

Standard Operating Procedure (SOP) and Processing Parameters for UAV Photogrammetry Using ArcGIS Drone2Map and ArcGIS Pro Reality Mapping

Introduction

This supplementary file provides a software-specific standard operating procedure for reproducing the UAV photogrammetric workflow. Screenshots are retained where they document the sequence of operations in ArcGIS Drone2Map and ArcGIS Pro Reality Mapping. Table S1 summarises the principal processing parameters.

Table S1. Principal UAV photogrammetric-processing parameters.

Parameter	Configuration
UAV platform	DJI Matrice 300 RTK
Camera	Zenmuse P1
Number of images	504
Processing software	ArcGIS Drone2Map and ArcGIS Pro Reality Mapping
Horizontal coordinate reference system	WGS 84 / UTM zone 17N (EPSG:32617)
Vertical reference	EGM96 geoid
Total RTK GNSS-surveyed ground points	8
GCPs used in the refined adjustment	4
Adjustment sequence	Initial adjustment without GCPs; four GCPs subsequently added; Adjust operation rerun
Final reference product	RGB true orthomosaic regenerated from the refined GCP-constrained adjustment
Orthomosaic GSD	Approximately 0.006 m
Other generated products	DSM, DTM and point cloud
Point-cloud density	High
Ground-control dataset accuracy summary	RMSE EN = 0.08 m; RMSE U = 0.09 m
Interpretation of accuracy values	Ground-control dataset indicators; not independent checkpoint residuals

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1. Name the project

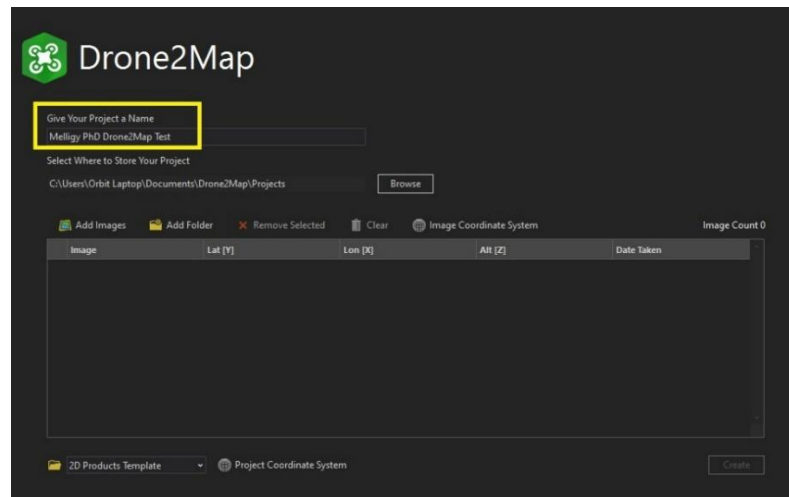


Figure 1. Drone2Map project-name entry.

2. Add the UAV images

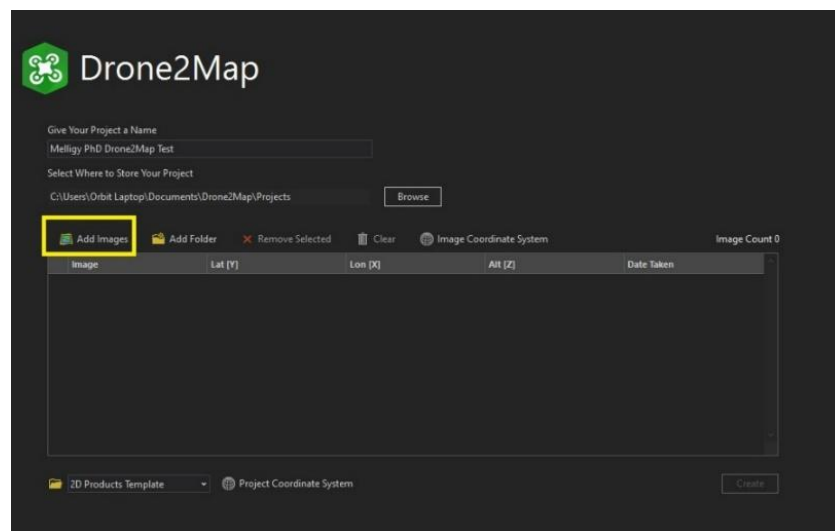


Figure 2. UAV image-upload interface.

3. Verify the uploaded images

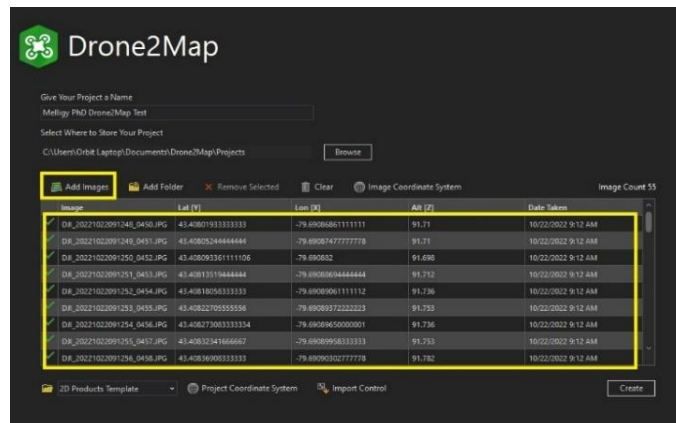


Figure 3. Uploaded image list.

