Evaluation of a Low-Cost Drone for Monitoring Restoration of Well Pads

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BC Oil and Gas Research and Innovation Society

by

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Executive Summary

Fieldwork was conducted in the summer and fall of 2017 to test and evaluate the capabilities of a small, low-cost drone for measuring and assessing the state of reclamation at five well pads on crown land near Hudson's Hope. A Phantom 4 Pro drone was used to fly over each well pad to capture aerial images. The images were then used to explore different ways to quantify the state of land disturbance and restoration activities under natural field conditions. In most cases, the drone was pre-configured to fly a grid pattern under autonomous control, and PixCapture software was used to setup the flight plan. The typical flying height was 50 m, and it took approximately 5 to 15 minutes of flying time to acquire the images at each well pad. No ground control targets were used so the fieldwork at each site could be very efficient. Because the drone flies under autonomous control after it takes off, the operator had a few minutes to wander around and inspect the well pad while the drone was flying.

Structure-from-Motion analysis of the acquired images was used in this research to generate highly detailed 3D point clouds, digital surface models, contour maps, and geo-referenced orthophotos. Pix4D software was used for this purpose. For the 50 m flight heights, the resulting density of points measured on the ground surface was often more than 1000 points/m^2, or the average ground sampling distance was 1.3 cm. The time required to process each set of images on a dedicated computer with a 3.7 GHz quad-core processor with 64 GB RAM ranged from about 1 to 4 hours.

Four of the well pads that were flown had only recently been reclaimed, either in the fall of 2016 or the spring of 2017. Thus vegetation was just starting to become established when these were flown in July 2017. Under these conditions, it was possible to create contour maps of the well pads with 0.25 m elevation intervals. Even lower elevation intervals would be possible for bare ground conditions. These maps can be used to assess the surface land drainage. The vertical aerial images and the resulting highly detailed orthophoto can be used to assess the degree of vegetation coverage on the well pad.

The BCOGC Certificate of Restoration Application Manual lists the site reclamation objectives need to obtain a Certificate of Restoration. These can be grouped into five categories to analyze reclamation of a well pad: geotechnical stability, land use or facilities affecting reclamation, vegetation growth, slope and drainage, and soil replacement and quality. The images acquired by the drone and the resulting 3D models can assist in the evaluation of many components of these restoration criteria. These are discussed individually for each well pad in this report. However some examples include:

- It is easy to identify the presence of visible slope movement, slumping, subsidence, or tension cracks on or around the well pad, and assess whether there are remaining cut and fill slopes.
- It is easy to determine if facilities remain on the surface of the well pad from oil and gas production or if industrial debris has been left on or around the well pad. Industrial debris was found at one well site, even though it had no road access and thus was flown from a short distance away.

- The distribution and areal coverage of vegetation on a well pad can be seen and evaluated on the orthophotos better than it can be done standing on the ground. This can aid in documentation that the 80% vegetation coverage requirement for a Certificate of Restoration has been met. Note that it is impractical to discern which small plant species are growing on the well pad using a drone only.
- The 3D topographic models made from the drone photographs can be used to evaluate minor changes in the ground topography that may not be visible from an inspection on the ground as well as to identify areas where water may pond on the surface of a well pad. It is easy to confirm that ditches have been removed.
- It is possible to confirm that salvaged soil has been spread throughout the site and there is no evidence of impact from surrounding land use. The aerial photographs may also assist in assessing whether the soil that was compacted from oil and gas development activities has been de-compacted.

In summary, the use of a drone to acquire aerial images of a well pad creates better opportunities to see, measure, and evaluate a range of restoration criteria compared to ground inspections alone. The time required in the field is no more than current site inspection times yet the data collected can be more comprehensive and valuable. Ground inspections and drone photography can be conducted simultaneously. Well operators are encouraged to conduct drone-based aerial photography and to archive the collected set of images and generated models for their well pads to have a permanent geo-referenced collection of data for various purposes including seeking a Certificate of Restoration when they are finished with the facility.

Acknowledgments

The research presented in this report was funded by the BC Oil and Gas Research and Innovation Society (BC OGRIS). Kevin Parsonage, Devin Scheck, and others from the BC Oil and Gas Commission (BCOGC) provided assistance in identifying well pads to document and aspects of concern regarding restoration of well pads in general. The project also received guidance from Brian Thomson from BCOGRIS. Wenbo Zheng from the UBC School of Engineering provided assistance during the July fieldwork. The drone and image processing software were provided by the principal investigator's (Dwayne Tannant) research lab.

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1 Introduction

Fieldwork was conducted in July and September 2017 to test and evaluate the capabilities of a small, low-cost drone for measuring and assessing the state of reclamation on five well pads near Hudson's Hope, BC. The well pads which were used were selected from a list of sites provided by Kevin Parsonage from the BCOGC. The five well pads were near Hudson's Hope and were all located on crown land. These are highlighted on the list that was sent to us as shown in Table 1.

Table 1 Candidate well pads (UTM zone 10 coordinates)

WA	Location	Company Name	Northing	Easting	Landowner
7078	COPOL W Stoddart 2-2-86-20W6M	ConcoPhillips Canada	6254841	620729	Private
19670	CE Portage D-12-H/94-B-1	Canada Energy Partners	6217361	561308	Private
21810	CE Portage 1-36-81-26 W6M	Canada Energy Partners	6213289	567463	Private
19518	CE Portage C-13-A/94-B-1	Canada Energy Partners	6207974	560259	Crown
23947	CE Portage A-24-A/94-B-1	Canada Energy Partners	6208493	559811	Crown
16176	CE PortageC-50-D/94-A-4	Canada Energy Partners	6210815	562556	Private
18592	CE TH PortageC-A50-D/94-A-4	Canada Energy Partners	6210841	562539	Private
16077*	CE Portage A-100-D/94-A-4	Canada Energy Partners	6214978	562768	Crown
16726*	CE Portage A-A100-D/94-A-4	Canada Energy Partners	6215004	562753	Crown
24673*	CE HZ Portage A-C100-D/94-A-4	Canada Energy Partners	6215038	562763	Crown
24004	CE Portage C-12-A /94-B-1	Canada Energy Partners	6208235	560702	Crown
18090	Connacher Mica 04-35-81-14 W6M	Connacher Oil and Gas Ltd	6216450	681441	Private
2384	Whitecap Et Al Boundary 7-19-86-13 W6M	Whitecap Resources Inc	6262309	682164	Private
21726	Progress Altares A-74-G/94-B-8	Progress Energy Ltd	6250275	551306	Crown
18513	CNRL Buick C-25-G/94-A-14	Canadian Natural Resources Ltd	6302888	610713	Private
15470	CNRL Buick C-98-B/94-A-14	Canadian Natural Resources Ltd	6300150	608264	Private

* Three wells on same well pad

A drone was used to fly over each well pad to take a series of photos. The photographs were then used to explore different ways for quantifying the state of land disturbance and restoration activities under natural field conditions. The approach used in this research to evaluate the usefulness of a drone was to simply use the drone photographs supplemented with field observations and photographs taken at the ground surface to characterize as many aspects of restoration as was possible. This report presents the results of the investigation and discusses the advantages and limitations of using a drone for well pad restoration assessment purposes.

2 Location of Well Pads

Figure 1 shows the location of the four well pads that were flown in July and again in September 2017. Three sites (WA 19518, 23947, and 24004) were clustered close to each other approximately 8 km west of Hudson's Hope. One site (WA 16077, 16726, 24673) had three wells on it and this well pad was located 7.4 km northwest of Hudson's Hope. These sites were accessible by road, with no gates. Figure 2 shows the location of a fifth well pad (WA 21726) that was flown in September 2017. This well pad did not have a road access as the final portion of the access had been decommissioned and reclaimed.

