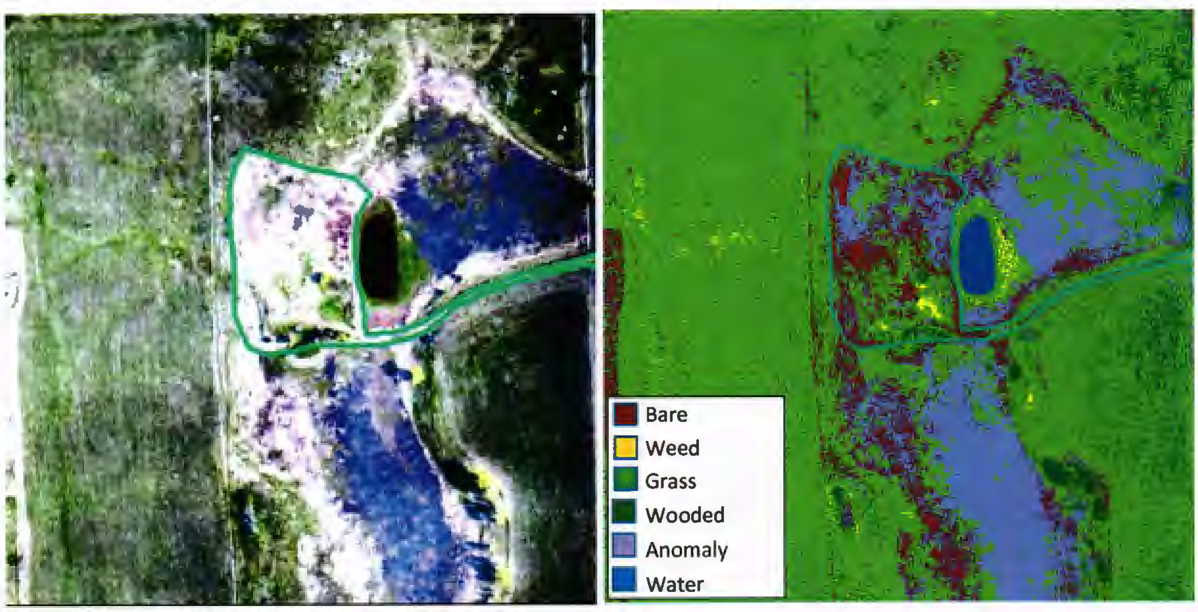


(a) Site F-429 (b)

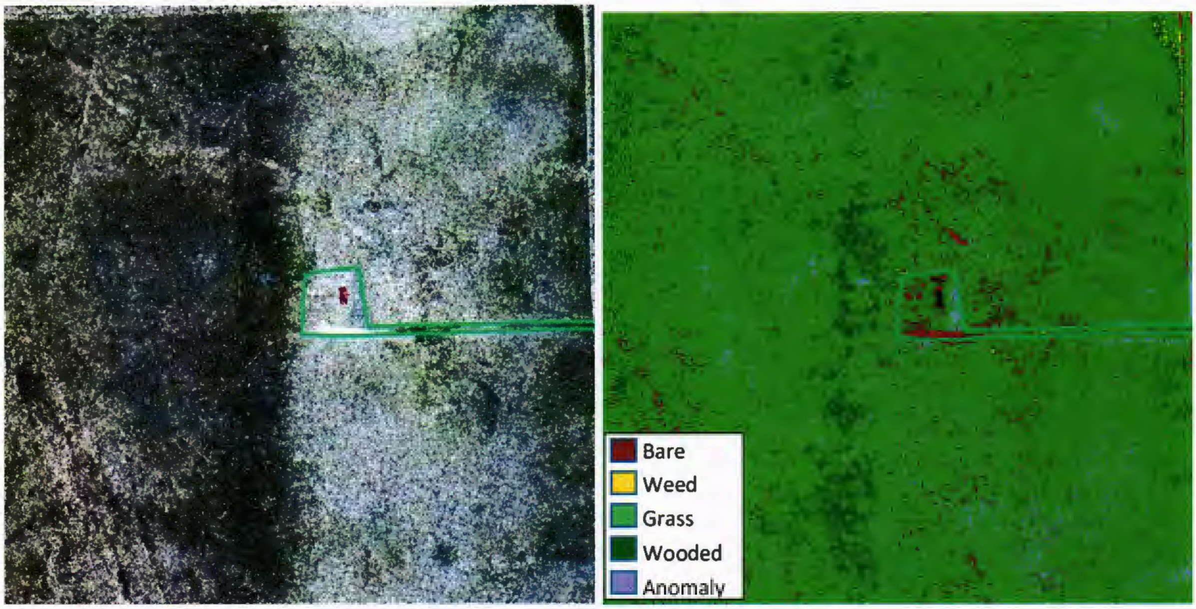


(a) Site G-316 (b)

(a) Site H-408 (b)



(a) Site N-130 (b)



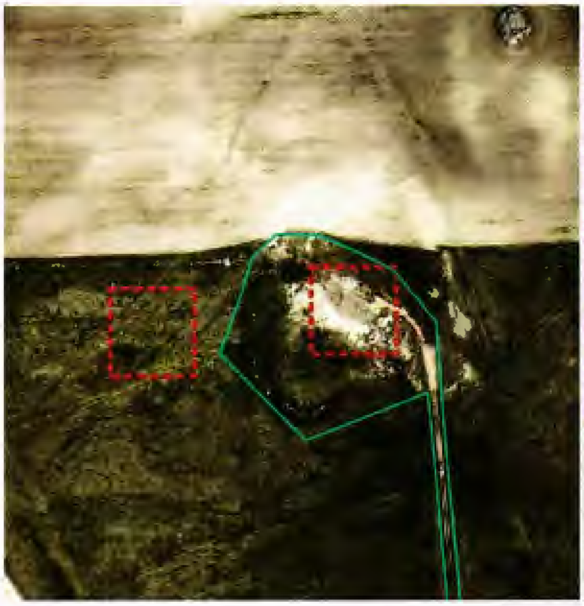
(a) Site N-152 (b)

Regarding the land cover classification, as can be seen in images of Figure 27, a comparison between the RGB image on the left (a) and its classified map on the right (b) shows good agreement, indicating the effectiveness of the classification approach used in this study. The accuracy of the classification was discussed in the *Accuracy Assessment* section, which was demonstrated on Site E-331, where ground truth was collected. The other nine sites showed strong correlation between visual assessments of their classification maps with the RGB images.

Though, without quantitative statistics, visual assessment is inherently subjective and one may not necessarily be able determine the magnitude of the change or damage without measurable quantities. In addition, the objective of this study is not only to assess the accuracy of the classification process, but also to qualify and quantify the site conditions as compared to its surrounding areas using HD-EO imagery to establish its conformity in accordance with North Dakota Administrative Code (NDAC) regulations.

Therefore, to quantify the magnitude of site degradation (or level or lack of restoration) and the introduction of invasive vegetation, a representative 50m x 50m square test area was selected inside the pad boundaries (disturbed area) and outside (undisturbed area), but with comparable land cover makeup (Figure 28). Though, the land formation inside the site may not be identifiable, due to the site disturbance, its surroundings usually provide sufficient evidence to select a comparable test area outside the site. The similarity characteristics between the two tests areas (i.e., squares inside and outside the pad boundaries) were an important factor in comparing their land cover statistics and derive meaningful conclusions. The 50m x 50m test areas, inside and outside the pad boundaries, are represented by the red-dashed squares in each study site in Figure 29 below.

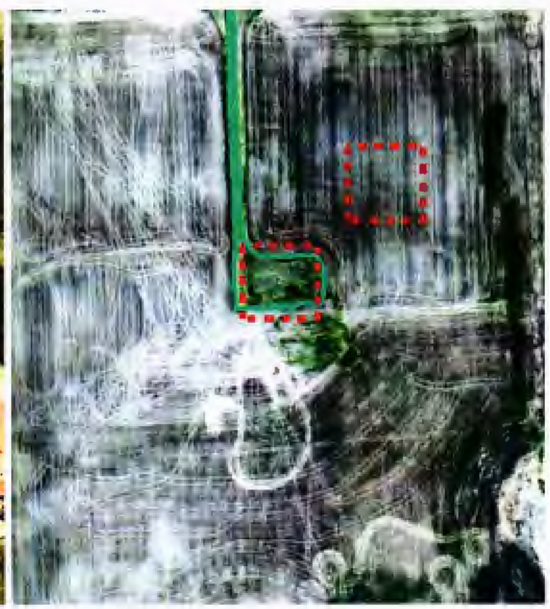
Figure 29: Selection of areas (50x50m) inside of pad boundary and outside pad for comparison.



