Ecological Recovery Monitoring Program for Certified Reclaimed Sites in Alberta:

Specialized Monitoring Protocols

By

InnoTech Alberta

ERMP Project Advisory Group

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Ecological Recovery Monitoring Program Development Project

The Alberta Biodiversity Monitoring Institute contracted InnoTech Alberta in 2017 to develop the direction, framework and implementation plan for the Ecological Recovery Monitoring Program. The Project has been divided into a series of Tasks:

Task 1: Describe the Goals and Objectives for a Long-Term Monitoring Program in Alberta

Task 2: Develop a Science-Based, Practical Protocol for the Long-Term Monitoring Program

Task 3: Develop an Information Distribution Plan

Task 4: Develop an Implementation Plan for the Long-Term Monitoring Program

Project Team

The Project was led by InnoTech Alberta Reclamation Team staff (Small, C., and Powter, C.) with the advice and guidance from a Project Advisory Group (PAG). The PAG consisted of members from: Alberta Environment and Parks, ABMI, the University of Alberta, InnoTech Alberta, Canadian Forest Service, ATCO Electric, and several technical specialist consultants. PAG members included:

- Chris Powter – Enviro Q&A Services Inc.
- Christina Small – InnoTech Alberta
- Andrew Underwood – InnoTech Alberta
- Jim Schieck – InnoTech Alberta/Alberta Biodiversity Monitoring Institute (ABMI)
- Jim Herbers – Alberta Biodiversity Monitoring Institute (ABMI)
- Arnold Janz – Alberta Environment and Parks (AEP)
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- Anne McIntosh – University of Alberta
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- Cindy Shaw – Canadian Forest Service
- Cindy Craig – ATCO Electric
- Ivan Whitson – I Whitson Innovations Inc.

Documents produced for each Task were developed as drafts by InnoTech Alberta and then discussed with the PAG in a workshop format to develop a consensus position on the key

Program components. The final draft document of each Task informed development of the next Task document.

Report

This report was prepared under Task 2. Other reports published under Task 2 provide protocols for grassland, forested land and cultivated land wellsites.

This report may be cited as:

ERMP Project Advisory Group, 2017. Ecological Recovery Monitoring Program for Certified Reclaimed Sites in Alberta: Specialized Monitoring Protocols. 30 pp.

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1 INTRODUCTION

Alberta has a large industrial footprint, consisting of >400,000 oil and gas wells, >500,000 km of pipelines, hundreds of thousands kilometres of roadways, prairie and mountain coal mines, oil sands mines, oil production sites (in-situ oil sands sites), sand and gravel pits, quarries, plant sites and transmission lines. These disturbed sites, termed *specified land* in the *Conservation and Reclamation Regulation* (Government of Alberta, 1993), must be reclaimed and certified as having an equivalent land capability (*Environmental Protection and Enhancement Act*; EPEA; Government of Alberta, 2000).

Ecological recovery is achieved when the biological, physical and chemical properties (in terms of vegetation, soil and biota) of a reclaimed site return to similar structure and function as found in a representative undisturbed reference area or in the pre-disturbance site. Requirements for certification noted above may or may not fully facilitate return of ecological function at a site. Further complicating matters is the practice of certifying forested land, native prairie, or peatlands/wetlands sites that take decades to reach ecological maturity based on expectations or predictions of future performance (often referred to as being on an accepted trajectory to full recovery). As a result, immediately following reclamation certification, and for some unknown period of time afterwards, most sites will not have fully recovered their ecological function. Previous studies (e.g., Avrimed et al., 2014; Desserud et al., 2010; McIntosh, 2014) and site inspections have identified cases where soil and vegetation chemical and physical parameters (e.g., pH, organic carbon, bulk density, plant species composition, aboveground biomass, crop yield) and presence of invasive and/or undesirable plant species indicate a lack of full ecological recovery on reclaimed certified sites.

1.1 Ecological Recovery Monitoring Program

The Ecological Recovery Monitoring Program is enabled through section 15 of EPEA (Government of Alberta, 1993). The goals of the ERMP (ERMP Project Advisory Group, 2017a) are to:

1. Monitor, evaluate, and report to Albertans regarding the science of potential long term impacts of human disturbance on landscape, soil and vegetation; and,
2. Better inform Albertans on the rate, magnitude, direction, and extent of ecological recovery at reclaimed and certified industrial sites in Alberta and to support government evaluation of current reclamation policies and practices.

The objectives of the Ecological Recovery Monitoring Program are to:

1. Provide landowners, the public and Aboriginal communities better understanding of the effectiveness and limitations of land conservation and reclamation practices;
2. Provide regulators with data to support: refinements to land conservation and reclamation requirements; land reclamation certification criteria; and, appropriate liability timeframes for different types of specified lands;

3. Provide data to support analysis of the impacts of changes over time in regulatory requirements and industrial practices on environmental outcomes;
4. Provide data to support development of reclamation trajectories that will better predict future performance and therefore permit certification of sites prior to full ecological recovery;
5. Provide data to assess which monitored parameters are key determinants of ecological recovery for disturbance types in each ecological zone (and therefore provide insights to improve conservation, reclamation and site assessment practices); and,
6. Improve understanding of linkages between monitoring parameters, ecological recovery, natural variability and regulatory requirements.

The Program consists of four core components, each supporting and interacting with the other in an adaptive management framework:

1. **Monitoring** – an annual field-based program to gather data on the ecological recovery status of reclaimed certified sites in Alberta. Methods to be used and the parameters to be evaluated are identified in Protocols developed for each disturbance type (e.g., wellsites, pits, mines) and each relevant site type (e.g., grassland, cultivated, forested).
2. **Evaluation** – analysis of monitoring data from individual sites and specified land types, and, where applicable, synthesis of parameters into integrated measures of ecological recovery.
3. **Reporting** – public dissemination of monitoring results in the form of summary reports (by year and/or by type of specified land) that provide information on the state and condition of reclaimed specified land. Results can also be provided as raw data or in various summary data formats.
4. **Research and Development** (R&D) – ongoing development and refinement of the monitoring program protocols and evaluation methodology[1].

1.2 Specialized Monitoring Techniques

This report describes several specialized monitoring techniques that were evaluated during the Pilot Program. At this time these techniques are not recommended for full-scale implementation in the ERMP – further research may lead to subsequent inclusion in the Program. This report provides an overview for each method – further details, including references and background information are available in the sources noted at the start of each method.

[1] Additional research using ERMP data may be carried out by external organizations. The Program managers will need to maintain awareness of the findings so they can be incorporated into the Program as necessary.

2 BRYOPHYTE AND LICHEN SURVEY

2.1 Rationale

Bryophytes and lichens are ubiquitous and important components of forest and grassland communities. The ERMP protocols collect plant community data based on percent cover by species for vascular, non-vascular, and lichen species – and also lumping estimates of vegetation cover at the level of forbs, grasses, and shrubs. A much more detailed understanding of the plant community can be obtained by determining species composition and richness on a site through a survey.

