USE OF AN UNMANNED AERIAL VEHICLE (UAV) TO ASSESS TRANSPORTATION INFRASTRUCTURE, IMMEDIATELY AFTER A CATASTROPHIC STORM EVENT

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ABSTRACT

From September 29 to October 1, 2015 over 200 mm of rain deluged parts of southern New Brunswick. The catastrophic rain event washed away bridge size culverts and conventional bridges, including the surrounding soil and asphaltic concrete pavement. Also erosion encroached on the driving lane of road and highway embankments at over 100 locations. Several homes and businesses were left stranded. A fast and efficient means was required to assess the impact on infrastructure after the storm. This paper presents the procedure and outcomes of using digital imagery captured with Unmanned Aerial Vehicles (UAVs) for post-disaster assessment. The use of a UAV to gather site images, at hard to access locations, allowed for the timely prioritization of needs and allocation of limited resources to areas most urgently in demand of emergency repairs. High quality aerial images were processed using commercial software specifically designed for the creation of 3D models and orthomosaics from aerial photos. This information, along with ground-level panoramas communicated the current condition of assets and roads. It provided engineers with the ability to complete initial assessment, create 3D models for design, and provide highly qualitative evaluation records. The successful use of a UAV for this storm event was preceded by other uses of UAVs for asset management within the New Brunswick Department of Transportation and Infrastructure.

Keywords: Unmanned Aerial Vehicle, post-disaster assessment

1. INRODUCTION

The University of New Brunswick's Construction Engineering and Management Group (UNB) and the New Brunswick Department of Transportation & Infrastructure (NBDTI) have been collaborating on the application of Unmanned Aerial Vehicles (UAV) since the spring of 2015. This collaboration studied the use of UAVs as an inspection tool for difficult to access sites including: one retaining wall, two cable-stay bridges, one arch bridge, one rock slope, and most recently as an impact assessment tool after a serve rain storm.

The use of UAVs is becoming prevalent with various transportation departments conducting pilot projects focused on the application of UAVs for inspecting infrastructure. According to Zink & Lovelace (2015) the Minnesota Department of Transportation inspected four bridges with a UAV and made several observations including that a UAV can be used to safely conduct inspections and collect detailed information that is equivalent to close up photos in a cost effective means. The Florida Department of Transportation also sponsored a study completed by Otero et al. (2015) that concluded that UAVs provide significant benefits for inspection purposes.

Ferguson & Waugh (2015) completed a literature review which included the application of UAVs and found that research on the applications of UAVs began to increase in 2011 and that there exists a range of disciplines exploring the benefits that are offered by UAVs, including the use for post disaster scenarios. Adams et al. (2012) used a UAV to collect images after a tornado in Alabama, USA of a neighbourhood for post disaster field studies . The case study resulted in images with a Ground Sampling Distance (GSD) of 0.007m and significantly improved the ability to assess buildings and the neighbourhood. Yamamoto et al. (2014) used a UAV to rapidly collect aerial images to conduct a survey that resulted in 3D data and drawings of two river sites impacted by heavy rainfall in Japan.

2. EVENT DESCRIPTION

Between September 29 and October 1 2015 southern New Brunswick (Figure 1) was hit with a serve rain-driven storm that had a major impact on the road network. With over 200mm of rainfall in the areas shown in Figure 2, major flooding devastated the local infrastructure. The rain storm has been classified as up to a one in 200 year storm in areas with the highest precipitation. There are six transportation Districts in New Brunswick and two Districts were heavily impacted by the rain event. The reported damage, 3 days after the heavy rainfall at District Five, included 46 partial road embankment failures and 28 full width road failures. From District Four, the reported damage included 52 partial embankment failures and 31 full width road failures.