Site D-306

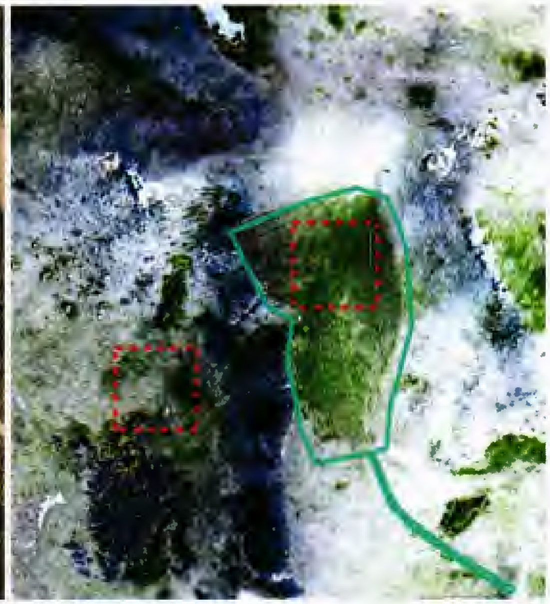
Site E-143

Site E-331

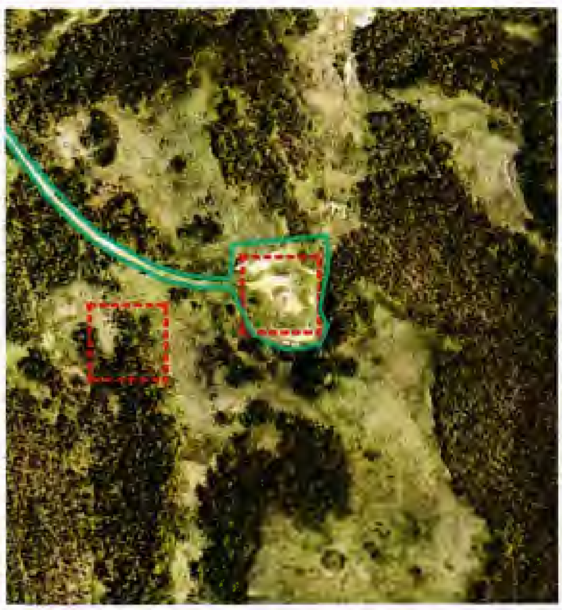


Site F-144

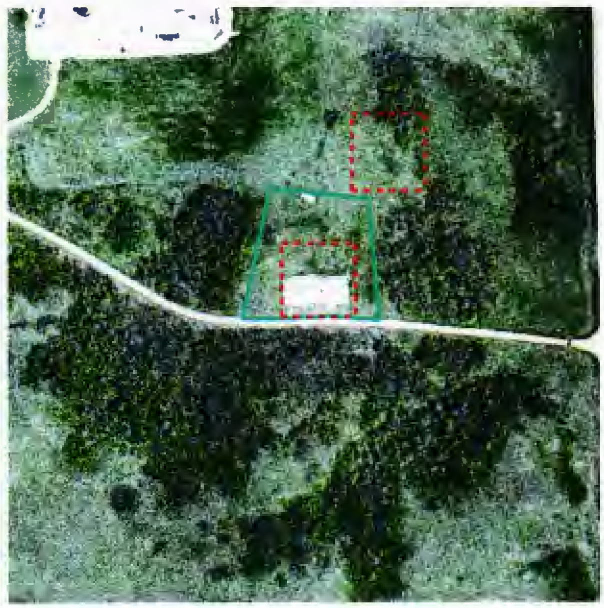
Site F-220



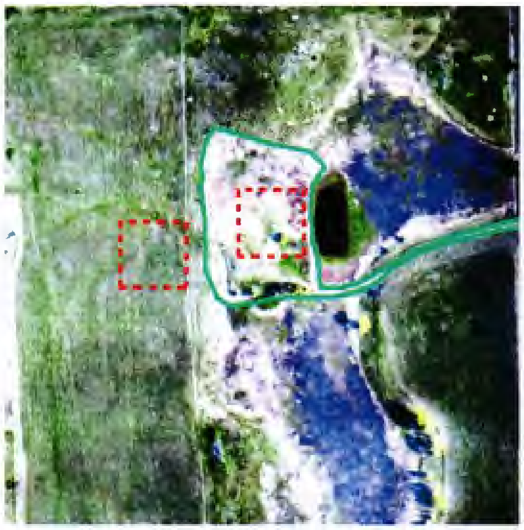
Site F-429



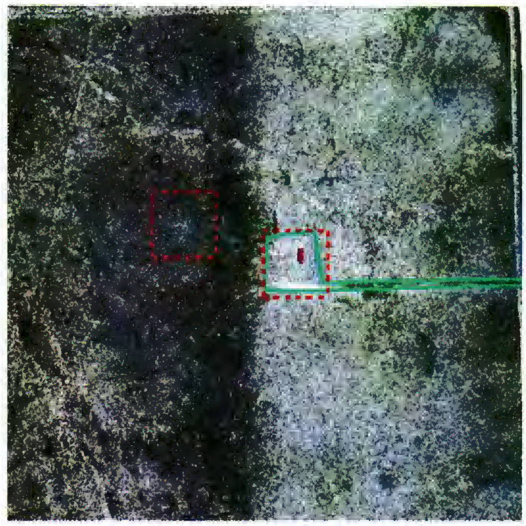
Site G-316



Site H-408



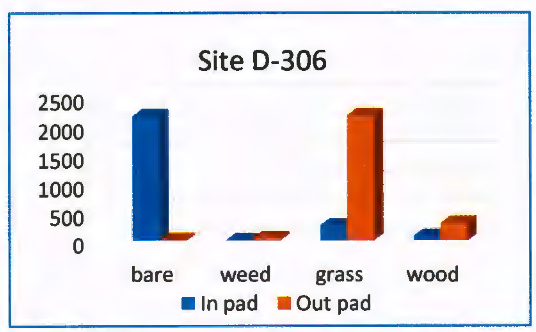
Site N-130

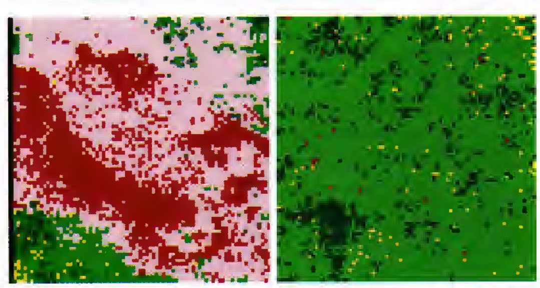


Site N-152

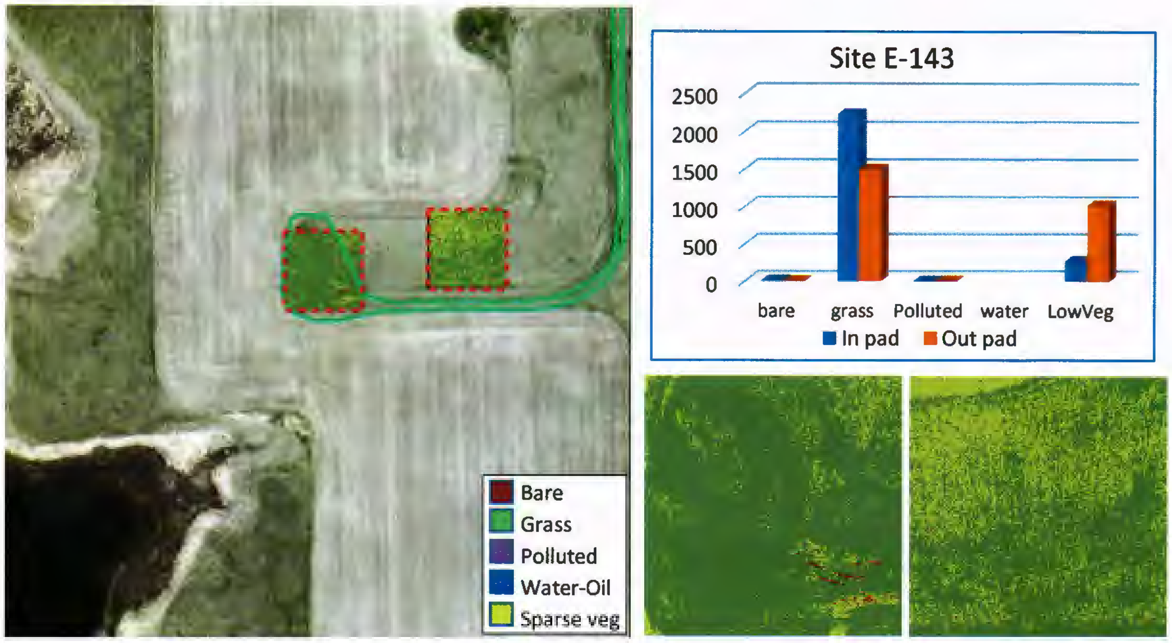
Land cover classes were extracted inside each of the 50m x 50m test areas (inside and outside the site) for all 10 study sites (Figure 30(a)), and statistics were computed for each land cover type to determine the land cover conditions inside and outside the pad boundaries. Table 2 and Table 3 present these statistics, in terms of area (m^2) and percentage (%), respectively, for all 10 sites examined in this study. The magnitude of the differences would provide information on the site restoration conditions. In addition to quantitative analysis, we also conducted a qualitative examination of land cover inside the test areas of Figure 30(a) to support our findings. For the visual assessment, land cover classes were clipped inside each of the test areas so they are easily compared side-by-side, as shown in Figure 30(b).

Figure 30(a)(b): The next series of images shows the quantitative analysis of land cover change inside the pad boundary as compared to undisturbed area outside the pad boundaries (expressed in m^2 in charts).

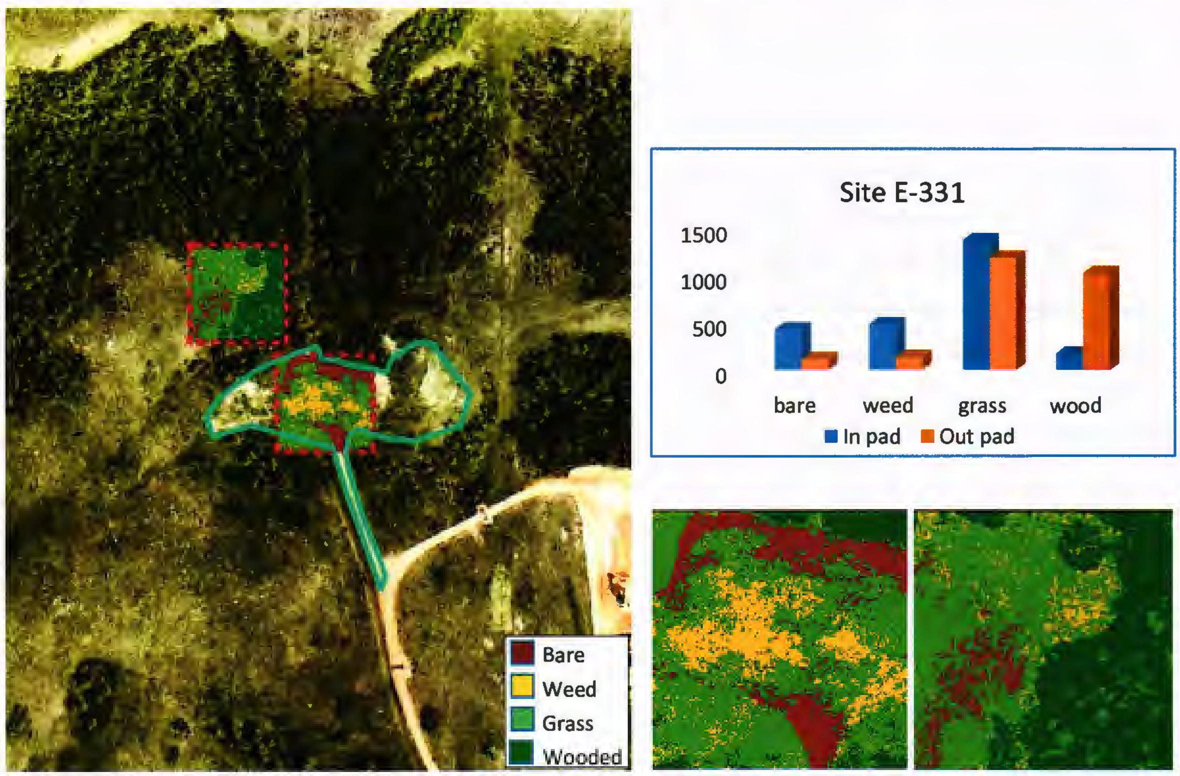




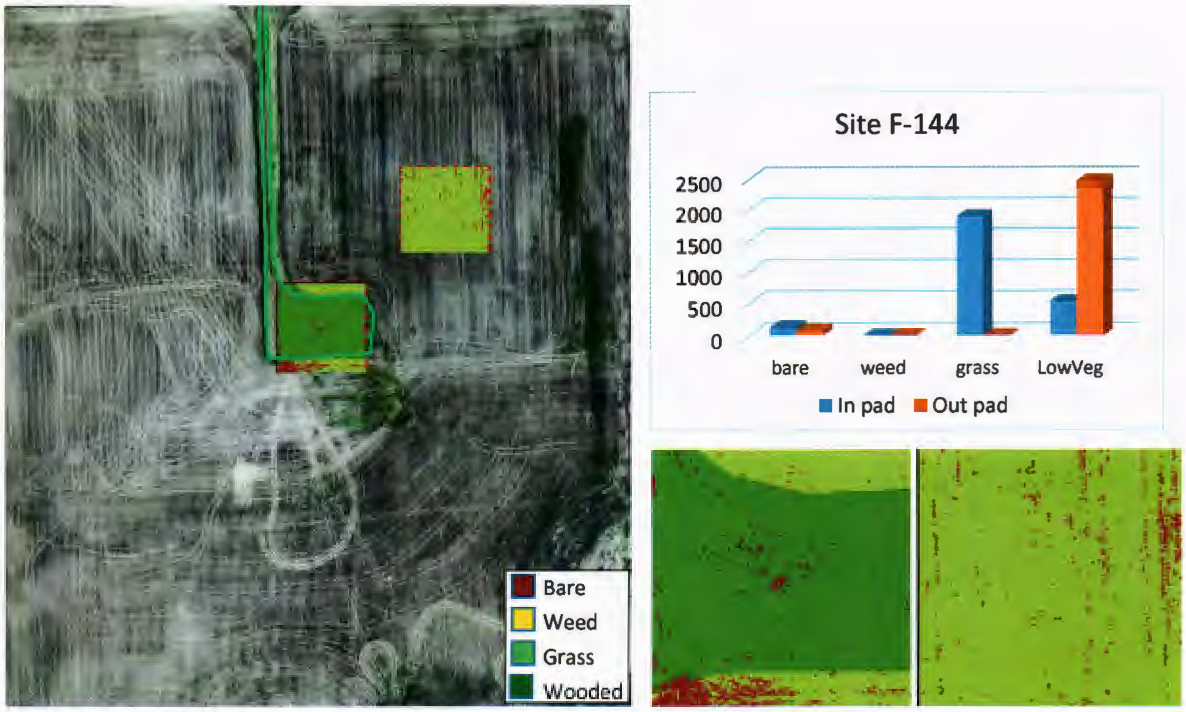
(a) Site D-306 (b)



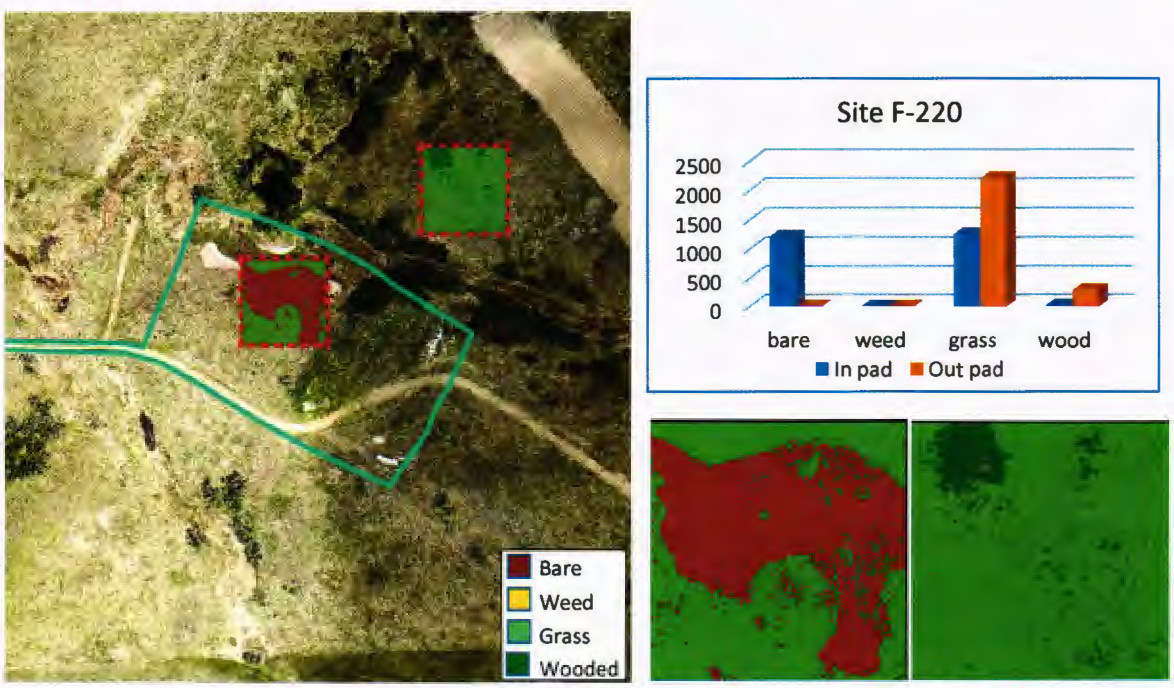
(a) Site E-143 (b)



