
RITARS-12-H-UVM

RAPID EXPLOITATION OF COMMERCIAL REMOTELY SENSED
IMAGERY FOR DISASTER RESPONSE & RECOVERY

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TABLE OF CONTENTS

Table of Contents	0
Glossary	2
Disclaimer	4
Introduction.....	4
Technical Summary	5
Task 1 - Creation of a Technical Advisory Committee	5
Task 2 - Creation of a project website	6
Task 3 - Damage detection system methods development	6
Task 4 - Fill calculation system methods development.....	12
Task 5 - Development of web portal decision support tool	38
Task 6 - Project outreach and communication	41
Conclusion	42
List of Advisory Committee Meetings	42
List of Meetings with the USDOT Project Management Team	43
Presentations.....	43
Publications	44
Partnerships.....	44

GLOSSARY

3D	Three Dimensional
AASHTO	American Association of State Highway Transportation Officials
CAD	Computer-Aided Design
CNL	Cognition Network Language
COA	Certificate of Authorization
CRS	Commercial Remote Sensing
DOT	Department of Transportation
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
GIS	Geographic Information Systems
HDDS	Hazard Data Distribution System
ICS	Incident Command System
LiDAR	Light Detection and Ranging
NAIP	National Agricultural Imagery Program
NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
OBIA	Object-Based Image Analysis
OGC	Open Geospatial Consortium
PI	Principal Investigator
PM	Program Manager
RiP	Research in Progress database
RITA	Research and Innovative Technology Administration
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SAL	Spatial Analysis Laboratory (University of Vermont)
SI	Spatial Information
TAC	Technical Advisory Committee
TRC	Transportation Research Center
UAS	Unmanned Aircraft Systems
USDOT	United States Department of Transportation
USGS	United States Geological Survey
UVM	University of Vermont

VAOT	Vermont Agency of Transportation (also known as VTrans)
VTrans	Vermont Agency of Transportation (also known as VAOT)
XML	eXtensible Markup Language

EXECUTIVE SUMMARY

Natural disasters can severely impact transportation networks. In the hours and days following a major flooding event, knowing the location and extent of the damage is crucial for incident managers for a number of reasons: it allows for emergency vehicle access to affected areas; it facilitates the efficient rerouting of traffic; it raises the quality and reduces the cost of repairs; and it allows repairs to be completed faster, in turn reducing the duration of costly detours. Commercial Remote Sensing (CRS) imagery is increasingly being used in disaster response and recovery, but the ability to acquire CRS data far surpasses the ability to extract actionable information from it. An automated approach to damage assessment is needed, but traditional automated image analysis techniques are inadequate for identifying or characterizing transportation infrastructure damage from high-resolution CRS imagery. Furthermore, new CRS technologies, such as Unmanned Aircraft Systems (UAS) provide a novel approach to gathering imagery during a crisis in which traditional satellite and aerial systems are either cost prohibitive, ineffective, or unresponsive. We propose a project with two objectives: 1) to develop, calibrate and deploy a decision support system capable of identifying road and bridge damage from high-resolution commercial satellite images and; b) to estimate the amount and type of fill material required for repairs using digital surface models derived from lightweight Unmanned Aerial Vehicles (UAS) programmed to fly over damage road segments. This approach would employ state-of-the-art, object-based image analysis techniques, cost-based image matching, and other advanced computing techniques. We also propose to collaborate with state departments of transportation to develop a web-based interface to share information derived from CRS Imagery.

DISCLAIMER

The views, opinions, findings and conclusions reflected in this presentation are the responsibility of the authors only and do not represent the official policy or position of the USDOT/OST-R, or any State or other entity.

INTRODUCTION

The University of Vermont Unmanned Aircraft Systems (UAS) team is made up of personnel from the Transportation Research Center and the Spatial Analysis Lab. Both of these research organizations are based at the University of Vermont. The Transportation Research Team brings its extensive knowledge of transportation systems and its ability to manage complex transportation research projects. The Spatial Analysis Lab is a leading research organization with a focus on remote sensing and geospatial information systems.

The RITARS-12-H-UVM project was born out the Spatial Analysis Lab as they struggled to acquire up to date and accurate imagery following the devastating impact of Tropical Storm Irene in the State of Vermont. A large portion of the state was severely impacted by the storm and many communities were completely cut off due to severe damage to the transportation infrastructure.

Aerial imagery is critical in assessing the extent of damage and assisting leaders in being able to make informed tactical decisions during disasters and emergencies. During a disaster there are many commercial and public sector assets that are made available, however, satellite systems are limited by weather, atmospheric conditions, and their orbit. Aircraft based imagery systems are expensive, limited by weather, and require a substantial amount of support infrastructure to map an area. The Vermont UAS team identified a gap in these assets that they believed could be filled through the use of small, lightweight, unmanned aircraft systems. These systems allow for highly accurate and low cost flights that require little to no infrastructure.

This project will explore the capabilities of UAS and the benefits of using UAS in a disaster with a focus on providing rapidly collected and actionable aerial imagery. The team has selected the Sensefly eBee UAS based on its safety features and its robust flight management and planning software. The team will work with the Vermont Agency of Transportation to coordinate flights and will work with local, state, and federal agencies for missions and project flights.

TECHNICAL SUMMARY

TASK 1 - CREATION OF A TECHNICAL ADVISORY COMMITTEE

The project team created a Technical Advisory Committee (TAC) that consisted of individuals who are partners with the Spatial Analysis Lab or the Transportation Research Center or have a vested interest in the project and unmanned aircraft systems.

The Advisory Committee was initially comprised of the following individuals:

- Guy Rouelle, Aviation Program Administrator, Vermont Agency of Transportation (VTrans)
- Stephanie Magnan, Asset Management Specialist, VTrans
- Wayne Gammell, Maintenance Administrator, VTrans
- Johnathan Croft, GIS Database Administrator, VTrans
- Zach Borst, Vermont Emergency Management (VEM) Regional Outreach Coordinator (Dec 2012-Nov 2013)
- Michele Boomhower, Chittenden County Regional Planning Commission (CCRPC) Assistant/Metropolitan Planning Organization (MPO) Director
- Christopher Jolly, Planning & Programming Engineer, Federal Highway Association (FHWA) - Vermont Division
- Roger Thompson, ITS/Safety Engineer, FHWA - Vermont Division
- Charles Hebson, Manager of Surface Water Resources, Maine Department of Transportation (DOT)
- Amanda Hanaway, Burlington International Airport Engineer (March 2015-May 2015)

The TAC met as a group and individually throughout the life of the project and provided input to all tasks and all stages. Key TAC Members became more involved in the project and assisted in

the development of further funding opportunities throughout the project. The original TAC members also assisted in creating connections with other State Agencies such as VT Agency of Natural Resources, VT DEMHS, the Vermont National Guard, and local Construction and Engineering firms. Many TAC members continued on as members for OASRTRS-14-H-UVM.

TASK 2 - CREATION OF A PROJECT WEBSITE

The project team identified a website as the easiest solution for providing data and outreach materials to our constituents and to the technical advisory committee. The website was designed primarily to serve as a repository for agreement documents, deliverables, and products including the following:

- Project Demographics (Team, TAC Members, TAC Minutes, Quarterly Reports and other project documents)
- Project Deliverables (News, Updates, Webinars, and White papers)

The project team created and maintained a project website for 30 months, the project website will be maintained and kept active as long as is possible though updates will cease 90 days past the end date of this agreement. Reports and documents will be maintained beyond the end of the agreement and it was determined that a more robust website and web services will be required for sustainment of the UAS project and for outreach purposes. A single location for information regarding the project and its materials is going to be highly desirable rather than a website for each individual project. Future operations of the UAS team will be more diversely funded and the information from this current project and future projects will be valuable as the use of UAS evolve and this project team expands its capabilities.

A password protected section exists and will remain the repository for our SOP, Flight Checklist, and application to the UVM UAS Working Group for flight operations on this project when finalized. These items will be maintained on any future websites as well.

The website can be visited here:

<http://www.uvm.edu/trc/rapid-exploitation-of-commercial-remotely-sensed-imagery-for-disaster-response-recovery/>

TASK 3 - DAMAGE DETECTION SYSTEM METHODS DEVELOPMENT

A video demonstrating the damage detection system can be viewed at:

<https://youtu.be/G3cEp-x4c1s>

Up to date imagery following a disaster is critical in ensuring an efficient and effective response. A consortium of commercial and public satellite systems called the International Charter is activated during a disaster and these datasets are made available to response teams through the USGS Hazard Data Distribution System (HDDS). Modern satellite systems can provide high resolution imagery over large areas in a timely manner. A key challenge that often arises during

response operations is that the locations of actual damage to transportation networks is unknown. It can be extremely daunting to search through the massive amount of imagery to identify a small section of damaged transportation infrastructure. The project team understood the limits of these systems as a result of their response to Tropical Storm Irene in the state of Vermont. Despite a huge amount of overhead imagery, it was nearly impossible to identify specific locations that would be of value to incident commanders. As part of this project the team set out to create a toolset that could automatically detect damaged roadways and help to identify areas for further investigation or to be further captured using another platform such as UAS.

The project team developed rule-based expert system to automate the detection of damage to roads stemming from a natural disaster, such as flooding and debris. The rule-based expert system was tested and validated across numerous satellite images that offered a variety of atmospheric and lighting conditions. To make the system more accessible, a user interface was developed that enabled a user with limited remote sensing expertise to adjust a limited number of parameters. This interface enables the system to work with varied data streams.

To develop and test the system, commercial satellite imagery was obtained from DigitalGlobe for three areas affected by natural disasters in Colorado, New York, and Vermont. This imagery is representative of what would be collected during a disaster. DigitalGlobe is the most frequent high-resolution imagery contributor to the International Charter.

An extensive knowledge base, including documentation and tutorials is posted to the website and kept available as a resource indefinitely for those agencies to call upon as needed during major disasters and other emergency events. A manual for the damage detection system was written and a tutorial video was developed.

The system was developed using the eCognition software platform, with the interface built on top of eCognition Architect. Two applications were designed for use with areas affected by: 1) river and stream flooding that washes out or covers roads, partially or fully disrupting a transportation network; and 2) coastal flooding that deposits sand and other debris on roads but then recedes. The application for the former was based on major flooding events in Vermont during August 2011 and in Colorado during September 2013. The latter was based on Hurricane Sandy damage in New York City, November 2012.

The first step is to collect the needed commercial remote-sensing multispectral imagery. A minimum of 4 spectral bands is necessary: the visible bands (Red, Green, and Blue) and a Near Infrared band. Note that some imagery datasets may need to be processed to improve their utility. For example, WorldView-2 imagery may be available as separate multispectral and panchromatic datasets acquired simultaneously at different spatial resolutions (e.g., multispectral with 2-meter resolution and panchromatic with 0.5-meter resolution). To lend the multispectral imagery more detail, it can be pan-sharpened in image-processing software by fusing it with the accompanying panchromatic dataset, creating a multispectral image that has the panchromatic dataset's higher resolution. This step can be performed in many GIS and image-processing software packages, including ArcGIS and ERDAS IMAGINE.

Two thematic GIS datasets are required to run the application, the study area boundary and road centerlines. The Study area boundary (also known as “area of interest,” or AOI). A GIS layer delineating the study area can be used to limit processing to only those areas affected by flooding or other storm-related damage. This layer is also useful for clipping other GIS datasets need by the analysis (see below). If the new polygon layer is not already in ESRI shapefile format, export it to this data type. The boundary layer must be in the same map projection as the multispectral imagery. A road centerlines layer that covers most, if not all, of the roads in the study area should be used. Road centerlines are available for most U.S. states and can often be downloaded from state GIS data clearinghouses. As with the study boundary layer, make that the map projection is the same as that for the multispectral imagery.

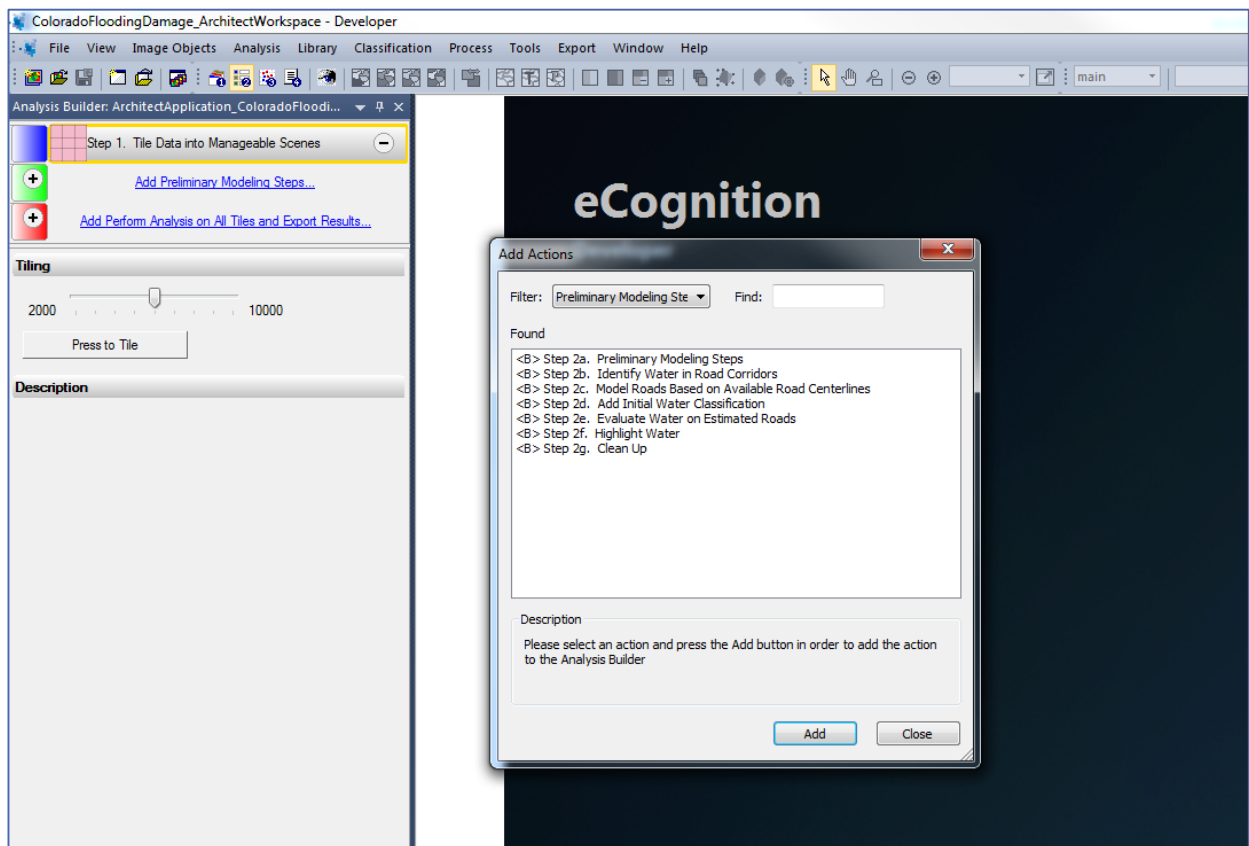


Figure 1. Establishing connection between Analysis Builder window and underlying rule set in eCognition Architect. Each button in an Architect application must be added to the Analysis Builder window using the Add Actions button.