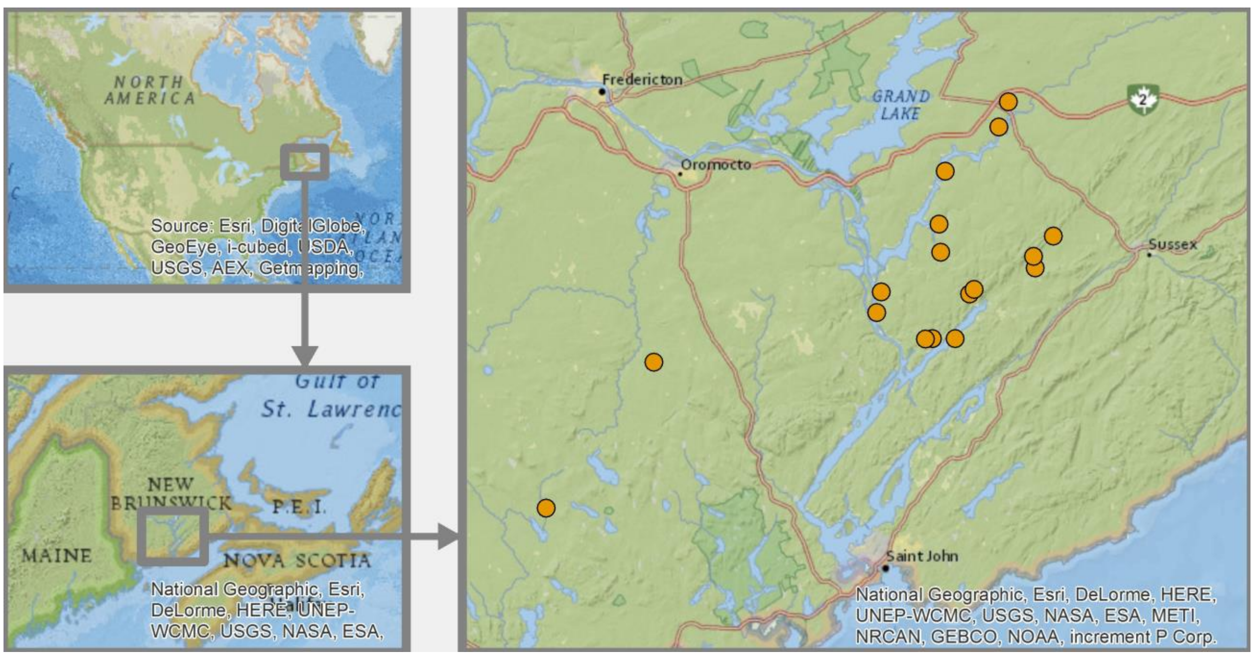

Figure 1: Base Map - Showing 17 UAV Site Locations

Instructions were given to the District crews to make repairs to road embankments as quickly as possible. For partial road failures, repairs could be made while leaving one lane open to traffic. For full width embankment failures, traffic was redirected to posted detour routes. Various roads were closed because portions of bridge decks were displaced or the bridge abutments were disturbed. Generally, the full width embankment failures occurred at culvert locations. In order to re-open many roads quickly, it was decided that:

- where the road was washed away and the culvert showed no signs of deformation, road embankment fill could be placed to match the original road grade.
- if the culverts were damaged and were less than 1600mm in size, it was replaced with the next larger size of a concrete culvert pipe.
- All other sites would need a survey and a hydraulic design to ensure replacement with proper size culvert, temporary modular bridge, or permanent bridge.

A priority list was quickly developed and consisted of approximately 20 sites. The top sites were selected that required a site visits to capture images using the UAV and can be found in Table 1. Additional sites were documented with the UAV, with all sites plotted in Figure 1. The highest priority sites were in order of the urgency for site information and repair. Top sites may not have had a detour or any other access. Some of these sites had property owners and businesses isolated and waiting for NBDTI to provide access. All sites had full culvert and embankment failure with the exception of asset K430, which had the bridge deck displaced. All proposed repairs began soon after Oct 8, 2015, expedited by the UAV assessment.