2.2 Field Methods

Field Equipment Needed:

- Mora knife
- Hand lens
- Toilet paper for fragile specimens
- Squares of paper/small envelopes for small specimens
- 20 paper bags (Kraft #8) per site
- 1 larger grocery-sized paper bag per site (plus additional large bag so that you separate lichens and bryophytes for storage)
- Sharpie
- Water
- Watch

Plot Layout Procedure

To mark the 25x15 m bryophyte/lichen survey plot in each of the wellsite and reference area quadrants to be surveyed add the following step to the layout procedures described in the *Ecological Recovery Monitoring Program for Certified Reclaimed Sites in Alberta: Monitoring Protocols for Forested Sites* (ERMP Project Advisory Group, 2017c):

- For the quadrant where you are doing the bryophyte/lichen plot, mark the distance 15 m from the corner of the 25x25 m plot that is closest to the wellsite centre that is not part of the 10x10 m plot to create the fourth corner of the 25x15 m bryophyte/lichen plot
    - Note this will require additional pigtails.

Sampling Procedure:

- For both the wellsite and the reference area, select the quadrant with the most diversity of microhabitats (or if they all appear similar randomly select one)[2]. For each of these two selected quadrants two types of sampling will be completed:
  - a 25x15 m plot (0.0375 ha) for the most diverse microhabitat types, and
  - a 2x25 m belt transect for the less diverse microhabitat types (Figure 1).

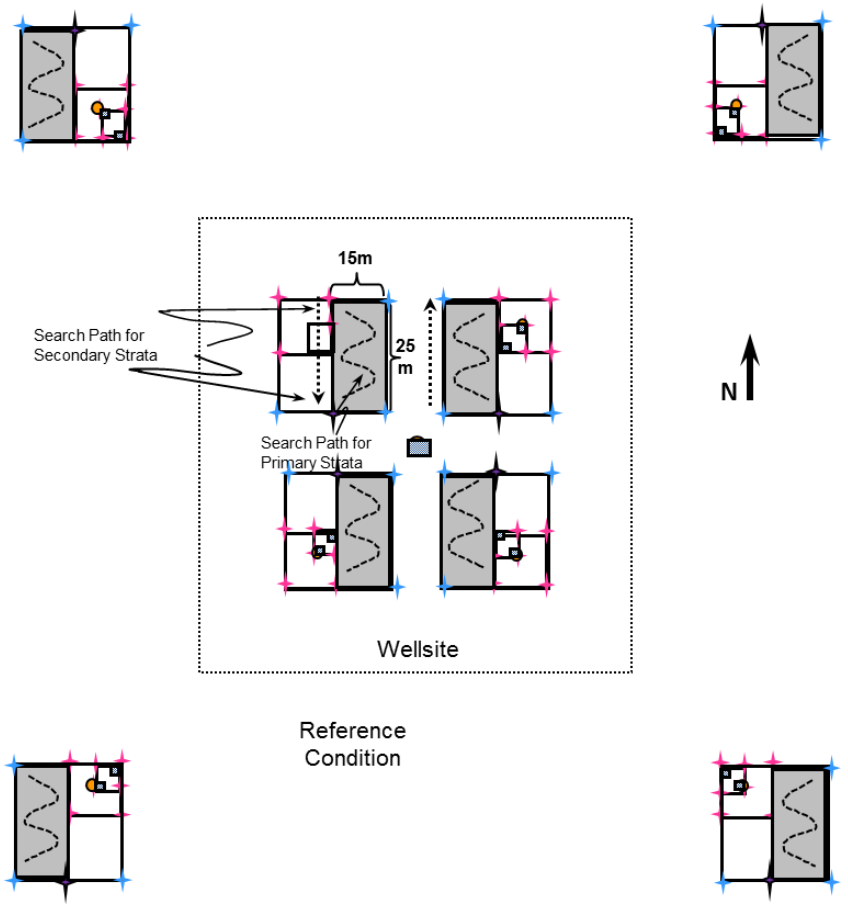

Figure 1. Description of the plots where bryophytes and lichens are sampled. Note only one wellsite 25x15 m plot and one reference area 25x15 m plot will be established and sampled (including the belt transect), but the figure includes all eight potential 25x15 m plots for clarity.

- A single person spends up to 35 minutes (25 minutes for 25x15 m plot, 10 minutes for 25x2 m plot) in each of the two 25x15 m plots (maximum total 70 minutes) collecting bryophytes. A second person independently completes the protocol for

[2] Only one wellsite quadrant is sampled to reduce time spent on site as reclaimed wellsites are generally low in diversity.

lichens (maximum total 70 minutes) OR the first person samples for lichens and then, in a separate time period, samples for bryophytes – do not try and simultaneously collect both sets of data.

- In each selected plot, surveys are divided into two periods:
    - First: the strata (microhabitat types) present are sampled in the 25x15 m plot.
        - For bryophytes: Search strata #1 logs/ stumps and strata #4 rocks (Table 1).
        - For lichens: Search the strata #1 logs/stumps, strata #2 trees/other structures and strata #4 rocks (Table 1).

Table 1. Strata and microhabitat types within strata used during searches for bryophytes and lichens.

Stratum #1: Logs and Stumps (samples in 1 bag)
LS: Soft stumps and logs (decay classes 3 – 5) – sample roots and all sides
LH: Hard stumps and logs (decay classes 1 – 2) – sample roots and all sides
Stratum #2: Trees, Shrubs and Other Vertical Structures (samples in 1 bag)
TD: Deciduous Trees – all sides of the roots, bases, trunks, and branches of both live and dead deciduous trees
TC: Coniferous Trees – all sides of the roots, bases, trunks, and branches of both live and dead coniferous trees
TS: Shrubs – all sides of the roots, bases, stems, and branches of live & dead shrubs
HB: Human Structures – vertical and horizontal parts of the structures (survey from the ground)
Stratum #4: Rocks and Cliffs (samples in 1 bag)
BC: Boulders (>50 cm diam.) – survey all surfaces (top, sides, and base) from the soil upwards
RR: Rocks (<50 cm diam.) – survey all surfaces (top, sides, and base) from the soil upwards
Stratum #5: Upland Soils (samples in 1 bag)
UC: Humus soils under trees/shrubs (shaded by canopy) – survey as large a variety as possible
UO: Humus soils without trees/shrubs (open to sunlight) – survey as large a variety as possible
DC: Agriculturally cultivated soils
DM: Mineral soil in upland areas from any causes

- To help maximize the number of species detected, begin the timed search by surveying one example from each stratum that has the most diverse

community of bryophytes/lichens. This must be completed within a maximum of 5 – 10 minutes. For example, large-diameter soft logs often have the highest diversity of both taxa, and when present in the plot, should be targeted early in the search.

- Then search for the three primary strata by zig-zagging through the plot (Figure 1).
- Stop every 4 or 5 steps to examine the microhabitat types in the immediate area. When examples of any of the primary strata are found, take samples as you encounter them.
- Note that if there are no examples of any of the primary strata in the plot, then the search can be terminated after 5 minutes. A minimum of 5 minutes must be spent searching for examples of the primary stratum in each plot as some microhabitats are small and dispersed in space (e.g., rocks).
- If there are microhabitats (strata) found within the plot, then a minimum of 10 minutes must be spent searching if all examples of primary strata have been searched (for example, if you are searching for lichens and there is a single tree, no logs, and no rocks/cliffs in the plot then sampling may be terminated after 10 minutes).
- Plots which have all of the primary strata should take the full 25 minutes to search.

o Second: the strata (i.e., the microhabitat types) that have less diverse communities are searched in a belt transect following the 2 long sides of the 25x15 m plot (Figure 1). Walk along the 25x15 m plot boundary and sample within 1 m of either side of the transect. This results in two 25x2 m transects, one for each of the wellsite and reference area quadrants.