The first modeling step is to divide the original scene into tiles that are appropriate for analysis; some experimentation may be necessary. The first step, *Step 1 Tile Data into Manageable Scenes*, reveals tiling options in a window below the application actions. The tile size can be adjusted with the slider bar (Figure 2).

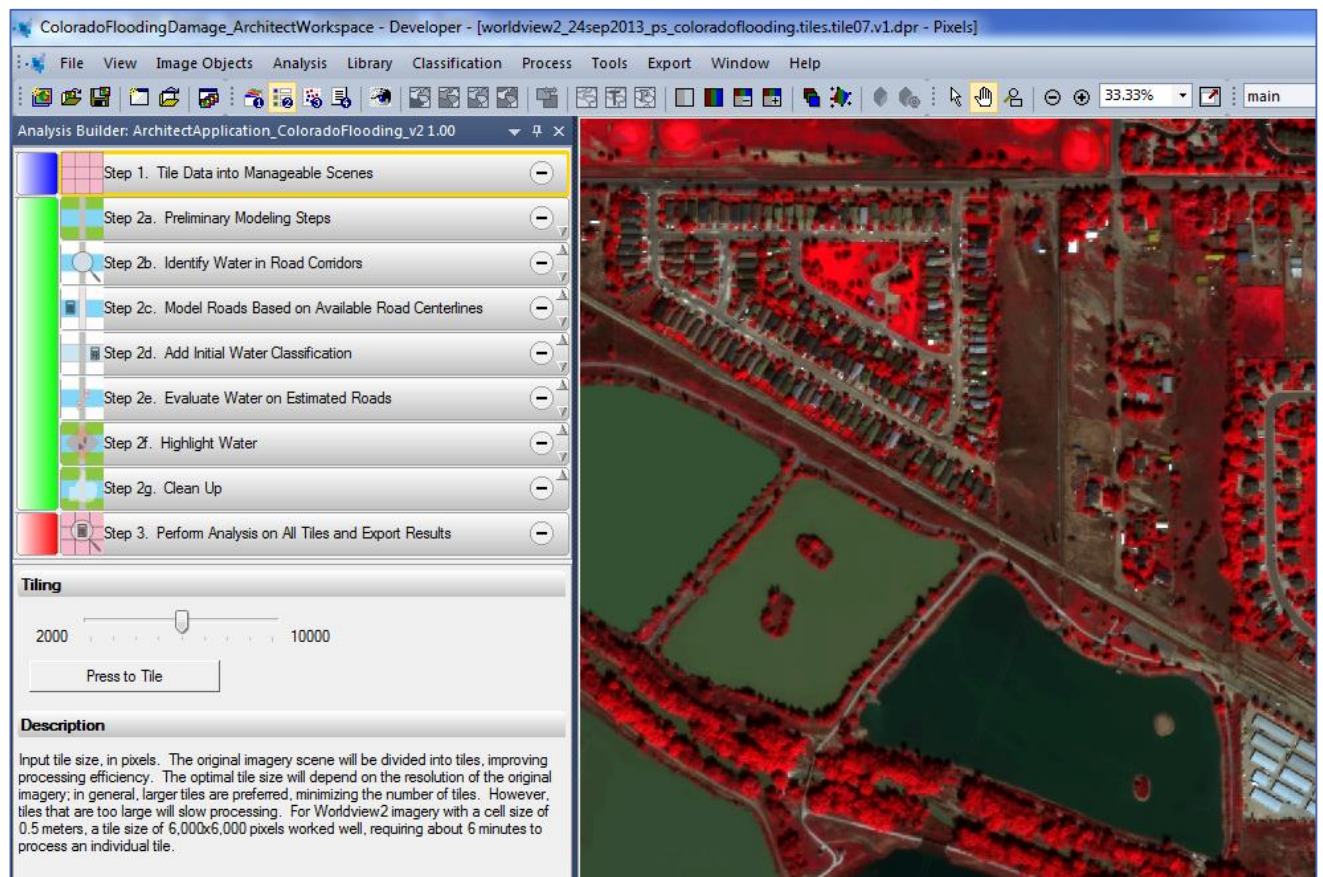


Figure 2. Step 1 in the Architect application divides the source multispectral imagery into tiles to facilitate efficient processing; a slider bar is used to interactively choose the tile size in pixels.

The user then selects an individual tile and examine it for roads that are partially or wholly disrupted by water or debris. If a pertinent example is located, the user moves to the next action: *Step 2a Preliminary Modeling Steps*. In this preliminary modeling step, an ESRI shapefile (.shp) delineating the study area (area of interest, or AOI) is selected. The user also selects an ESRI shapefile (.shp) that contains road centerlines for the AOI. After selecting the necessary shapefiles, the routine is executed. Clicking on Step 2a reveals a set of sliders used to identify water or debris in or adjacent to roads (Figure 3). The Flooding and Coastal Storm Debris applications handle this step in slightly different ways. The former uses simple thresholds with a Vegetation Index (normalized difference vegetation index, or NDVI) and the Near Infrared band to identify water; the latter uses a combined probability with a Vegetation Index and Visible Brightness (the sum of the Red, Green, and Blue bands). In the Flooding application, the user selects values for Vegetation Index and Visible Brightness. If the results are unsatisfactory (i.e., they under- or over-estimate actual surfaces), the user can adjust the values and re-run Steps 2a through 2b. In the Coastal Storm Debris application, the user chooses a Classification Value between 0 and 1. If the results are unsatisfactory, the user selects a different classification value and re-run Steps 2a through 2b. The optimal classification value for the Coastal Storm Debris application will likely be greater than 0.3 but will depend on the nature and quality of the input multispectral data.

Step 2d models the actual road surfaces using a combination of a Vegetation Index (NDVI) and Visible Brightness. This step is necessary to avoid identifying water or debris that is near roads but does not actually disrupt them. For both applications, note that this modeling routine only estimates road surfaces; it will not achieve a perfect delineation of the extent and shape of individual roads. Accordingly, this step can be considered complete if it adequately represents roads that are clearly disrupted or covered by water or debris. This step adds the water or debris initially identified in Step 2b to the road surfaces modeled in Step 2c.

The next step, Step 2e, evaluates the water or debris on or adjacent to estimated roads, eliminating erroneous or insignificant water or debris objects from consideration. In Step 2f a bright magenta buffer around each instance of water or debris partially or wholly covering roads is created to highlight potential disruptions to the road network.

Step 2g is a clean-up routine. The above modeling steps create a series of temporary layers. Step 2g eliminates these layers, freeing disk space. If necessary, steps can be re-executed to refine the modeling parameters of the application, and perform these steps on other tiles to verify their suitability.

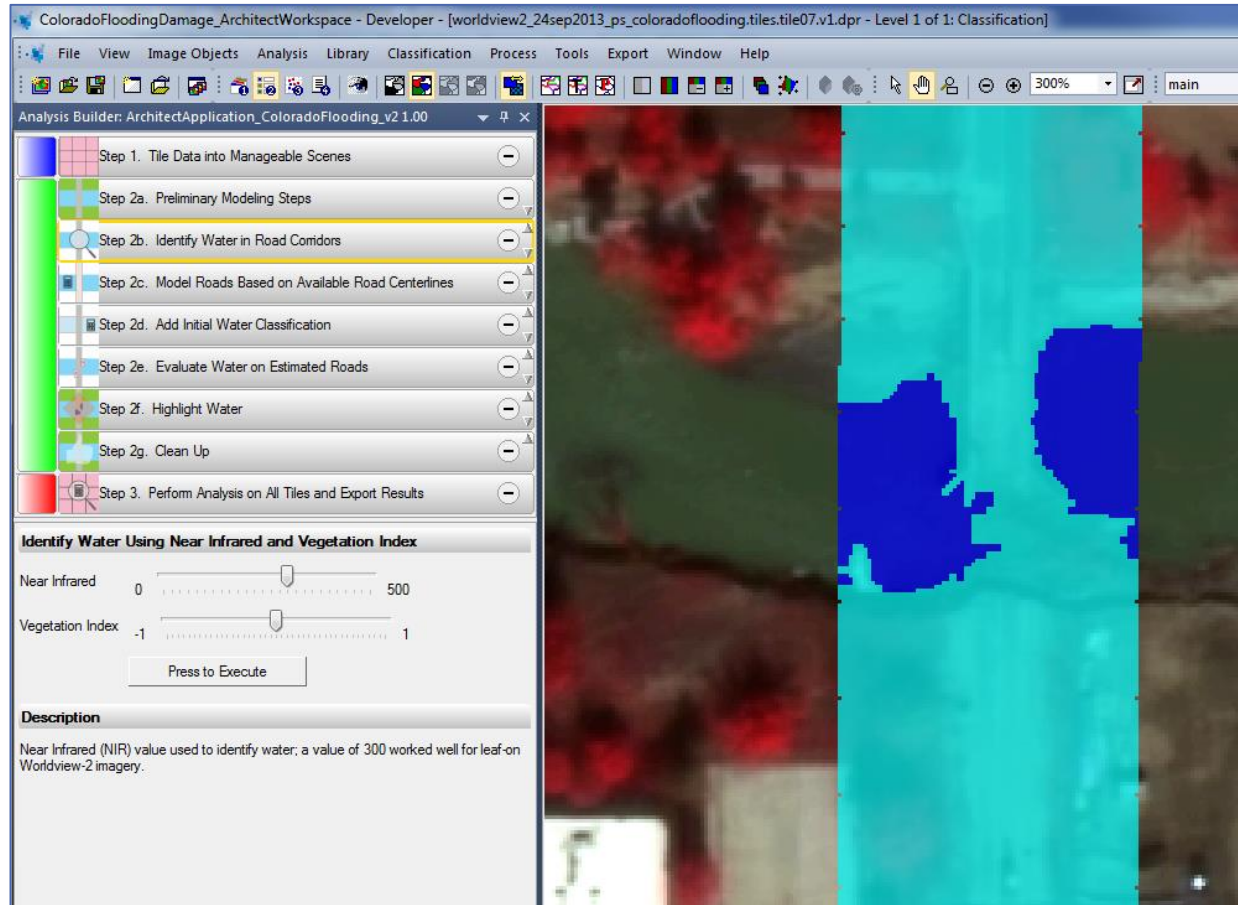


Figure 3. Step 2b identifies water or debris in road corridors using spectral case. In this case, a vegetation index and the Near Infrared band are used to identify the presence of water.

When the modeling parameters adequately capture actual road disruptions have been set, those parameters are applied the complete set of tiles in Step 3 (Figure 4). This step will perform the application on all tiles and output the results in several formats: 1) ESRI shapefiles that can be compiled and viewed in a GIS program, 2) raster files, and 3) image-file “snapshots” (JPEGs) that show, at a fine scale, individual road disruptions. These JPEG files can be examined closely to determine whether the disruption is real and to gauge the severity of the damage. Each file is named by the projection coordinates of the mapped water disruptions, which permits further query of the locations in a GIS program with other imagery and thematic datasets. Note that the coordinates are in the same projection as the one for the original remote-sensing imagery. Further note that a set of point shapefiles is created for the imagery snapshots. These shapefiles contain a point for the centroid of each snapshot and permit efficient geolocation of snapshots in Google Maps and other online mapping utilities.

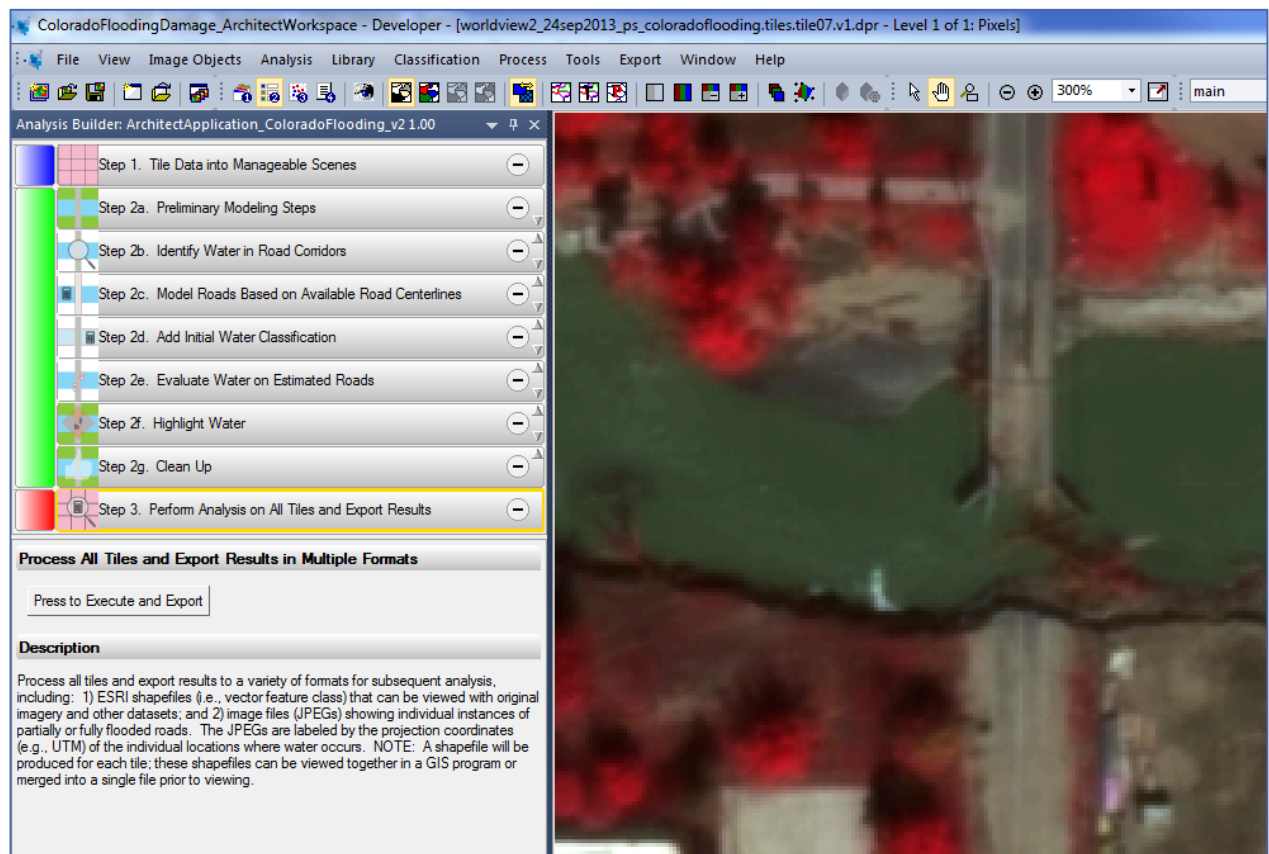


Figure 4. Step 3 runs the established parameters on the complete set of tiles and exports the results to multiple GIS-ready and static formats.