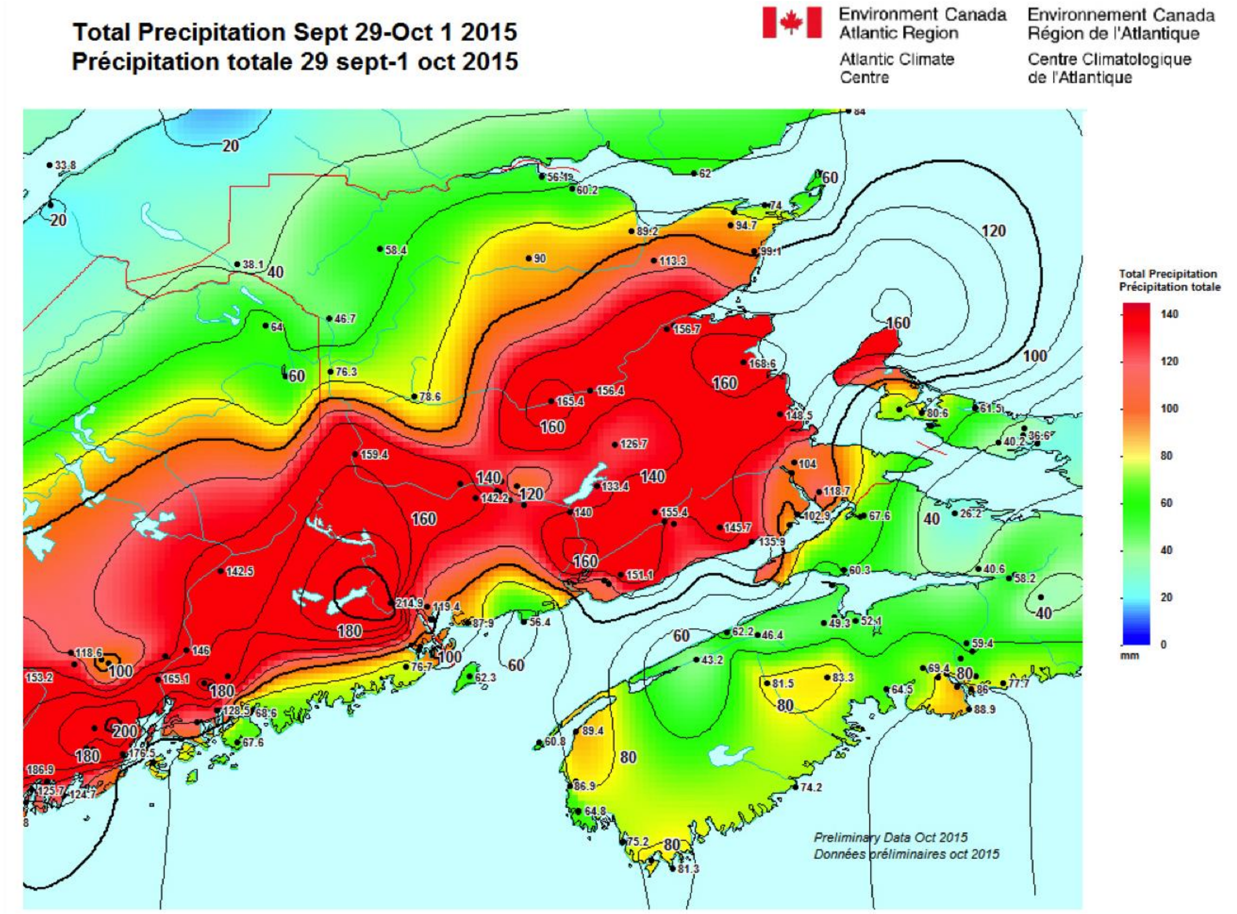

Figure 2: Total Precipitation

Table 1: Select UAV Sites – Previous & Proposed Structures

Asset #	District	Priority	Previous Structure	Proposed Structure
TB06	5	9	CSP	Steel Bridge Deck: Length 30m
C140	5	7	SPCSP Arch	Steel Bridge Deck: Length 30m
N810	5	8	SPCSP Pipe	Steel Bridge Deck: Length 33.53m
QX06	5	6	SPCSP Pipe	Reinforced Concrete (RC) Pipe: Diameter 2400mm
K300	4	2	Steel Stringer	Panel Bridge: Length 28.81m
F770	4	3	SPCSP Arch	RC Pipe Twin: Diameter 2400
S225	4	4	RC Arch	RC Box Twin Box: Cross Section 2400mm
J360	4	5	Steel Rolled Beam	Panel Bridge: Length 24.38m
K430	4	1	Steel Stringer	Panel Bridge: Length 24.38m

The impact was the greatest on large infrastructure such as bridges and large culverts due to the long duration of the storm. Long duration storms typically do not impact small culverts because the flow is spread out over the storm duration and results in a constant, manageable flow. However, due to a long time of concentration, when the accumulated rainfall reaches larger watercourses, the flow exceeds the capacity of large culverts or bridges. A short duration storm will have a greater impact on smaller culverts because the high intensity storm will result in a flow that quickly exceeds the design flow, but the short duration storm will have a minor impact on larger culverts and bridges.

3. METHODOLOGY

From the previous UAV work, it was speculated that deploying a UAV for image reconnaissance would be potentially beneficial to rapidly collect high-resolution overview images and site specific details in remote locations. An ad-hoc decision was made the morning of October 2 to use a UAV as an assessment tool and within hours of the decision, the first flight was conducted. This resulted in little time for flight planning and as a result, flight operations were revised and optimized throughout the three days of data collection. The following sections outline the equipment used, the data collection and improvements made, along with the delivery interface.

3.1 Equipment

The UAV used was a Phantom 3 Professional (P3P) manufactured by DJI (www.dji.com). The UAV is a quadcopter that is controlled by a remote controller (RCt) which uses a phone (iPhone 5S for this case) or tablet as the control device through the manufacture's app (DJI GO). Using the control device, the aircraft and camera settings (ISO, shutter speed, camera angle, etc) can be adjusted, along with a live stream from the camera. The camera is mounted on a 3-axis gimbal attached to the aircraft and captures 12MP stills and records up to 4K video. Figure 3 shows the UAV, RCt, and the control interface. A canon 60D camera with a 20mm lens mounted on a virtual reality panoramic head attached to a tripod was utilized to capture ground level panoramas. The camera captures 18MP stills and the panoramic head provides the ability to capture a 360^0 view.