4. Create the Drone2Map project

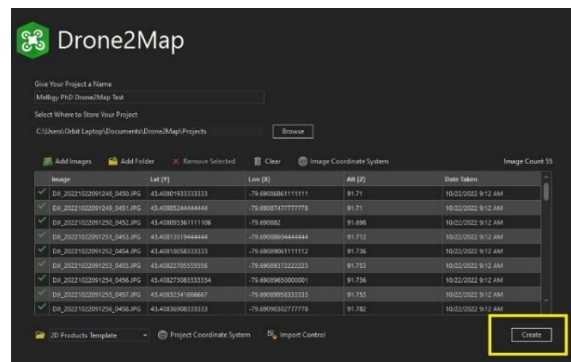


Figure 4. Drone2Map project creation.

5. Review the created project



Figure 5. Project data displayed in Drone2Map.

6. Configure processing methods and output products

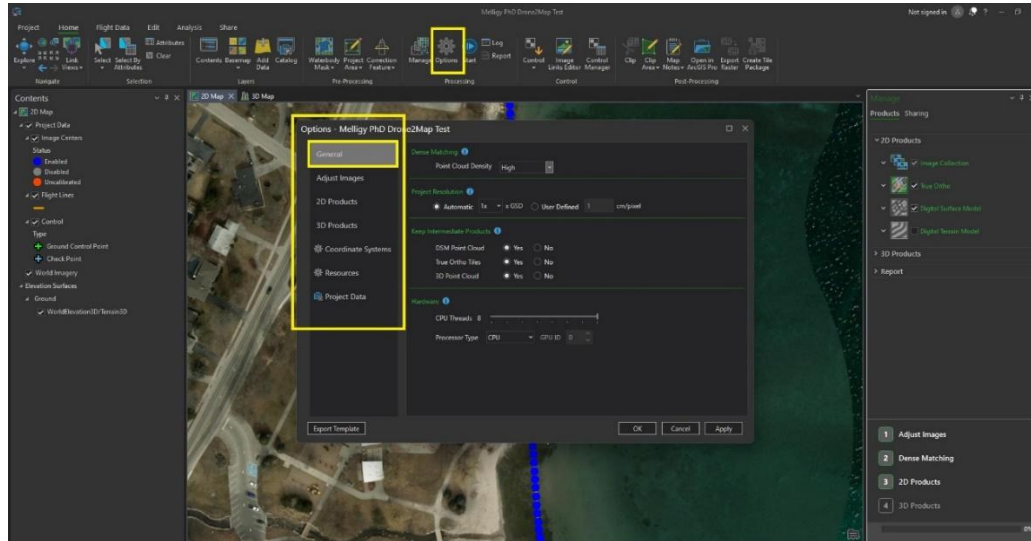


Figure 6. Drone2Map processing-options interface.

Point-cloud density was set to High.

High point-cloud density was selected to retain geometric detail in the reconstructed surface.

Project resolution was set to $1\times$ (the default recommended image scale), which permits use of the High point-cloud setting.

- a) DSM (Digital Surface Model) was checked
- b) 3D point cloud was checked.
- c) True Ortho was checked.

7. Configure image adjustment

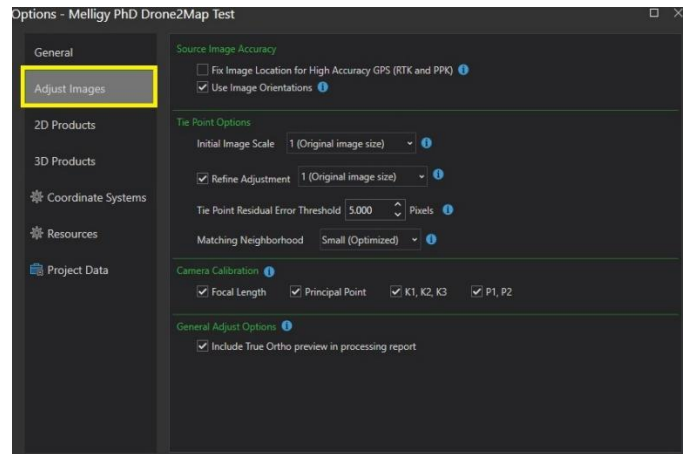


Figure 7. Image-adjustment settings.

The following image-adjustment settings were used:

- Image orientation was enabled.
- The original image size was used for adjustment.
- A small matching neighbourhood was selected.
- All available camera-calibration parameters were enabled.

8. Configure 2D products

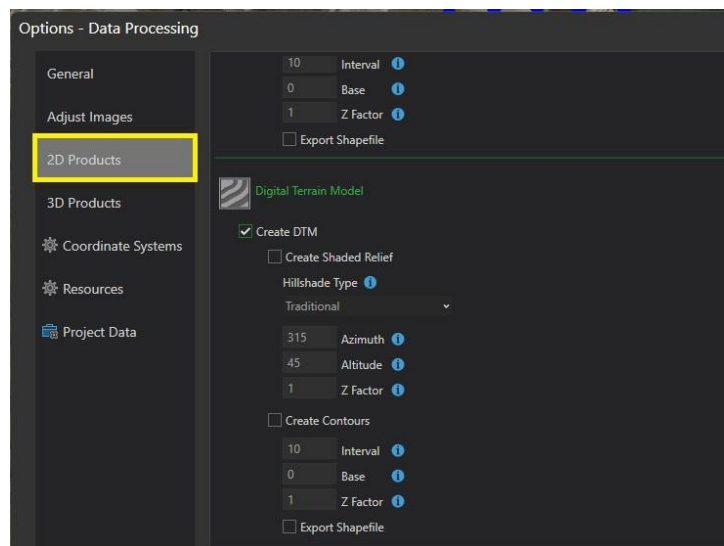


Figure 8. 2D product settings.

The following 2D products and settings were selected:

- Solution points were used for orthorectification.
- The RGB true orthomosaic was created and enhanced.

- c) A digital surface model (DSM) was created without contours.
- d) A digital terrain model (DTM) was created without contours.

