Hell Creek Environmental
15399 Cranes Mill Rd Canyon Lake TX, 78133 ● www.hellcreekenvironmental.net ● 701-500-9825

January 15, 2018

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 E. Boulevard Avenue
State Capital, 14th Floor
Bismarck ND, 58505-0310

Dear Ms. Fine:

Subject: Status report for the project "Collection and Development of Actionable Reclamation Data Using Aerial Remote Sensing"; Contract No. G-037-73; Hell Creek Environmental LLC.

Hell Creek Environmental is pleased to update the council with the complete final report for the project involving the collection and development of data and imagery enabling qualitative and quantitative analysis of ten locations at various stages in the reclamation process. This report applies to the period from May 11,2016 through, June 2017.

If you have any questions please contact me at (701) 500-9825, or via email at mark.hellcreek@gmail.com

Sincerely,

Mark Jackson,
Principal Researcher
VP / Business Development

Enclosures

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
> Y	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/RGBI	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] ă l· á LJNJ2 Ždz Ő ű é Ŧ 2 NJ b 5 L / L y˘ ă LJ Ŝ Ő ű ǎ 2 This analysis and display of the remote imaging was successful in projecting reclamation á NJ Ŝ ă dz f ű ă é NJ Ŝ North Dakota Administrative Code[2] criteria, namely: removal of infrastructure, remediation of and reestablishment of the original land contours, and re establishment of native vegetation. 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 imagery 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 seed bed growth 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 NJ Ŝ Ő f l· Y l· ű ǎ 2 y˘ ǎ y˘ ă ǎ ∃ Ƙ ű ă Φ ¢ Ƙ Ŝ ă Ŝ ǎ y˘ Ő f dz Ř Ŝ Ř Y f ǎ Y˘ ǎ ű ǎ 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 biomes. 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 to 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] { dz Ő K l· ă I l· NJ NJ ǎ ă Ω 9 b ± L 2 NJ 9 NJ Ř l· ă L Y˘ l· ∃ ǎ y˘ Ŝ

[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 85.68 million barrels produced in 2005 and over 432.29 million barrels produced in 2015.[9]

b 2 NJ ű K 5 l· ļ 2 ű l· Ω ă 2 ƛ f l· y Ř Ǝ l· ă NJ l· LJ ƛ Ř and Ř Ŝ Ø Ŝ f 2 LJ Y Ŝ y ű long-standing industry partners and inevitably other companies that took for short term returns and leave their lease acreage out of compliance with State and Federal 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] 5 ƛ NJ Ŝ Ŏ ű 2 NJ Ω Dakota Production Outlook 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 accurataccurately e assess ment of site reclamation activity. There is no standard or definition as to what a finished and acceptable reclais 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 resources 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 ø Ŝ f f ă ƛ ű Ŝ Ω ă y ˜ Ŝ Ŝ Ř dúred. Therefore, a viable procedure to safely, efficiently, and cost-effectively evaluate the reclamation process is warranted. A more automated and more effective monitoring strategy is possible through advancement in remote sensing technology and may be 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 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 well site 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, 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 LAS á

[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 ! D L Ω ă ¢ Ŝ l· Y˝ Ƙ l· ă Y˝ l· Ř Ŝ ű Ƙ ƛ ă Ř l· ű l· l· y˝ Ř l 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 l· LJLJ f ƛ Ŏ l· ű ƛ ƨ y˝ Y˝ dz ă ű Ƙ l· Ø Ŝ l· dz ű Ƙ Ŝ y˝ ű ƛ Ŏ l· ű ƛ ƨ y˝ ă ƨ
- 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 ű Ƙ ƛ ă N Ŝ Ř È Ŝ ă ć Ø ƛ Ŝ ó ˝ ƛ Ŝ y ă ability of the analyst to view and compare each site's 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 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 ă ƛ ű Ŝ Ω ă Ŏ ƨ Y LJ f ƛ l· y Ŏ Ŝ ø ƛ ű K b ƨ NJ ű K 5 l· ļ ƨ ű l· Ω ă LJ ƨ ă ű Ŏ f ƨ ă dz NJ Ŝ NJ 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 world's 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) and 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 [illegible] access and visualization capability, resulting in a major gain in efficiency to the regulatory agencies and regulated industries by [illegible] 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 (BBMU). These ten sites are in the northwestern region of North Dakota (ND). The sites selected in the TMU field were the TMUE-143, TMUE-144, TMUN-130, and TMUN-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 BBMUE-331, BBMUF-220, BBMUF-429, BBMUG-316, and BBMUH-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.