- For bryophytes: Search strata #2 trees/structures and strata #5 upland soils (Table 1).
- For lichens: Search strata #5 upland soils (Table 1).
- Ensure that examples of both secondary strata are searched if they occur in the transect.
- Search as many examples (or as much area) of the secondary strata as possible as you encounter them.

- In each stratum in each plot/transect collect examples of all the bryophytes/lichens that appear distinctive.
- When collecting specimens:
  - Select only a small sample (i.e., 4 – 6 cm^2) so that the vegetation community remains intact.

- If the specimen is growing on mineral soil, wrap the sample gently with toilet paper so it does not break apart (disintegrate) once the soil dries.
- If the specimen is growing on a large boulder/rock/cliff, wet it thoroughly to help detach it from the substrate. Place small/fragile specimens in paper packets so they don't get lost.
- If the specimen is very wet (e.g., moss from a wetland stratum) carefully squeeze out the specimen before placing it in the bag. Be mindful to fluff the specimen back out after squeezing.
- When in doubt about whether a specimen is unique or has been collected already, collect it again.
- We do not sample crustose lichen; however, when in doubt about whether a specimen is crustose, collect it.

- For each taxon (bryophytes/lichens), all specimens collected from a stratum are placed as a composite sample in a single bag.
  - Be diligent to not collect the same species repeatedly from a stratum as it takes considerable time to sort through duplicates in the lab.
- If no specimens are found in a stratum of a plot/transect, then indicate "None" on the empty paper bag and on the field data sheet. If no example of a stratum is found in a plot/transect (all microhabitats are absent), then indicate *Variable Not Applicable* "VNA" on the bag for that stratum and on the field data sheet. Paper bags without either a "None" or a "VNA" are assumed to contain specimens.

2.3 Constraints

Sampling for bryophyte and lichen species composition:

- Requires additional time (up to two and half hours).
- Requires collection of numerous specimens for later identification.
- Requires specialized expertise in identification.

3 SOIL MESOFAUNA

Adapted from Battigelli (2016).

3.1 Rationale

Most post-reclamation monitoring of soils uses soil chemical and physical properties to infer soil quality. In fact, many projects only evaluate reclamation and recovery based on re-establishment of vegetation. The ideal restoration/reclamation of disturbed soils re-establishes the pre-disturbance ecosystem structure, function and diversity of flora and fauna. While data for chemical, physical or vegetative indicators may be easier and/or less expensive to collect, soil organisms are part of the ecosystem biota and are better able to integrate all these values and provide an enhanced understanding of the ecological functions and processes occurring in the soil.

Soil mesofauna occupy a wide range of trophic levels in the soil including predators, parasites, phytophages, fungivores, microbivores, saprophages, detritovores and omnivores. Coupled with these feeding modes are their important roles in decomposition, nutrient cycling, carbon sequestration and soil formation. Soil mesofauna are involved in every transformation of organic matter and play a variety of functional roles in soil processes including: regulating bacterial and fungal biomass; liberating immobilized nutrients; stimulating fungal and bacterial activity; enhancing plant growth; transporting microbial propagules and spores into new substrates; and, contributing to soil structure development through the deposition of fecal pellets and humus formation.

3.2 Field Methods

Materials/Equipment

- Rite in rain labels
- Pencil
- Soil corer, plunger, core tray
- Cooler
- Ice/cold packs
- Small Ziploc bags
- Measuring tape
- Knife

Methods:

- Sample the top 5 cm (0-5 cm) of collected soil core including any surface litter.

- Samples should be collected at the start of each site survey. Excessive surface trampling around the center sample point (i.e., auguring activities, foot traffic) will disturb the fauna sample point surface.

For each plot:

- Collect one soil core 50 cm due north of the centre soil sample point of each 10x10 m plot[3].
    - Soil fauna sample to be collected before any other sample work is completed.
    - Total fauna samples collected at each wellsite will be 9 (5 onsite and 4 offsite).
    - Do not mix (composite) the wellsite or the reference area samples.
- Push core from bottom out onto core tray using plunger.
- Measure and remove top 0-5 cm section of soil core from tray. Try to keep core intact as much as possible.
- Place section into small Ziploc bag.
- Fill in data label in pencil. Use same sample labeling scheme as rest of site but include "-fauna" on label.
- Put data label into Ziploc bag with soil core sample. Make sure to leave air in the bag.
- Place sample in cooler with ice.
- Ship samples on ice in cooler as soon as possible for extraction.

3.3 Laboratory Methods

- To extract soil mesofauna, place soil cores into a modified Merchant-Crossley extractor for seven days.
- Extract specimens into specimen cups containing ethylene glycol for storage purposes.
- To prepare samples for sorting, identification and enumeration, specimens are rinsed with water through a 54 µm sieve until no ethylene glycol remained.
- Backwash sieve contents with water into watch glasses for sorting and counting under a dissecting microscope.
- Identify specimens to the following levels: *Acari* (mites) to suborder, *Collembola* (springtails) to family and the remaining specimens to class, order or family level depending on the group. Store sorted material in 70% ethanol.

[3] Note – you can improve sampling efficiency by: (1) taking a bulk density core, (2) extracting soil fauna, (3) air drying and weighing the sample to provide data for bulk density, and (4) grinding and using the sample for routine chemical analyses.

3.4 Constraints

- Requires a soil mesofauna expert.

4 E-TILLER

Adapted from Small and Underwood (2016, 2017) and Underwood and Small (2017a).

This protocol is only used in cultivated land sites after the crop has been harvested.

4.1 Rationale

Inadequate topsoil and subsoil salvage, stockpiling, replacement and contouring have been observed to directly impact surface soil structure in comparison to surrounding undisturbed lands. This can result in differences in plant abundance and vigor, accumulated standing water on compacted zones, and soil clods that alter soil aeration and water infiltration.

Selecting methods for measuring and evaluating soil physical properties in the field remains a challenge. Traditionally, evaluation has been done by collecting spot samples randomly in the field for laboratory analysis (e.g., bulk density, particle size analysis). Due to the heterogeneity of soil across landscapes, quarter sections, cultivated plots, etc., spot measurements do not provide confidence in the spatial variability of the collected data.

Measurement of draft force in soils is considered to be the most accurate method for measuring soil mechanical resistance; a surrogate for evaluating physical soil characteristics in terms of soil structure. On-the-go soil proximal sensors that measure mechanical resistance have been proposed to be sensitive enough to characterize differences on and off of disturbed areas, by delineating contrasts in bulk density with depth. In 2015, InnoTech Alberta designed and fabricated an Electronic Tiller (E-Tiller), updated from the initial design and concept conceptualized by the Alberta Research Council (ARC) and Alberta Environment in 1999.