9. Configure 3D products

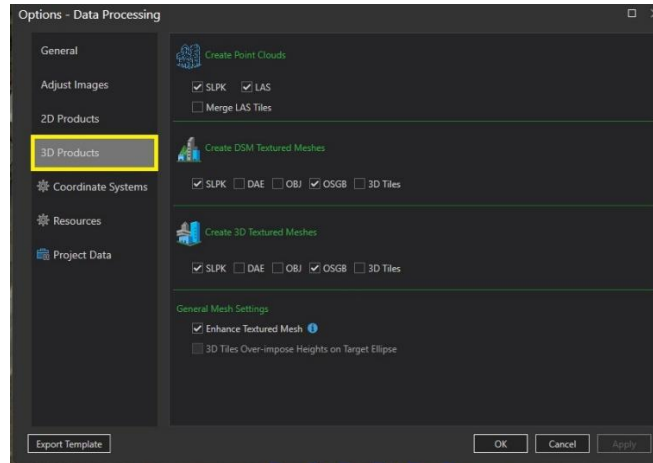


Figure 9. 3D product settings.

The enabled 3D outputs included Esri scene-layer packages (SLPK) and OSGB textured-mesh products for compatible software environments.

10. Set the coordinate reference systems

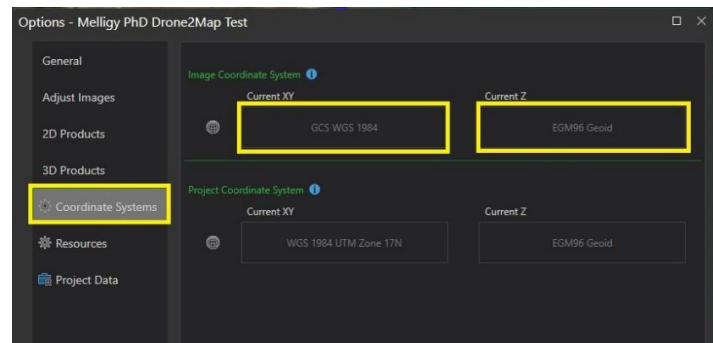


Figure 10. Coordinate-reference-system settings.

The horizontal coordinate reference system was WGS 84 / UTM zone 17N (EPSG:32617), and elevations were referenced to the EGM96 geoid.

11. Review project-data settings

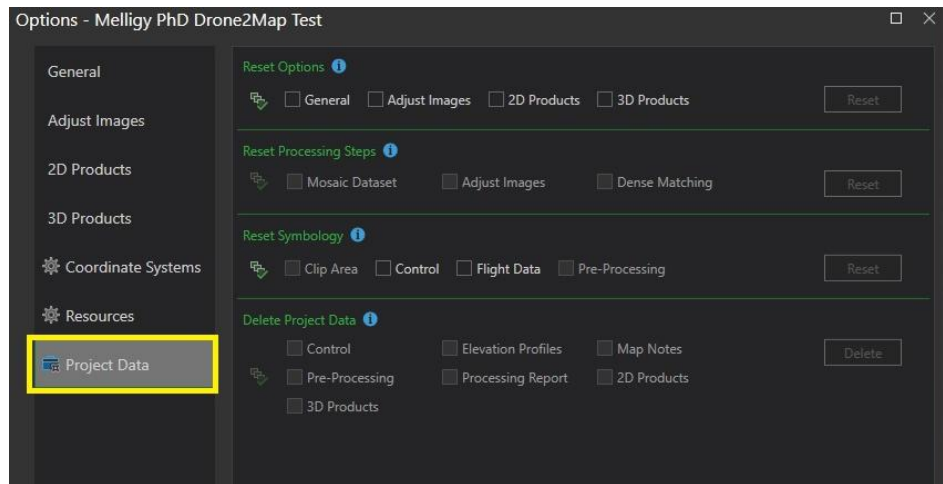


Figure 11. Project-data management settings.

The project-data options were reviewed without resetting previously configured processing settings.

12. Apply the processing settings

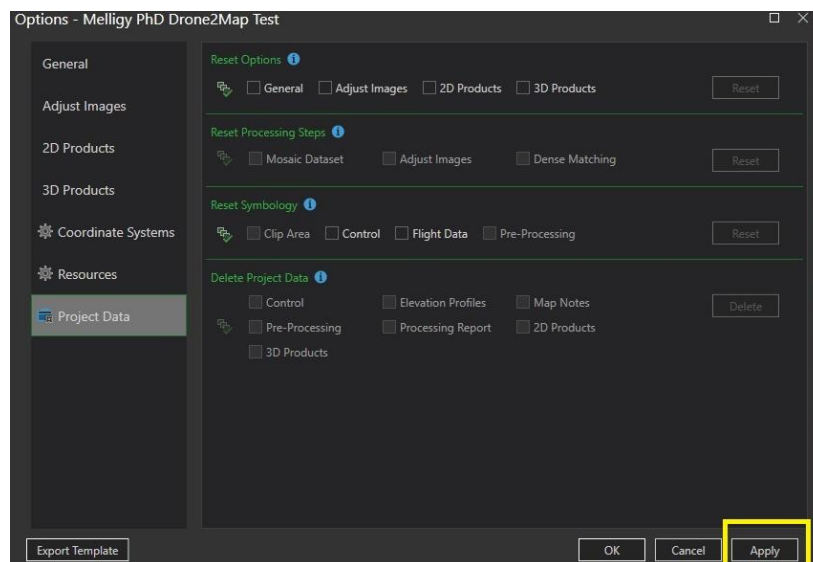


Figure 12. Application of processing settings.

The configured settings were applied and saved before processing.