Figure 3: P3P & RCt

3.2 Data Collection

Once the decision was made to use a UAV to collect data, the conditions and constraints of UAV operations were reviewed to determine that it was possible to use a UAV for the reconnaissance project. The relevant limitations included: weather conditions, traffic & regulations, and mobilization. The weather conditions were not a limiting constraint because the storm had passed. As a result there was no precipitation, low wind speeds, and the temperature was within the UAV operating temperature. Current regulations in Canada require that no flight take place within "30m from people, animals, buildings, structures, and vehicles that are not involved in the operation" and requires that no flight take place within 9 km of an airport and the flight altitude must be below 90m (Transport Canada, 2014). The majority of the sites were in remote areas or not within 30 m of buildings. Persons in 30m of the area of the interest were notified that a UAV would be in operation and the UAV was not within 30 m of buildings or structure not involved in the operation. All sites that were being investigated were culvert or bridge washouts, therefore there was no traffic on the roadways. As a result, no flight took place within 30m of vehicles. Also no flight was within 9 km of an airport and the flight altitude was limited to 90m and visual line of sight (VLOS) was always maintained. Mobilization of a UAV operation does not require significant resources, however multiple washouts occurred on a single route and to maintain VLOS it was required to walk to sites that were located in between washouts.

Figure 4: GCP Marking

The first step at each site was to paint Ground Control Points (GCP); they were distributed across the site. The GCPs were surveyed at a later date by high accuracy positioning survey methods. The GCP markings were painted throughout the site with at least five points per site and each point in at least three images. A cross (see Figure 4) was determined from previous operations to be the best symbol as it is easily identifiable in post processing. With GCPs marked, a flight plan was then created. This consisted of creating a grid to capture images with a 75% overlap between images. This was completed by drawing a scaled grid on the UAV map in the control device. A spreadsheet was developed to determine the required grid spacing to achieve a 75% overlap based on the altitude of the UAV and the camera sensors. Once a grid was created the flight was completed to capture vertical (or nadir) images at each grid intersection. The procedure of drawing a grid on the manufacture's app was required because a third party flight planning app was not updated to include the P3P. Once the images were captured for the creation of a 3D model, overview images were captured. Vertical overview and oblique perspective images were collected at a max altitude of 90m to capture a site overview, as well lower altitudes images of site specific details were captured. Finally, on select sites, video was captured of the site to simulate a car driving on the road. While traveling between sites, the batteries for the UAV as well as the control device were charged using a power converter in the vehicle. This was identified to be necessary from the start of the project and as a result no operation was delayed because of low batteries.

During the first two sites, the grid was created and did not extend over the entire area of interest or was on the opposite side of the point of interest. This error occurred because several of the washouts were located in remote areas that did not have a distinguishable land features that appeared on the interface map. Therefore, it was determined that it would be more efficient to capture the overview images before creating the grid. It was beneficial to capture overview images first, because it simplified the grid development process by identifying the boundaries of site during the overview flight. It was later determined that the video taken should have been captured in 1080p quality because a standard NBDTI computer is not currently capable of viewing 4K video because of the required computing power. It was also an issue in some cases that the video would become corrupted and was later determined to be a hardware issue with the UAV. Oblique images of the downstream area would have been beneficial, these images were captured at later sites when a standard flight plan was developed. After the first day of data collection it was decided that panoramas would add value for the documentation of the site to provide ground level visualization details. At major sites, one or two panoramas were captured onsite. Panoramas were taken at the edge of the washout along the road and if it was feasible a panorama was taken at stream level where the culvert had previously existed.

3.3 Delivery Interface

The delivery interface that was used to present the data was developed by UNB. The Virtual Reality Documentation (VR Doc) interface is a web-based interface that provides users the ability to access information via the web. It was originally designed for progress monitoring of construction sites (Waugh et al. 2007). The interface was recently updated to deliver visual inspection data collected from a UAV as part of previous work between UNB and NBDTI. Different icons were created to represent image direction and perspective, as well as to distinguish between images and panoramas. Hotspots were also added to link a large overview area to specific detailed images.

A password protected interface was created for this project and access was provided to select NBDTI employees. At the end of each day all the images were downloaded from the UAV SD card and separated by project and image type. For each day of operation a separate Google Earth map was created and all sites were plotted on the map to represent the location over a large geographical area as seen in Figure 4 (see Figure 1 for a full view of the area with all UAV inspected locations). For each site, Google Earth images were also used as a map to plot all the overview images to show their relative location. Each site map is represented in an individual tab and was labelled according to its asset number (if known at time of site visit), otherwise it was labelled according to the site visit sequence.

The panoramic images were also downloaded from the camera SD card. The images were first corrected for distortions before being stitched together. Stitching errors were then corrected before exporting the cropped image and converting the cropped image into a virtual reality file. This was all completed immediately following the collection of the data to provide rapid access for key users.

