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Application of UASs to augment ground surveys in cranberry agriculture development: a proof of concept for the integration of UAS into the site identification and monitoring of cranberry farms in Newfoundland

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APPLICATION OF UASs TO AUGMENT GROUND SURVEYS IN CRANBERRY AGRICULTURE DEVELOPMENT

A Proof of Concept for the Integration of UAS Into the Site Identification and Monitoring of Cranberry Farms in Newfoundland

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Masters Thesis

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CONTENTS

LIST OF FIGURES

ABSTRACT

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Keywords: UAV (unmanned aerial vehicle), UAS (unmanned aerial system), remote

sensing, cranberry, newfoundland, ground survey, terrain, hydrology, wetland.

Assessing the potential for developing wetland environments into cranberry

agricultural lands is time consuming and expensive. The addition of unmanned aerial

systems (UAS) to augment current ground survey techniques has the potential to

increase assessment accuracy and cranberry production while reducing costs.

Newfoundland's extensive wetlands offer significant opportunities for the development

of cranberry agricultural lands. Due to a large international demand for raw cranberries,

there is great potential economic benefit in the rapid development of cranberry farms.

This study focused on using UASs to assess wetland areas in Newfoundland by applying

suitability criteria developed by the Newfoundland Government. This was done through

the use of GIS, image classification, and photogrammetry to assess these criteria over

three site locations. The viability of expanding UAS data collection over larger areas to

develop a province-wide model was explored through an assessment of current fixed

wing UAS technology. Given the novelty of this area of study, this research aimed to

serve as a proof of concept where the validity of results was measured against real world

applicability, not statistical analysis. The results showed that because UASs cannot

assess all of the required wetland criteria, they are not a viable replacement for current

ground surveys, but do have the potential to augment current techniques. UASs make it possible to survey larger areas, as well as reduce time and cost. The assessment of current fixed wing UAS technology concluded that given the continuously improving technology and further testing, there is the potential for these systems to collect comparable data over a larger area. Overall, the study concluded that through the strategic integration of the UAS techniques developed in this study with existing ground survey methods, Newfoundland has the potential to increase cranberry agricultural development and capitalize on the global demand for this crop.

LITERATURE REVIEW

LITERATURE SEARCH

Compared to the large body of literature pertaining to the use of more traditional forms of remote sensing, such as airplanes and satellites, there is little published that references the use of UAS (unmanned aerial system). UASs use small remotely controlled aircraft (commonly referred to as drones) that fly at low elevations and can capture high resolution image data. The lack of literature is particularly acute when it comes to information about specific applications, such as the assessment of sites for cranberry agriculture. Due to the lack of authoritative resources relevant to this research, it was decided that a different approach must be taken to search for relevant literature. A focused approach was taken to find literature that had significant relevance to the topic of study by using keyword searches with inclusion and exclusion factors.

There is a growing body of work that concerns UAS applications in general and works that cover UAS use to assess wetlands. While valuable, this existing literature is narrow in focus, and not applicable to UAS assessment of wetlands for agricultural development. Agriculture is one of the rapidly-expanding fields of research involving this technology. There are enough similarities and overlap between agricultural analysis and wetland assessments performed in this research to warrant the use of this body of literature as a foundation for this thesis.

Other sources of research include peatbog assessments (e.g. Knoth et al. 2013; Lehmann et al. 2016; Julie Lovitt et al. 2017), agricultural monitoring (e.g. Yue et al. 2012; Zhang and Kovacs 2012; Arnold et al. 2013; Anthony et al. 2014), terrain-mapping (e.g.

Stefanik et al. 2011; d'Oleire-Oltmanns et al. 2012; Flener et al. 2013), and volumetrics (e.g. Messinger and Silman 2016; Jin et al. 2017; Rusnák et al. 2018). After assessing these works and their relation to this project, potential knowledge gaps were identified. These gaps relate to methods of data collection, the accuracy difference between these options and UAS, the feasibility of collecting this information, and the various types of information that can be collected by the different methods using UAS. Identified gaps in the literature suggest the following primary research questions: (i) Are UAS a viable replacement for the existing method of assessing locations for cranberry (*vaccinium oxycoccos*) agriculture development? (ii) Can UAS provide a high enough spatial resolution to classify an area to the same detail as the current ground survey technique? (iii) Do UAS provide a cost effective and accessible alternative to other survey options? (iv) Can UAS be used to collect novel relevant types of information, given the current sensor technology?

CRANBERRY AGRICULTURE

Cranberry farming is a unique form of agriculture due to the environment required for cranberry production. The organization Agriculture in the Classroom provides basic information on cranberry production, describing the various stages from growth to harvest (Agriculture in the Classroom 2013). Cranberries are a tart berry native to the boreal wetlands of Canada that grow as a prostrate vine. These vines are perennial and have two cycles of berries growing at any one time. As one set of berries becomes ready for harvest, the next year's crop is beginning to bud. The Cape Cod Cranberry Growers' Association provides details on the "background, classification, cultivation and location" (Cape Cod Cranberry Growers' Association 2016) of cranberry

agriculture on their website, Massachusetts Cranberries (Cape Cod Cranberry Growers' Association 2016). Soil conditions and the available water supply are important factors for cranberry growth and harvest. The cranberry vines require a layer of sand approximately 15 cm thick over a layer of peat (The Forestry and Agrifoods Agency 2017). For harvesting, the cranberry beds need to be flooded to approximately one meter deep, therefore, a good water supply is needed not only for irrigation but also for harvest (The Forestry and Agrifoods Agency 2017). Because of this need for peat and water, the ideal locations for farm development are in wetland areas, which are the natural habitats for cranberry growth. Cranberry fruit is ready for harvest in October. The harvesting is done by flooding the beds and then running equipment known as beaters through the beds. This separates the fruit from the vines and the four internal air pockets of the fruit allow the berries to float to the surface. Once the berries are separated from the vines, they are pushed into a central location and a pump pulls the berries from the water's surface and deposits them into a collection container where they are then shipped off for processing. Once the harvest is complete, the beds are drained. The beds are flooded one last time in December to prevent frost from damaging the vines over winter.
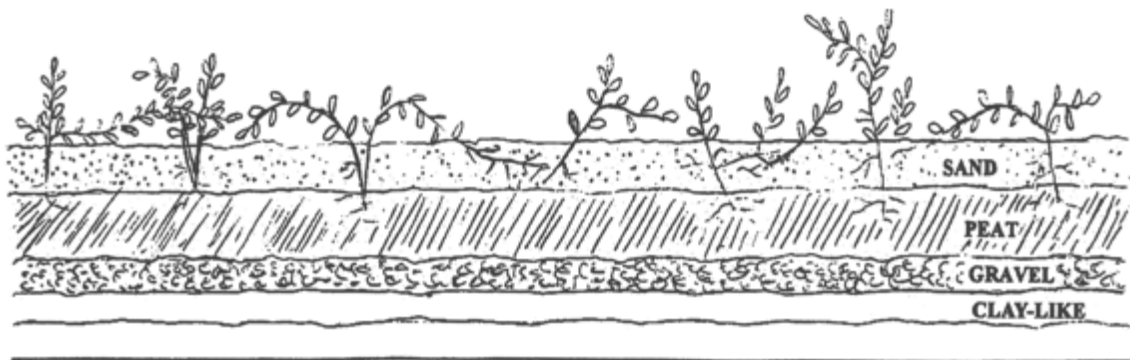
Figure 1: Cross section of soil layers ideal for cranberry production. Source: Cape Cod Cranberry Growers' Association (2016).

ENVIRONMENTAL IMPACT

Cranberry farms typically are developed by modifying elements of existing natural wetlands. While this causes some transformation of the environment and hydrology, it is considered relatively benign compared to the much more disruptive process of resource extraction associated with peat mining. No peat is removed from the wetland; sand and cranberry vines are placed on the surface but do not impede water flow. While this may be considered to alter sensitive wetland environments, the context of where this agriculture is happening is important. Newfoundland's landmass is composed of a large proportion of wetland. Therefore, there is potential for developing some wetland areas into agricultural lands while maintaining the overall ecological integrity of wetland environments across the province.

UNDERSTANDING THE CURRENT REGULATIONS AND SURVEY METHODS REQUIRED BY THE GOVERNMENT PRIOR TO DEVELOPMENT

The first major step for this study was to research the workings of cranberry farming. This background research ensured that the project design was appropriately tailored to cranberry agriculture and not designed as a generic geomatics survey. Native wetlands need to undergo significant modification to permit commercial agricultural operations. Determining the site suitability for cranberry agricultural development presents unique challenges, as a site not only needs to be leveled, but also has specific bed requirements. For example, the beds should be no less than 30 m wide and have no less than 15 cm of sand graded to approximately 30 cm. Due to these prohibitively expensive construction requirements, it is vital to accurately and efficiently determine the site suitability before considering development. The Soil and Land Management Division, Department of Forestry and Agriculture in St. John's. Newfoundland (1992)

outlines each of the wetland criteria the Newfoundland government assesses when determining the viability of a wetland site for cranberry agriculture. The document is attached in Appendix A.

Creating a cranberry farm is ecologically disruptive and expensive, therefore accurate and efficient preliminary assessment is essential. Ground survey techniques are time consuming and expensive. There is strategic value in using remotely sensed data in preliminary site evaluation and UAS offer the potential to improve quality and reduce the costs of acquiring sensed data in such assessment.

UNMANNED AERIAL SYSTEMS (UAS)

As the field of remote sensing has grown and diversified into different disciplines, new technologies and techniques have been tested and adopted, including UAS. While remote sensing and photogrammetry has been a field of study for many years, UASs provide a new type of platform to collect data. By mounting sensors like those used in conventional airplane-based remote sensing onto smaller and cheaper aircraft, remotely sensed information becomes more accessible at higher spatial resolutions. This high spatial resolution makes collected data useful to a number of fields. These changes in usability and resolution have developed new areas of application for remote sensing. With higher spatial and temporal resolutions come new challenges; older methods for assessment of the remotely sensed data may no longer work correctly due to the potential for added or extrapolated errors, so new methods must be established. This creates the opportunity to see problems and limitations of old methods, because errors become more glaringly obvious when higher resolution data becomes readily available by using UAS. However, it is important to note that UASs do

not replace ground surveys or manned aircraft remote sensing. This technology has created a new niche in the overlap between ground-based and manned aircraft/satellite-based remote sensing where neither of these existing methods is well-suited. This could be due to cost constraints, data accuracy, time requirements, or project scale. UASs have a wide variety of different airframes so they are very customizable to specific tasks. If a large aerial survey requires multiple or heavy sensor payloads, fixed wing systems provide excellent flight time and carrying capacity due to the inherent lift provided by the airfoils of wings. If the task involves small, open areas that are difficult to land in, or needs the ability to remain in one place, then a multirotor design allows for more flexibility with a reduced range. This variety of options allows the user to pick the right tool for the job, providing additional data and opening new areas of analysis that are not practical with other methods. Regardless of the specific vehicle (UAV), it is the system (UAS) that provides the real benefit. Regardless of whether a fixed wing or a multirotor design is used, the most important hardware is the sensor payload carried by the vehicle. Numerous different types of sensors are available, which is one of the great advantages of using UASs (Bloss 2014). These vehicles can fly very close to the ground, so expensive and specialized sensors are not required to collect sub-meter accurate data. Cameras such as digital single-lens reflex (DSLRs), normal point-and-shoot, cameras modified to collect near infrared light, hyperspectral, thermal, and LiDAR (light detection and ranging) sensors are all available options for UAS platforms. Some UAVs are also capable of carrying multiple sensors to collect different types of data simultaneously. This flexibility in type, capability, and sensor option is what renders UAS such a powerful tool.

INTRODUCTION

Cranberries are currently a high-demand agricultural commodity in the global market (Anderson 2016). The Province of Newfoundland has ideal natural landscape conditions for the development of cranberry agriculture and hopes to capitalize on global demand by expanding its agricultural capability. To achieve this goal, more natural wetland areas need to be developed into cranberry farms. Current methods of assessing sites for cranberry production require extensive field surveys, yet the cost and time required makes assessing the overall provincial capacity very difficult to evaluate. This study examines how emerging survey technology using Unmanned Aerial Systems (UAS) combined with image-analysis techniques can be used to identify ways to improve the quality, efficiency and scope of Newfoundland's assessment capability.

These assessments are currently performed by ground surveys assessing the wetland criteria that are outlined in Report No. 15 (Soil and Land Management Division. Department of Forestry and Agriculture. St. John's. Newfoundland 1992). This document outlines the individual criteria that are used, as well as the degree of difficulty of developing a bog location. These degrees of difficulty are broken down into minor, moderate, and major as outlined in Report. No. 15. Full details on the degree of difficulty breakdown, as well as all relevant information on the wetland criteria, can be found in Appendix A. The criteria assessed in Report Number 15 (Soil and Land Management Division 1992) include:

- Surface topography or slope which indicates how much material will have to be moved/removed to level the bog; the more level, the better;

- Composition of the parent material and decomposition for soil and landform classification;

- Composition of the material underneath the organic soil to ensure the water table is apparent and stable; identify any perched water table;

- Pattern and density of any "brooks" running through the deposit; is the deposit fragmented?

- Overall size such that the larger, more continuous landform is more desirable;

- Vegetative cover indicates the amount of land clearing necessary;

- Excess water and inundation hazard indicates special drainage and water control works requirements; is flooding a factor?

- Surface roughness (microtopography) dictates the amount of land leveling required;

- Percentage open water specifies the amount of pools to be filled in or, if >30%, to be avoided;

- Percentage coarse wood fragments indicates the amount of tree stumps and branches to be removed; and at depth identifies layers in the deposit where stumps and other wood debris exist;

- Depth of the deposit gives an indication of the life span of the deposit and thickness after settlement.

Unmanned Aerial Vehicles (UAVs) provide easy-to-use, cost-effective platforms to conduct low-altitude remote sensing that can yield high spatial and temporal resolution (Nikolakopoulos et al. 2017). These systems offer considerable potential in assisting ground-based evaluation of wetlands for their agricultural suitability. Three test locations near Corner Brook, Newfoundland were used to identify the wetland criteria that could be evaluated by using current UAS technology combined with GIS assessment techniques. A second component of the study sought to investigate the feasibility of using fixed wing UAVs to expand the area for UAS assessments while maintaining the high resolution spatial data required for detailed wetland surveys. This expansion can create challenges that are unique to the increase in the study area, such as longer flight times of the vehicle, different sensor requirements, and survey efficiency. The use of a fixed wing UAV has the potential to resolve all of these issues.

Effective production of cranberries requires very specific environmental conditions. Due to a cranberry bog's need for peat and water flow, there are not many places that have the natural landscape characteristics that can efficiently support this type of agriculture. Newfoundland is well-known for its wetland environments and these areas provide the natural formations and soil types that are conducive to the production of cranberries. The current tools for assessing these wetland environments are ground-based, requiring a survey crew to survey the study areas. However, many sites may be difficult to access and movement within sites may be challenging, limiting the utility of ground-based surveys at large scales. It is the goal of this study to determine if UAS remote sensing technologies can assess wetland environments in Newfoundland to determine if a target area is viable for cranberry agriculture. Through the application of

UAS, these difficult-to-access areas can be assessed with a high degree of accuracy to determine their viability for development from agricultural, economic, and environmental perspectives.

Also, the study examines ways to enlarge the landscape area that can be assessed using advances in low cost fixed wing UAS technology. The topic for study was developed in partnership with the company Resource Innovations Inc. Their aim is to apply the findings outlined in this study to expand the scope of their business. This study was also developed with recommendations from Newfoundland and Labrador Government representatives. The Province's goal is to increase cranberry production through the implementation of the CIDP (Cranberry Industry Development Program 2014/15 – 2018/19) by financially supporting the creation of cranberry farms (The Forestry and Agrifoods Agency 2017). Due to the high current global demand for raw cranberries, an increase in production has significant economic potential. The current demand from the Caribbean market alone is sufficient to buy every cranberry that Newfoundland can produce, according to conversations between the head of Resource Innovations and Caribbean delegates (Anderson 2016). With the application of UAS technology, Newfoundland has the potential to become a major global producer of cranberries and to benefit from the current demand.

The production of cranberries is a field of interest from many perspectives. This includes an industrial interest to develop a new field of work involving the application of UAS for agricultural site feasibility, but the general interest goes much deeper. The Government of Newfoundland and Labrador is interested in expanding the province's overall production of cranberries to capitalize on the current demand for the product in

the international market. This is being done through the CIDP, which has $7 million in funding available to be distributed to farmers on a $30,000 per acre basis for financial assistance in the construction costs of cranberry farms. With this demand for production, government interest, and industry support, there is a clear, practical area of research to be pursued. This research focuses as the proof-of-concept for the feasibility and practicality of using UAS to assess cranberry production potential, including the development of methodology and enhancement of UAS technology to identify areas suitable for cranberry production.

Due to the recent increase in availability of UAS technology, a new approach is possible for data collection to achieve the objectives of this research. While remote sensing itself is not considered to be a new field of research, when it is combined with the use of UAS it becomes a novel area of study that has only recently started to be explored. The basis for this new area of research was brought about by the enhanced spatial resolutions that UAS can provide over satellite and manned aircraft platforms. UASs have the capability to fly lower, more often, and with less atmospheric interference, thereby increasing temporal and spatial resolution while reducing radiometric interference. UAS fills a niche in between a survey using a manned aircraft to cover large areas and data collection performed by field crews on the ground covering smaller areas. The overall intention of UAS-based surveys is not to replace manned aircraft or field crews, but to augment both by creating efficiencies. Manned aircraft have been able to capture sub-meter spatial resolution imagery for over 50 years, but it remains a difficult and expensive undertaking that greatly limits the accessibility of such high-resolution imagery (Nikolakopoulos et al. 2017). However, for large areas where

sub-meter spatial resolution is not required, manned aircraft can travel faster and more efficiently than UASs. When it comes to performing tasks such as soil sampling and highly accurate engineering surveys, field crews are more efficient and more accurate. UASs can create efficiencies in situations where manned aircraft cannot capture high spatial resolution and field crews are limited to small areas and can only generate non-continuous data. The methodology for this study was developed with the intention that the integration of UAS surveys could generate detailed information in a more efficient way, while also recognizing that other forms of assessment are completed most effectively by conventional manned aircraft and field crews. This change requires that new analysis methods must be developed, and the methodologies used to approach this high spatial resolution remote sensing research problem need to be re-evaluated. The main areas of previous academic research that have used UAS focused heavily on agriculture. They largely focused on crop health and only looked at traditional types of agricultural lands. There is less research on cranberry agriculture, and no research on the evaluation of site suitability of existing wetlands for agricultural development using UAS.

The goal of this study was to effectively determine site suitability of natural wetlands in Newfoundland for cranberry agriculture development based on remotely sensed data collected by a UAS. The intention was to create a survey method that can assess development potential of natural wetlands more efficiently than traditional techniques and make site assessment easier for potential farmers. This would reduce the data collection time, help to increase provincial cranberry production, and assist the

Newfoundland government and industrial partners to meet their objective. Specifically, this study sought to:

(i)   Determine if UAS can be used as a viable replacement or augmentation for ground surveys in the assessment and identification of potential locations for cranberry agricultural development in Newfoundland. The main objective of this research was to determine the viability of UAS in performing these assessments and to what extent it was practical to do so, with the end goal of being able to assess potential locations for cranberry agricultural development more easily than by using current ground surveys.

(ii)   Understanding the current regulations and survey methods required by the government prior to development. The study began by identifying the general workings of a cranberry farm, as well as the current survey methods used for determining the location for a new farm. This objective was focused on gaining the specific, contextually sensitive knowledge that was needed.

(iii)   Identify the locations in the target district of Newfoundland to perform further UAS-based analysis. The geographic area to which this study applies is too extensive to have been surveyed in this study. Therefore, the study area was confined to a set of ideal locations for analysis. The selection process considered factors such as local knowledge, accessibility, permission, and size.

(iv)   Perform an assessment of specific sections of the target areas using a proven multirotor UAS. Once the required data was collected from the specific site locations, the data was then processed to determine the specific wetland

criteria outlined in Report No. 15 (Soil and Land Management Division. Department of Forestry and Agriculture. St. John's. Newfoundland 1992) to determine the viability of the locations for cranberry agricultural development.

(v) Assess the current UAS technology for the potential to replace or augment current ground survey techniques. The key component to this study was to determine whether the current UAS technology has the capability to replace the existing ground survey method by employing a UAS with an appropriate sensor and software paired with an appropriate topic specific analysis method for data processing.

(vi) Determine if the current UAS technology can assess large enough areas that these same survey methods can be used in the future throughout the Province of Newfoundland. One of the primary areas of interest for the industrial partner was to determine whether this technology has the potential to be used on a large area.

METHODS

STUDY AREA DETERMINATION

When determining the best possible locations to conduct this study, there were a number of limitations and constraints in place, meaning not all locations across the province of Newfoundland were possible to examine. One of the main limiting factors was the need to stay within reasonable proximity to the industry partner's head office in Corner Brook. Due to the fact that the process of data collection relied on access to one of Resource Innovations' vehicles and the assistance of a staff member acting as ground crew for the UAS, it was important to have study locations that were within a reasonable travel time to Corner Brook. While this study does cover the theoretical prospects for expansion of data collection and analysis from a targeted site by site basis to a complete provincial surveying effort, the data collection was performed by a UAS only capable of assessing small areas and no accuracy assessments were performed. As such, the locations for data collection needed to be small, targeted areas that were reasonable to access in order to effectively use the chosen UAS, the DJI Inspire 1 v.2. This is a multirotor quadcopter UAS that has an approximate flight time of 18 minutes. This relatively short flight time and the Transport Canada requirement to keep the UAS within unaided visual line of sight meant that it was not possible to fly the UAS to a site

location far from the takeoff point.

Figure 2: Overview of Site Locations

The final limiting factor was the requirement to have permission of the

landowners for any site that we would be operating on. While most potential locations

were within Crown land and therefore no special permissions were needed, there were

certain other locations of interest. One of which was an existing cranberry farm and

another was a farm under development. With the help of the Agriculture Division of the

Newfoundland and Labrador Government, permission was obtained from the landowner

to survey both locations using the Inspire 1 UAS. Landowner permission, in

combination with other difficulties, resulted in the decision to use the recommendations

from the Agriculture Division of the Newfoundland and Labrador Government when

determining the data collection site locations. Their recommendations offered several

advantages, including local knowledge of the area and the ability to provide data on the

selected locations, should the government decide to pursue further research. These

locations created a more realistic representation of how the workflow would be performed, if the government decided to perform either targeted or extensive surveys. Therefore, due to the difficulties with location, personnel, physical limitations of the UAS, combined with the connections to local landowners, active cranberry farms, local knowledge, and the potential for overlapping research areas in future projects, the final decision was made to use the locations recommended by the Newfoundland and Labrador Government for this project. These locations can be seen in Appendix D.

Site 1 is a wetland at the junction of Highway 460 and Highway 1, just south of the city of Corner Brook. This location is over 2000 hectares in size and has very limited road access. Due to its scale and inaccessibility, it was not suitable for the small area data collection of the Inspire 1 UAS. Site 2 is a large wetland area just to the south of site 1 on Highway 1. It is approximately 1000 hectares in size, which made it an excellent location for long-range UAS testing. This site was also suitable for data collecting using the Inspire 1 UAS due to its easy accessibility from Highway 1. A small section of this wetland was flown to collect data of an undeveloped location. Site 3 is a future cranberry farm currently under construction. The main wetland, designated as site 3-A, is half developed with beds presently being dug into the bog. This provided an opportunity to map both a current cranberry bog and one that will become a developed farm in the next few years. Access to this location was obtained through the Newfoundland and Labrador Government and their connections to the local farmer. The landowner requested that a wetland on the western edge of Site 3 be investigated for potential future development. In this location, it was possible to use a fixed wing system for data collecting, but with a total size of 211 hectares and individual wetland areas

smaller than this, the area was easily covered by a multirotor system like the Inspire 1. Through analysing a section of site 2, as well as sites 3-A and 3-B, there was enough data to meet the goals of this study.

SURFACE TOPOGRAPHY

Surface Topography is a measure of the material needed to level the bog for the cranberry beds to be prepared. These calculations were done using an integrated tool in the Agisoft software that supports a "Cut and Fill" tool. This is a process by which a mesh between the individual points in a point cloud is made, the software then closes any gaps in the mesh layer, and calculates the required volume to either cut ground from an area or to fill an area to level the surface of the mesh. This can be done on a site-by-site basis to determine the required fill volume. It is important to note that this technique does not account for the makeup of the fill. Determining the fill composition and depth of the deposit cannot currently be determined by UAS data. These limitations are described further when covering the assessment method for the soil decomposition, the material under organic soil, and the depth of deposit criteria. Additionally, this volume can be calculated and the volume of material to be removed from the individual beds can be subtracted to get a more accurate representation of the total volume needed. Depending on the desired bed construction, the bed volume to subtract will vary although it is easily calculated using the desired length width and depth.

