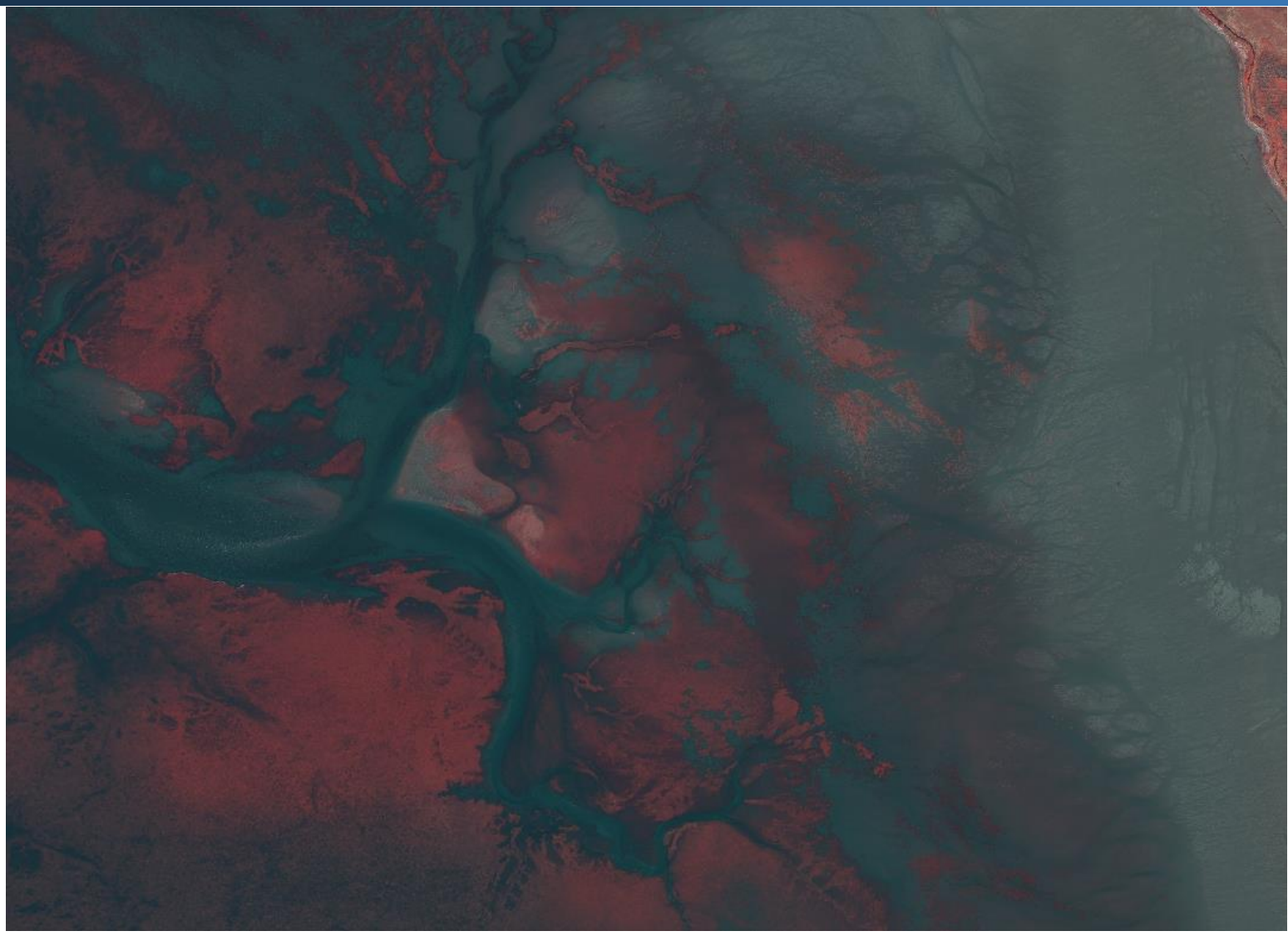
NV5 GEOSPATIAL

February 6, 2024



Kelp and Seagrass 4-band Orthophotography

WASHINGTON STATE DEPT OF NATURAL RESOURCES

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Cover Photo: View of North Puget Sound AOI at 1:8,000 scale.

INTRODUCTION

On June 29th, 2023, NV5 was contracted by the Washington DNR to collect 4-band imagery for the Puget Sound located in northwestern Washington. This report accompanies the delivered imagery and support files, and documents data acquisition procedures, processing methods, and results of all accuracy assessments. Project acquisition details are shown in Table 1, the project extent can be seen in Figure 1 (Admiralty Inlet was canceled), and a complete list of contracted deliverables provided to the Washington DNR can be found in Table 2.