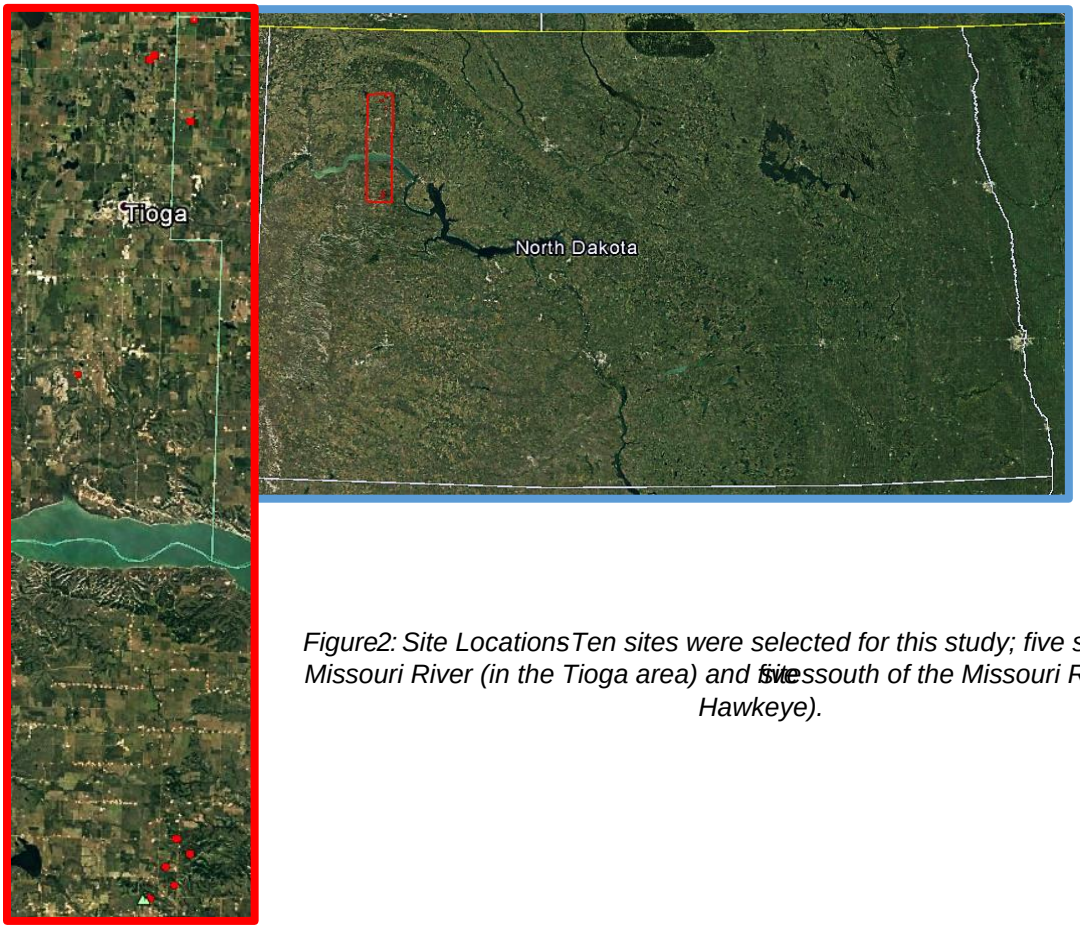

Figure2: Site LocationsTen sites were selected for this study; five sites north of the Missouri River (in the Tioga area) and five sites south of the Missouri River (south of Hawkeye).