BROOK MAPPING

Mapping of brooks is used to determine the level to which the site is fragmented (Soil and Land Management Division 1992). This could increase the difficulty of

developing the location, due to potential drainage and access problems. Brooks[1] in a

wetland are a particularly difficult feature to map accurately due to their small size,

potential to be concealed by vegetation, and occasional tendency to run dry. These

characteristics mean that traditional methods of automated classification using the

image's pixel values does not always work effectively. This method of unsupervised

image classification utilizes information on water colour, therefore if the brook is too

small, overhanging vegetation is present, or if water levels are low at time the time of

image acquisition, the software will not able to recognize an area as containing a brook.

The method used to overcome this issue was to incorporate elevation data to predict

where streams are likely to form (ESRI Inc. 2016). A combined approach of

segmentation, classification, and hydrologic modeling was used in this study. It is

necessary to use both tools in this instance, as the hydrologic topographic modeling

cannot definitively predict where brooks are located, but estimates where they could be

located based on potential surface flow. When paired with unsupervised image

classification, the software can identify potential brooks and determine whether they are

active based on the presence of water. This workflow uses eCognition v9.0.1 (Trimble

2014) for image classification and Arc GIS v 10.2.2 (ESRI 2014) to perform hydrologic

modeling and results in a more accurate model. An alternative method would be to use

only the hydrologic model while setting threshold conditions to eliminate any potential

streams with fewer than a specified number of tributary cells. This technique only uses

elevation data, but identifies the most likely locations where brooks might be found. One

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[1] Brooks are a small stream with periodic water flow

of the key weaknesses of this method is that data would need to be collected for a large area outside of the specific area of interest to determine the hydrological characteristics of the potential farm location.

LARGE LANDFORMS

Determining the features of an area on a large landform scale can impact site suitability, because the ideal cranberry farm locations are within larger, contiguous wetland areas. Constructing in the middle of a wetland environment can mean higher costs for infrastructure, such as access roads, so it is important to understand the area of interest as it is situated relative to the landforms around it. While there are no technical limitations to the data collection sensors for mapping these larger landforms, there are reasons why this is best left to a more traditional manned aircraft survey. Since the requirement is to map large landforms, a lower spatial resolution is acceptable, and from a data processing and storage perspective, more beneficial. Therefore, there is no advantage to collecting this large landform data with a UAS. Additionally, this type of information tends to be readily available. The final main driving reason is that using a UAS to collect this information is currently limited by both legal and technological constraints. To cover a large area, the UAV would have to fly at a high elevation and for an extended period. While there are ways of forcing a UAV into the upper limits of its performance, and of obtaining Transport Canada permission to do so (Government of Canada 2017), the difficulty is not necessarily worth the effort given the availability of existing data. Therefore, this study is not pursuing the use of UAV-based data collection to map large landforms.

VEGETATION COVERAGE

The classification of vegetation helps to determine the degree of difficulty that will be encountered when preparing land for construction. The wetland criteria divide this difficulty into three categories: minor, moderate (reclamation warranted), and major (reclamation seldom warranted). A minor degree of difficulty is characterized as having a vegetation cover of "grasses, sedges, reeds" (Soil and Land Management Division 1992), moderate difficulty is characterized by "brush, small trees" (Soil and Land Management Division 1992), and major difficulty is characterized by "many large trees, heavy shrub" (Soil and Land Management Division 1992). By performing unsupervised image classification on the generated photomosaic combined with values from the DEM, a classification was performed to generate a minor, moderate, and major land classification. This was done by using the photomosaic to classify vegetation cover and then using the DEM values within that classification to determine elevation change. Due to the uneven surfaces of tree, shrub, and brush cover, as the elevation values in the DEM became more extreme in relation to their neighboring objects, this indicated a larger amount of heavy vegetation cover.

FLOODING HAZARD

While adequate water supply is essential for cranberry production, it is important to not construct in an area that has a high risk of flooding. As such, it is important to assess this criterion to protect the infrastructure of the farm. This assessment may lead to the implementation of measures such as "special drainage and water control works" (Department of Forestry and Agriculture 1992). Like other criteria, this one is divided into minor, moderate, and major degrees of development difficulty. There are some data

products, such as drainage basin hydrologic models based on DEM data, that UAS can provide to aid in decision-making, but landscape scale data collection tools are generally more suitable. Accurate flooding hazard models are complex to create, given that they require a large amount of data to be acquired over a long time frame. As a result, flooding hazard was not considered to be a criterion suitable for assessment using UAS-based data for the purposes of this study.

Precipitation data and soil permeability information also help determine flooding risk and need to be collected for UAS data to have validity. However, available precipitation data is not useful because it lacks the detail needed for accuracy when compared to the UAS data products at 10 km grids from Canadian Forest Service (McKenny et al. (ongoing)). The soil permeability data needed to develop a flooding hazard model cannot be gathered remotely, because there is not an accurate method to collect data on soil characteristics from a UAS.

The final major barrier to determining flooding hazard is that a UAS cannot map large land features. To create accurate models, large areas must be considered to properly determine the water flow through the development location. This has the same challenges as the Large Landforms criteria, which are mainly the legal and technological difficulties encountered when trying to get a UAS to perform on this scale. Given the problems involved with performing flooding hazard analysis using a UAS, it was concluded that this must be evaluated using existing methods. It is worth noting that the Newfoundland Government is actively performing flooding hazard mapping for 1:20 and 1:100-year floods as shown in the example in Appendix C that includes the area of the existing cranberry farm that was visited during the data collection field work for this

thesis (Environment Canada and Newfoundland Department of Environment and Labour 1997). This illustrates that the work is being undertaken, and while it may be a topic for future research, this thesis does not include the integration of UASs in flood hazard mapping practices.

SURFACE ROUGHNESS (MICRO TOPOGRAPHY)

Surface roughness is considered when determining the effort necessary to clear land prior to constructing a cranberry farm. Surface roughness is a measure of the change in elevation at a micro-topological scale. It is a factor used to determine site suitability for cranberry production, because higher levels of surface roughness indicate an increase in the difficulty and cost of construction. Like other criteria, surface roughness was classified into three sections: minor, moderate, and major. These categories are defined as "none, hummocks and mounds (30-60 cm micro relief), and holes and mounds (>60 cm micro relief)" (Soil and Land Management Division. Department of Forestry and Agriculture. St. John's. Newfoundland 1992). Surface roughness was calculated using the DEM data generated in preprocessing. The raw data collected by the UAS achieved a spatial resolution of approximately 3cm x 3cm. Therefore, this fine grained data made it possible to perform image segmentation of approximately 18cm x 18cm and undertake an analysis to determine an elevation change of 30cm or less between image objects.

OPEN WATER

The percentage of open water in a location is a factor when determining the degree of difficulty that is going to be encountered during construction. With a minor percentage of open water (<10%) there is little to no added difficulty for construction,

with a moderate percentage (10-30%) the added difficulty might be considered as a deterrent, and with a major percentage (>30%) it is recommended that the area should be avoided for development. This is because areas with minor and moderate pools of water can be filled in, whereas when open water covers over 30% of the site the added difficulty becomes more than should be pursued (Department of Forestry and Agriculture 1992).

Open water percentages were determined by automatic image classification using the orthomosaic images generated in the preprocessing stage. This is a fairly simple process because of the unique spectral signature of water. One major problem encountered when trying to classify water is that it can get confused with shadows when the computer views the image. This was solved by collecting the imagery on a day with overcast skies that provided flat lighting and eliminated shadows. Another method for removing shadows is to include elevation information, so the classification ignores anything it thinks is water if it is close to an object that has enough elevation to cast a shadow (Silva et al. 2017). Once the image is classified, it is a simple matter of determining the area of water divided by the total area of the site * 100 to calculate a percentage. This can be done either by bringing the data into ESRI ArcGIS to calculate these numbers or by simply using the number of pixels for both the classification and the total image.

COARSE WOOD FRAGMENTS

The percentage of coarse wood fragments has a significant potential to impact the development difficulty of a location. This criterion provides an indication of the trees that are present and the potential for stumps and other wood debris. The degrees of

difficulty that could be encountered during construction are minor (<1%), moderate (1-5%), and major (>5%) (Soil and Land Management Division. Department of Forestry and Agriculture. St. John's. Newfoundland 1992). Wetland environments tend to be relatively flat when compared to a stand of trees. Therefore, the classification of tree cover percentage can be determined through the same method used to distinguish between moderate and major vegetation clearing, with the addition of a percent coverage calculation of the site. By classifying the vegetation coverage and any areas with high elevation change between the neighboring image objects, wooded areas can be identified. Analyzing this classification in ESRI ArcGIS produces a percentage of the total area of the site containing coarse wood fragments.

SOIL DECOMPOSITION / MATERIAL UNDER ORGANIC SOIL: / DEPTH OF DEPOSIT

Unfortunately, soil data collection is still out of the realm of practical UAS data collection. As this research focused on the UAV as a remote sensing platform and is not looking at the development of a soil sampling sensor that are UAV mountable, there is very little that can currently be done to assess the soil composition from an aerial platform. There is the potential to derive a correlation between the vegetation type and health to identify the potential soil conditions that would support such vegetation (Zhang and Kovacs 2012). However, this is an area of future study not covered under this research and these methods do not provide information about the depth of the deposit or information about the parent material.

IMAGE ACQUISITION

The data acquisition was performed on August of 2016 at the specified locations found in Appendix D using a DJI Inspire 1 V.2 from the Lakehead University Center for

the Application of Resource Innovation Systems (LU-CARIS) Lab. August 2016 was chosen to accommodate all parties' schedules and because the sites' vegetation cover would be fully foliated. While all vegetation foliage needed to be developed for the summer to assist in remote sensing classification, there was no need for any specific length of time after leaf-out or prior to abscission. This provided a large window of time for data acquisition, so the primary deciding factor was the coordination of schedules.

The Inspire 1 platform was selected as the UAS to be used for data collection because of its common availability and capability. At the time of data collection, the Inspire 1 was a prevalent UAS for professional applications in the Thunder Bay area. The Inspire 1 is a very capable platform for collecting data with the intention of surveying. See Appendix G for the manufacturer specifications for the Inspire 1 V.2. Its automated flight capabilities through its software development kit (SDK), such as MapPilot, provide an ease of use for fully autonomous mapping missions that is unparalleled in the industry. The Inspire also has the capability to carry a variety of sensors, including near infrared, thermal, and a variety of visible light cameras. While this platform is technologically capable of carrying a large suite of sensors, this study was limited to what was available through the LU-CARIS lab at the time. This was a DJI Zenmuse X3 that takes red, green, blue (RGB) visible light images at 12 megapixels.

The data collection timeline was to be completed over the course of two weeks in order to provide a large buffer time to ensure availability of optimal flying conditions. While the data collection was not expected to take more than a few days, because of the inclement weather of Newfoundland's west coast at that time of year, the field data collection trip was extended as a precaution. After data was acquired, its quality and

usability was inspected. If any of the data had been unusable, this would have allowed for a revisit to the location for a second survey.

PREPROCESSING

Ten computers were used to process the data, each with the appropriate software and computing power. All of the preprocessing was completed to generate the orthomosaic image, digital elevation model (DEM), and a point cloud[2] of the locations. This provided and tested the idea of the high, medium, and low end of the processing capabilities of the software.

Preprocessing was performed in the software Agisoft v1.2.6 (Agisoft LLC 2017a), which is a photogrammetric software package specifically designed for taking a series of overlapping images and developing three-dimensional models. This software is the standard in the computer lab for processing UAS imagery, so it was readily available on all workstations. This software creates DEMs, orthomosaics, and point clouds through a process of pixel matching and parallax[3] calculations. The required input is a set of images that have no less than 50% front and side overlap, meaning that no less than 50% of the next picture is in the previous picture. As a general rule, it is best to collect as much overlap as possible to ensure the software can properly render the data set. All of the images collected for this research were done with 80% front and side overlap. This is a relatively simple process when using the automated data collection applications built specifically for DJI products such as MapPilot.

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[2] A three-dimensional vector layer of points as they relate spatially to one another or a coordinate system.
[3] The difference in relative position of an object as observed from more then one viewing angle.

Agisoft is a unique software when it comes to performing photogrammetry, because it allows the user to have a large amount of control over the processes. To generate all the required data products, the software must perform a photo alignment, generate a dense point cloud, build a DEM, and build an orthomosaic. During the photo alignment process, the software individually assesses each image and tries to find commonly occurring features called tie points. Once these tie points are established, a low-density point cloud is created that is used in the next step—seen in Figure 2.
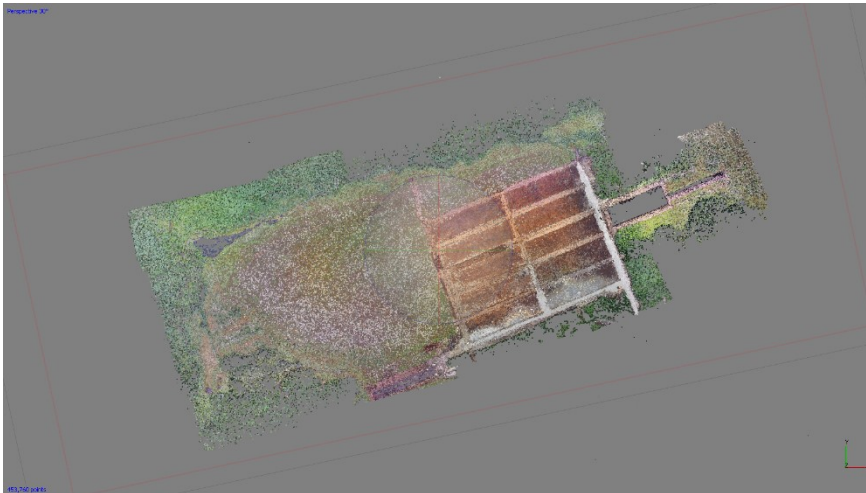
Figure 3: Photo Alignment of Site 3-A

In the alignment phase, the user can control the level of accuracy, whether Agisoft considers information such as global positioning system (GPS) information embedded in the images, whether there should be a maximum number of key or tie points, whether any masking should be used, and whether an adaptive camera model fitting should be used. Once this step is complete, the dense point cloud can be generated—as seen in Figure 3. This is where Agisoft goes through every pixel in every

image and generates a three-dimensional point for the image pixels. This is done through

the process of parallax calculations where the difference in position of the same pixel

across multiple images can be used to triangulate a three-dimensional position of that

pixel. In this process the user can select the density of the point cloud, whether depth

filtering is used, and if Reuse depth maps are generated.
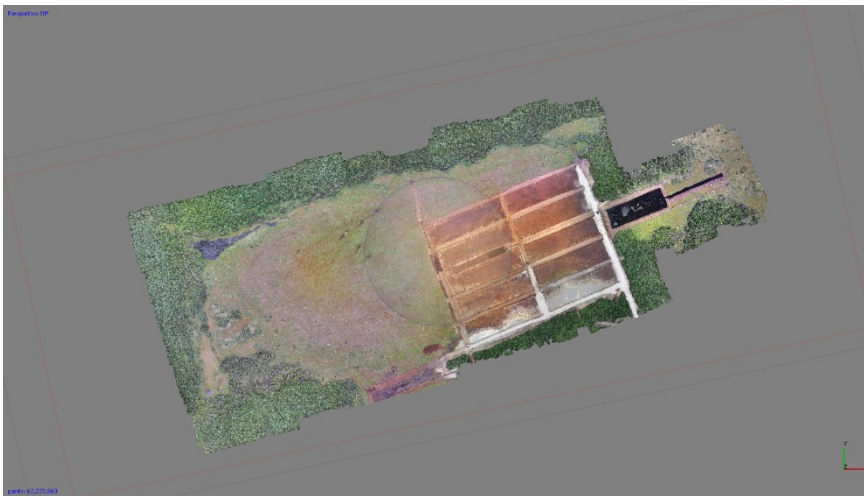

Figure 4: Dense Point Cloud of Site 3-A

After the dense point cloud is made, a digital elevation model (DEM) can be

generated—seen in Figure 5. By using the elevation values calculated through the point

cloud vertical positions, a raster image of elevations is made. The user has the options of

altering the source of the DEM if other source data is available, using interpolation to

smooth the DEM, using only specific point cloud classes if any classification has been done, deciding on a specific geographic projection, lowering the spatial resolution, and only using a specific region of the workspace. The final step for the preprocessing required for this study is to generate an orthomosaic—seen in Figure 4. This is the resulting image after the software takes the original images and finds the best way to stitch them together to provide an aerial image of the whole area. When performing this function, the user can alter the spatial resolution, the surface used to determine how images should be stitched together, the blending mode, whether colour correction should be used, whether a projection should be applied, and whether there is a specific area of the workspace to be used. There are many other tools and options that exist in the Agisoft software, as well as the ability to build custom scripts, but for the purposes of this study these are the only tools that were needed in the preprocessing stage.
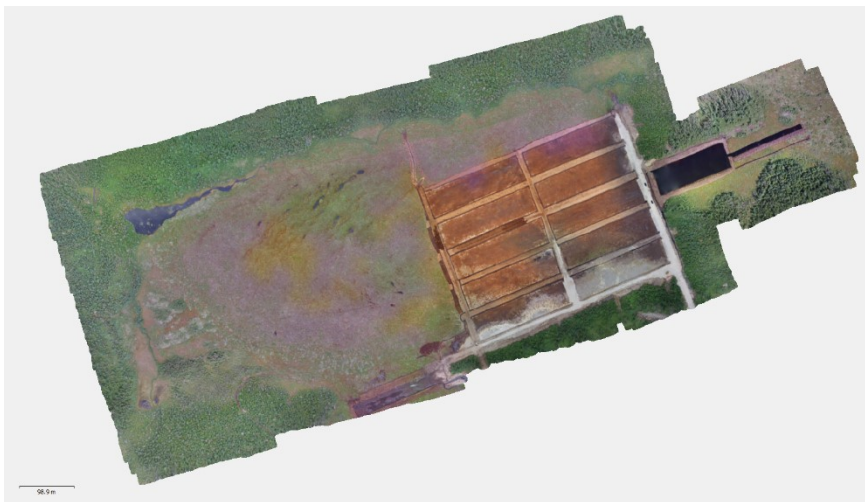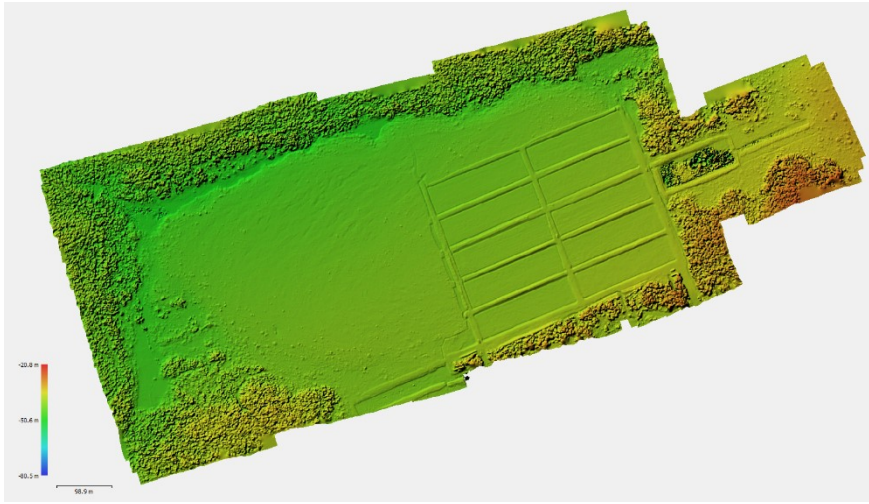

Figure 5: Orthomosaic of Site 3-A

Figure 6: Digital Elevation Model (DEM) of Site 3-A

Agisoft allows for a great deal of control over its processes, letting the user determine things such as depth filtering and the level of accuracy desired. To ensure that the best data products were used in the next stage of processing, each site was analysed at the highest, medium, and lowest set of parameters. This ensured that a usable result was created and determined the most efficient settings. The best result used the medium settings, because they provided more detail than was needed for further analysis while taking a much shorter time to produce. A full set of reports can be found in Appendix H, but one example of the difference in efficiency can be found by looking at the variance in processing time between the medium and highest accuracy processing that occurs on site 3-A. In the point cloud generation alone, there is over a 31-hour difference while providing no practical difference in accuracy. The medium accuracy level of processing was also chosen because some instances of the lowest accuracy did not provide usable results, such as the results for site 3-A. At this stage, the preprocessing was complete,

and the main analysis began. For a complete list of the Agisoft parameters used for the

low, medium, and high settings, refer to Appendix B.

PROCESSING

The data was analysed after the preprocessing was completed and the best data

products were determined. The data analysis was the development of the specific tools

to find the wetland criteria listed in first specific goal of the methods section. Only the

criteria that were determined to be feasible were pursued. This involved the use of the

software packages eCognition, Agisoft, and ESRI ArcGIS. eCognition was used for all

automatic classification because of its ability to perform multiresolution image

segmentation. Traditional image classification software looks at each individual pixel

and classifies it based on the pixel values. When working with the increased level of

detail provided by UAS imagers, some pixel values are not representative of the actual

area captured due to anomalies that can be captured with high spatial resolution imagery.

eCognition is different because it first groups adjacent pixels together based on user

inputs tailored to the type of data being extracted (Definiens Imaging 2005). The user

can instruct the software how heavily to weigh the different bands of input data, how

large groupings of pixels should be, how strongly the pixel values should influence the

groupings, and whether the software should look for compact or oblong shapes. These

groups are called segmentations.

Once the segmentations are developed, then classification is performed on each

segmentation based on the collective pixel values in the grouping. This helps when

classifying high spatial resolution imagery, because small anomalies in the data are

distributed through the segmentation they are part of, such as a single pixel of shadow in

a stream. eCognition also can develop rulesets when classifying imagery. Ruleset classification is a process where the classification is based on a set of parameters given to the software in stages. This is a highly customizable method of classification that can involve the spatial relationship between image objects, the creation of customized criteria, the averaging of pixel values within image objects, the development of classifications building on one another, and any other process an individual can come up with using the ruleset function and available tools. The software Agisoft was used to calculate the cut and fill volumes of areas. These volumetric assessments can be done easily and accurately within the software. Since Agisoft was already in use during preprocessing, utilizing it for the calculation of volumes was a simple process. ESRI ArcGIS is the industry standard in geographic information system software. Due to the ease of access, its wide use, and its powerful hydrology tools, it was the chosen software to perform the needed calculations to generate flow accumulation maps and hydrologic basin maps.

Once all the preprocessing data products were created, the main analysis began. This was the development of data products, such as classifications and surface area calculations, that can be used to assess the wetland criteria, as described in Report No. 15 from the (Soil and Land Management Division. Department of Forestry and Agriculture. St. John's. Newfoundland 1992). The criteria are discussed in the preceding methodology section of this thesis, which does so from an analytical perspective and provides results. It was not feasible to cover all criteria in Report Number.15, as was discussed in the methods section, but Surface Topography, Brook Mapping, Vegetation

Coverage, Surface Roughness, Coarse Wood Fragment, and Open Water are all areas that will be covered in this section.

HYDROLOGY

While flood hazard mapping is not something that was able to be covered in the scope of this study, some hydrological analyses can be performed to help identify water flow and demonstrate the potential to use UAS data in future flooding hazard assessments. Hydrologic modeling used the DEM data generated during preprocessing and was performed in the software package ESRI ArcGIS using the spatial analyst extension. The necessary results were basin output and flow accumulation output. To generate these models, a flow direction model can be created by inputting the DEM data into ArcMap. A fill tool closes any holes in the topology of the DEM. The fill output is then used in the flow direction tool to develop the flow direction model.

The basin tool is used to generate a model of the drainage basins. This is determined using a flow direction model and creates boundaries of drainage basins that flow toward the edge of the data extent.

Flow accumulation is a tool that calculates the flow of cells into one another from the flow direction model. This is used to delineate potential streams in a given area. This will be essential when classifying brooks in a later processing step. When this process was performed during this analysis, the DEM used was a pure elevation model and not refined to be a surface model. This is acceptable because the flow accumulation layer is being used for the Brook Mapping criteria where water must already be present for it to be classified as a brook. Therefore, any imperfections caused by elevation changes, such

as trees and shrubs, will not affect the final results for the Brook Mapping Wetland criteria.

SURFACE TOPOGRAPHY

Surface Topography is the measure of the effort required to level the wetland and the corresponding addition or removal of material. A perfectly level area is ideal for construction, because it allows for manipulation of the land with less effort to create the ideal flow of water over the cranberry beds. As the leveling effort increases, so does the difficulty of construction for the farm. As was discussed with the local farmer (Mcfatridge 2016), the ideal setup for a cranberry farm is to have beds constructed so that by opening flood gates, water will flow from the reservoir area into one bed after another purely through the force of gravity. This means that less energy is expended on pumping water, which can be time consuming and costly. A substantial amount of water is needed to flood the average cranberry bed for harvesting. The minimum recommended water level is no less than 1m.

Accurate surface topography makes farm construction and operations efficient and helps controls costs. Thankfully, this process is fairly easy to perform using UAS data and three-dimensional modeling software that has volumetric calculation capabilities, such as Agisoft. There are many software packages currently available that are able to calculate volumes from point cloud data, but many of these are expensive and complicated. Agisoft was used for the volumetric calculations, because it can perform these calculations accurately and it had already been used for the preprocessing stage of this research.

