Volumetric change calculation for a rock quarry using LiDAR and UAV data

Abstract:
Volume calculations for quarries have traditionally been performed using surveying techniques, with tools like the total station theodolite. This method is time consuming and often dangerous, as employees are expected climb loose gravel and peer over the edge of unsafe cliffs. By collecting data with an unmanned aerial vehicle (UAV), the time it takes to make these measurements is greatly reduced and the risk to employees is virtually negated. This study used the UAV, DJI Phantom 4 Drone, to collect imagery of Graves Quarry in Molalla, Oregon. DroneDeploy used structure from motion (SfM), a photogrammetric range imaging technique, to calculate the three-dimensional structure from two-dimensional UAV images. A Digital Surface Model (DSM) was created in ENVI LiDAR. Light Detection and Ranging (LiDAR) data was collected from Oregon Department of Geology and Mineral Industries (DOGAMI). This data contained a bare earth Digital Elevation Model (DEM) and highest hit DSM covering the study site from 2013. Volumetric change for the quarry from 2013 to 2017 was calculated in ArcMap. To do this, UAV imagery was first reprojected, georeferenced, and resampled to match the 2013 LiDAR DSM. Ordinary Least Squares (OLS) regression was performed to adjust the UAV DSM to match the LiDAR DSM elevation values. A change detection raster was created using the Cut Fill in ArcMap tool to show which areas have been excavated, filled, and by how much. UAV and LiDAR data provide a quick, safe means for estimating volume of quarries. However, there are numerous limitations with this method, including weather and non-systematic variations in the drone.

Keywords:
Unmanned aerial vehicle (UAV)
DJI Phantom 4 Drone
Structure from Motion (SfM)
Light Detection and Ranging (LiDAR)
Digital Surface Model (DSM)
Digital Elevation Model (DEM)
Ordinary Least Squares (OLS)

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Background:

Quarry mapping, stockpile surveying, and related tasks have traditionally been performed using tools like Total Station theodolites. These techniques are often very time consuming and dangerous. A Surveyor needs to be able carry equipment across steep slopes, and along high cliffs to record measurements.

With the unmanned aerial quadcopters becoming increasingly affordable and accessible to the general public, it seem advantageous for people in this industry to use UAV (unmanned aerial vehicles) to safely and quickly gather measurements like stockpile volumes or to determine the amount of material that has been excavated from the earth from one date to the present.

Is this type of surveying sufficiently accurate when conducted with a UAV? Can we determine the volume of material removed from the earth, using data collected from DJI's Phantom 4 with historical LIDAR data downloaded from DOGAMI (Oregon Department of Geology and Mineral Industries)?

Data and Software Used:

Data:

- Oregon Department of Geology and Mineral Industries (DOGAMI):
  - Bare Earth (DEM) and Highest Hit (DSM) from 2013
- DJI Phantom 4 Drone
  - Point Cloud from December 2017