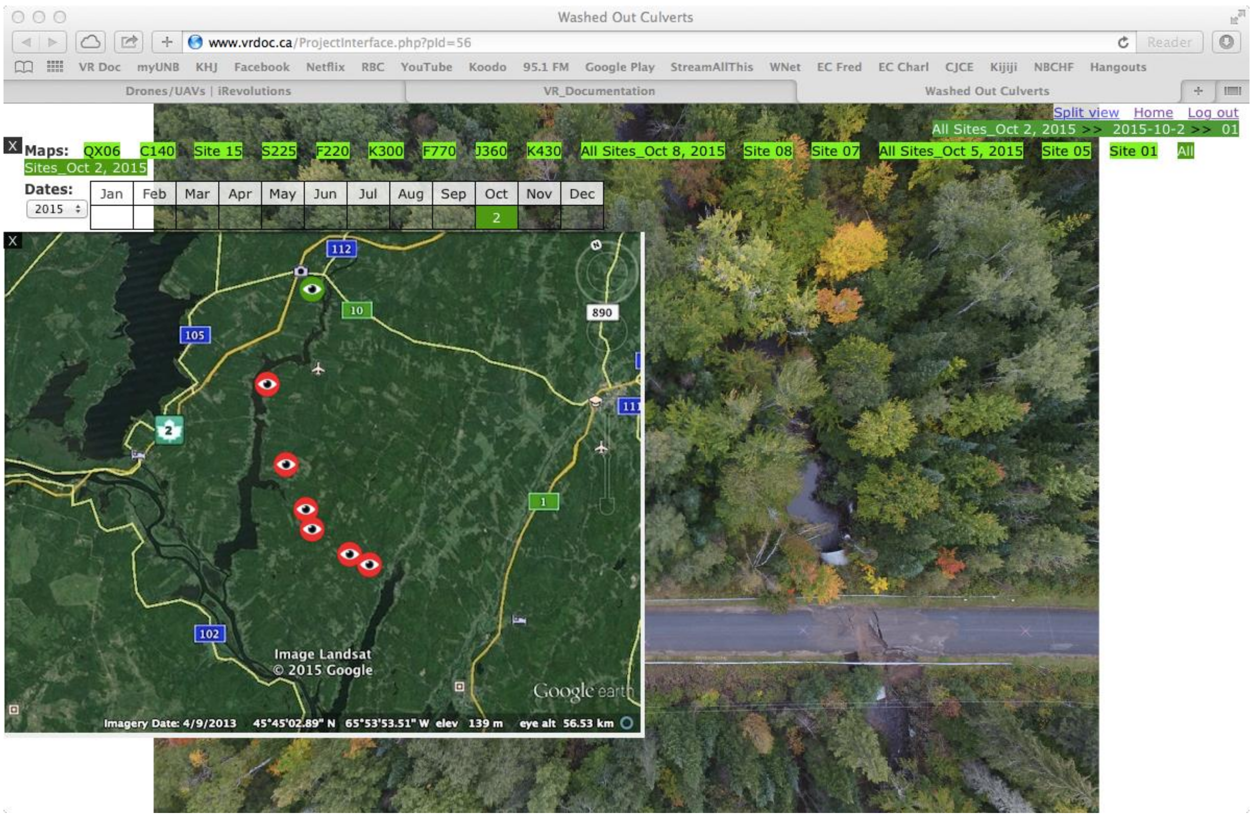

Figure 4: VR Doc Site Overview

4. VALUE

The collected images provided an aerial perspective that was previously impractical to obtain. The initial value of the collected data was an aid for the initial assessment to determine the impact of the storm. Once the images were processed to create a 3D model, then they could be used in the design phase, as well as for further advantages such as long term evaluation records.

4.1 Initial Assessment

The initial value was immediately recognized by NBDTI managers, directors, and key decision makers. The imagery was uploaded onto VRDoc immediately following the data collection and access was provided to select NBDTI employees, providing them with the ability to view the site status. By plotting all sites on an overview map as seen in Figure 4 it was possible to understand what routes had the largest impact. Overview images of each area showed the extent of the damage and the upstream and downstream area as seen Figure 5. Figure 5 also provided the ability to view the culvert as it was washed almost 100m downstream and was out of view from the roadway. The panoramas that were collected on selected sites as seen in Figure 6 provided the ability to see the impact at the ground level in a virtual reality mode. The results provided decision makers that were unable to see the site in the field with ability to quickly recognize the impact and the damage through the rapid collection and delivery of the data. As a result decision makers were able to complete a triage of the damage and were able to better assess the areas in urgent need and direct the limited resources available. This resulted in a faster decision making process that accelerated the recovery after the storm event.