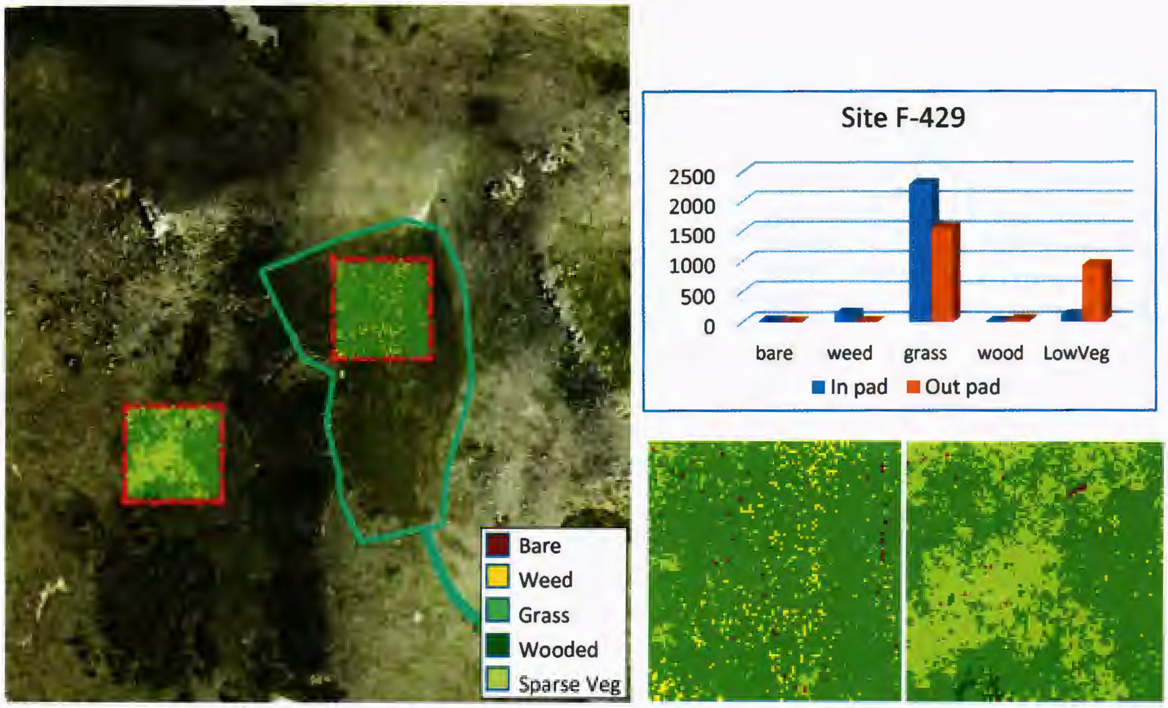
(a) Site E-331 (b)



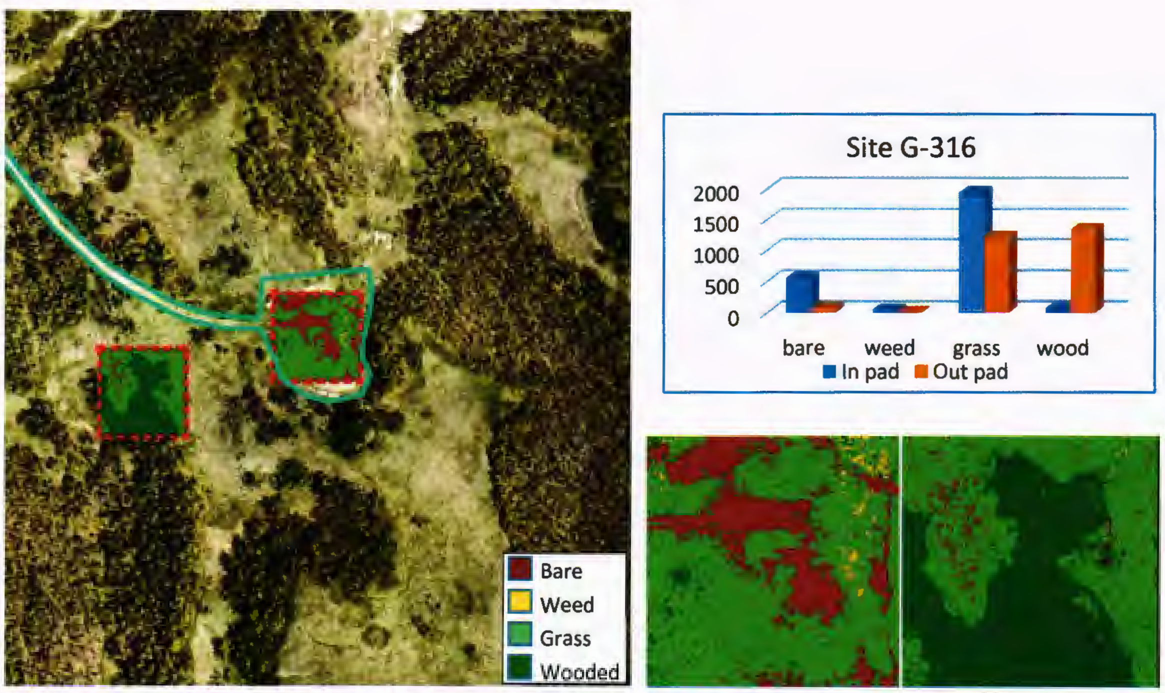
(a) Site F-144 (b)



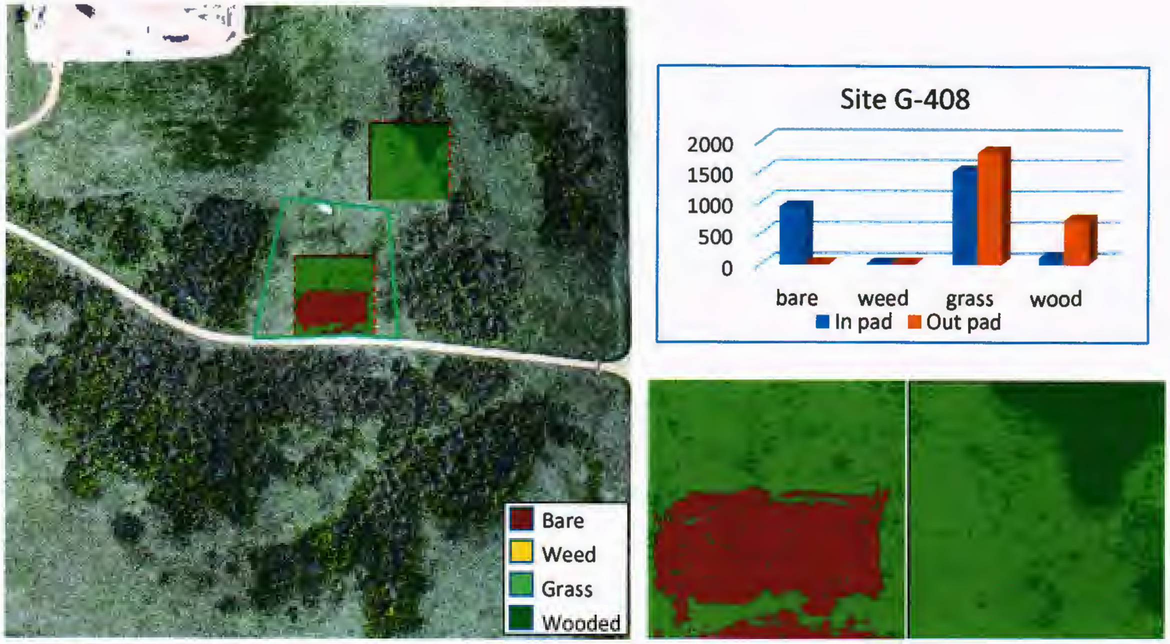
(a) Site F-220 (b)



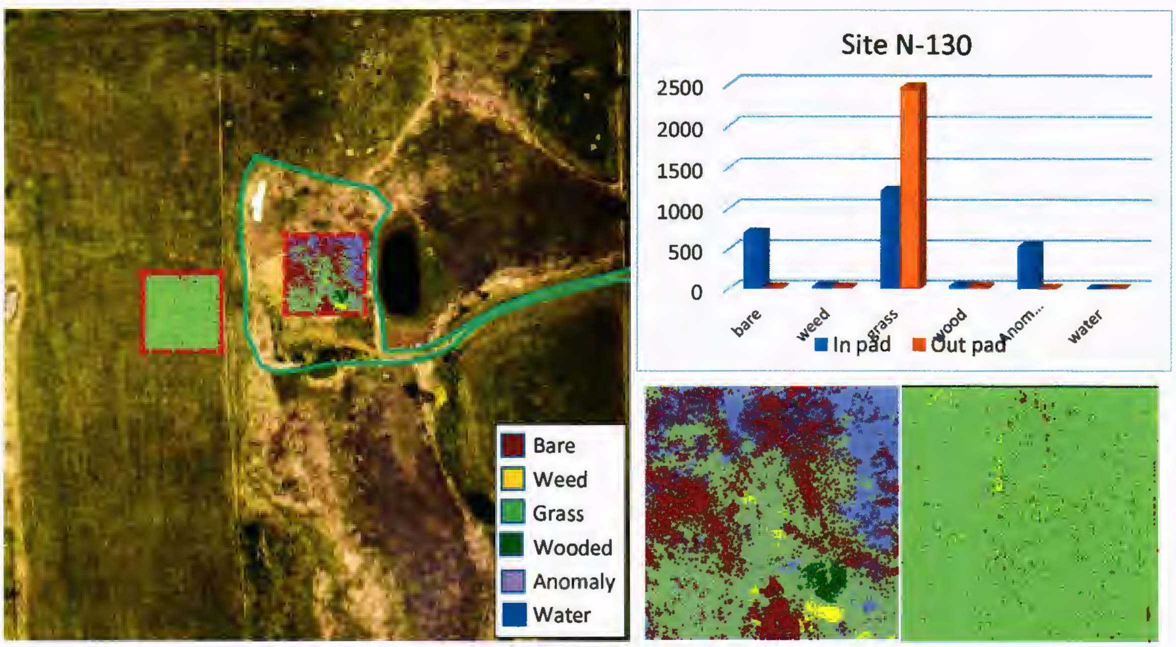
(a) Site F-429 (b)



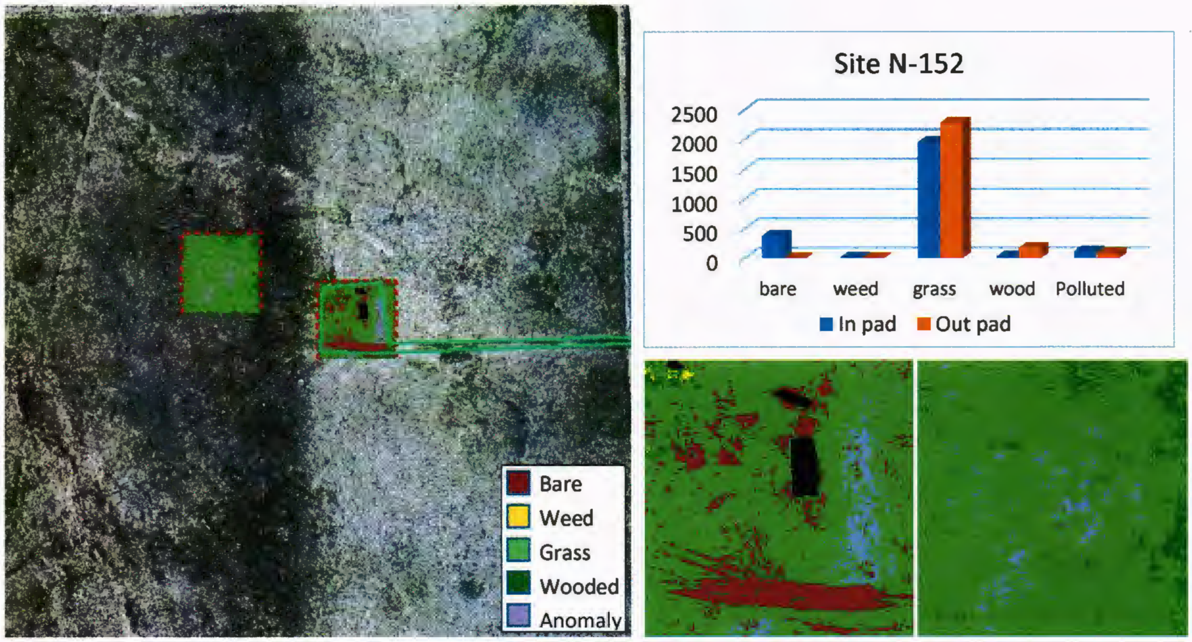
(a) Site G-316 (b)



(a) Site H-408 (b)



(a) Site N-130 (b)



(a) Site N-152 (b)

If the distribution of land cover classes within the site matches the distribution outside the site, it can be assumed natural vegetation has been re-established to its native conditions, otherwise, the magnitude of differences was computed . The statistics in Table 4 and 5 reflect the visual analysis of the sites; large differences in early stage restoration and small differences in advanced stage restoration. For example, site D-306, which has not been restored (or poorly restored), 2176 m^2 (87%) is bare soil inside the site, compared to 6.5 m^2 outside the site. Consequently, grass and wooded areas are significantly reduced inside the site.