Table 1: Acquisition dates, acreages, and data types collected for the Kelp and Seagrass photo project

Project Site	Contracted Acres	Buffered Acres	Acquisition Date	Acquisition Window (PST)	Deliver Date	Air Craft	Sensor	Elevation (ft)
Aquatic Reserves	51,655	54,620	08/02/2023 09/01/2023	9:35 – 10:32 13:26 – 13:34	02/02/2024	N5549A N30VG	Falcon M2 Falcon Prime	8,200 8,200
North Puget Sound	134,725	140,517	09/14/2023 09/15/2023	11:26 – 12:46 10:57 – 12:41	02/02/2024	N5549A N5549A	Falcon M2 Falcon M2	8,200 8,200
San Juan Islands	243,951	247,565	08/15/2023 09/01/2023 09/01/2023 09/15/2023	10:50 – 11:40 11:15 – 13:16 12:24 – 13:09 9:36 – 10:23	02/02/2024	N30VG N5549A N30VG N5549A	Falcon Prime Falcon M2 Falcon Prime Falcon M2	8,200 8,200 8,200 8,200
Saratoga Passage	94,279	99,582	08/16/2023 09/29/2023	10:53 - 11:48 11:57 – 12:26	02/02/2024	N30VG N5549A	Falcon Prime Falcon M2	8,200 8,200
Strait of Juan de Fuca East	67,318	71,823	08/03/2023 08/15/2023 09/01/2023	10:00 – 10:37 9:17 – 10:35 10:23 – 10:36	02/02/2024	N5549A N30VG N5549A	Falcon M2 Falcon Prime Falcon M2	8,200 8,200 8,200
Strait of Juan de Fuca West	36,430	40,791	07/19/2023	8:35 – 9:54	02/02/2024	N5549A	Falcon M2	8,200
Tacoma Narrows	5,023	7,917	09/29/2023	12:45 – 13:19	02/02/2024	N5549A	Falcon M2	8,200