4.2 Field Procedure

- Mount the E-Tiller on a suitable farm tractor (a John Deere 5205 tractor was used in a field trial).
- Measure draft force at both 6 inch (roughly 0 to 15 cm) and 12 inch (roughly 0 to 30 cm) depths.
    - Manually set the E-Tiller ripper blade to 15 cm and 30 cm using the depth adjustment wheels while configured at pivot position 3. The 15 cm and 30 cm depths used sensor positions 2 and 3 respectively.
- For a standard 100x100 m wellsite and adjacent reference areas a total of six transects, spaced 40 m apart, are made for each measurement depth (Figure 2).
    - Make passes, at least 200 m in length, across both the wellsite and adjacent reference areas in a direction parallel to the direction of the farming equipment and any resulting soil ridges.
    - The advantage of the double-back technique shown in the figure is that data quality can be compared between adjacent transects, better ensuring transect

repeatability in addition to the real-time identification of instrument data collection error.

- At the end of each transect raise the instrument out of the ground to permit the tractor to turn; data are not recorded during this time.
- Transects spaced 20 m apart may be required for sites showing more heterogeneity.

- Independent measurement depths (i.e., 6” and 12”) are offset by 10 m (Figure 2).
- Following measurements, drive the tractor over the ruts created by the ripper blade to close the ruts up.

Soil samples are taken to build a standard calibration curve:

- Collect samples using an AMS bulk density sampler at the same soil depth intervals (i.e., 0 to 15 cm and 15 to 30 cm) as the E-Tiller sampling depths.
  - Soil sample methodology using the bulk density sampler followed the ERMP protocols for cultivated reclaimed wellsites (ERMP Project Advisory Group, 2017b).
- Take samples within 1 m of the E-Tiller sampling path (Figure 2).
  - Take samples between the shallow (0 to 15 cm) and deep (0 to 30 cm) E-Tiller measurement transects.
- Choose sample locations based on the real-time monitoring of soil mechanical resistance recorded by the E-Tiller; target the highest and lowest areas of soil mechanical resistance as a means of building a standard calibration curve.
  - Collect an equal number of samples from areas of high and low mechanical resistance per site.
  - At a minimum, collect 12 samples for each depth, resulting in a total of 24 samples per site.
- Store samples in plastic bags at 4°C prior to laboratory analysis.
- Analyze samples for soil moisture, particle size/texture, wet bulk density and dry bulk density.

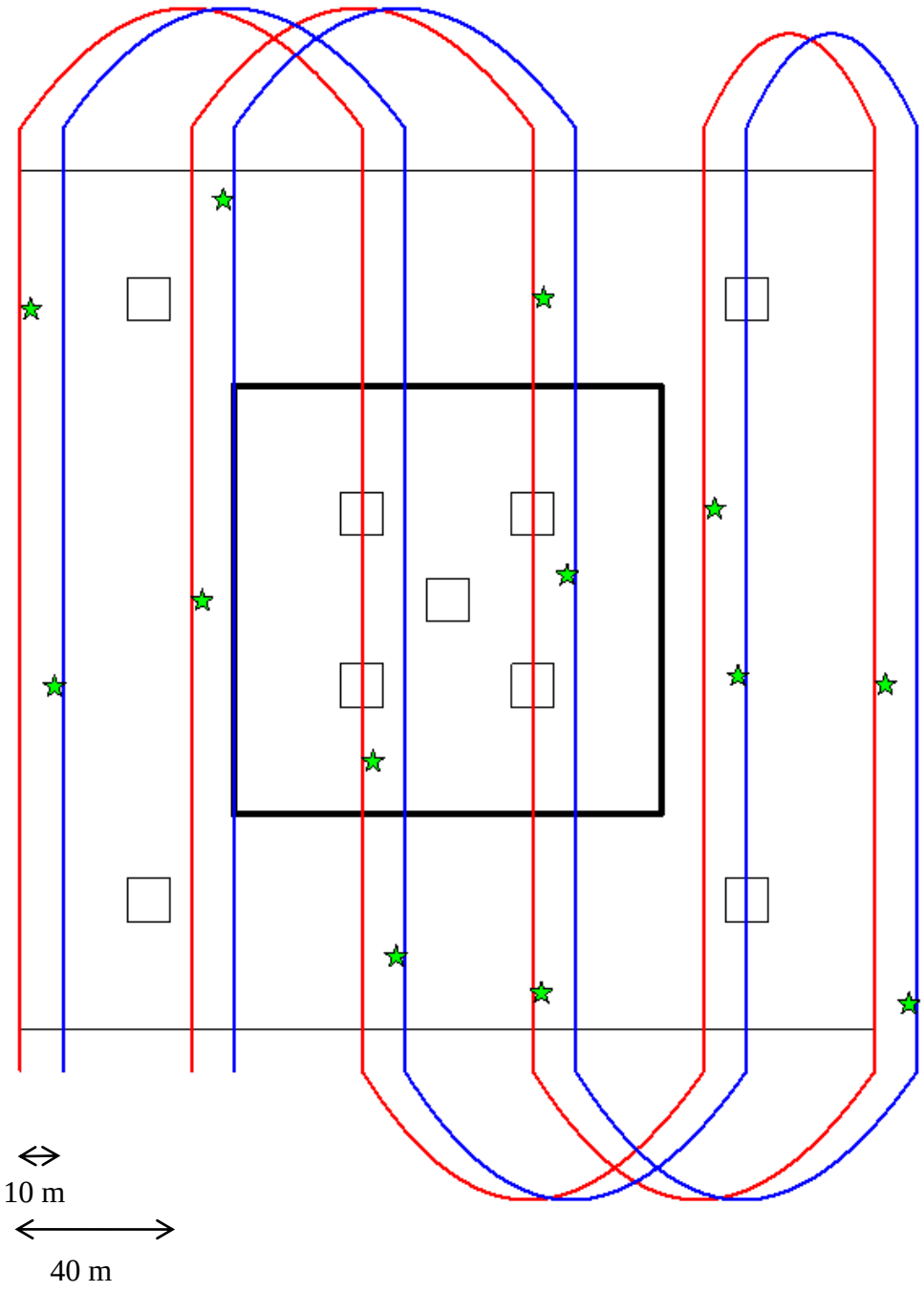

Figure 2. Sampling design for the E-Tiller across the wellsite (bold black box) and adjacent reference area.
Measurement depths – 6” or 15 cm (red) and 12” or 30 cm (blue).
Soil sample locations are indicated by green stars.
The small black boxes indicate the ABMI ERMP sampling locations on the wellsite and adjacent reference area.

4.3 Data Analysis

- Convert the E-Tiller mechanical resistance values to mass force using the calibration curve equation.
- Develop a calibration curve for physical soil properties using the multivariate analysis of lab values for the samples and the nearest soil force value.
- Generate mechanical resistance maps using the processed data and ArcMap 10.2 (Esri; CA, USA) GIS software (Figure 3).
    - For GIS mapping, build the map designs from the quality controlled data files.
    - Colour individual data points using a gradient, depending on the relative magnitude of measured draft force.
    - Interpolate data points using the Kriging method to create a contour map of draft force.