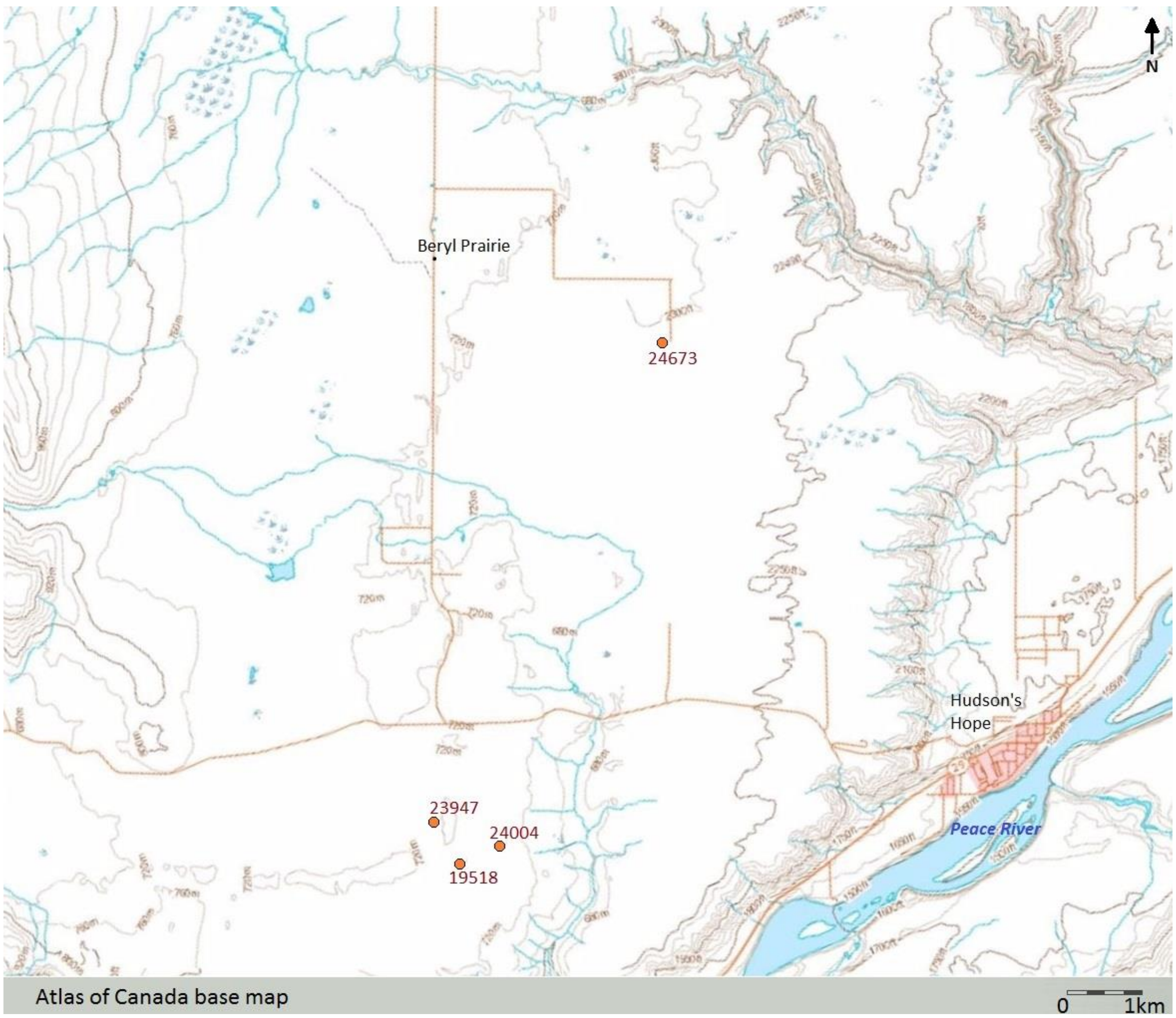


Figure 1 Location of four well pads

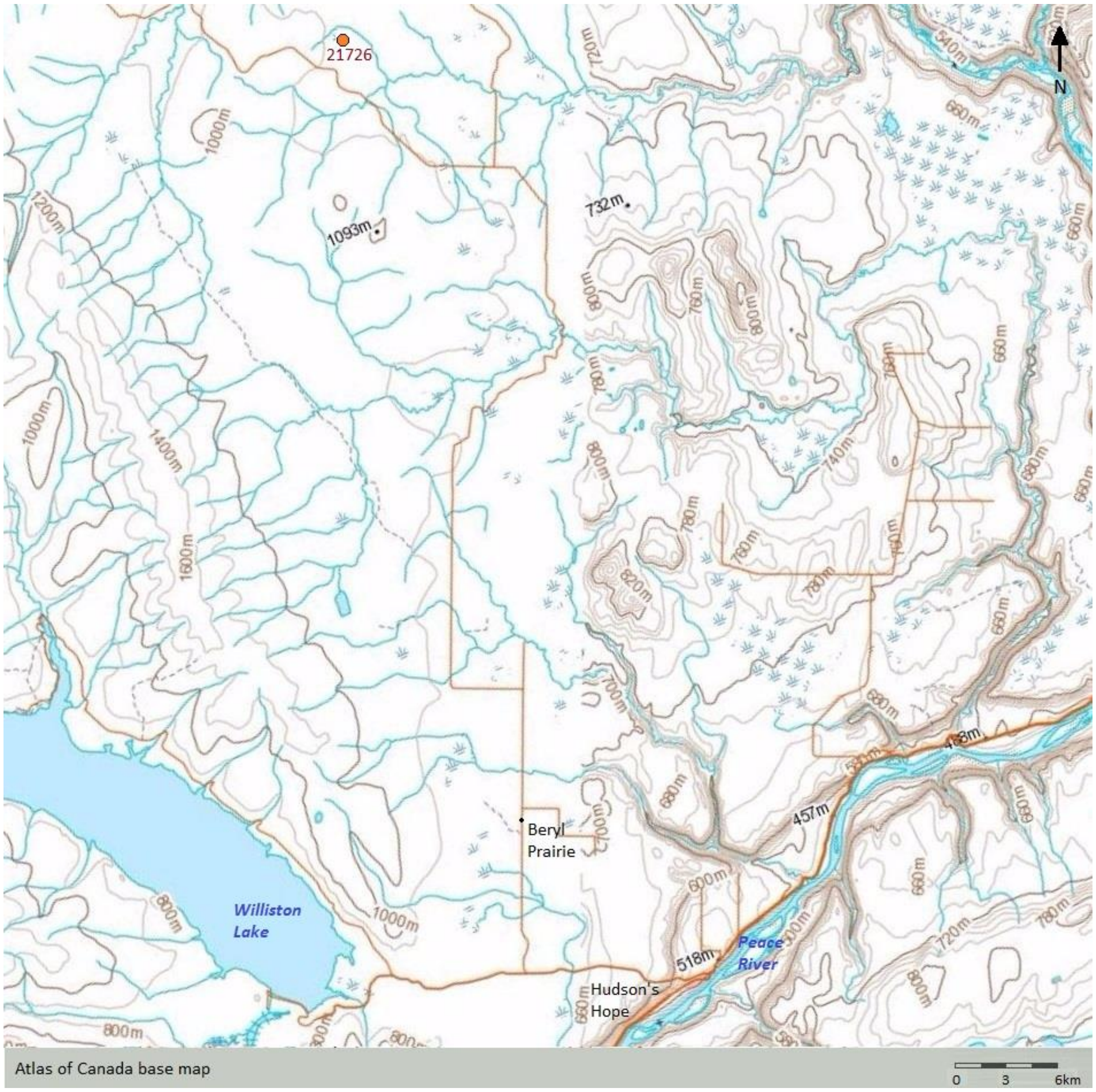


Figure 2 Location of well pad 21726

The land surrounding the four well pads shown in Figure 1 is relatively flat, sloping gently eastward. Several smaller creeks flow through the area, from the Butler Ridge west of Beryl Prairie, toward the Peace River. The area around Beryl Prairie is used for crops and livestock. Other uses of the surrounding land include oil and gas exploration, timber extraction, hydroelectric power generation, and recreational hunting (Hilton et al., 2013).

All sites are located in the BWBS biogeoclimatic zone (Boreal White and Black Spruce). Because of its location east of the Rocky Mountains, this region experiences a cold, humid continental climate similar to that of the Canadian Prairies. The climate around Hudson's Hope is also influenced by Williston Lake approximately 20 km to the west.

3 Drone and Flight Planning

A small, low-cost drone was used to acquire the photographs. A DJI Phantom 4 Pro drone, seen in Figure 3, was selected because it can be easily carried to the site and can be rapidly deployed. Furthermore, this drone model carries a relatively good camera with a mechanical shutter. At the time of its purchase in the summer of 2017, this drone cost $2100 plus taxes. An extra battery and larger capacity microSD card were also purchased for another $300 plus taxes.

Figure 3 DJI Phantom 4 Pro drone (DJI, 2017)

Different flight plans were tried at the well pads. In most cases, the drone was pre-configured to fly a grid pattern under autonomous control. For these cases, PixCapture software was used to set up the flight plan. The details of each flight plan are listed in Table 2 for the four July flights and in Table 3 for the five September flights. A summary of the drone characteristics is presented in Appendix 1.

Table 2 Flight details for each well pad (July flights)

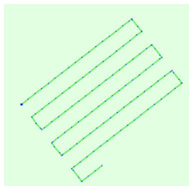
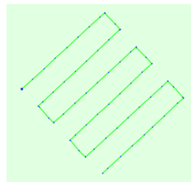
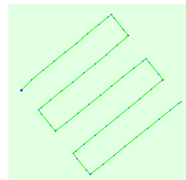
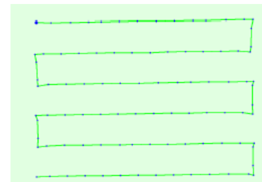
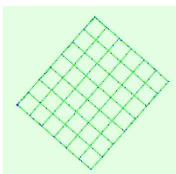
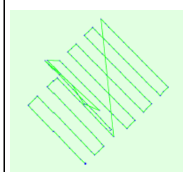
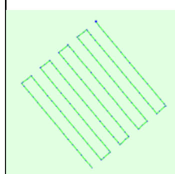
	Well Pad			
Flight Details	19518	23947	24004	24673/16077/16726
Drone height (above takeoff point) [m]	50	50	50	50
Flight path (80% overlap)	Grid 	Grid 	Grid 	Grid 
Average distance between photograph centres [m]	10.59	10.95	10.13	13.15
Average Drone speed [m/s]	2.47	2.92	2.70	2.41
Area covered [ha]	2.77	1.66	1.56	3.83
Flight start time	09:49 06/07/2017	09:16 06/07/2017	08:53 06/07/2017	14:40 06/07/2017
Flight duration	7 min (approx.)	3 min (approx.)	4 min (approx.)	5 min (approx.)

Table 3 Flight details for each well pad (September flights)

	Well Pad				
Flight Details	19518	23947	24004	24673/16077/16726	21726
Drone height (above takeoff point) [m]	50	50	50	50	50
Flight path (80% overlap)	Double grid 	3 x Grid 	Grid 	Grid 	Manual 
Average distance between photograph centres [m]	9.14	10.98	9.72	10.13	varies
Average Drone speed [m/s]	2.87	2.92	2.98	2.43	varies
Area covered [ha]	3.26	3.07	3.83	5.91	2.80
Flight start time	09:46 27/09/2017	09:59 10:09 10:12 27/09/2017	09:19 27/09/2017	17:38 26/09/2017	13:39 26/09/2017
Flight duration	13min10s	4min2s 6min19s 1min33s	9min50s	15min44s	11 min (approx.)

4 Structure-from-Motion Photographic Analysis

Structure-from-Motion photographic analysis of the acquired photographs was the key tool used in this research. Hence an overview of this technique is provided. Structure-from-Motion (SfM) is an advanced photogrammetric technique that was initially developed for computer vision (Snavely et al., 2008). SfM is based on the same basic principle as stereoscopic photogrammetry meaning that a 3D structure can be constructed from a series of overlapping images. However, a fundamental difference between SfM and conventional photogrammetry is that it can compute camera pose/orientation and 3D scene geometry without internal or external control points (Snavely et al., 2008; Westoby et al., 2012).

Traditional photogrammetric techniques require either the 3D position of the camera locations or the 3D locations of a network of ground control points to determine the 3D location of points within a scene. With camera locations, the scene is reconstructed using triangulation, whereas, with ground control points, resectioning is performed after manually identifying ground control points in images to determine camera positions (Westoby et al., 2012). In contrast, SfM does not need the locations of the cameras or ground control points prior to scene reconstruction. It simultaneously determines both camera pose and scene geometry by automatically identifying keypoints in a series of overlapping images.

Initial estimates of camera positions and object coordinates are determined by tracking keypoints from image to image. As the computation progresses, multiple solutions become available from the wide range of keypoints in the images, and the initial estimates are then iteratively refined using non-linear least-squares minimisation (Snavely et al., 2008; Westoby et al., 2012). However, the 3D point cloud generated by SfM lacks the scale and orientation provided by ground control points. As a result, the generated point cloud is in an arbitrary (or relative image-space) coordinate system. The transformation of that point cloud to a real-world coordinate system is then achieved by georeferencing it with ground control points measured in the field or with known camera locations.

Most commercially available UAVs include a GPS that automatically tags the camera position in the UAV acquired photograph. However, the accuracy of ordinary (i.e., single-point) GPS varies between ±1.5 to ±5 m. Positional accuracy can be increased to a few centimetres by incorporating a highly accurate compact RTK-GNSS receiver onboard a UAV or by establishing a network of precisely measured ground control points. For the work presented in this report, no ground control points or precise camera locations were used.

The SfM processing can be divided into four steps.

4.1 Keypoint extraction

The first step is the detection of features in multiple images that can be used to describe image correlations. Most commercial SfM software uses the Scale Invariant Feature Transform (SIFT) object recognition system (Lowe, 1999, 2004). In each image, SIFT detects those features that do not vary with image rotation or scaling but may partially vary with camera orientation and illumination changes. However, the local pixel gradients are then transformed to compute a descriptor for each feature that is largely insensitive to variations in camera orientation and illumination. These unique features with descriptors (also called keypoints) are then automatically matched in subsequent images (Lowe, 2004; Westoby et al., 2012).

The number of keypoints in an image depends on its resolution and texture, as well as the complexity or texture of the scene captured by it. A dense, sharp, and high-resolution image of a natural scene with a range of texture will result in many keypoints. SIFT is particularly effective for UAV aerial imagery, which is often of high to very high resolution. The minimum requirement for scene reconstruction is that keypoints be matched in at least three images. However, it is recommended to acquire as many images as possible as it will increase the number of keypoint matches thereby optimizing system redundancy.

4.2 Bundle adjustment and sparse 3D point cloud generation

In the second step, SIFT uses a bundle adjustment process (Triggs et al., 1999) from photogrammetry to estimate the camera pose for each photograph. Using approximate nearest neighbour and random sample consensus algorithms, keypoints are matched in multiple images. Keypoint matching helps to establish tracks that link specific keypoints in a group of images. For scene reconstruction, only those tracks that comprise a minimum of two keypoints matched in at least three images are used. The rest are automatically discarded. This process helps to automatically remove transient features like moving cars, people, or birds prior to scene reconstruction (Snavely et al., 2008; Westoby et al., 2012).

The correspondence between keypoints applies constraints on camera pose. Using similarity transformation, extrinsic (location, scale, and orientation) and intrinsic (focal length and radial distortion) parameters of the camera are estimated for each frame. A pair of images with best feature matches is initially used, and using a one-at-a-time scheme, additional images are added and solved for. Triangulation is then performed to estimate the 3D position for each keypoint. The combined output of SIFT and bundle adjustment is a sparse 3D point cloud along with camera pose for each image in a relative coordinate system (Snavely et al., 2008; Westoby et al., 2012).

4.3 Dense matching

For projects requiring high detail, further processing is needed to enhance the density of the point cloud. For this purpose, algorithms like the Clustering View for Multi-View Stereo (CMVS) and Patch-based Multi-View Stereo (PMVS2) (Furukawa and Ponce, 2010) are used. The camera positions computed in the bundle adjustment are used as input. Using CMVS, overlapping images are partitioned into smaller subsets or clusters. PMVS2 is then used to establish correlations between these patches and these locally correlated patches are expanded iteratively to reconstruct 3D data (Furukawa and Ponce, 2010). MVS results in a significant increase in point density, usually two to three orders of magnitude higher than that of the sparse point cloud obtained in the previous step.

4.4 Post-processing

Post processing includes the transformation of the dense point cloud from a relative coordinate system to a real-world coordinate system, as well as the creation of various output files such as a digital surface model, digital elevation model, orthomosaic, and contour maps. For point cloud transformation, GCPs measured in the field are manually identified in the point cloud and using a rigid body transformation, a rotation plus translation matrix along with a scale factor is applied. Once the point cloud is transformed into the real-world coordinate system, an orthomosaic and DSM/DEM are extracted. In most commercial software, the transformation is usually performed after the bundle adjustment where GCPs are manually marked in individual images, and the solution is then re-optimized. After re-optimization, the dense matching and Ortho/DSM/DEM extraction steps can be executed automatically without the need for manual interruption.

4.5 Pix4D SfM software

The photographs from each flight were uploaded into Pix4D software (version 4) for processing and were used to create the point clouds and generate orthomosaics, contour maps, digital surface models, and other outputs. The points are georeferenced using the drone's built-in GPS, and no ground control points were used. While the UTM Northing and Easting coordinates are likely within a few metres of accuracy, the elevation values associated with the point cloud could be off by 10s of metres, however the relative coordinates of the points within the generated point cloud provide a more reliable and useful measure with accuracies estimated to be within a range of 0.1 m.

