

**1 Introduction**

Digital photogrammetry (DP) is a technique involving the capture of overlapping images to analyze an object; it is especially useful for detailed analyses of geologic and geomorphic sites. Ground and/or air-based photogrammetry (Fig. 1; Panel 4) were used to analyze Diana's Pool in Chaplin, CT, the Arboretum at Eastern, and West Beach, Block Island using Adobe Lightroom, Agisoft Metashape, Drone Deploy, and ArcGIS. Overriding objectives are:

- (1) Image geological sites on ground and in the air.
- (2) Create related maps and 3D printed models, and
- (3) Analyze change (deposition/erosion) and topography to understand geologic conditions at these sites.

**Figure 1.** Landing the Mavic Pro 2 Drone at the Arboretum site. The Arboretum is an on-campus wetland used by a variety of classes in the Arts and Sciences. Drone imagery is used to map a variety of sites (see panels) in Connecticut and Rhode Island.

**2 DP Use at Geologic Sites in CT and RI**

DP was used at several sites in CT and RI. Diana's Pool, a bedrock-controlled reach of the Natchaug River in Chaplin, CT, is underlain by lapetos-east terrane characterized by coarse-grained pegmatite and banded gneiss. Stream erosion and differential weathering have exploited joints and foliation to create topographically distinct geomorphic features (Fig. 2).

Also in CT, the Arboretum is a small stream system that drains Eastern's campus to flow Northward through a wetland complex. This complex flows over glacial till and stratified drift deposits.

Block Island in RI experiences wave erosion that has modified shorelines and exposed metal and plastic refuse from an abandoned dump site at West Beach, Block Island (Fig. 3). The site was mitigated in the summer of 2018 with a \$1.8 million revetment project to reduce pollution offshore (Monieson, 2018).



**Figure 2.** Alternating pegmatite and banded gneiss weather differentially creating overhangs beside the river. Also, jointing often contributes to stair-like bedrock in the stream.

**Figure 3.** West Beach, BI in 2018 revealing wave eroded debris from a former dump site. Rusted metal, plastic, cement and other detritus were introduced to the beach and littoral zone, ultimately prompting a \$1.8 million mitigation effort.



**Figure 6.** Aerial view of the Arboretum taken from the Drone Deploy website after uploading the 956 images captured with two flight lines at 90° to each other. Flights used 2 sets of parallel flight lines with 75% forward overlap and 80% forward and 75% side overlap. Insets show close views of (a) a stream section separated into two segments. A photogrammetric target can be viewed as well. Inset (b) shows a close-up view of a site from the upper flight. Note extensive shadows caused by sunny conditions during the flight. This upper-lower flight boundary causes elevation mismatches (see Fig. 7).

**3 Ground and Drone Image Capture**

**Ground:** Images were captured to characterize microtopography of a stream-eroded cavity on a jointed outcrop at Diana's Pool using an iPhone XR under diffused natural lighting. A photogrammetric target was placed on the outcrop to provide ground control for scaling 3D models. A total of 36 images were captured using a pattern of 8 images passing 4 times across the outcrop (Fig. 4). At West Beach (RI), images were captured using a Nikon D610 on a tripod images were captured at ~1.5 m intervals along 5 shore-parallel to shore-oblique lines to ensure >60% overlap. Scale bars were placed at varying elevations and surveyed using Real Time Kinematics (RTK) GPS (Fig. 6).



**Figure 4.** (a) Pattern of image capture for the stream-eroded outcrop at Diana's Pool. A photogrammetric target at the top of the outcrop to be used for 3D modelling. Eight images were taken at 45° positions around the site from a high angle. (b) View of the image capturing process with an arrow indicating the erosional cavity.

**In the Air:** A total of 956 images were captured ~75 m above the Arboretum using a Mavic Pro 2 Drone. Photogrammetric ground targets were placed throughout the Arboretum to provide ground control for 3D modelling (Fig. 5). Surveying was performed using RTK GPS for ground control. DJI Fly was utilized to create a specific linear flight pattern that could then be transferred to the drone. Images for the site were uploaded to Drone Deploy for DP analysis.