TASK 4 - FILL CALCULATION SYSTEM METHODS DEVELOPMENT

A video demonstrating the fill estimation tool is available at <https://youtu.be/nreeLlgcKy4>

Natural disasters can have profound impacts on the transportation networks of our nation. Accurate information about the location and extent of damage is critical for coordinating both short- and long-term recovery efforts. This demand is especially high in rural areas, where networks are more vulnerable. In the case of Tropical Storm Irene, which passed over Vermont on August 28, 2011, an estimated 260 roads were made impassable and all east-west road systems in the southern portion of the state were closed. The majority of state government offices were flooded and key telecommunications infrastructure was damaged. This combination posed a considerable challenge for the Vermont Agency of Transportation (VTrans) in locating and repairing the damaged infrastructure.

Crucial data needed for the recovery process are estimates of the volume of fill required to repair road damage. Current practices for determining this amount of material are field-based and can range from a detailed survey-grade mapping to a best guess made from a single observation. Detailed surveys are arduous, requiring specialized equipment, highly trained personnel, and

lengthy data processing and analysis times. During Irene, these methods of field surveying were found to be both slow and dangerous due to the periodic flash floods in the wake of the storm. Basic surveys and “eye- balling” by field engineers are quicker processes, but rely on cursory data, instinct, and general rule of thumb. Without complete knowledge about the extent of the damage, engineers must err on the side of caution regarding fill estimates. This inaccuracy can result in excess orders of fill, unnecessarily increasing the total cost of the recovery effort. Roadways consist of multiple layers of different fills costing different prices, so a reliable estimate of the amounts of each needed are critical for an efficient and cost-effective recovery effort.

This project assessed the ability of UAS to accurately estimate volume and developed a straightforward mechanism for volume estimation using UAS data. Reference data was collected with a RIEGL VZ1000 Terrestrial Laser Scanner provided by the University of Vermont College of Engineering and Mathematical Sciences. This device, pictured in Figure 5, is capable of taking high resolution and accurate 3D measurements using LiDAR technology. Each return from the laser pulse system has range and intensity values, as well as spatial location measured in three dimensions. When plotted in 3D space, these returns are referred to as a point cloud. By distributing reflective control targets around an area of interest, it is possible to combine the data collected by several scans at unique locations into a single composite point cloud. A control target can be seen in the left portion of Figure 5.



Figure 5. RIEGL VZ1000 Terrestrial Laser Scanner and control point.



Figure 6. senseFly eBee.

The senseFly eBee was selected as this project. The eBee, shown in Figure 6, is a lightweight autonomous foam aircraft that contains an integrated 16 MP camera capable of recording aerial imagery at resolutions as fine as 2 cm/pixel. The entirety of this system's hardware can be easily transported in a flight case and rapidly assembled in the field. With a well-practiced team following a set of established standard guidelines, the eBee can be deployed in a matter of minutes. A field-swappable rechargeable battery provides up to 45 minutes of flight time and allows the eBee to cover areas up to 10 km² (3.9 mi²) in a single flight. The system can be used in light rain or snow and can tolerate winds as high as 10 m/s (22 mph).

Flight planning functionality and in-flight controls for the eBee are accomplished using a laptop or tablet running senseFly's eMotion2 software package. Flight patterns can be created prior to deployment in a safe and comfortable location, such as an office, or generated on the fly in the field. This flexibility could prove crucial by providing the ability to adjust to rapidly changing conditions in a post-disaster scenario. An integrated GPS unit and radio module facilitates communication between the eBee and the software to provide real-time flight monitoring. Notifications of in-flight warnings are displayed in the software. Through this interface, the eBee's mission can be aborted if necessary or, if the landing zone is not clear, the UAS can be put into a circular holding pattern. Refer to the Standard Operating Guidelines attached as Appendix F for an in-depth tutorial on mission planning.

The simplicity of the eBee's launching and landing procedures could allow for rapid and repeated deployment following a disaster event. The launching procedure is demonstrated in Figure 7. The operator shakes the eBee three times to engage the motor. Once the motor reaches full power,

the operator takes two steps forward and releases the eBee at a ten-degree angle above the ground. The aircraft climbs steeply and circles around a user-specified waypoint to gain altitude before starting its preprogrammed mission. When the mission is complete and the landing procedure has been initiated by the flight operator, the eBee circles above the specified landing area to measure wind conditions. Once the direction and velocity of the wind is determined, the system calculates the ideal linear approach within an approach sector defined by the operator. The eBee decreases in altitude as it flies along this vector. As the system nears the landing zone, its optical sensor determines the location of the ground surface. When the aircraft is a few meters above the ground, the motor reverses abruptly in order to reduce velocity and then powers down. The eBee glides to the ground where it can be collected and prepared for its next mission.



Figure 7. senseFly eBee launch procedure.

UAS and terrestrial LiDAR data were collected for a stockpile on November 21, 2013. This pile was located at the construction site for the VTrans Morrisville Alternative Truck Route project in Morrisville, VT. The location of the pile relative to Morrisville is shown in Figure 8. An initial UAS survey of the 3km construction corridor was conducted on November 20, 2013, during which the stockpile was identified as an ideal feature to use in this assessment.

Five unique scans were conducted around the perimeter of the stockpile with the RIEGL VZ1000 in order to create a composite point cloud that represented the entire feature. Ten reflective targets were placed around the vicinity of the stockpile to act as control points. Due to the height of the stockpile and limitations of the scanner, no returns were collected along the top surface of the pile, although reference was provided by a control target placed on top of this surface. The total on-site time from set-up to take-down for this data collection was approximately 3.5 hours.

Prior to the flight, four ground control points (GCPs) were established around the extent of the area of interest (Table 1, Figure 9). The use of GCPs ensures vertical and horizontal accuracy in the processed UAS dataset. Each GCP was created by folding two white trash bags to a width of 2-3 inches and laying them across each other to form a cross. The GCPs were secured with small rocks and a survey-grade Trimble GPS unit was used to record their coordinate locations in the NAD 1983 Vermont State Plane datum.

Table 1. Coordinates of GCPs (NAD83 VT State Plane)

GCP	X (m)	Y (m)	Z (m)
1	491718.777	229299.768	190.321
2	491742.907	229260.175	188.612
3	491722.086	229208.375	187.54
4	491693.816	229207.564	187.085



Figure 8. Location of stockpile in relation to Morrisville, VT



Figure 9. GCP locations in relation to stockpile

The characteristics of the eBee flight used in this analysis are presented in Table 2 and the flight path is displayed in Figure 10. Image count represents the total number of photographs taken by the eBee during the mission. The overlap of the collected imagery is displayed graphically in Figure 11. Image overlap is reduced significantly around the perimeter of the surveyed area. Ground resolution, measured in cm/pixel, is a function of the eBee's altitude above ground level (AGL). The surveyed mission area is tabulated in hectares. GCP error is a measure of deviation between the actual location of the GCPs and their locations determined during data processing. The flight time for this area was approximately 30 minutes from take-off to landing, with less than an hour of total time spent on-site, including assembly and disassembly.

Table 2. Properties of Morrisville UAS Flight

Image count	Flight lines	Resolution (cm/pixel)	Surveyed area (ha)	Total GCP error (cm)
166	Perpendicular	3.25	3.814	1.3

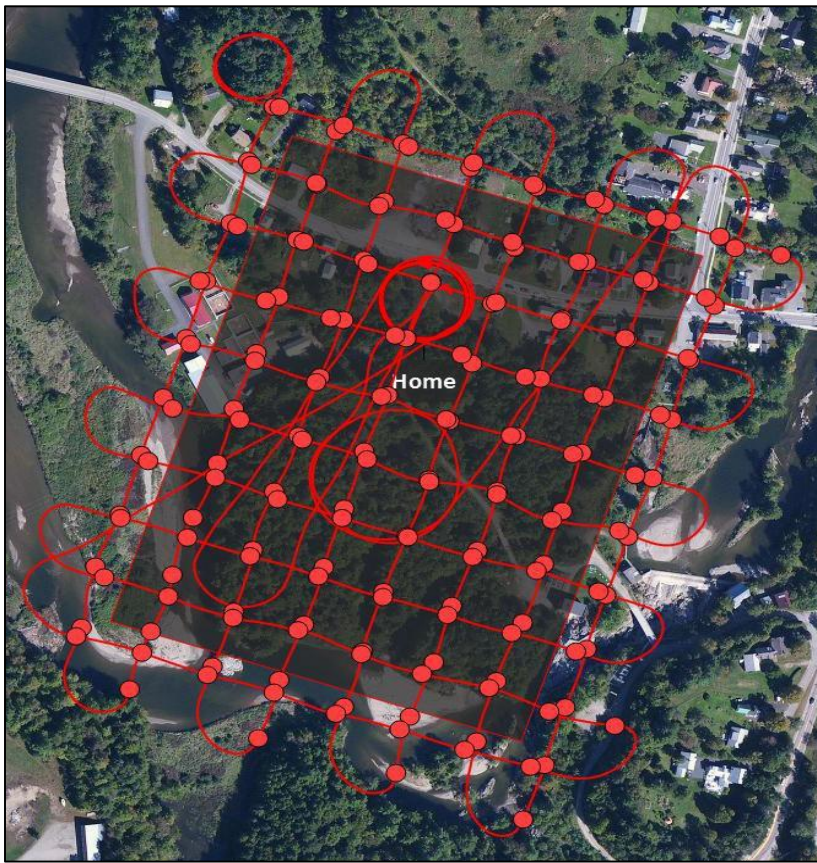


Figure 10. Flight lines for the Morrisville UAS flight.

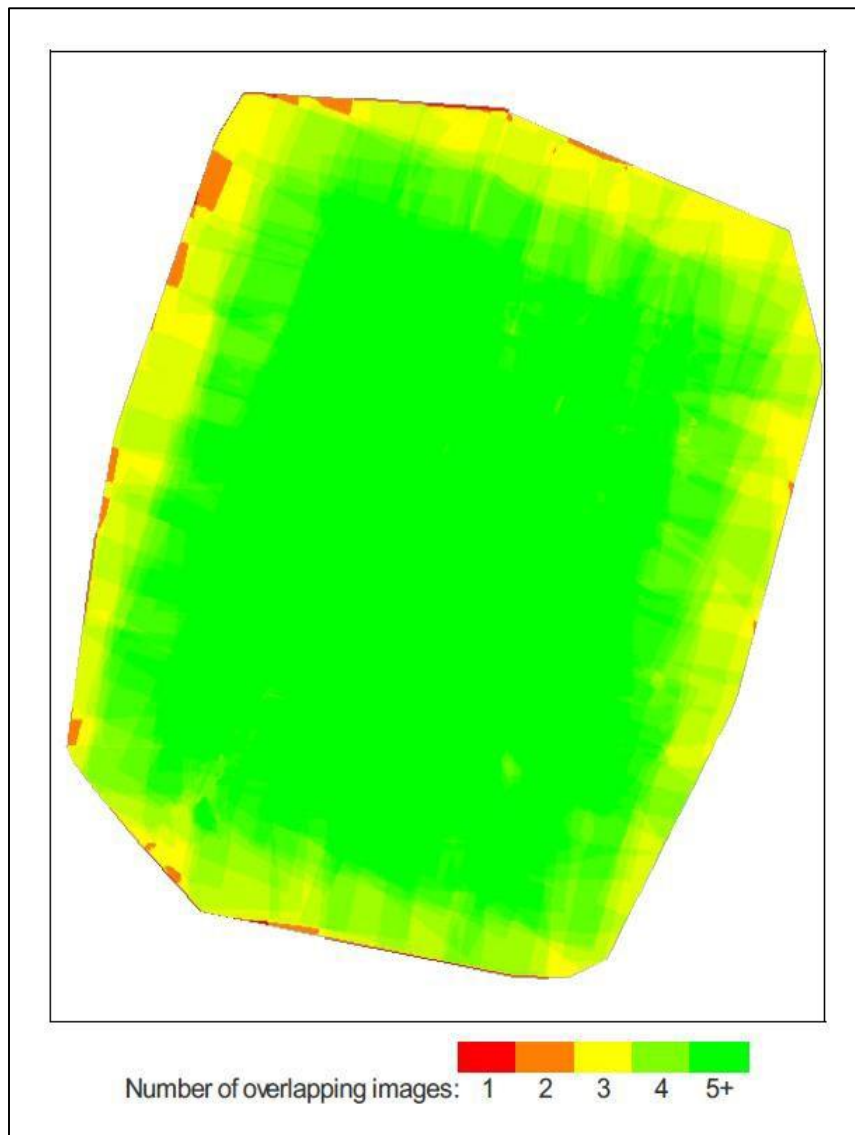


Figure 11. Overlap of UAS imagery for stockpile mission.