Depending on what outputs are generated and which settings are selected, processing of the acquired photographs for one well pad in Pix4D software can take many computer hours. The cumulative time to run each model is included in Table 4 and Table 5, in addition to other processing details. These times were obtained when the computer was dedicated to running only one model. The image processing was performed on a desktop computer with an Intel Xeon® ES 1607 V3, 3.7 GHz quad-core processor with 64GB RAM and Nvidia® Quadro K2200 GPU.

In contrast to the computer time that is needed, the human time needed to set-up and run the software is roughly five minutes after each set of photographs is downloaded and organized on the computer. Much more time would have been needed if ground control points had been used, which they were not.

Each model was run with an image scale of one half (the default setting), and points were set to have a minimum of 3 matches. The contours were generated at 10 cm resolution and 25 cm intervals. To generate the digital surface model (DSM) and the orthophotographs, the pixel size was set to the default setting of 1xGSD, where the GSD is the average ground sampling distance, which was equal to 1.3 cm for these models.

Table 4 Model details for each well pad (July flights)

	Well Pad			
Model Details	19518	23947	24004	24673/16077/16726
Photographs taken	131	69	62	94
Calibrated photos	131	69	61	94
Median number of matches per image	20,704	31,065	40,162	16,020
Points in point cloud	12,407,572	6,111,281	5,718,613	5,167,844
Point density [points/m^2]	1316	1482	1212	305
Post-processing Time [h:mm:ss]	1:36:33	0:48:31	0:47:00	1:11:51

Table 5 Model details for each well pad (September flights)

	Well Pad				
Model Details	19518	23947	24004	24673/16077/16726	21726
Photographs taken	250	204	183	296	164
Calibrated photos	248	162	163	240	164
Median number of matches per image	15,153	11,944	11,294	9,997	20,689
Points in point cloud	25,439,582	14,527,424	13,201,262	26,336,840	17,913,506
Point density [points/m^2]	1396	1315	1127	1321	885
Post-processing Time [h:mm:ss]	4:11:02	2:04:40	1:54:39	2:49:25	2:37:03

5 Certificate of Restoration Requirements

The Version 1.2 of the BCOGC Certificate of Restoration Application Manual lists the site reclamation objectives; these are provided in Appendix 2. To assess the capabilities and limitations of the drone for evaluating reclamation, the objectives were summarized into five categories which were used to analyze reclamation at each of the well pads.

5.1 Geotechnical Stability

There is no visible slope movement, slumping, subsidence, or tension cracks on the well pad surface. On-site cut and fill slopes should be stabilized.

5.2 Land Use and Facilities

Any facilities remaining from oil and gas development activities are not affecting the natural drainage or sloping of the area. There are no gravel or rock piles or windrows. There is no industrial debris and no woody debris that is interfering with reclamation efforts.

5.3 Vegetation

There are no prohibited nuisance weeds and no infestation of any particular species on the well pads. There is an even distribution of vegetation density with no bare areas, and a sustainable, intentional plant community is growing such that at least 80% of the well pad surface area is covered with vegetation, as outlined in Schedule B, BCOGC Site Reclamation Requirements (BCOGC, 2013).

5.4 Slope and Drainage

There are no areas where ponding or erosion are occurring resulting from slopes that would affect land reclamation. The land slope has been restored to the original slope of the site, or to a condition that is compatible with the surrounding landscape. Ditches should be refilled along the edges of the well pad and their access routes.

5.5 Soil Objectives

Any salvaged soil which was piled on the well pad has been replaced throughout the site over the surface area. Soils which were compacted from oil and gas development activities have been de-compacted to assist with plant growth. There is no evidence of impact from adjacent land use.

6 Well Pad Characterization Using Drone Photography

This section of the report summarizes the observations and the features that were extracted from the drone photography for each well pad and illustrates possible uses for a drone in assessing well pad restoration.

6.1 Well Pad 19518

Details for well pad 19518 were obtained from a BC Oil and Gas Commission database. These are summarized in Table 6.

Table 6 Well pad 19518 details

WA Number	19518	Well Name	CE PORTAGE C- 013-A/094-B-01
Well Operator	Canada Energy Partners Inc.	UTM Zone Num	10
UTM83 Easting(m)	560,259.3	UTM83 Northing(m)	6,207,974.0
Surf(NAD83) Longitude	122 02' 00.46"	Surf(NAD83) Latitude	56 00' 47.64"
Total Depth (m)	950.0	Proposed Ground Elevation (m)	726.7
Casing Cut Off	Y	Certificate of Restoration	N
Well Classification	EXPERIMENTAL	Cancel w Surface Disturb	N
Operation Type	PRODUCTION	Fluid Type	GAS
Spud Date	30/Jun/2005	Rig Rels Date	21/Jul/2005
Initial Production Date	Jan/2009	Last Production Date	Apr/2010
Well Status	ABANDONED	Status Effective Date	31/Jul/2016

The approximate surface area of this well pad is 1.02 hectares (ha) as of July 2017. Figure 4 provides a comparison of this well pad site before reclamation began (top) in 2012, and after reclamation in July 2017 (centre) and September 2017 (bottom).

Figure 4 Restoration progress of well pad 19518 (2012, July 2017, and September 2017)

6.1.1 Geotechnical Stability

There is no visible slope movement, slumping, subsidence, or tension cracks on or around the well pad, and there are no remaining cut and fill slopes.

6.1.2 Land Use and Facilities

There are no facilities remaining on the surface of the well pad from oil and gas production. However, there were signs indicating that a pipeline remains beneath the ground and some survey stakes at the surface as shown in the photographs taken on the well pad in Figure 5.

Figure 5 A sign indicating the presence of subsurface facilities and survey stake

It is not possible for the drone to provide evidence of subsurface facilities unless there is some indication of these facilities at the surface to be captured in photos. Even small signs like the ones shown in Figure 5 are difficult to see in aerial photographs unless their shadows are seen on the ground. Since this well pad was flown on a sunny day, the sign and its shadow can be seen easily in Figure 6. However, cloudy or overcast skies might limit what can be seen in aerial photos.

Figure 6 Sign indicating a pipeline seen in an aerial photo

Pipelines may have been left behind on this well pad for numerous reasons. Leaving facilities is allowed if removing them would pose more risk or cause greater disturbance to the land area, which would impede or hinder reclamation activities more than having them remain.

There are no piles of gravel or rock on the well pad although there is some sporadic woody debris on the well pad itself, as seen in Figure 7. However, it is unknown if the wood on the well pad surface is intentional to assist with vegetation growth and reclamation or not. There is no evidence of industrial debris on or around the well pad.

Figure 7 Woody debris on the well pad

6.1.3 Vegetation

Production equipment can still be seen in the 2012 photograph on the well pad near its centre. In the July 2017 photo, vegetation appears to be growing more on the western portion of the well pad than the eastern, and there is noticeably less vegetation around the edges of the site. Vegetation coverage appears much more evenly distributed and dense in the September 2017 photo and is uniformly green.

Although it is difficult to discern from the September 2017 orthomosaic due to the shadows from trees, the vegetation appears less developed along the southeast edge of the well pad compared to other locations. This is highlighted in Figure 8. This could be because the salvaged soil was piled on this part of the well pad as shown in the 2012 GoogleEarth photo, causing the soil to be more compact in this area than on other parts of the well pad.

Figure 8 Reduced vegetation density where salvaged soil pile was located

The other areas on the well pad with noticeably less dense vegetation growth are the tire tracks from where vehicles have driven through the centre of the well pad despite there being vehicle access by driving around the eastern side. This is demonstrated in the right photograph of Figure 4, and going through the centre of Figure 7. It is evident that areas of increased soil compaction reduce vegetation growth on this well pad.

In the July 2017 orthomosaic the 80% vegetation coverage requirement for a Certificate of Restoration may not have been met, but the well pad surface area does appear to be more than 80% covered in vegetation in the September 2017 orthomosaic. It appears that the intended seed mixture is growing uniformly throughout most of the well pad surface area as of September 2017. While the species that are growing are seen easily from the ground level, it is impractical to discern which plant species are growing on the well pad using the drone only.

6.1.4 Slope and Drainage

A 2D digital surface model of the well pad and a contour plot showing contours at 25 cm intervals were created in MatLab using a low-density version of the point clouds generated in Pix4D software. These are seen in Figure 9 and Figure 10 respectively.

The tire tracks going through the centre of the well pad are noticeable in Figure 9, and from Figure 9 and Figure 10 it can be deduced that drainage is generally toward the north corner of the well pad. The well pad is relatively flat with a total elevation change of less than 2 m from the highest to lowest points captured by the point cloud. The increased elevation at the southern corner could be the result of higher vegetation, as vegetation is captured in the point clouds as shown in Figure 11, or it could be that the access road going around the southeast edge of the well pad is higher than the well pad itself.

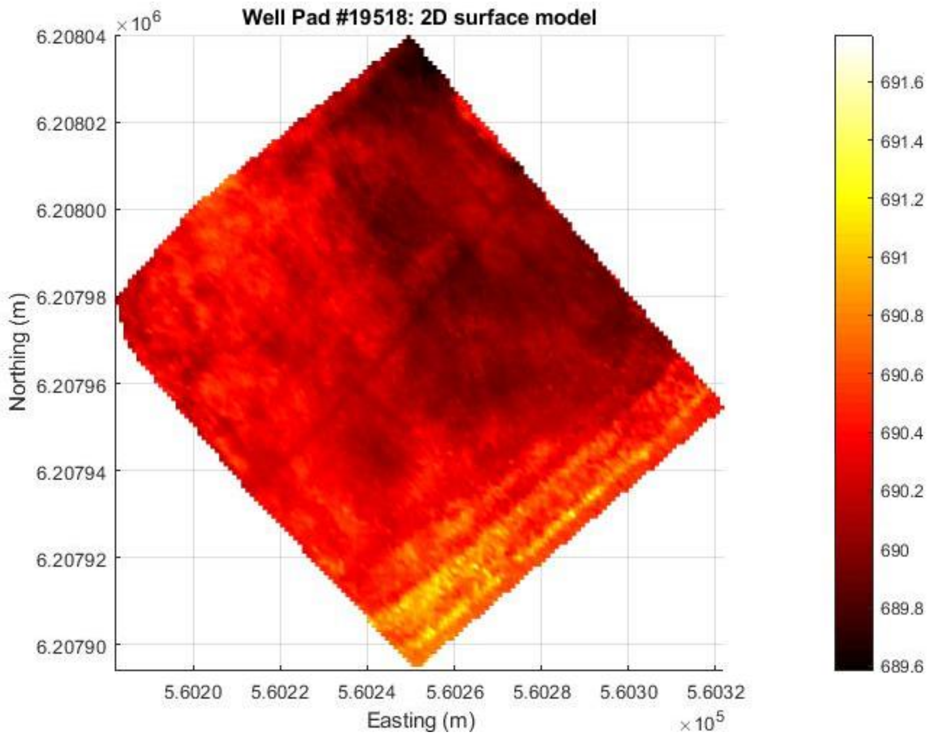


Figure 9 2D surface model of well pad 19518

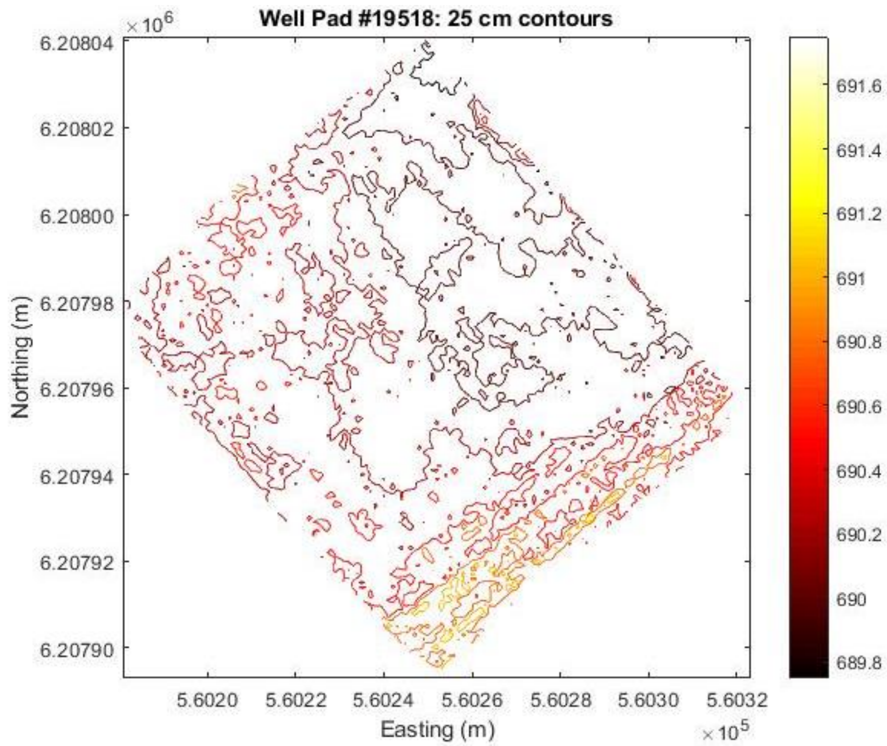


Figure 10 Contour map of well pad 19518

Figure 11 Increased vegetation density next to the southeast access road

There are no drainage ditches around the well pad, although it is possible that water drains or ponds in the tire tracks going through the centre of the well pad. There is no other evidence of ponding or erosion in Figure 9 and Figure 10 or the drone photographs. This would suggest that the criterion of restoring drainage to its original condition or to a condition compatible with the surrounding land area has been met for the Certificate of Restoration.