13. Start data processing

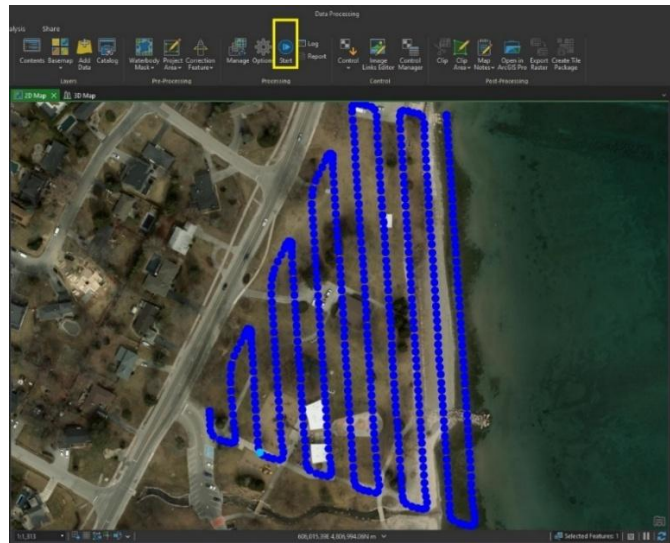


Figure 13. Drone2Map processing workflow.

The application and workstation were kept running until processing was complete.

14. Interpret processing outputs

Drone2Map reconstructs overlapping UAV images into georeferenced products. The processing report documents the project configuration, image adjustment, internal matching diagnostics, coordinate systems, and generated outputs.

14.1 Project summary

Table 1. Drone2Map project summary.

Project Summary	
Project Name	FINAL DATA PROCESSING MELIGY57
Processed On	12/5/23, 06:58 AM
Camera Model	DJI ZENMUSEP1
Images	504 out of 504 images calibrated
Project Area	0.056 km ² / 5,644 ha / 0.022 sq. mi. / 13.947 acres
Ground Resolution	0.006 (m)
Processing Time	14h:32m:23s

Table 1 reports the project name, processing date and duration, camera model, number of calibrated images, project area, and ground sampling distance. All 504 images were calibrated successfully.

If a substantial number of images fail to calibrate, image quality, flight overlap, camera metadata, and project settings should be reviewed before product generation.

The principal project-summary values were:

- a) Processed project area: approximately 0.056 km² (5.64 ha).
- b) Ground sampling distance: approximately 0.006 m (6 mm).

14.2 Image-adjustment summary

Table 2. Image-adjustment summary.

Adjust Images

Summary

Number of Tie Points	3,526,878
Number of Solution Points	807,321
RMSE of Reprojection Error / Sigma Naught (Pixel)	0.228 / 0.282
Initial Processing Time	59m:13s

Processing Options

Initial Image Scale	1/8 (Eighth image size)
Refine Adjustment Scale	1 (Original image size)
Matching Neighborhood	Small (Optimized)

Internal Camera Parameters

DJI ZENMUSEP1 35.1mm 8192x5460
3XMDK6D0014474

Focal Length	Principal Point X	Principal Point Y	K1	K2	K3	P1	P2
35.100	-0.188	-0.041	-3.748e-005	1.346e-008	-3.971e-011	-4.529e-005	-4.463e-005

Drone2Map identifies common features in overlapping images and generates tie points and solution points for relative image alignment. Their distribution and reprojection behaviour support assessment of the internal adjustment network; their counts alone do not quantify absolute positional accuracy.

- a) The adjustment generated 3,526,878 tie points across the 504 calibrated images.
- b) The adjustment generated 807,321 solution points for relative image alignment.
- c) An initial image scale of 1/8 was used to reduce processing time, followed by a refine-adjustment scale of 1 (original image size).
- d) The matching neighbourhood was set to Small (Optimised). These internal settings supported relative block adjustment and were not interpreted as independent measures of absolute positional accuracy.

14.3 Internal camera parameters and tie-point diagnostics

Figure 14 summarises the number of tie points detected for each image. Images with comparatively low tie-point counts can indicate limited texture, insufficient overlap, blur, or other image-quality constraints.

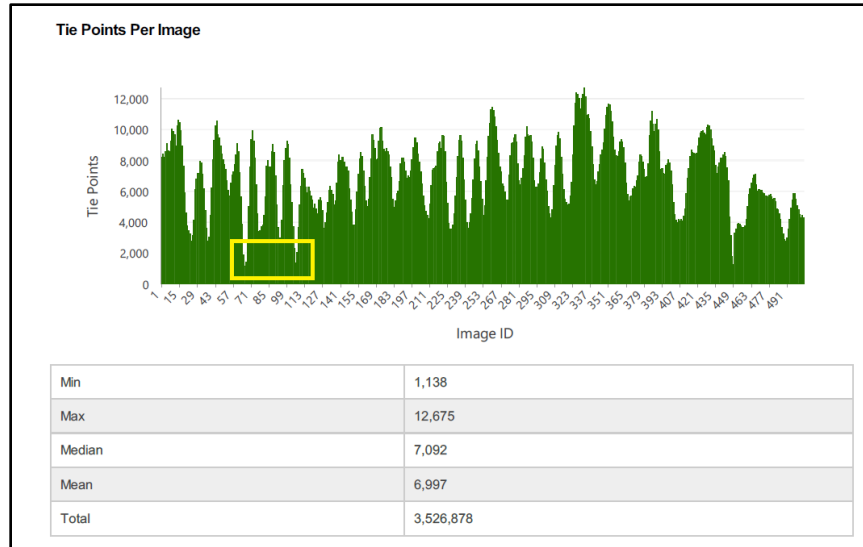


Figure 14. Tie points per image.

The distribution was inspected to identify images or parts of the flight block that might require further review.

The highlighted portion of Figure 14 identifies images with the lowest tie-point counts, including images near IDs 71 and 113.

Tie-point counts were treated as internal matching diagnostics rather than evidence of absolute positional accuracy.