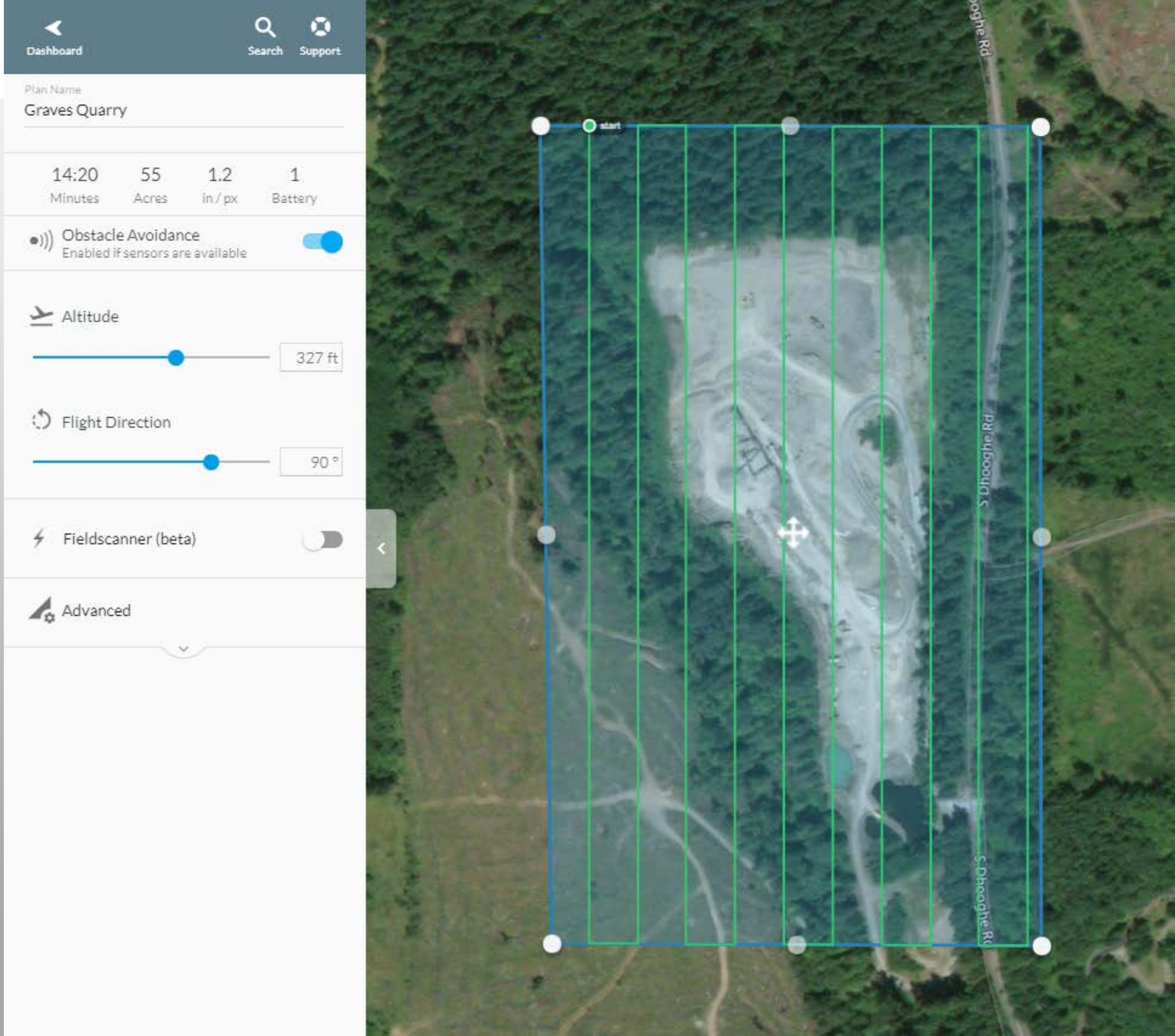
Software:

- DroneDeploy
- ENVI LiDAR
- ArcMap

Mission Planning:

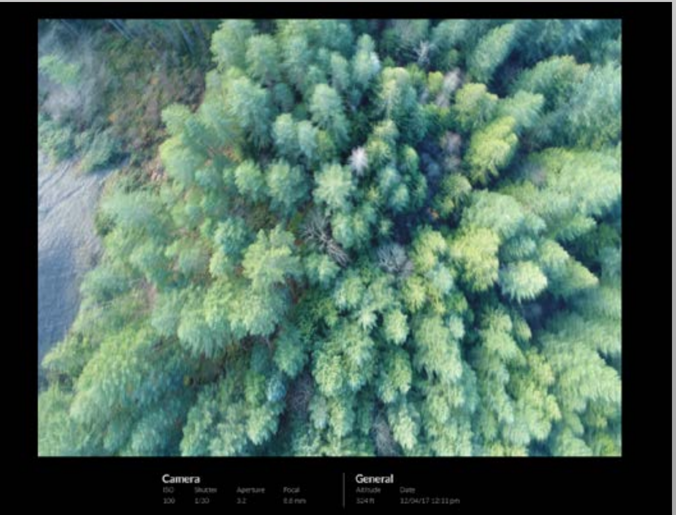
- Altitude 327 ft.
- Speed 28 mph

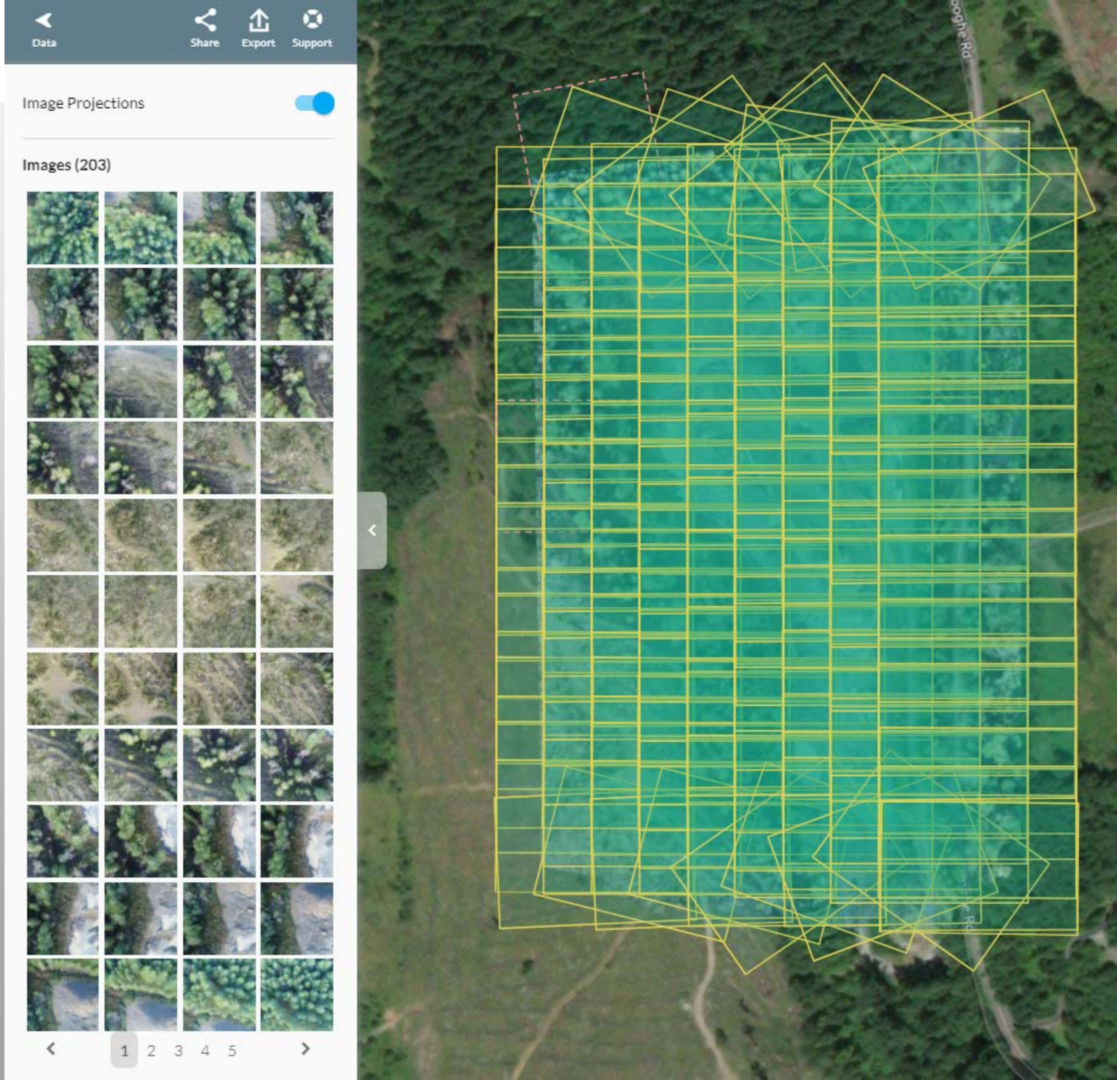
- Sidelap 75%
- Frontlap 75%



Processing:

- 202 of 203 images used





Drone Deploy:

- DroneDeploy estimates a resolution of 1.2 in / pixel
  Determined by the flight settings, not the average altitude from the ground

Drone Deploy:

Methods:

ENVI LiDAR and ArcMap

- Load DroneDeploy point cloud product, “points.las”
- Points.las > Processing > Produce DSM (geoTIFF)
- Create polygon shapefile covering Graves Quarry:

- Clip LiDAR DEM and DSM rasters from shapefile extent

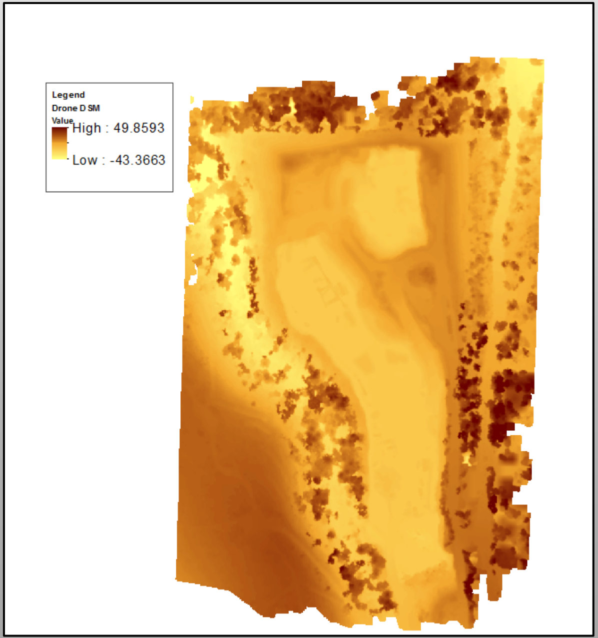
Methods cont’d:

Matching UAV DSM to LiDAR DSM

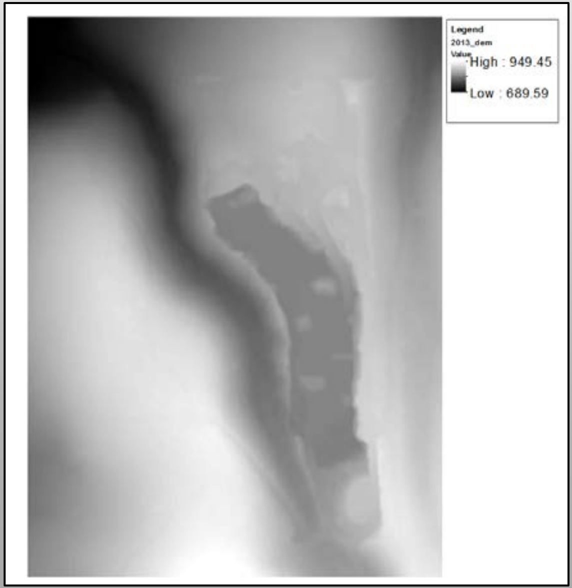
- Reprojected 2017 DSM to NAD_1983_HARN_Lambert_Conformal_Conic
- Georeferenced 2017 DSM → 2013 DEM using 3 GCPs in ArcMap
    - DroneDeploy imagery is locally (not globally) accurate
- Resample Tool: Resampled 2017 DSM from 1x1ft → 3x3ft
- Raster Calculator: 2017 DSM vertical units from meters → ft

Difference in elevation values:

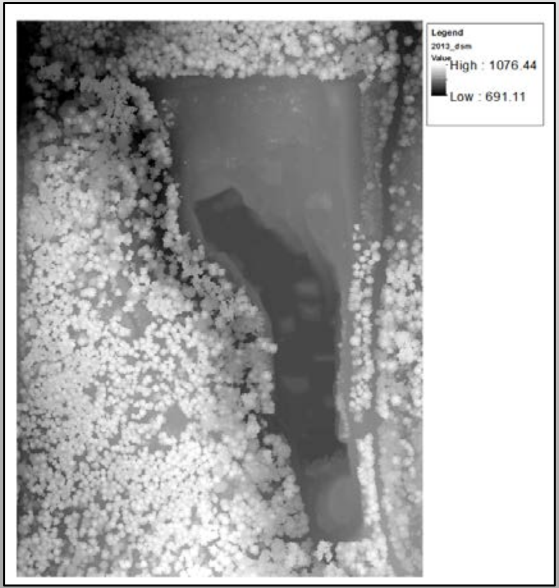
2017 DSM:



2013 DEM:

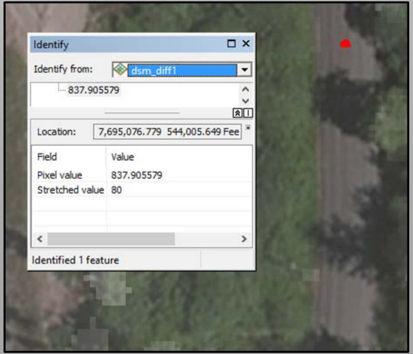


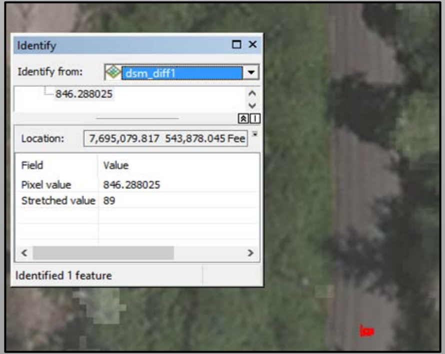
2013 DSM:



UAV Tilt:

- Raster Calculator: 2013 DSM - 2017 DSM = DSM_diff1
    - If no tilt: Different points on the road should have the same difference in elevation
    - Able to add road pixel value to whole 2017 DSM to standardize elevation (Z values)
- Points on south side of the road had a larger difference in elevation than the north side.





Ordinary Least Squares (OLS):

Creating a regression model of Z values on “no change” surfaces:

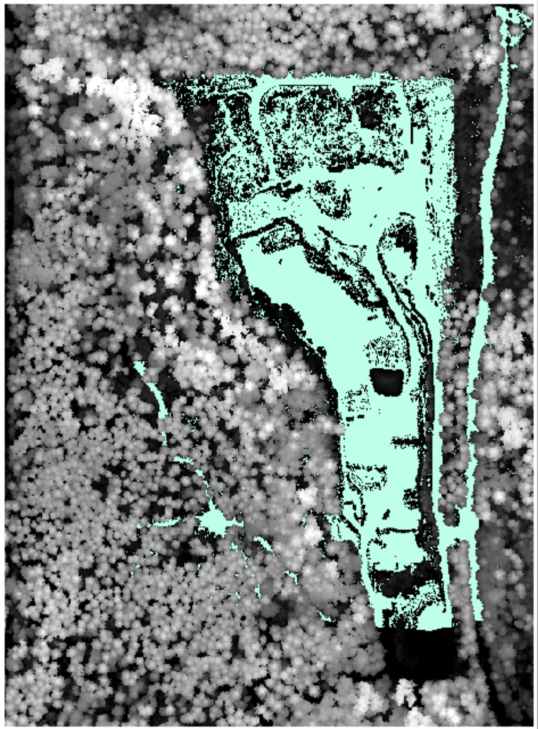
Remove landscape features from DSMs based on LiDAR feature height:

- Raster calculator: “Lidar_DSM” - “Lidar_DEM” = “Feat_Height”
- Removed false negative feature height values:
  - Con (“Feat_Height” < 0, 0, “Feat_Height”)
- Created mask in Raster Calculator: Candidates for pixels that didn’t change
  - Con (Feat_Height > 1, 1)

Extract elevation values from “no change” UAV and LiDAR DSMs on randomly selected locations:

- Create Accuracy Assessment Points:
  - 500 points
- Extract Multi Values to Points:
  - Input rasters: 2013 DSM & 2017 DSM
- Add New Field, “Z-diff”:
  - Z-diff = Abs(2013 DSM - 2017 DSM)

Mask:



OLS cont’d:

Remove outliers based on z-diff, ‘no data’ DSM values, and excavated pit values:

Select by attributes (points with minimal change):

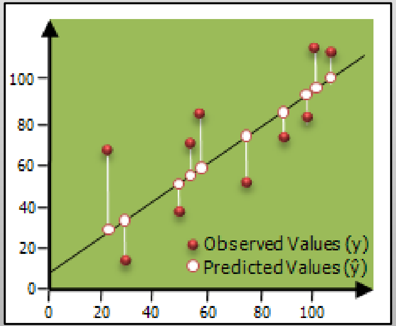
- Exclude no data points that had -9999 for 2017 DSM; switch selection to exclude these points from analysis

- Exclude every value in the pit: created polygon shp of pit, select points within the polygon; switch selection