6.1.5 Soil Objectives

From the progression of the well pad over time shown in Figure 4 it is evident that salvaged soil has been spread throughout the site, and there is no evidence of impact from surrounding or adjacent land use. However, it is likely that soil that was compacted from oil and gas development activities may not have been fully de-compacted, due to the presence of the bare areas mentioned above. It is clear that this well pad has been driven over numerous times creating compacted soil along the tire tracks. Further evidence of this is given in Figure 12.

Figure 12 Reduced vegetation on soil compacted by vehicles

6.2 Well Pad 23947

The details of well pad 23947 were obtained from the BC Oil and Gas Commission database and are summarized in Table 7.

Table 7 Well pad 23947 details

WA Number	23947	Well Name	CE PORTAGE A- 024-A/094-B-01
Well Operator	Canada Energy Partners Inc.	UTM Zone Num	10
UTM83 Easting(m)	559,810.8	UTM83 Northing(m)	6,208,493.4
Surf(NAD83) Longitude	122 02' 25.93"	Surf(NAD83) Latitude	56 01' 04.64"
Total Depth (m)	910.5	Proposed Ground Elevation (m)	718.5
Casing Cut Off	Y	Certificate of Restoration	N
Well Classification	EXPERIMENTAL	Cancel w Surface Disturb	N
Operation Type	PRODUCTION	Fluid Type	GAS
Spud Date	31/Jul/2008	Rig Rels Date	08/Aug/2008
Initial Production Date	Nov/2008	Last Production Date	Apr/2010
Well Status	ABANDONED	Status Effective Date	31/Jul/2016

As of September 2017, this well pad has an approximate surface area of 0.98 ha. This well pad is shown in Figure 13 before reclamation began (top) in 2012, and after reclamation in July 2017 (middle) and September 2017 (bottom).

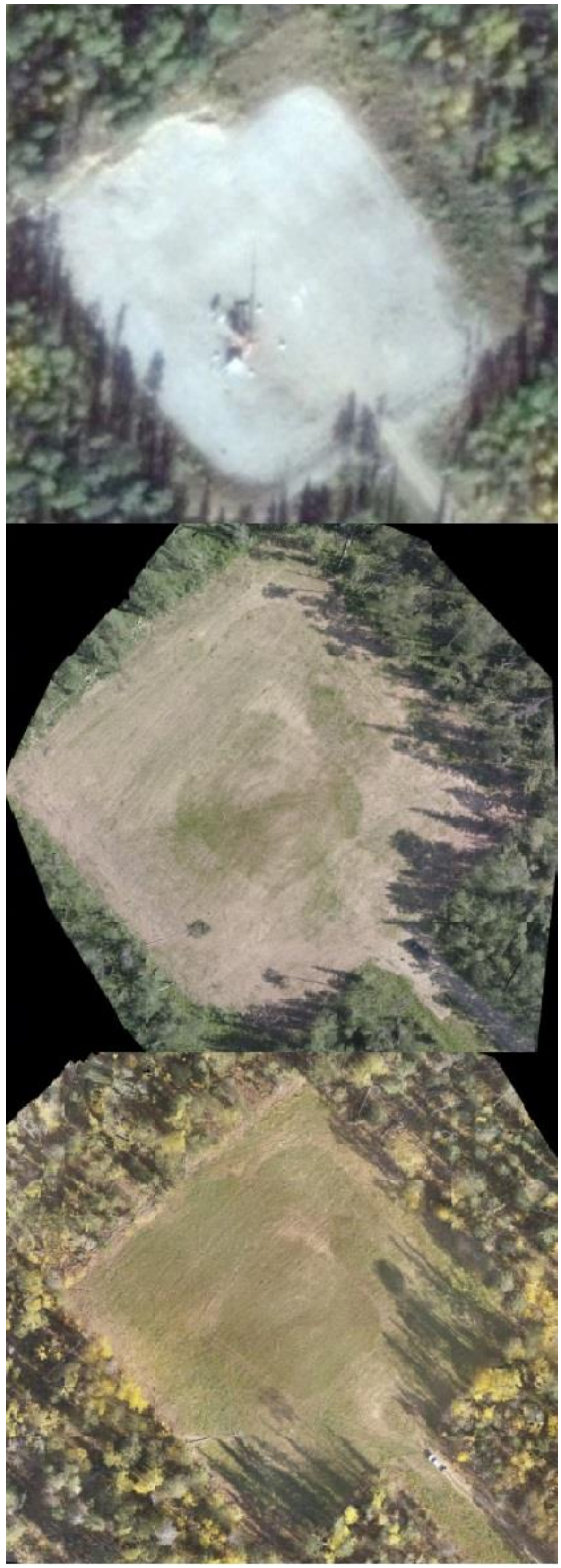


Figure 13 Restoration progress of well pad 23947 (2012, July 2017, and September 2017)

6.2.1 Geotechnical Stability

There is no visible slope movement, slumping, subsidence, or tension cracks on or around the well pad, and there are no remaining cut and fill slopes.

6.2.2 Land Use and Facilities

There are no piles or rock or gravel on or around the well pad, and no industrial debris was found. However, some woody debris, including several fallen trees around the edges of the well pad, was identified in the aerial photos. These are highlighted in Figure 14. Certificate of Restoration criteria require these to be removed if they are not part of the reclamation activity.

Figure 14 Woody debris on and around the well pad

Approximately 40 m northwest of the well pad there is a large gravel quarry. This is not shown on GoogleEarth where the 2012 image was obtained, but it was detected by aerial photographs while flying the drone over the well pad. The northwest edge of the well pad and the southeast edge of the gravel quarry are both captured in the aerial photograph shown in Figure 15.

Figure 15 Aerial photograph showing edge of a gravel quarry 40 m northwest of the well pad

Because of the trees between the well pad and the gravel quarry, this quarry is something that may not be seen by just doing a manual inspection at the ground surface, and since it is not shown in GoogleEarth. The quarry does not seem to affect the drainage of the well pad area. However, it is worth noting the proximity of the quarry to the well pad.

6.2.3 Vegetation

There is a substantial increase in vegetation density from the July 2017 to the September 2017 orthomosaics. In the July orthomosaic, there is some vegetation mostly concentrated at the centre of the well pad, but not enough to fulfill the 80% well pad surface area coverage requirement to warrant a Certificate of Restoration. In the September 2017 orthomosaic, there is a much a better distribution in terms of vegetation density and green colour. However, the higher vegetation density in the middle of the well pad which was seen in the July 2017 orthomosaic can still be distinguished. There is a square outline around it that is experiencing reduced vegetation growth. There is no correlation between this area and where the equipment was located on the well pad in 2012, although it is possible there were equipment or activities impacting this area before 2012.

Another area of reduced vegetation growth is in the northern corner of the well pad. In the 2012 photograph, it can be seen that salvaged soil was piled here and along the northeastern edge of the well pad. The boundary of the soil pile is still distinguishable in both of the 2017 orthomosaics. Similar to well pad 19518, it is possible that this soil pile resulted in increasingly compacted soil beneath it, which is impeding vegetation growth in this area. A closer view of the reduced vegetation density in this area is shown in Figure 16. It is useful to have ground photographs to supplement the drone photographs when assessing plant species that are growing on the well pad.

Figure 16 Reduced vegetation density where salvaged soil pile was located

6.2.4 Slope and Drainage

A 2D digital surface model of the well pad and a contour plot with 25 cm intervals were created in MatLab using low-density versions of the point clouds generated in Pix4D software. These are shown in Figure 17 and Figure 18 respectively.

With less than a 2 m change in elevation from the highest to the lowest point, this land area is flat. The overall drainage is from the northwest to the southeast. There is no evidence of erosion, and no ditches are present around the well pad.

Figure 17 and Figure 18 shows possible minor water ponding could occur near the centre of the well pad where there is a slight topographic low area. Contour lines at a smaller interval than 25 cm would be necessary to examine this further, but this area of potential ponding is consistent with a defined bare outline in the September 2017 orthomosaic. Possible ponding and lack of drainage in this specific area could be hindering growth since there is no evidence that the vegetation pattern is caused by heavily compacted soil or any other cause. The area of possible ponding is shown in Figure 19.