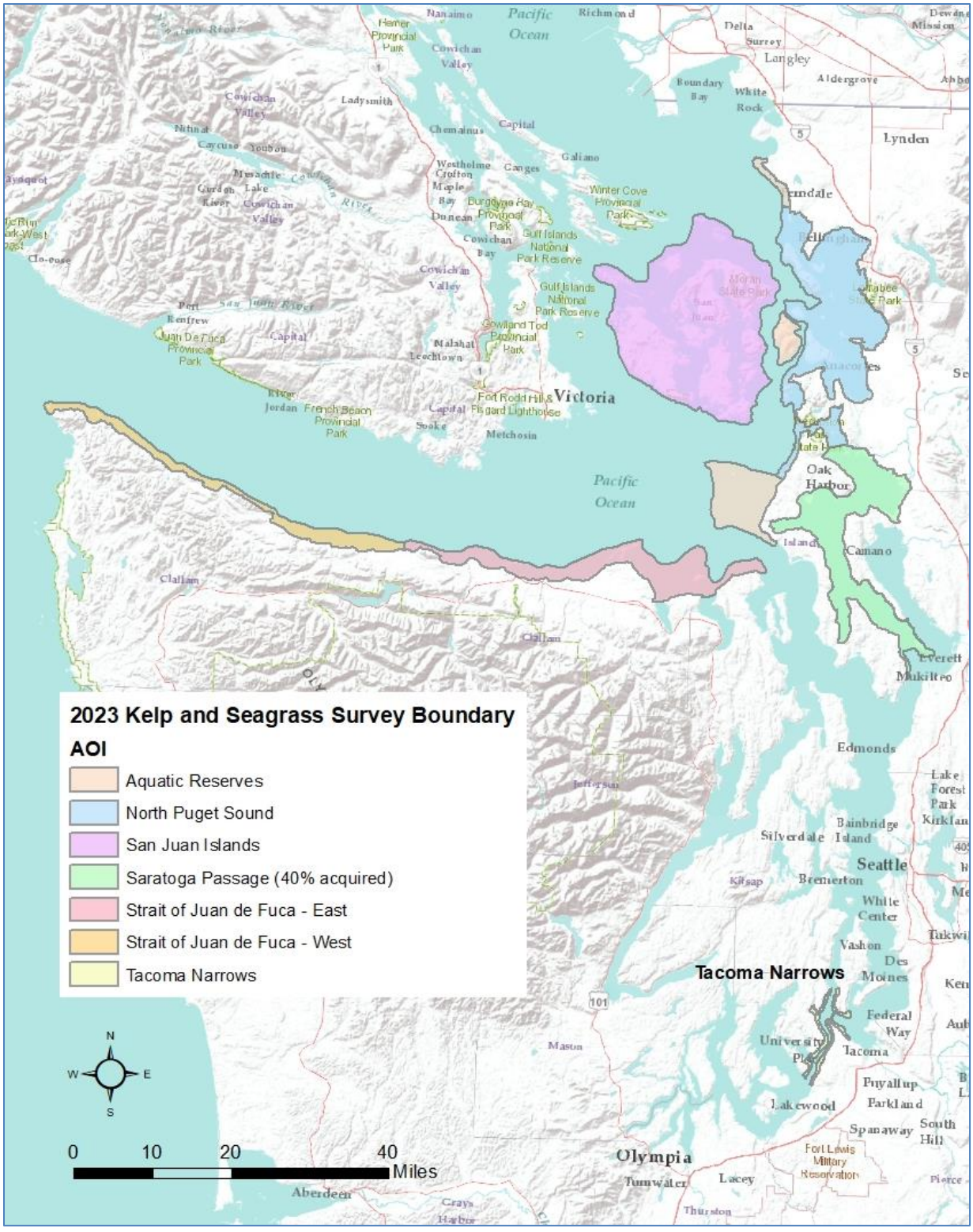

Figure 1: Location map of AOIs surveyed for the Kelp and Seagrass project

Table 2: Orthophoto products delivered to the Washington DNR

Projection: Washington State Plane South Horizontal Datum: NAD83 (HARN) Vertical Datum: NAVD88(Geoid12b) Units: US Survey Feet			
Deliverable		**File Count**	**Total Data Size**
Vectors	Photo Flight Plan (*.kml)	14	12 MB
	Photo Survey Flight Index Footprints (*.shp)	14	7 MB
	Ortho Tile Index	7	2 MB
	ArcGIS Geodatabase (*.gdp)	7	6 MB
	• Ground Control		
	• Flight Lines		
	• Job Survey Boundary		
	• Orthophoto Mosaic Tile Index		
	• Photo Center Points		
Digital Imagery	4-band (RGBI) Imagery		
	• Tiled Imagery Mosaics (*.tiff)	4,819	802 GB
	• Tiled Imagery Mosaics (*.sid)	6,622	44.7 GB
	• AOI Imagery Mosaic Compressions (*.sid)	10	84.6 GB
	• AOI Imagery Mosaic Compressions Adjusted (*.sid)	9	89.3 GB
	• Raw Frames (8bit, *.tiff)	15,550	5.64 TB
Documents	Orthophoto Metadata Report (*.pdf)	7	1 MB
	Camera Calibration Report (*.pdf)	16	17 MB
	Airborne GNSS (*.txt)	15	1.8 MB
	Acquisition Report (*.pdf)	14	7 MB

ACQUISITION

Aerial photo acquisition was performed by Geoterra, in coordination with NV5. The acquisition windows targeted sun angles between 25° and 45°, low tides (less than 1 ft MLLW), ocean swell less than 1.5 m, calm sea states (surface winds less than 10 knots) and cloud free or overcast conditions. Figure 2 displays photo acquisition flightlines by date. Note, only 40% of Saratoga was acquired while Admiralty Inlet was canceled due to insufficient flight windows.

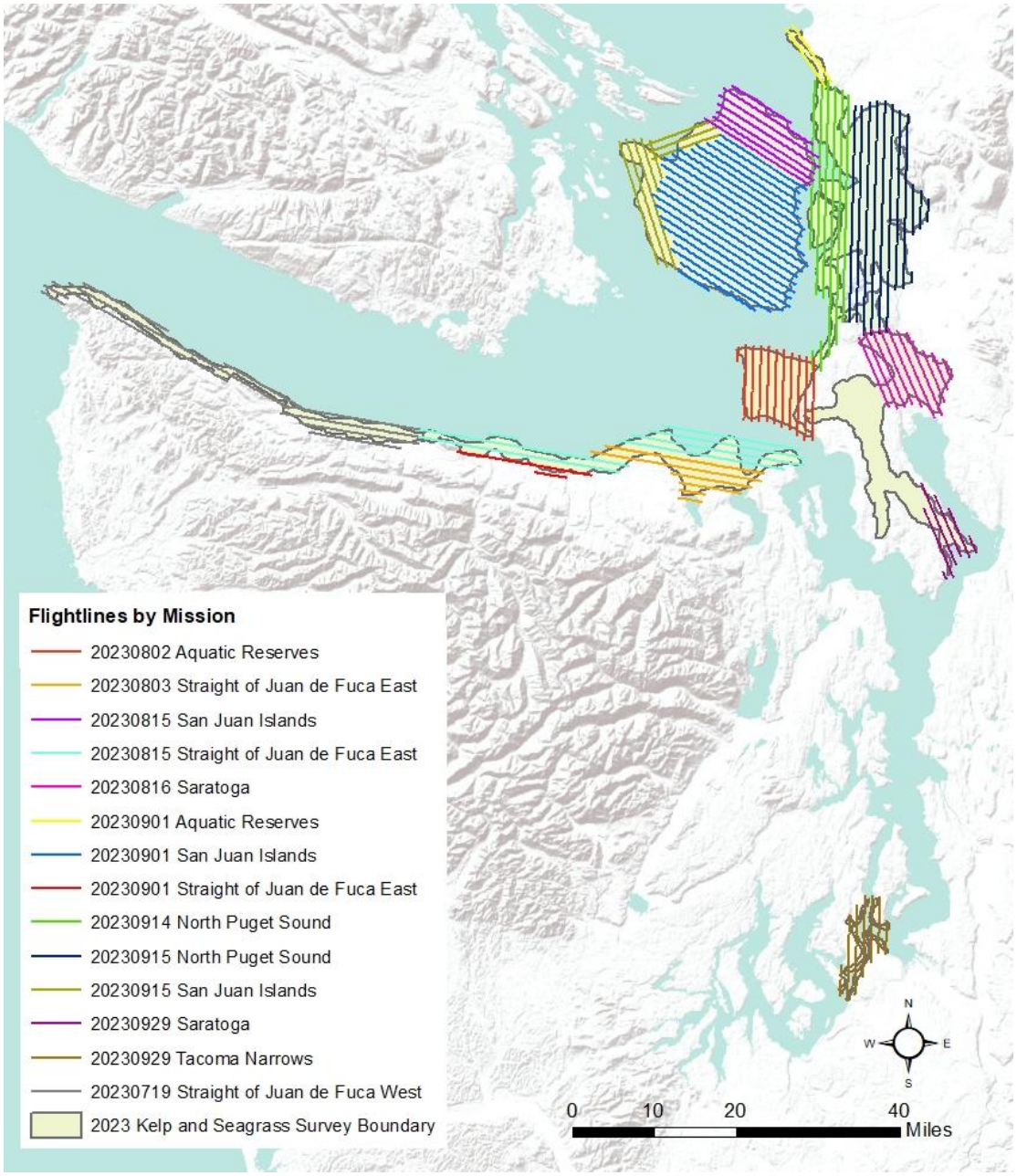

Figure 2: Acquisition Overview Map for the Kelp and Seagrass photo survey.