Calculating the volume of material that will be added or removed is critical to determine the difficulty of leveling an area. This is called a cut and fill calculation, where the cut is the material that needs to be removed and the fill is the amount of material that needs to be added. This is calculated by taking the surface model of the area of interest and determining the volume of material that the surface can hold. This can be visualized as the amount of water that would pool on the surface if there was no permeation. It is also important to note that this does not consider differences in compaction of various types of soil material. Therefore, for a non-deformable material such as gravel, the calculated volume will be accurate, whereas materials such as organic soil will have the potential to compact. This should be considered when reviewing these results and planning for construction.
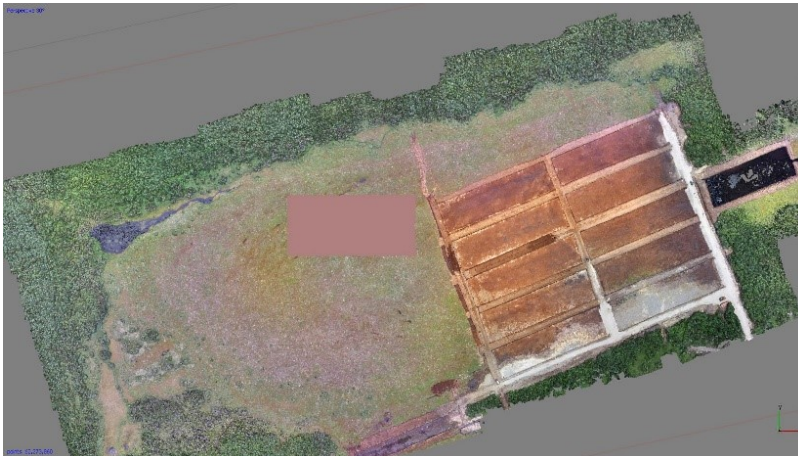

Figure 7: Area Selected for Cut and Fill Calculation
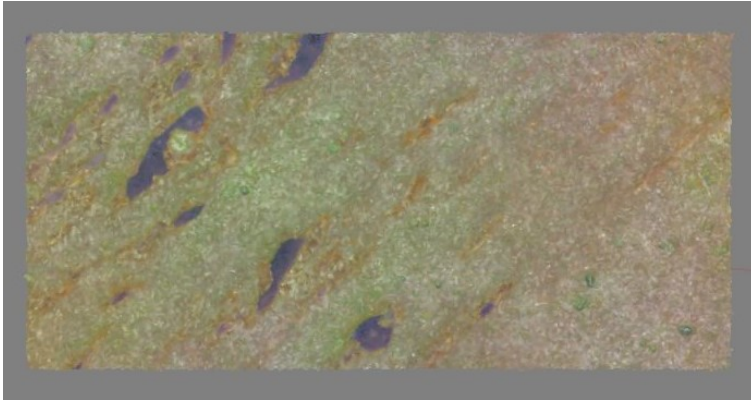Highlighted in Pink

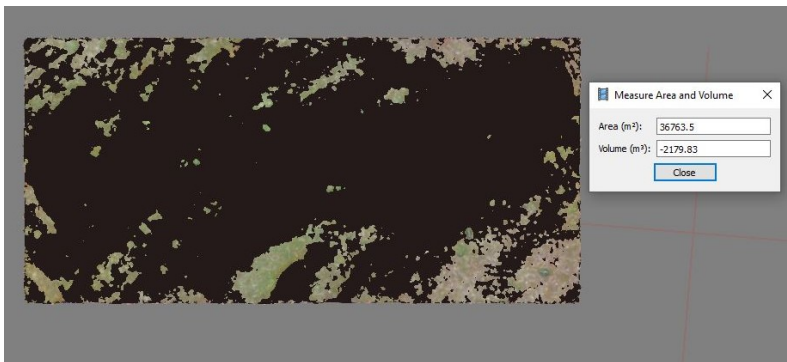Figure 8: Cropped Area for Cut and Fill Calculation

Figure 9: Cut and Fill Calculation. Fill Highlighted in Black.

To perform this assessment, the dense point cloud that was generated in Agisoft during the preprocessing is required. This point cloud is very detailed and extremely accurate. However, before the fill volumes can be calculated, some additional processing must occur. While point clouds hold a tremendous amount of data, they are individual points that do not create a continuous surface. A continuous surface is required to calculate volumes. By connecting the points of a point cloud together with polylines, a mesh is generated allowing for continuous surface data to be calculated along and between these points and lines. This mesh surface is what allows the volumetric tools to work. In Agisoft, once a dense point cloud is generated the mesh tool can be used. This

tool works as described above and creates connections between the point data generating a continuous surface. Like all other tools in Agisoft, it allows the user to customize the processing in certain ways. With the mesh tool, the user can change the surface type from the vertical height field to an arbitrary surface, decide if the dense point cloud or the photo alignment point cloud should be used, decide how detailed the mesh surface should be (between a low, medium, high, or custom face count setting), enable interpolation or extrapolation, and/or select based on point cloud classification, if one exists. One of the disadvantages of using Agisoft for this step is that with extremely large data sets the software tends to be unable to complete the function and crashes. The data sets collected in this study contain millions of points and crashes occur if a high face count is used or interpolation/extrapolation is enabled. This is due in large part to a lack of random access memory. This issue can be avoided by selecting and cropping the areas of interest so the software is not processing a computationally overwhelming data set. This is a fairly common problem among point cloud processing software when dealing with high spatial resolution UAS data (Cura et al. 2017).

An analysis of the accuracies of this processing is not covered in this study due to the amount of statistical validity that already exists for these processes, as well as the difficulty required in performing such analyses. Agisoft was used to perform volumetric analysis. The consensus in the literature is that Agisoft is a reliable and valid way of performing this analysis accurately (Messinger and Silman 2016; Agisoft LLC 2017b; Jin et al. 2017; Rusnák et al. 2018).

CLASSIFICATIONS (BROOK MAPPING, OPEN WATER, COARSE WOOD FRAGMENT, VEGETATION COVERAGE)

Once the surface topography was calculated, the remaining criteria were determined by automatic image classification. This processing technique was chosen because it is a proven method of remote sensing analysis that will create a data product containing the information required to satisfy the wetland criteria. The software eCognition was used because of its ability to perform multiresolution segmentation operations and classification based on ruleset inputs. This portion of the analysis was divided into two separate classifications.

The first is a combination of the brook mapping, vegetation cover, coarse wood fragment, and open water wetland criteria. These criteria are grouped together in an effort to avoid overlap, because they all have a relationship to one another as different form of land cover. An area designated as vegetation cannot also be designated as water, or soil. There is a potential that this overlap could occur if these criteria are classified separately, but when classified together, classification rules can be put in place to only allow one type of land cover to be present in an image object. Also, this grouping is important because some criteria build on each other. For example, when vegetation is classified, the tree class will be a subsection of the vegetation class. This relationship is true for brooks, as well as the open water class.

The second image classification is the surface roughness wetland criteria. This is separate because it must be performed for the entire area, so all image objects will fall into one of the three classes outlined in the wetland criteria. Also, while the other criteria are directly linked to one another, the surface roughness calculation is not related to any

form of land cover classification. Whether the surface is soil or vegetation, the elevation change of the surface is of interest. The final step before either set of classifications can be performed is to create the image segmentation parameters.

With an understanding of the desired data products, a rough set of parameters were developed for the segmentation. This involved an even weighting on all colour input bands with very little weight given to the flow accumulation data and a higher weight given to the elevation data. The size of the segmentations should result in image objects approximately less than 20 cm x 20 cm. The spectral values of the pixels should give an even weighting to the object shape and the software should identify longer, thinner objects. This was necessary because the lower spatial resolution DEM requires a higher weight to compensate the higher spatial resolution colour images. The flow accumulation layer is only for the final classification of brooks and should not affect the other classifications. Size is to maintain the value of the highly accurate UAS data, and the spectral value weighting is because the reflectance is equally valid to the classification as object shape. Additionally, the longer shape bias is to help identify small streams and define shared lines of elevation change and class change. Once these rough parameters were established, the computer lab was used to run multiple segmentations at once using different computers. All the segmentations had different parameters that fell within the predetermined specifications. Once computation of all segmentations was completed, the results were assessed and the one that was presented in the findings as ideal was selected. The parameters of this final segmentation can be seen in Figure 10.
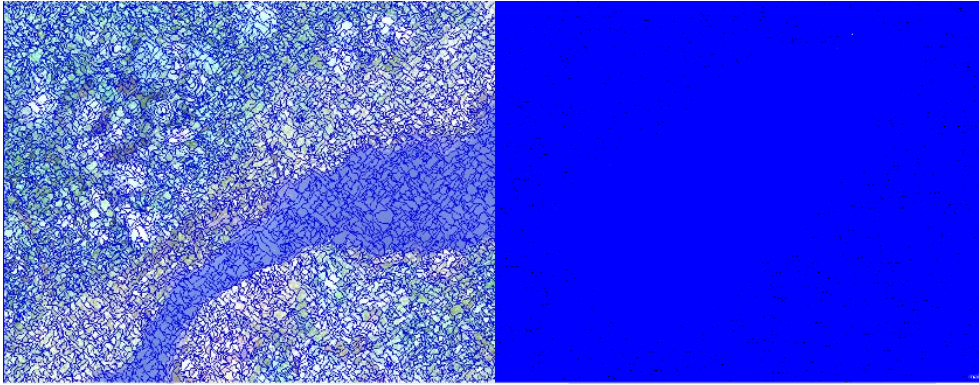
Figure 10: Side by Side Comparison of Small Area Segmentation (on Right) and Large Area Segmentation (on Left).
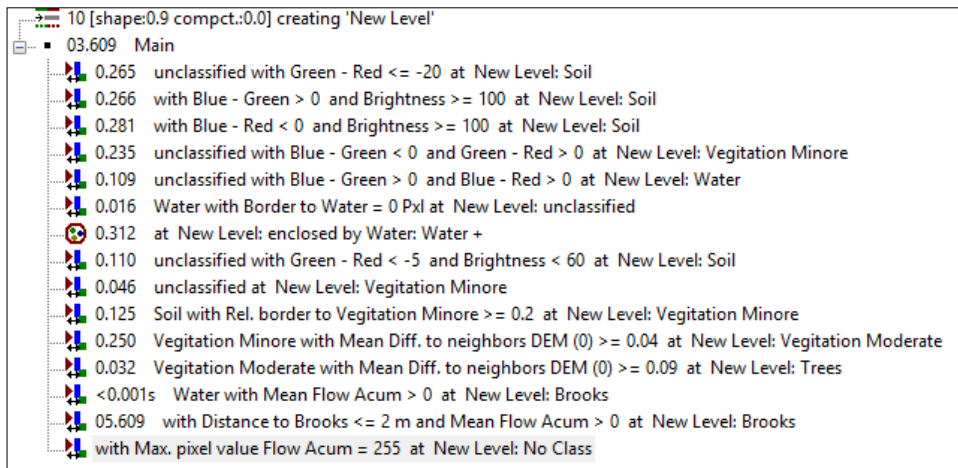
Figure 11: Classification Ruleset for Image Analysis

IMAGE ANALYSIS

The image analysis process was performed to determine the brook mapping, vegetation cover, coarse wood fragment, and open water wetland criteria simultaneously. This was necessary because all of these criteria are forms of land cover classification and have the potential to overlap when performed separately. Classifying simultaneously ensures there is no overlap and means criteria can be determined based

on their relationship to each other. An example of this cross classification can be seen when determining brook mapping. Since brooks are a subset of water, when water is properly classified from an image then brooks can be determined based on additional conditions from the water class.

Using the segmentation parameters determined in the previous section, the segmentation process was executed by creating image objects. From this point, the specific parameters used in the final classification were developed for site 3-A. This development process was a series of iterative evaluations of different areas of the image known to belong to a certain class based on manual photo interpretation. Features such as mean reflectance across all bands of imagery, mean difference to neighbour, presence of a specific class, and custom calculations were all evaluated to determine trends and distinct differences between areas. The custom calculations were undertaken to determine if red, green, or blue had the highest mean reflectance in an image object. This was done by creating three new parameters. The first was the mean blue reflectance subtracted by the mean green reflectance. The second was the mean blue reflectance subtracted by the mean red reflectance. The third was the mean green reflectance subtracted by the mean red reflectance. This is explained further in Table 3. From that point, a rough ruleset was created and through the process of trial and error, was refined until an expected classification ruleset was created.

Table 1: Dominant Reflectance Calculations (RGB)

Blue – Green	= mean blue reflectance – mean green reflectance
Blue – Red	= mean blue reflectance – mean red reflectance
Green – Red	= mean green reflectance – mean red reflectance

Table 2: Dominant Reflectance Values Breakdown (RGB)

Red Highest	Blue – Green = na	Blue – Red = <0	Green – Red = <0
Green Highest	Blue – Green = <0	Blue – Red = na	Green – Red = >0
Blue Highest	Blue – Green = >0	Blue – Red = >0	Green – Red = na

Since the criteria involved in this classification included vegetation and water based land cover, a ruleset was devised that would extract everything else. In the images of site 3-A, the majority of this extracted information was exposed soil and rock. This class was named soil. It was assumed that the majority of future UAS surveys for potential wetland development will be for areas where the land cover can be broken down into vegetation, water, and soil. This assumption applied to the circumstances for all three sites evaluated in this study. Soil was the first feature to be classified due to its large spectral range of reflectance from dark to light. It was classified coarsely and then narrowed after vegetation was classified. Next, spatial relationships to other classes were made. The first step in the ruleset was to classify all areas with a Green – Red reflectance less than or equal to -20 as soil. This identified all cells with a high red reflectance as soil since soil tends to have higher red values than vegetation or water. Once this process was completed, the next step was to find the soil areas that were primarily blue. In order to not confuse these with water, a second condition was added that filtered through only objects that were very bright. Since water absorbs a lot of light, this helped to eliminate overlap between the classes. The purpose of this step in the

ruleset was to classify soil as any image objects with the Blue – Green of >0 that also

had a Brightness >= 100. The final step at this stage of the ruleset was to classify any

image objects with a Blue – Red value <0 and a Brightness >=100. This step was similar

to the previous one, but added areas that have more red than blue, regardless of their

green value. This created a lot of overlap in areas known to be vegetation, but these were

corrected later in the ruleset. The next stage involved the classification of vegetation.

Water was classified later in the process due to its fairly distinct spectral reflectance

when compared to vegetation on soil making it easier to classify later in the process.

Based on the requirements of the wetland criteria, vegetation was divided into

three separate categories—minor, moderate, and major—referring to the amount of

vegetation present. In the ruleset, all vegetation is classified into the minor class to begin

with, and the moderate and major coverage classes are distinguished later on. This first

step of classifying vegetation in the ruleset uses the values of Blue – Green = <0 and

Green – Red = >0, only selecting from image objects that are not yet assigned to a class

through a class filter option. This involves selecting image objects whose dominant

mean reflectance is Green. Once this is complete, water is then classified out before the

vegetation and soil classes are refined. The first step in the ruleset is to select all

unclassified image objects that have blue as their highest mean value. This is done

through the parameters of Blue – Green = >0 and Blue – Red = >0 using a class filter for

unclassified image objects. Small image objects that are on their own and not connected

to any other water classified image objects are then removed from the water class and

labeled as unclassified. This is done because these small image objects are usually micro

shadows with the same reflectance as water, not extremely small, isolated pockets of

water. This step is executed in the ruleset using a tool that assesses the number of pixels of a certain class (such as water) and makes a decision. In this case, the value was Border to Water = 0 Pxl and then the object became unclassified. This was executed using a class filter which only applied to image objects already in the water class. The final step for classifying water was to close any holes in large water areas that could be caused by objects such as reeds, which may distort the spectral reflectance of the underlying water. To accomplish this, the enclosed feature was used. This function finds any grouping of image objects completely enclosed by a certain parameter; in this case it was image objects assigned to the water class. All objects found to be enclosed were assigned to the water class, regardless of whether they were unclassified or in an existing class. At this point, water was fully classified and vegetation became the focus.

Like the beginning stages of the ruleset, soil was refined further so vegetation could cover the remaining area. To accomplish this, a similar process was run to find unclassified areas with higher red mean reflectance values than green but using a value that would include objects with a higher green value. To reduce any potential overlap that might have occurred between the soil and vegetation classes, a second condition was added requiring the image objects to have a low brightness to reduce the inclusion of any brighter red vegetation. The parameters were a class filter allowing only unclassified objects to be selected and values of Green – Red = <-5 and Brightness = <60. This was added to the soil class. Since all water was classified, all soil was over classified, and there was nothing else in the site to warrant a class, the remaining unclassified areas were assigned to the vegetation minor class. This included the area around the site where the data frame extends, but was rectified in the final stage.

The final step to complete the differentiation between soil, vegetation, and water was to balance the vegetation and soil classes. This was done through a spatial process where if soil image objects have a certain percentage of their bordering objects as vegetation then their classification would also change to vegetation. This was done to extend the bordering areas between vegetation and soil towards vegetation. This was executed by applying a class filter to select only from the soil class image objects and using the parameter of Relative Border to Vegetation Minor class = >=0.2. This meant that any soil classed object that had 20% or more of its border covered by vegetation classed objects would then be classified as vegetation. From here, the delineation between minor, moderate, and major vegetation coverage could begin.

This was performed through the use of elevation data in the DEM. Since vegetation coverage has more erratic elevation changes than the bare ground, and since these elevation changes become larger as the vegetation coverage increases, determining the difference in elevation change between cells within the vegetation class can establish the difference between the three classes. Using a class filter to only select the vegetation class, a parameter from the DEM data was executed to classify the moderate vegetation coverage. This was the mean DEM difference to neighboring image objects = >=0.04. Once the Vegetation Moderate class was created, the Vegetation Major class was created using a more extreme value of the same parameter. The class filter was also changed to the Vegetation Moderate class, because this contains all image objects that will become part of the next class. Using the same mean DEM difference to neighboring image objects parameter, the value was increased to >=0.09. All of these image objects were classified as trees, because at this stage of vegetation classification, all Vegetation Major

objects are trees. This means that a completely separate classification does not have to be performed to extract the coarse wood fragment characteristic. Once all processing was completed for the vegetation land covers, the final step for the water land cover could be performed.

At this point the flow accumulation layer was used. To map brooks in the area, the flow accumulation input was combined with the water class. This occurred anywhere there was overlap between water and a positive value on the flow accumulation data. These segmentations were then added to the brook class. A second step was used to assist in identifying potential brooks that were not added to the water class initially. Any image object, regardless of class, with a positive value in the flow accumulation data and bordering a water class image object was added to the brook class. The final step removed the surrounding null area from any active class. To do this, a No Data class was created. Since all of these image objects did not include the data of the site location and since the flow accumulation data set specifically assigned this outer area a value of 255, separating it into the No Data class was fairly straightforward. By selecting all objects that had a maximum pixel value of 255 in the flow accumulation layer, all outside objects were added to the No Data class. This expression is Max. pixel value Flow Acum = 255. This was the final stage necessary for classifying the required data to assess the wetland criteria for brook mapping, vegetation cover, coarse wood fragments, and open water. This segmentation and ruleset where then applied to site 3B and site 2. These results can be seen in Figures 26 and 28.
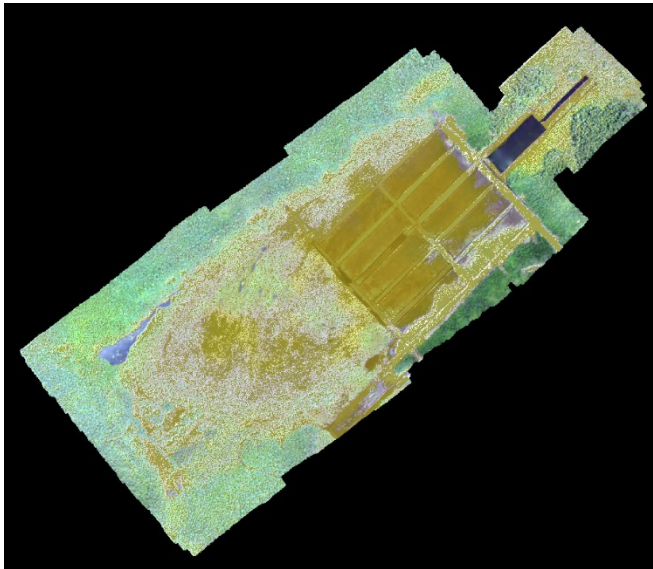
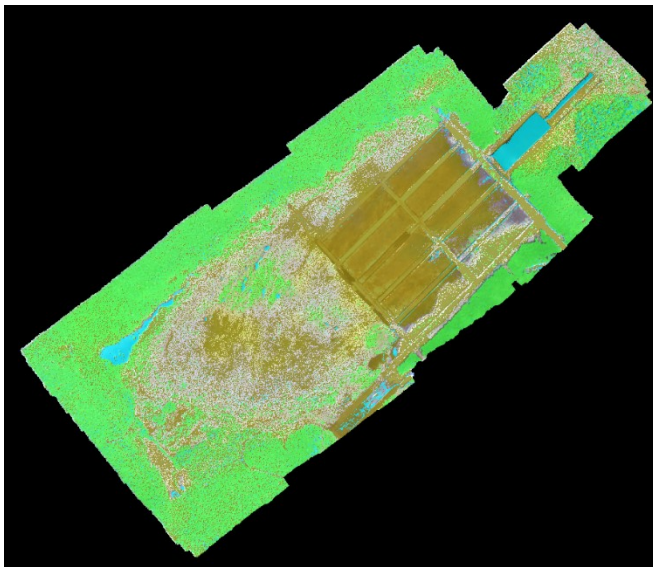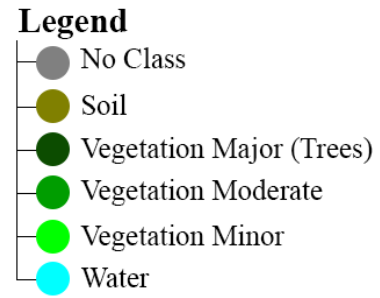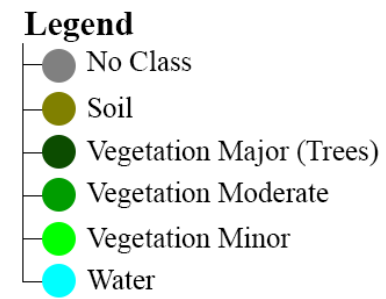Figure 12: Ruleset Step 3 - Soil Classification

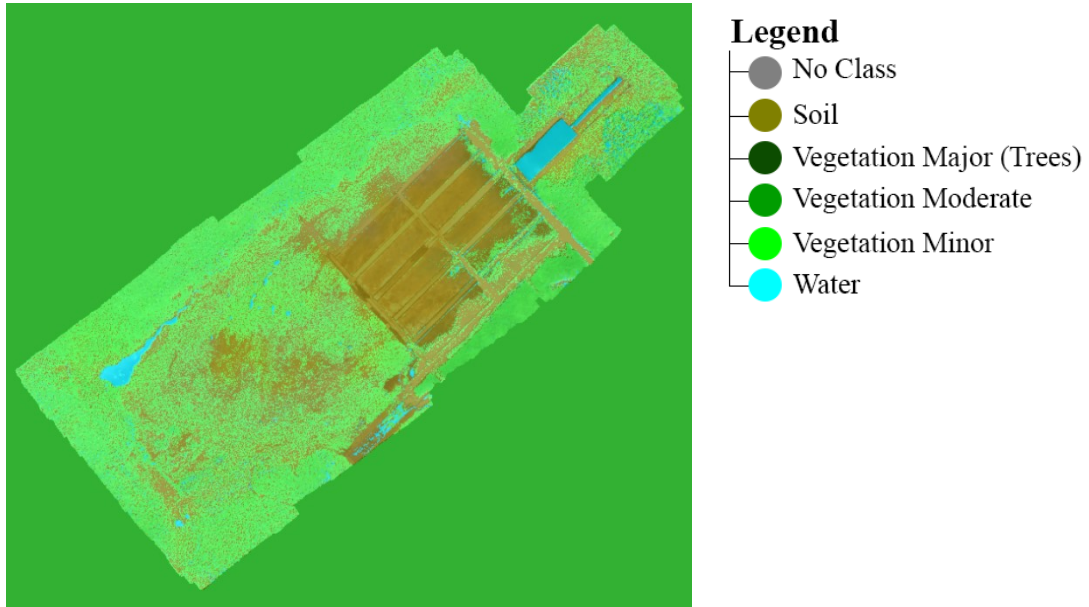Figure 13: Ruleset Step 5 - Water Classification

Figure 14: Ruleset Step 9 - Vegetation *Classification*

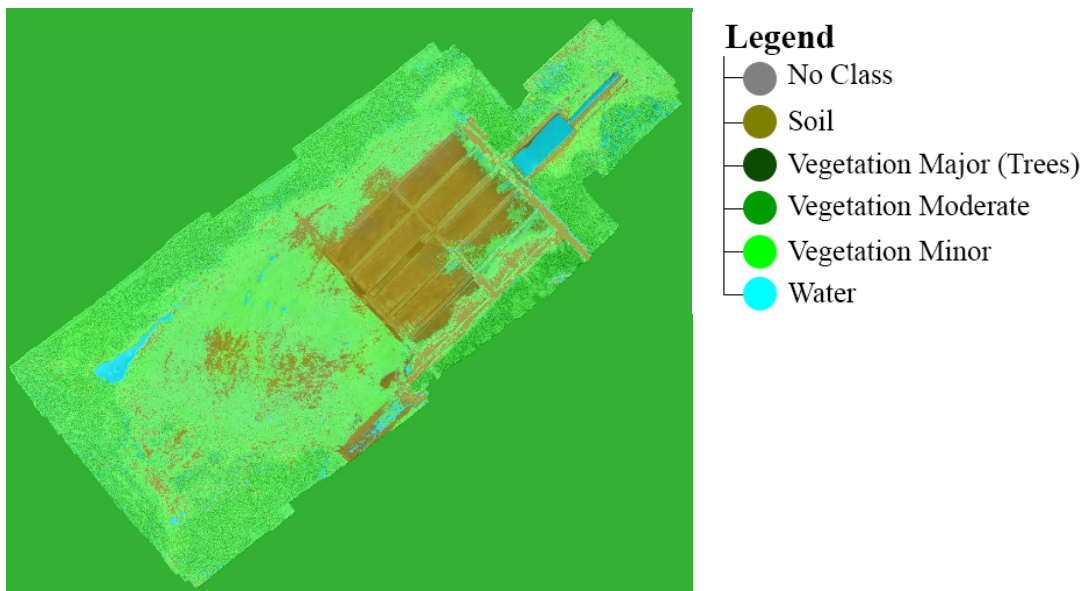Figure 15: Ruleset Step 11 - Vegetation Moderate
Classification

Once the classification was completed, the remaining step was to calculate the

areas and percentage coverage of the individual classes. There are two methods for

accomplishing this. The first is to determine the number of pixels in the image that fall

within a given class and then calculate the surface area based on the known spatial

resolution of the camera mounted to the UAV. By multiplying these numbers, the area

covered by the class is calculated. Percentage can then be calculated by dividing this

number by the area of the site surveyed. While this is a reliable way of determining area

without any additional software, ESRI ArcGIS was used to determine the area because it

was readily available. To calculate area in ArcGIS, the export vector layer tool was used

in eCognition to create a polygon shapefile of the classes. All classes were selected

except the No Data class, because its use as a placeholder was finished. The shapefile

was a multipart file divided by the segmentation boundaries. The attributes of the

shapefile contained individual attributes for each class with the sections of the polygon

assigned a value of 1 for the class attribute it belonged to and 0 assigned to all others.