In contrast, the difference in surface area (and %) between the different land cover types inside and outside site E-143 are insignificant, which suggests that the site has nearly been re-established to its natural condition. By analyzing the statistics for the other sites, one can determine their restoration state. This can also be estimated by simply viewing the HD-EO RGB images.

Sites	Bare soil		Weed		Grass		Wooded		Water/oil		Other	
	In pad	Out pad	In pad	Out pad	In pad	Out pad	In pad	Out pad	In pad	Out pad	In pad	Out pad
D-306	2176	6	15	51	274	2178	83	312	0	0	1329	0
E-143	9	2	0	0	2226	1487	0	0	0	0	266	1013
E-331	430	115	479	134	1381	1192	178	1027	0	0	0	0
F-144	123	74	0	0	1884	0	0	0	0	0	532	2465
F-220	1212	0	0	0	1254	2200	16	283	0	0	0	0
F-429	16	7	135	7	2288	1553	0	30	0	0	113	928
G-316	552	53	45	2	1935	1209	67	1333	0	0	0	0
H-408	920	0	0	0	1492	1803	99	705	0	0	0	0
N-130	698	11	29	15	1217	2458	38	25	2	1	530	2
N-152	371	2	6	0	1950	2276	21	170	0	0	115	82

Table 4-Computed land cover area expressed in m^2 for the 50m x 50m ($2500m^2$) square area inside and outside the pad boundaries

Sites	Bare soil		Weed		Grass		Wooded		Ag.		Other	
	In pad	Out pad	In pad	Out pad	In pad	Out pad	In pad	Out pad	In pad	Out pad	In pad	Out pad
D-306	87	0.3	0.6	2.0	11	87	3.3	12	0	0	53	0.0
E-143	0.4	0.1	0.0	0.0	89	59	0.0	0	0	0	11	41
E-331	17	4.6	19	5.4	55	48	7.1	41	0	0	0.0	0.0
F-144	4.9	3.0	0.0	0.0	75	0	0.0	0	0	0	21	99
F-220	48	0.0	0.0	0.0	50	88	0.6	11	0	0	0.0	0
F-429	0.6	0.3	5.4	0.3	92	62	0.0	1.2	0	0	4.5	37
G-316	22	2.1	1.8	0.1	77	48	2.7	53	0	0	0.0	0
H-408	37	0.0	0.0	0.0	60	72	3.9	28	0	0	0.0	0
N-130	28	0.4	1.2	0.6	49	98	1.5	1.0	0.1	0	21	0.1
N-152	15	0.1	0.2	0.0	78	91	0.8	6.8	0	0	4.6	3.3

Table 5-Computed land cover area expressed in percentage for the 50m x 50m ($2500m^2$) square area inside and outside the pad boundaries

The analysis presented so far in this study focused mainly on comparing the statistics between the activities inside the pad boundaries and its surrounding area. This type of analysis, however, does not account for illegitimate activities occurring far from the site, nor does it account for the quality of the site re-establishment. Even if the site were analyzed using remotely sensed imagery, or inspected onsite, and found adequately re-established to its native conditions, the analysis would not have included the activities just outside the site. Therefore, thanks to its broad aperture, the imagery provides the analyst an ability to quickly identify areas of interest that have potential to be the result of well site activity. When these areas are identified, pending resolution with the landowner and operator, there is opportunity to solve potential issues early in the reclamation process as initial reclamation planning is accomplished, saving time and funding for the operator and improving the outcome for the landowner and regulatory agency.

Furthermore, quantitative change analysis of land cover enables the analyst to interpret the data statistically and make mathematical judgments about the results in terms of magnitude or surface area, but it does not provide information on the quality of change. Taking the case of Site N-130 for example, statistical analysis does provide evidence of land cover change, but the statistics do not reveal the impact of the change. The merit of qualitative analysis is demonstrated in Figure 30. To the trained analyst a routine visual examination of the RGB and CIR images of site N-130 in Figure 31 (A) and (B) respectively show uncharacteristic tints in the water body and the surrounding soil fields. The color of water in RGB is typically blueish, not black as seen in this image, which suggests the water may contain other substances like fertilizers, chlorides, or other anomalies. Either way this spectral information can indicate that further investigation is needed and provide exact locations as to where to focus resources. Likewise, the color of soil is typically in shades of grey, depending on soil makeup and moisture content. Thus, the purplish color observed in the RGB image is atypical and indicates of the potential of other substances in the soil. This analysis is also supported by the fact that the areas showing normal hues are higher in elevation than the pond indicating the possibility of seepage from the pond. This indicates it may be the source or ground water levels have seasonally risen and is accounted for in lower lying areas.

While RGB imagery may be sufficient to visually determine anomalous features, these anomalies are also reinforced in the color infrared (CIR) imagery in this case. This is due to the high sensitivity of the ground features to the spectral energy in the infrared wavelengths. Taking the example of the two features (i.e., water and soil) examined in the RGB image earlier, we can verify these observations with the CIR imagery. The color of clear water in the infrared region of the spectrum typically ranges from shades of blue to black depending on the clarity and depth of the water. This is due to the high absorption of infrared energy by water. This is not the case we see for site N-130 in Figure 31(A) and (B). In this case, we see the water shows in shades of green. This type of color shift is indicative of the presence of compounds that have lower absorption in infrared wavelengths and the alteration of water reflectance in the infrared is another indication of additional substances in the water.

Another indicator of growth inhibitors or other anomalies not visible to the field inspectors is the vegetation condition. The red tone of CIR imagery is almost always associated with live vegetation; bright tones of red typically indicate vegetation which is growing vigorously and is quite dense. As the vigor and density of vegetation decreases, the tones may change to light reds and pinks, or even various shades of greens, and possible tans. By examining the CIR images in Figure 31, native vegetation (outside the pad boundaries) in atypical areas is clearly in shades of light reds and pinks indicating stressed vegetation. However, vegetation around the pond (inside the pad boundaries) is bright red in the IR image (Figure 31B), suggesting vigorous broad leaf vegetation.

The insights presented here are based on experience and a theoretical understanding of the spectral characteristics of the ground features is discussed in this section and requires validation by the appropriate personnel in the field. However, it also reinforces the additional information imagery of this type can provide operations personnel and with the introduction of these insights during the planning process; prior to reclamation start; operators have the opportunity to more effectively diagnose and plan for the most effective reclamation activities. This broader understanding of the wellsite and its surroundings will allow operators and regulators to plan with greater transparency and manage reclamation execution to reduce unnecessary work and expense for a more streamlined project and positive outcome for all players.

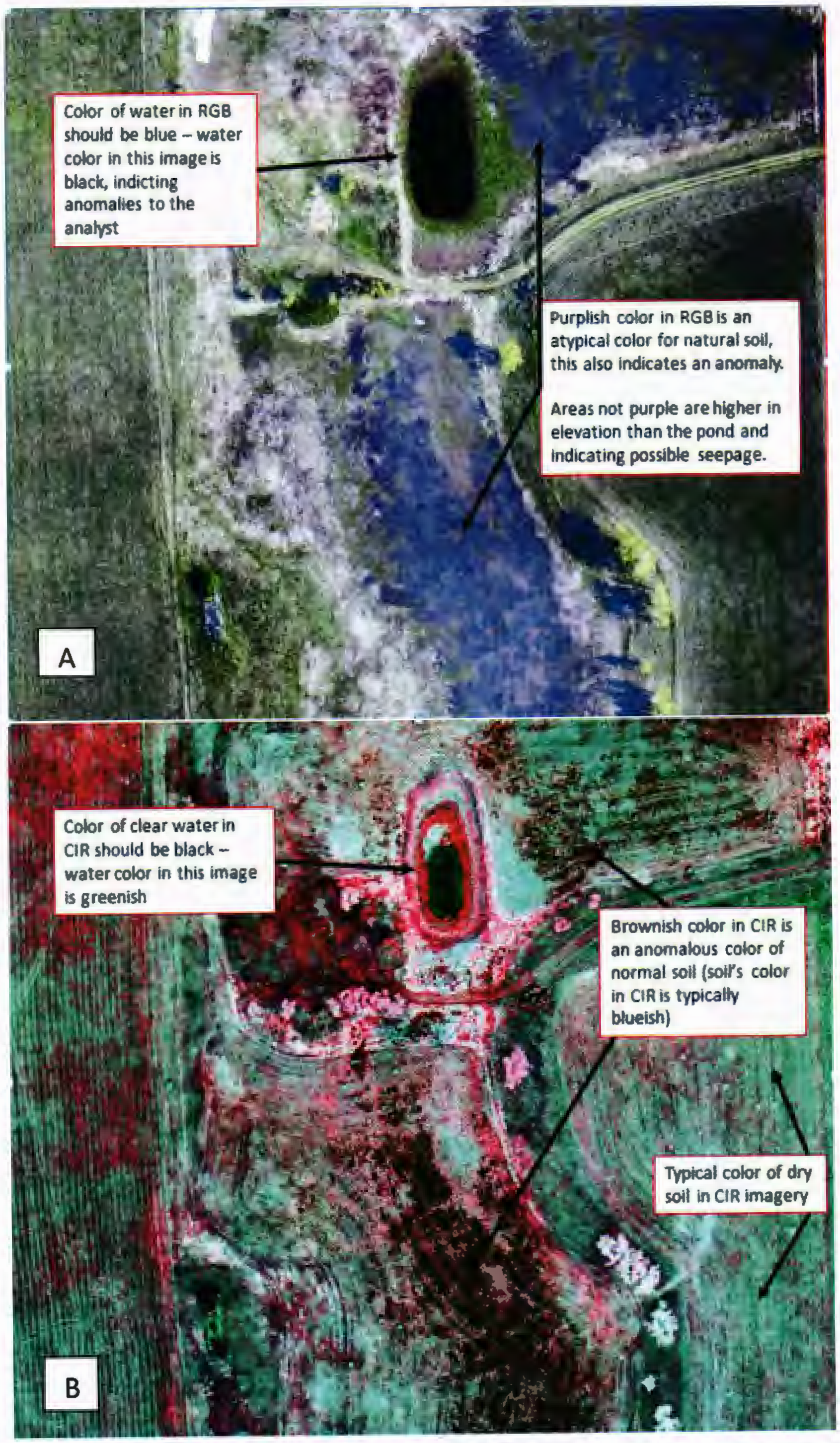


Figure 31: *RGB (A) and CIR (B) imagery showing anomalies in soil and water.*

High Resolution 2D Imagery Inspections

Infrastructure Detection

The State requires that all infrastructures be removed from site post abandonment. Many oilfields across the country are impacted by the inability of the original operator to fully remove and restore a site, which ultimately is left with the State and taxpayers to rectify. Many of the issues related to aging infrastructure also relate to the "status" of a well in terms of the operator's intent and administrative classification of the wellsite, meaning if infrastructure is filed annually as temporary, in a state of indecision, or as prospective intent by an operator the infrastructure can persist and degrade for decades. Figure 31 depicts two areas (A and B) in Site D-306 to illustrate the ability of HD-EO imagery to detect infrastructure.

Figure 32: *Selected areas for infrastructure detection inside the pad boundaries of Site D-306.*

By magnification into the identified areas of figure 32 A and B, one can easily detect the majority of infrastructure features with reasonable accuracy. In Figure 32A, for example, multiple debris areas of various sizes and materials are clearly visible at modest image enlargement. Likewise, Figure 32B clearly identifies other types of infrastructure, in this case a pipeline riser and fencing.

Similarly, Figure 34 and Figure 35, representing restoration conditions at a moderate phase (Site E-331) and an advanced phase (E-143), respectively demonstrate the ability of HD-EO imagery to detect infrastructure at various reclamation stages. This capability is important as it reinforce the potential of HD-EO imagery to quantify the conditions of a site to establish its conformity in accordance with North Dakota Administrative Code (NDAC) regulations.