Digital Imagery

The aerial imagery acquisition was performed between Geoterra. Geoterra deployed an UltraCam Falcon Prime and UltraCam Falcon Mark 2, (identical interior orientations) large format cameras manufactured by Vexcel. The systems were gyro-stabilized and simultaneously collected panchromatic and multispectral (RGB, NIR) imagery, camera specifications can be found in Table 3.

Table 3: UltraCam Camera manufacturer's specifications

UltraCam Falcon Prime and Mark II	
Focal Length	100.5 mm
Data Format	RGB NIR
Pixel Size	6.0 µm
Image Size	17,310 x 11,310 pixels
Frame Rate	2.0 seconds
FOV	55 x 37 degrees

For the Puget Sound Kelp and Seagrass study area, images were collected in 4 spectral bands (red, green, blue, and NIR) with 80% along track overlap and 40% sidelap between frames. The acquisition flight parameters were designed to yield a native pixel resolution of ≤ 6 inches (15 cm). Orthophoto specifications particular to the Kelp and Seagrass photo project are in Table 4.

Table 4: Project-specific orthophoto specifications

Digital Orthophotography Specifications	
Equipment	UltraCam Falcon, UltraCam M2,
Spectral Bands	Red, Green, Blue, NIR
Ground Sampling Distance (GSD)	≤0.5 ft
Along Track Overlap	≥80%
Cross Track Overlap	≥40%
Flight Altitude (AGL)	8,200 ft
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Image	8-bit GeoTiff

Ground Survey

Monumentation

Monument locations were selected with consideration for client preference, satellite visibility, field crew safety, and optimal location for GSP coverage. The survey monuments listed in Table 5 provided redundant control (1Hz) within 20 nautical miles of the NV5 ground survey. Each monument had two separate occupations with different heights of instrument (HI) using Trimble R7's (Zephyr Geodetic Model 2 RoHS antenna). Monument coordinates are presented in Table 5 and shown in Figure 3.

Table 5: Monuments used to support the Kelp and Seagrass ground survey. Coordinates are on NAD83 (HARN) datum

Monument PID	Latitude	Longitude	Ellipsoid (m)
BBAY	48 53 56.66428	-122 46 10.02479	-7.928
BELI	48 45 18.95007	-122 28 44.23878	10.889
CHCM	48 00 38.20699	-122 46 33.06174	20.707
COUP	48 13 02.30253	-122 41 08.11687	21.329
JOBO	48 33 44.51834	-122 26 14.21597	-11.218
MKAH	48 22 14.41053	-124 35 21.14638	23.961
P403	48 03 44.34175	-124 08 27.09162	285.016
P437	48 00 06.49695	-122 27 32.90646	12.798
PFLD	47 53 54.60780	-122 16 55.79701	160.617
PTAA	48 07 00.56954	-123 29 39.63890	67.151
SANJ	48 31 57.93445	-123 01 07.45565	9.818
SKGT	48 26 00.35365	-122 20 32.82654	-6.416
TACO	47 13 43.90572	-122 28 17.36727	81.440
UFDA	47 45 18.01646	-122 40 02.63848	76.92
WADNR_KELP_02	48 29 07.37317	-122 55 19.37323	30.760

Air Targets

Ground survey data were collected by NV5 Geospatial to adjust aircraft positional and attitude data and to perform an accuracy assessment of final orthophoto products. NV5 Geospatial collected hard surface air targets (112 total) typically on high visibility road markings or painted chevrons. High contrast road markings typically consisted of stop bars, turn arrows or cement corners. Air target points were surveyed throughout the Kelp and Seagrass study area, prior to imagery acquisition, using fast static or RTK techniques (Figure 3). Air target point data (Point ID, Easting, Northing, Orthometric Elevation) were provided to WADNR in the flight data geodatabase (Flight_Index.gdb) within the GIS Data folder of each AOI.