**Figure 5.** Map view of the Arboretum including photogrammetric target locations in yellow. The Arboretum was separated into 3 subsections for imaging to limit the distance the drone had to fly away from the operation.



**Figure 6.** Gathering RTK GPS data on Block Island.

**Table 1.** Camera settings for the 36 images captured of the Diana's Pool feature.

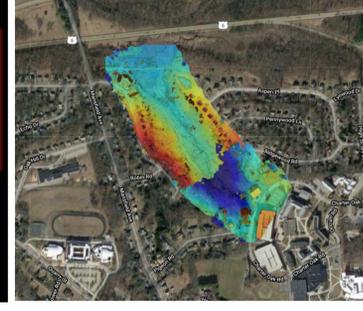
	Shutter Speed	ISO	Aperture
Images	1/120, 1/130, 1/150, 1/200, 1/240, 1/290, 1/380, 1/400	ISO 25, ISO 32, ISO 40	f/1.8

**4 Drone Deploy**

Drone Deploy software was utilized to develop aerial models of the field sites from UAV imagery captured during two flights ~ 75 m above the forest floor. A drone and a compatible mobile device is used with the Drone Deploy app. We performed mission-planning using DJI Pilot professional edition. Images uploaded to DD are used to map elevation changes, create a 3D model (Fig. 7), and present maps of plant health (Fig. 6-8). Two take-off locations were used (Fig. 6) to minimize flight distance and conserve batteries. However, this creates a mismatch in orthoimages due to differing shadows (Fig. 6) as well as an offset in elevation (Fig. 7 inset). Future flights will recapture images from one take-off location to resolve these problems.



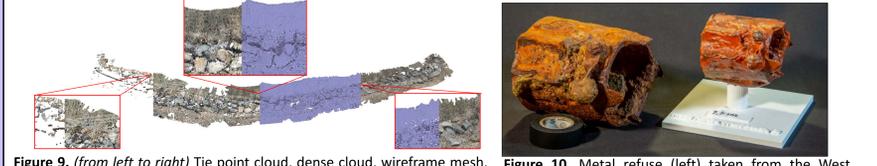
**Figure 7.** 3D model of the Arboretum created in Drone Deploy. While detail is realistic, the inset shows error associated with merging model data from two flights with differing take-off elevations. This can be addressed within DD software, but is better resolved by using a single take off location.



**Figure 8.** Aerial view of the Arboretum with elevation shown in color. The elevation estimates are mismatched at the boundary between upper and lower flight images (e.g. blue to green boundary).

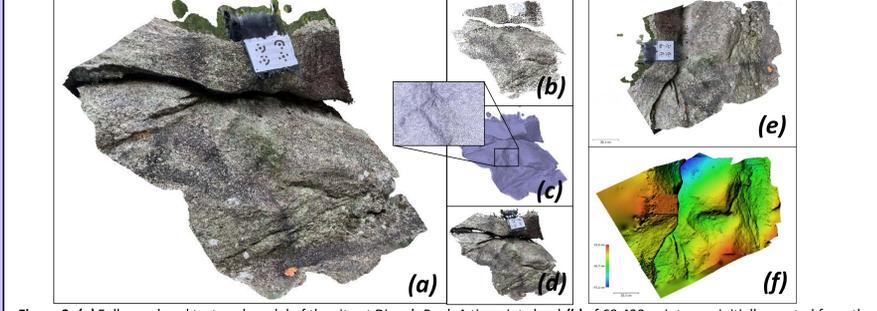
**5 Building a Model with Agisoft Metashape (AM)**

AM is suitable for modelling geologic sites. We use AM to model West Beach (Fig. 9) and to create a file suitable for 3D printing a sample recovered from the site (Fig. 10). The print file was constructed from point cloud data converted to a printable format (.stl). Similar approaches were used to develop a 3D point cloud (x-y-z points) and textured mesh of the Diana's Pool outcrop (Fig. 11).