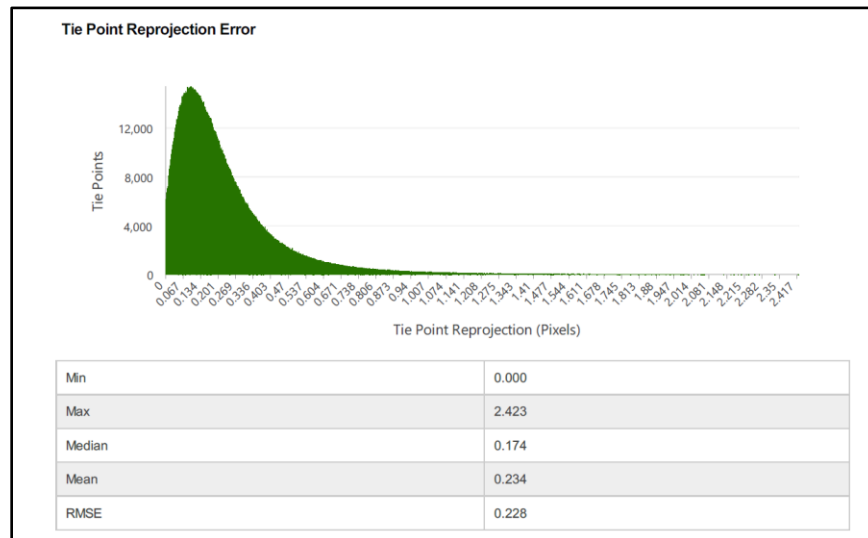


Figure 15. Tie-point reprojection-error distribution.

Figure 15 reports the tie-point reprojection-error distribution used to assess the internal consistency of the image adjustment.

Reprojection error reflects the difference between observed tie-point locations and their positions projected from the adjusted camera and block parameters.

Lower reprojection errors indicate better internal agreement between observed image measurements and the fitted photogrammetric model, but do not by themselves establish external positional accuracy.

Most tie-point reprojection errors were below one pixel, supporting the internal consistency of the relative adjustment.

14.4 Image-position adjustments

Figure 16 shows the shifts between the initial image-centre positions and the positions estimated during adjustment. These shifts describe changes within the fitted image network and should not be interpreted as independent ground accuracy.



Figure 16. Adjusted image positions.

The initial and adjusted image-centre positions were closely aligned across most of the flight block.

14.5 Image-overlap assessment



Figure 17. Image-overlap distribution.

Figure 17 indicates generally strong image overlap across the principal study area, with lower overlap concentrated near the outer margins of the flight block. The shoreline-analysis area was located within the well-overlapped portion of the imagery.

14.6 Cross-image matches

Figure 18 visualises cross-image links after the Adjust Images stage. Darker areas indicate more image-to-image matches. Match density and distribution were reviewed together with reprojection error to assess internal image-network connectivity.

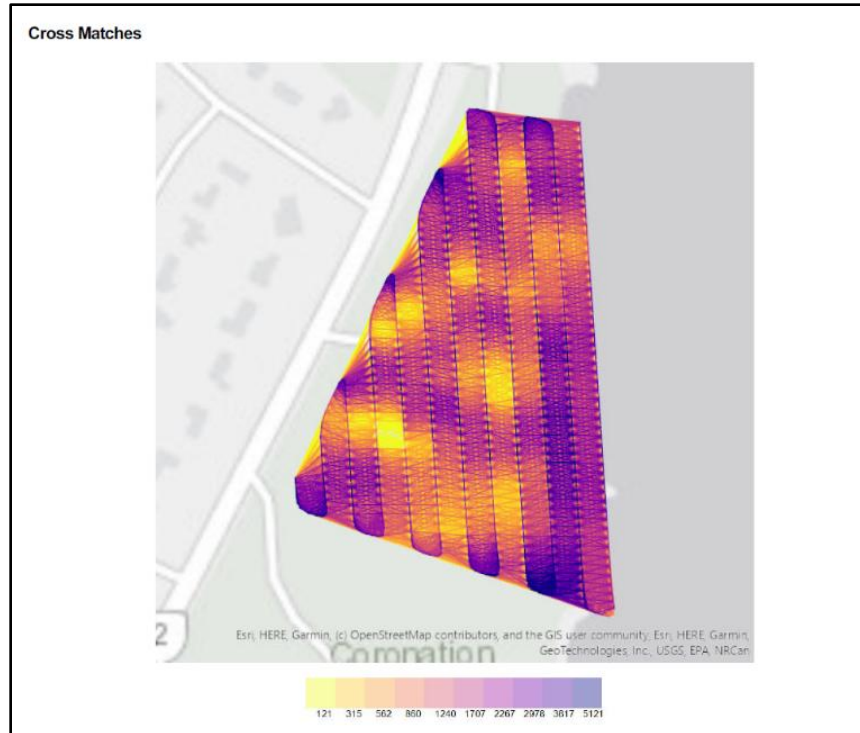


Figure 18. Cross-image matching distribution.

The principal shoreline-analysis area contained a dense network of cross-image matches. This supported relative image connectivity but was not used as evidence of absolute positional accuracy.

14.7 Solution points

Solution points are reconstructed object-space points derived from corresponding tie points in overlapping images. They support relative image alignment; their number alone does not quantify the external positional accuracy of the final products.

Table 3. Distribution of solution points by number of contributing images.

Solution Points	
2 Images	358,871
3 Images	141,196
4 Images	78,138
5 Images	50,589
6 Images	36,012
7 Images	26,627
8 Images	20,360
9 Images	16,730
10 Images	13,735
11 Images	11,533
12 Images	9,667
13 Images	8,371
14 Images	6,875
15 Images	5,842
16 Images	4,879
17 Images	4,199
18 Images	3,500
19 Images	2,904
20 Images	2,066
21 Images	1,483
22 Images	988
23 Images	753
24 Images	598
25 Images	456
26 Images	337
27 Images	219
28 Images	120
29 Images	88
30 Images	71
31 Images	56
32 Images	41
33 Images	16
34 Images	1

The large number of solution points indicates a dense internal reconstruction network but does not independently establish the absolute accuracy of the final orthomosaic.