After the process was executed in eCognition, the shapefile was then brought into

ArcGIS. From here, a new attribute field was added so area could be calculated, and

then the Calculate Geometry function was used to populate the area attribute with the

size of each segmentation in square meters. To find the total area and the areas of the

individual classifications, a specific class was selected by its attribute value and statistics

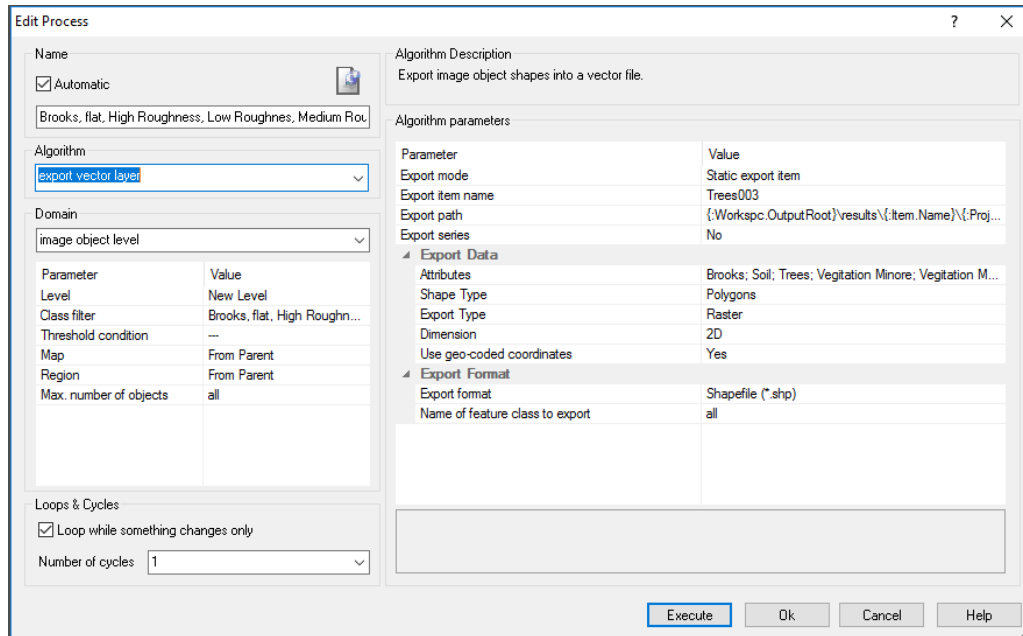for the area attribute of that specific selection were extracted.

Figure 16: Export Process for eCognition

The final stage was an assessment of the accuracy of the classification. This was done using the accuracy assessment tool within eCognition. In order for independent statistical analysis outside that of the internal analysis performed by the software, field data collection would have had to be performed using highly accurate positioning equipment with an extremely dense sampling intensity. This was too complex to be covered by this study. There is also the question of the need for such an intense method in this situation because of the end use of the results. The intention of these criteria is to provide the potential developer with insights into the difficulties that will be encountered if the location were to be developed. These assessments are not designed to be engineering planning documents requiring extreme accuracy but broader planning tools for overall site suitability. As such, an in-depth statistical analysis is not required to meet the end goal of this research, as it is a proof of concept.

Regardless of the lack of overall impact the statistical analysis has on determining the potential for UAS to change how wetland assessments are performed, some accuracy assessments were performed. These assessments were performed on all three site locations. The Soil, Water, and Vegetation Minor classes were evaluated leaving out the Brooks, Vegetation Moderate, and Trees / Vegetation Major classes. These three classes were not included due to the inability of the user performing the accuracy assessment to properly distinguish the small elevation changes that distinguish these three classes from their parent classes respectively. If an accuracy assessment were to be performed for these classes, there is a high probability that the user inputting sample areas would select incorrect samples causing a false drop in accuracy. As such, it is not possible to state with any statistical validity that the Brooks, Vegetation Moderate, and Trees / Vegetation Major classes are an accurate representation of real world conditions. However, these classifications can provide an understanding of surface conditions as they relate to their respective criteria—as seen in Figure 24. Here, large trees and small trees are clearly highlighted by the appropriate classes, as well as small areas of water covered by vegetation being highlighted in the Brooks class. Accuracy assessments were performed on the Soil, Water, and Vegetation Minor classes since these areas were the three dominant classes and therefore small imperfections in user sampling had far less of an impact. This impact is further reduced due to the fact that these areas have a tendency to form in larger, more homogeneous patches, as compared to the other three classes. Therefore, when the user selected the sample locations it was simpler to find appropriate representations of the class features. The assessments were performed by executing the Sample Selection tool. This automatically turns off the classified image leaving the orthomosaic. The user then selects sample locations for the

class. A minimum of 50 samples were taken for the assessment of each class. The
samples were then converted into a TTA mask and an accuracy assessment was
performed. This was completed for all three site locations using all three classes.
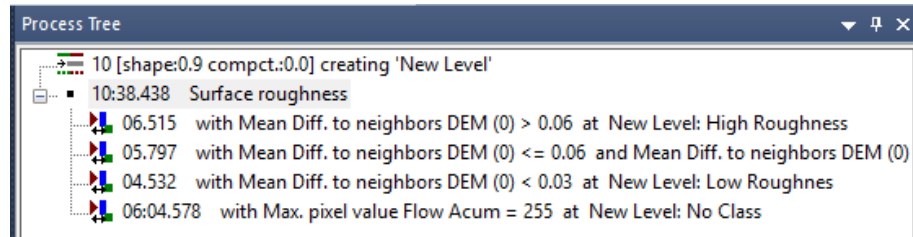

Figure 17: Surface Roughness Ruleset

SURFACE ROUGHNESS

To determine the surface roughness of an area, a DEM was brought into
eCognition so automatic image classification could be undertaken. Once the
segmentation was complete, the classification ruleset was developed to determine the
surface roughness. Since the exact classes and value ranges are outlined in the wetland
criteria, the ruleset simply had to abide by these values. The first stage of this ruleset
was to classify the image into the major classification indicated by greater than 60cm of
elevation change. This was established by classifying image objects as major if they had
an average elevation difference to a neighboring object greater than 0.06. The moderate
class is defined as an area that has 30 – 60cm of elevation change. Using the same
criteria, image objects were classified as moderate if their average elevation difference
to a neighboring object was between 0.06 and 0.03 inclusively. The final section was
classified as minor if the average elevation difference to a neighboring object was less
than 0.03 (30cm). After all of these classes were established, the remaining null area was
classified as No Data. This was performed for each of the three site locations.

The validity of the results is not measured by statistical significance, but rather practical application of the data. Like the Brooks, Vegetation Moderate, and Trees / Vegetation Major classifications performed in the previous analysis section, Surface Roughness is not a distinction that can be made. The human eye using an orthomosaic cannot distinguish the difference in values separating these classes when the spatial resolution of the input data is 11cm in elevation. Regardless of the inability to use traditional accuracy assessment tools on this classification, the accuracy can be determined by looking at the DEM used as the source data. This is because the separation values used to create the classes was already predetermined as is outlined in the wetland criteria document (Soil and Land Management Division. Department of Forestry and Agriculture. St. John's. Newfoundland 1992). This means that the accuracy of the DEM is the accuracy of the classification. The DEM was generated through the software Agisoft and, as previously stated in the Surface Topography criteria section, the algorithms used in the software to generate its outputs are well established as being accurate. Performing in-depth statistical analysis on this data would require intensive field work and statistical development that are outside the scope of this thesis (Uysal et al. 2015). The application in a real world environment to advise decision making is the required validity of the assessment tools created in this research.

DETERMINE IF THE CURRENT UAS TECHNOLOGY CAN ASSESS LARGE ENOUGH AREAS THAT THESE SAME SURVEY METHODS CAN BE USED IN THE FUTURE THROUGHOUT THE PROVINCE OF NEWFOUNDLAND

One of the key interests from the industry partner was to determine if UAS technology could be used to assess the wetland characteristics for large areas. Since this is an emerging area of research that requires the assessment of the advantages and limitations of fixed wing UAS technology, it was a far more experimental and exploratory objective than the other research objectives that relied on proven technologies. To study this objective, the LU-CARIS lab's fixed wing UASs were assessed for their potential to be used for this specific application. The assessments were performed on fixed wing style UASs due to the theoretical efficiency of this type of aircraft in collecting information over large areas. While multirotor UASs have excellent stability and control, they require a large amount of power to remain airborne just as helicopters do. Conversely, fixed wing systems inherently stay airborne because of the lift effect of their larger wings. This means less power is needed, so fixed wing systems can fly faster and operate longer than their multirotor counterparts. The end goal was to determine whether fixed wing UASs have the potential to collect remotely sensed data with detail comparable to that of the DJI Inspire 1 used for the other objectives, while also surveying larger areas in less time and with greater efficiency. The effectiveness of fixed wing systems was determined by deciding if the analysis performed on the target site could be expanded to large areas and potentially to the rest of the province. While researching the experiences of LU-CARIS in their previous development of fixed wing UASs and the equipment available in the lab, it became apparent that there was no prescribed methodology to assess the available UASs. Instead, a familiarization was developed with the components of the systems and their practicality during their use. By

building on this knowledge base, the advantages and limitations of the general category of fixed wing systems was developed.

At the time of the development of this research, there were two commercially available fixed wing UASs suitable for data collection, the Precision Hawk and the Trimble eBee, both of which were very expensive and experimental. During a demonstration of the Precision Hawk, the UAS could not takeoff on multiple attempts, until it finally launched and immediately flew into a tree, destroying the airframe. It was this lack of system reliability, as well as the high cost of the commercially available models, that lead this research to assess the use of a custom built, fixed wing UAS. The objective was to discover whether low cost hobby fixed wing UAV technology had progressed sufficiently to provide the capabilities needed to cover large areas using high quality sensors. This would have made it possible to scale this wetland assessment technique from single site surveys to larger areas and potentially to a provincial level at a reasonable equipment cost.

The LU-CARIS lab has been developing fixed wing UASs since 2014. This led to the development of three systems built on the Skywalker, Skyhunter, and Skywalker X8 hobby airframes. The Skywalker had mapping capabilities using a Sony a6000 mirrorless SLR camera with 24.3 megapixels. It had a flight time of approximately thirty minutes. The Skyhunter was fitted with five separate cameras for the purposes of performing mouse surveys. Biologists stationed at the ground control location viewed live video feeds from the cameras. This airframe also had an approximate flight time of thirty minutes. The X8 (Skywalker X8) airframe is a flying wing design with a large internal payload capacity. It is in the final stages of development and has the ability to

carry two gimbal stabilized sensors operating in tandem. The X8 is designed to be a general purpose fixed wing UAS. It is this principal of developing custom made, fixed wing UASs from inexpensive, prefabricated, plug and play, hobby components and high-quality sensors that guided the development of these platforms. Due to the need to scale the research area from a site by site based approach to a province wide assessment, assessing the airframes payload capacities and flight time endurances were key considerations.

Figure 18: Skywalker X8 Sitting on Launch Catapult

The fixed wing research took place in tandem with the research development for the other research objectives discussed previously. The background research on fixed wing systems involved gaining an understanding of the requirements of an operational UAS, the technologies involved, the aerodynamic principles, the qualities of existing airframes, and general training on fixed wing UAVs. To obtain information regarding current hobby technologies, resources such as forums and YouTube channels were consulted. This was due to the fact that no relevant information could be found through

academic sources (NorthSweden and Blog 2009; NoFlyZone 2009; FlightTest 2015;

Lidbom 2015; Octane81 2017). Once a basic understanding of the components,

communication systems, power and control systems was obtained, the UASs were

assessed for basic flight characteristics with no payload. This developed a familiarity

with the handling and programming of the flight systems without risking the sensors

while developing an understanding of the differences in flight characteristics between

the airframes.

The catapult launch system was another component of this initial familiarization.

Both the Skyhunter and the X8 require a catapult to safely takeoff. The design of the

Skywalker airframe allows it to be launched by hand. The catapult system is a key part

to the operation of the Skyhunter and X8 platforms, because both airframes have rear

mounted engines. If these UAVs were launched by hand, there is a high likelihood that

the rear mounted propeller would cause significant injury to the arm of the person

launching the UAV. To avoid this possibility, a catapult was developed. The Skywalker

airframe avoids this danger by mounting the engine higher. The arm on which the tail is

attached is placed between the propeller and the person launching the UAV.

The flight controller chosen was the 3D Robotics PixHawk, because of its ability

to perform automated flight and control the planned payload options that included Sony

a6000 cameras and Flir Vue Pro thermal cameras. A variety of different configurations

of the software parameters were assessed for the usability of the software and the

potential for custom configurations.

During these test flights, it became evident that balancing the airframe's center of gravity was critically important with fixed wing systems. With no vertical propulsion systems, such as helicopter style rotors, there was no way for these fixed wing systems to self-stabilize if their center of gravity was not perfectly balanced. Different fixed wing designs also have varying sensitivities to center of gravity balance (NorthSweden and Blog 2009). For example, because the Skywalker has a tail with an elevator and rudder control surface, it was less sensitive to small imbalances in its center of gravity compared to the flat flying wing design of the X8 which does not have a tail for added stability. This means that the Skywalker's airframe is very sensitive to misalignment of the center of gravity, which can cause a nose dive or tail strike. This issue was solved by using a balancing device before every flight to ensure the center of gravity was properly aligned. While this was not an overly onerous task to perform in the field, it is a critical step that must be taken when using a fixed wing system.

A method to increase lift for a fixed wing UAS without increasing the propeller and engine size is to takeoff into a strong head wind, which adds wind speed as an advantage. This additional airflow over the wings generates lift even while the airframe is stationary. Performing a test flight in these conditions not only assessed the impact of using a head wind for take-off, but also provided the opportunity to assess fixed wing flight performance in high wind conditions. This was done on a very windy day that is not representative of the conditions that would provide usable data for aerial surveys due to turbulence. Regardless, the added head wind allowed the X8 to takeoff and ascend to altitude with relatively little thrust. Once at altitude, the flight controller was switched to automated flight mode. The controller banked appropriately, but the added wind resulted

in the aircraft performing a nose dive from an elevation of forty meters above ground

level that it was not able to recover from before crashing. Upon impact, the airframe was

destroyed along with the propeller and GPS attachment point to the PixHawk. While

these conditions were not representative, the event illustrated the lack of stability in

windy conditions that fixed wing UASs are prone to and their inability to self-recover

(Lidbom 2015).

Fixed wing UAS power systems have the ability to run more efficiently than

those of multirotor designs, because they can run at lower speeds, drawing less power

while the airfoils generate lift. The optimal efficiency of any fixed wing UAV depends

on finding the best combination of motor, engine control system (ESC), and propeller.

To accommodate the added weight of the sensor payloads and the reinforcing needed to

turn a hobby airframe into a survey capable UAS, more robust power systems were

needed. Full takeoff weight, including the cameras, needs be factored when determining

the power system specifications. The first step in examining propulsion options was the

development of an in-depth understanding of the components of hobby aircraft electric

propulsion systems. This involved considering the electrical power systems and

propeller forces. Once this knowledge was gained through forums and other non-peer

reviewed materials (FliesLikeABeagle 2004; NoFlyZone 2009; FlightTest 2015;

Capable Computing, Inc. 2017; Mueller 2017), the use of a free online calculation tool

was used to help determine the optimal specifications for sustaining flight as long as

possible with the airframe specifications and the desired takeoff weight. To gain a

practical understanding of these power systems, a variety of motors and propellers were

used to assess their performance differences. All motor and propeller combinations were

bench tested in order to gain a preliminary understanding of the actual loads created. This was done through the on-board logging feature built into the Turnigy Super Brain ESC. This data was anecdotal, but it helped build an understanding of what was happening with the power system. After comparing the performance changes of different propeller and motor combinations in a bench testing environment, a better understanding of the requirements was formed. This testing, combined with the results from the calculators, made it clear that the ideal setup to carry the required heavy payloads was a very large propeller and a motor that spun very slowly with a lot of torque. Further research into developing the ideal power system was conducted using the software MotoCalc. This was the most comprehensive simulator found. It required detailed information on the airframe and intended performance requirements. It then provided power graphs over time and throttle conditions with different setups. The ideal flight performance results determined by MotoCalac can be seen in Appendix F. The power system for fixed wing UASs is a critical component. Given the demanding project requirements for multiple sensor payloads and the need to perform automated flight missions it was discovered that a great deal of effort is needed to maximize the performance of all components when using hobby components that need to operate at the upper limit of their design specifications.

Through the appropriate application of this methodology, results were obtained to answer the gaps that exist in the literature, the overall objective was met, and a more efficient data collection method was developed for practical use. All the objectives were thought to be feasible within the allotted time frame of this study with no delays occurring. Once completed, an important and significant data point was created to

provide information on the new topic area for both academic knowledge and for industrial applications.

RESULTS

FLOOD HAZARD MAPPING

While no flooding hazard model was made, general hydrologic information can help planners understand how an area drains. One of the key problems with using this data for any substantial decision making is the scale of the data. These models have traditionally been used on large watersheds, so a complete understanding of the watershed area can be represented. As the UAS data for this study only covered the extent of the site locations, there was no relationship to the surrounding area and therefore could not show any flooding risks. However, the results can help to provide an understanding of how the hydrology of the small area works. The intention of including these results is to demonstrate the types of hydrologic data products that can be produced from UAV derived data. These data products can be seen in Figures 18 and 19.
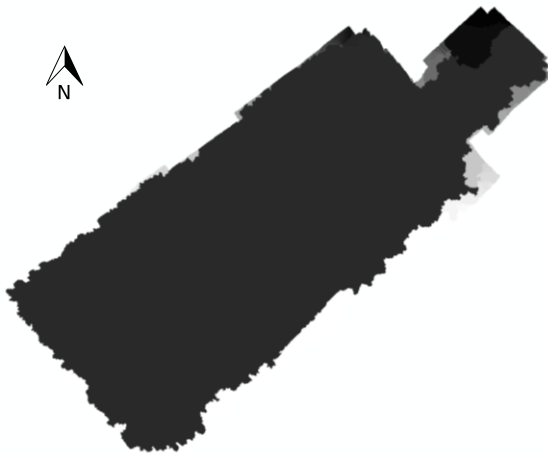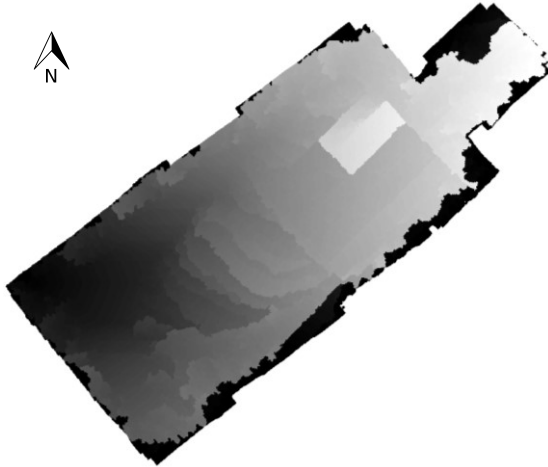
Figure 19: Hydrology Basin Model for Site

Figure 20: Flow Length Model for Site 3-

SURFACE TOPOGRAPHY

Measuring the leveling effort of an area was determined by calculating the volume of material that must be added or removed, referred to as the "cut and fill". While it is possible to calculate the cut and fill for an entire area of interest, it is more practical to determine the desired locations for construction and then perform the cut and fill process for that specific area. This was the approach used in this step of processing where a theoretical bed would be located, and the cut and fill volume calculated for that area. Using the data from site 3-A, a simulated area of expansion was determined, and the change in volume required to level the area was calculated. As this data set contained over 62 million points, the area of interest was identified and then cropped. This reduced the data to a size that was reasonable for the software to handle and the surface mesh was generated. Once the mesh was generated, the percentage to be filled was input. Since the goal was to determine the cut and fill volume to completely level the area, this parameter was set to 100%. After this was complete, the final results were viewed with the *measure area and volume* tool. In the example, this resulted in a volume of approximately 2179.83m^3 of space that would need to be filled over the whole

$36763.5m^2$ of area. The negative volume value shows that this is empty space needing to be filled rather than material to be removed. With the validity of this assessment for determining cut and fill volumes already having been proved (Uysal et al. 2015; Messinger and Silman 2016; Jin et al. 2017; Rusnák et al. 2018), this method has the ability to provide valid and valuable information for determining surface topography as it relates to developmental difficulty for a cranberry farm location.

CLASSIFICATION

The classification is a combination of assessing multiple wetland criteria through the same method of automatic image classification. The goal of the classification is to provide both a map of the area classified, as well as the measured area coverage of each class. The method outlined in this research provides the foundation for how these results were obtained with the classification ruleset developed on site 3-A. This classification was also used on the other two site locations, site 3-B and site 2. These results can be seen in Figures 20 to 25 and Tables 3 to 5. With no statistical significance determined for these results, informal evaluation suggests the approach has value in identifying suitable locations for the agricultural production of cranberries.
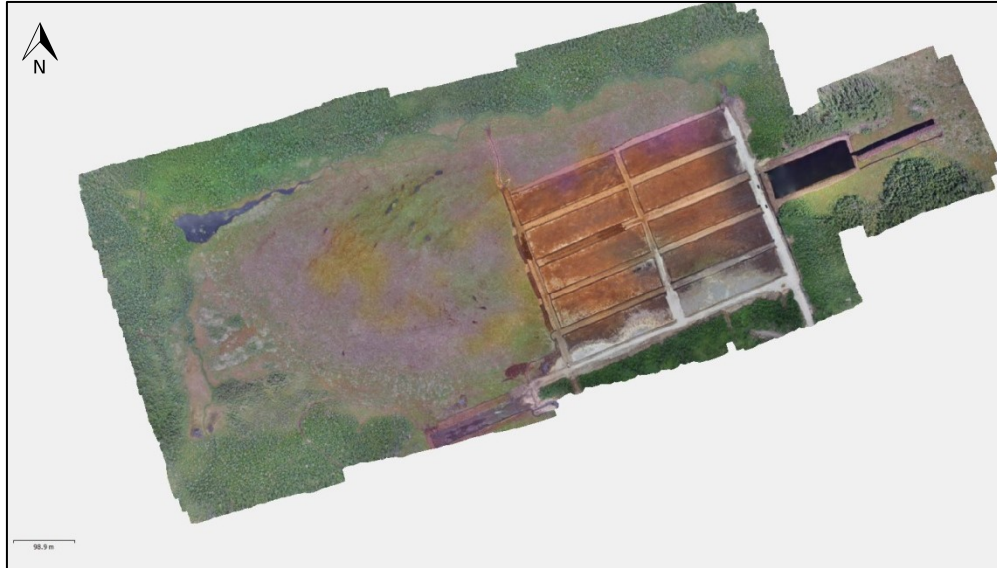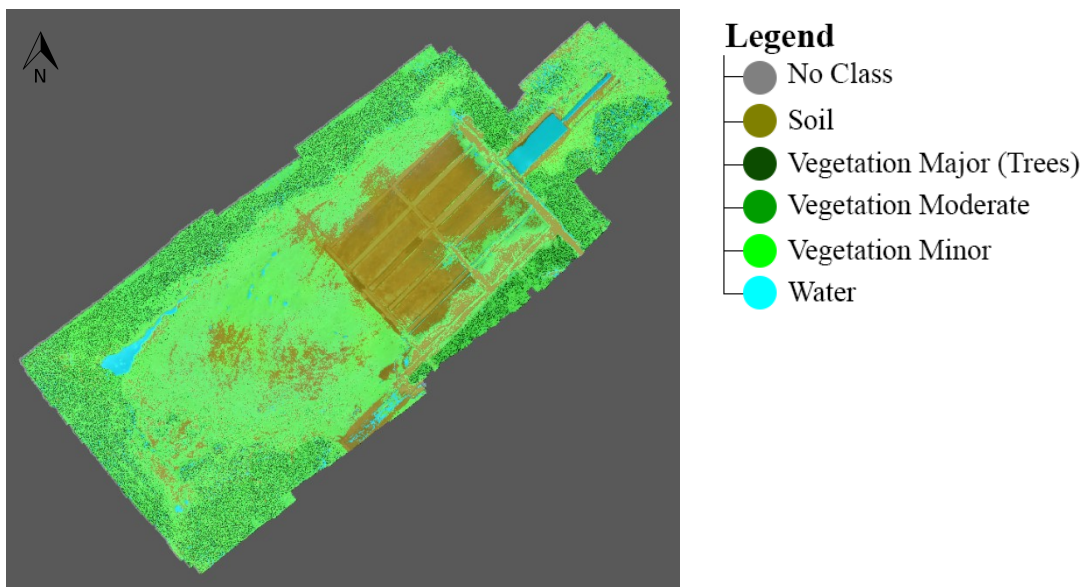
Figure 21: Orthomosaic of Location 3-A

Figure 22: Ruleset Step 13 - Complete Classification

Location 3-A can be seen in Figures 20 and 21. The first is a true colour
orthomosaic of the study area. This area was under development at the time of data
collection as can be seen with 10 cranberry beds, 2 roadways, and the water reservoir
area visible on the right side of the image. These areas are constructed in the bog area at
the center of the image with treed area surrounding the perimeter of the study location.