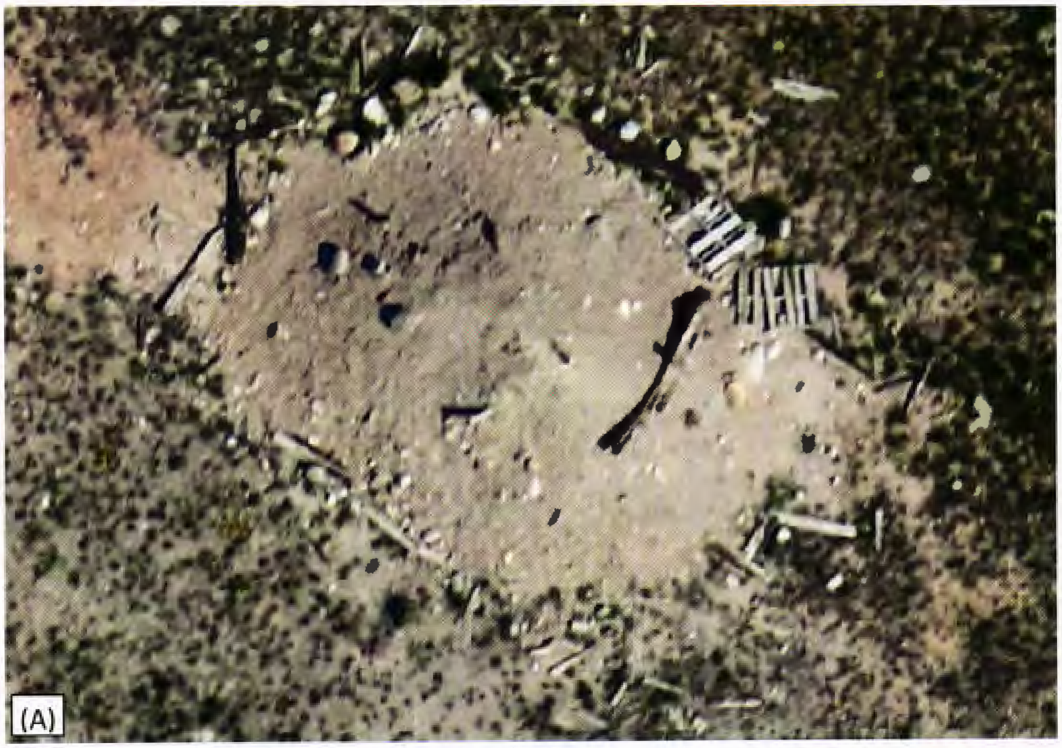


Figure 33A: Visual detection of multiple debris piles in RGB imagery at 3-cm resolution are clearly visible at modest image enlargement (image not maximum zoom)

Figure 34B: Visual detection of piping infrastructure of various sizes in RGB imagery at 3-cm resolution are also clearly visible at modest image enlargement (image not maximum zoom).

Figure 35: Infrastructure detection in an intermediate restored site (E-331); pipes and debris have been picked-up from the site and stockpiled, but have not yet been removed from the site

Figure 36: Infrastructure detection at a site at an advanced stage of restoration (E-143); site mostly cleared of infrastructure, but some structures are still standing at the site.

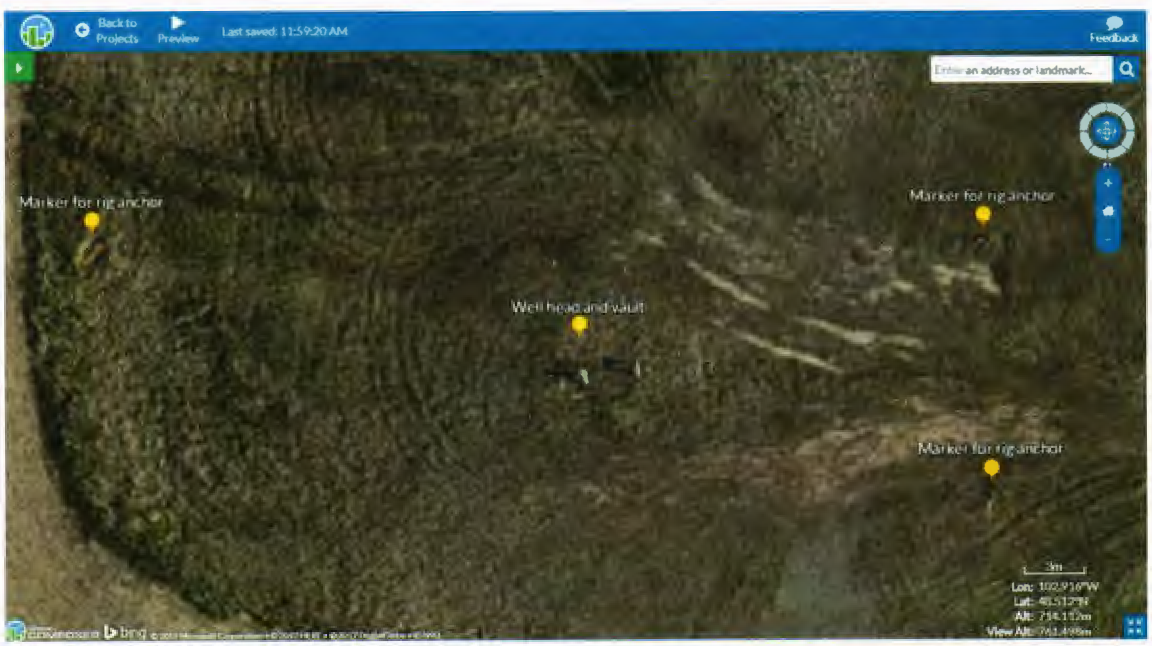


Figure 37: 3-cm resolution infrastructure detection at a site with advanced restoration (E-143); annotations are added to the features in Cesium

2D Imagery Inspections and Analysis

Cesium can host any level of resolution imagery collected and there are tools allowing the user to add annotations to isolate or mark any site attribute of interest, similar to other GIS platforms. Figure 36 shows some of the utility that the remote sensing imagery and associated inspection capability provides regulators and industry from the desktop. The Figure 36 image can be emailed via a URL link or can be printed. In the geographically precise format hosted in Cesium the latitude and longitude of any point in the field of view can be displayed. The distance between features can also be annotated and used to find smaller features in late season with taller vegetation. Area and volumetric analysis can also be accomplished with the platform and can provide enough information to generate the scope and location for reclamation work without having to visit the site in the field.

Figure 38: High resolution image of a 4 foot field marker for the location of a rig anchor.

3D Imagery and Terrain Model Inspections and Analysis

Rendering the data as a 3D representation of the sites surface adds the capability to assess the contouring of a site both within the site boundary but also in context of the adjacent lands and associated contours. The high-resolution imagery is draped over the terrain models so that a complete site reconstruction is achieved. Site attributes such as erosional features, depressions, mounding, and other topological features which may affect the reclamation of a site can easily be discerned.

Digital Elevation Model (DEM)

A DEM is a representation of the elevation of the Earth's surface above a certain datum (e.g. mean sea level) in digital form. This is achieved taking elevation measurements at regular (e.g. every 50 meters) or irregular spaced points (e.g. every 3 arc seconds) over the Earth's surface.

There are two main elevation models which were included in the research. The based data allowed for the two renderings and other types of analysis besides elevation models can be generated from the raw data. The two model types are; Digital Terrain Models (DTM), and

Figure 39: Ground truth photograph of D-306 debris pile.

Digital Surface Models (DSM). A DTM is a DEM that represents the elevation of the bare earth without considering any over ground features (e.g. trees, buildings). The DSM on the other hand is a DEM that represents the elevation of the surface terrain plus the natural (e.g. trees, shrubs) and man-made features (e.g. buildings).

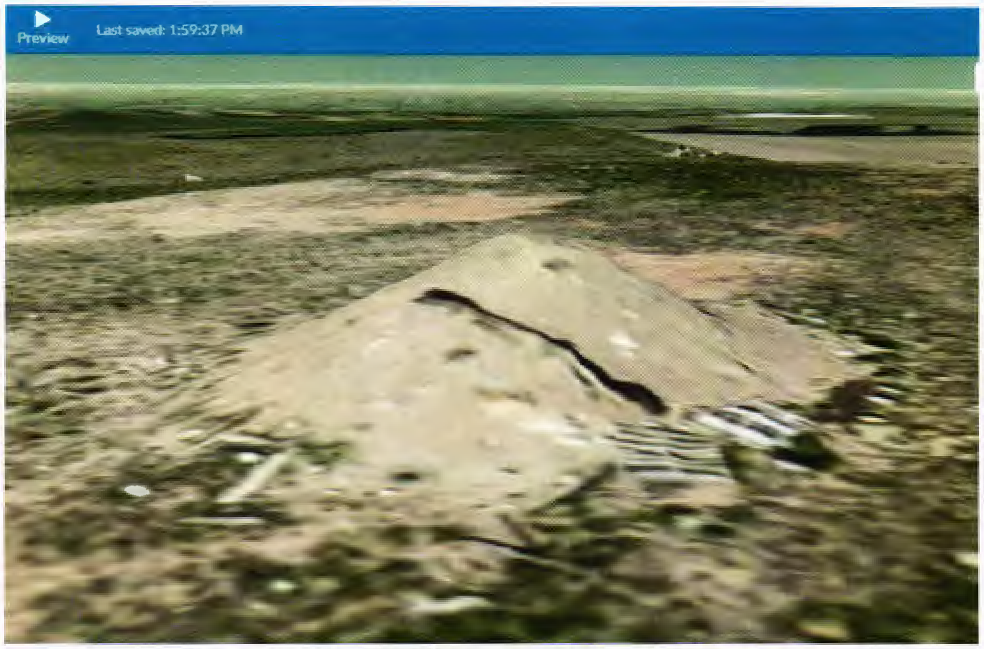


Figure 40 High resolution imagery of the D-306 debris pile (3-cm) draped over a Digital Terrain Model (DTM) hosted in Cesium.

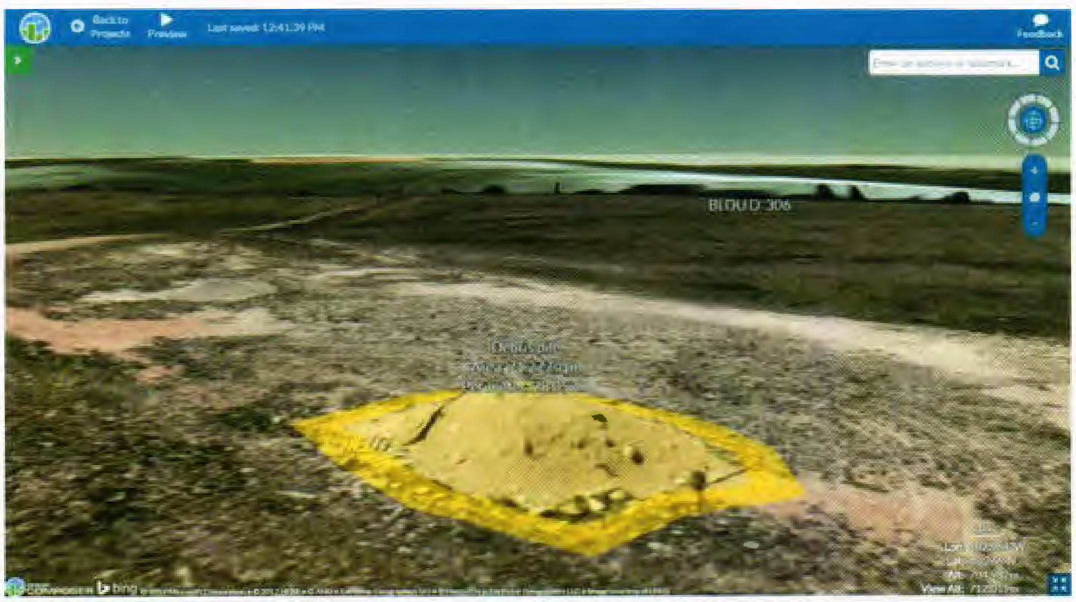


Figure 41: High resolution imagery of D-306 debris pile (3 cm) draped over a Digital Terrain Model (DTM) with volumetric analysis and values annotated and displayed in Cesium.

The ability of Cesium and other GIS programs to render volumetric and other measurement demonstrates the ability to scope and draft work orders and resource allocation from the desktop. In the case of D-306 decision makers can clearly identify from the 3D DTM the need for excavating and hauling equipment capable of decommissioning the pile which would not be possible from just a HD photograph in 2D. This capability can be readily adapted as a business intelligence tool.