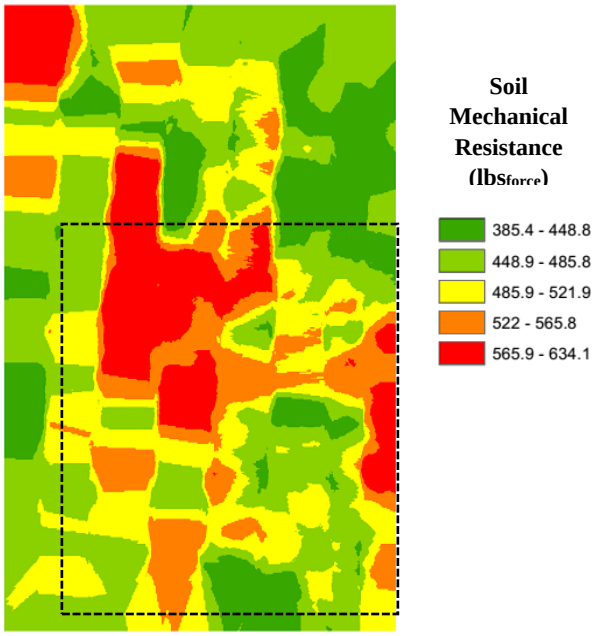

Figure 3. Soil mechanical resistance values spatially represented 10” depth interpolated by Kriging.
The black dashed box represents the approximate location of the wellsite.
Instrument passes are in the North-South direction.

A preliminary assessment of the potential to use E-Tiller soil force data to predict and map soil physical properties such as %sand, %silt, %clay, dry bulk density and %moisture was undertaken by Underwood and Small (2017a). Calibration models using multivariate analysis were developed and a linear calibration curve was constructed for each soil parameter. The predicted values were then mapped following similar data processing described above (Figure 4).

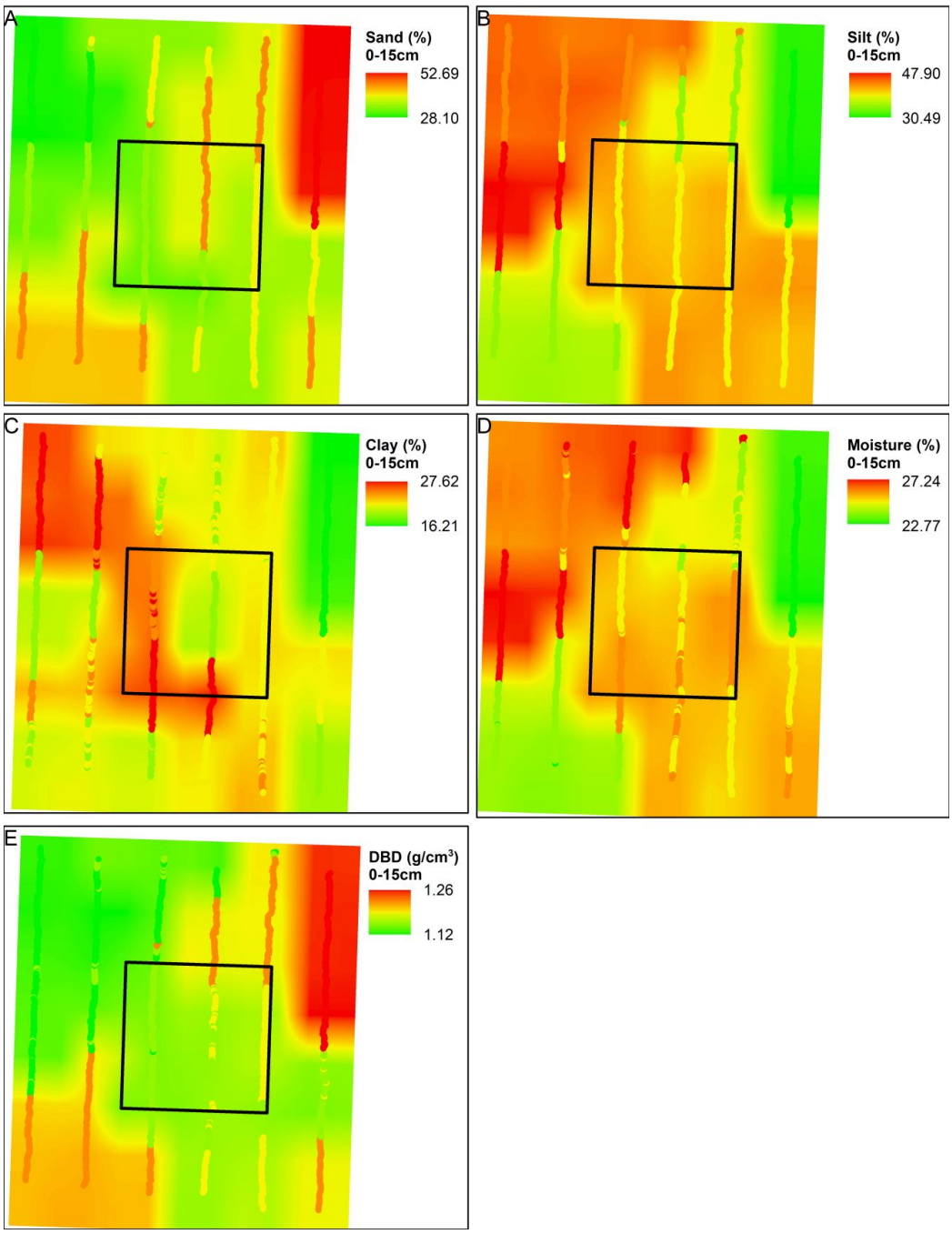

Figure 4. Predicted value maps for (A) %sand, (B) %silt, (C) %clay, (D) %moisture, and (E) dry bulk density (DBD) measured at 0-15 cm.
The location of the wellsite is indicated by a black square. Raster colours represent the range of values for the soil parameter as indicated in the frame's legend.
The location of the data points collected by the E-Tiller, are provided by coloured data points on each map.

4.4 Constraints

Constraints on E-Tiller use include:

- Soil samples to calibrate the model.
- Qualified operator/trained personnel required for instrument operation.
- Limited window for sampling on cultivated lands (between harvest and soil freezing).
- Rocky fields limit use (breaking of multiple shear pins is expected).

5 OPTIC MAPPER

Adapted from Degenhardt et al. (2016).

5.1 Rationale

The Veris Technologies OpticMapper (soil proximal sensor) can be used to map the spatial distribution of soil organic matter (OM) and cation exchange capacity (CEC) across wellsites and adjacent reference areas. If good correlation between soil sample lab analyses and the OpticMapper's electrical conductivity and reflectance data is achievable, then the OpticMapper data could be used to produce a predicted spatial map of %OM and/or CEC across the wellsite and reference areas instead of point values that soil samples alone provide.

5.2 Field Methods

- Mount the OpticMapper onto a suitable vehicle (a 1 ton pickup truck was used in the trials).
- Clean the sapphire window and place the test reference block underneath the wear plate so that the window is covered.
- Perform system software check.
- Confirm resistance readings are less than 2 ohm for each electrical path between the coulter blades and the test box.
- Configure the unit so that the sapphire window enclosure is in good contact with the soil, penetrating at least 1 inch and the coulter blades are penetrating the soil by 2 to 3 inches.
- While slowly moving forward, lower the unit into the soil using the hydraulic controls until it reaches the pre-set depth.
- Raise the unit before making a turn.
- Transect spacing strategy:
    - 16 – 24 m transect spacing is adequate.
    - Avoid areas of heavy residue in combine swath.
    - Avoid sensing in wheel ruts.
- Check furrow closing and adjust pressure as needed using the lever at the back of the machine.
- Space initial passes at double the width you want to map and when you have gotten to the end of the field, go back the other way going in between your original passes. This can help identify if there were any instrument problems that could crop up while mapping.