Using the methodology outlined in the methods section, the classified image in Figure 21 was developed. This figure displays the location of 3-A, with the pixel values representative of the class they represent. The intention of this classification is to provide information on the type of land cover and its location on the study site. The specific values of the area covered by these classes can be seen in Table 3, displaying the total area of coverage, as well as the percent coverage of the study area with the majority of the $1024310m^2$ area being part of the minor vegetation class. This provides information on land cover trends cross the whole site, whereas the classified image provides more contextual information on the spatial distribution and relationship of these classes.

Table 1: Site 3-A Classification Landcover

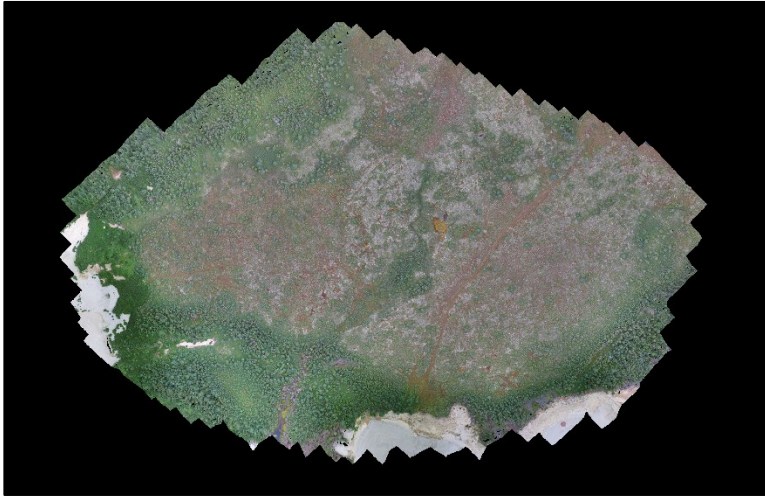| Classification	Area (m2)	% Coverage
Water	36979	4
Veg Minor	240466	54
Veg Moderate	553401	11
Trees	112949	8
Soil	80515	23
Total	1024310	

Figure 23: Orthomosaic of Site 3-B

Locations 2 and 3-B were also classified using the same method with no alterations of the ruleset. This provides information on the ability of this ruleset to function outside of the study location it was developed in. Figures 22 and 23 display the orthomosaics, which provide contextual information on the locations to better understand the classifications.
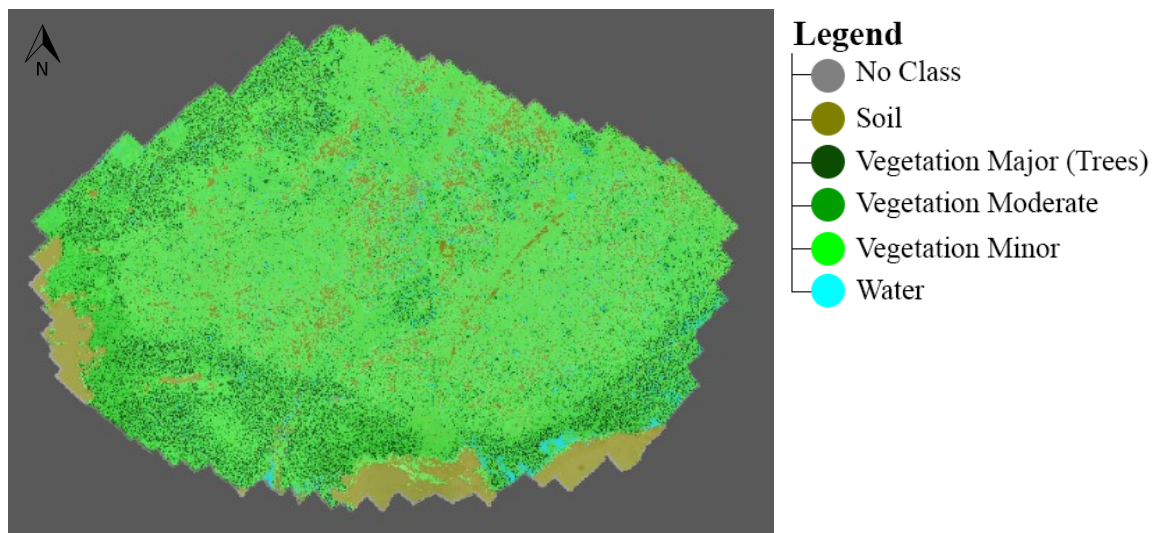

Figure 24: Classification of Site 3-B

Figures 24 and 25 show sites 2 and 3-B as classified images respectively, using the same ruleset used to classify site 3-A. These figures show the spatial distribution of the classes across the site. The classified land cover can be found in Tables 4 and 5, displaying both the total area coverage of each class, as well as the percent coverage of each site with the minor vegetation class being the predominant class in the both areas followed by the soil class.

Table 2:Site 3-B Classification Landcover

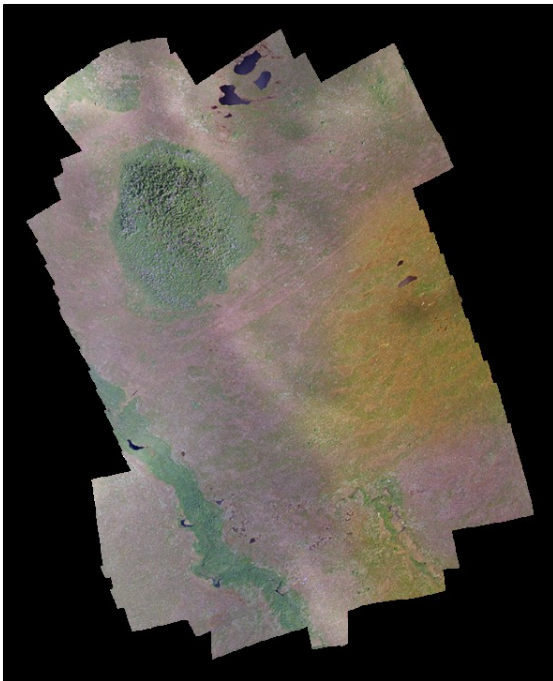| Classification	Area (m2)	% Coverage
Water	5443	2.5
Brooks	429	0.2
Veg Minor	157928	71.8
Veg Moderate	14629	6.7
Trees	16999	7.7
Soil	24450	11.1
Total	219879	

Figure 25: Orthomosaic of Site 2
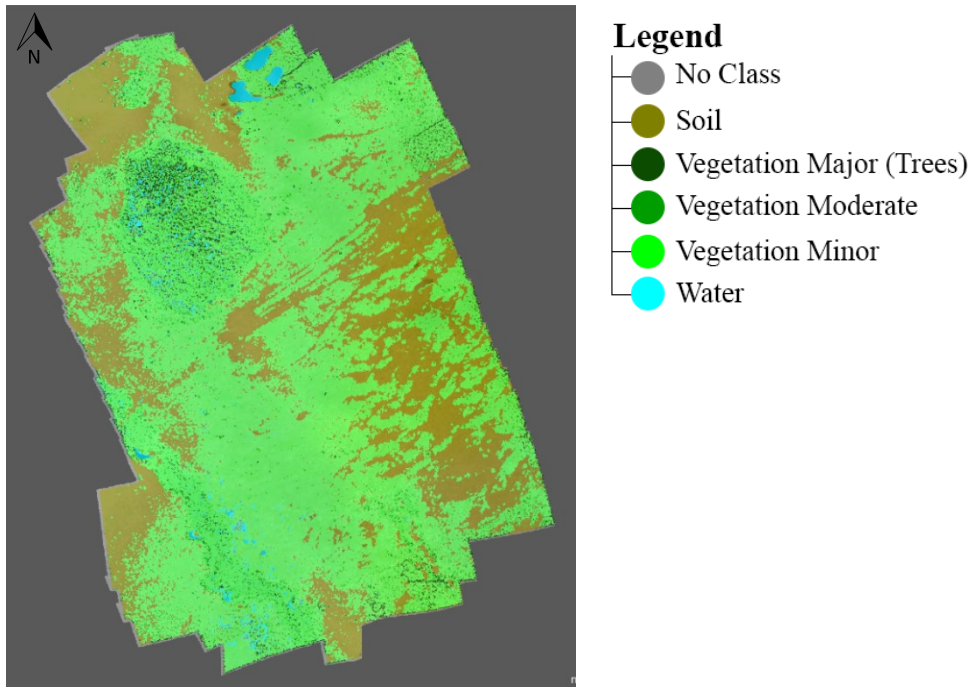
Figure 26: Classification of Site 2

Table 3: Site 2 Classification Landcover

Classification	Area (m2)	% Coverage
Water	2293	1.3
Brooks	420	0.2
Veg Minor	111504	63.5
Veg Moderate	6929	3.9
Trees	4013	2.3
Soil	50380	28.7
Total	175539	

SURFACE ROUGHNESS

The surface roughness of a wetland was assessed to determine the impact it has on the developmental difficulty of the location. This was determined by using the specific values outlined in the wetland criteria (Soil and Land Management Division. Department of Forestry and Agriculture. St. John's. Newfoundland 1992) and classifying the derived DEM accordingly. This produced a classification of areas with Minor Moderate and Severe coloured green, yellow, and red in the corresponding order.

Unlike the classification that was used to determine land cover type, this classification simply identifies differences in elevation values. To help provide contextual information, the hillshade DEM created by Agisoft is included in Figure 26. In this figure, higher elevation points are represented with colours closer to the red end of the spectrum and lower elevations are represented with colours closer to the blue end of the spectrum. The results from the surface roughness classification are presented in Figure 27. In this classification areas shaded green have a low difference in elevation to their neighbours, yellow are areas of medium elevation difference, and red are areas of high elevation difference.
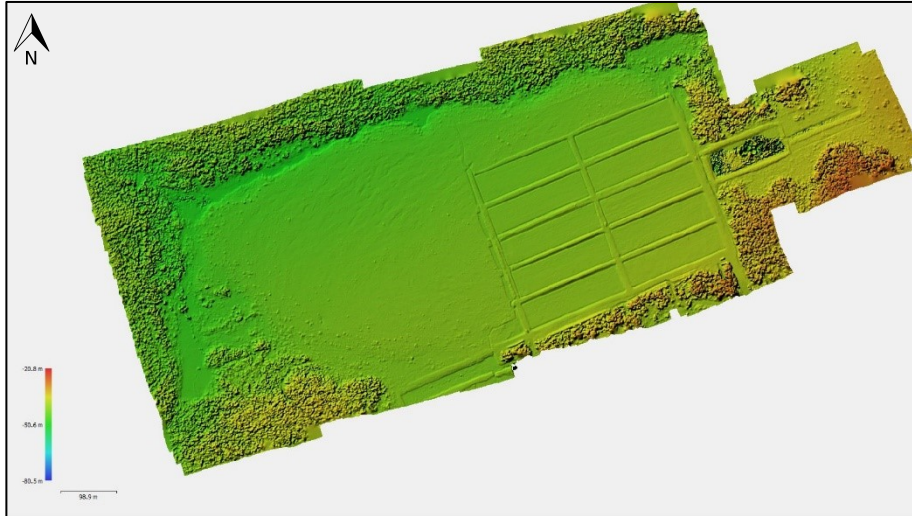
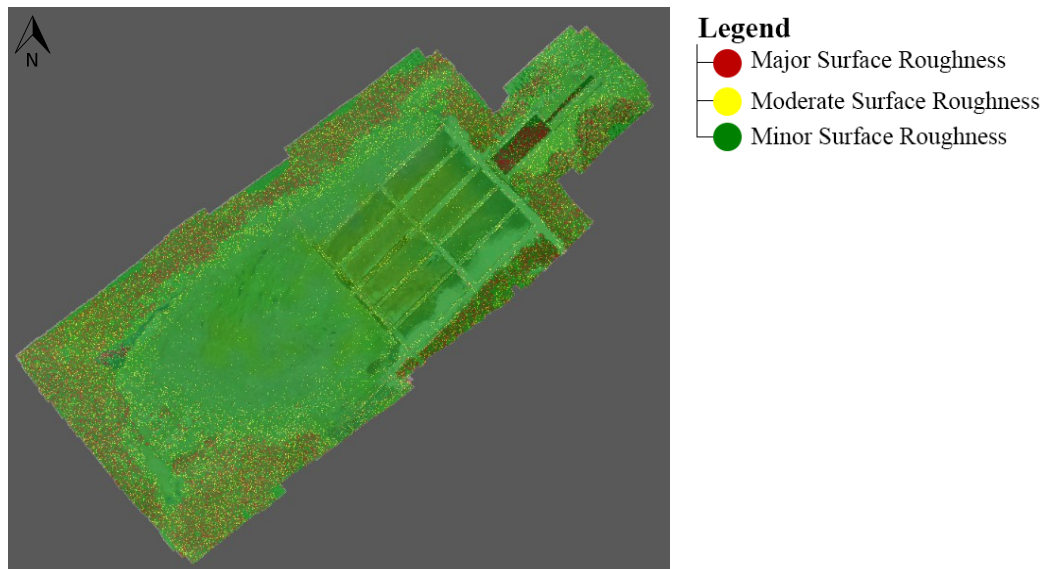*Figure 27: Digital Elevation Model (DEM) of Site 3-A*

Figure 28: Surface Roughness Classification

FIXED WING PRACTICALITY ASSESSMENT

After assessing all available fixed wing UASs and contrasting their theoretical performance benefits against their limitations, the conclusion of this study is that there was insufficient research data available to make any definitive determination on the use of a fixed wing option. When this study was completed, there was progress being made to develop an operational UAV supporting the theory that a fixed wing UAS would be

more efficient in this application over a multirotor design. If this topic were to be revisited, a functional UAS would most likely be able to be developed. The conclusion to this research objective was that it can neither be confirmed nor denied that the current UAS technology has the potential to cover large enough areas to apply the survey methodology across the Province of Newfoundland and Labrador. This leaves opportunities available for future research. The advantages that fixed wing UASs provide are significant in some circumstances, such as covering a large area in the most power efficient manner. Even so, there are also applications that benefit rotor designs over fixed wings, such as areas with limited launch space or structure inspections. In addition to these application-specific limitations, there are also challenges associated with building a custom fixed wing UAS. With the rapid progress of the UAS industry, these conclusions could become outdated rather quickly, but at this time, a determination could not be made regarding the applicability of fixed wing UASs in wetland surveying for the potential of cranberry agricultural development in Newfoundland.

DISCUSSION

DEVELOPMENT OF A GIS-UAS-REMOTE SENSING WETLAND ASSESSMENT
METHOD FOR CRANBERRY AGRICULTURE IN NEWFOUNDLAND

The bulk of this research focused on the development and assessment of the third

objective: to assess current UAS technology for the potential to replace or augment

ground survey techniques. The research was performed by taking the current assessment

method and the individual criteria it uses to compare against the capabilities of UAS

technology and the requirements of the wetland criteria. Some of these criteria

requirements are outside the scope of current UAS technologies and some fell well

within what was possible. The criteria that were able to be assessed were taken, data

were collected, and an analysis was performed to generate the specific data requirements

for each of the criteria for cranberry agriculture suitability. Those criteria were organized

so they could be used for real world wetland assessment, as well as how UAS could fit

into the Province's wetland assessment system.

The current method of evaluating the suitability of an area for cranberry farming

is initiated by the proponent (the farmer) in coordination with the provincial

government, and involves a ground survey using assessment criteria found in Report 15

(Soil and Land Management Division. Department of Forestry and Agriculture. St.

John's. Newfoundland 1992). Once this assessment is performed, the site is either

determined to be a suitable location for further study and development or the site is

deemed not suitable and a new candidate location needs to be found and assessed.

The first finding that was identified in this research was that current UAS technology does not have the ability to fully replace field crews when performing wetland assessments in Newfoundland. This is because UASs currently lack the capability to generate data for all of the criteria used in the wetland assessment process. Large watershed scale surface topography, large landform mapping, flooding hazard modelling, soil composition, material under organic soil, and depth of deposit were all determined to be outside the information gathering capabilities of current UAS technology and were unable to be assessed. This means that regardless of the efficiencies gained from the use of a UAS, a field crew is still required to gather data and assess these criteria using the current method. The other aspect to this objective was to determine if there is potential to augment the current survey method. This potential was tested.

When reviewing the results of this study's testing of UASs in the gathering of information for the assessment of each criteria, a distinction must be made between academic validity and applied validity. In order to definitively state to academic standards that the results generated by this research are more accurate than those collected by current field survey crews, a more in depth statistical analysis would be required, control data would have to be collected by survey crews, and more intensive data collections would need to be performed to create statistical models. All of this falls outside the scope of this thesis due to time and financial constraints. As such, the results should be viewed as exploratory with the intention of identifying a new area of research. Due to the novel application of UAS technology in this work, and the primary focus on the development of a proof of concept analysis where the results could be used in real

world applications, it was decided that findings would be compared to applied field techniques instead of seeking statistically defensible results.

The data and analysis that were achieved using the UAS appear to have many benefits over a traditional survey with almost no significant drawbacks. In terms of the factors of time, accuracy, continuity of data, and record keeping, UAS-based data collection presented advantages over ground crew data collection. UASs present a great potential for time savings because of their ability to collect data for a large area in very little time. In addition, UASs have the ability to access more remote locations without worrying about obstacles on the ground. While the data processing can be time consuming to develop the final data products, this can be done during times that workstations would otherwise be idle, such as overnight and weekends. UAS data also presents an increase in accuracy over ground surveys. Data accuracy is directly related to the continuity of data that is collected. With the UAS imagery collected in this study, a measurable point was created with a spatial resolution of three centimeters, resulting in millions of data points used to generate the final data products. This number of sample points is virtually impossible for a manned, terrestrial survey to perform using current methods. Additionally, because such high spatial resolution imagery is created by UAS, the data is continuous across the site with no gaps. Imagery represents a permanent record of the surveyed information. This means that exact records of the survey can be retrieved regardless of personnel changes and contain more detail than field notes.

The data collected by the UAS is very precise and has the advantage of being densely and evenly sampled over the surface of the area surveyed, as opposed to current field survey point sampling. However, this does not mean that the data is inherently true.

Developing data products, such as the ones in this study, require an individual who has expertise in remote sensing data collected by UAS to assess and process the UAS imagery. Changing factors, such as cloud cover, vegetation health, and shadow, can influence the way the analysis is performed. This means that small changes need to be made on a site by site basis to develop the best possible data products. While this is a change to the workflow and the required skills of the survey crew, it does not diminish the validity or benefit of incorporating UAS data into wetland assessments. The transition to incorporate UAS into the assessment workflow is not something that can happen overnight; it is worth using pilot projects to develop a system that works. The advantages that UAS provides, and the potential for expansion of the cranberry agricultural industry in Newfoundland, means that this is a technology that is worth exploring in an applied way.

Since field crews are still required to perform some aspects of wetland assessments, there is no potential for UAS to completely replace the current method. However, there is potential to enhance it. While survey crews will continue to perform field work, there will not be the need for field crews to assess as many criteria.

The findings of this study suggest that UAS can be used to determine the brook mapping, vegetation coverage, microtopography, open water coverage, and coarse wood fragment criteria at a level of accuracy that provides equivalent or better information for these criteria. This means that crews can spend less time performing an individual survey and increase their overall efficiency.

There are two main ways that UAS could be integrated into the existing workflows of wetland surveys. The first is to perform preliminary assessments of potential site locations to refine the criteria that UASs are capable of collecting for a given location. Once this assessment has been completed, a decision can be made as to whether a ground survey should be performed or if the site is deemed non-viable using the UAS data. This approach has the advantage of only using a ground survey when necessary. The second approach would be to have a UAS team perform the data collection while other criteria are being assessed simultaneously by ground crews. The specific procedures would need to be assessed further to determine the ideal efficiency of data collection by both the UAS crew and the traditional field crew. This is something that should be examined closely, as there is potential for inefficiencies if other influencing factors such as travel time are not factored, as was pointed out in the Biomass Utilization – Inventory and Economics Report (Lakehead University CARIS 2017). Even though that study addressed forestry applications where the movement of harvesting machinery had the potential to cause inefficiencies, there could be similar logistical problems that would need to be taken into account, such as sending crews to the same location twice. Logistical problems could be assessed through a pilot program where UAS-based assessments are selectively introduced and workflows are optimized.

While this thesis is focused on evaluating the potential for UASs to assess wetlands based on criteria used by the government, there is potential that this technology could be used by individual farmers for both initial suitability assessment, as well as ongoing monitoring once the farm has been constructed. The relatively low price point of UASs means that this technology is no longer outside the means of an individual

farmer to purchase one of these systems for private use. The user-friendly interface and advancements in safely functions that have found their way into the sub $2000 UAVs, such as the DJI Phantom series, means that it is no longer necessary to have a large amount of experience to be able to operate these systems safely and effectively. This change in the technology means that if an individual has an area in mind for the development of a cranberry farm, it is completely attainable for them to acquire an introductory UAS, such as the DJI Phantom series, along with all the required permissions from Transport Canada and do a preliminary assessment on their own. This is not to say that they would be able to develop the same data products that were created in this study for the specific criteria, but that UAS could be used as a scouting tool to provide a different perspective to potential developers. The main barrier to individuals being able to develop the data products for assessing the individual criteria is the access and training needed to operate the software packages used, such as Agisoft, eCognition, and ESRI Arc GIS. However, it is possible for the average individual to perform automated data collection and generate orthomosaics using the free online tool found on the Precision Hawk website (PrecisionHawk 2017a). The potential uses for a UAS operated by an individual go beyond preliminary scouting and include monitoring the day to day operations of the farm. The wetland environments needed for cranberry agriculture have a tendency to shift and move during construction. This can happen every couple of weeks, but by using a UAS there is the potential to see these changes over time by comparing orthomosaics taken at different periods. There is also a potential use for UAS to assist in the farming operation of a cranberry farm. By using a near infrared camera, UAS can help to identify areas of vegetation stress in the field. This can help aid farmers' decision-making process regarding the management of their crops. The

viability of the continued use of UASs in farm operations following site selection is an interesting topic for future research.