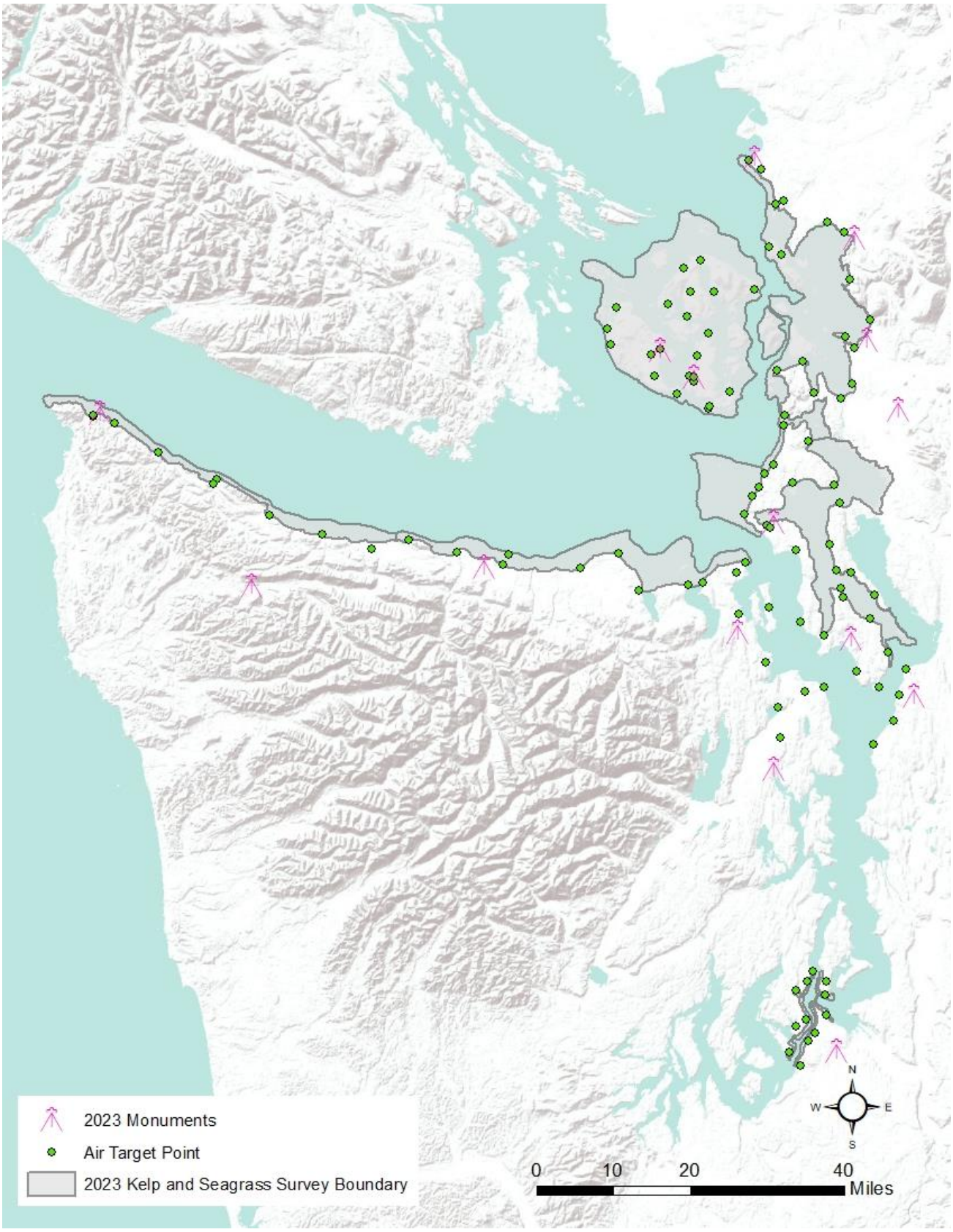

Figure 3: Location map of ground survey data collected for the Kelp and Seagrass photo project

Digital Imagery

The collected digital photographs went through multiple processing steps to create final orthophoto products. Initially, images were corrected for geometric distortion to yield level02 image files. Next, images were color balanced and levels were adjusted to exploit the full 14bit histogram and finally output as level03 pan-sharpened 8bit TIFF images. Photo position and orientation were calculated by linking the time of image capture to the smoothed best estimate of trajectory (SBET). Within Inpho's Match AT softcopy photogrammetric software, analytical aerial triangulation was performed using ground control, automatically generated tie points, and camera calibration information.

Adjusted images were orthorectified using the best publicly available DEM to remove displacement effects from topographic relief inherent in the imagery. The resulting images were mosaicked within Inpho's Ortho Vista blending seams and applying automated project color-balancing. Special care was taken to use glare free imagery in the final mosaic where possible. The processing workflow for orthophotos is summarized in Table 6.

Table 6: Orthophoto processing workflow

Orthophoto Processing Step	Software Used
Resolve GPS kinematic corrections for the aircraft position data using kinematic aircraft GPS (collected at 2 Hz), onboard IMU (collected at 200 Hz) and PPP data	Inertial Explorer v8.90
Develop a smooth best estimate trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	Inertial Explorer v8.90
Create an exterior orientation file (EO) for each photo image with omega, phi, and kappa.	Inertial Explorer v8.90
Convert Level 00 raw imagery data into geometrically corrected Level 02 image files.	UltraMap v4
Apply radiometric adjustments to Level 02 image files to create Level 03 Pan-sharpened TIFFs.	UltraMap v4
Apply EO and camera calibration parameters to photos; perform aerial triangulation using automatically generated tie points and ground control processed on project datum	Inpho Match AT v10.0.2
Import DEM and generate individual ortho frames.	Inpho OrthoMaster v10.0.2
Mosaic orthorectified imagery, blending seams between individual photos and correcting for radiometric differences between them.	OrthoVista/SeamEditor v10.0.2
Review seamlines and edit to make sure most nadir part of each image is used and that water glare is reduced or eliminated and seams don't cut through buildings or other manmade features.	OrthoVista/SeamEditor v10.0.2

Orthophoto Absolute Accuracy

Image accuracy was assessed using air target points, collected by NV5, which were used in the aerial triangulation procedure as control points. These points were found in the final adjusted orthophoto mosaics and the displacement was recorded for further statistical analysis. This methodology was applied to all air targets which intersected each AOI boundary. Note that some air targets fell outside the AOI boundaries but within the footprint of the full aerial imagery acquisition; for example there were thirteen air target points surveyed for Tacoma Narrows but only two were inside the AOI boundary thus only two points could be used for an absolute accuracy assessment.