**Figure 9.** (from left to right) Tie point cloud, dense cloud, wireframe mesh, and textured model of the West Beach model developed in AM.

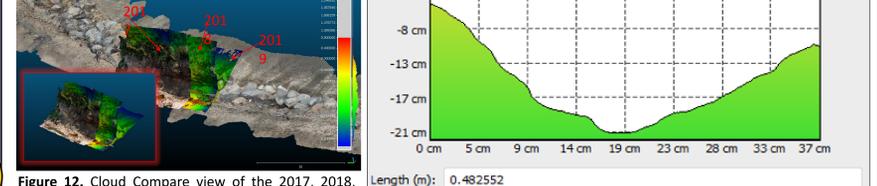
**Figure 10.** Metal refuse (left) taken from the West Beach site compared with the 3D printed model



**Figure 8.** (a) Fully-rendered textured model of the site at Diana's Pool. A tie point cloud (b) of 69,433 points was initially created from the 36 aligned images. This was used to create a wireframe mesh (c) of 788,346 triangulated faces that connected at common points. A dense cloud (d) of 49,963 points was finally created after careful removal of unnecessary tie points through gradual selection. An orthomosaic photo (e) and DEM (f) could be created and exported to quantify erosion at the outcrop.

**6 Change Detection**

The value of 3D data is to support analyses that are difficult or impossible to do otherwise. For example, 3D models are well-suited for characterizing topographic change through time. Cloud Compare freeware was used to compare topography in two or more dense clouds. This enables characterizing change between 2 points in time (an analysis referred to as change detection). Block Island models from 2017, 2018, and 2019 of West Beach, before and after the revetment project (Fig. 12), were analyzed in Cloud Compare to determine erosion. ArcGIS can also represent erosion/deposition as it was used for the Diana's Pool site. Erosion refers to where the surface has been carved while deposition refers to where the surface has been raised.



**Figure 12.** Cloud Compare view of the 2017, 2018, and 2019 dense clouds of the West Beach site. Inset details the changes; erosion signifies shoreline retreat with the armored revetment project.

**Figure 13.** Cross-sectional view of the erosional depression at Diana's Pool site. This GIS cross-section in ArcGIS reveals ~0.48 m length ~19 cm depth.

**7 Initial Modelling and Ongoing Actions**

This project introduced techniques used to create photogrammetric models of field sites using images captured through drone and ground imaging. This can be used to measure microtopography of detailed erosion (e.g. at Diana's Pool), ~ 3.5 m topographic change change associated with the West Beach Revetment (Fig. 14), and topography at the Arboretum forest canopy. Additional mapping is anticipated at the Arboretum using Drone Deploy to create resolve flight matching errors and to map and analyze stream and valley geomorphology beneath the forest canopy.



**Figure 14.** View facing the West Beach location after the revetment project in June of 2019. Boulders and native coastal grasses were strategically placed along the beach face to anchor sediment to prevent erosion. The RTK GPS and imaging setup is viewed on the right.

**Acknowledgements and Citations:** I would like to thank Dr. Drew Hyatt and Dr. Bryan Oakley for their assistance on these projects. Also, thanks to Arlene Blackwell and Jack Cerra for their teamwork on the Block Island field work. Permission from Eastern's Chief of Police to fly the drone is greatly appreciated.

Monieson, A. 2013. Storms expose debris from old town landfill: <https://www.blockislandtimes.com/article/storms-expose-debris-old-town-landfill/33594> (accessed Nov. 2019)

Nordstrom, S. (n.d.). What is an Orthomosaic Map and How Does Mapping Benefit My Property? Retrieved December 03, 2020, from <https://blog.dronebase.com/what-is-an-orthomosaic-map-and-how-does-mapping-benefit-my-property>