FIXED WING PRACTICALITY ASSESSMENT

While this study was not able to prove that current UAS technology has the capability to perform wetland mapping for all of Newfoundland, the results indicate that there is promising potential to use the cranberry assessment techniques developed in this thesis across much larger areas as the prototype fixed wing UAV is explored further. It is also worth noting that at this time, there are major legislative barriers to implementing a fixed wing UAS with the ability to cover large areas. The most notable of these limitations is the inability to legally operate a UAV beyond the unaided visual line of sight of the pilot (Transport Canada 2014). With the long range capable of UAVs, such as large fixed wings, limiting their operational distance to the pilot's line of sight is a significant limitation to the usability of this platform. One of the main limiting factors that encumbered making a solid determination about the practicality of using fixed wing UASs in this study was the available airframe and sensor combinations accessible for analysis. It is worth continuing to explore whether an inexpensive UAS for wetland mapping can be developed using hobby components. This would involve selecting an airframe and sensor payload that is more appropriate for the task and more realistic to pack into common hobby airframes without overstressing the components. Experience and familiarization with the commercially available components shows that a potential alternative airframe would be the Cloud X-UAV with a V-tail design and twin front motors. This would provide more stabilization from the tail and the ability to hand launch safely with its front motor layout. Potential sensor payload options for this

application could include a single Sony a6000 paired with the Parrot SEQUOIA camera. The a6000 offers extremely high 24.3-megapixel resolution that can be used though the pan sharpening function in image processing software to increase the spatial resolution of the near infrared, red edge, green, and red image bands of the SEQUOIA. This system has the potential to scan large areas while capturing information beyond the RGB used in this research. It is also worth reinvestigating the potential for using commercially manufactured fixed wing UASs. At the time of the writing this thesis, Parrot had just released a new UAS. It is called the Parrot Disco-Pro AG and it is a fixed wing UAS with a SEQUOIA installed. The UAS from Trimble and Precision Hawk cost upwards of $50,000, but the Parrot Disco-Pro AG is priced under $5000 USD (Parrot 2017; PrecisionHawk 2017b). This shift in the commercial market brings a fixed wing system to the same price point as DJI Inspire used in this research. Cranberry farmers, surveyors, and future researchers will be able to benefit from these recent improvements in the very rapidly advancing field of UAS technology.

AREAS OF FURTHER RESEARCH

Despite the inability to definitively determine whether there is a benefit to using fixed wing UASs based on this particular project, there remains potential for further research into the cost threshold as each stage of technological development occurs. For instance, if equivalent sensors and batteries become lighter, then the weight constraints found in the course of undertaking this study would be relaxed. The hypothesis regarding the utility of fixed wing systems is still valid due to the added lift provided by the wings. One difficulty that occurs when using UASs for small area surveys is the added preparation time for the use of a fixed wing which can negate its benefits

compared to using a multirotor. Finding the site survey conditions for scale, time, and required payload that transition the benefit to a more complex fixed wing UAS is an area that has not yet been assessed in the literature.

Since there were only specific airframes and payloads available for assessment when this research began, a fixed wing UAS could not be created specifically for this project. If there was an opportunity to develop a UAS from the ground up specifically for this research, then it may have been possible to come to a different conclusion in regard to the research question and determine if the current UAS technology has the ability to assess large enough areas that these same survey methods can be used in the future throughout the Province of Newfoundland. This would provide the chance to leverage different airframes and sensors, such as front engine planes and compact cameras like the Parrot SEQUOYA.

At the time of writing, there was also the release of a new out-of-the-box fixed wing UAS designed for remote sensing. This system is called the Parrot Disco Pro Ag and is at a comparable price point to the DJI Inspire series. This opens a new opportunity to reassess the potential of commercial fixed wing UASs, compared to multirotor designs and custom built fixed wing options. Comparing capability, cost, and appropriate applications would provide an important data point in the literature that is sorely missing.

These areas of further research regarding UAS technology highlight the novelty of this topic area and the potential for research and development in the field of UAS-

based remote sensing. This area is rich with potential research topics and the more that it is explored, the more potential there seems to be.

CONCLUSION

Cranberry agricultural development presents a great potential for an expansion of the agriculture industry of Newfoundland. This study demonstrates that the addition of UAS technologies to the survey and selection process has the potential to increase the efficiency and accuracy of wetland surveys while reducing cost. This technology has the potential to reduce the time required to perform a site assessment and to create a series of highly accurate data products, improving the quality of assessments. The study demonstrated that UASs can be used to reduce barriers to development and increase cranberry production in Newfoundland by aiding in selection of the most ideal locations for cranberry farming.

Since this was a relatively new area of research and the study was a joint partnership with the company Resource Innovations Inc. (through the NCERC IPS funding program) the intention was to develop a proof of concept study focused on developing usable and relevant results for real world applications. This led to the conclusion that, while not scientifically proven, there is potential for the integration of UAS into wetland surveys to help improve the assessment of site suitability for cranberry agricultural development in Newfoundland. The assessment of the academic validity of this method, and the optimization of the method with existing survey methods, are areas for further study.

The study looked to assess the potential and practicality of using fixed wing UAVs to perform data collection rather than multirotor systems. At the time of the creation of the methodology, there was no low cost, existing, out-of-the-box, fixed wing UASs that could be used. Commercial fixed wing systems were unrealistically expensive, which led to an assessment of the potential for using fixed wing UASs created from relatively inexpensive, hobby components that could carry high quality cost effective sensors. Due to limitations such as the weight of sensor payload and short theoretical maximum flight times, no definitive determination was able to be made regarding the practicality of using fixed wing UASs to perform this type of wetland assessment. Although no conclusions regarding fixed wing UAS applications for wetland assessments were made, the rate of technological change and advancement holds great potential to advance the usability of fixed wing UASs.

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Yue J, Lei T, Li C, Zhu J (2012) The application of unmanned aerial vehicle remote sensing in quickly monitoring crop pests. Intelligent Automation & Soft Computing 18:1043–1052

Zhang C, Kovacs JM (2012) The application of small unmanned aerial systems for precision agriculture: a review. Precision Agriculture 13:693–712 . doi: 10.1007/s11119-012-9274-5

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APPENDICES

A

CHARACTERISTICS USED TO DETERMINE ORGANIC BOG DEVELOPMENT

Characteristics used to determine organic bog development

In order to determine the Development Difficulty rating of an organic deposit, a field investigation is required. The factors of organic soils and their landform characteristics needed to determine the rating include:

- surface topography or slope which indicates how much material will have to be moved/removed in order to level the bog; the more level, the better;

- composition of the parent material and decomposition for soil and landform classification;

- composition of the material underneath the organic soil to ensure the watertable is apparent and stable; identify any perched water table;

- pattern and density of any "brooks" running through the deposit; is the deposit fragmented?

- overall size such that the larger, more continuous landform is more desirable;

- vegetative cover which indicates the amount of land clearing necessary;

- excess water and inundation hazard, indicating special drainage and water control works requirements; is flooding a factor?

- surface roughness (micro topography) which dictates the amount of land leveling required;

- percentage open water specifies the amount of pools to be filled in or, if >30%, to be avoided;

- percentage coarse wood fragments indicates the amount of tree stumps and branches to be removed; and at depth identifies layers in the deposit where stumps and other wood debris exist;

- depth of the deposit gives an indication of the life span of the deposit and thickness after settlement.

The factors used to determine the degree of development difficulty for organic soils is illustrated in the table below. Whether an organic deposit is determined to have minor, moderate or major development difficulty is based on the limiting factor that has the greatest influence. For example, a bog may be vegetated with grasses, sedges and reeds; may have no underground seepage; no inundation hazard or surface roughness but have 40% open water. The development difficulty would be Major because the percent open water exceeds 30%.

Degrees of Development Difficulty of Organic Soils

Major Soil Properties Influencing Uses	Degree of Development Difficulty		
	Minor	Moderate: Reclamation Warranted	Major: Reclamation Seldom Warranted
Vegetative cover	Light: grasses, sedges, reeds	Moderate: brush, small trees	Heavy: many large

			trees, heavy shrub
Excess water	No underground seepage and surface runoff from surrounding areas	Underground seepage and surface runoff from surrounding areas	--
Inundation hazard	None	Slight	Severe
Surface roughness	None	Hummocks and mounds (30-60 cm micro relief)	Holes and mounds (>60 cm micro relief)
% open water	<10%	10 – 30%	>30%
% coarse wood fragments	<1%	1 – 5%	>5%
Depth of deposit if underlain by: sand clay or marl	>160 cm >120 cm	120 -160 cm 80-120 cm	<120 cm <80 cm

Van de Hulst, J.W. <u>Soils of the Comfort Cove Area, Newfoundland.</u> Report No. 15. Soil and Land Management Division. Department of Forestry and Agriculture. St. John's. Newfoundland. 1992.

This rating system does not account for distance to sand, distance to electricity, roads, and water supply.

B

AGISOFT PROCESSING PARAMETERS

High

Figure 30: Digital Elevation Model - High Parameter Settings

Figure 29:Photo Alignment - High Parameter Settings

Figure 32: Dense Point Cloud - High Parameter Settings

Figure 31: Orthomosaic - High Parameter Settings

Medium

Figure 34: Photo Alignment – Medium Parameter Settings

Figure 33: Dense Point Cloud - Medium Parameter Settings

Figure 36: Digital Elevation Model - Medium Parameter Settings

Figure 35: Orthomosaic – Medium Parameter Settings

Low

Figure 38: Photo Alignment - Low
Parameter Settings

Figure 37: Dense Point Cloud - Low
Parameter Settings

Figure 40: Digital Elevation Model - Low
Parameter Settings

Figure 39: Orthomosaic - Low Parameter
Settings

C

HYDROLOGIC STUDY OF STEPHENVILLE

Figure 41: Flood Information Map: Stephenville Newfoundland

D

SITE LOCATIONS

Site 1

The desired operational area at site1 is depicted in Figure 41. The overall boundary of the property is also shown.

The area is non-restricted and uncontrolled airspace with no obstacles above ground. The flight areas will be away from hazards such as power lines and major transport arteries.
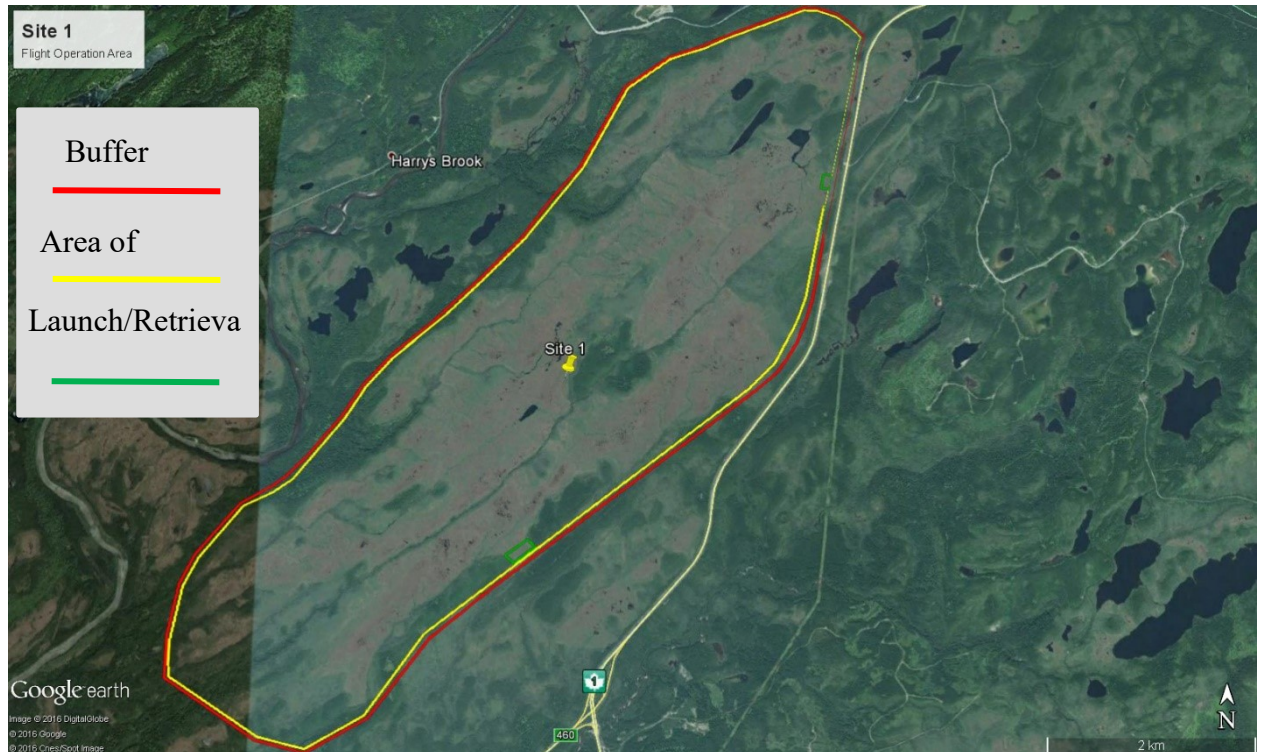
Coordinates: 48°38'18"N 58°14'17"W

Figure 42: Flight area for Site 1

Site 2

The desired operational area at site2 is depicted in Figure 42. The overall boundary of the property is also shown.

The area is non-restricted and uncontrolled airspace with no obstacles above ground. The flight areas will be away from hazards such as power lines and major transport arteries.
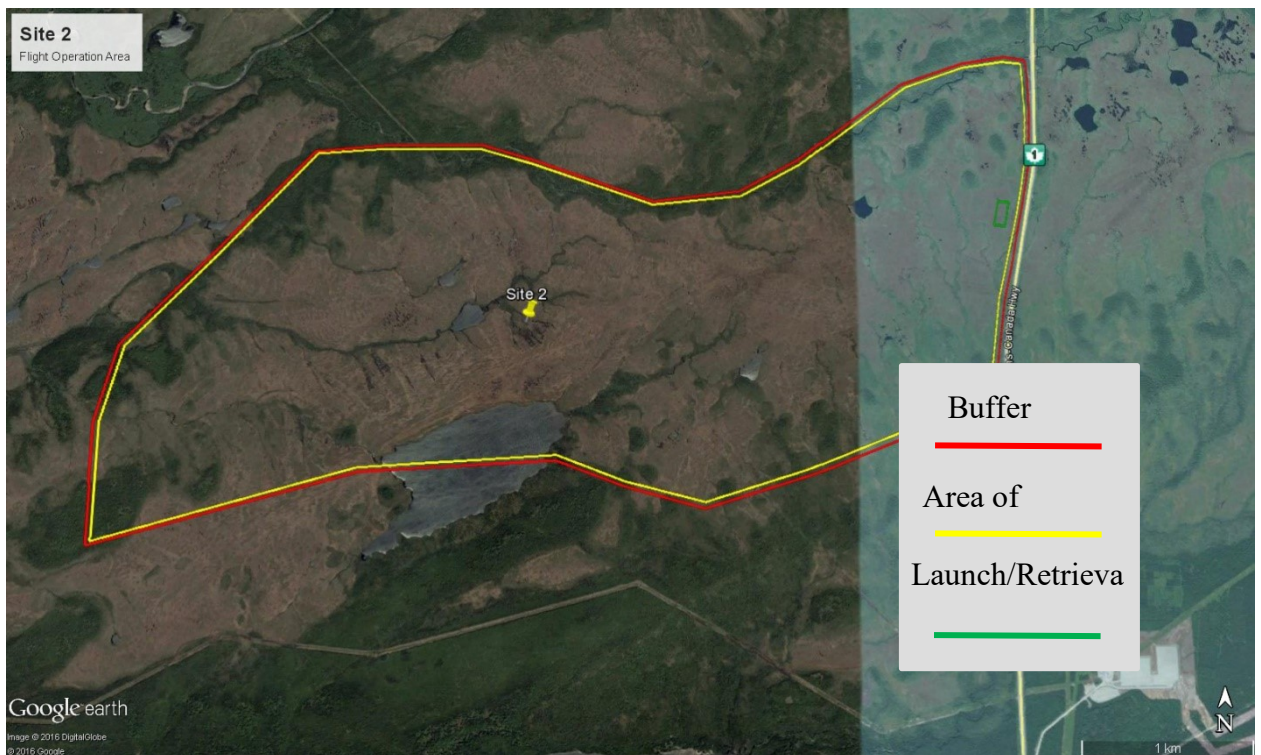
Coordinates: 48°32'57"N 58°18'26"W

Figure 43: Flight area for Site 2

Site 3

The desired operational area at site3 is depicted in Figure 43. The overall boundary of the property is also shown.

The area is non-restricted and uncontrolled airspace with no obstacles above ground. The flight areas will be away from hazards such as power lines and major transport arteries.

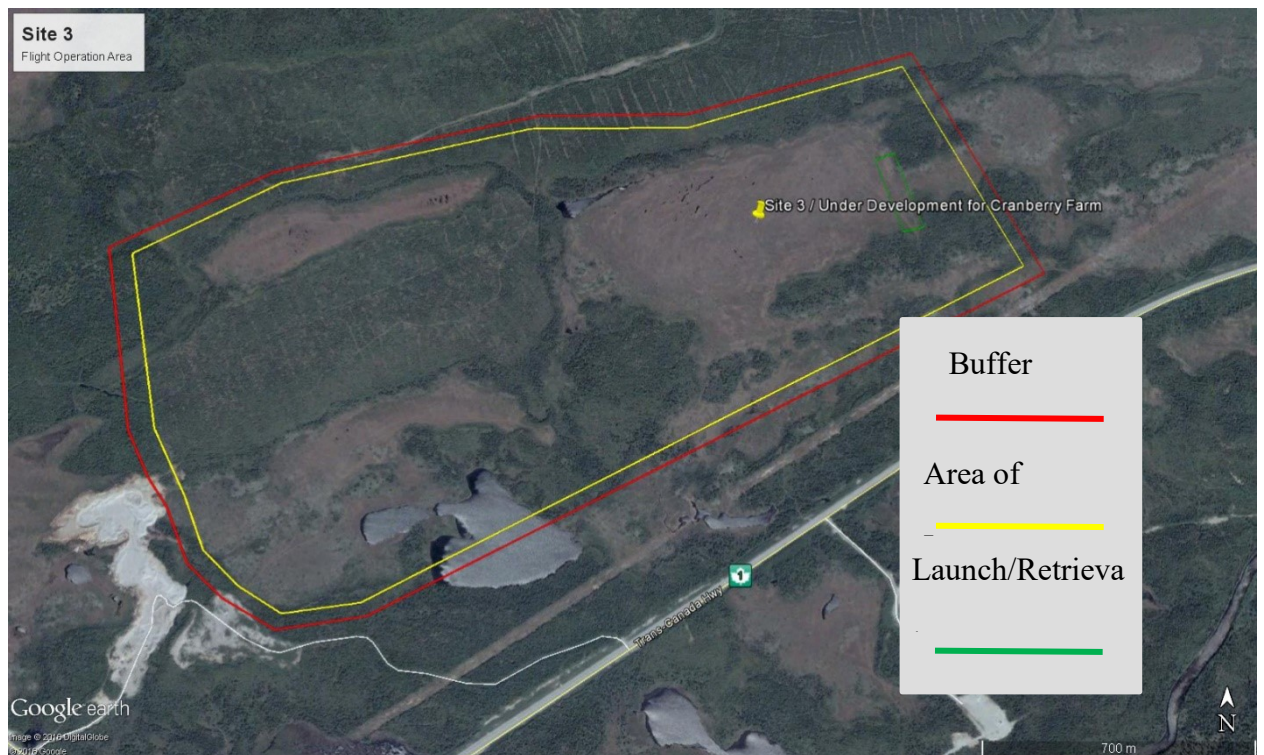Coordinates: 48°27'55"N 58°22'10"W

Figure 44: Flight area for Site 3

E

SITE 3-A FULL CLASSIFICATION FOR THE IMAGE ANALYSIS AND THE
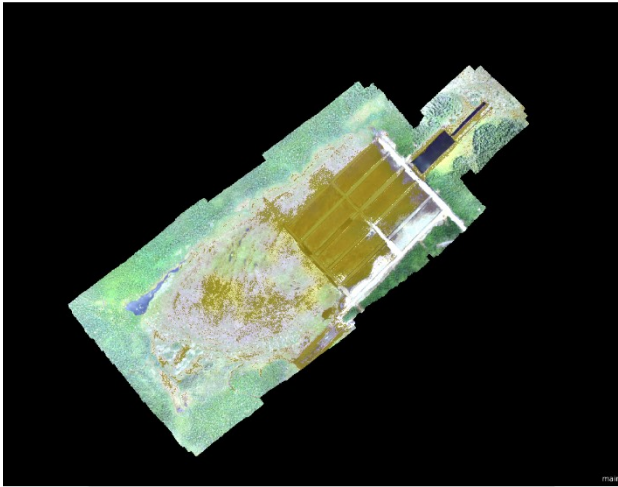
SURFACE ROUGHNESS

Image Analysis

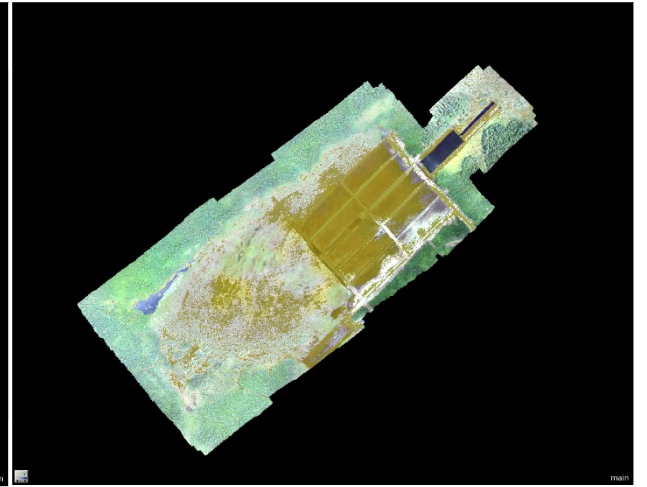Figure 44: Image Classification Step 1

Figure 45: Image Classification Step 2

Figure 46: Image Classification Step 3

Figure 47: Image Classification Step 4

Figure 48: Image Classification Step 5

Figure 49: Image Classification Step 6

Figure 50: Image Classification Step 7

Figure 51: Image Classification Step 8
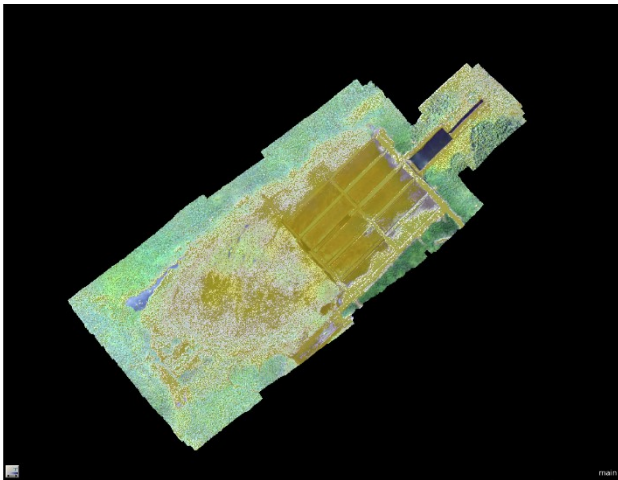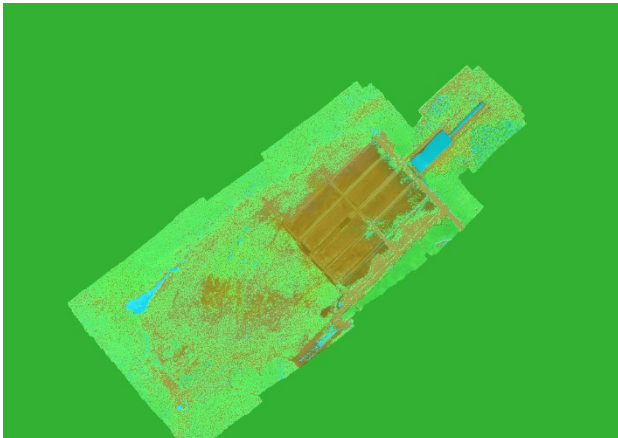

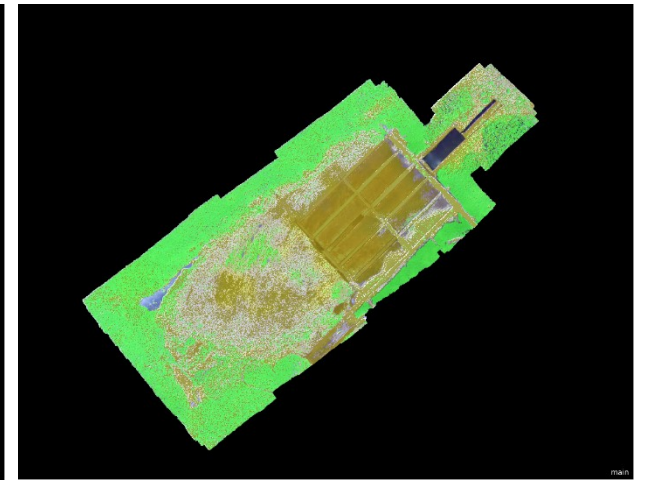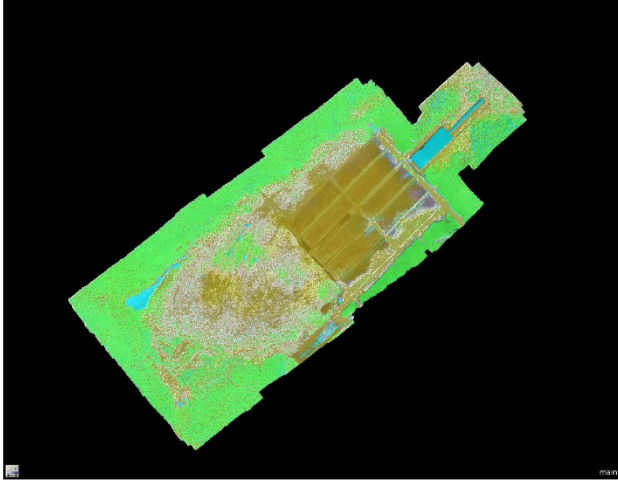Figure 52: Image Classification Step 9