- Maintain a speed of 8 km/h, but slow down if soil is rocky.
- Check the data status light on the logger or laptop display to make sure that it is green. If it is not green then either the EC readings or the GPS readings aren't right. Data will not log unless this light is green.
- Always start a new working directory in the Veris software if adjustments are made or field conditions change.
- Collect composite soil samples from the 0-15 cm depth in areas identified to be high and low electrical conductivity for lab analysis; composites are made from samples within a 1 m radius.

5.3 Data Analysis

- Submit georeferenced soil calibration data to Veris (Salina, TX) along with the OpticMapper data files for sensor data calibration.
    - Based on the laboratory soil analysis, Veris determines the best proxy for calibration (i.e., infrared reflectance, red reflectance, shallow apparent electrical conductivity, or deep apparent electrical conductivity).
    - If calibration is successful, estimates for organic matter (OM) and cation exchange capacity (CEC) are provided.
- Import processed and calibrated data into ESRI ArcMap, and overlay a fishnet polygon layer on calibrated OM and CEC georeferenced values (Figure 5).
    - The fishnet pattern is composed of 121 20x20 m squares centred on the wellsite centre – mean values are calculated from OpticMapper values that fell within them.
    - A 100x100 m wellsite size is assumed for consistency in data comparison.
- Apply Kriging interpolation method to a create raster layer that provides a background for each fishnet pattern and property.
- Average OpticMapper calibrated values falling within each square and label the values on each map.
- Export data from the fishnet layers to Microsoft Excel for comparison of OM and/or CEC between wellsite (on) and reference (off) area.
    - The reference area is represented by the 20x20 m grids directly adjacent to the wellsite (n = 24) (Figure 5).

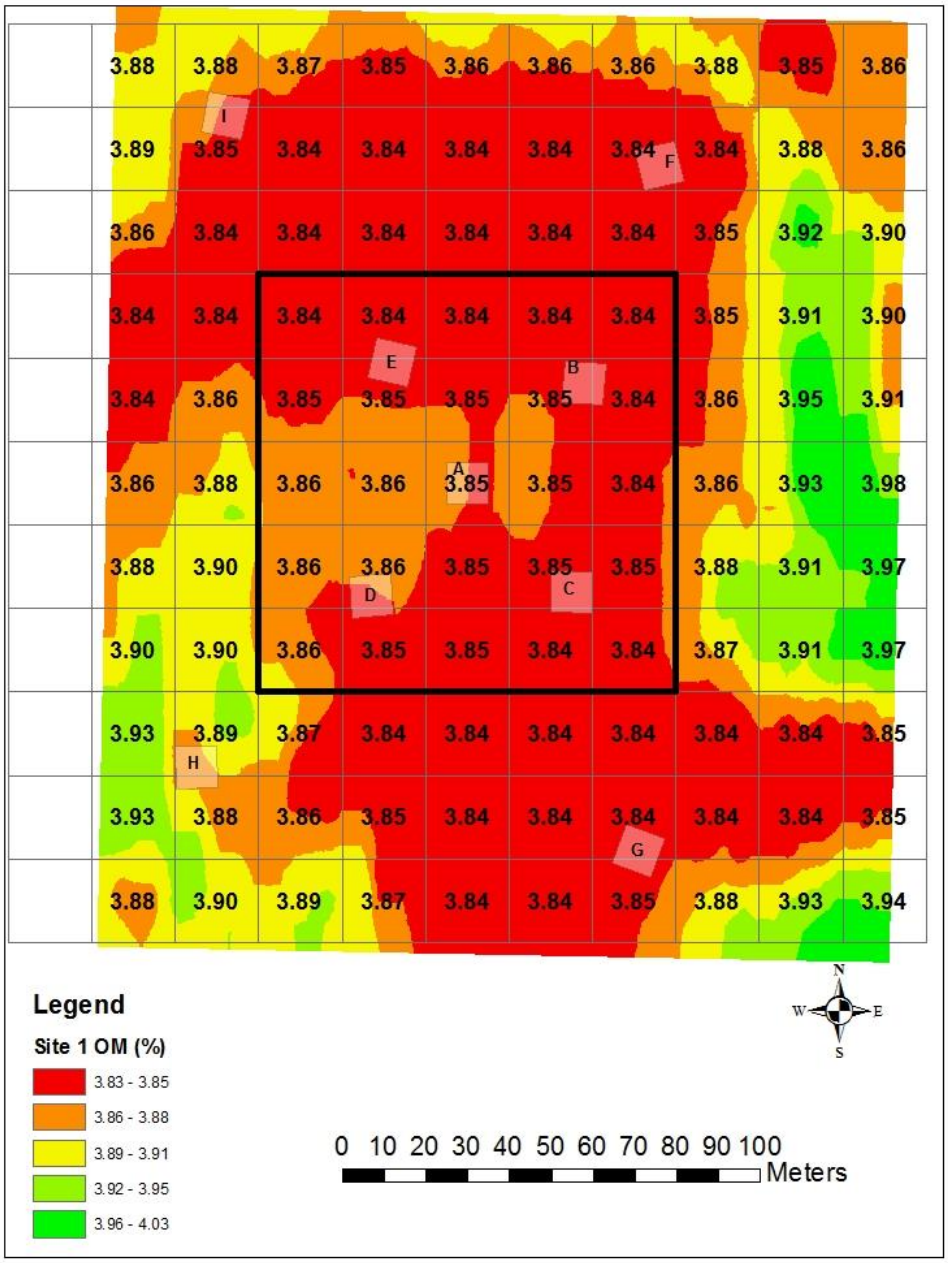

Figure 5. OpticMapper %OM output.
Each colour represents a range of values, averaged within 20x 20 m grids both on the wellsite and across the reference area. The black square represents the wellsite boundary. The lettered 10x10m boxes represent the location of the soil sampling areas in the ABMI Pilot program.
Note: CEC or OM maps are not meant to be used for comparison between sites, since each map has an individual scale for OM and/or CEC, depending on the range of data measured on site.

5.4 Constraints

It is recommended that the OpticMapper be limited to the initial characterization of cultivated sites, where data would be valuable for the identification of anomalies and the set-up of plots for use in the long-term monitoring program.

- Calibration is required for each site.
- Calibration was only found to be successful if the laboratory to OpticMapper sensor correlation was high (RPD = standard deviation/ root mean squared error of prediction is >1.5), prediction error was low, field variability was high, and sample point selection was of high quality.
- Soils must be moist to allow for conductance readings.
- Mapping cannot be done immediately after tilling or in frozen conditions.

6 GIS-BASED CROP MAPPING

Adapted from Underwood and Small (2017b).

This protocol is only used in cultivated land sites after the crop has been harvested.