On December 3, 2013, UAS and terrestrial LiDAR data were collected for a manure pit located on the grounds of Shelburne Farms in Shelburne, VT. This feature is somewhat analogous to a damaged roadway because it represents a void volume. The location of the manure pit is shown in Figure 12.

Three scans were conducted at unique locations around the perimeter of the manure pit with the RIEGL VZ1000. Ten reflective targets were scattered throughout the area to ensure that the individual scans could be referenced to each other and combined into a single composite point cloud. Sparse returns were collected along the bottom of the manure pit because standing water has a tendency to scatter the light pulses from the sensor.

The characteristics of the UAS flight at this location are presented in Table 3. A total of 37 images were taken at a resolution of 3.14 cm/pixel over an area of 2.33 hectares. The weather conditions

during this flight were not ideal, with winds gusting as high as 9 m/s (20 mph). Perpendicular flight lines, shown in Table 3, were programmed to ensure sufficient imagery overlap. The variability seen in these flight lines is a direct result of the high winds. The level of imagery overlap obtained during this flight is displayed in Figure 14. High overlap is evident in the middle of the surveyed area, which corresponds to the location of the manure pit. No GCPs were used during this mission.

Table 3. Properties of Shelburne UAS Flight.

Image Count	Flight Lines	Resolution (cm/pixel)	Surveyed Area (ha)
37	Perpendicular	3.14	2.33



Figure 12. Location of manure pit in relation to Shelburne, VT

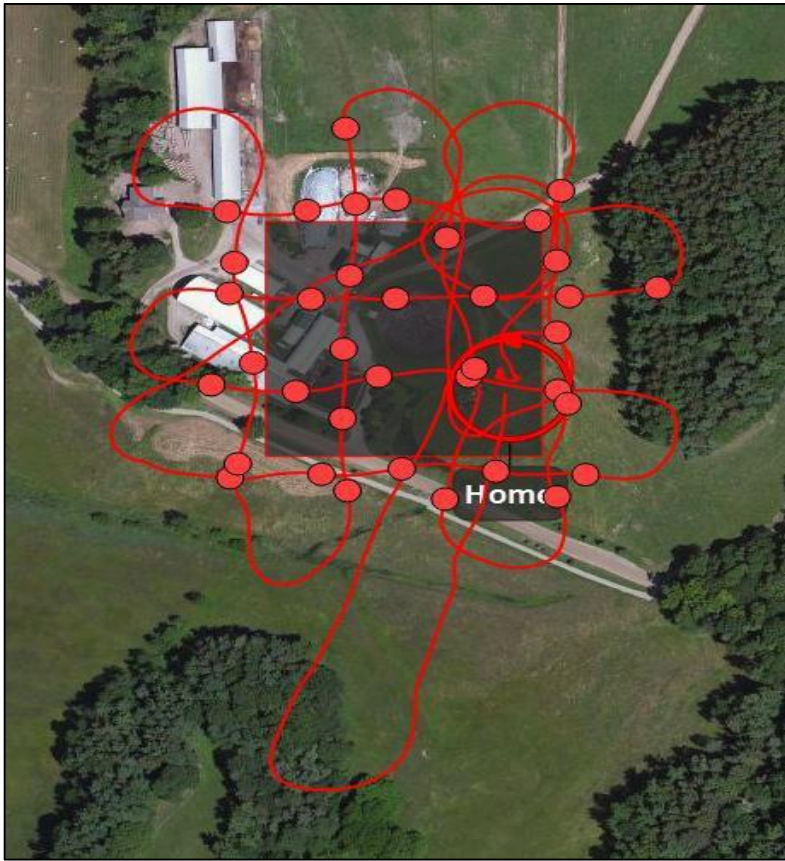


Figure 13. UAS flight lines for manure pit mission.

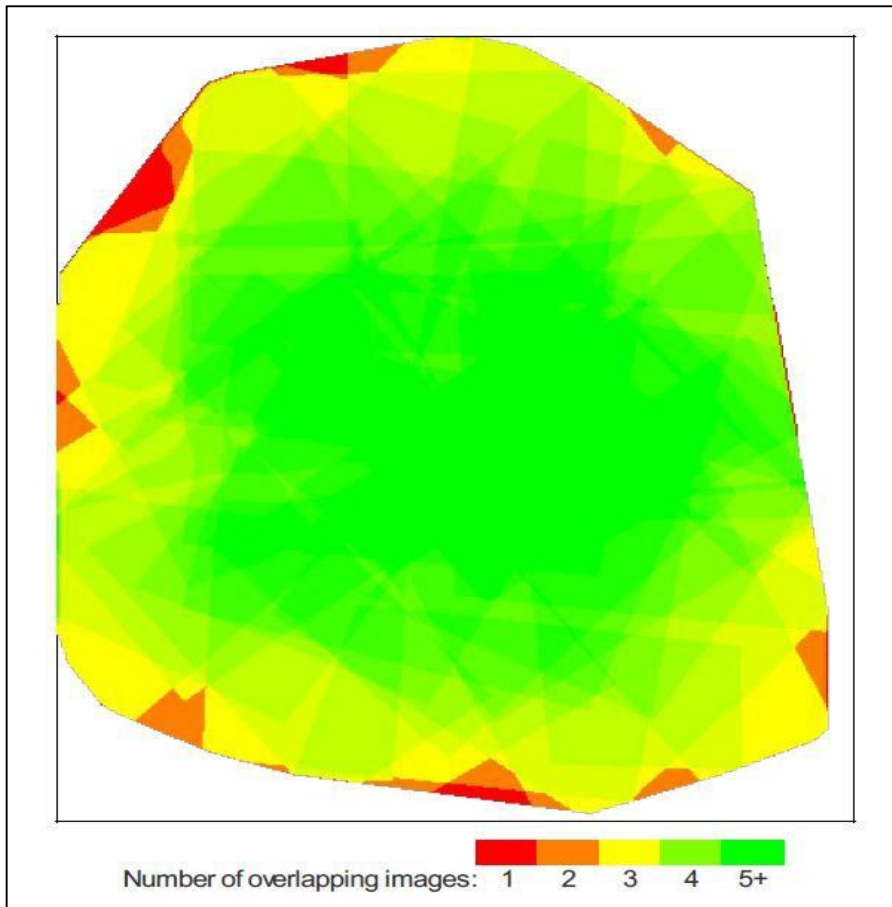


Figure 14. Overlap of UAS imagery for manure pit mission.

Composite point clouds of the collected terrestrial LiDAR data were created using the RIEGL RiSCAN PRO software package. For both surveyed features, the composite point cloud incorporated all of the returns of the scans undertaken at each site. The composite point clouds were exported to LAS files with metric coordinates in an arbitrary reference frame. Due to this limitation, it was not possible to spatially overlay the UAS and LiDAR data sets for direct comparison. These LAS files were imported into Quick Terrain Modeler (QTM) and cropped to the general location of each feature in order to reduce processing time. Extraneous returns above and below both features were filtered with a clipping plane in QTM.

The cropped and clipped point clouds were exported to LAS files and individually re-imported into QTM as a QTT (gridded surface) to create a digital surface model. For the stockpile point cloud, the import settings were: grid sampling of 0.0360 meters with Adaptive Triangulation Mean-Z algorithm as the hole-fill method and antialiasing enabled. The top and bottom images in Figure 15 show the cropped point cloud and interpolated DSM of the stockpile. Note the absence of returns for the top of the stockpile in the point cloud and the resulting interpolated surface in the DSM.

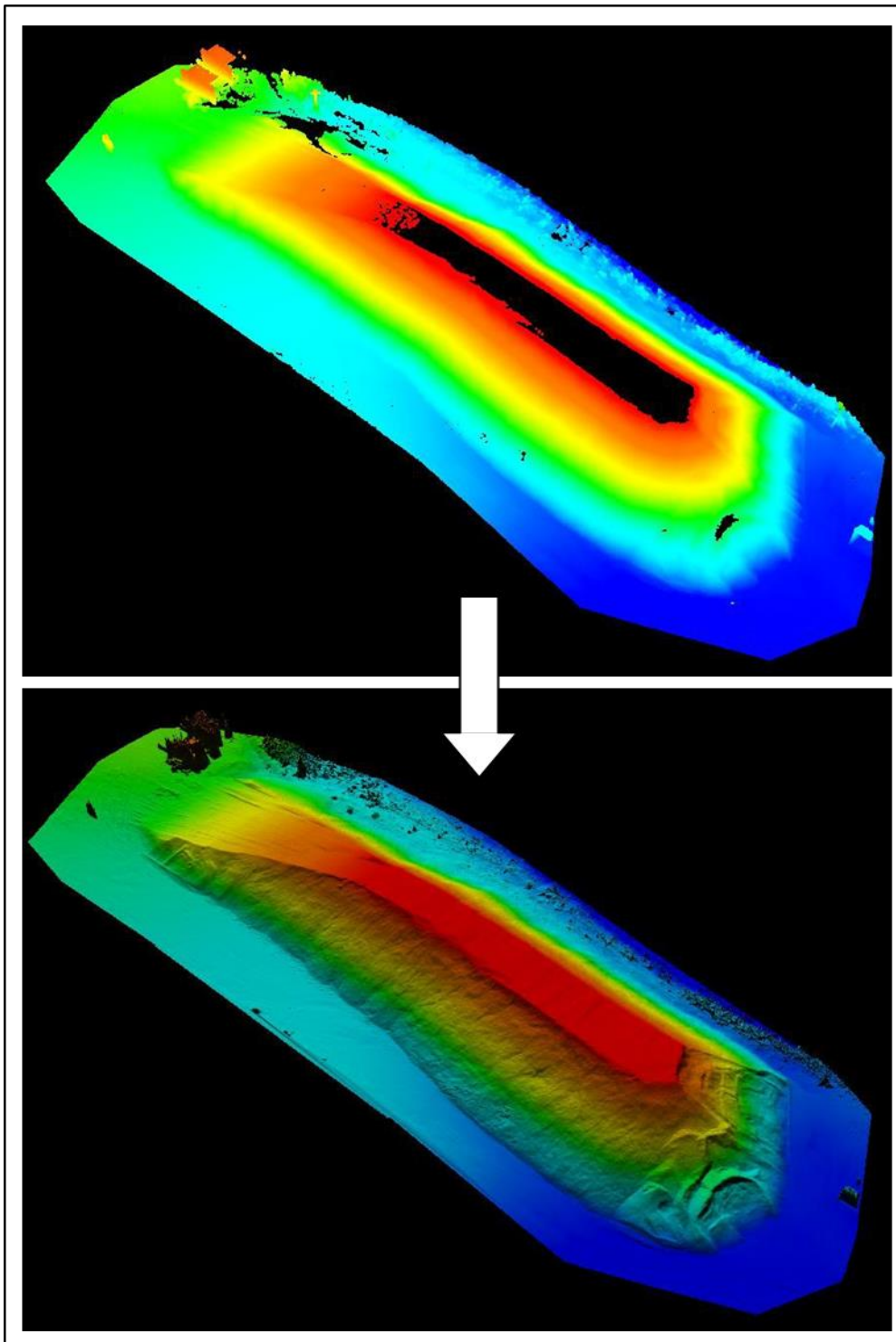


Figure 15. LiDAR point cloud and interpolated DSM (stockpile).

For the manure pit data, the import settings were: grid sampling of 0.0180 meters with Adaptive Triangulation Mean-Z algorithm as the hole-fill method and antialiasing enabled. The composite point cloud and interpolated DSM are respectively displayed as the top and bottom image in Figure 16.

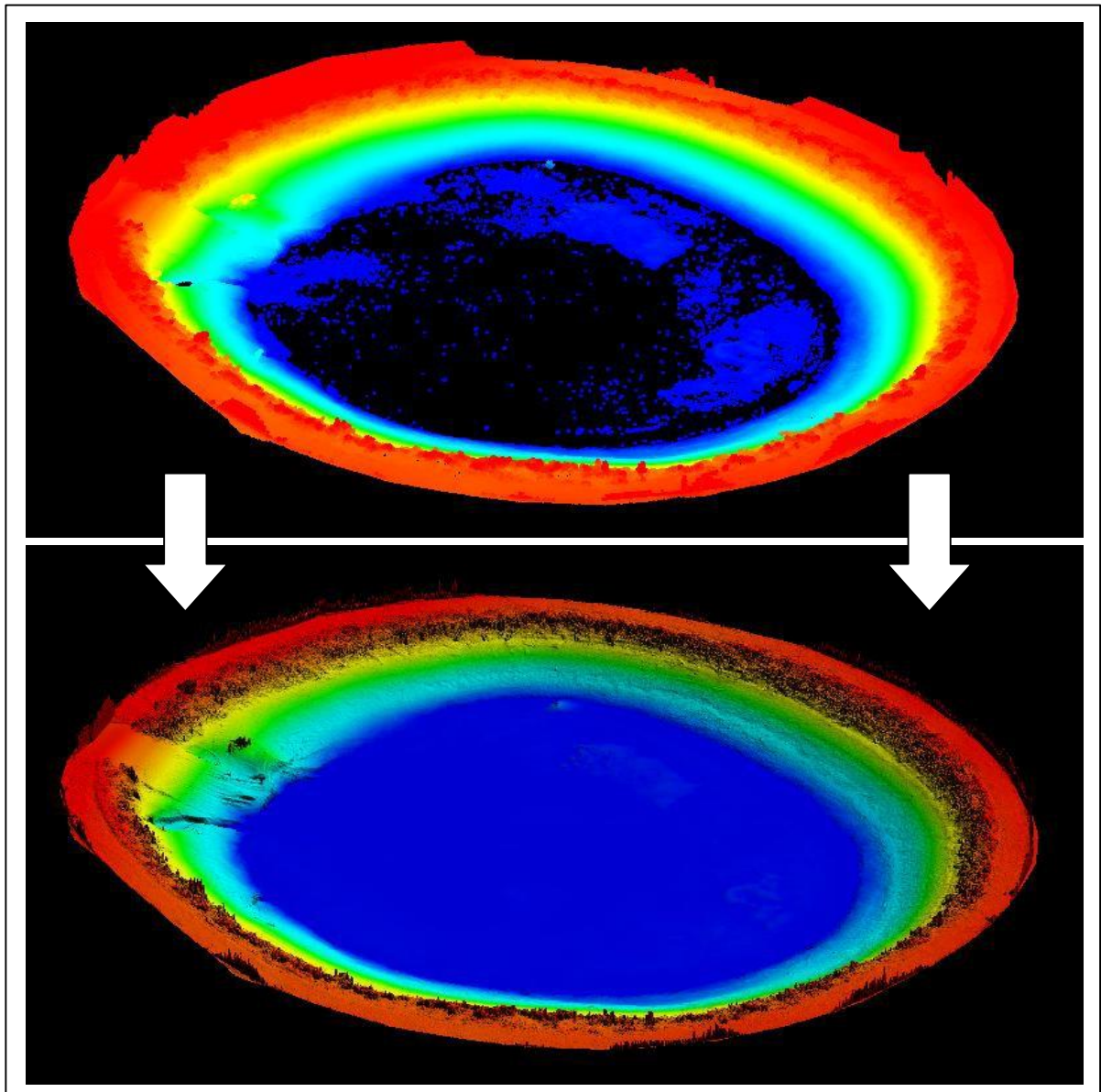


Figure 16. LiDAR point cloud and interpolated DSM (manure pit)