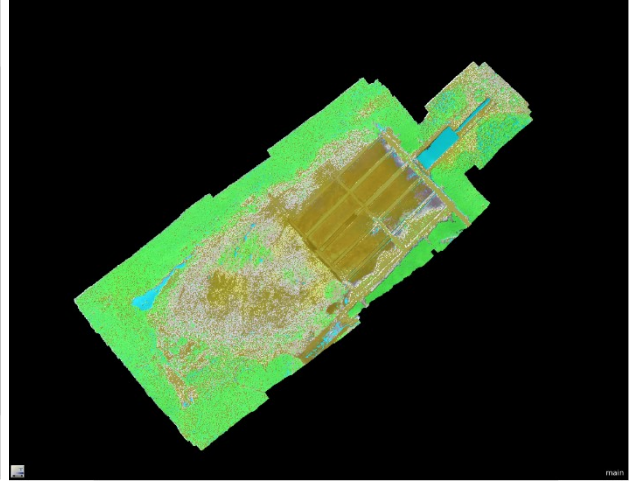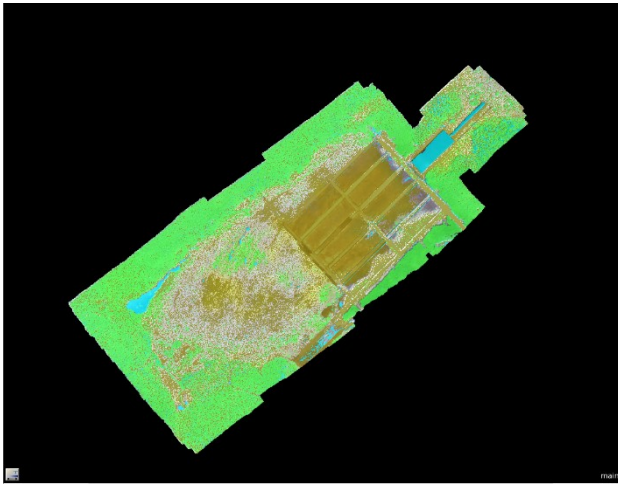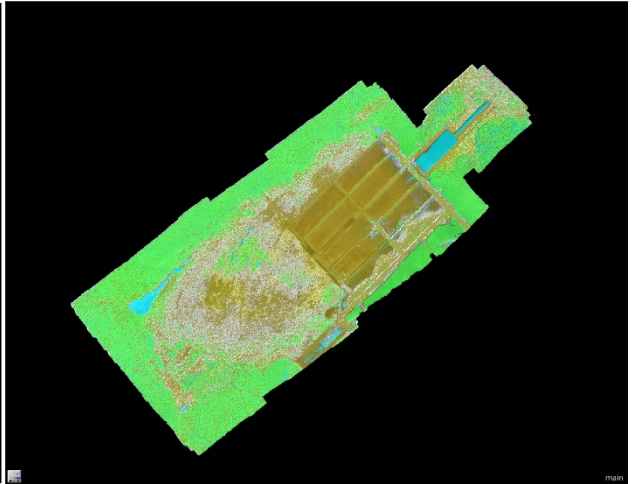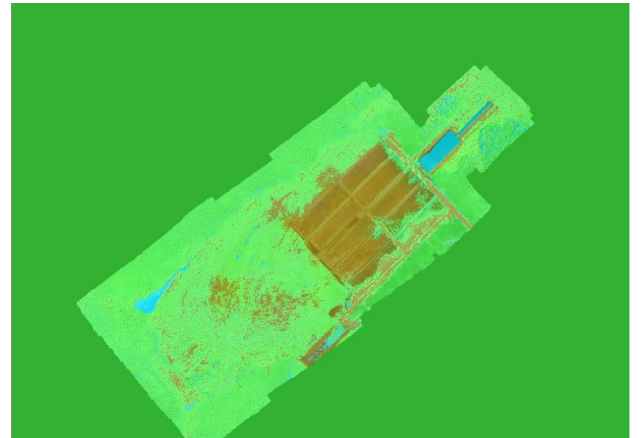Figure 53: Image Classification Step 10
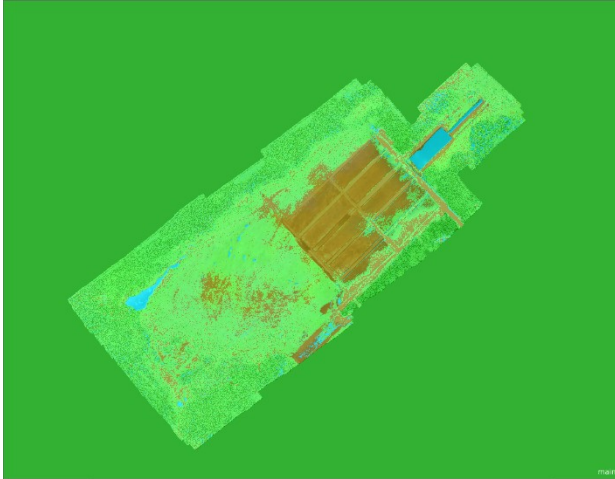
Figure 54: Image Classification Step 11
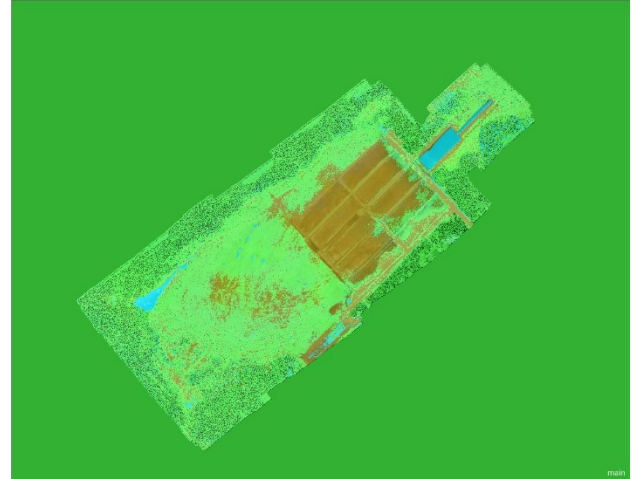
Figure 55: Image Classification Step 12
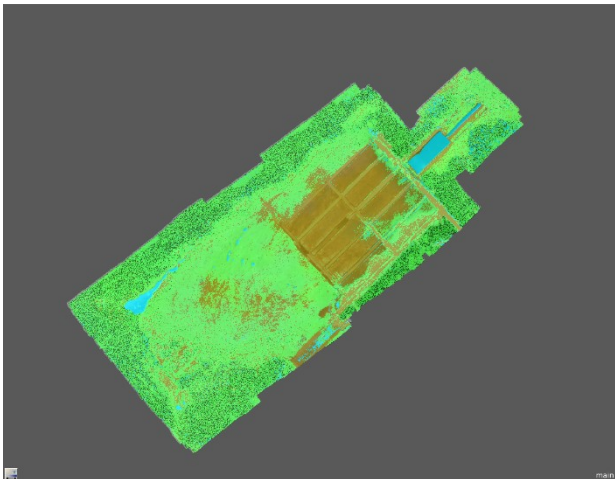
Figure 56: Image Classification Step 13

Surface Roughness
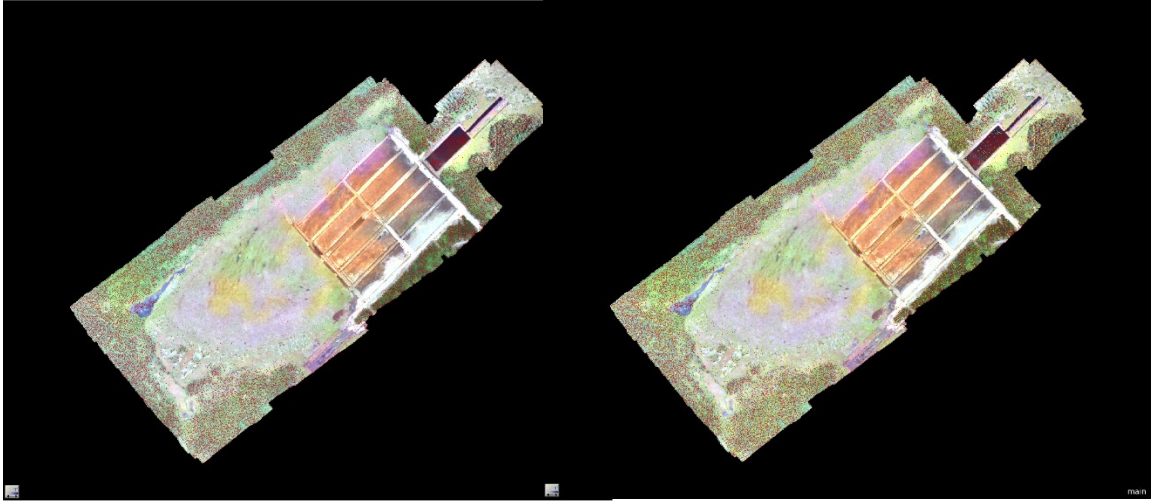
Figure 57: Surface Roughness Step 1

Figure 58: Surface Roughness Step 2
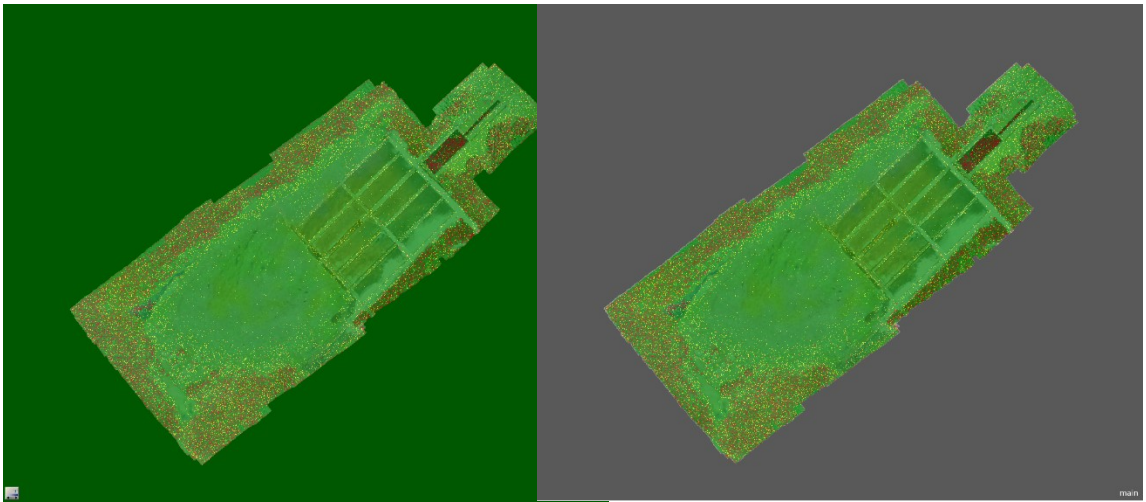
Figure 59: Surface Roughness Step 3

Figure 60: Surface Roughness Step 4

F

MOTOCALC SIMULATION RESULTS

MotoWizard Results - Skywalker X8

Desired Full-throttle Performance: Hotliner

Minimum Partial-throttle Flying Time: 30 minutes

Number of Motors: 1

Wing Span: 212.2 cm

Wing Area: 80 dm ²

Empty Weight: 3300 g

Airfoil: Thin Flat Bottomed

Elevation: 400 m

Sea-level Pressure: inHg

Air Temperature: °F

Drive System Type: Direct Drive Only

Propeller Size: Any Size

Motor Type: Brushless Only

Manufacturer: Any Manufacturer

Battery Type: Lithium Polymer (LiPo) Only

Maximum Number of Cells: 18 NiCd/NiMH or 6
LiPo

Motor	Battery	Gear	Prop	Rating
Aveox 1817/4Y	5x3200SH5PD		18x12	1.000
Mega RC 41/30/9	6x3200SH4PD		16x9	1.000
Mega RC 41/30/9	5x3200SH5PD		18x12	0.998
Hacker A60 5S V2	5x3200SH5PD		19x13	0.998
Dualsky XM6360DA-9	6x3200SH4PD		19x13	0.995

Dualsky XM6355DA-9.5	6x3200SH4PD	18x11	0.993
Mega RC 53/30/8	5x3200SH5PD	19x13	0.991
Hacker A60 6XS V2	5x3200SH5PD	17x10	0.990
Mega RC 53/30/11	6x3200SH4PD	19x15	0.987
Mega RC 53/30/8	6x3200SH4PD	17x10	0.984
Dualsky XM6355DA-11	6x3200SH4PD	19x14	0.982
Mega RC 41/30/9	4x3200SH5PD	19x14	0.982
Hacker A60 7XS V2	5x3200SH5PD	19x12	0.982
Hacker A50 16L V3	6x3200SH4PD	19x12	0.980
Hacker A50 14L V3	6x3200SH4PD	17x11	0.980
Hacker A60 20S	6x3200SH4PD	19x13	0.977
Hyperion HP-Z5025-20	6x3200SH4PD	19x14	0.974
Great Planes Rimfire 63-62-250 (#4795)	6x3200SH4PD	19x13	0.971
Hacker A50 14L	6x3200SH4PD	17x10	0.970
Hacker A50 12L Glider	5x3200SH5PD	18x11	0.969
Hacker A50 12L V3	5x3200SH5PD	18x11	0.969
Hyperion Zs4035-10	5x3200SH5PD	18x11	0.968

FSD FC6362-6T	4x3200SH6P D	19x13	0.965
FSD FC6362-8T	5x3200SH5P D	19x14	0.965
Hacker A50 16L	6x3200SH4P D	18x12	0.964
FSD FC6362-10T	6x3200SH4P D	19x14	0.962
Hacker A60 6XS V2	4x3200SH6P D	19x14	0.961
Scorpion S-4035-250	6x3200SH4P D	19x14	0.959
Scorpion SII-4035-250	6x3200SH4P D	19x14	0.959
Hyperion Zs4045-12	6x3200SH4P D	19x13	0.954

Generated by MotoCalc 8.09, 2016-12-08 11:21 AM.

G

DJI INSPIRE 1 V.2 SPECIFICATIONS

Model   T600

Weight 6.27 lbs (2845 g, including propellers and battery, without gimbal and camera)

6.74 lbs (3060 g, including propellers, battery and Zenmuse X3)

GPS Hovering Accuracy   Vertical: ±1.64 feet (0.5 m)

Horizontal: ±8.20 feet (2.5 m)

Max Angular Velocity   Pitch: 300°/s

Yaw: 150°/s

Max Tilt Angle   35°

Max Ascent Speed   16.4 ft/s (5 m/s)

Max Descent Speed   13.1 ft/s (4 m/s)

Max Speed   49 mph or 79 kph (ATTI mode, no wind)

Max Takeoff Sea Level   1.55 mi (2500 m)

2.8 mi (4500 m with specially-designed propeller)

Max Wind Speed Resistance 10 m/s

Max Flight Time   Approx. 18 min

Motor Model   DJI 3510H

Propeller Model   DJI 1345T

Indoor Hovering   Enabled by default

Operating Temperature   14° to 104° F (-10° to 40° C)

Diagonal Distance(propeller excluded)   22.8 inch (581 mm, Landing Mode)

Max Takeoff Weight   7.71 lbs(3500 g)

H

AGISOFT PROCESSING REPORTS

Site 3-A - Highest

Processing Report
23 August 2016

Survey Data

> 9
9
8
7
6
5
4
3
2
1

200 m
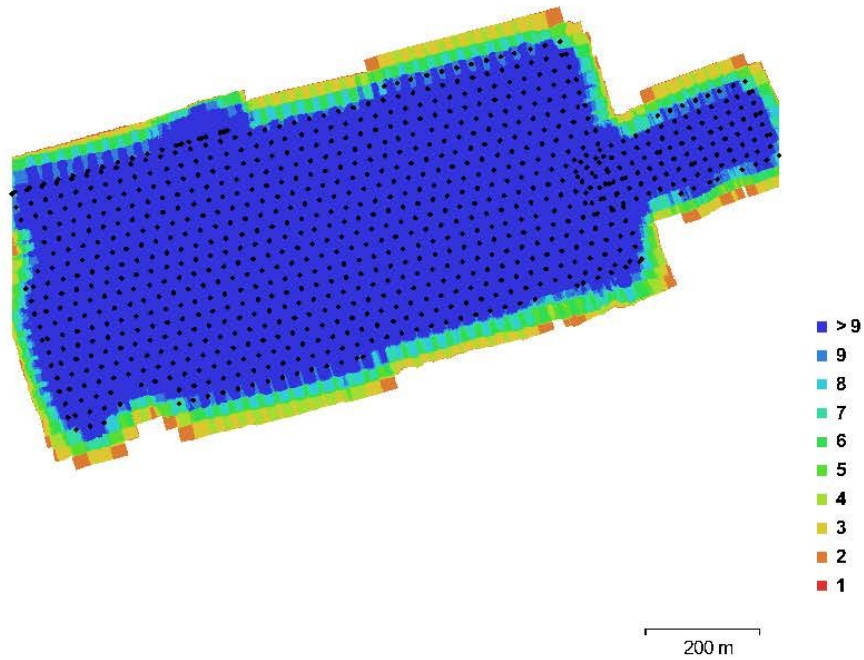
Fig. 1. Camera locations and image overlap.

Number of images:	902	Camera stations:	869
Flying altitude:	78.9 m	Tie points:	475,712
Ground resolution:	3 cm/pix	Projections:	2,901,146
Coverage area:	6.63e+05 sq m	Reprojection error:	0.344 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
FC350 (3.61 mm)	4000 x 3000	3.61 mm	1.56 x 1.56 um	No

Table 1. Cameras.

Camera Calibration
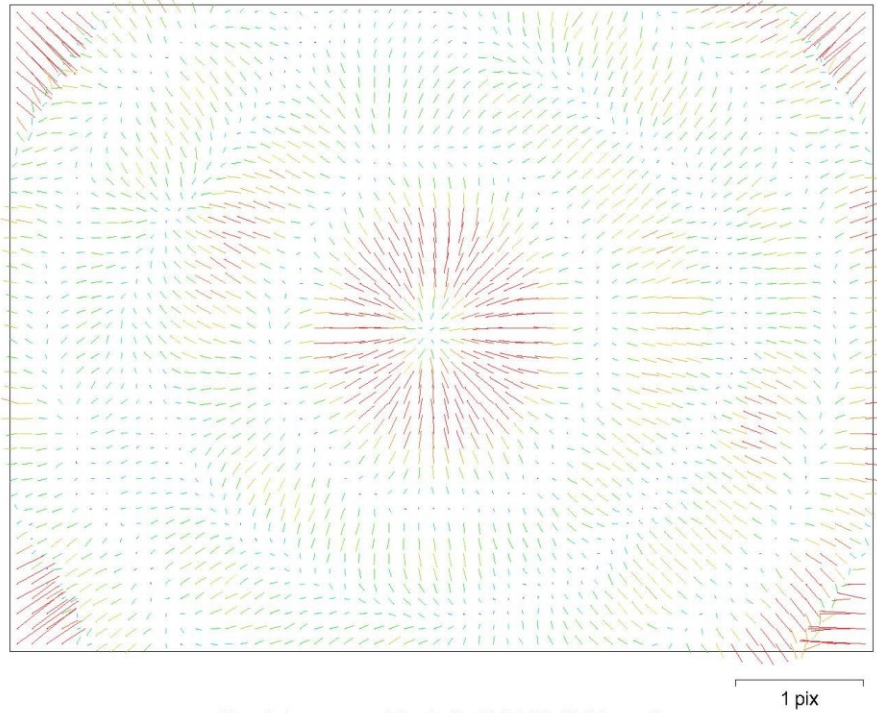
Fig. 2. Image residuals for FC350 (3.61 mm).

FC350 (3.61 mm)

902 images

Resolution	Focal Length	Pixel Size	Precalibrated
4000 x 3000	**3.61 mm**	**1.56 x 1.56 um**	**No**

Type:	Frame	Skew:	0
Fx:	2251.06	Cx:	2006.36
Fy:	2251.06	Cy:	1507.04
K1:	-0.12193	P1:	-0.000727001
K2:	0.0961321	P2:	0.000353466
K3:	-0.0128377	P3:	0
K4:	0	P4:	0

Camera Locations
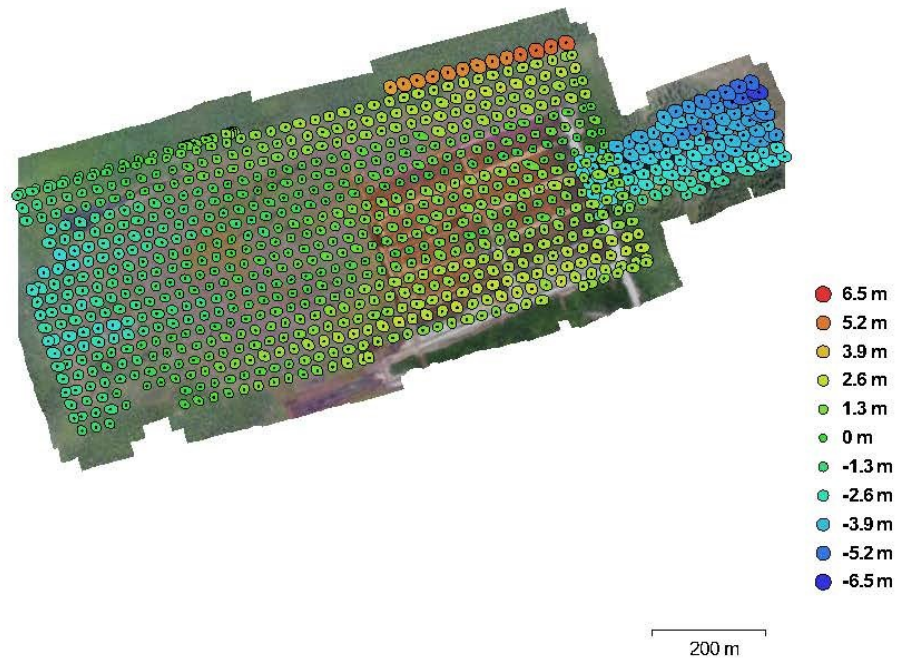
Fig. 3. Camera locations and error estimates.
Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.
Estimated camera locations are marked with a black dot.

X error (m)	Y error (m)	XY error (m)	Z error (m)	Total error (m)
2.1962	0.964234	2.39855	2.03363	3.14463

Table 2. Average camera location error.