Image orthorectification was performed using the best publicly available DEM, the quality of the DEM used for this process directly effects horizontal accuracy of the final orthophoto products such that erroneous elevations due to temporal differences, DEM survey methodology or coarse DEM resolution can cause offsets in the resulting orthophotos. In some areas of the Kelp and Seagrass photo project offsets were observed, primarily along the inland areas of the shoreline. So while control point residuals in the aerial triangulation report (provided below) are within the accuracy specifications for the project the DEM contributed to horizontal offsets which in some cases fell outside of spec.

Accuracy reporting for both ASPRS guidelines and the National Standard for Spatial Data Accuracy (NSSDA) require at least twenty independent check points per aerial triangulation block for validation, in the case of the Kelp and Seagrass photo project all air targets were used as control points (no independent check points were withheld) in the aerial triangulation procedure due to the limited amount of control available. Table 7, Table 8 and Table 9 present the summary photo accuracy statistics for control points in all AOIs.

Table 7: Orthophotography accuracy statistics Aquatic Reserves, North Puget Sound and San Juan

		Aquatic Reserves			North Puget Sound			San Juan		
		Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$
Count		3			7			20		
Mean	*ft*	-0.057	-0.187	0.195	0.160	-0.120	0.200	-0.039	0.011	0.040
	m	-0.017	-0.057	0.059	0.049	-0.037	0.061	-0.012	0.003	0.012
RMSE	*ft*	0.177	0.942	0.959	0.568	0.307	0.646	0.348	0.386	0.519
	m	0.054	0.287	0.292	0.173	0.094	0.197	0.106	0.118	0.158
1σ	*ft*	0.205	1.131	1.150	0.589	0.305	0.663	0.355	0.396	0.531
	m	0.062	0.345	0.350	0.179	0.093	0.202	0.108	0.121	0.162
1.96σ	*ft*	0.402	2.217	2.253	1.153	0.598	1.299	0.695	0.775	1.041
	m	0.122	0.676	0.687	0.352	0.182	0.396	0.212	0.236	0.317

Table 8: Orthophotography accuracy statistics for Saratoga Passage, Strait of Juan de Fuca East, Strait of Juan de Fuca West

		Saratoga Passage			Strait of Juan de Fuca East			Strait of Juan de Fuca West		
		Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$
Count		5			5			5		
Mean	*ft*	0.176	0.848	0.866	-0.166	-0.012	0.166	0.054	-0.046	0.071
	m	0.054	0.258	0.264	-0.051	-0.004	0.051	0.016	-0.014	0.022
RMSE	*ft*	1.057	2.042	2.299	1.347	0.506	1.439	0.198	0.346	0.399
	m	0.322	0.622	0.701	0.411	0.154	0.439	0.060	0.105	0.122
1σ	*ft*	1.166	2.077	2.382	1.495	0.565	1.598	0.213	0.383	0.439
	m	0.355	0.633	0.726	0.456	0.172	0.487	0.065	0.117	0.134
1.96σ	*ft*	2.285	4.070	4.668	2.930	1.108	3.132	0.417	0.752	0.860
	m	0.696	1.241	1.423	0.893	0.338	0.955	0.127	0.229	0.262

Table 9: Orthophotography accuracy statistics for Tacoma Narrows

		Tacoma Narrows		
		Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$
Count		2		
Mean	*ft*	-0.280	0.045	0.284
	m	-0.085	0.014	0.086
RMSE	*ft*	0.283	0.114	0.305
	m	0.086	0.035	0.093
1σ	*ft*	0.057	0.148	0.159
	m	0.017	0.045	0.048
1.96σ	*ft*	0.111	0.291	0.311
	m	0.034	0.089	0.095

Overview

Aerial triangulation was performed in nine blocks to support kelp and eel grass mapping of the Puget Sound and surrounding areas. The nine blocks consisted of 116 flight lines flown at a scale of 1:1,200 between July 19th and September 29th, 2023. Block adjustments were made to ground control established by NV5 referencing NAD83(HARN) horizontal datum and NAVD 1988 vertical datum (Geoid12b). Digital imagery along with ground control and camera calibration data were used as input to Inpho's Match AT softcopy photogrammetry program. Of the 112 total surveyed air target points all were used for aerial triangulation and zero were withheld from the block adjustment as independent check points.

Aquatic Reserves – Smith and Minor Islands

Air target points used in the aerial triangulation adjustment are listed with their location in Table 10, and RMSE values can be found in Table 11.

Table 10: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 5 Total Points					**Control Point Residuals (US ft) -** 5 Total Points		
Point ID	**X**	**Y**	Z	**# Photo Measurements**	**X**	**Y**	Z
AT037	1103096.81	1057512.81	176.02	5	0.0133	0.0417	0.1114
AT051	1101738.89	1092416.09	39.76	5	-0.019	0.0023	0.032
AT055	1087868.96	1065204.05	20.05	10	0.024	-0.1125	-0.0741
AT056	1097780.74	1083459.7	245.77	8	-0.0084	0.0664	0.0265
AT089	1093111.08	1076959.75	27.02	10	-0.01	0.002	-0.0958

Table 11: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 5 Total Points		
US survey feet		
X	**Y**	Z
0.016	0.0614	0.0759

Aquatic Reserves – Cherry Point

Air target points used in the aerial triangulation adjustment are listed with their location in Table 12, and RMSE values can be found in Table 13.

