SACRAMENTO RIVER AERIAL IMAGERY, TOPOGRAPHIC AND BATHYMETRIC DATA ACQUISITION TECHNICAL REPORT

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Prepared for:

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List of Acronyms

AGL Above Ground Level
AOI Area of Interest
ASPRS American Society for Photogrammetry and Remote Sensing
CH4X Leica Chiroptera 4X
CIR Color Infrared
CORS Continually Operating Reference Stations
CSDS RTN California Surveying and Drafting Supply, Inc.'s Real Time Network
CUBE Combined Uncertainty and Bathymetry Estimator
CVPIA Central Valley Project Improvement Act
DTM Digital Terrain Model
GAMS GNSS Azimuth Measurement System
GNSS Global Navigation Satellite System
GSP Ground Survey Points
IMU Inertial Measurement Unit
INS Inertial Navigation System
LSS Leica Survey Studio
NAD83 North American Datum of 1983
NAVD88 North American Vertical Datum of 1988
NGS National Geodetic Survey
NIR Near-InfraRed
NVA Non-Vegetated Vertical Accuracy
PAT Painted Air Targets
PDOP Position Dilution of Precision
PPK Post-Processed Kinematic
RGB Red-Green-Blue
RM River Mile
RMSE Root Mean Square Error
RPM Revolutions Per Minute
SBET Smoothed Best Estimate of Trajectory
TBC Trimble Business Center
TIN Triangulated Irregular Network
UTC Universal Time Coordinated
UTM Universal Transverse Mercator
YT TSP Yurok Tribe Fisheries Department Design and Technical Services Program

EXECUTIVE SUMMARY

The Yurok Tribe Fisheries Department Design and Technical Services Program (YT TSP) was tasked by the Bureau of Reclamation's (Reclamation's) Central Valley Project Improvement Act (CVPIA) Program to conduct a base-line data collection effort on the Sacramento River to support habitat and decision support modeling. High resolution aerial imagery, topography, bathymetry, and water surface elevations were provided to Reclamation and are intended to support the development of a hydrodynamic model framework for predicting habitat across a range of flows. The model will support measures needed to restore anadromous fish to optimum and sustainable levels in accordance with the restored carrying capacities of Central Valley rivers, streams, and riparian habitats. The data will also be used to support planning, design, and analysis of current and future restoration projects on the Sacramento River.

The topo-bathymetric survey area along the Sacramento River spanned from the Clear Creek confluence at approximate river mile 290 to Wilkins Slough at approximately river mile 117 (174 miles). The imagery survey area was larger, starting from the Clear Creek confluence extending down to Freeport at approximate river mile 45 (246 miles).

To develop a seamless topographic and bathymetric terrain model multiple techniques were used to efficiently collect the required data. Airborne topo-bathymetric lidar was flown to rapidly collect data over the entire project area using a Leica Chiroptera 4X sensor. Multibeam sonar was used to collect bathymetric data in deeper and more turbid areas of the river where lidar penetration was not expected using two vessels equipped with NORBIT iWBMSh systems. Data from the different platforms were processed and merged into an integrated LAS format dataset that was cut into 500 m x 500 m tiles. Lidar data were tested to meet a 10 cm $RMSE_V$ vertical accuracy class using independent ground survey points.

Due to unexpected flooding in the spring of 2023, the topo-bathymetric lidar was not able to be flown first due to high water levels and extremely poor water clarity. YT TSP performed the sonar data collection first, then flew the lidar later in the fall when conditions improved. This resulted in a less efficient data collection campaign as more multibeam data were collected to ensure overlap with the bathymetric lidar.

High resolution imagery over the project area was collected during separate dedicated flights using a PhaseOne PAS280i sensor. Orthorectified imagery was produced at 10 cm resolution and was cut into 500 m x 500 m tiles and delivered in TIFF format. The overall imagery was also split into five segments designated by the closest river mile and exported in both JPEG 2000 and TIFF formats. Imagery products were tested to meet a 10 cm $RMSE_H$ horizontal positional accuracy class.