Digital Elevation Model
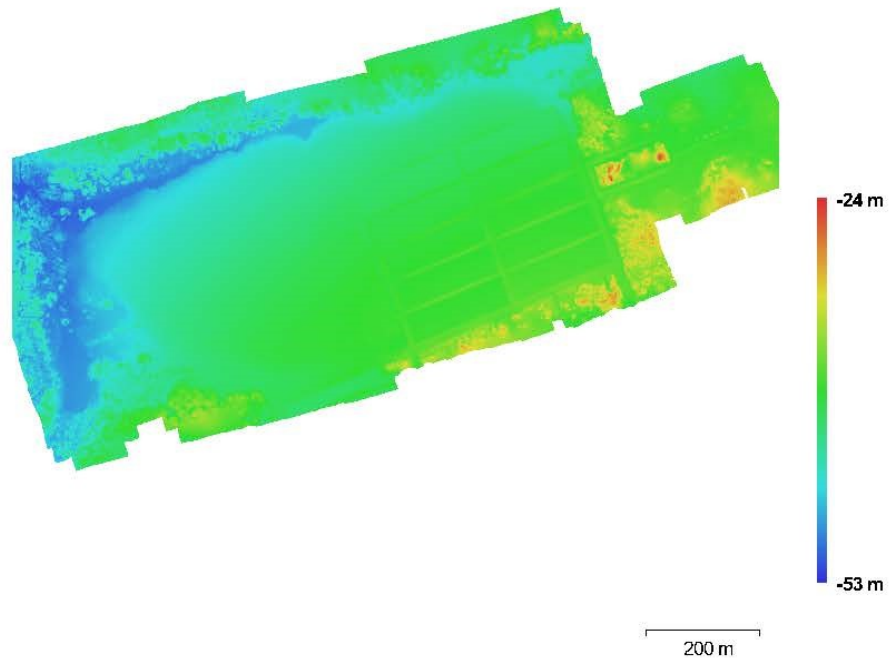
Fig. 4. Reconstructed digital elevation model.

| Resolution: | 3 cm/pix |
| Point density: | 1113.25 points per sq m |

Processing Parameters

General
    Cameras   902
    Aligned cameras   869
    Coordinate system   WGS 84 (EPSG::4326)
Point Cloud
    Points   475,712 of 542,673
    RMS reprojection error   0.184288 (0.34413 pix)
    Max reprojection error   0.554375 (13.648 pix)
    Mean key point size   1.91215 pix
    Effective overlap   6.5083
    Alignment parameters
        Accuracy   Highest
        Pair preselection   Reference
        Key point limit   40,000
        Tie point limit   4,000
        Constrain features by mask   No
        Matching time   1 hours 45 minutes
        Alignment time   12 minutes 1 seconds
Dense Point Cloud
    Points   871,372,260
    Reconstruction parameters
        Quality   Ultra High
        Depth filtering   Aggressive
        Processing time   1 days 12 hours
DEM
    Size   70,130 x 40,535
    Coordinate system   WGS 84 (EPSG::4326)
    Reconstruction parameters
        Source data   Dense cloud
        Interpolation   Enabled
Orthomosaic
    Size   48,130 x 27,120
    Coordinate system   WGS 84 (EPSG::4326)
    Channels   3, uint8
    Blending mode   Mosaic
    Reconstruction parameters
        Surface   DEM
        Enable color correction   No

Site 3-B - Highest

**Processing Report**
23 August 2016

Survey Data
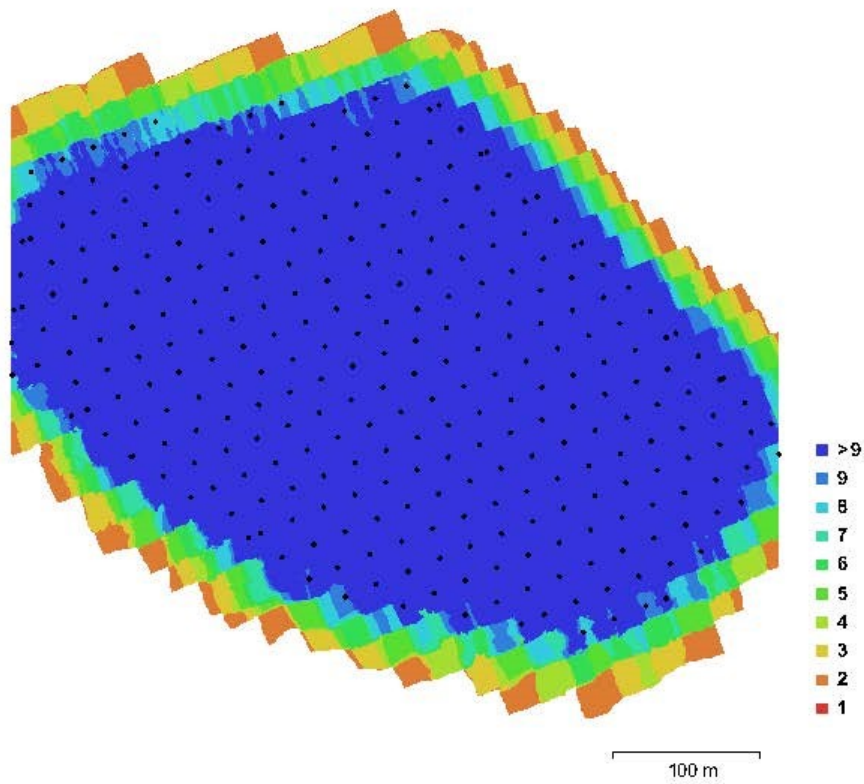
Fig. 1. Camera locations and image overlap.

Number of images:	305	Camera stations:	304
Flying altitude:	69.6 m	Tie points:	206,099
Ground resolution:	2.65 cm/pix	Projections:	921,015
Coverage area:	1.86e+05 sq m	Reprojection error:	0.359 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
FC350 (3.61 mm)	4000 x 3000	3.61 mm	1.56 x 1.56 um	No

Table 1. Cameras.

Camera Calibration
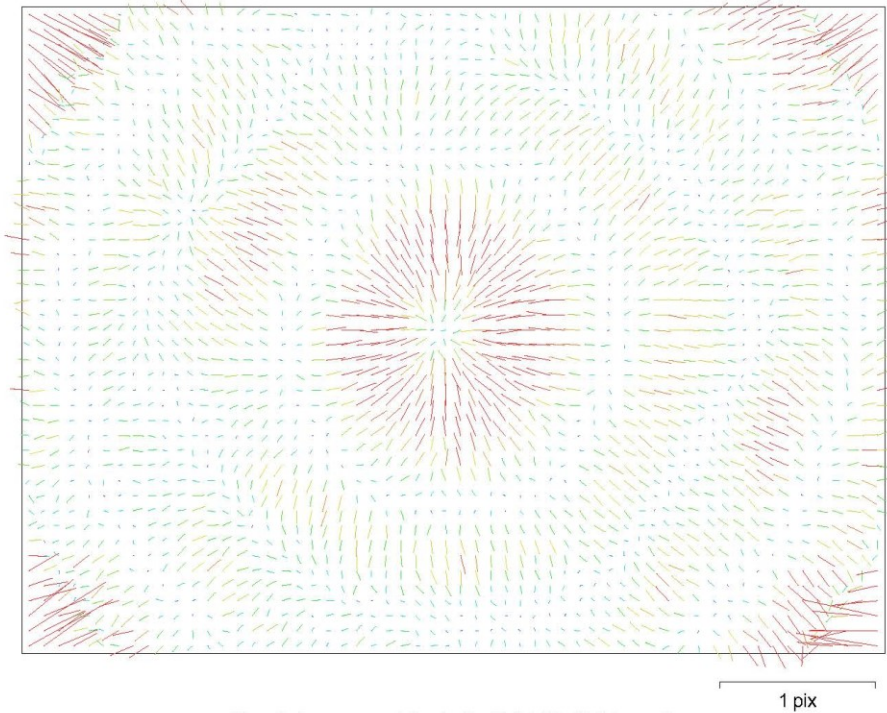
Fig. 2. Image residuals for FC350 (3.61 mm).

FC350 (3.61 mm)
305 images

Resolution	Focal Length	Pixel Size	Precalibrated
4000 x 3000	**3.61 mm**	**1.56 x 1.56 um**	**No**

Type:	Frame	Skew:	0
Fx:	2217.23	Cx:	2006.73
Fy:	2217.23	Cy:	1507.81
K1:	-0.116917	P1:	-0.000763384
K2:	0.0907503	P2:	0.000354588
K3:	-0.0116789	P3:	0
K4:	0	P4:	0

Camera Locations
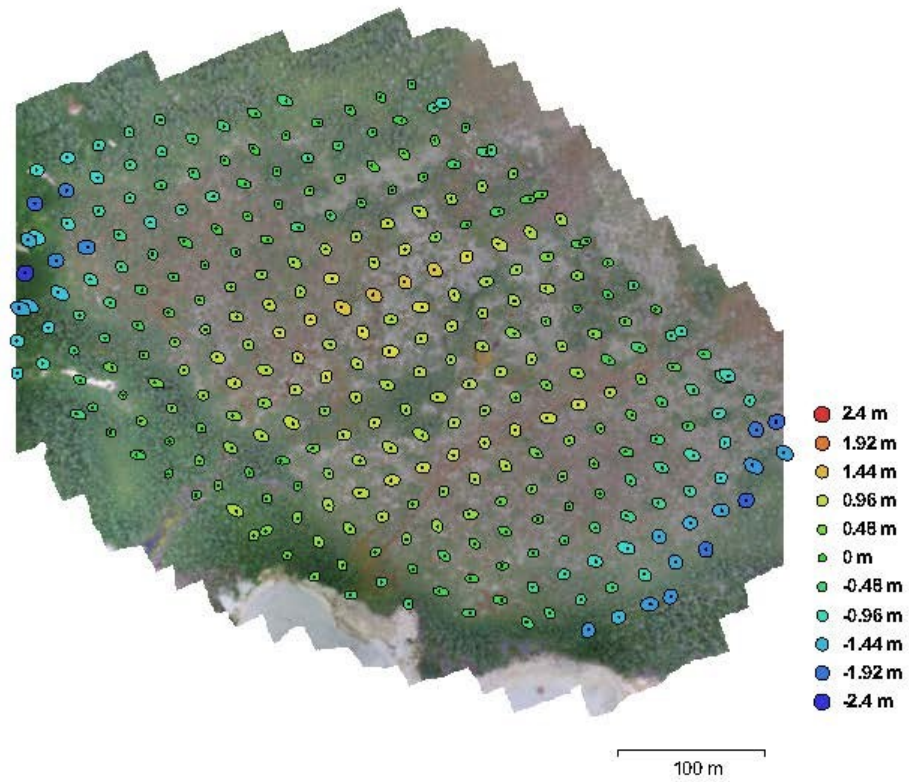
Fig. 3. Camera locations and error estimates.
Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.
Estimated camera locations are marked with a black dot.

X error (m)	Y error (m)	XY error (m)	Z error (m)	Total error (m)
1.12418	0.593675	1.27131	0.81039	1.50763

Table 2. Average camera location error.

Digital Elevation Model
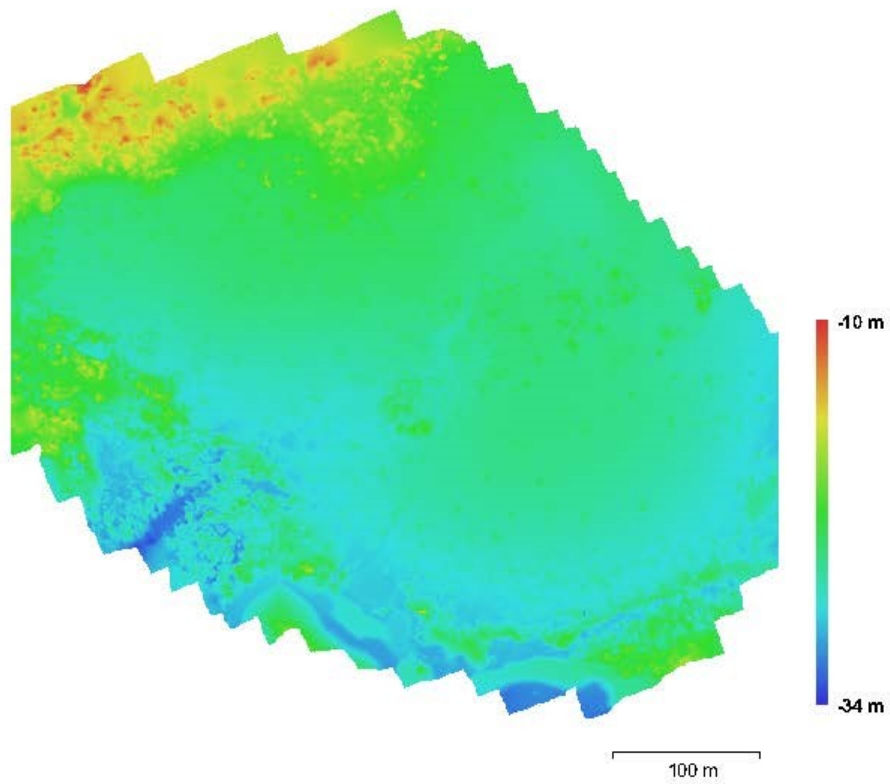
Fig. 4. Reconstructed digital elevation model.

Resolution:	2.65 cm/pix
Point density:	1426.44 points per sq m

Processing Parameters

**General**

Cameras	305
Aligned cameras	304
Coordinate system	WGS 84 (EPSG::4326)

Point Cloud

Points	206,099 of 219,369
RMS reprojection error	0.168517 (0.358793 pix)
Max reprojection error	0.506798 (16.2681 pix)
Mean key point size	2.14534 pix
Effective overlap	4.82654

Alignment parameters

Accuracy	Highest
Pair preselection	Reference
Key point limit	40,000
Tie point limit	4,000
Constrain features by mask	No
Matching time	30 minutes 35 seconds
Alignment time	2 minutes 28 seconds

Dense Point Cloud

Points	371,548,946

Reconstruction parameters

Quality	Ultra High
Depth filtering	Aggressive
Processing time	7 hours 11 minutes

DEM

Size	30,898 x 25,871
Coordinate system	WGS 84 (EPSG::4326)

Reconstruction parameters

Source data	Dense cloud
Interpolation	Enabled

Orthomosaic

Size	23,542 x 18,308
Coordinate system	WGS 84 (EPSG::4326)
Channels	3, uint8
Blending mode	Mosaic

Reconstruction parameters

Surface	DEM
Enable color correction	No

Site 2 - Highest

Processing Report
23 August 2016
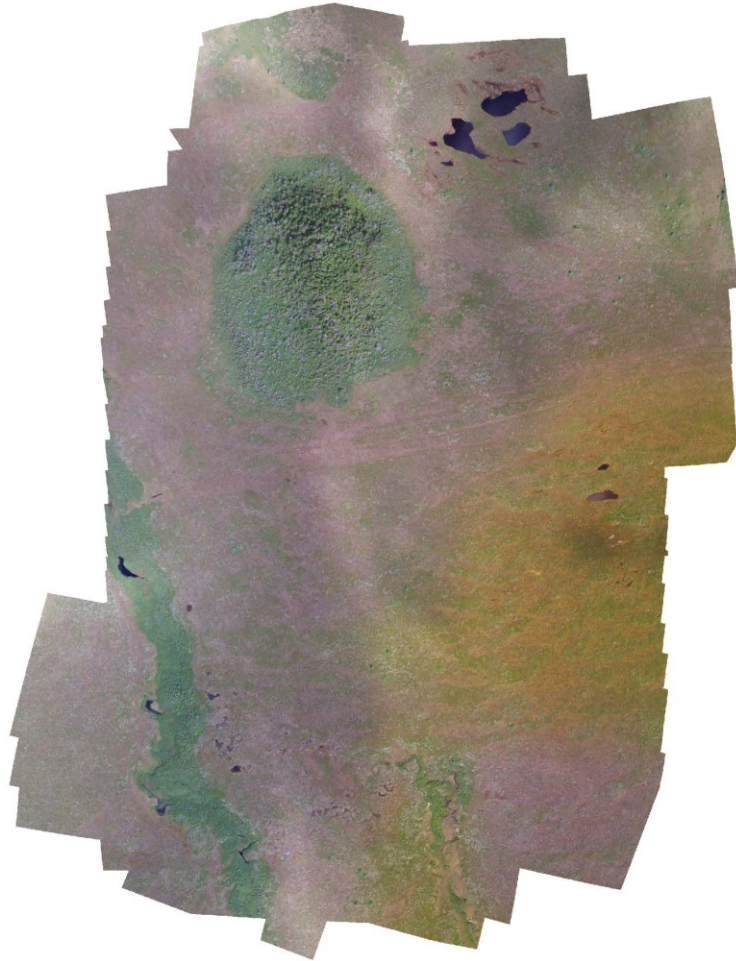
Survey Data
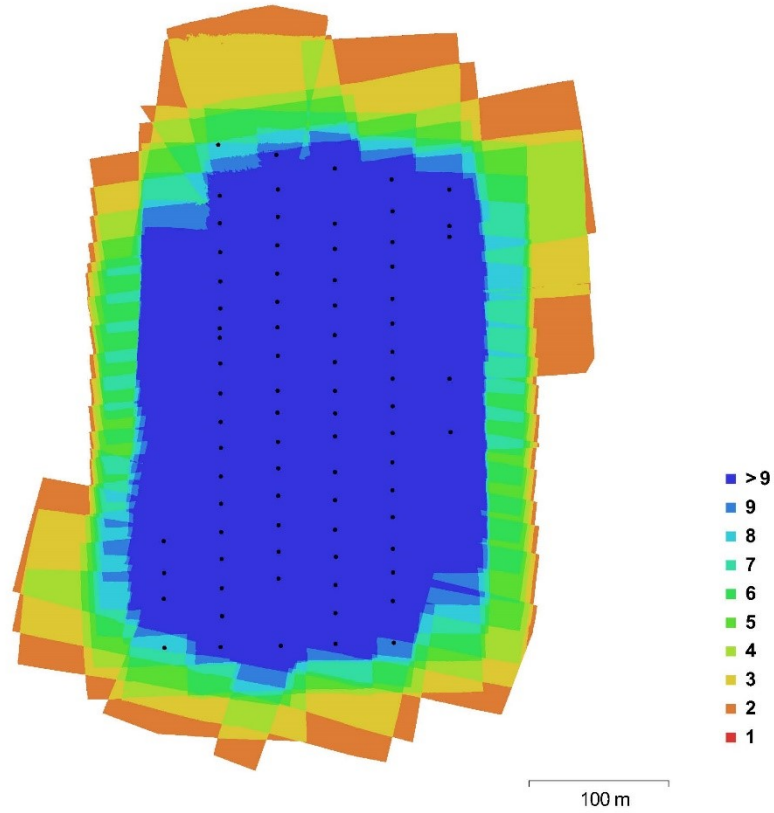
Fig. 1. Camera locations and image overlap.

Number of images:	81	Camera stations:	81
Flying altitude:	128 m	Tie points:	39,150
Ground resolution:	4.76 cm/pix	Projections:	229,169
Coverage area:	0.169 km²	Reprojection error:	0.361 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
FC350 (3.61 mm)	4000 x 2250	3.61 mm	1.7 x 1.7 µm	No

Table 1. Cameras.

Camera Calibration
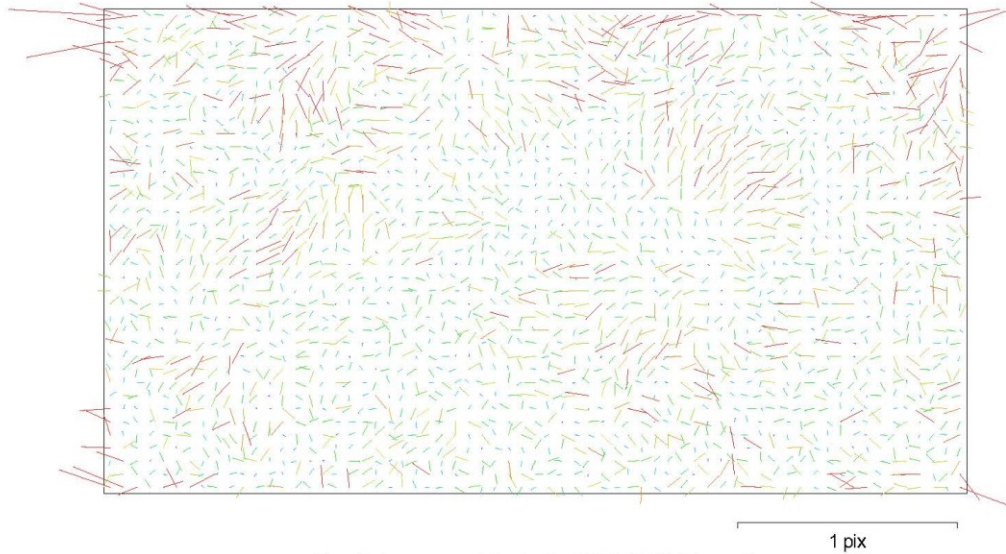
Fig. 2. Image residuals for FC350 (3.61 mm).

FC350 (3.61 mm)

81 images

Resolution	Focal Length	Pixel Size	Precalibrated
4000 x 2250	**3.61 mm**	**1.7 x 1.7 μm**	**No**

Type:	Frame	F:	2388.81
Cx:	7.0561	B1:	-1.64097
Cy:	9.09134	B2:	1.03927
K1:	-0.146054	P1:	0.000374989
K2:	0.1593	P2:	-0.000804213
K3:	-0.0753129	P3:	0
K4:	0.0287729	P4:	0

Camera Locations

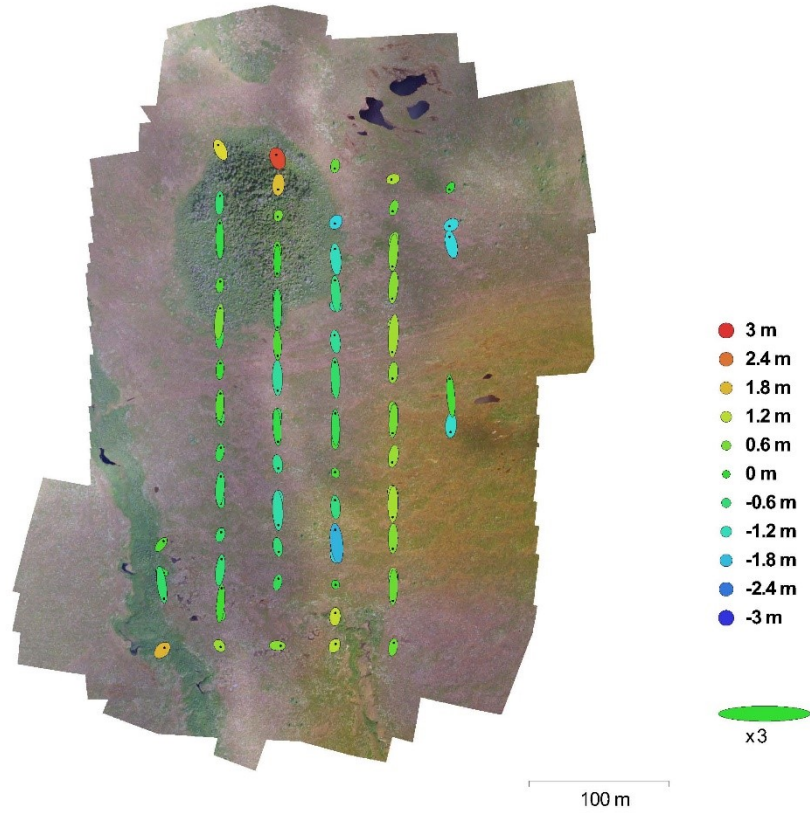Fig. 3. Camera locations and error estimates.
Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.
Estimated camera locations are marked with a black dot.

X error (m)	Y error (m)	Z error (m)	XY error (m)	Total error (m)
0.491687	4.0324	0.862593	4.06227	4.15284

Table 2. Average camera location error.

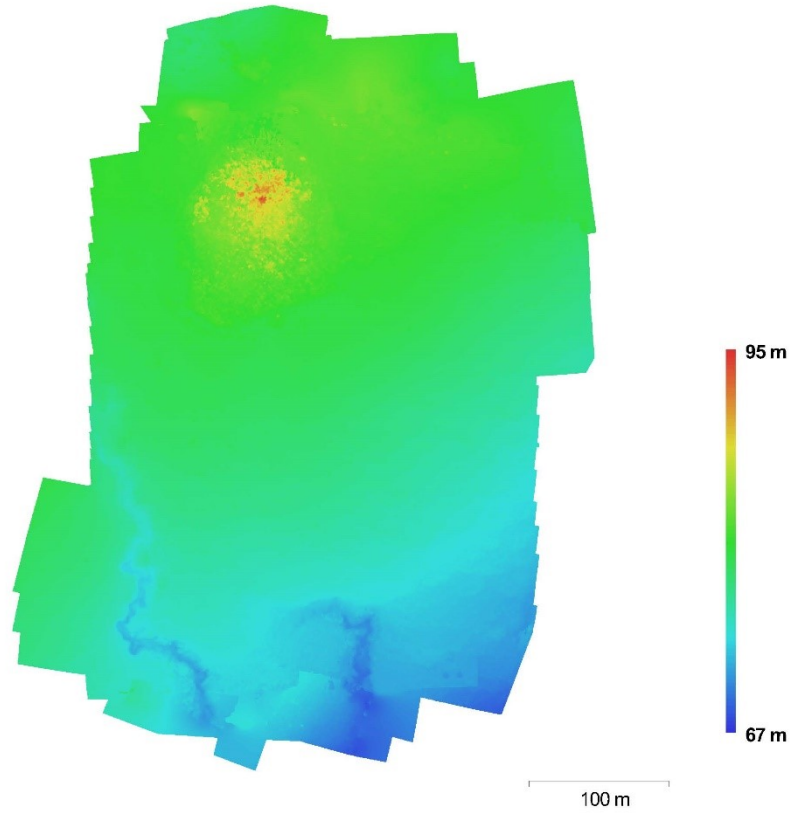# Digital Elevation Model

Fig. 4. Reconstructed digital elevation model.

Resolution: 4.76 cm/pix

Point density: 442 points/m²

Processing Parameters

General
Cameras   81
Aligned cameras   81
Coordinate system   WGS 84 (EPSG::4326)
Point Cloud
Points   39,150 of 53,698
RMS reprojection error   0.227191 (0.360707 pix)
Max reprojection error   0.693565 (8.62433 pix)
Mean key point size   1.58954 pix
Effective overlap   6.43363
  Alignment parameters
  Accuracy   Highest
  Pair preselection   Reference
  Key point limit   40,000
  Tie point limit   4,000
  Constrain features by mask   No
  Adaptive camera model fitting Yes
  Matching time   9 minutes 13 seconds
  Alignment time   49 seconds
Dense Point Cloud
Points   82,090,726
  Reconstruction parameters
  Quality   Ultra High
  Depth filtering   Aggressive
  Depth maps generation time   12 hours 12 minutes
  Dense cloud generation time   1 hours 2 minutes
DEM
Size   12,781 x 14,044
Coordinate system   WGS 84 (EPSG::4326)
  Reconstruction parameters
  Source data   Dense cloud
  Interpolation   Enabled
  Processing time   1 minutes 24 seconds
Orthomosaic
Size   8,796 x 11,547
Coordinate system   WGS 84 (EPSG::4326)
Channels   3, uint8
Blending mode   Mosaic
  Reconstruction parameters
  Surface   DEM
  Enable color correction   No
  Processing time   1 minutes 23 seconds
Software
Version   1.2.6 build 2834
Platform   Windows 64 bit