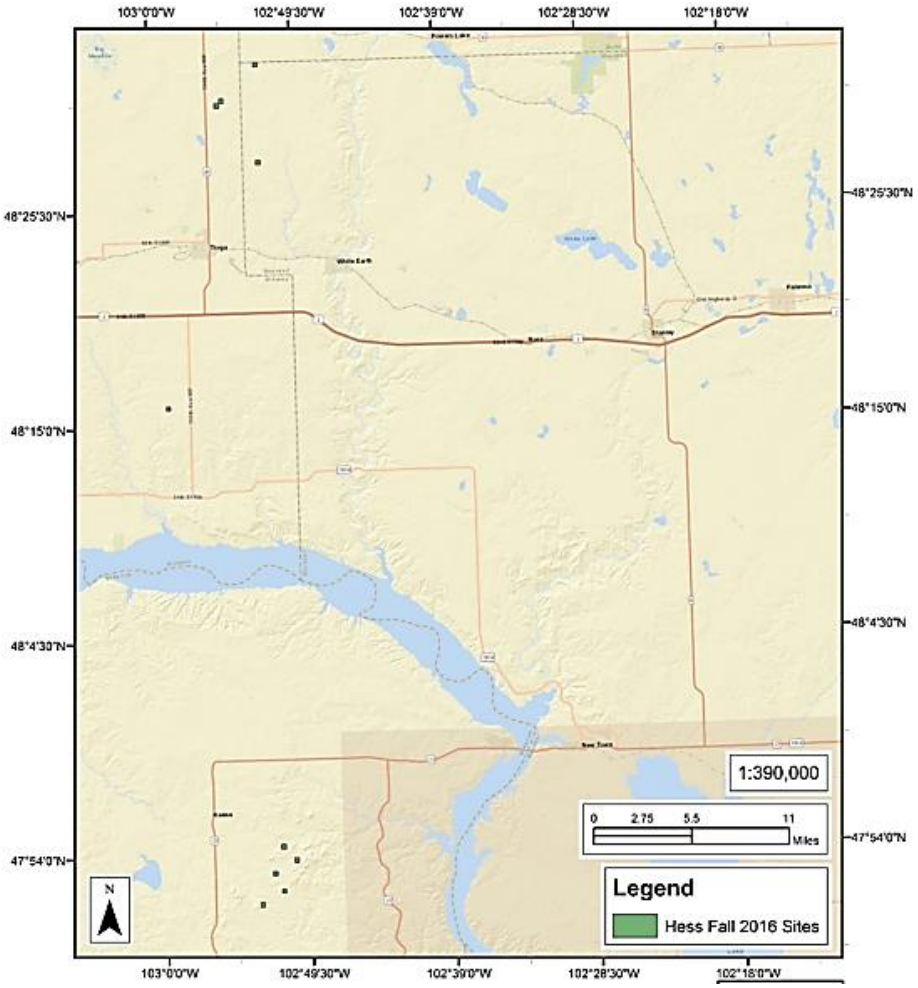

Figure 3: Reference location of the ten study sites

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 surveys 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 imagery. 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 Φ τ . 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 (0.75-5 Φ π 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 algorithm and output data add gain and color balancing to create natural looking photos, which are more ά NJ Ŝ l· p ŕ ŭ ŕ ŭ Ŏ ś 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 l· f Ǝ 2 NJ ƛ ű Ƙ Y ø Ƙ ƛ Ŏ Ƙ NJ Ŝ ă data but as for pallet but retained the ability to be y Ř f Ŝ 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 low solar angle. The lower frame rate induce a lot of motion blur, high shadows and poor light quality also made it difficult to visually discern the 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

Table1 - 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 surrounding (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 topographic 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 152 to highly wooded area, such as Site 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)