Project files for the two missions were created using eMotion2 and imported into Pix4D's PostFlight Terra 3D software, which was used to create a true-color orthomosaic, DSM, and colorized point cloud from the imagery and GPS data collected during each eBee mission. This software, customized for the eBee, uses digital photogrammetric algorithms to create a composite of the images captured during a flight and utilizes multi-view stereoscopic techniques to densify and filter a point cloud. The points created in this process are assigned color values that correspond to the imagery, resulting in the creation of a true-color 3D model. Local processing settings specified high tolerance algorithms to create the best possible resolution and 3D point density. These products are automatically exported to the same folder that the project

file is stored. The orthomosaic and DSM are generated as rasters with a GeoTIFF file extension, while the point cloud is exported to a LAS file.

Prior to processing in PostFlight, GCP locations were integrated into the stockpile project data by entering their coordinates (refer to Table 1) and visually selecting their locations in all images in which they appeared. This software interface used for this process is shown in Figure 17. The coordinates of the four GCPs are tabulated in the upper portion of this image. The green number to the left of each GCP represents the number of images that this point was captured in. To the left is the list of all images taken during the mission. The preview pane in the bottom of the figure is used to digitize the location of a GCP within an image. This process was not carried out for the manure pit data because no GCPs were identified during the mission

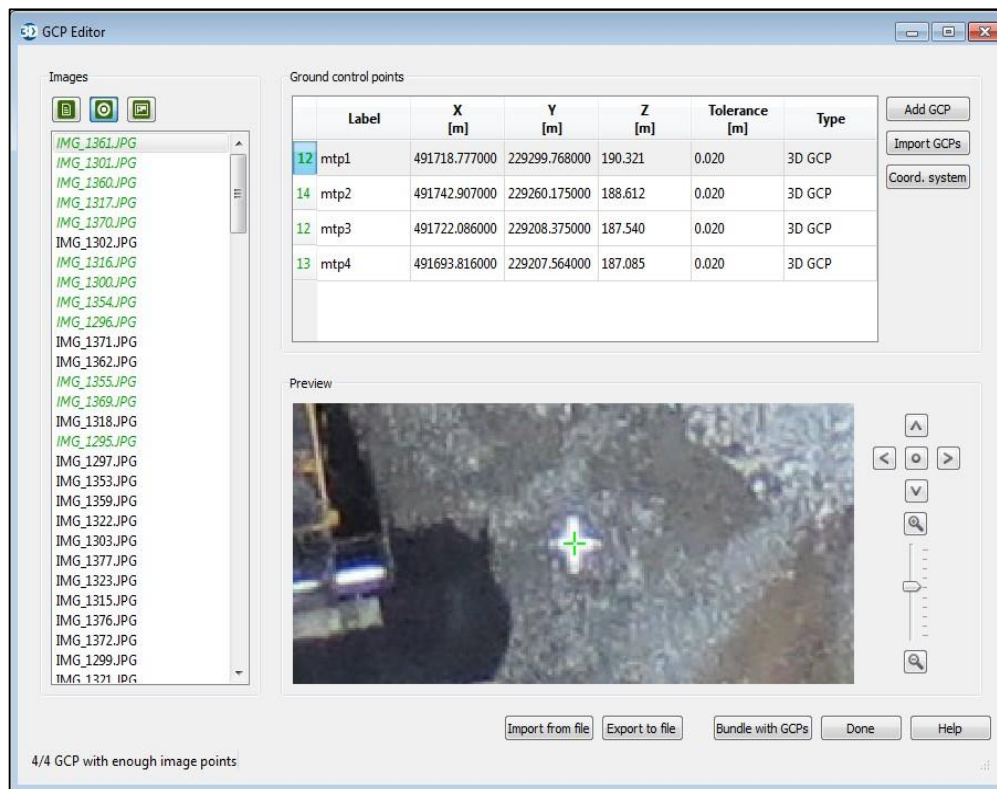


Figure 17. PostFlight Terra GCP editor.

From the generated 3D surface models, two methods were utilized to calculate the volume of the stockpile and manure pit. For this assessment, the volume of the stockpile was defined as the volume of the feature above its apparent base and the volume of void space below the ring of vegetation was determined for the manure pit. A process diagram of the volume calculation process is presented in Figure 18.

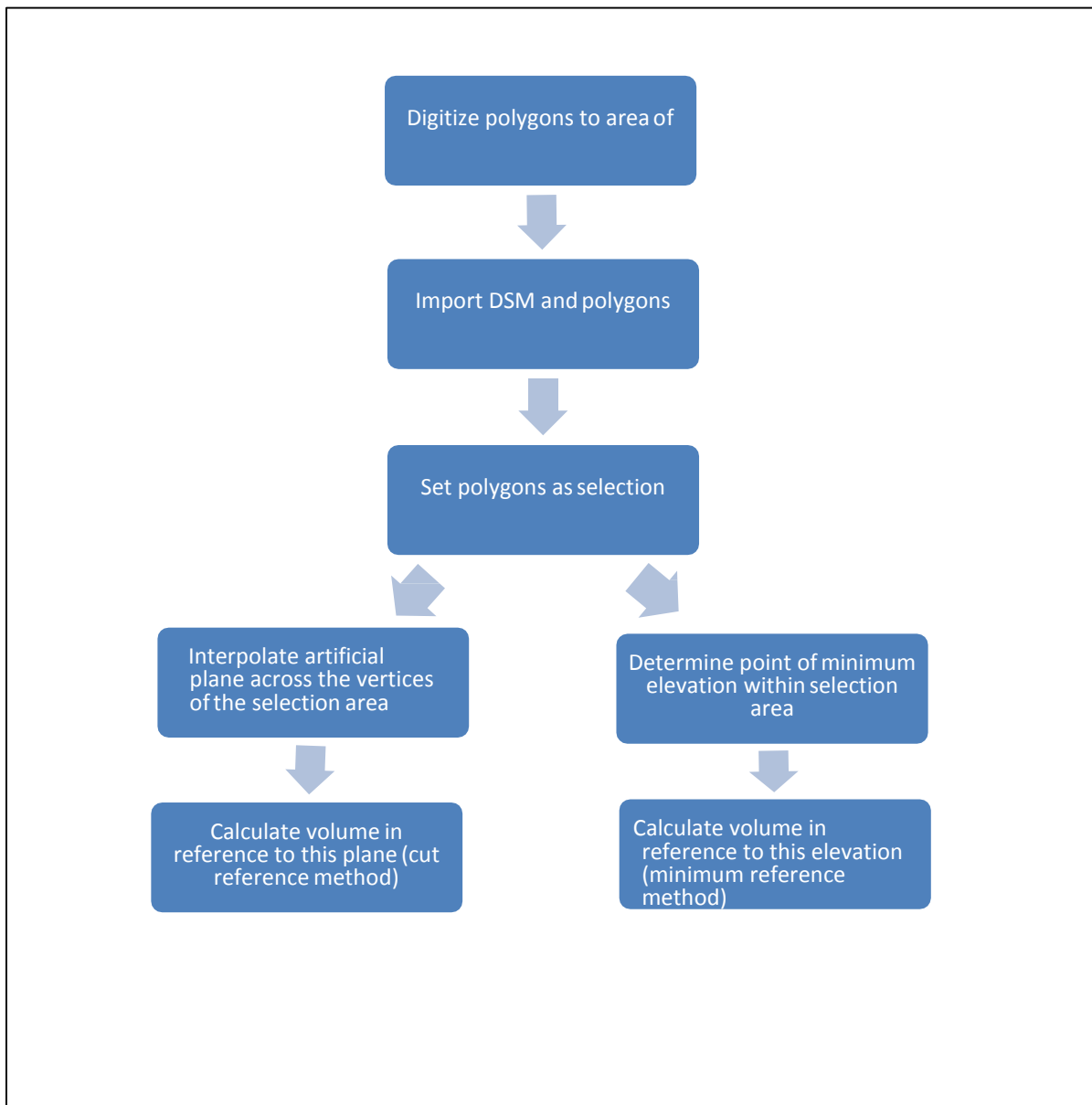


Figure 18. Volume calculation process.

The minimum reference method, was used to determine volume above a reference plane of constant elevation corresponding to the minimum height of the selection area. The 'Find lowest point in area' tool within the QT Modeler software package was used to determine the minimum elevation within a selection area. The 'Volume Calculation' functionality of QTM was used to calculate the volume of the 3D model in relation to a horizontal plane at this elevation.

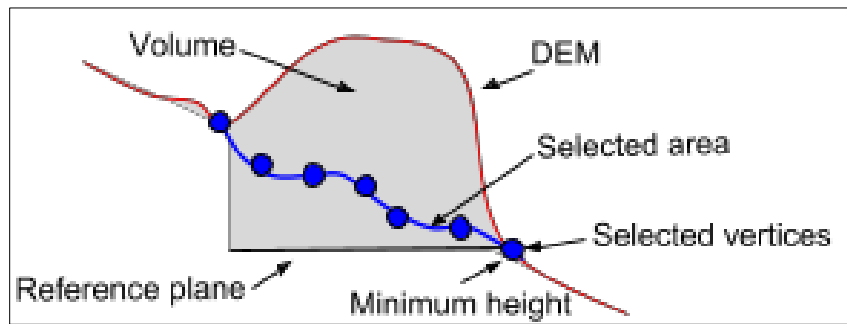


Figure 19. Volume calculation example.

Volume can also be determined using the cut reference method, in which an artificial surface is created by interpolating across the vertices of a selection area. A diagram of this method is presented in Figure 19. QT Modeler's 'Smooth Area' tool was used to interpolate a plane across the extent of a vector polygon. The 'Volume Calculation' function in QTM was used to calculate the volume of the 3D model relative to this artificial plane. Typically, the cut reference method will yield estimates of volume that are less than those determined by the minimum reference method. Minimum reference would be applicable to scenarios in which a roadway has a known and constant elevation. This method also allows some flexibility because any arbitrary elevation can be specified to act as the reference plane. Cut reference would be more valid for complex features, including sections of road with intermediate or steep grades, as well as stream and road banks.

Polygons representative of each feature were digitized in ArcMap using the orthomosaic images as reference. These polygons were digitized to the perimeter of stockpile and the perimeter of the manure pit below the ring of vegetation. Eight GIS technicians created 30 unique polygons for each feature to ensure statistical validity. These polygons are overlaid on the stockpile orthomosaic (Figure 20) and on the manure pit orthomosaic (Figure 21). Note the variation between individual polygons for both locations.

The DSM and the digitized polygons were imported into QT Modeler. Minimum and cut reference volumes were calculated for the selection area defined by each individual polygon. The minimum reference elevation of the stockpile was defined as the lowest point within the polygon selection area. Due to the inverse geometry of the manure pit, the minimum reference elevation for this feature was defined as the highest point within the selection area. This allows for accurate calculation of the void volume.

To determine cut volume, QT Modeler's 'Smooth Area' tool was used to create an interpolated plane for the DSM across the extent of the defined selection area. This process is shown in Figure 22 for the stockpile and in Figure 23 for the manure pit. Note that the interpolated surfaces are not of constant elevation. Pile volume was calculated in QTM as the volume of the DSM above this interpolated plane. The volume of the manure pit was calculated as the volume of void below this plane.



Figure 20 : Stockpile base polygons (UAS).