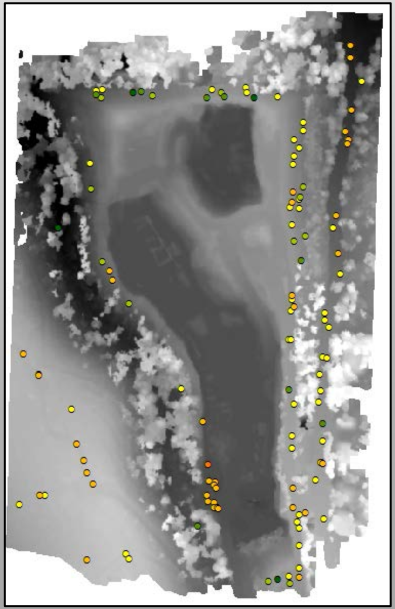
- Statistics: Mean(841.27) & SD(11.3):
    - (Z-diff <= mean + 1SD) AND (Z-diff >= mean -1SD)

- Result: 116 points given unique PID for Ordinary Least Squares (OLS) tool

OLS:



Final 116 points:



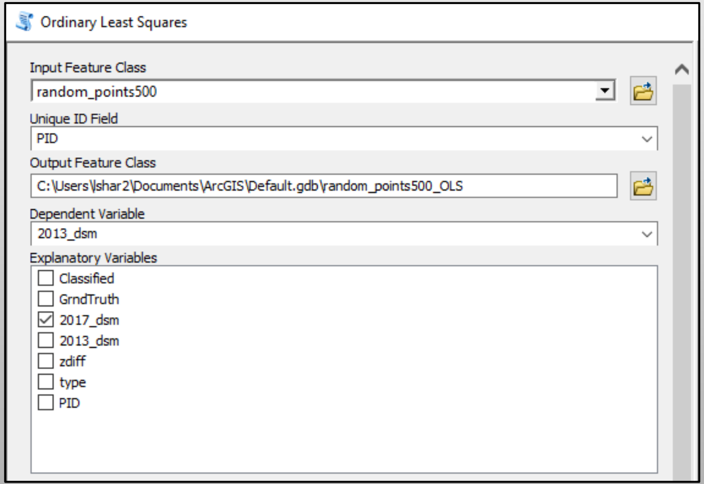
OLS Tool:

OLS:

- Input Feature Class: 116 of the 500 selected points
- Dependent Variable: 2013 DSM
- Explanatory Variable: 2017 DSM

Summary of OLS Results - Model Variables

Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]
Intercept	842.728122	0.285699	2949.701696	0.000000*	0.313179	2690.880596	0.000000*
2017_DSM	1.032130	0.007180	143.741047	0.000000*	0.008020	128.693136	0.000000*

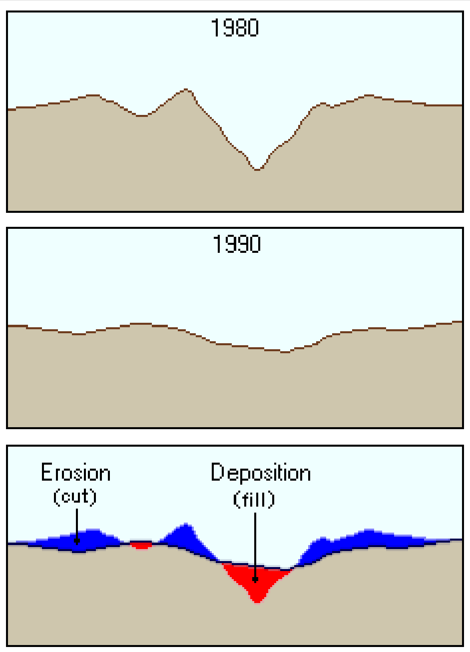


- Adjust UAV DSM to match LiDAR DSM:

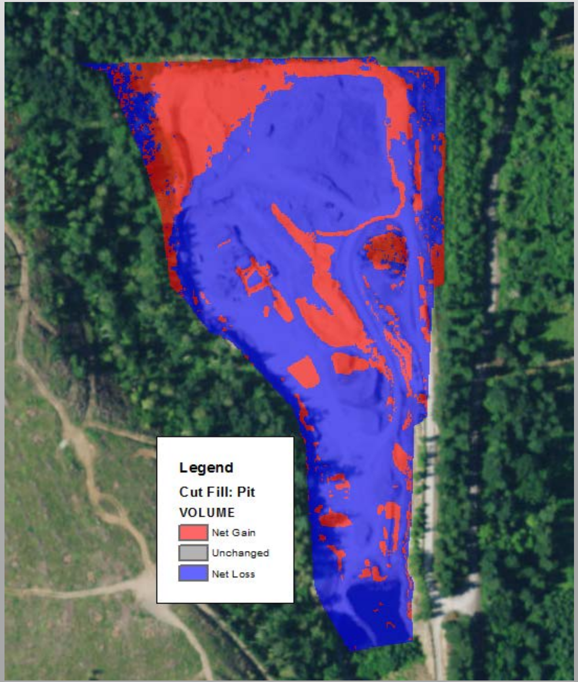
  Raster Calculator: **Adjusted UAV DSM = (2017_DSM*1.032130) + 842.728122**