14.8 Dense matching

Dense matching reconstructs a high-density point cloud after image adjustment. The dataset was divided into processing tiles to improve computational efficiency.

High point-cloud density was selected, and the reconstruction was processed in 2,907 tiles. Processing time depended on data volume, selected density, and workstation performance.

Table 4. Dense-matching summary.

Dense Matching	
Summary	
Point Cloud Density	High
Number of Tiles	2907
Processing Time	05h:43m:33s

14.9 Project settings

Table 5 summarises the workstation, software version, coordinate reference systems, and project resolution used for processing.

Table 5. Project settings.

Project Settings	
System Information	
Hardware	CPU: AMD Ryzen 5 PRO 3500U w/ Radeon Vega Mobile Gfx RAM: 14GB
Operating System	Microsoft Windows 11 Pro, 64-bit
ArcGIS Drone2Map Version	2023.1.0
Coordinate Information	
Image Coordinate System	GCS_WGS_1984/VCS:EGM96 Geoid
Project Coordinate System	WGS_1984_UTM_Zone_17N/VCS:EGM96 Geoid
Project Resolution	
Project Resolution	Automatic 1 x GSD (0.006 m)

14.10 2D product settings

Table 6 summarises the enabled 2D products and their processing times. The RGB true orthomosaic, DSM, and DTM were generated.

Table 6. 2D product settings.

2D Product	
Summary	
Processing time for DSM	04m:50s
Processing Time for Point Cloud Classification	02h:48m:50s
Processing Options	
Create True Ortho	Yes
Create Digital Surface Model	Yes
Create Digital Terrain Model	Yes
Color Balance	Yes
Enhance True Ortho	Yes
Merge Tiles	Yes

14.11 3D product settings

Table 7 summarises the enabled 3D products and their processing settings.

Table 7. 3D product settings.

3D Product	
Summary	
Processing Time for 3D Mesh Generation	04h:16m:24s
Processing Options	
Create Point Cloud	Yes
Merge LAS Tiles	No
Create DSM Textured Mesh	Yes
Create 3D Textured Mesh	Yes
Enhance Textured Mesh	Yes

15. Initial positional-mismatch assessment

The initial Drone2Map processing and the initial ArcGIS Pro Reality Mapping adjustment were completed without GCP constraints. Comparison with the RTK GNSS-surveyed ground points identified a positional mismatch exceeding 1 m at some locations. This diagnostic comparison motivated a refined adjustment in which four surveyed points were incorporated as GCPs.

Table 8. Initial differences between surveyed and unconstrained processed ground-point coordinates.

GCP ID		Surveyed coordinates		Coordinates extracted from initial unconstrained processing
pt3	605948.38	4807222.24		605,948.57 E 4,807,223.19 N
pt4	605934.91	4807159.49		605,934.76 E 4,807,160.1 N
pt5	605890.27	4807098.74		605,889.91 E 4,807,098.68 N
pt6	605932.1	4807020.63		605,932.07 E 4,807,020.13 N

16. Refined GCP-constrained adjustment

Figure 19 illustrates the positional mismatch observed before the GCP-constrained refinement.

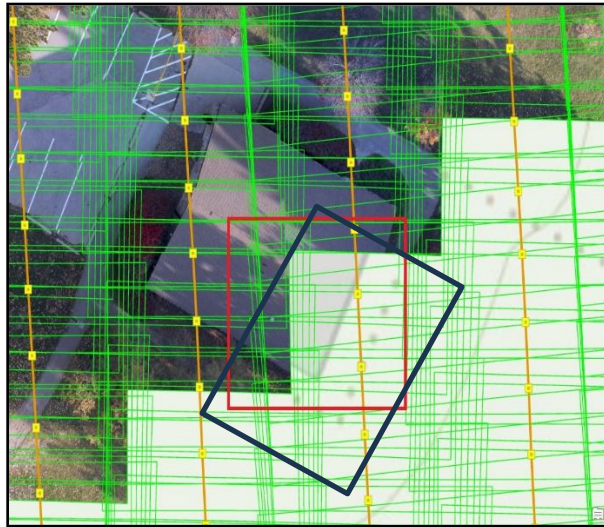


Figure 19. Positional mismatch before GCP-constrained refinement.

Because the offsets were not uniform across the surveyed points, a single fixed translation was not considered an adequate correction. The imagery was therefore refined using ArcGIS Pro Reality Mapping.