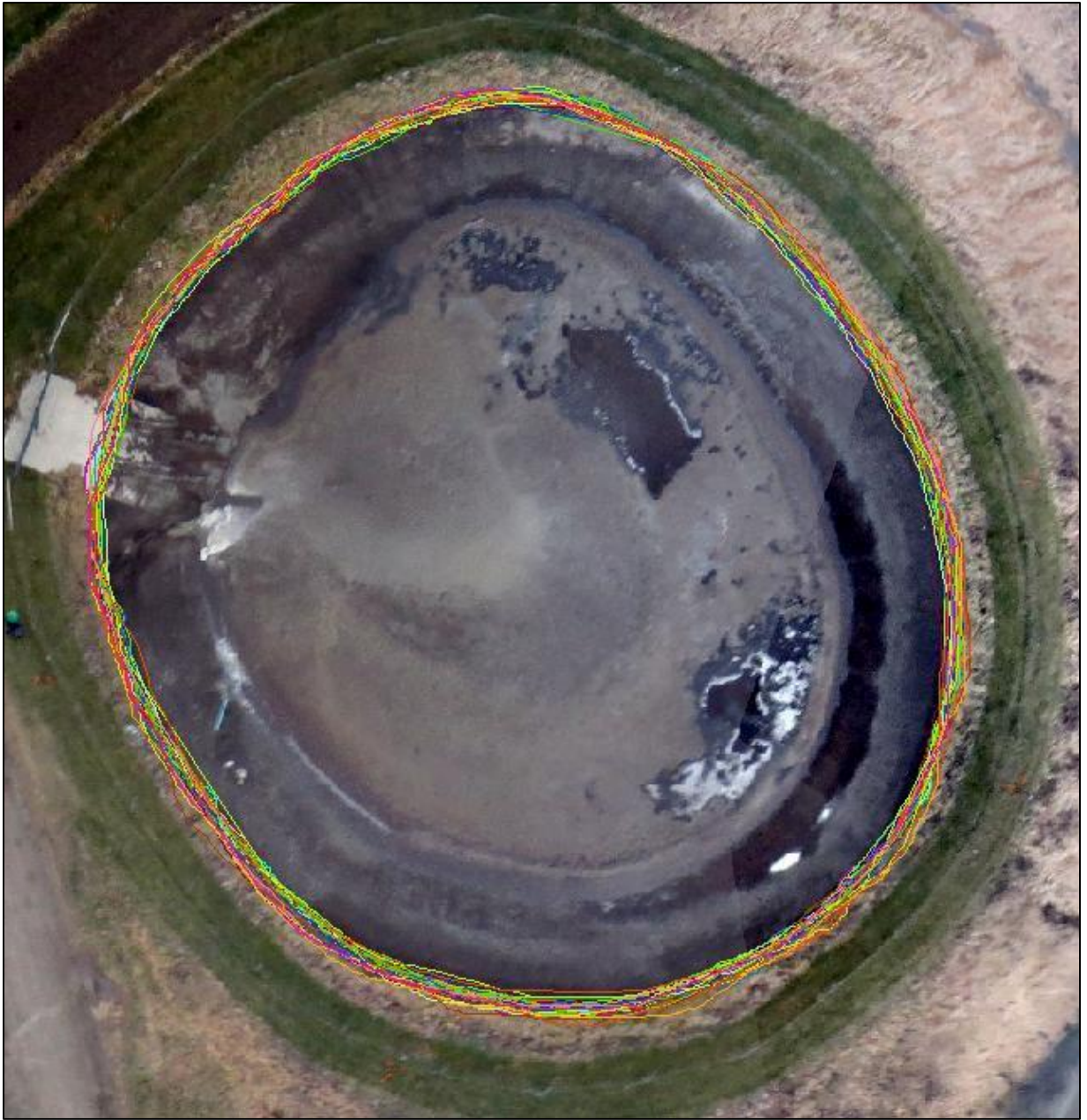


Figure 21. Manure pit polygons.

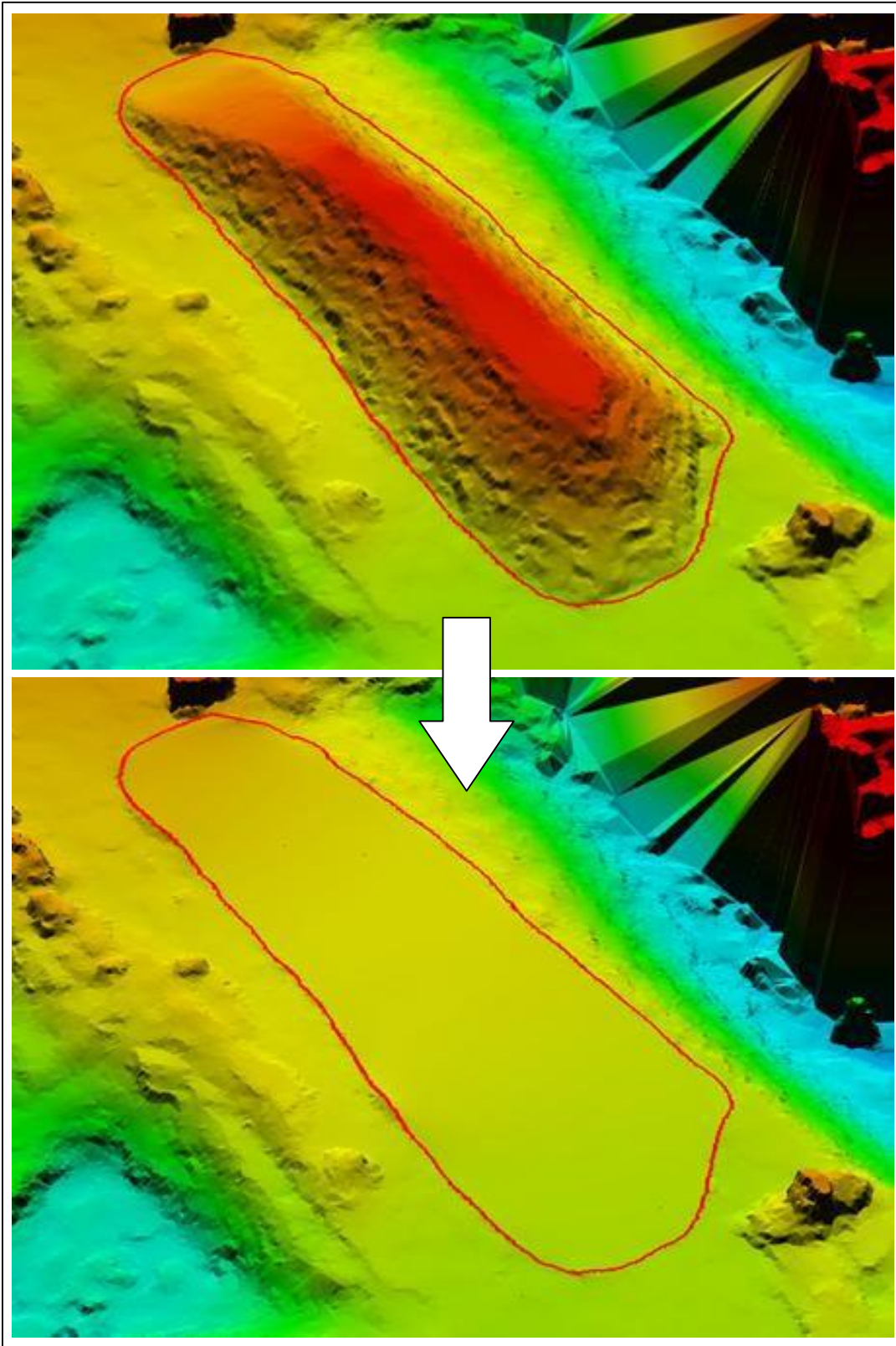


Figure 22. Interpolation of stockpile cut reference plane (UAS).

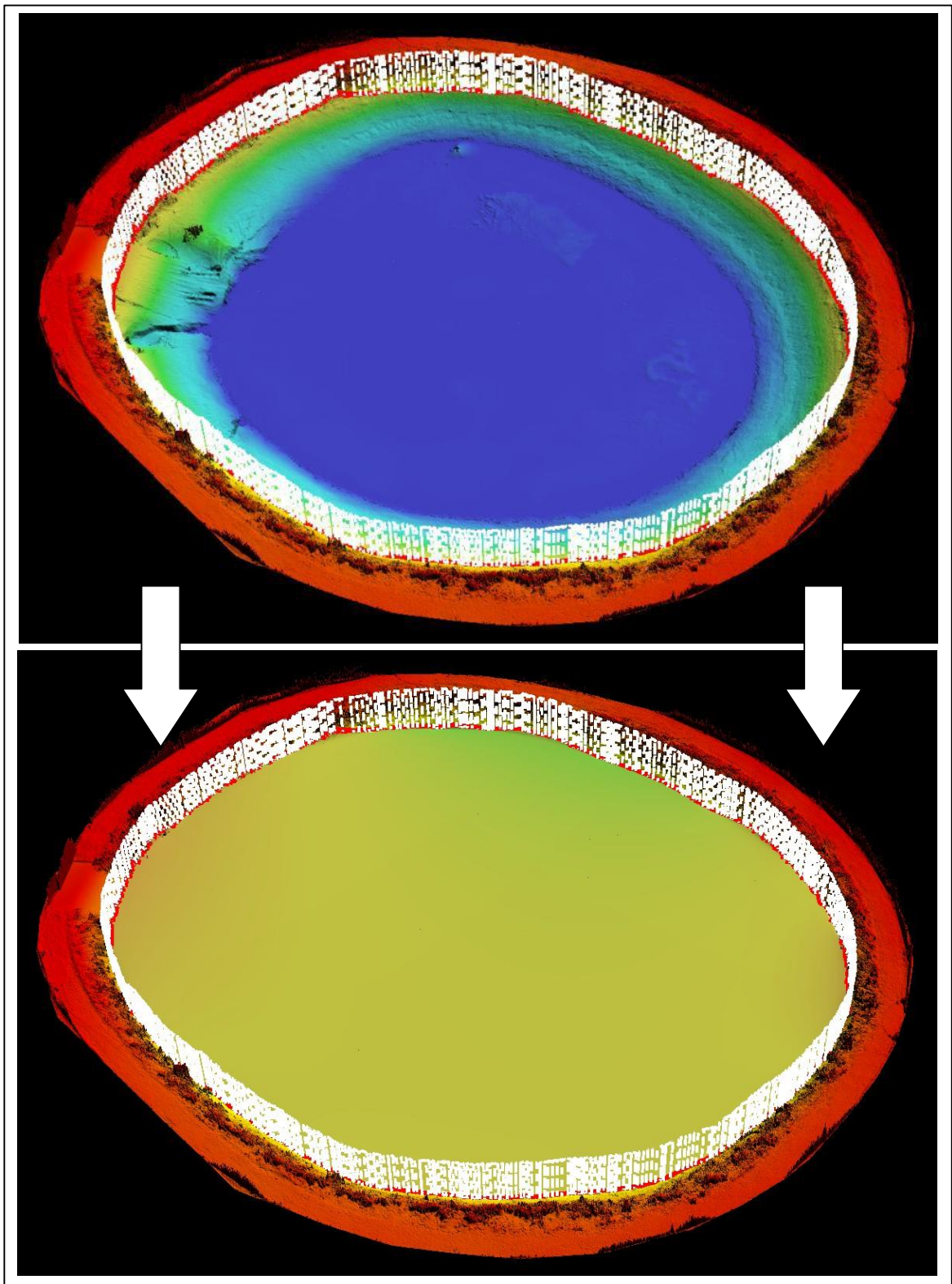


Figure 23. Interpolation of manure pit cut reference plane (UAS)

The DSM created from the LiDAR point cloud was imported as an ArcMap layer and manual digitization techniques were used to create 2D polygon shapefiles around the base of the stockpile and around the vegetation ring of the manure pit. Again, eight GIS technicians created a total of 30 unique polygons for each feature. These polygons are overlaid on the stockpile DSM in Figure 24 and the manure pit DSM in Figure 25. For both locations, the polygon vectors and the DSM were imported into QTM and the extent of each vector layer was set as the selection area. Cut and minimum reference volumes for the LiDAR DSM were determined using the same workflow as the UAS calculations. The cut reference interpolation process is shown in Figure 26 for the stockpile and Figure 27 for the manure pit.

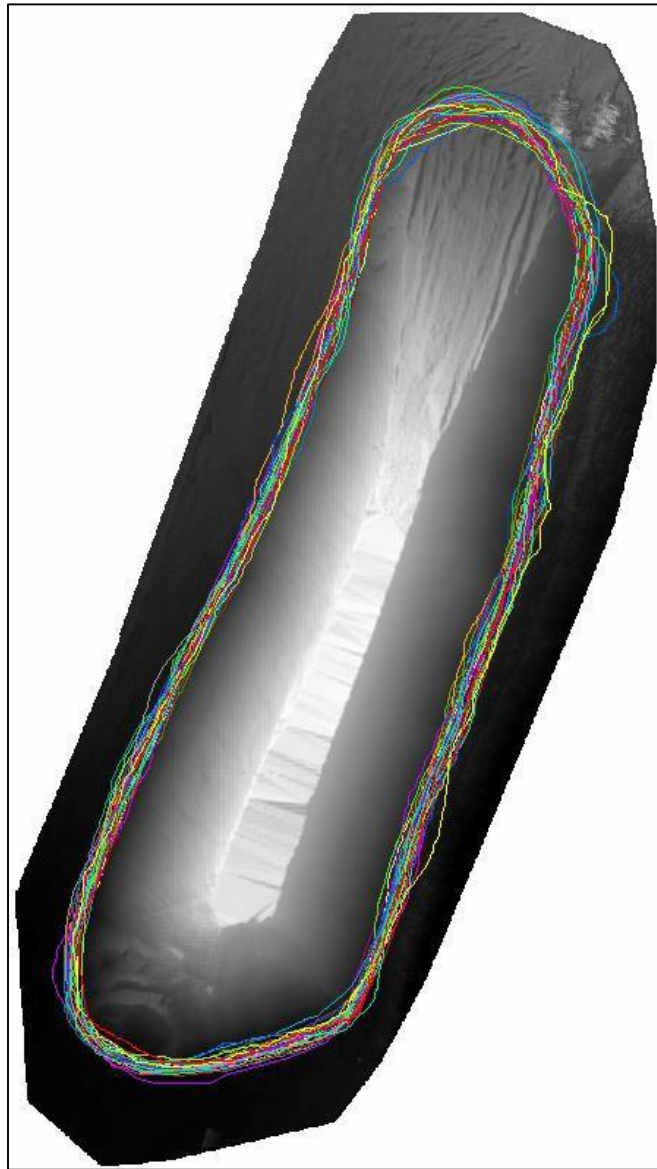


Figure 24. Stockpile base polygons (LiDAR)

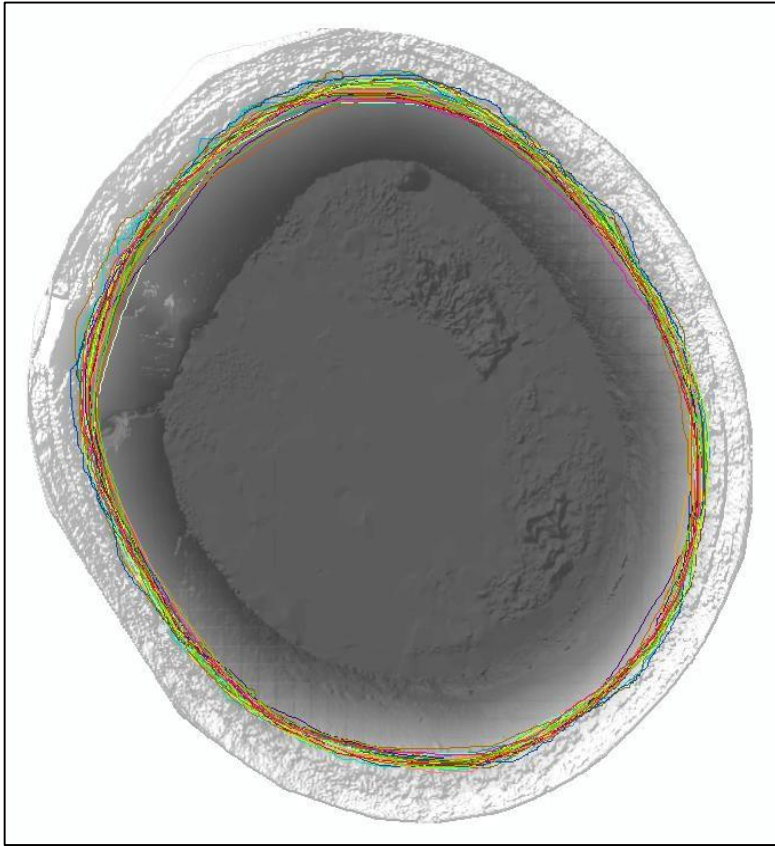


Figure 25. Manure pit base polygons (LiDAR).