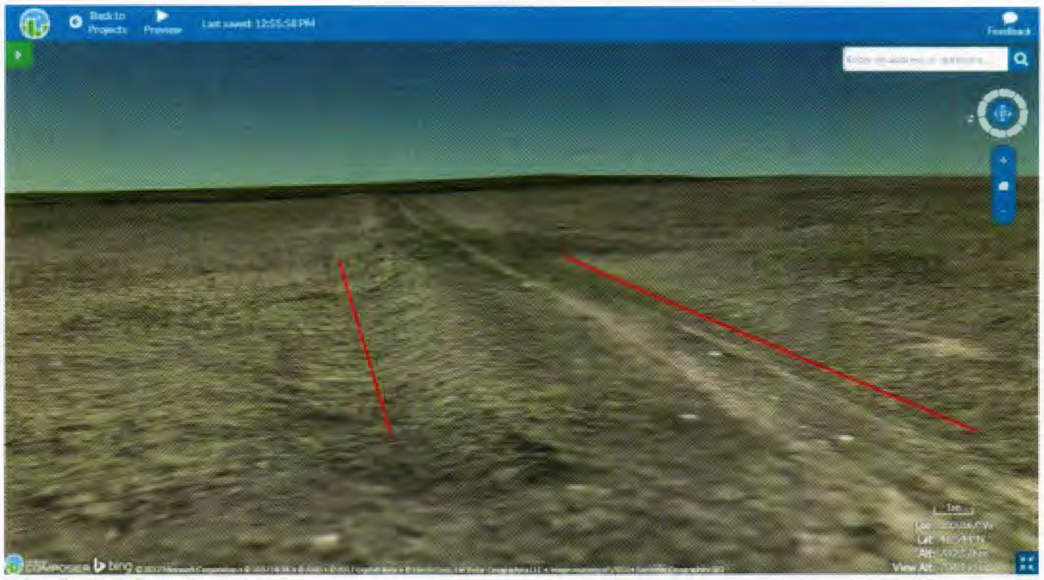


Figure 42: High resolution imagery of N-152 access road (3-cm) draped over a Digital Terrain Model (DTM). This image shows the ability to discern modest elevation change in the access road features.

When we evaluated the DTM imagery for sites with dominating wooded ecologies (trees; shrubs) we found that the images were skewed with un-rectifiable shapes as the data was rendered including the surface of the trees themselves (figure 42), thus limiting the evaluation of the contours and clarity of the HD imagery. We reprocessed the data to be rendered as a surface model instead of the terrain model (figure 43); the DSM was much better in terms of clarity and analysis of infrastructure and contouring. The smoothing of the surface through masking the vegetation made for a better image and is a requirement over the terrain models. Trees and structures are still easily discerned from vegetation in the HD photograph component of the images.

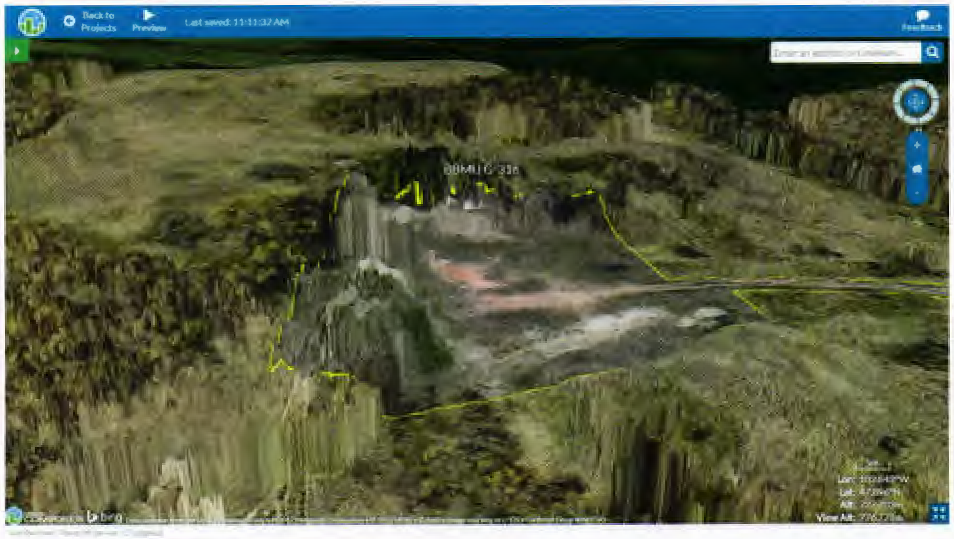


Figure 43: High resolution imagery and DTM of G-316.
Vegetation (trees and shrubs) is represented as surface features.

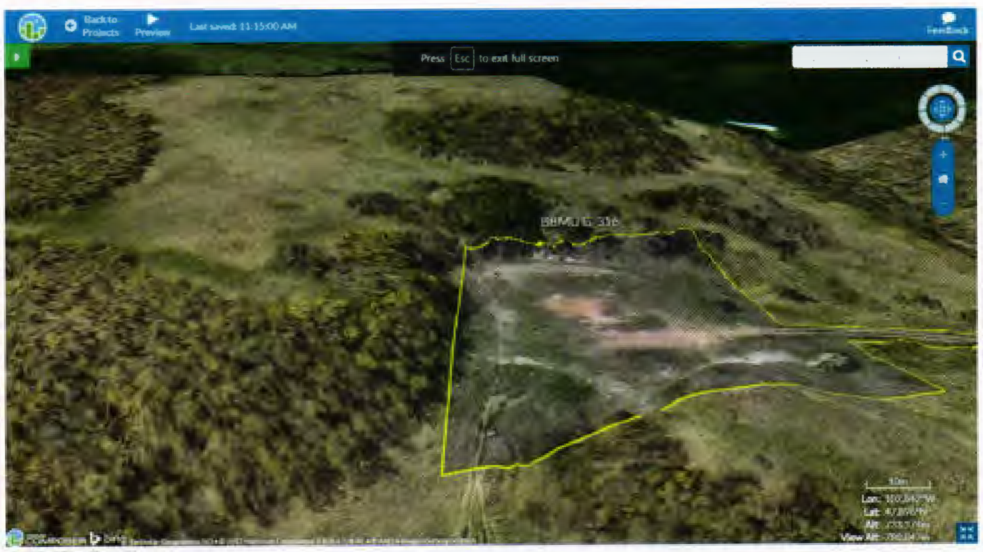


Figure 44: High resolution imagery and DSM of G-316.
Vegetation (trees and shrubs) are masked and are not included as surface features.

Figure 45: High resolution imagery and DTM of G-316 looking to the east. The site appears to have been excavated out of the hillside.

The capability to visualize a location with such precision in 3D from the desktop allows inspections and analysis of the contouring of a site in context of the surrounding land without having to make a field visit. The G-316 would need extensive earth work to return the site to its natural contouring. The access road to the site was also very degraded and unstable; site visits were time consuming and also posed an element of risk due to the conditions. A top soil pile can be seen in Figure 43 just to the left of the road but over time the soil pile has eroded and large quantities of top solid would be needed to replace the scoria base and reseed the site. Without erosion control down the slope inspected in Figure 44 the areas devoid of vegetation will increase leading to further degradation of the site and more cost to reclaim.

Figure 46: High resolution imagery and DTM of G-316 looking to the south west. The imagery suggests that the excavated soil was pushed down the slope at the front of the image (North East).

Figure 47: High resolution imagery and DTM of H-408 and erosion features.

Remote inspection of the BBMU H-408 shows headward erosion consuming the former well pad due to a lack of vegetation coverage. Exploitation of these erosion feature by cattle and other range species serves as an example as to how neglect can lead to further degradation and increased cost to reclaim. Degraded sites consume more time, energy and resources for operators to stabilize. There would be no need to make a field inspection of this site based on the imagery captured during this study. This type of erosion feature can also degrade pipeline right of ways even in areas of modest slopes.

Figure 48: Ground truth photograph of the H-408 and erosion features.

Figure 49: Imagery and DTM of the E-331 looking west showing persisting disturbed conditions. Contours and ground cover can be evaluated in context of the surrounding areas.

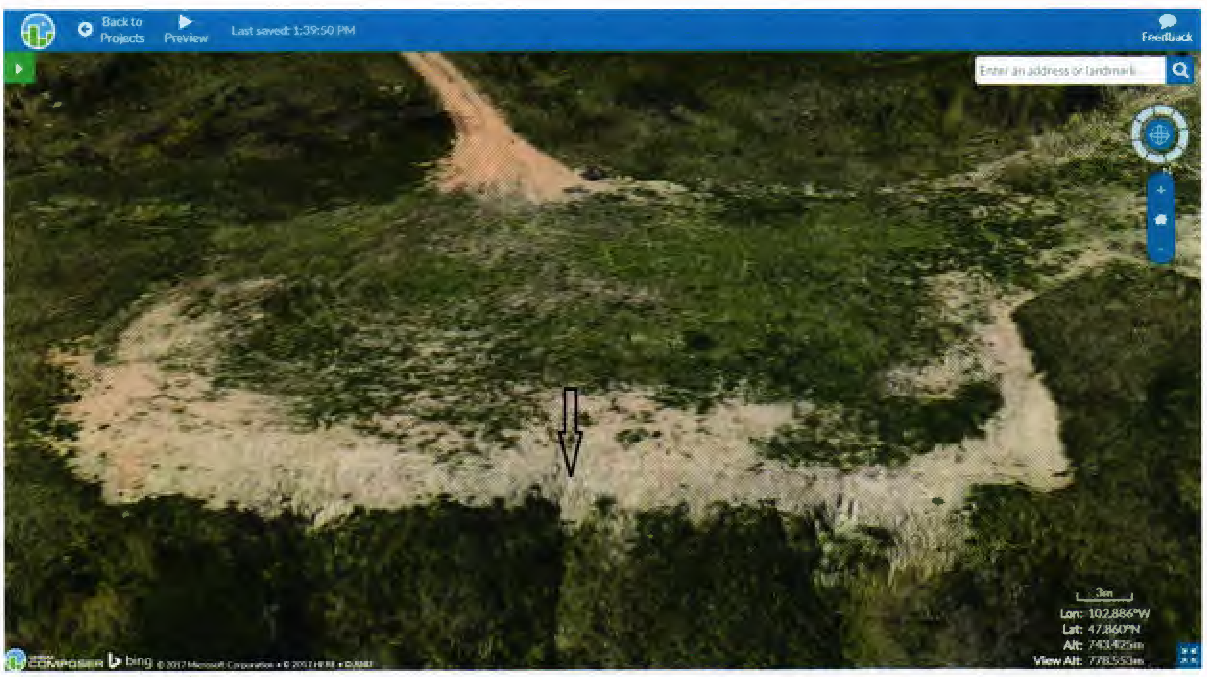


Figure 50: Imagery and DTM of the E-331 looking south. Erosion and contour features identified by black arrows

Inspection and Site Closure

Using the remote sensing data and the Cesium platform desktop inspections can provide the necessary insights to determine if a final site vast should be made saving the resources which would have otherwise occurred during interim site visits. The F-429 site is a candidate for release and the imagery supports this analysis. Figures 48 and 49 show the vegetation has recovered and generally looks to have better coverage than the surrounding areas. The re-contouring has held even on the extreme slopes across the site.

Figure 51: Imagery and DTM of the F-429 looking north east.

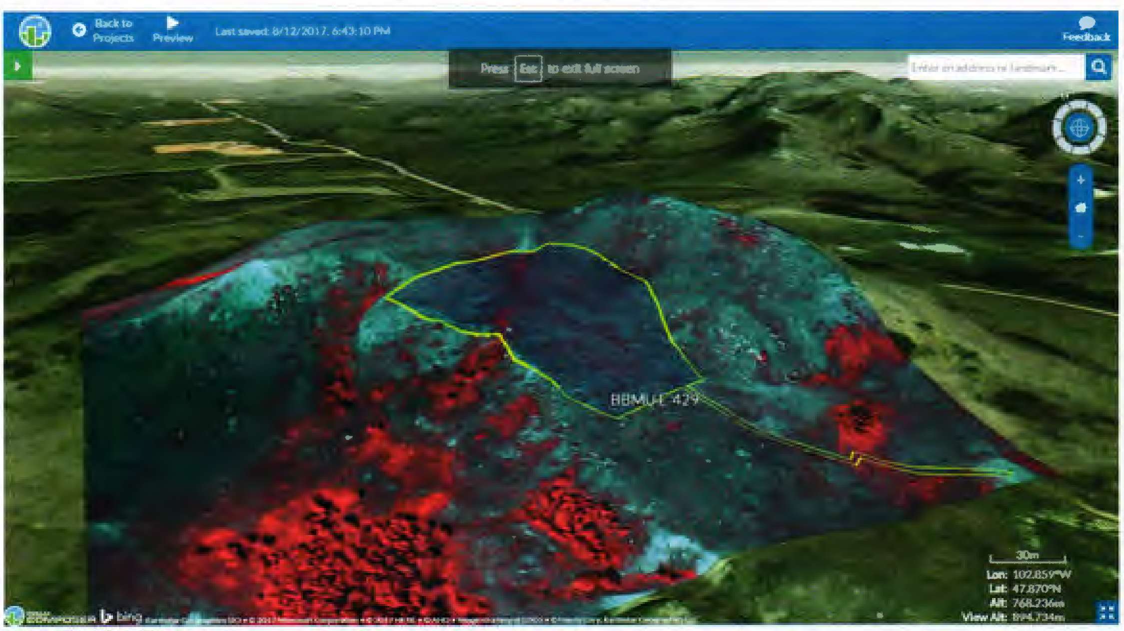


Figure 52: Color Infrared (CIR) Imagery and DTM of the F-429.