Water surface profiles at different flows were collected along the entire Sacramento River reach as well as the lower 2 miles of Clear Creek and the lower 6 miles of Battle Creek. Data were processed and delivered as separate three-dimensional vector point feature SHP files.

SURVEYOR'S STATEMENT

I, Benjamin Lane Hocker, as a licensed land surveyor in the state of California (No. 9924) certify that the imagery and lidar data sets were compiled by the Yurok Tribe's Fisheries Department Design and Technical Services Program and tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2 (2023). The imagery was tested for a 10 cm $RMSE_H$ horizontal positional accuracy class. Actual horizontal accuracy was found to be $RMSE_H$ = 8.9 cm. The lidar was tested for a 10 cm $RMSE_V$ vertical accuracy class. NVA accuracy was found to be $RMSE_V$ = 6.3 cm.

Benjamin Lane Hocker, CA PLS 9924

October 17, 2024

The data collected for this project are intended for purposes of topographic and bathymetric modelling and visualization only, and not for boundary determination or depiction. Nor are these data, nor any products derived therefrom intended to be used for marine navigation. All information provided represents the results of the surveys on the dates collected and can only be considered as an indication of the general conditions existing at the time.

INTRODUCTION

The Yurok Tribe Fisheries Department Design and Technical Services Program (YT TSP) was tasked by the Bureau of Reclamation's (Reclamation's) Central Valley Project Improvement Act (CVPIA) Program to conduct a base-line data collection effort on the Sacramento River to support habitat and decision support modeling. High resolution aerial imagery, topography, bathymetry, and water surface elevations were provided to Reclamation and are intended to support the development of a hydrodynamic model framework for predicting habitat across a range of flows. The model will support measures needed to restore anadromous fish to optimum and sustainable levels in accordance with the restored carrying capacities of Central Valley rivers, streams, and riparian habitats. The data will also be used to support planning, design, and analysis of current and future restoration projects on the Sacramento River.

The topo-bathymetric survey area along the Sacramento River spanned from the Clear Creek confluence at approximate river mile 290 to Wilkins Slough at approximately river mile 117 (174 miles). The imagery survey area was larger, starting from the Clear Creek confluence extending down to Freeport at approximate river mile 45 (246 miles).

This report summarizes the data collection techniques and procedures as well as the processing and data integration methodologies used to develop each product.

METHODOLOGY

The broad tasks completed by YT TSP to comply with the scope of work included:

- Coordinating with Reclamation staff and project partners on timing of sonar and lidar surveys,
- Establishing and verifying a control network for the project,
- Completing multibeam sonar surveys during high water periods in the spring of 2023,
- Completing topo-bathymetric lidar surveys during the low water period in the fall of 2023,
- Completing high resolution airborne digital imagery surveys in the fall of 2023,
- Collecting accuracy assessment data,
- Collecting water surface data during high and low flow periods,
- Integration of data to construct a seamless digital terrain model, and
- Developing data deliverables and products.

Developing a seamless digital terrain model (DTM) of the project area, as shown in Figure 1, required multiple technologies to efficiently collect the required data. An airborne topo-bathymetric lidar survey was proposed to first collect data in the upland and wetted areas to extinction, where multibeam sonar would then be used to fill in the gaps. Bathymetric lidar is an extremely fast and efficient technology, but penetration is dependent on factors such as water clarity and riverbed reflectivity. It was expected that the conditions in the Sacramento River would result in a penetration of approximately 2 meters in most circumstances. In areas deeper than this at the time of the survey, multibeam sonar would then be used to complete the model. Vessel based multibeam sonar surveys are a much slower method, becoming more inefficient in shallow water, but would not be limited by greater depths or turbidity in the river. As such, an approach was designed that leveraged the advantages of each technology.