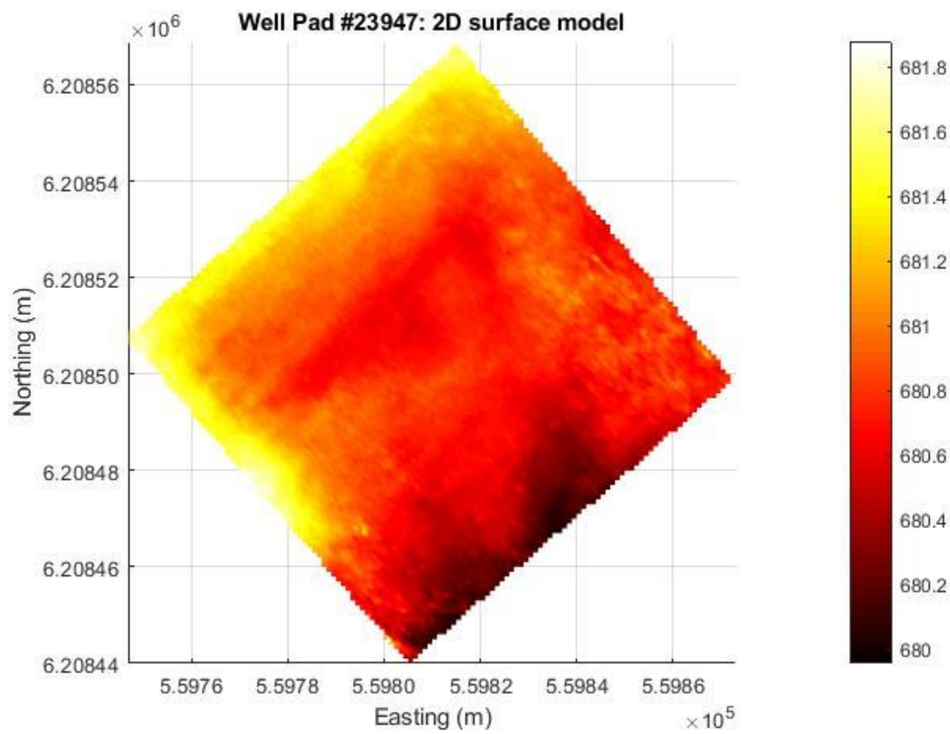


Figure 17 2D surface model of well pad 23947

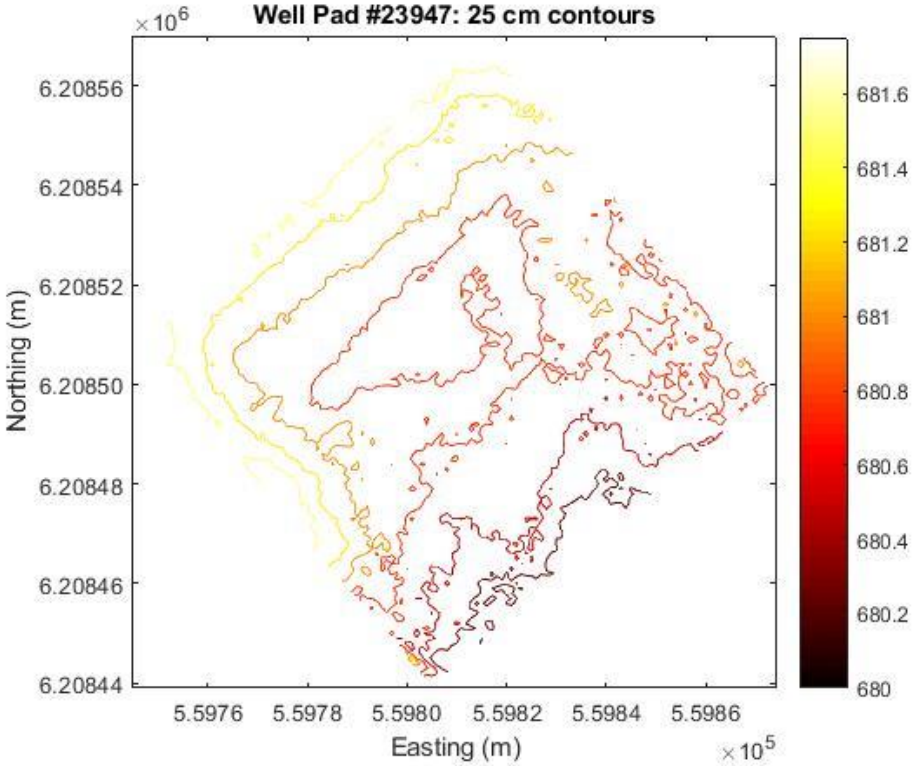


Figure 18 Contour map of well pad 23947

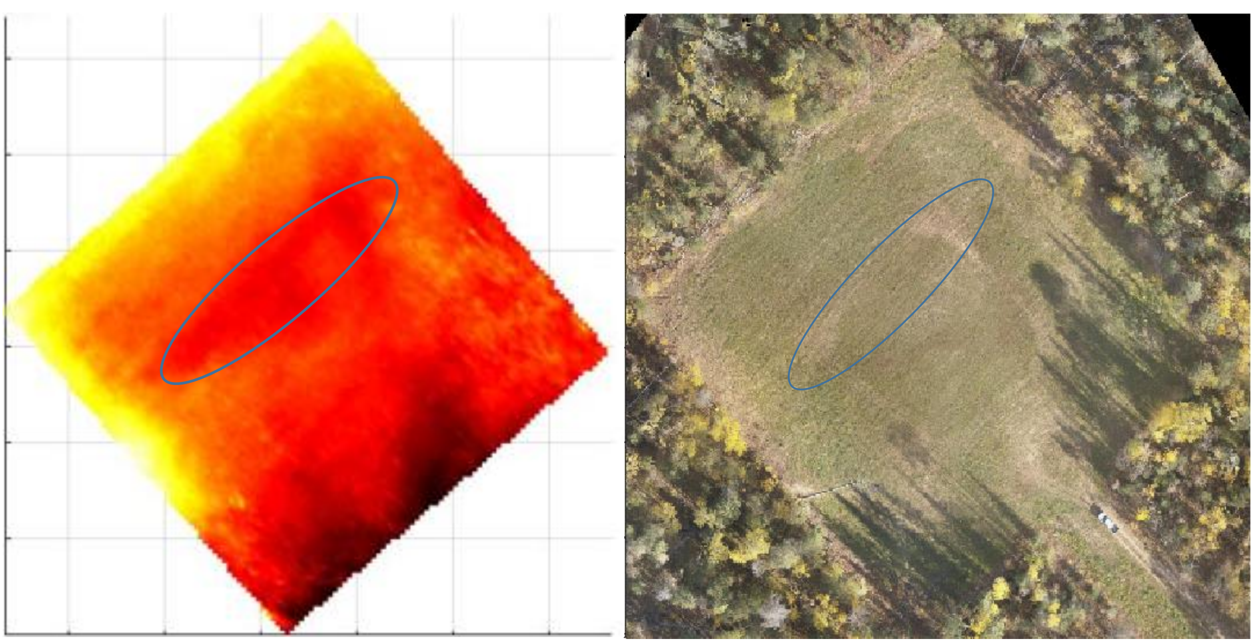


Figure 19 Potential ponding identified which may impede vegetation growth

The criteria for a Certificate of Restoration require that there not be ponding of water on the surface of the well pad being reclaimed, and that drainage be restored to the original site conditions or conditions compatible with the surrounding landscape. This example shows that the drone photographs can be used to assess minor changes in the ground topography and vegetation density that may not be visible from an inspection on the ground.

6.2.5 Soil Objectives

In the 2012 photo, it can be seen that salvaged soil was piled on the northeastern side of the well pad. This appears to have been spread throughout the site. While the gravel quarry was excavated nearby, there is no evidence to suggest that it has affected the soil of the well pad area. However, it is not clear whether the soil which was compacted from oil and gas development activities was fully de-compacted as required for a Certificate of Restoration. Evidence that is was not de-compacted is suggested in the northern corner beneath the former salvaged soil pile as mentioned, and the well pad itself has been driven over by numerous vehicles, as shown in Figure 20.

Figure 20 Evidence of vehicles driving over the well pad

6.3 Well Pad 24004

The details of well pad 24004 were obtained from the BC Oil and Gas Commission database and are summarized in Table 8.

Table 8 Well pad 24004 details

WA Number	24004	Well Name	CE PORTAGE C- 012-A/094-B-01
Well Operator	Canada Energy Partners Inc.	UTM Zone Num	10
UTM83 Easting(m)	560,702.1	UTM83 Northing(m)	6,208,235.1
Surf(NAD83) Longitude	122 01' 34.68"	Surf(NAD83) Latitude	56 00' 55.89"
Total Depth (m)	892.0	Proposed Ground Elevation (m)	724.1
Casing Cut Off	Y	Certificate of Restoration	N
Well Classification	EXPERIMENTAL	Cancel w Surface Disturb	N
Operation Type	PRODUCTION	Fluid Type	GAS
Spud Date	08/Aug/2008	Rig Rels Date	14/Aug/2008
Initial Production Date	Nov/2008	Last Production Date	Apr/2010
Well Status	ABANDONED	Status Effective Date	02/Aug/2016

The surface area for this well pad is approximately 1.04 ha based on analysis in 2017. This well pad is shown in Figure 21 for September 2012, July 2017, and September 2017 from top to bottom, respectively.

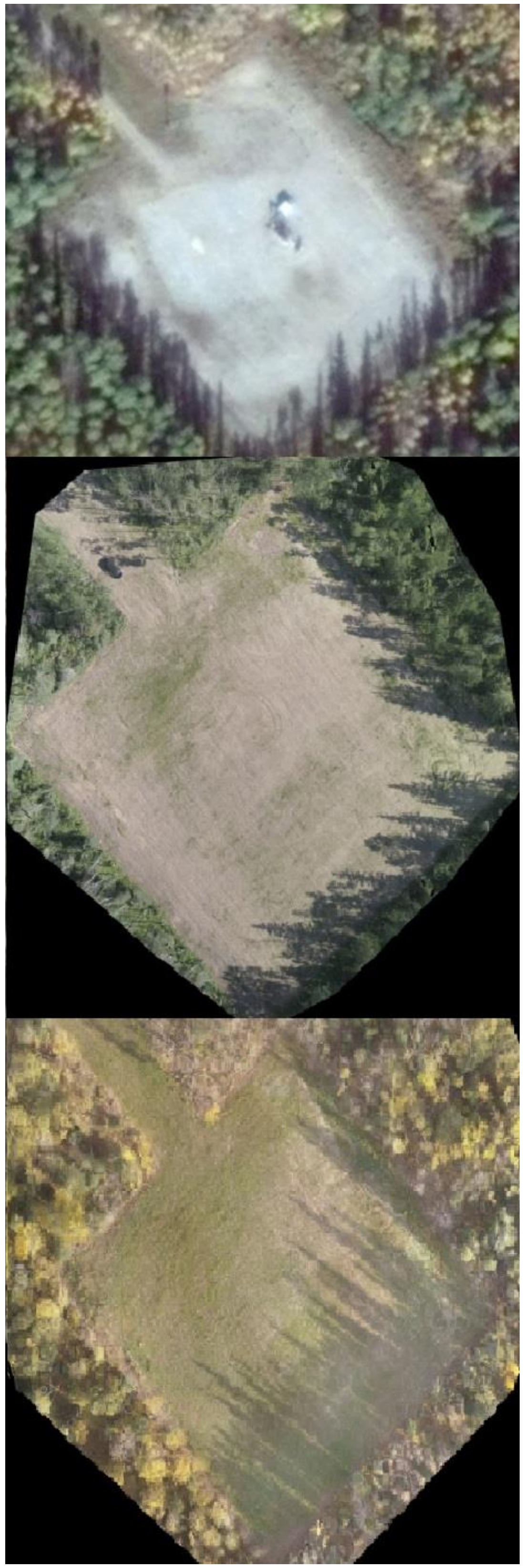


Figure 21 Restoration progress of well pad 24004 (2012, July 2017, and September 2017)

6.3.1 Geotechnical Stability

There is no visible slope movement, slumping, subsidence, or tension cracks on or around the well pad, and there are no remaining cut and fill slopes.

6.3.2 Land Use and Facilities

There are no facilities remaining on the surface of the well pad from oil and gas production. However, there were signs present that indicate a pipeline remaining beneath and some survey stakes at the surface as shown in the photographs taken from the ground surface in Figure 22.

Figure 22 Indication of subsurface facilities from ground photos

These signs are similar to the ones found on well pad 19518. However, because of trees blocking the sun, these signs cannot be identified by their shadows in the aerial photographs taken by the drone as they could be on 19518. As these facilities are subsurface, they do not affect the surface drainage.

There are no piles of gravel or rock or industrial debris remaining on or around the well pad. However there was a noticeable amount of woody debris, particularly around the edges of the well pad. The debris was in the form of logs and branches, and occasional rocks. The debris was easily seen in the drone photographs, and an example is shown in Figure 23.

Figure 23 Woody debris around the edges of the well pad

6.3.3 Vegetation

The vegetation on the well pad appears uniform in terms of both density and colour across the area as of September 2017. There is a substantial increase in vegetation density from July 2017 to September 2017, and there is no correlation between where equipment was located on the well pad in 2012 and vegetation growth or density in the 2017 photos.

As seen in the 2012 photo, the salvaged soil was piled around the edges of the well pad while oil and gas development activities were taking place. Unlike on well pads 19518 and 23947, this does not appear to have drastically impacted vegetation growth due to increased soil compaction. There is a minimal impact that can be observed, particularly in the southern corner of the well pad, as highlighted in Figure 24. However, it is also a possibility that the planted seed mixture for reclamation was not extended this far.

Figure 24 Reduced vegetation density at the south corner of the well pad

Except for a minor reduction in vegetation density around the edges of the well pad, the vegetation coverage of both the well pad and its access route is green and even and meets the 80% coverage requirement needed to obtain a Certificate of Restoration.

The ground photographs highlighted a variety of plant species growing on this well pad, some of which are not native to the area. These include thistles, which were also seen on well pad 23947. The variety of species growing on the well pad is very difficult to discern from the drone photographs alone.

One area of interest that the drone did pick up is on the northeast edge of the well pad where shrub or small trees are growing (Figure 25). There is no reason to believe that they are unintended or invasive species, but their growth in this area is dense.

Figure 25 Shrubs or small trees growing on the northeast edge of the well pad

6.3.4 Slope and Drainage

A 2D digital surface model of the well pad and a contour plot showing contours at 25 cm intervals were created in MatLab using low-density versions of the point clouds generated in Pix4D software. These are shown in Figure 26 and Figure 27 respectively.