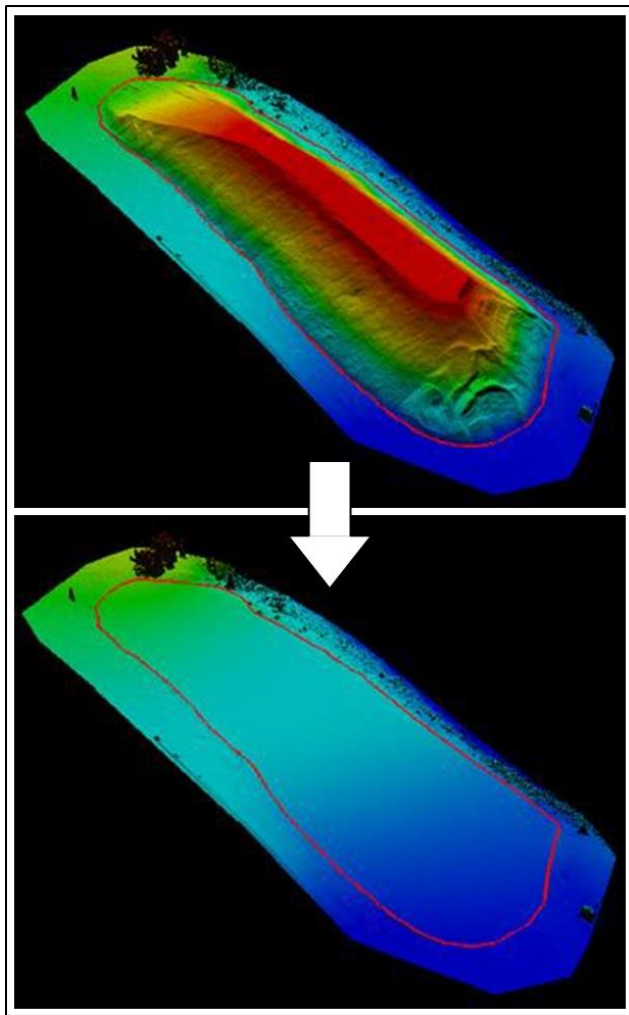


Figure 26. Interpolation of stockpile cut reference plane (LiDAR).

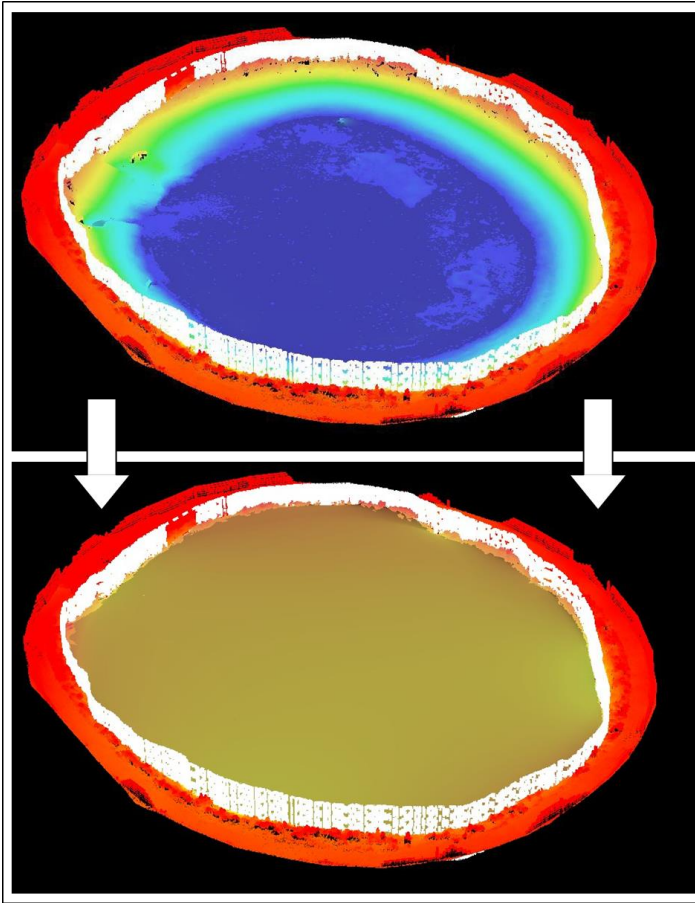


Figure 27. Interpolation of manure pit cut reference plane (LiDAR).

Summary statistics of the stockpile volumes are presented in Table 4. The mean volumes and standard deviations (STDEV) are tabulated in cubic meters and the relative standard deviation (RSD) is expressed as a percentage. “Relative difference” expresses the variation in mean volume between the UAS and LiDAR sensor. This difference is also presented percent wise as “Relative error.”

For the minimum reference method, deviations in volume for both platforms are small, which suggests that the minimum elevation within the digitized polygons was consistent. The difference in calculated volume between the two platforms for this method is less than 22 m^3 , which is less than a one percent difference. This suggests high confidence in the accuracy of the UAS.

Although the same selection area polygons were used for both the cut and minimum reference calculations, the relative standard deviations were larger when calculating cut reference volumes. This is likely a result of the variations in the polygons. The difference in cut reference volume between the UAS and LiDAR data is less than 100 cubic meters, which corresponds to an error of 3.72%.

Table 4. Volumetric comparisons for the stockpile.

Platform	Minimum reference (m ³)			Cut reference (m ³)		
	Mean	STDEV	RSD	Mean	STDEV	RSD
<i>LiDAR (n=30)</i>	3761.33	64.33	1.71%	2595.09	90.7	3.49%
<i>UAS (n=30)</i>	3782.64	69.03	1.82%	2691.65	56.4	2.10%
<i>Relative difference</i>	21.31			96.55		
<i>Relative error</i>	0.57%			3.72%		

Summary statistics of the determined manure pit volumes are presented in Table 5. The mean volumes are displayed as positive numbers for ease of interpretation but represent the void volume of this feature.

For the minimum reference method, the relative standard deviations from the mean volumes of both platforms are under 2%. This indicates that the maximum elevation of the DSM within each of the digitized polygons was consistent. The UAS underestimated the volume of void space by nearly 600 m³, which corresponds to a relative error of nearly 16%. This is considerable error and it suggests that the minimum reference method may be only marginally valid for this type of feature.

The results of the cut reference calculations show that both platforms have moderate deviations from their mean volumes. The relative standard deviation for the LiDAR sensor is nearly 8%. It is likely that this is a result of variations in the digitized polygons because the ring of vegetation around the manure pit was difficult to identify in the DSM used as a digitizing reference. Compared to the LiDAR sensor, the UAS underestimated the void volume by 24 m³. This corresponds to an absolute relative error of 1.15%.

Table 5. Volumetric comparisons for the manure pit.

Platform	Maximum reference (m ³)			Cut reference (m ³)		
	Mean	STDEV	RSD	Mean	STDEV	RSD
<i>LiDAR (n=30)</i>	3638.95	416.24	1.71%	2081.63	159.36	7.66%
<i>UAS (n=30)</i>	3068.54	281.36	1.82%	2057.63	93.10	4.52%
<i>Relative difference</i>	-570.41			-24.00		
<i>Relative error</i>	-15.68%			-1.15%		

As expected, the volumes calculated using the minimum reference method were greater than the volumes determined with the cut reference method. For both the stockpile and the manure pit, this difference was on the order of 1000 cubic meters, which indicates that base of the pile was not at a constant elevation. The cut reference volumes may be considered the more accurate estimation for this scenario. However, the appropriate method of volume calculation relies heavily on the topology of the surveyed area and the goals for volumetric estimation. In the case of a damaged roadway, the best approach for determining fill volumes may be to calculate the void area below the known constant elevation of the road surface.

The results of this assessment demonstrate that a lightweight commercial UAS has the potential to provide estimates of volume with enough accuracy to be considered a valid resource for disaster response and recovery. The 3D surface models generated from aerial images captured by the Sensefly eBee are comparable to data collected by a terrestrial LiDAR sensor. Volume estimations by UAS using the cut reference method are within 4% of the values calculated with LiDAR data for two types of features. Clearly, this system is able to provide estimates of volume with more accuracy than “eye- balling” by a field engineer. In addition, the lightweight platform of a UAS allows for on-site data collection to be carried out in a fraction of the time of a LiDAR scan or traditional survey. The ability to remotely survey an area from a secure nearby location is also an advantage over more traditional techniques that require a crew on the ground. Applied to a post-disaster scenario, this inherent capability of UAS could reduce potential safety risks and hazards for members of the agency involved in the response. In conjunction with the ability of these systems for rapid and repeated deployment in the immediate aftermath of a disaster event, UAS can allow disaster response to be carried out in a more immediate timeframe with increased precision and reduced cost.

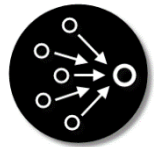
TASK 5 - DEVELOPMENT OF WEB PORTAL DECISION SUPPORT TOOL

The response to Tropical Storm Irene was hindered by the difficulty in getting imagery from the field into the hands of decision makers and GIS professionals. The UVM Spatial Analysis Lab spent many hours converting files into maps or other deliverables that could aid in the response. The project team recognized that their automated damage detection system would benefit greatly from a web based portal. This tool would allow responders and decision makers to utilize the data produced from the automated system without having to procure special software or struggle finding compatible file formats.

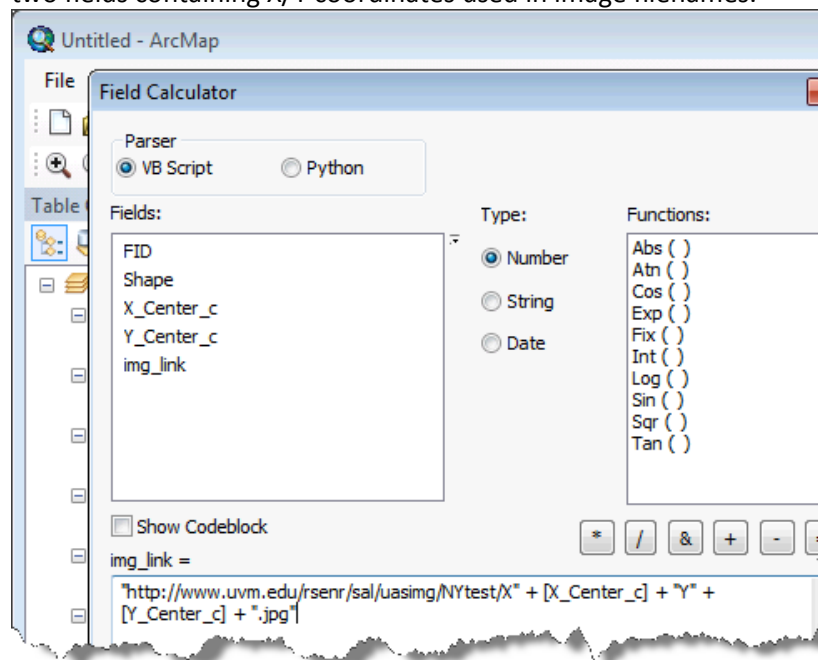
A web-based decision support tool was developed to display the results of the automated damage detection system using three online platforms, allowing for a flexible yet robust implementation. A manual on how to implement the web-based decision support tool was published to the web site and is attached as an appendix. The web-based system allows nontechnical GIS and remote sensing users to access data quickly and easily.

Several alternatives are available for creating a simple map display that allows easy access to imagery snapshots from damage detection point locations. All of the options described here rely on initial processing in ArcGIS Desktop, but other data conversion tasks necessary for web map development could be achieved by using other techniques

(e.g., creating a KML file from scratch by using the point coordinates embedded in snapshot filenames). Use the following workflow to prepare a clickable map in ArcGIS Desktop that can optionally be viewed or published in Google Earth, Google Maps or arcgis.com, a.k.a. ArcGIS Online (AGOL):

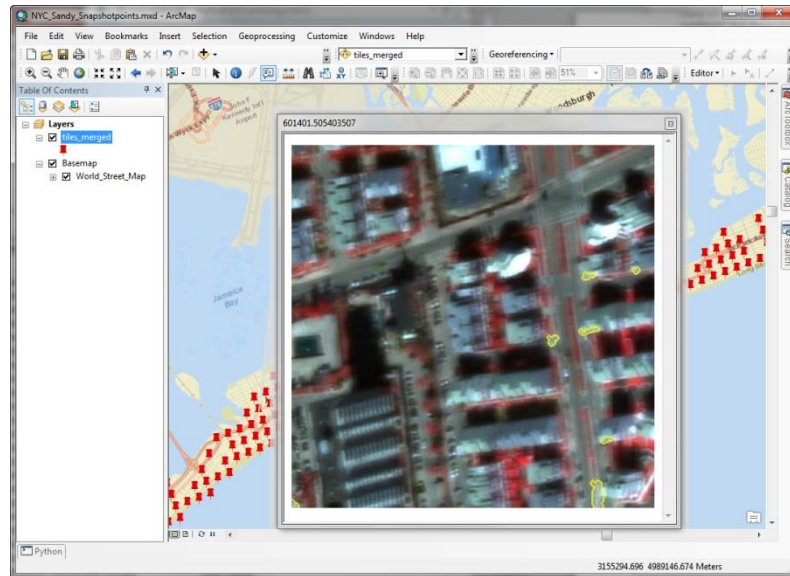


1. Copy image files from the ImagerySnapshots folder to a web server so that they will be accessible via web browser.
2. Merge shapefiles of snapshot point locations into a single layer (using the Merge tool in the ArcGIS Data Management -> General toolset).
3. Add a text field for storing hyperlinks to imagery snapshots in the attribute table of the merged points layer. Field width will need to be large enough to accommodate the hyperlinks. Populate this field with hyperlinks constructed from the web server URL and the two fields containing X/Y coordinates used in image filenames.