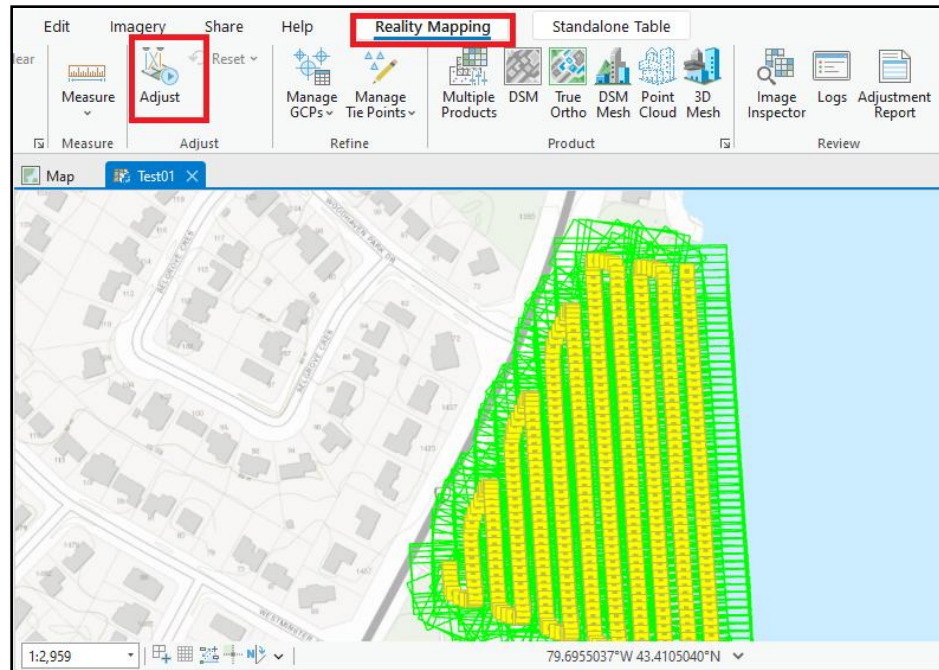


Figure 20. ArcGIS Pro Reality Mapping tools used to add GCPs and rerun the refined block adjustment.

Following the initial processing, two correction approaches were considered. A uniform horizontal translation was rejected because the offsets varied among the surveyed points and could not be corrected reliably using a single shift.

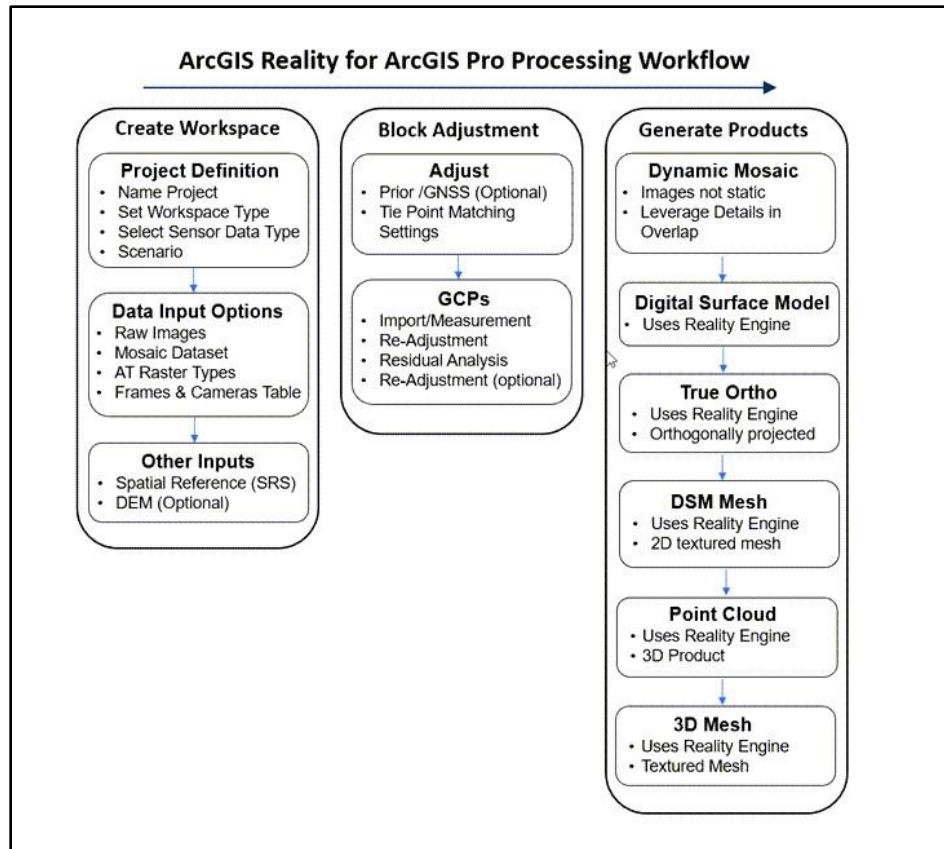
The adopted approach used ArcGIS Pro Reality Mapping. An initial block adjustment was performed without GCPs to establish image geometry, camera parameters, tie points, and image-to-image relationships. Four of the eight RTK GNSS-surveyed points were then added through Manage GCPs and manually identified in the relevant overlapping images.

The Adjust operation was rerun with the four GCPs constraining the refined block adjustment. The final RGB true orthomosaic, DSM, DTM, and point cloud were regenerated from this GCP-constrained adjustment. The RGB true orthomosaic was the reference image used for manual shoreline digitisation.

After the refined adjustment, the product-generation tools were used to create the final RGB true orthomosaic and ancillary DSM, DTM, and point-cloud products. The orthomosaic was visually inspected for spatial consistency before shoreline-reference digitisation.

The refined ArcGIS Pro Reality Mapping workflow is summarised in Table 9.

Table 9. ArcGIS Pro Reality Mapping workflow (source: Esri).



Following the initial unconstrained adjustment, four RTK GNSS-surveyed points were added through Manage GCPs and used to constrain the refined adjustment. The final RGB true orthomosaic was subsequently regenerated from this GCP-constrained adjustment.

The Reality Mapping adjustment and product-generation settings are shown in Figures 21 and 22.

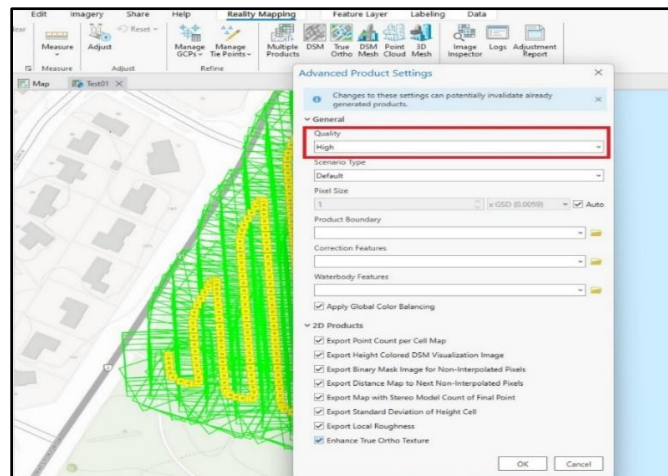


Figure 21. Reality Mapping adjustment settings.