6.1 Rationale

Crop yield maps, developed through the application of precision agriculture during crop harvest, are used to visually assess the spatial output of crop production. This georeferenced data can be used to (1) identify areas of poor crop yield that warrant for further investigation to determine cause(s); and, (2) inform the prescription and distribution of agricultural inputs (e.g., fertilizer application). This technology may be applied to reclamation monitoring of cultivated areas to provide information on whether previous industrial disturbance has affected crop yield (as it compares to non-disturbed reference areas within the same field and same management regime). If variability in crop yield is identified between the reclaimed wellsite and the reference area, further investigation on physical, chemical and/or biological conditions of the soil is needed to determine the cause of change in crop performance. Therefore, crop yield maps may be used as an additional indicator of vegetative productivity on reclaimed wellsite in cultivated areas.

6.2 Data Processing

- Export the raw yield and GIS data from the farm operator as comma separated values (.csv) after coordinates are added to the individual shapefiles.
    - Raw data are provided as a yield per area (i.e., bushels per acre).
- Import comma separated values into Microsoft Excel for data cleaning.
- Clean data files by removing data points that do not accurately represent crop yield at a corresponding location (use crop flow rate and dry yield as indicators to identify data artifacts). For example:
    - Data points at the beginning and end of measurement transects accounting for start- and end-pass delay (this occurs when the combine grain elevator is initially filling or gradually emptying at the start and end of each crop harvest pass);
    - Data points corresponding to when the harvest combine stopped, slowed down, or changed direction; and,
    - Data points that were more than 30% higher than the average of 6 surrounding data points (based on the normalized yield or ratio of the actual yield to the surrounding yield average).

6.3 Map Generation

- Import cleaned data to ESRI ArcMap for data visualization.

- Conduct map averaging or smoothing to produce individual field maps through interpolation rasters using the Kriging method, clipped to the extent of the available harvest data.
- Represent dry yield visually by three different maps for each site (Figure 6):
    - Field View – Include the interpolated data layer over satellite imagery, showcasing the location of the wellsite and reference area.
    - Grid with Dry Yield View – Place a 6 x 6 grid pattern over both the wellsite and reference area, resulting in 25 m x 25 m grid squares. The wellsite and reference area contain 16 and 20 grid squares, respectively. Average data points within each grid square and place the value in the centre of each grid square. Overlay this map on the Field View map.
    - Data Collection Points over Wellsite and Reference Areas View – Plot individual data collection points across both the wellsite and reference area, as a gradient of low, medium, and high crop yields (bushels per acre). Overlay this map on the Field View map.

6.4 Data Analysis

- Test cleaned harvest data for normality using the Shapiro-Wilk Normality Test.
- Assess statistical significance (alpha = 0.05) using one-way analysis of variance (ANOVA) tests for normal data and Kruskal-Wallis for non-normal data.
- Compare average crop yield between the wellsite and reference area.
- If data are available for the entire field, compare average crop yield between the wellsite and field.

6.5 Constraints

Site data should be discarded, or at least used with caveats disclosed, when:

- The harvester adjusts course within the wellsite or reference areas (i.e., only rely on data from straight passes through the site).
- Data points are missing due to harvester problems
- Data points are missing or suspect due to site location (e.g., in the 2017 field trial Underwood and Small (2017) reported problems with a site that had a road within the site sampling area and another where the site was split between fields).

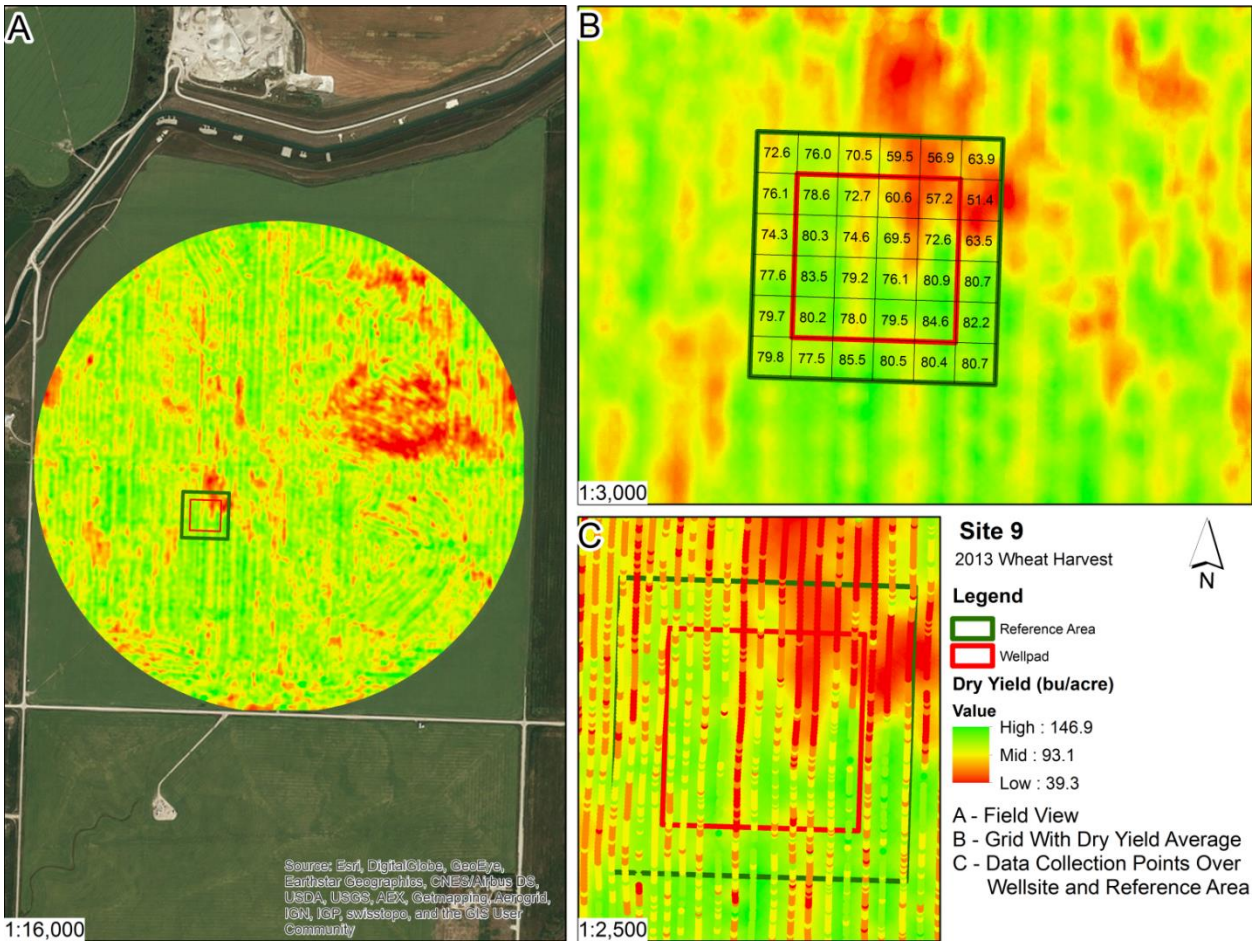

Figure 6. Dry yield data.
Views A (*Field View*), B (*Grid with Dry Yield View*), and C (*Data Collection Points over Wellsite and Reference Areas View*) indicate the wellsite area (red square) and the reference area (green square) area.
Colours represent the range of crop yield in bushels per acre (bu/acre).
The numbers within the grids in View B are an average of crop yield (bu/acre) within each grid.