Volume Change Detection:

Cut Fill Tool:

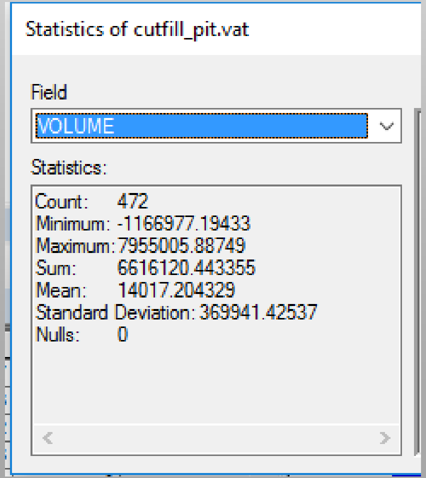


Product:



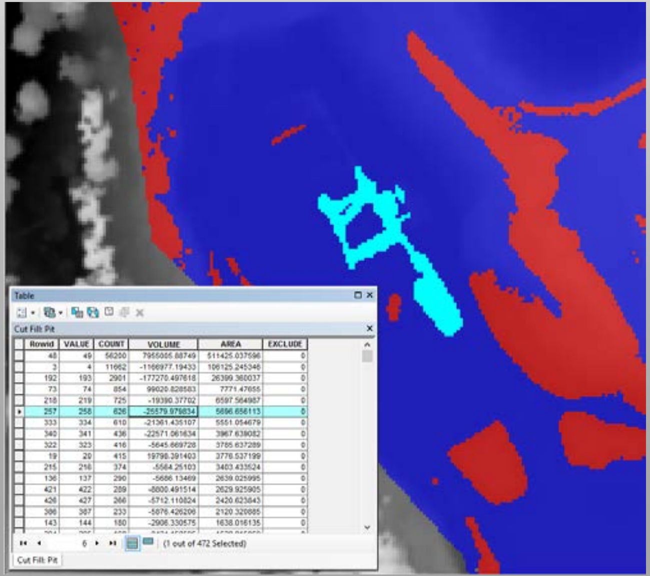
Attribute Table Statistics:

- Volume sum - 6616120.44 ft^3



Volume Change Detection:

Had to go back to exclude tools like the “rock crusher” that was considered “fill”:



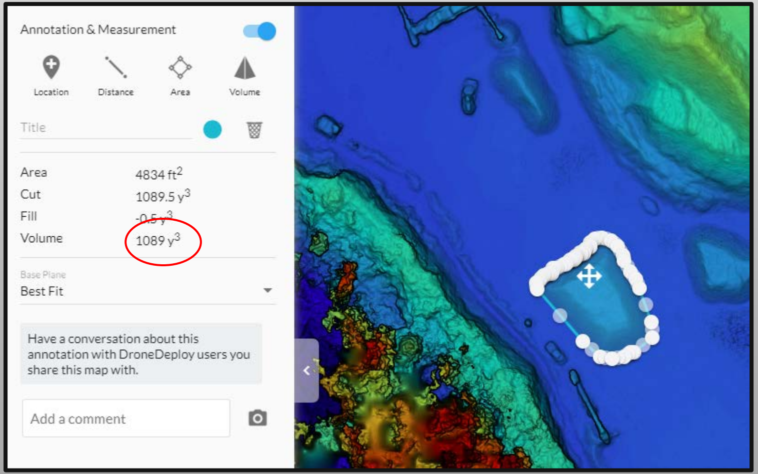
Rowid	VALUE	COUNT	VOLUME	AREA	EXCLUDE
48	49	56200	7955005.88749	511425.037596	0
3	4	11662	-1166977.19433	106125.245346	0
192	193	2901	-177270.497618	26399.360037	0
73	74	854	99020.828583	7771.47655	0
218	219	725	-19390.37702	6597.564987	0
257	258	626	-25579.979834	5696.656113	0
333	334	610	-21361.435107	5551.054679	0
340	341	436	-22571.061634	3967.639082	0
322	323	416	-5645.669728	3785.637289	0
19	20	415	19798.391403	3776.537199	0
215	216	374	-5564.25103	3403.433524	0
136	137	290	-5686.13469	2639.025995	0
421	422	289	-8800.491514	2629.925905	0
426	427	266	-5712.110824	2420.623843	0
386	387	233	-5876.426206	2120.320885	0
143	144	180	-2906.330575	1638.016135	0