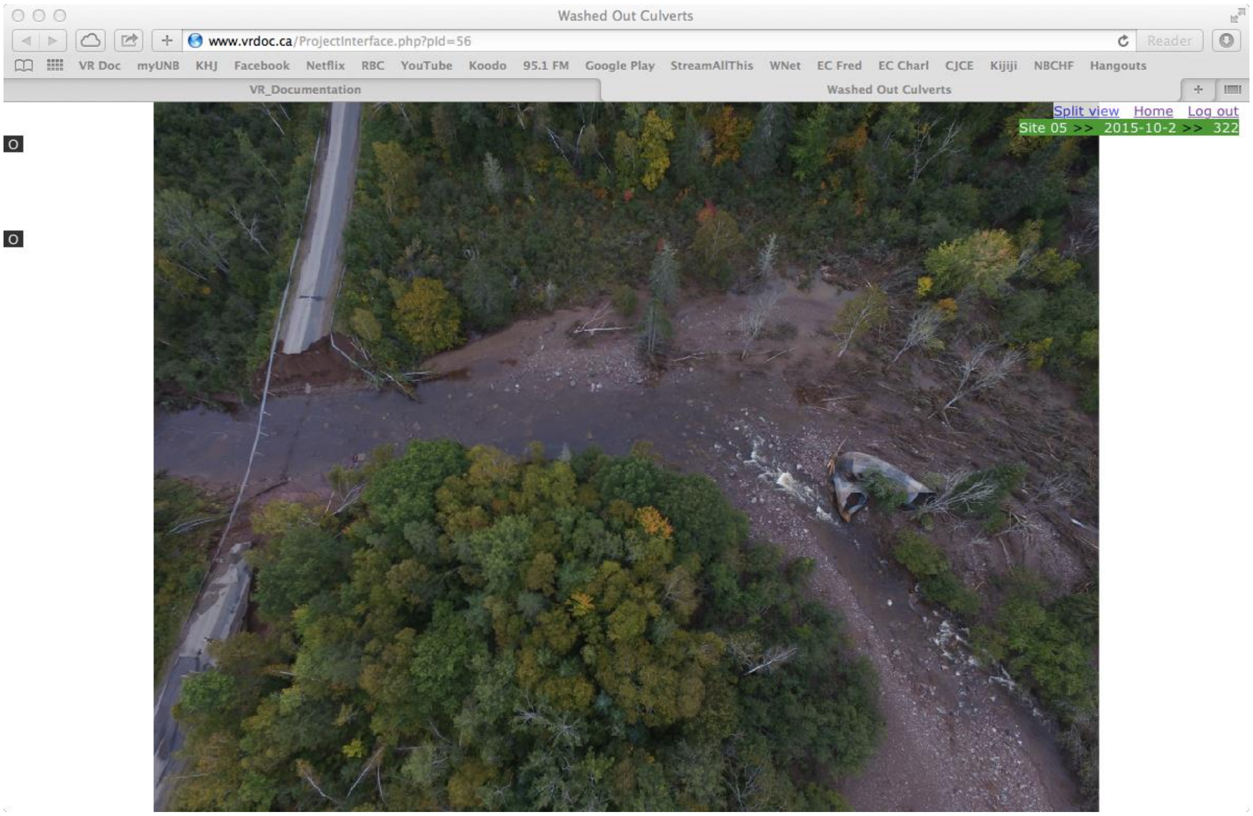

Figure 5: Downstream Overview

4.2 3D Modeling and Orthomosaics

After the initial assessment, the images that were collected for the purpose to create a 3D model were processed using aerial photogrammetry software Pix4D (www.pix4d.com). This software processes aerial images and creates a 3D model including a point cloud, mesh, and orthomosaic. By using computer visioning techniques the software can identify and match thousands of common pixels in overlapping images. Then by utilizing photographic processing algorithms it extracts the geometry of the camera positions and consequently can generate 3D models and orthorectified maps. The spatial accuracy of the model is increased with the use of GCPs. The GCP were collected by high accuracy positing methods and were inputted into the model which increases the accuracy of the model to within 2-6 cm. The resulting model can be exported in various formats, with the point cloud capable of being exported in LAS, LAZ, XYZ, and PLY. The data storage requirements for the models can range from 2GB to 20GB per project file. The models were created a week after the images were collected and were intended to be used for design of new structures.