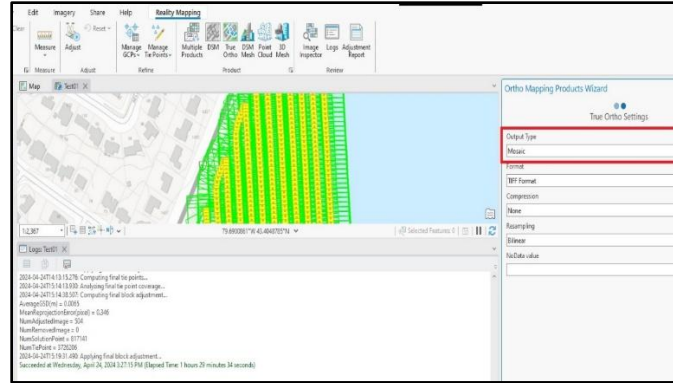


Figure 22. Reality Mapping product-generation settings.

Processing time depended on the dataset size and workstation performance. The final RGB true orthomosaic is shown in Figure 23.

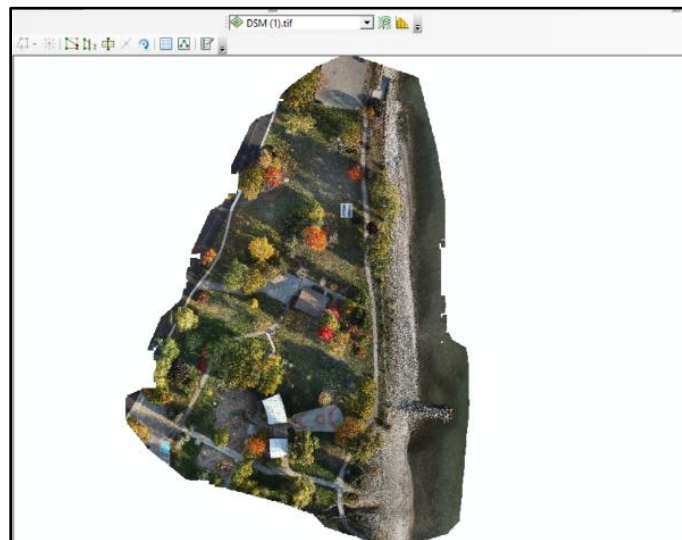


Figure 23. Final RGB true orthomosaic.

The complete eight-point RTK GNSS ground-control dataset produced summary values of RMSE EN = 0.08 m and RMSE U = 0.09 m. Because the dataset included points used to constrain the refined adjustment and no independent checkpoints were available, these values are reported as ground-control dataset indicators rather than independent orthomosaic-accuracy residuals.

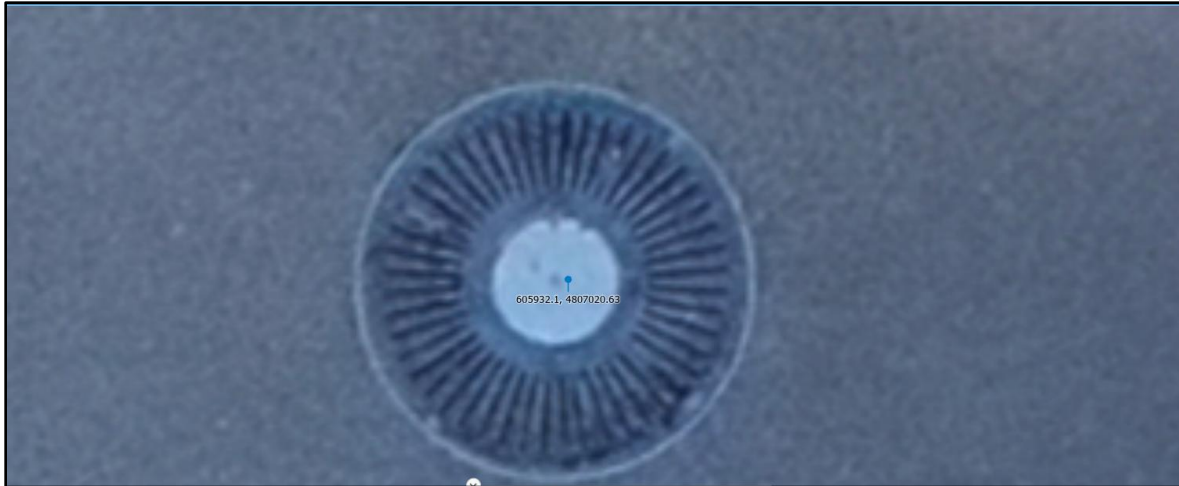


Figure 24. Comparison of surveyed and post-adjustment ground-point positions.

Table 10. Surveyed and post-adjustment ground-point coordinates.

GCPs	Original Coordinates		GCPs	From true ortho after processing without using the original control points	
3	605948.38	4807222.24	3	605948.45	4807222.20
4	605934.91	4807159.49	4	605934.88	4807159.45
5	605890.27	4807098.74	5	605890.25	4807098.71
6	605932.1	4807020.63	6	605932.08	4807020.65

The final RGB true orthomosaic was generated from the refined GCP-constrained adjustment and used as the image source for reference-shoreline digitisation. The DSM, DTM, and point cloud were retained as ancillary products.