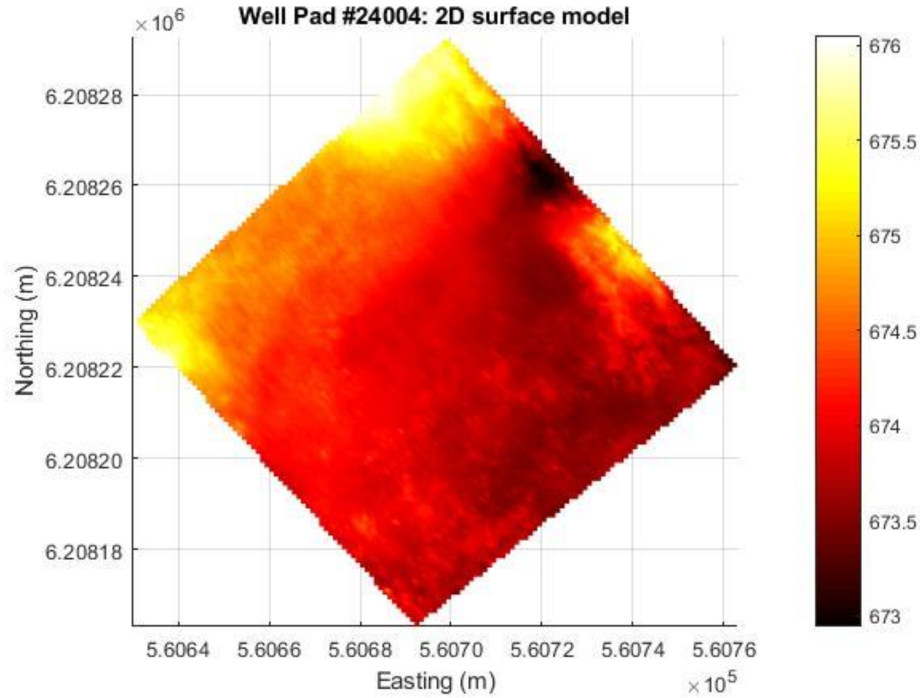


Figure 26 2D surface model of well pad 24004

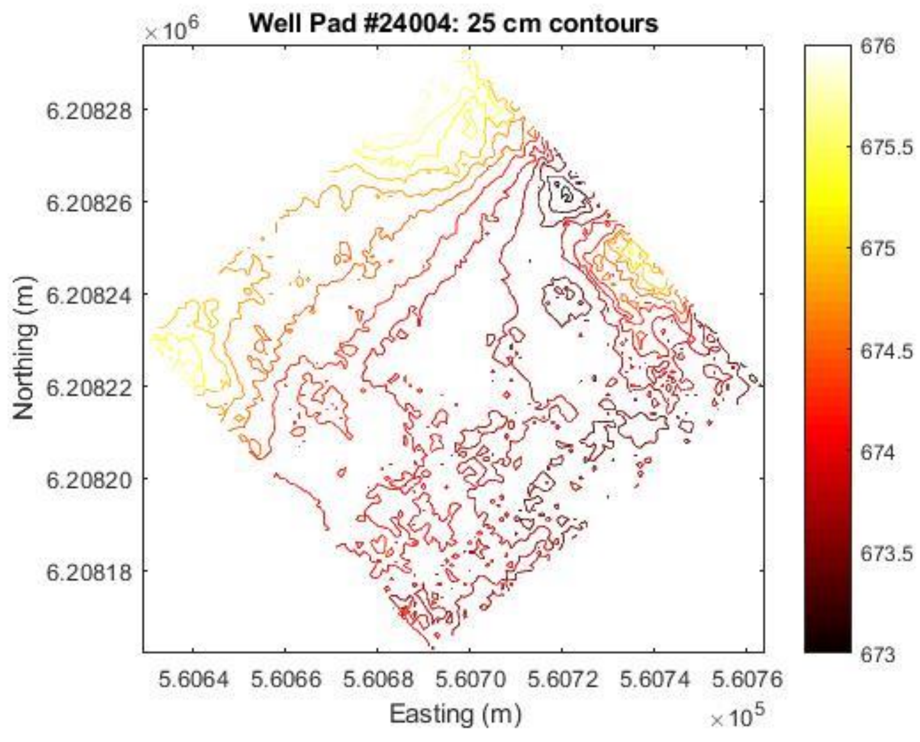


Figure 27 Contour map of well pad 24004

The land area at this well pad is not quite as flat as well pads 19518 or 23947, with a 3 m elevation difference between the highest and lowest points and slopes that can be observed at the ground surface. The land area drains to the east or southeast. There are three distinct high spots on the well pad the northern corner, the western corner, and an area along the northeastern edge. The drone photographs suggest that the land is actually higher in these spots and the results in Figure 26 and Figure 27 and are not affected by vegetation. This is confirmed in the photograph taken from the ground surface shown in Figure 28 which shows a distinct low spot between the northern corner and the high spot along the northeastern edge.

Figure 28 Contrasting surface elevations along the southeast edge of the well pad

Because of the uniformity in vegetation, there is nothing to suggest that there is an issue of ponding in this low spot. It is likely that drainage continues northeast from this low spot, although this is not something that could be confirmed by the drone as the point cloud would extend to include the trees.

There are no ditches around the well pad or along its access route, and there is no evidence of erosion on the well pad surface. Impeded drainage due to overly compacted soil does not appear to be an issue on this well pad from an examination the vegetation density. The area has been restored to drainage conditions that are compatible with the surrounding landscape, fulfilling that criterion for a Certificate of Restoration.

6.3.5 Soil Objectives

The salvaged soil piles shown in the 2012 photograph appear to have been replaced throughout the well pad site since then. There is no evidence of impacts from adjacent or surrounding land uses. The well pad does not appear to be as extensively driven on by vehicles. Soil compaction does not appear to be an issue that is affecting vegetation growth at this well pad.

6.4 Well Pad 24673/16077/16726

The details of well pad 24673/16077/16726 were obtained from the BC Oil and Gas Commission database and are summarized in Table 9. This well pad, referred to herein as well pad 24673, was also the well pad used for wells 16077 and 16726 on the list in Table 1. Details from the BCOGC database for these wells are also included.

This well pad had an approximate surface area of 1.81 ha in July 2017, and appears to have been expanded as seen in a comparison between photographs taken 2012 and 2017. Photographs taken in September 2012, July 2017, and September 2017 are shown from top to bottom, respectively, in Figure 29.

Table 9 Well pad 24673, 16726, 16077 details

WA Number	24673	Well Name	CE HZ PORTAGE A-C100-D/094-A-04
Well Operator	Canada Energy Partners Inc.	UTM Zone Num	10
UTM83 Easting(m)	562,763.0	UTM83 Northing(m)	6,215,037.9
Surf(NAD83) Longitude	121 59' 29.95"	Surf(NAD83) Latitude	56 04' 34.94"
Total Depth (m)	1,570.0	Proposed Ground Elevation (m)	692.9
Casing Cut Off	Y	Certificate of Restoration	N
Well Classification	EXPLORATORY WILDCAT	Cancel w Surface Disturb	N
Operation Type	UNDEFINED	Fluid Type	UNDEFINED
Spud Date	30/Jan/2009	Rig Rels Date	09/Feb/2009
Initial Production Date	UNKNOWN	Last Production Date	UNKNOWN
Well Status	ABANDONED	Status Effective Date	13/Jul/2016

WA Number	16726	Well Name	CE PORTAGE A-A100-D/094-A-04
Well Operator	Canada Energy Partners Inc.	UTM Zone Num	10
UTM83 Easting(m)	562,753.1	UTM83 Northing(m)	6,215,003.6
Surf(NAD83) Longitude	121 59' 30.56"	Surf(NAD83) Latitude	56 04' 33.83"
Total Depth (m)	603.0 960.0	Proposed Ground Elevation (m)	693.0
Casing Cut Off	Y	Certificate of Restoration	N
Well Classification	EXPERIMENTAL	Cancel w Surface Disturb	N
Operation Type	UNDEFINED	Fluid Type	UNDEFINED
Spud Date	29/Nov/2003 29/Nov/2003	Rig Rels Date	10/Dec/2003 05/Mar/2005
Initial Production Date	N/A	Last Production Date	N/A
Well Status	ABANDONED	Status Effective Date	13/Jul/2016

WA Number	16077	Well Name	CE PORTAGE A- 100-D/094-A-04
Well Operator	Canada Energy Partners Inc.	UTM Zone Num	10
UTM83 Easting(m)	562,768.1	UTM83 Northing(m)	6,214,977.6
Surf(NAD83) Longitude	121 59' 29.71"	Surf(NAD83) Latitude	56 04' 32.99"
Total Depth (m)	860.0	Proposed Ground Elevation (m)	692.5
Casing Cut Off	Y	Certificate of Restoration	N
Well Classification	EXPERIMENTAL	Cancel w Surface Disturb	N
Operation Type	DISPOSAL	Fluid Type	UNDEFINED
Spud Date	09/Jul/2003	Rig Rels Date	19/Jul/2003
Initial Production Date	N/A	Last Production Date	N/A
Well Status	ABANDONED	Status Effective Date	13/Jul/2016

Figure 29 Restoration progress of well pad 24673 (2012, July 2017, and September 2017)

6.4.1 Geotechnical Stability

There is no visible slope movement, slumping, subsidence, or tension cracks on or around the well pad, and there are no remaining cut and fill slopes.

6.4.2 Land Use and Facilities

Land near the well pad is used for agricultural purposes. This was picked up in aerial photographs taken by the drone, as shown in Figure 30. The agricultural land is at the top and the well pad on the bottom, with coniferous trees covering the 25 m separation of land use in between.

Figure 30 Strip of trees and agricultural land north of the well pad captured by the drone

The adjacent land use, despite its proximity to the well pad, does not appear to impact the drainage or vegetation on the well pad from the September 2017 orthomosaic. There are no piles of rock or gravel on or around the well pad or its access route. There is no industrial debris remaining around the site, and all equipment from oil and gas development activities has been removed. There is some minor woody debris and fallen trees as seen in the right and left photographs of Figure 31, respectively.

Figure 31 Woody debris and fallen trees on the well pad

6.4.3 Vegetation

Although there is a significant increase in vegetation density on the well pad between July and September 2017 as seen in Figure 29. The vegetation density is not uniform, and there is a wide variety of plant species present.

Some species such as thistle, which is present, are not native to the area. The thistle does not appear to be causing infestation on the well pad or hindering reclamation. However, these weeds should be monitored and Certificate of Restoration criteria should be consulted to determine if they are prohibited or not. Examples are shown in photographs taken at the ground level in Figure 32.

Figure 32 Variety of species found on the well pad including thistle

Identification of small plant species in photographs taken 50 m above the ground by a drone is impractical. Hence it is useful to have ground photographs to supplement the drone photographs when assessing plant species that are growing on the well pad.

Despite the lack of uniformity in vegetation density and type, examination of the September 2017 orthomosaic in Figure 29 shows that the 80% vegetation coverage requirement to warrant a Certificate of Restoration has been met.

While there are no areas on the well pad that are entirely bare, there is noticeably less vegetation around the outline of the original well pad, shown in the 2012 GoogleEarth photo, and increased vegetation density where the well pad area was expanded north. This contrast in vegetation density is particularly strong in the July 2017 orthomosaic, and still noticeable in the September 2017 orthomosaic although the distribution has become more uniform. One possible reason for reduced vegetation growth on the original well pad area is that the soil is more compacted beneath the surface in this area due to a longer duration of oil and gas development activities taking place. There does not appear to be a direct correlation between where equipment was located on the well pad in 2012 and where the vegetation density is reduced.

Further evidence of the lack of uniformity in the vegetation on the well pad can be seen along the northern edge. In the July 2017 orthomosaic, this is where the most green and the highest vegetation density is observed. While the vegetation is still dense in this area in the September 2017 orthomosaic, it seems that while the rest of the well pad has become greener, this previously green vegetation has become brown. This is highlighted in Figure 33.

Figure 33 Different coloured vegetation along the northeastern edge of the well pad

6.4.4 Slope and Drainage

A digital surface model of the well pad and a contour plot showing contours at 25 cm intervals were created in MatLab using low-density versions of the point clouds generated in Pix4D software. These are seen in Figure 34 and Figure 35, respectively.

At this well pad, drainage generally occurs from north to south. Although the well pad is quite flat with only a 2.5 m change in elevation from the highest to lowest points, the slope is not uniform across the area, with a steeper slope occurring in the northern portion and almost flat land in the southern half. There are no ditches around the well pad and no evidence of erosion. However, Figure 34 indicates that there is a potential for ponding to occur in the southwest part of the well pad, and there is a correlation between the presence of a low spot on the well pad and reduced vegetation density. This can be seen in Figure 36.

An important note is that the areas of higher elevation shown in Figure 34 and Figure 35 may be overemphasized due to the increased vegetation density in the northeast portion of the well pad, since the point cloud used to make these figures includes vegetation. Therefore, without examining the well pad from the ground surface, it is not possible to confirm with certainty that the "low spot" indicated in Figure 36 is actually due to lower land elevation, or lower vegetation. Therefore a limitation of using a drone is the inability to precisely determine the ground elevation when the vegetation is dense and tall.