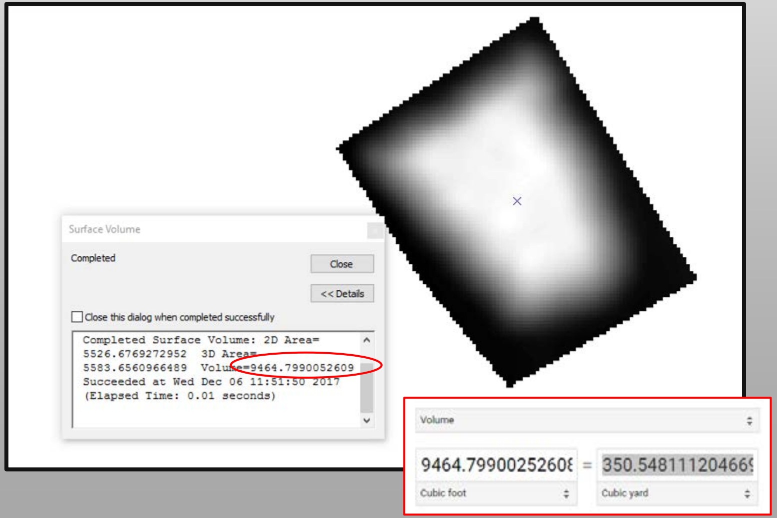
Volume sum - 6616120.44ft^3 + 25579.98ft^3

= 6,641,700.42ft^3 removed from 2013 to 2017

Accuracy Assessment:

- Volume Calculations in Drone deploy do not correspond with the volume calculations in ArcGIS.



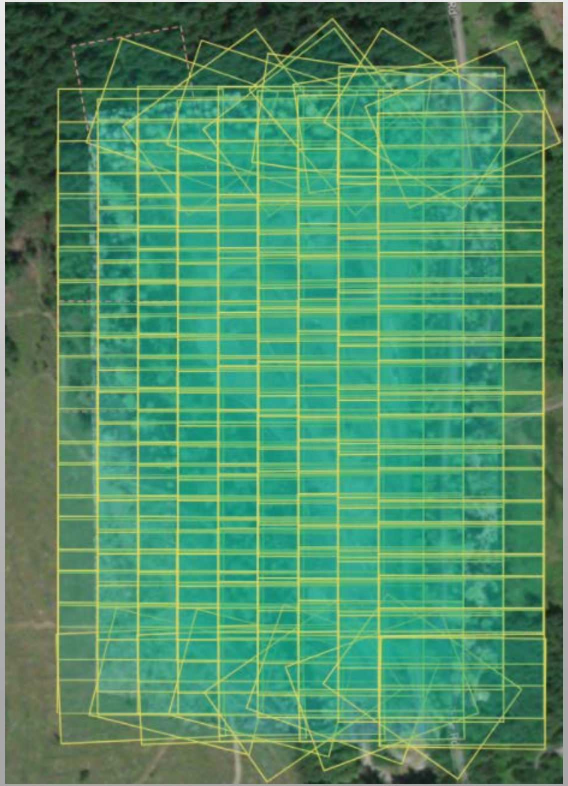


Conclusion:

Limitations

- Weather:

- LiDAR data availability
- Areas around the edges of the flight path don't have as many contributing images as areas in the center
- Non-systematic limitations within the drone (roll, pitch, yaw)
- Ordinary Least Squares vs Geographically Weighted Regression



Questions?

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