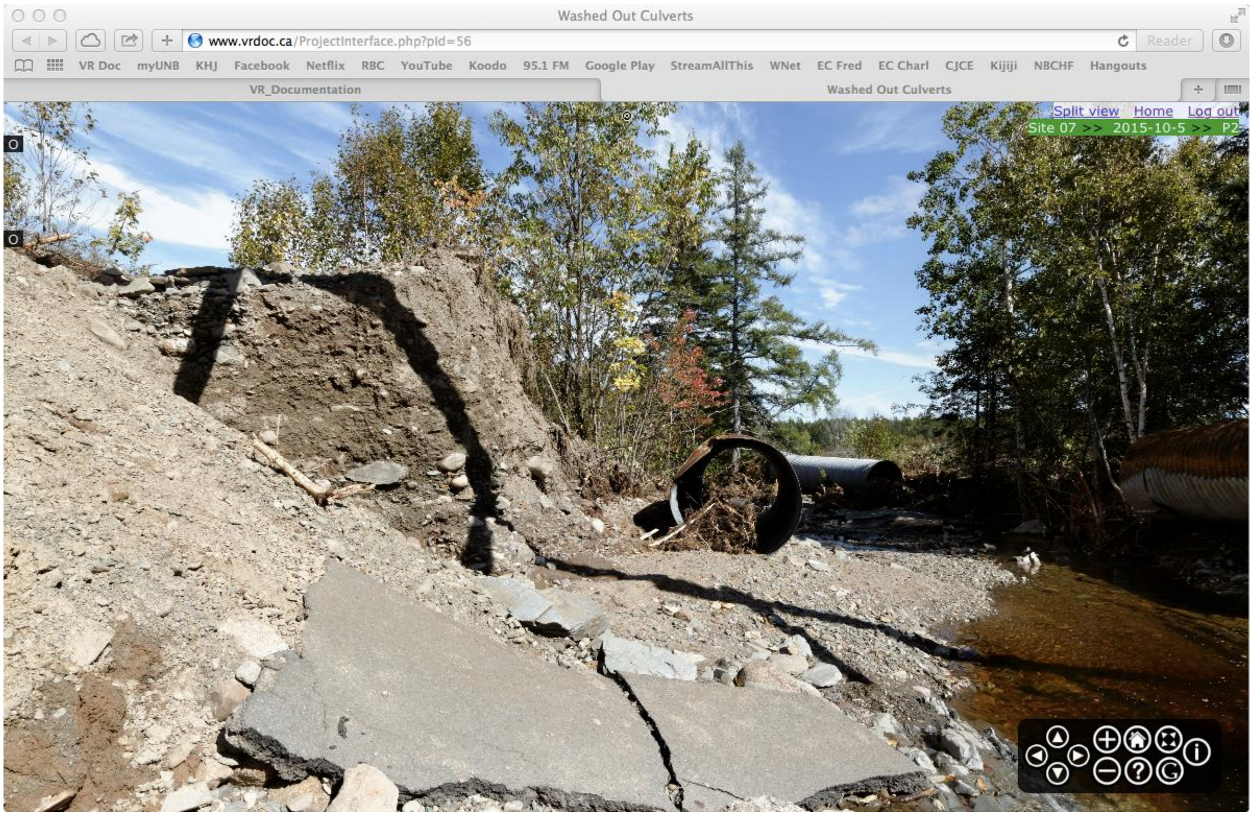

Figure 6: Site Panorama

The resulting models of the various sites provided some added value in the design phase. The high resolution images provided an aerial perspective of the site that is not possible through traditional methods and provides a new perspective versus traditional topographic ground surveys. However, the current computing resources and processing workflows were not optimal and the advantages of the 3D model were not utilized to the full extent in a CAD design working environment. Transportation infrastructure design is moving from a paper-based 2D plan and profile workflow to digital 3D models (Olsen et al. 2013).

The orthomosaics that were created from the aerial photography were used as a high resolution background image by survey engineers to enhance the topographic line survey for each site as seen in Figure 7. A fully detailed topographic survey was not conducted at the washout sites. The topographic surveys for these sites were limited in detail since the survey crew resources were spread thin in an effort to acquire survey data from many sites in a limited time frame. Additionally, washout sites were unstable in some locations and washout debris limited the ground access for the topographic survey. This provided design engineers with a highly detailed and comprehensive survey of the washout site that could be used in the design phase of replacement culverts. As shown in Figure 8 the orthomosaic was also used by design engineers to indicate replacement details using scaled measurements. The site was easily communicated to design engineers and preliminary drawings could be quickly developed to identify replacement details such as the approximate abutment locations and rip-rap placement to begin the design phase. Details such as the washout sediment, location of the damaged culvert, guiderail, temporary structures, and the extent of the road asphalt damage were clearly visible in the augmented plans. The beneficial opportunity of this product can lead to more informed decision making and better use of scarce resource, especially for rapid response to emergency situations (Olsen et al. 2013), such as seen in this case study.

4.3 Evaluation Records

The value of the data set also provides accurate visual and spatial data for long-term records. These records provide high qualitative information that can be used for disaster relief funding applications. The high-resolution images provide a means to communicate the full extent of the damage to other agencies. These records are also useful for future work. The images also provide an accurate representation of the environmental impact of the washouts as sediment washed downstream can easily be seen from the aerial images.