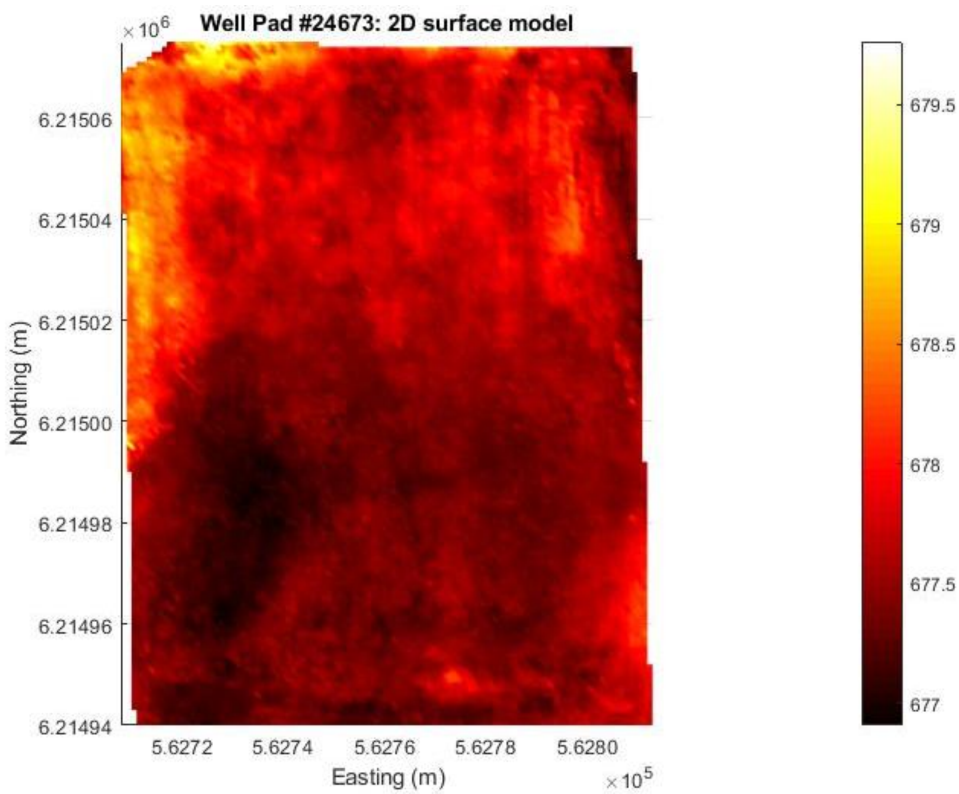


Figure 34 2D surface model of well pad 24673

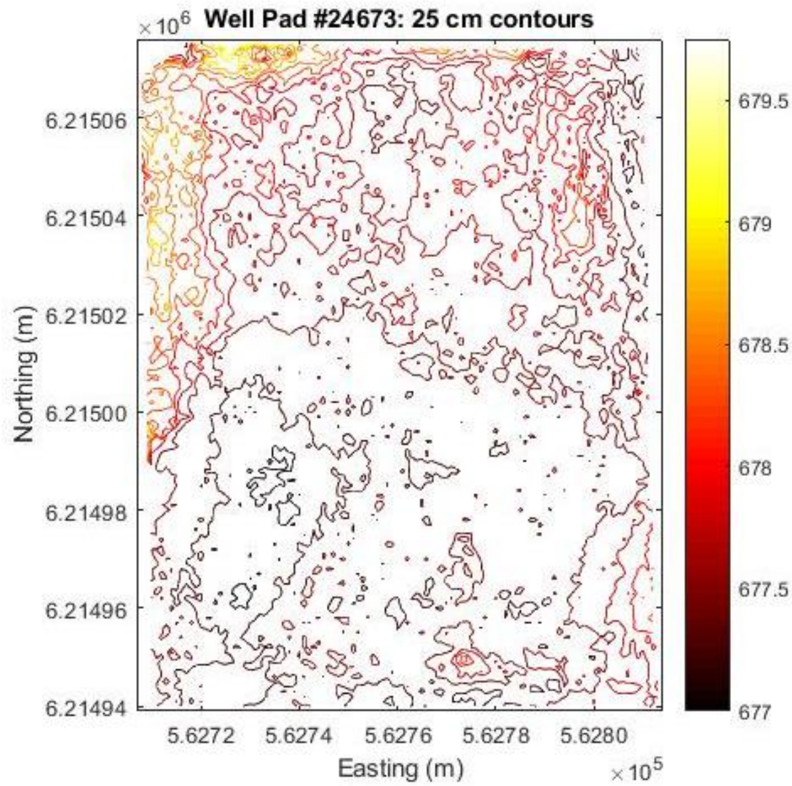


Figure 35 Contour map of well pad 24673

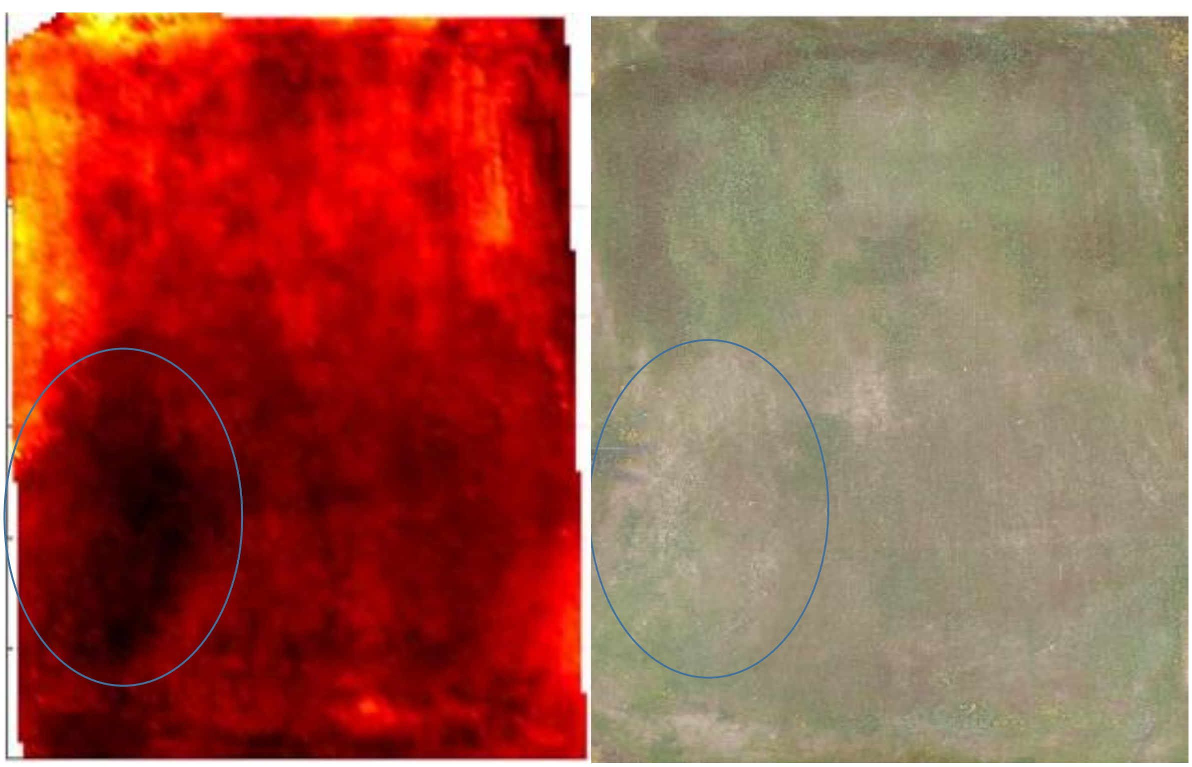


Figure 36 Potential ponding identified which may impede vegetation growth

6.4.5 Soil Objectives

The 2012 GoogleEarth image in Figure 29 does not show any salvaged soil piled around the site, so it is possible that any soil removed from the surface was removed from the site and not replaced throughout the site after decommissioning.

As mentioned previously, it is possible that the reduced vegetation growth in the area of the original well pad shape could be due to the compacted soil in this area. However, this is difficult to determine from drone aerial photography.

6.5 Well pad 21726

Well pad 21726 was not flown in July 2017 with the other four well pads. It was added to the research and flown in September 2017. This well pad had a different operator from the other four well pads and as it is not accessible by vehicle due to the restoration of the access road. This well pad was used as an opportunity to test the drone's capabilities for assessing reclamation of a well pad that is otherwise inaccessible for easy inspection.

The drone was flown a short distance manually along the reclaimed access road and into the well pad. The drone was then flown over the well pad to capture photographs manually. An oblique photograph taken from above the well pad showing its access route is seen in Figure 37.

A grid pattern was not flown to avoid concerns over losing line of sight to the drone and concerns about the unknown elevation difference between the take-off location and the well pad. At the time of the flight, it was windy with very light rain. These conditions combined with the manual flight mode created more challenging conditions for the camera, and many of the photographs that were acquired were blurry or out of focus. Most blurry photographs were never used, while some less than ideal photographs were used to construct the model of the well pad.

Figure 37 Access road for well pad 21726 viewed from a location above the well pad

The details of well pad 21726 were obtained from the BC Oil and Gas Commission database and are summarized in Table 10.

Table 10 Well pad 21726 details

WA Number	21726	Well Name	PROGRESS ALTARES A- 074-G/094-B-08
Well Operator	Progress Energy Canada Ltd.	UTM Zone Num	10
UTM83 Easting(m)	551,306.0	UTM83 Northing(m)	6,250,275.0
Surf(NAD83) Longitude	122 10' 07.94"	Surf(NAD83) Latitude	56 23' 39.47"
Total Depth (m)	1,120.0	Proposed Ground Elevation (m)	775.5
Casing Cut Off	Y	Certificate of Restoration	N
Well Classification	DEVELOPMENT	Cancel w Surface Disturb	N
Operation Type	UNDEFINED	Fluid Type	UNDEFINED
Spud Date	27/Sep/2006	Rig Rels Date	03/Oct/2006
Initial Production Date	N/A	Last Production Date	N/A
Well Status	ABANDONED	Status Effective Date	23/Jan/2012

The surface area for this well pad is approximately 1.42 ha based on the 2017 flight data, excluding the access road. This well pad is shown in Figure 38 in September 2012 (top) and September 2017 (bottom). In the September 2012 photo, equipment can still be seen on the well pad and soil piled on the eastern side, although at the time of this photograph the well had an abandoned status.

Figure 38 Well pad 21726 in September 2012 (top) and September 2017 (bottom)

6.5.1 Geotechnical Stability

There is no visible slope movement, slumping, subsidence, or tension cracks on or around the well pad, and there are no remaining cut and fill slopes.

6.5.2 Land Use and Facilities

There does not appear to be any gravel or rock on the well pad, and the well pad itself is free of debris although there are several larger rocks and fallen trees on the former access route. However, these do not appear to be hindering reclamation activities, and it is unlikely that they are the result of oil and gas activities. It is more likely that they are being used to prevent vehicle access to the well pad. No facilities from oil and gas activity have been left in place on the well pad. While there is no debris on the well pad itself, on a secondary, all-terrain vehicle access route wrapping around the south and west sides of the well pad, a piece of equipment or debris which is not natural to the area shows up in the aerial photos. This is indicated in Figure 39. While it is hard to identify what the black object is, it is clear that it is not a natural object.

Figure 39 Unidentifiable industrial debris on a secondary access route west of the well pad

There is nothing to suggest that reclamation activities are being impacted by uses of adjacent or surrounding lands.

6.5.3 Vegetation

Because the access road has been restored and the drone had to be flown into the well pad, photographs could not be taken of the vegetation on the well pad from ground level to supplement the aerial photos. However, the drone was lowered to capture a photograph of the vegetation growing on the well pad, shown in Figure 40.

Figure 40 Vegetation on well pad 21726 in September 2017

The vegetation appears uniform in terms of both density and colour. There does not appear to be any infestation of weeds. The vegetation growing on this well pad is mostly brown, appearing slightly greener near the edges of the well pad, closer to where coniferous trees are growing. This is highlighted in Figure 41. Additionally, there are some shrubs growing on the eastern side as shown in Figure 42, which may or may not be part of the planted seed mixture.

Figure 41 Green vegetation at the edges of the well pad

Figure 42 Shrubs or small trees on the eastern side of the well pad

There does not appear to be a connection between vegetation growth or health and where equipment had been located on the well pad, shown in the top photograph of Figure 38. The vegetation appears to be dominated by just one or a few species on the well pad. Although this does not necessarily mean that a mixture of species was not planted, it may indicate that some species from the seed mixture are not growing successfully. Examining the orthomosaic of the well pad it is clear that the surface area of the well pad is more than 80% covered by vegetation. Therefore, this criterion would be met for a Certificate of Restoration for this well pad.

6.5.4 Slope and Drainage

A 2D digital surface model of the well pad and a contour plot showing contours at 25 cm intervals were created in MatLab using low-density versions of the point clouds generated in Pix4D software. These are seen in Figure 43 and Figure 44, respectively.

In comparison with the other well pads, 21726 has a much greater slope of approximately 9%. However, the well pad drains uniformly to the northeast. There are no drainage ditches remaining either around the well pad edges or along the access road, suggesting that the drainage pattern has been restored to the condition prior to alteration, or at least to a drainage pattern that is compatible with the surrounding area and land uses. There are no areas of potential ponding or erosion seen in the photographs or landscape models. The uniformity in vegetation height likely contributes to the uniformity in the land slope shown in Figure 43 and Figure 44, as vegetation is included in the point cloud. Figure 37 shows that the land is sloping as suggested by these figures.