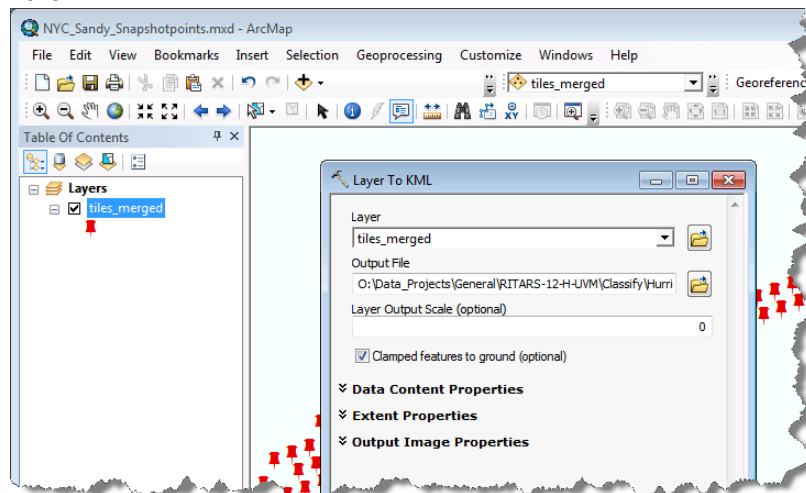
4. Open layer properties for the merged points and enable HTML Popups using the image hyperlink field created in the previous step. This results in an ArcMap display with point locations that can be clicked to display the imagery snapshot for a point of interest.



- 5.



6. Option 1: Use the KML to Layer tool (in the ArcGIS Conversion Tools -> To KML toolset) to export the merged point layer to KML/KMZ. The resulting output file is ready for use in Google Earth.



Creating a Google Map with the KML output requires additional steps:

7. Sign in to Google Maps and navigate to "My Maps" via the menu button attached to the search box.
8. Create a new map
9. Import the KML/KMZ file.

10. Name and style the map as desired.



11. Option 2: From ArcMap, publish the merged point layer to AGOL as a feature service (and create/style a web map if desired):

12. In ArcMap, pulldown File -> Sign In and enter your AGOL credentials.

13. Pulldown File -> Share and select Share as Service.

14. Set the Capabilities to Feature Access and allow Query options (at minimum).

15. Complete the Name, Description, Tags and other fields, as necessary.

16. Click the Analyze button to check for any potential issues, then Publish the service.

17. In a web browser, sign in to AGOL and view the resulting feature service. This layer can now be viewed, shared or used to create a web map in AGOL.

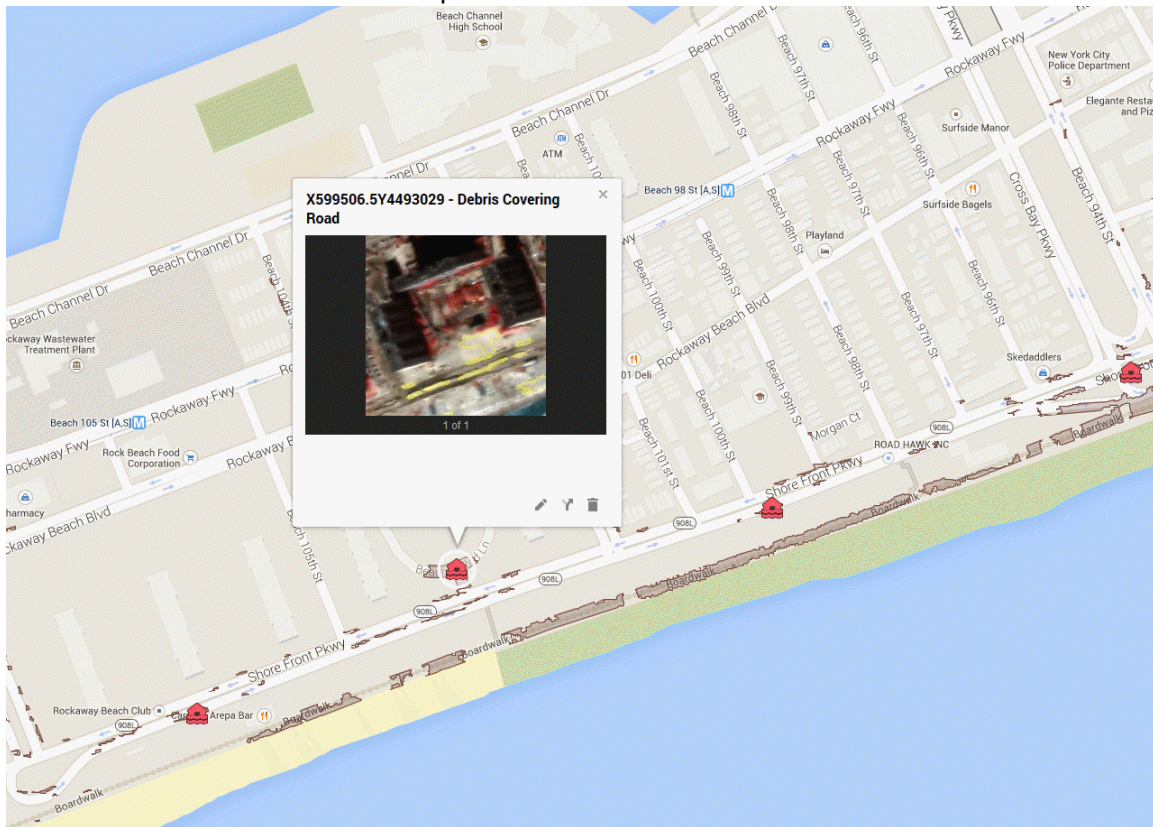


Figure 28. Web-based decision support interface.

TASK 6 - PROJECT OUTREACH AND COMMUNICATION

The aforementioned tools, methods, and corresponding videos and documentation were made available through the project web site (<http://www.uvm.edu/trc/rapid-exploitation-of-commercial-remotely-sensed-imagery-for-disaster-response-recovery/>)

Our outreach efforts were multifaceted and consisted of push efforts by us to get in front of targeted audiences with a vested interest in this topic as well as pull efforts such as keeping all presentation and documents available on our website. The team was able to reach out to many external entities through social media, the website, webinars, in person presentations at local and national conferences, and during flight operations. Key accomplishments include four blog posts, three videos, four technical documents, nine presentations, and two publications.

Numerous informal briefings were given to the Vermont Agency of Transportation, the Vermont Agency of Natural Resources, the Vermont National Guard, the Vermont Department of Homeland Security and Emergency Management, Regional Planning Commission, Local Emergency Planning Commissions, and elected officials, and local transportation planners.

CONCLUSION

This project succeeded in meeting its two main objectives. The first, to automate the detection of damaged transportation infrastructure from commercial satellite imagery was accomplished through the development of software that provides users with limited remote sensing expertise the ability to rapidly locate areas of damage. The second objective, to develop techniques that enable the volume of fill needed to repair damaged roadways to be estimated from data collected by UAS, was accomplished through the integration of commercial UAS hardware and geospatial software. Perhaps most importantly, the UAS work conducted as part of this project laid the foundation for UAS operations in support of transportation decision support in State of Vermont.

This project has provided several tools to assist local, state, and federal agencies respond to disasters and has opened a dialog about future UAS missions and opportunities. The UAS has proven itself to be a versatile and efficient platform capable of providing decision makers rapid and accurate information which will lead to better disaster response and ensuring a safer Vermont.

MEETINGS

LIST OF ADVISORY COMMITTEE MEETINGS

- 3/19/2013 Meeting. Meeting minutes and webinar recording are provided on the project website.
- 12/6/13 Meeting. Meeting minutes and webinar recording are provided on the project website.
- 6/12/15 Meeting. Meeting minutes are provided on the project website.

LIST OF MEETINGS WITH THE USDOT PROJECT MANAGEMENT TEAM

- 1/15/14 Meeting. A technical and financial update was provided to Caesar Singh and Vasanth Ganesan. The meeting minutes will not be posted to the website due to the detailed level of information exchanged in the meeting.
- 8/8/14 Meeting. The USDOT Project Manager, Caesar Singh, visited the University of Vermont. The visit included a demonstration of the UAS flight and post-processing procedures. It also included a discussion of a Modification to the original proposal. The modification would act as a Phase II and would focus on more flights that demonstrate the versatility of the UAS, as well as establishing a process whereby it can be incorporated into State Agency operations.
- 1/12/15 Meeting. The project team met with Program Manager Caesar Singh for the Annual Project Progress Meeting. Principal Investigator Jarlath O'Neil-Dunne presented on project updates and the roadmap to completion. The meeting minutes will not be posted to the website due to the detailed level of information exchanged in the meeting.
- 4/29-30/2015. US DOT CRS & SI Workshop in Oklahoma City, OK.

PRESENTATIONS

- Emerging Remote-Sensing Technologies for Studying the Vermont Landscape. December 12, 2013, University of Vermont, Burlington, VT
- Rapid exploitation of commercial remotely sensed data for transportation damage assessment. January 12, 2014, Transportation Research Board, Washington D.C.
- Rapid Assessment of Storm-related Damage Using Commercial Remote-sensing Imagery. May 8, 2014, Geospatial Information Systems for Transportation Symposium in Burlington, VT.
- Rapid Exploitation of Commercial Remotely Sensed Imagery for Disaster Response & Recovery. June 6, 2014. University of Vermont Transportation Research Center, Brown Bag Lecture Series, Burlington, VT
- Unmanned Aerial Systems for Disaster Response and Recovery. May 6, 2014, Geospatial Information Systems for Transportation Symposium, Burlington, VT
- Unmanned Aerial Systems for Disaster Response and Recovery. July 16, 2014, Office of the Assistant Secretary for Research and Technology (OST-R) Transportation Innovation Series, Washington DC.
- Commercial Unmanned Aerial Systems for Transportation Decision Support. January 11, 2015, Transportation Research Board, Washington D.C.

- UAS for Transportation Decision Support. DOT CRS & SI Workshop, Oklahoma City, OK
- A Tool for the Automated Detection of Damaged Transportation Infrastructure. May 7, 2015, Imaging & Geospatial Technology Forum, Tampa, FL.

PUBLICATIONS

- MacFaden, S.W. and J.P.M O’Neil-Dunne. 2015. A Tool for the Automated Detection of Damaged Transportation Infrastructure. *Proceedings from the Imaging and Geospatial Technology Forum*, Tampa, FL, May 4-8, 2015.
- O’Neil-Dunne, J.P.M. A. Zylka, and S.W. MacFaden. In Review. A Methodology for Fill Estimation of Damaged Roadways Using UAS. *Urban, Planning, and Transport Research*.

PARTNERSHIPS

The Project Team collaborated not only with the project’s Technical Committee, but the following organizations as well:

- Vermont Agency of Natural Resources. The project team worked with ANR on their stream monitoring program. The discussions focused around using Unmanned Aerial Vehicles to monitor sections of rivers and streams that are difficult to access on the ground. After Tropical Storm Irene, it was determined that debris which had accumulated upstream was forced downstream and caused severe blockages.
- Vermont Agency of Transportation. The project team worked with the Maintenance and Operations Department at VAOT on their culvert maintenance program. The discussions focused on what is happening upstream which may be causing culverts downstream to become blocked. This working is being continued under the Vermont Research Advisory Council (RAC) Program project: “Using Remote Data Collection to Identify Bridges and Culverts Susceptible to Blockage During Flooding Events.
- Department of Emergency Management and Homeland Security. The project team is working with DEMHS on their critical infrastructure program. The discussions have been focused on how UASs and GIS data can be used to determine what should be considered critical infrastructure, and how to maintain and protect it better in the future. The project team also conducted a demonstration of the UAS flight operations to DEMHS. The project team will be participating in the VT DEMHS and VT National Guard exercise, Vigilant Guard 2016, putting their Disaster Response capabilities into practice and further solidifying their ties with the emergency management community.
- Green Mountain Power. The project team met with Green Mountain Power to determine ways that a UAS could be incorporated into their processes and procedures.

- Vermont Department of Environmental Conservation. The project team worked with Todd Menees, P.E., P.H., a River Management Engineer in the Watershed Management Division of the Rivers Program at VT DEC, flying sites eligible for Hazard Mitigation Grant Program (HMGP) Buyout money through FEMA. The homes demolished by Irene are removed and the flood zone needed survey data to determine how to re-stabilize the banks.
- Town of Readsboro. The project team assisted the town by acquiring UAS data of an area damaged by flooding. The data is being used by the town for transportation and disaster response planning.
- Town of Wardsboro. The project team assisted the town by acquiring UAS data of an area damaged by flooding. The data is being used by the town for transportation and disaster response planning.
- Windham Regional Planning Commission. The project team assisted the commission by acquiring UAS data of an area damaged by flooding. The data is being used for transportation and disaster response planning.
- UVM, Dr. Jeff Frolik. The project team was able to borrow a Terrestrial LIDAR scanner from Dr. Frolik for use in the fill estimation validation task. The Terrestrial LiDAR scanner was obtained through a previous National Science Foundation Grant.