Cost Summary and Analysis

Major Cost Areas

The project funding and a future program would be broken into four main cost areas: imagery collection, data analysis, and data display and data management. During this proof of concept data management was small enough (less than 4 terabytes for 10 well sites) that no additional costs were incurred for data architecture and the bulk storage of raw and processed imagery. However, should a program be developed for implementation, this will be a significant additional cost that will need to be addressed. Additionally, for the purposes of this project Hess supported an additional approximate 10% of funding above and beyond the original proposal for direct Hess personnel and personnel related infrastructure support (computers/salaries/travel et. al.) during the extended project.[17]

Imagery Collection

As previously identified, the imagery collection for this project was accomplished utilizing manned aviation. The budget expended for this was approximately $118, 760 which represents 42% of the project budget. The bulk of the expense was the relocation of and flight hour costs associated with the aircraft. To note however is that the flight cost had two components; the mobilization, and a daily rate. Efficiencies and cost reduction per site for this component maybe realized through reclamation program progress planning and flight planning to collect data on more sites per day than the 10 sites included in this study. Many areas of the Bakken have multiple stakeholder's infrastructure and assets in very close proximity which may provide cost sharing per flight by adding other producers or midstream companies into an imagery program. Additional sites data collected per flight would increase processing and data storage needs but not all sites would need all of the analysis utilized in this study.

Data Analysis

Data computation and analysis was accomplished as identified by N-Link (parent company of Paradigm ISR), Textron Systems and by an independent imaging expert brought in by N-Link. The budget expended for this was approximately $64,830 which represents 23% of the budget. The entirety of this was spent on computation and analysis. It is important to note that due to exigencies beyond the scope of the original proposal additional resources were provided gratis to accomplish the contractual requirements. Comments provided by regulators within the NDIC[18] indicated that the advanced vegetation classification analysis and some of the advanced contouring analysis most likely would not be needed to for them to make remote inspections.

---

[17] No project funds were used for Hess support.

[18] Comments provided by multiple NDIC reclamation inspectors and planners via email on March 8, 2017

The at gratis hours and effort put into the development and the actual budget allocation for that capability would greatly reduce the cost of a baseline program per site and the advanced analysis could still be used on an as needed basis or regularly generated for highly sensitive areas such as near waterways. The advanced analysis using CIR or RGB imagery could also be used to confirm that no anomalies are present and add a capability to inspect post spill/leak cleanup efforts.

Data Display

Display of the imagery as identified was through AGI's open source Cesium application. Approximately $65,380 and represented 23% of the budget. The bulk of the expense in this category was the licensing fee for the use of Cesium and AGI development support. The licensing of Cesium is a onetime cost which can be spread out over an infinite number of sites but the data storage cost would increase. Cesium indicated that pricing becomes more competitive as the amount of data increased.

Ground Support

This category encompassed Hell Creek/Paradigm direct field support and travel to provide validation criteria and assure ground truth to the imagery analysis. Approximately $31,030 and represented 11% of the budget. The bulk of the expense was for travel in support of multiple visits across three seasons to the study areas, and travel to support data analysis and documentation. Per the comments provided by the NDIC a final site visit will always be necessary to clear a location. No conclusion or consensus was determined as to how many actual site visits in total between regulators and operators occur for each site during the reclamation process. However, a relevant estimate would be two by regulators (minimum of any site per the NDIC) and two by operators on a purely inspection basis and under ideal conditions.

Cost Analysis and Additional Risk/Cost Reduction Opportunities

The expenses were as expected focused primarily in aerial imaging and the licensing of the Cesium application. With only 10 sites accomplished in this risk reduction effort, this would nominally have led to charges of approximately $25,000 per site for the study. This would be an unsustainable cost structure for a larger program, but there are significant opportunities for decreasing overall unit cost as a function of volume, imaging vehicle and synergies associated with state and multiple operators requiring similar/the same data.

The sample size for this project was limited due to the "pure" research nature of the mission. However, the most effective extension of this project would be to increase the sample size by at least an order of magnitude. Decreased unit cost would be realized in both data acquisition and data display since both have significant up-front costs with only smaller incremental costs for additional locations. Though not evaluated, there may also be synergies available for data processing as well with a suitable partner capable of significant parallel processing capability and a firm understanding of desired outcomes in the imaging.

The FAA has now created a licensing program greatly improving the availability of UAS[19] for commercial activity. With their approval of BLOS[20] operations and evaluation in conjunction with the Northern Plains UAS Test Site, further opportunities are available for a streamlined application of the project goals with a potential for greatly reduced imaging vehicle expenses over a larger test group. Additionally, due to the regulatory environment at the time UAS were not a part of this project, but for suitably dense oilfield operations such as in/around Tioga, Watford, Killdeer and Williston the opportunities for the use of LOS[21] UAS to greatly reduce expenses without significant additional flight risks are available today for the suitably designed program.

The final area likely to produce significant programmatic savings will be the synergies created by the number of operators/regulatory agencies needing the data. With a central contracting body leveraging both regulatory and operator requirements into the same dataset, additional cost reduction measures can certainly be realized, and identical data sets captured, that will be suitable for all parties.

With these opportunities and discounting the necessary up-front costs to establish the program, we conservatively estimate the per location acquisition and processing costs can easily be cut in half and potentially much further if a larger study were confirmed and the regulatory/operations environment embraced the product.

Conclusions and Recommendations

Vegetation mapping

Overall, the research team was pleased at how well the results of the manual analysis correlated to the automated statistical analysis.

- 10 cm imagery is sufficient for vegetation/land cover mapping, but not as effective as the 3-cm imagery for the detection of infrastructure. Therefore, we recommend the 3-cm resolution as a baseline requirement.
- IR would produce more accurate classification than RGB, especially for anomalous features and oil contamination detection.

---

[19] Unmanned Aerial/Aircraft Systems (drones, Remotely Piloted Vehicles, et. al.)
[20] Beyond Line of Sight
[21] Line of sight

- Late spring/early summer imagery would be better for vegetation/land cover mapping because vegetation types are easier differentiated at advanced than early stages (at early stages most vegetation types are similar spectrally and texturally).
    - Spring vegetation growth, there is high contrast between vegetated and bare earth areas.
    - Advanced fall growth showed better results in discriminating between grasses and invasive vegetation.
- For change detection analysis, imagery collection should be done during the same season and same date ideally.

- Because of the high spectral reflectance of vegetation in the NIR range of the electromagnetic spectrum and the high sensitivity of NIR to vegetation types, vegetation attributes can be better mapped using NIR imagery than RGB alone.

This initial collection included a high-resolution RGB camera at low altitude, producing 3-cm GSD resolution digital images. Data was acquired over the 10 well sites with the solar angle below 40 degrees. The solar angle between the fall 2015 flight and the spring 2016 flight varied by 30 degrees. The effects of the low solar angle were compared between the fall and spring imagery by a trained analyst. The implications of low sun angle on imagery are multifold: lowered signal-to-noise and increased shadows. Depending on the imaging system there is generally less contrast, meaning decreased quality of the light during low sun angles. Late season imagery also captures a vegetative condition after the growth cycle is complete and plants have fully matured which makes the infrastructure difficult to detect. Shadows are cast over a larger distance with a lower sun angle. Mature plant growth, shadows, and poor light quality were found to impede the interpretation of a site condition and made it difficult to detect evidence of smaller infrastructure items. The late fall season also made it difficult to visually discern native vegetation from possible invasive vegetation, because the color discrimination between vegetation was greatly diminished.

Generally, we learned that early-season imagery is more informative for detecting infrastructure and discerning vegetative differences. The early-season images capture vegetation in a state where phenological differences highlight different plant communities, whereas late-season Imagery often appears in the same state (senesced or dead). The early-season vegetation also has implications for infrastructure detection. The fall die-off and subsequent winter snow and freezing temperatures knocks-down the vegetative litter so the aerial view of the ground (and low infrastructure) is much improved.

Re-contouring and Infrastructure Detection

- 3 cm DSM data is more accurate for re-contouring analysis and infrastructure/man-made object detection
- Imagery collection should be done in spring because ground is not fully covered by vegetation and, therefore, ground contouring and man-made objects are more readily

visible (not covered under vegetation). Also, late fall season would make it difficult to visually discern native vegetation from possible invasive vegetation. Collection and evaluation of the data needs to happen at a time of the year when differences in plant phenology would allow spectral/color discrimination between communities of interest.

- Because vegetation reflects highly in the NIR spectrum, vegetation attributes can easily be determined using spectral discrimination algorithms.
    - Change in re-contouring and remediation should be done between collection in Fall to accurately detect change at the ground level, not at the vegetation surface level
- For re-contouring, use DSM, not DTM (though, if the surface is not highly disturbed, the two models may be similar)
    - LiDAR is more accurate because of the much higher density of the point cloud and therefore would depict even more subtle changes in elevation
    - Thermal imagery may detect infrastructure (metal objects, plastic) more accurately than reflective IR or RGB due to solar heating/insulation and resulting changes in temperature between material types and biomass.

Automatic analysis has multiple advantages over manual interpretation and/or ground surveys. Not only is it repeatable, but it also reduces subjectivity in human manual analysis, is faster, more transparent and cost effective for both regulators and operators.

Program Evaluation & Policy Guidance Evolution

It has been clearly shown that remote imaging with today's technology is more than capable, when properly captured, processed, analyzed and displayed, of demonstrating the efficacy of reclamation efforts and their effectiveness in meeting the primary evaluation criteria contained in the North Dakota Administrative Code (NDAC) 43-02-03-34.1. The results have been proven to meet a threshold which would allow NDIC analysts and operators to determine whether a final site visit could be performed with a high degree of reliability that a reclaimed wellsite would pass inspection. The question then becomes, how do these study results become actionable guidance in the NDAC which operators can follow to reproduce these results?

To be effective the NDIC, in collaboration with industry, will need to provide the necessary guidance and direction to ensure the operators are postured for success by:

a) Ensuring the imaging data is capable of ingestion by the selected data management architecture available and in use by both entities
b) Ensuring the data captured is of the minimum resolution necessary to determine the requirements by analysts accomplishing visual surveys
c) Ensuring the minimum processing is accomplished with appropriate commercial off the shelf products to support quantitative analysis and generation of all required products

Additionally, internal to the NDIC an administrative evaluation must be made to determine how an electronic product and analysis can be successfully merged into the current administrative process utilizing the existing well file. For example, once imaging data is available post reclamation, will the operator provide a Sundry Notice identifying the availability of the data or will the data be centrally managed by a third party? One of the largest hurdles this review will need accomplish to succeed will be the establishment of a Common Operating Picture between the NDIC and its reclamation specialists, the operators and landowners as they accomplish reclamation activities.

A potential process flow diagram based on intent to develop a Common Operating Picture can be seen in Table 6. With a Common Operating Picture on how the process would flow, the final requirement would be to identify the actual steps in the imaging products necessary to create the desired outcomes. Based on the study the following would be the minimum information to convey to operators:

a) Imager type, resolution and wavelength
b) Processing tool and products to be created
c) Identify the way the imagery will be ingested into the visualization tool

Though this seems simple there is a myriad of implied administrative and operational tasks buried within each that will need to be evaluated and defined. Once the volume of these tasks is fully understood for the reclamation activity the regulatory agency will need to internally determine the best form of program management to control this process. Two typical ways include a centrally managed program led by the regulatory agency or a third party; or a decentralized program with individuals allowed to participate on an ad hoc basis as their needs require. Each will provide benefits and drawbacks, but effectiveness and responsiveness to the customer needs will need to be fully evaluated to determine which program management style will work best for this task and its expected scope.