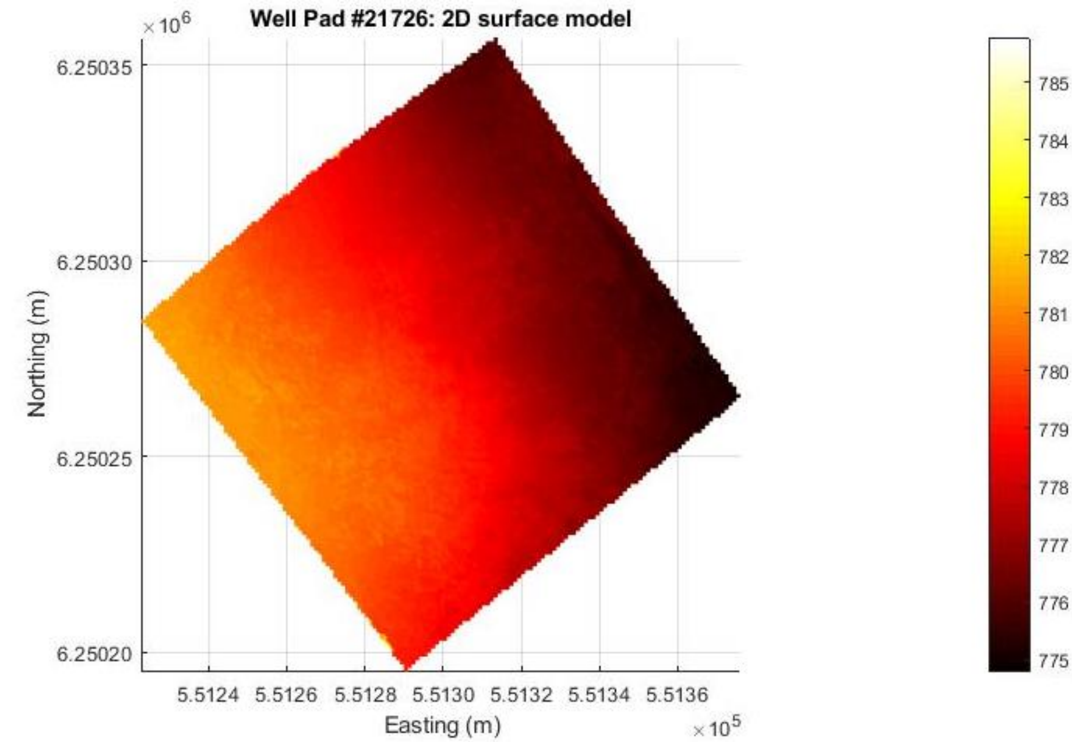


Figure 43 2D surface model of well pad 21726

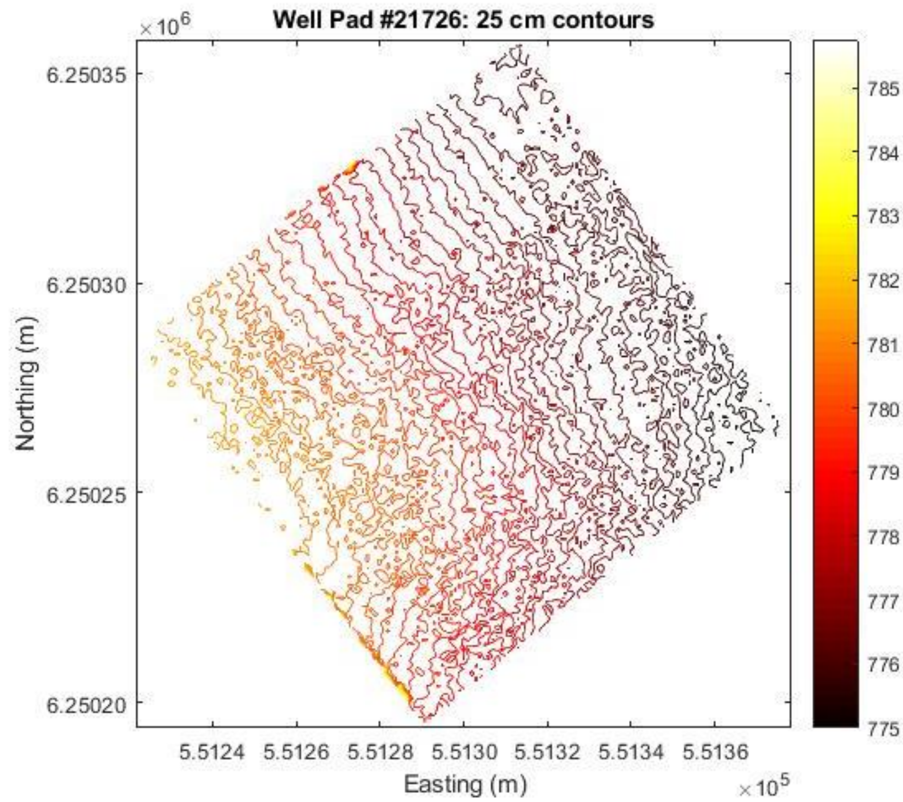


Figure 44 Contour map of well pad 21726

6.5.5 Soil Objectives

Because there was a pile of soil on the eastern side of the well pad in 2012, and this is the low side of the well pad in 2017 as shown from the contours. It can be inferred that this soil was salvaged during oil and gas development activities and subsequently spread out over the well pad as part of the reclamation effort. The well pad would, therefore, comply with surface soil replacement objectives as the salvaged soil must be replaced throughout the site.

However, note that there are distinct patches or spots on the well pad which are not bare, but where the vegetation is visibly different from most of the surface area. These areas do not appear to have any correlation to where equipment was located on the well pad in 2012. They also do not appear to be areas where ponding occurs, as no low areas were observed in the surface model. These patches be seen from the orthomosaic in Figure 38 and also from the oblique photograph in Figure 37 and the aerial photograph in Figure 45.

Figure 45 Areas with different vegetation type or density on the well pad

It cannot be inferred from these photographs that these are areas of contamination, or that they are a direct result of oil and gas activities beyond those which have impacted the entire well pad area. However, it is possible that the soil is more compact in these areas; one is in a spot where vehicles would have had to drive over to enter and exit the well pad site, and one is where salvaged soil was piled up on the eastern side.

7 Discussion and Conclusions

Using well pad 21726 as a case study, it was demonstrated that a small drone could be used to monitor well pads that are otherwise inaccessible for inspection. Flying up the former access route into the well pad enabled aerial inspection of the access route, which is also in the process of being reclaimed. However, there are restrictions that must be followed, such as the distance from the takeoff point and maintaining line-of-sight with the drone. Additionally, having the drone fly far from the operator raises concerns about keeping the flight time within the battery life of the drone. Fortunately, the location of the drone and its remaining battery life can be monitored in real time. Seeing the drone's surroundings in this way is useful in avoiding obstacles such as trees, and indicates how close to the ground the drone is flying if there is a significant change in elevation from the takeoff point, but midflight adjustments can only be made in manual mode.

Using the drone to obtain aerial photographs of the often heavily forested areas surrounding the well pads enables detection of features and surrounding land uses that are difficult to see through the trees from ground level. From examining the aerial photographs of well pad 23947, the gravel quarry northwest of the well pad is easily seen, as are the agricultural lands north of well pad 24673. These nearby surrounding features are almost impossible to see from the ground level through the trees. The ability to see adjacent land uses and their location relative to the well pad can give insight as to whether these land uses are impacting reclamation practices. Another example was the industrial debris found in the aerial photographs near the western edge of well pad 21726 despite being surrounded by tall trees.

By comparing the GoogleEarth imagery from 2012 and the orthomosaics generated in 2017, it seems there is not a direct correlation between where on the well pad various equipment or the wells were located and where vegetation is healthy and dense, or the ground is bare. However, there does appear to be a connection between where the salvaged soil was piled on a well pad, which is usually at one or more of the edges, and vegetation growth. A criterion for a Certificate of Restoration is that soil that was compacted as a result of oil and gas development activities be de-compacted, and that the salvaged soil be redistributed across the well pad. Since the salvaged soil piles are no longer on the well pads, it can be inferred that the soil was spread back out over the pads. However, the soil compacted as a result of being beneath the piles of salvaged soil may not have been fully de-compacted. Soil compaction does impede vegetation growth, and therefore land reclamation. Reduced plant growth where vehicles have repeatedly driven over a well pad after reclamation is seen on well pads 19518 and 23947.

For the four well pads which were flown in both July and September of 2017, the contrast in vegetation coverage over this two-month period are significant. In September, the well pads had fewer bare areas and a more uniform distribution of vegetation, and the aerial photographs and orthomosaics really emphasize this. Photographs taken at ground level are a helpful supplement to the aerial photographs regarding what specific plant species are growing, and if weeds are present. Knowing the composition of the seed mixtures planted on these well pads for reclamation purposes would be useful in determining whether the intended plant community is growing and if any non-native, invasive, or otherwise undesirable plant species are present.

When Pix4D is used to generate a contour plot or surface model, it uses the 3D coordinates of a dense point cloud, which includes all features captured in the aerial photographs, such as trees, rocks, debris, vegetation, etc. Therefore, the generated contour plots and surface models may not correspond to the bare-earth topography and can be affected by variance in vegetation height over the well pads. The ideal time to fly to create detailed topographic maps would be immediately after the reclamation activities have been completed and before the vegetation begins to grow. Then later flights would be needed to assess the state of vegetation development on the well pad.

The results of the study suggest that drones can be a valuable tool to evaluate reclamation progress of well pads. In many cases, the data that can be produced from the drone imagery can be used to rigorously assess multiple requirements needed for a Certificate of Restoration.

8 References

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Appendix 1 – DJI Phantom 4 Pro Specifications

AIRCRAFT

Weight (Battery & Propellers Included)	1388 g
Battery Capacity	5870 mAh
Battery Type	15.2 V LiPo 4S
Battery Energy	89.2 Wh
Diagonal Size (Propellers Excluded)	350 mm
Max Ascent Speed	P-mode 5 m/s
Max Descent Speed	P-mode 3 m/s
Max Speed	P-mode 50 kph
Max Tilt Angle	P-mode 25°
Max Angular Speed	A-mode 150°/s
Max Service Ceiling Above Sea Level	6000 m
Max Wind Speed Resistance	10 m/s
Max Flight Time	Approx. 30 minutes
Operating Temperature Range	0° to 40°C
Satellite Positioning Systems	GPS/GLONASS
Hover Accuracy Range Vertical	±0.5 m (with GPS Positioning)
Hover Accuracy Range Horizontal	±1.5 m (with GPS Positioning)

CAMERA

Sensor	1’’ CMOS
Effective pixels	20 million
Lens	FOV 84° 8.8 mm/24 mm (35 mm format equivalent) f/2.8 - f/11 auto focus at 1 m - ∞
ISO Range Photo	100 - 3200 (Auto)
	100- 12800 (Manual)
Mechanical Shutter Speed	8 - 1/2000 s
Electronic Shutter Speed	8 - 1/8000 s
Image Size	32 Aspect Ratio 5472 × 3648
	43 Aspect Ratio 4864 × 3648
	169 Aspect Ratio 5472 × 3078
Photo	JPEG, DNG (RAW), JPEG + DNG
Video	MP4/MOV (AVC/H.264; HEVC/H.265)
Supported SD Cards	Micro SD, 128GB max capacity
Write speed	≥15MB/s, Class 10 or UHS-1 rating required
Operating Temperature Range	0° to 40°C

REMOTE CONTROLLER

Operating Frequency	2.400 - 2.483 GHz and 5.725 - 5.825 GHz
Max Transmission Distance (Unobstructed, no interference)	FCC 7 km
Operating Temperature Range	0° to 40°C
Battery	6000 mAh LiPo 2S

Appendix 2 – Certificate of Restoration Criteria

Criterion	Description
Soil Objectives	The differences between the reclaimed site and adjacent land should not be significant enough to interfere with normal land use and should be no evidence of negative impact on vegetative growth.
Surface Soil Replacement	Salvaged surface soil should be replaced throughout the site Soils compacted by the oil and gas activities should be de-compacted.
Landscape Objectives	The differences between the reclaimed site and adjacent land should not be significant enough to interfere with normal land use and there should be no evidence of negative impact, either on or off-site.
Drainage	Restoring to the drainage pattern, to extent practicable, to its condition before the alteration, or otherwise Facilities that are left in place (i.e. clay pads) should not negatively impact natural drainage. There should not be evidence of surface water ponding on the location. It is important to ensure that surface water does not pond over a sump location as this may result in the upward movement of salts over time.
Contours	Contour and roughness should conform and blend with the adjacent contours, or be consistent with the present or intended land use.
Stability	Site should be geotechnically stable (no visible slope movement, slumping, subsidence, tension cracks). Site should be stable from erosion due to overland water flow. On-site cut and fill slopes should be stabilized.
Debris	Site should be free of industrial debris. Slash and roots and woody debris should not interfere with the intended land use and should not conflict with current forest protection policy and regulation.
Gravel and Rocks	No piles or windows. No increase in concentration of gravel and rock compared to control.
Vegetation Objectives	Vegetative characteristics between the reclaimed site and adjacent land should not show adverse impact as a result of oil and gas activities.
Species Composition	The species planted on the site should form a sustainable desired plant community that is, or is likely to become, similar to the original or control plant community, or that is compatible with accepted end land use and land management objectives of the landowner. There should be no prohibited or noxious weeds onsite. Nuisance weeds should not exceed the degree or extent of offsite infestation.
Plant Health	Plant growth should be healthy and vigorous with no evidence of plant disease or stress than is found on off-site controls.
Plant Density	Vegetation should be well distributed across the site with no bare areas.