7 UNMANNED AERIAL VEHICLE (UAV) RECONNAISSANCE

Adapted from Tan and Nielsen (2014) and Hird and McDermid (2015).

7.1 Rationale

The use of unmanned aerial vehicles (UAVs) has become an increasingly popular technique in remote sensing and environmental surveying due to their ability to provide detailed, spatially explicit, local views of the Earth's surface on short time scales and at a greatly reduced cost, when compared to more traditional field data collection or Light Detection and Ranging (LiDAR) acquisition. Aerial imagery captured by UAVs can be processed using specialized computer photogrammetry software to generate colour point clouds and terrain models of intricate resolution and complexity.

UAVs range in size, flight duration, payload (e.g., camera/sensor weight), level of automation, etc., and the choice of which to use and what sensor or sensors to employ is highly dependent upon the application. UAVs are particularly useful in locations with limited accessibility, or where long-term, repeating measurements are necessary, such as in monitoring programs.

7.2 Field Methodology

The following instructions assume that all necessary regulatory approvals have been received:

- Select site and identify suitable weather window for deployment.
- Lay out Ground Control Points (GCP)(e.g., ten upturned red flower pots painted with bold white roman numerals).
- Record GCP locations by a survey-grade GPS unit.
- Set up the ground station and conduct pre-flight checks.
- Program the mission waypoints into the UAV from a laptop.
- Position at least two spotters around the site to track and report on the progress of the UAV, especially in case it leaves the visual range of the pilot.
- When a window of calmness is present, arm the camera and UAV and launch the UAV.
- Fly the UAV to a sufficient height to clear trees then engage the autopilot.
- Fly the UAV to the target altitude then begin the lawnmower pattern on autopilot (Figure 7).

- Fly the UAV back to the launch site at the end of its programmed flight path and land it (in forested areas the pilot must manually land the craft as automated landings are not reliable).

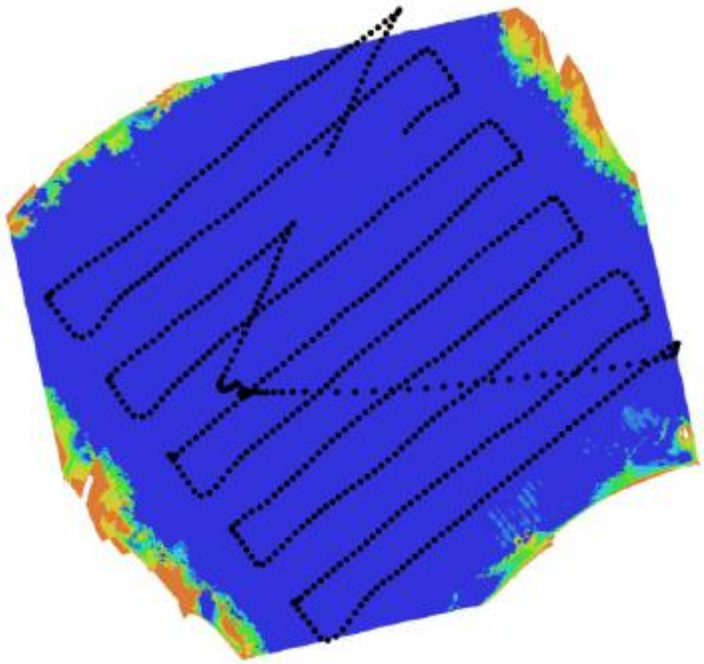

Figure 7. Sample lawnmower UAV flight pattern.
Adapted from Hird and McDermid (2015).

7.3 Data Processing

- Process the sets of UAV images obtained for the site, using the x, y and z coordinates of the GCPs to georeference the resulting point clouds.
- Convert images to a JPEG format.
- Import the data into the selected software program and use it for image alignment, construction of a dense point cloud (Figure 8), and manual identification and flagging of GCPs within each individual photo containing a GCP within its extent as a means of georeferencing the resulting point cloud.
- Calculate desired height and canopy cover variables and associated statistics (e.g., see Tables 5 and 6 in Hird and McDermid (2015)).

Figure 8. Three-dimensional view of the UAV photogrammetric point cloud for a reclaimed wellsite.
Adapted from Hird and McDermid (2015).

7.4 Minimum UAV Capabilities

Tan and Nielsen (2014) summarize five minimum capabilities a multi-rotor UAV surveying an approximately 4 ha plot should have:

1. At least 10 minutes of flight time, including accounting for the energetically costly ascent to mission altitude.
2. Autonomous, waypoint-directed flight.
3. Real-time telemetry and location feedback to a ground station.
4. A payload of a higher-grade compact with a large sensor size, optimally 16 megapixels or higher.
5. Deployment without the need for a large amount of setup time, and be operable by technicians without the need for intensive training or a steep familiarization curve.

7.5 Constraints

Constraints on UAV use include (Tan and Nielsen, 2014):

- Requirement for a Special Flight Operations Certificate (federal).
- Weather, especially wind and precipitation.
- Fuel capacity (restricting the areal extent of monitoring).
- Line-of-sight requirements for UAVs without autonomous capabilities.
- Clear space requirements for takeoff and landing for fixed wing UAVs.

8 GLOSSARY OF TERMS AND ACRONYMS

8.1 Terms

Bulk Density

Weight of soil particles (and water for wet bulk density) divided by the sample volume.

Wet bulk density is measured on an as-received soil sample, Dry bulk density is measured after the sample is oven-dried.

Draft Force

The force required to pull a tillage implement through the soil.

Pilot Program

A four-year research program (2012-2015) to determine the need for, and if required the design of, an integrated, scientifically robust and financially sustainable program for the long-term assessment of ecological recovery of certified reclaimed specified lands. Partners in the Program included Alberta Environment and Parks (formerly the Alberta Environmental Monitoring, Evaluation and Reporting Agency), the Alberta Biodiversity Monitoring Institute, and InnoTech Alberta (formerly Alberta Innovates – Technology Futures).

Program

The Ecological Recovery Monitoring Program.

Reference Area (often called a control)

Undisturbed location adjacent to, or nearby, the certified site, from where data are collected for comparison to the certified site data. Each reference area represents the ecological target for the entire certified site, or for a specific portion of the certified site where there is more than one ecological target represented. Note that reference areas for some site types will represent very long-term reference conditions (e.g., a 100-year-old forest).

Soil Clod

An aggregate 100 mm or more in length formed by soil disturbance such as cultivation.

Soil Mesofauna

Invertebrates between 0.1 mm and 2 mm in size which live in the soil or in a leaf litter layer on the soil surface. Members of this group are predominantly mites (Acari) and springtails (Collembola) but also include nematodes, proturans, pauropods, , tardigrades, small Araneidae (spiders), pseudoscorpions, opiliones (harvestmen), Enchytraeidae (potworms), insect larvae, small isopods and myriapods.

8.2 Acronyms

CEC	Cation Exchange Capacity

csv	Comma Separated Values
ERMP	Ecological Recovery Monitoring Program
GCP	Ground Control Point
LiDAR	Light Detection and Ranging
OM	Organic Matter
SE	Standard Error
UAV	Unmanned Aerial Vehicle

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