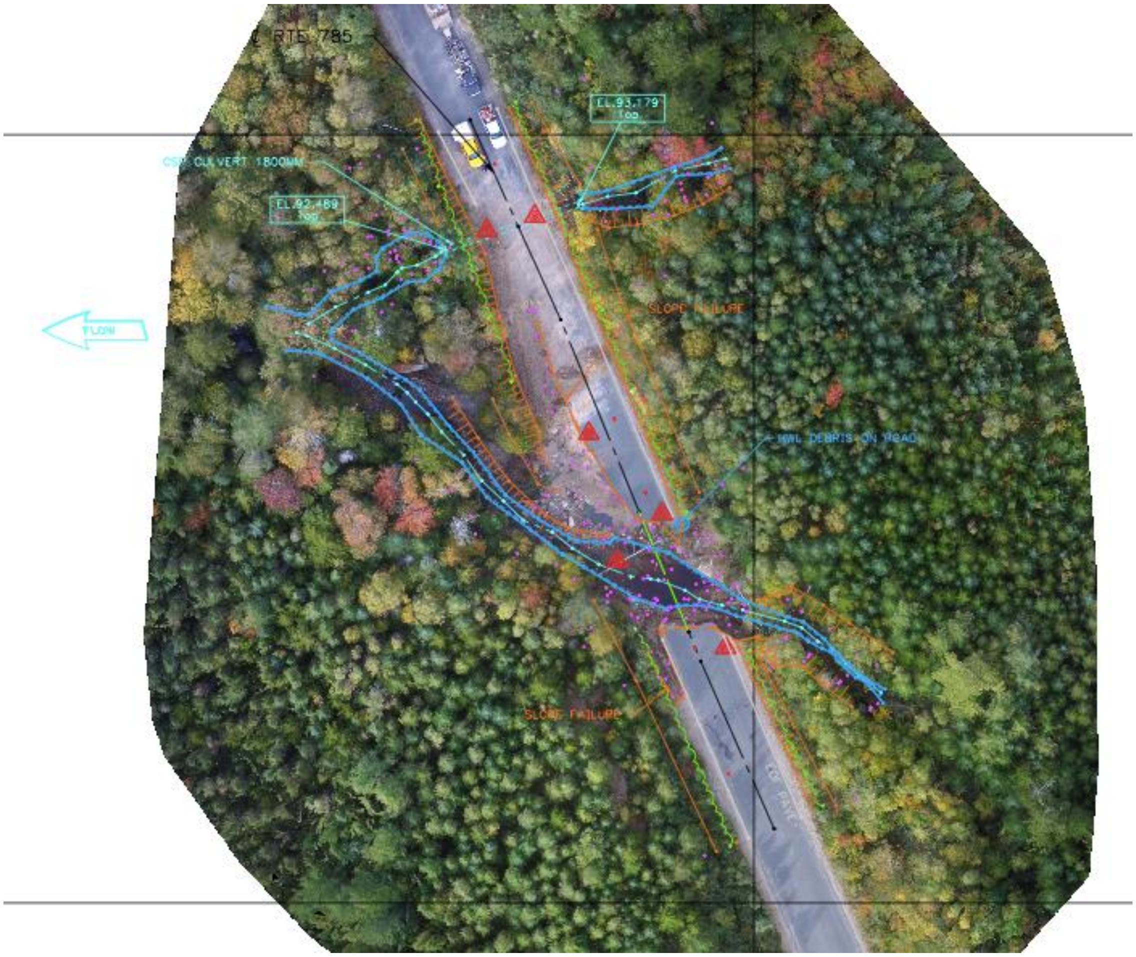

Figure 7: Augmented Line Survey

5. CONCLUSION

The use of UAVs within Department of Transportations (DoTs) for various applications such as post-disaster scenarios is being studied by select DoTs, including NBDTI through collaboration with UNB. The rain-driven storm event between September 29 and October 1, 2015 had a major impact on southern New Brunswick’s road network. Aging and under-resourced infrastructure can not withstand major storms. This storm had a major impact on large infrastructure. However, even if maintenance was completed regularly, it is estimated that the impact would have only been reduced by 30% because of the storm duration.

The decision to use a UAV to collect site overview images and images to create a 3D model, provided value for initial assessments, 3D modeling, and evaluation records. The rapid collection of data provided key decision makers the ability to quickly assess the impact of the damage and accelerate the recovery process. The creation of the 3D models provided added value during the design phase. However, a detailed workflow should be created to better utilize the advantages that a 3D model from aerial images offer, including the augmentation of a topographic line survey over an aerial orthomosaic and the value of scaled orthomosaics for preliminary design drawings. The long term value provides qualitative record of the event that visually communicates the damage.

Disaster mitigation techniques have become normal practise to sustain aging infrastructure. The potential use of UAVs for disaster mitigation has been shown to be useful. It is recommended that future work be completed to develop a strategic plan within DoTs for the use of UAVs as an assessment tool for future storm events to maximize the potential benefits for initial assessments and the design phase. However innovative designs, quality construction, and well funded maintenance phases must be the focus to build resilient infrastructure for the future.

Figure 8: Preliminary Bridge Design

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