Table 12: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 4 Total Points					**Control Point Residuals (US ft) -** 4 Total Points		
Point ID	**X**	**Y**	Z	**# Photo Measurements**	**X**	**Y**	Z
AT052	1114268.76	1278909.32	176.65	3	0.0031	0.0144	0.0387
AT052A	1109039.17	1277207.48	36.16	9	-0.0045	-0.0053	-0.0259
AT053	1090774.67	1306496.23	96.61	5	0.0094	-0.0096	0.0119
AT053A	1098921.09	1300649.01	102.61	4	-0.0081	0.0005	-0.0247

Table 13: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 4 Total Points		
US survey feet		
X	**Y**	Z
0.0068	0.009	0.027

North Puget Sound and Aquatic Reserves Cypress Island

Air target points used in the aerial triangulation adjustment are listed with their location in Table 14, and RMSE values can be found in Table 15.

Table 14: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 19 Total Points					**Control Point Residuals (US ft) -** 19 Total Points		
Point ID	**X**	**Y**	Z	**# Photo Measurements**	**X**	**Y**	Z
AT045	1130971.87	1114649.97	347.52	3	0.0177	0.0209	-0.0822
AT045A	1114610.96	1125796.19	12.36	5	0.0164	-0.0109	-0.0032
AT051 (vert)	NA	NA	39.76	7	NA	NA	0.0039
AT051A	1107341.69	1098901.17	95.84	7	-0.0045	-0.0426	-0.1565
AT052A	1109039.17	1277207.48	36.16	9	0.0222	0.0263	0.2504
AT054	1144328.69	1264831.26	95.74	6	-0.0112	0.0163	0.0722
AT057	1155835.08	1257629.12	69.09	4	0.0023	-0.0049	-0.0056
AT058	1162533.7	1178675.22	8.31	7	-0.0082	0.0011	0.0074
AT058A	1156502.55	1186180	51.93	10	-0.0035	0.0148	0.0281
AT059	1173865.35	1198112.07	44.64	5	0.016	0.0014	-0.0042

Control Point Coordinates (US ft) – 19 Total Points					Control Point Residuals (US ft) - 19 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT060	1127817.88	1169177.69	20.05	8	-0.0181	0.0135	-0.0514
AT060A	1135023.84	1148175	30.5	5	-0.0017	0.0069	-0.0192
AT061	1109766.27	1163317.28	117.09	9	-0.0127	-0.0379	-0.0751
AT061A	1115016.38	1132371.79	29.42	5	0.0068	-0.0257	-0.009
AT062	1153808.06	1144236.78	11.9	4	-0.0173	0.0149	-0.0197
AT064	1161679.63	1153842.95	25.76	8	-0.0244	0.0191	-0.0175
AT065	1159581.34	1225193.59	52.47	5	-0.0097	0.01	0.0393
AT066	1113219.27	1242228.52	32.8	5	0.0183	-0.0069	0.0176
AT066A	1113239.2	1242563.2	26.28	5	0.0119	-0.016	0.0246

Table 15: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 19 Total Points		
US survey feet		
X	Y	Z
0.0141	0.0196	0.0768

San Juan

Air target points used in the aerial triangulation adjustment are listed with their location in Table 16, and RMSE values can be found in Table 17.

Table 16: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 22 Total Points					Control Point Residuals (US ft) - 22 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT067	1062801.77	1137053.29	38.62	5	-0.0177	-0.001	-0.0098
AT068	1063682.59	1138948.41	9.83	8	0.0001	0.0116	-0.0537
AT069	1052992.78	1155818.97	190.78	7	0.0001	-0.0439	-0.0997
AT070	1049523.36	1159187.77	202.09	10	-0.0094	-0.0165	-0.0908
AT070A	1052853.87	1158782.31	171.22	5	0.0014	-0.0044	-0.0094
AT071	1041685.97	1147196.13	61.49	9	0.0087	-0.034	-0.045
AT072	1026288.49	1159583.31	190.33	4	-0.0017	-0.0142	-0.0177
AT073	994007.16	1191866.27	13.38	2	-0.0104	0.0022	0.0051
AT073A	995881.04	1181190.73	14.28	10	-0.0542	0.0179	0.1645
AT074	999665.71	1206271.77	65.06	12	-0.0224	0.0609	-0.0722

Control Point Coordinates (US ft) – 22 Total Points					Control Point Residuals (US ft) - 22 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT075	1057791.49	1238116.35	41.19	10	0.0224	-0.0627	0.2121
AT076	1094230.24	1218280.6	83.21	4	0.0032	-0.0102	-0.0004
AT078	1077226.22	1148527.92	16.44	4	0.0246	-0.0078	-0.0053
AT079	1062865.56	1188890.73	68.44	10	0.0061	0.0903	0.1701
AT080	1054945.08	1173060.72	34.83	5	-0.0037	0.0144	-0.017
AT081	1029745.1	1178111	99.66	4	0.0115	0.01	-0.0117
AT081A	1023464.17	1174233.5	109.66	10	0.005	0.0063	-0.0712
AT082	1048715.27	1199949.26	32.67	4	0.0148	0.0114	-0.0119
AT082A	1050364.87	1217282.14	188.76	8	0.0241	-0.0144	-0.0802
AT083	1046377.49	1232973.42	10.77	5	0.0146	-0.0003	-0.0174
AT084	1035466.54	1208379.34	53.21	4	0.0061	0.0014	-0.0064
AT085	1066988.62	1217000.66	13.57	8	-0.0233	-0.017	0.068

Table 17: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 22 Total Points		
US survey feet		
X	Y	Z
0.0178	0.0309	0.0817

Saratoga

Air target points used in the aerial triangulation adjustment are listed with their location in Table 18, and RMSE values can be found in Table 19.