Imager, Resolution and Wavelength

The selection of imagers will be heavily dependent on the operator's intent for imagery usage and the opportunities available for synergies within their business; just as it will be for a regulatory agency. It is not uncommon though for individuals and group to mistake imaging vehicles, with the imager itself. Imaging vehicles currently in vogue include unmanned aerial vehicles/remotely piloted vehicles (re: drones) of all types. Though they may have significant cost-effective applications for some operators such as around a fixed area like a plant or station; they would currently be unsuitable for operators of systems over vast areas or in/around densely populated areas due to current FAA restrictions. On the other hand, satellite

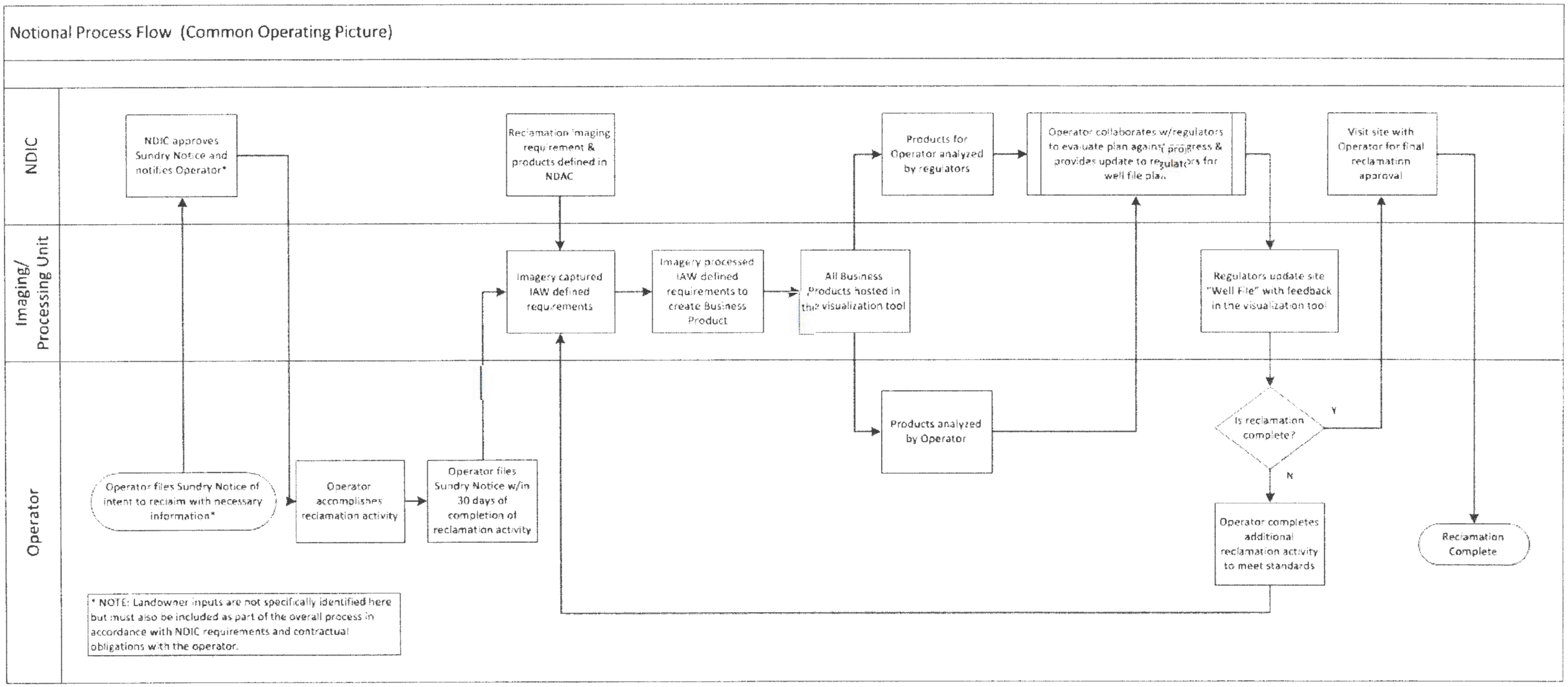


Table 6 - Notional Common Operating Picture

imagery though easy to get access to, may be unsuitable from a cost perspective for a small company when attempting to get sub-10 cm four band data. The bottom line for the regulator becomes, the manner of acquisition is unimportant[23] compared with the need for the imagery to be of suitable resolution, wavelength, and ready for processing to achieve the desired products. This in turn, will assure an effective evaluation by the regulator, operator and potentially the landowner. In the end the entire program is intended to find synergies capable of reducing time, energy, effort and cost by all parties while ensuring transparency and improving effectiveness. When this can be accomplished collaboratively at a desktop through remote technology (Go to Meeting, Skype for Business et. al.) true leap ahead progress can be made with reclamation management.

Processing Tools and Products

As with the selection of imagers, the selection of processing, though more technical, needs to be left to the individual operators/regulators to determine what best will work for their imager and processing needs. The key to success will be the analysis algorithms and defined products which will likely be agreed to collaboratively beforehand, but ultimately directed by the regulatory agency. Based on this analysis an initial basic requirement would be:

1. 2D RGB orthomosaic of the imaged area
2. 3D point cloud of the imaged area
3. 3D Digital Elevation Model of the image area
4. Digital Terrain Model of the imaged area
5. Digital Surface Model of the imaged area
6. NDVI of the imaged area
7. Color Infared of the imaged area

These can be created using a variety of commercial software including Harris ENVI, Erdas IMAGINE, et. al. Given the tremendous capability of the prepackaged software solutions, an initial trial period will be necessary to assess the capability of operators/regulators for operational implementation. The NDIC's ability to become familiar with and execute analysis for reclaimed sites will drive the initial effectiveness of the program. Though the data once produced can be very intuitive for minimally trained persons, the production itself will require individuals with significant imaging and environmental background to ensure the products, and program, are effective.

[23] The primary message here is, operators will work to capture and process imagery in the manner most cost effective and simple to absorb for their operation. What the system must concerned with is that the imagery meets the basic 4 band criteria, is coregistered and of 3 cm resolution.

Image Ingestion into the Visualization Tool

Once products have been created and finalized the final step prior to analysis will be importing into the system of record for visualization, which in this evaluation was Cesium[25]. This becomes a potential first touch point of captured and processed data becoming part of the official legal record for an operator. As such, great care must be taken that the data ingested is of the required quality and meets the standards provided by the state. Once ingested, determination of who will "officially" analyze the products must be made. As with photos, the information will find ambiguities that are not explainable by the individuals reviewing it. Some determination must be made whether this is a processing issue or a real ambiguity at the site. Once these issues are resolved are a final "analyzed" product can be made with associated actions defined and timelines established for completion. Once complete the appropriate form of the analysis will need to be uploaded to the isolation tool for dissemination to the appropriate agencies.

---

[25] Cesium is an Analytical Graphics Inc. (AGI) web-based tool used for globe and map visualization of dynamic data. It is an open source JavaScript library for creating 3D geospatial visualizations and enables a web hosted multi-user/agency interface and cloud storage of data.

Literature Review

Covenant consulting Group. 2016. Stakeholder Assessment of the North Dakota Badlands and Little Missouri River Valley. Whitepaper.

Dickinson Press. 2013. When drilling for oil in North Dakota, land reclamation a must. http://www.thedickinsonpress.com/content/when-drilling-oil-north-dakota-land-reclamation-must

Saskatchewan Oil Report. 2014. Oil-well reclamation processes across the Bakken. http://saskatchewanoilreport.com/oil-well-reclamation-processes-across-the-bakken/

Sedivec, K. and Saxowsky, D. 2015. Reclamation of Oil and Gas Industry-impacted Land. A Guide and Checklist. North Dakota State University Fargo. USDA.

Sedivec, K., C. Piper, J. Printz, A. Wick, Daigh A., Limb R. 2014. Successful Reclamation of Lands Disturbed by Oil and Gas Development and Infrastructure Construction. North Dakota State University, Fargo. USDA.

Sedivec,K. J.Printz. Ecological sites of North Dakota accessed via web; www.ag.ndsu.edu/pubs/ansci/range/r1556.pdf

Sedivec, K., Printz, J.Ranchers Guide to Grassland Management IV (R1707) accessed via web; https://www.ag.ndsu.edu/publications/livestock/ranchers-guide-to-grassland-management-iv

https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

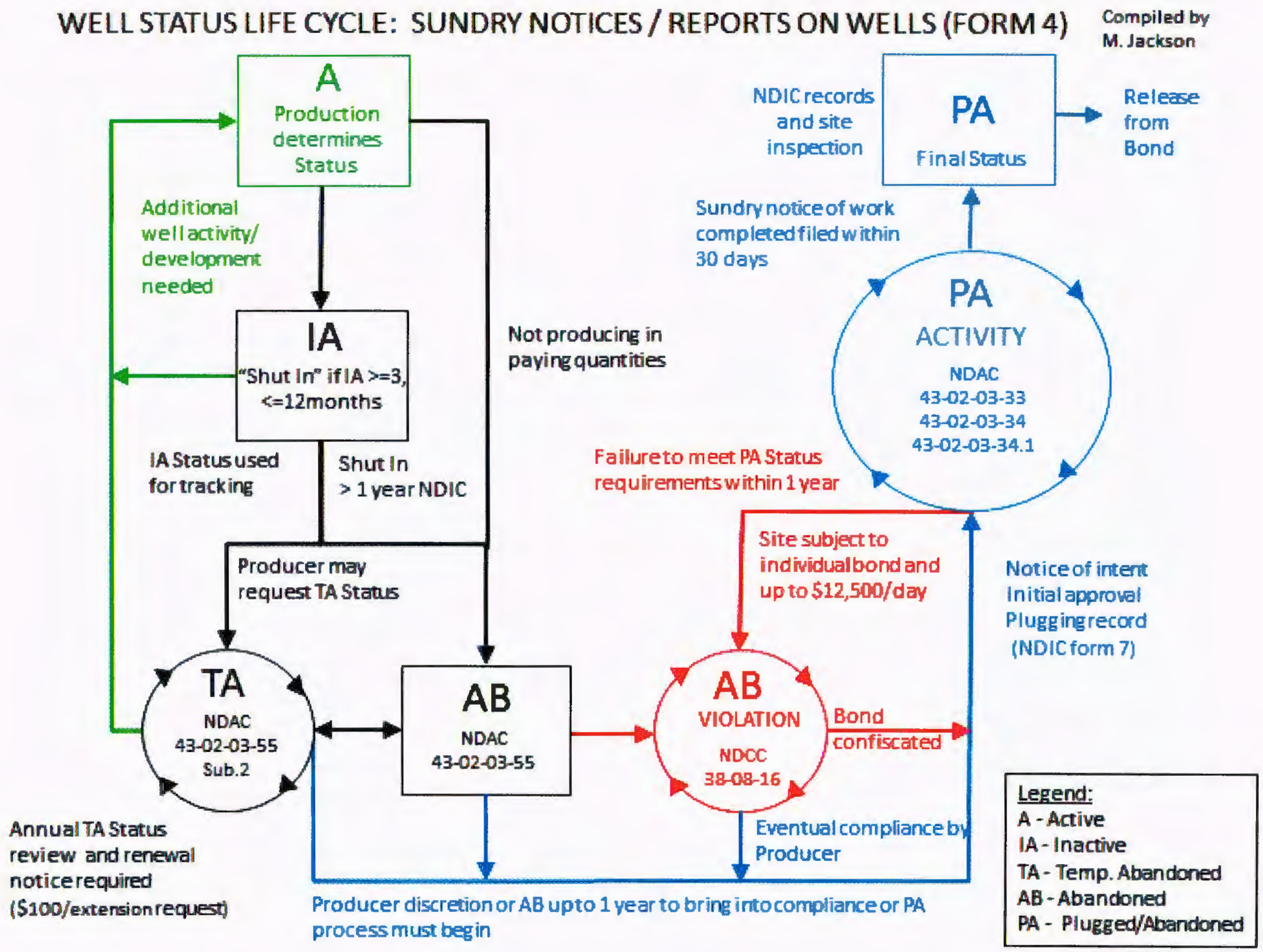
Appendix A – Final Schedule of Values

RECLAMATION RESEARCH PROJECT SCHEDULE OF VALUES CONTRACT G-037-73

TASK NUMBER	TASK LUMP SUM ITEMS	QTY	UNITS	NDIC SHARE (ND Ind Commission)	SPONSOR SHARE (Hess)	Total	Complete This Period % or Units	AMOUNT	Previously Completed	Complete To Date	Total Amt of Payment Requisition	NDIC SHARE (ND Ind Commission)	SPONSOR SHARE (Hess)
1	Hell Creek Project Management / field work	1	LS	15,380	15,380	$30,760	30%	$9,228.00	70.0%	100%	$9,228.00	4,614.00	4,614.00
2	Paradigm Project Management / Pilot	1	LS	15,380	15,380	$30,760	30%	$9,228.00	70.0%	100%	$9,228.00	4,614.00	4,614.00
3	Sensors & Equipment	1	LS	7,690	7,690	$15,380	30%	$4,614.00	70.0%	100%	$4,614.00	2,307.00	2,307.00
4	Data processing and analysis	1	LS	3,600	3,600	$7,200	30%	$2,160.00	70.0%	100%	$2,160.00	1,080.00	1,080.00
5	Policy review, reporting/documentation	1	LS	2,880	2,880	$5,760	30%	$1,728.00	70.0%	100%	$1,728.00	864.00	864.00
6	GIS	1	LS	2,880	2,880	$5,760	30%	$1,728.00	70.0%	100%	$1,728.00	864.00	864.00
7	Travel expense	1	LS	10,730	10,730	$21,460	30%	$6,438.00	70.0%	100%	$6,438.00	3,219.00	3,219.00
8	Manned aircraft	1	LS	44,000	44,000	$88,000	30%	$26,400.00	70.0%	100%	$26,400.00	13,200.00	13,200.00
9	Software Development & Data Reduction	1	LS	25,000	25,000	$50,000	30%	$15,000.00	70.0%	100%	$15,000.00	7,500.00	7,500.00
10	Ground Truth equip	1	LS	2,460	2,460	$4,920	30%	$1,476.00	70.0%	100%	$1,476.00	738.00	738.00
11	Data processing and storage	1	LS	10,000	10,000	$20,000	30%	$6,000.00	70.0%	100%	$6,000.00	3,000.00	3,000.00
	Sub Total Base Contract Items			**$140,000**	**$140,000**	**$280,000**		**$84,000.00**			**$84,000.00**	**42,000.00**	**42,000.00**

	NDIC	SPONSOR
Amounts Received	**$0.00**	**$42,000.00**
Amount Requested this Period (Completion)	$42,000.00	$0.00

Appendix B – Well Status Flow Diagram



Appendix C – Cesium Process and Data Flow Diagram