Table 18: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 6 Total Points					Control Point Residuals (US ft) - 6 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT044B	1148707.21	1084533.76	13.01	11	0.0391	0.0332	-0.1241
AT045	1130971.87	1114649.97	347.52	6	-0.0296	-0.0039	0.1317
AT046	1152868.93	1072161.76	10.67	5	-0.0095	-0.0293	-0.0076
AT035	1185858.24	970074.49	129.49	5	0.0231	0.0076	-0.0876
AT047A	1176315.66	1009263.08	151.84	10	0.0312	0.1056	-0.1042
AT048	1173215.58	993084.3	44.29	2	-0.0544	-0.1132	0.1918

Table 19: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 6 Total Points		
US survey feet		
X	Y	Z
0.0341	0.0658	0.1212

Strait of Juan de Fuca East

Air target points used in the aerial triangulation adjustment are listed with their location in Table 20, and RMSE values can be found in Table 21.

Table 20: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 9 Total Points					Control Point Residuals (US ft) - 9 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT017	858149.02	1047263.95	22.52	4	-0.0193	-0.0055	-0.0228
AT018	922179.95	1029925.47	17.92	5	0.0262	0.0431	-0.0635
AT018A	926032.58	1037488.5	13.81	8	-0.0912	0.0198	0.0054
AT018B	890910.23	1038894.48	16.08	10	-0.0172	-0.1025	0.2178
AT019	975543.75	1028080.55	124.87	7	0.0192	0.1005	-0.2744
AT020	1001107.72	1037778.87	10.68	5	0.0508	0.0276	0.0228
AT021	1015381.83	1012365.72	25.61	8	0.0378	-0.0175	0.0997
AT086	1088366.11	1031681.43	18.79	5	-0.0367	-0.0216	0.0869
AT092	1059080.94	1018293.26	164.01	4	0.0305	-0.044	-0.0717

Table 21: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 9 Total Points		
US survey feet		
X	Y	Z
0.0426	0.0541	0.1293

Strait of Juan de Fuca West

Air target points used in the aerial triangulation adjustment are listed with their location in Table 22, and RMSE values can be found in Table 23.

Table 22: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 9 Total Points					**Control Point Residuals (US ft) -** 9 Total Points		
Point ID	**X**	**Y**	Z	**# Photo Measurements**	**X**	**Y**	Z
AT011	641591.28	1132033.94	22.65	4	-0.1123	-0.0094	0.251
AT011A	642141.85	1132379.58	21.04	9	-0.0923	-0.0704	0.2177
AT011B	656355.29	1127048.43	53.94	5	0.0492	-0.0079	0.1268
AT012	686153.29	1106726.8	18.69	5	0.1171	-0.0539	-0.3531
AT013	726672.73	1088615.82	17.25	3	0.0171	0.0502	0.0038
AT014	724292.11	1085912.24	56.6	7	0.0197	0.0096	0.1513
AT015	762321.9	1064230.52	126.18	7	0.1117	0.2673	-0.5607
AT016	798382.37	1051049.25	29.46	9	-0.0148	0.0542	-0.0169
AT016A	832806.71	1040796.57	270.31	4	-0.0954	-0.2397	0.18

Table 23: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 9 Total Points		
US survey feet		
X	**Y**	Z
0.0815	0.1258	0.2627

Tacoma Narrows

Air target points used in the aerial triangulation adjustment are listed with their location in Table 24, and RMSE values can be found in Table 25.

Table 24: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 12 Total Points					**Control Point Residuals (US ft) -** 12 Total Points		
Point ID	**X**	**Y**	Z	**# Photo Measurements**	**X**	**Y**	Z
AT022	1126254.72	687605.93	233.46	3	-0.0096	-0.0127	-0.0366
AT023	1123025.78	714726.33	159.08	5	-0.0006	0.0021	-0.0112
AT024	1136108.86	709542.03	367.18	2	0.0005	-0.0042	0.0106
AT025	1129646.42	719336.47	247.41	10	0.0274	-0.0311	0.094

Control Point Coordinates (US ft) – 12 Total Points					Control Point Residuals (US ft) - 12 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT026	1143286.72	722493.46	29.49	4	-0.0308	0.0052	-0.0532
AT026A	1142898.79	735645.3	58.95	4	0.0155	-0.0076	0.0018
AT026B	1143884.45	744955.73	383.82	4	-0.0211	0.0051	-0.0403
AT027	1122530.15	738924.06	57.13	4	0.0206	-0.0046	-0.0521
AT029	1118227.61	696879.55	214.62	5	-0.0061	0.008	-0.0146
AT030	1130255.15	745074.11	347.98	7	0.0129	0.058	0.0401
AT031	1131453	704849.99	14.31	5	0.0005	0.0089	0.027
AT090	1129572.35	719374.88	243.33	10	-0.0091	-0.0272	0.0345

Table 25: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 12 Total Points		
US survey feet		
X	Y	Z
0.0163	0.0215	0.0422

GLOSSARY

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96-sigma (σ) Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set.

Accuracy: The statistical comparison between known points (air target points) and the same point found in photo mosaics. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

> **Root Mean Square Error (RMSE):** A statistic used to approximate the difference between ground control points and the same point in the orthoimagery. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between images, typically expressed as percent forward and side overlap.