The original project plan specified the airborne topo-bathymetric lidar survey would have been completed first at the lowest possible flow (lowest water levels) at the start of the year to maximize coverage then processed to develop preliminary data extent. The multibeam sonar survey would then follow, with the lidar coverage used in real-time to navigate the survey boats, filling in data only where required. Unfortunately, the spring of 2023 saw unexpected, extensive flooding in the area. Water levels and turbidity were extremely high, negating the possibility of a successful topo-bathymetric lidar survey campaign.

YT TSP mobilized the bathymetric lidar aircraft and equipment to the area but due to the river conditions, it remained on standby for the month of March. To keep the project on track, YT TSP in consultation with Reclamation, elected to collect the multibeam sonar first, using the higher water levels to maximize sonar coverage. Sonar data were collected from April 29 to July 30, 2023. The lidar was then flown at low water in the summer/fall of 2023 from September 22 to October 3. Completing the surveys in this order was not the most efficient approach, as it led to considerably more overlap in some areas to reduce the risk of gaps between the datasets.

Airborne imagery was collected over a larger Area of Interest (AOI) as shown in Figure 1. The imagery AOI was collected during dedicated flights on September 5 through 7, 2023, tailored to the best times of day for sun angle. Imagery was also co-collected in the lidar AOI during the topo-bathymetric flights. These flights prioritized lidar data collection, and the generated orthoimagery were only used to colorize the lidar point clouds and assist in editing.

Water surface profiles were also collected along the Sacramento River, Clear Creek and Battle Creek. The collections were to target a high flow and low flow condition for the purpose of hydrodynamic modelling.

Prior to airborne or vessel-based data collection, a detailed control survey was done to establish the reference network of control points to be used for the project from March 31 to May 2, 2023. Using these control points, ground surveys were conducted to collect independent check points to validate horizontal and vertical accuracy of the products.

YT TSP partnered with Marker Offshore, LLC and Hexagon, Inc. to build capacity and provide additional equipment necessary for a project of this size. Marker Offshore provided additional resources to assist with the vessel-based surveys along the Sacramento River while Hexagon provided the topo-bathymetric lidar sensor, operator and data processing support.

Figure 1: Project Location and Survey Extent

GEODETIC CONTROL

The horizontal datum for this project is based on NAD83 (2011) Epoch 2010.00 with coordinates projected to UTM zone 10 North. The vertical datum is based on NAVD88 using GEOID18. Linear (horizontal and vertical) units are meters with all times relative to UTC.

National Geodetic Survey (NGS) control points, Continually Operating Reference Stations (CORS), and the California Surveying and Drafting Supply, Inc.'s Real Time Network (CSDS RTN) were used to control the project. Prior to data collection, a control survey was completed to establish or verify coordinates for control points to be used on the project. This work and the results are documented in the accompanying *Sacramento River Topographic and Bathymetric Data Acquisition Control Survey Report, Yurok Tribe Fisheries Department, September, 2024*. From this report, the coordinates used for the project are presented in the following tables: CSDS RTN stations in Table 1 and published NGS control points in Table 2.

Table 1: CSDS RTN Stations

Station ID	Northing (m)	Easting (m)	Elevation (m)	Comment
CH1G	4401895.184	597057.674	62.312	Adjusted CSDS
OR1K	4373844.263	624441.360	68.467	Adjusted CSDS
RD1L	4487051.663	560656.072	160.510	Adjusted CSDS
SACR (DH8725)	4279776.703	643204.811	37.939	NGS CORS - HELD
WD1J	4281430.019	607210.869	31.267	Adjusted CSDS
WI1H	4334394.239	573472.349	31.733	Adjusted CSDS
YC1I	4333788.301	617298.868	25.802	Adjusted CSDS
LD1K	4222467.086	653009.529	24.380	Adjusted CSDS

Table 2: NGS Control Points

PID	Northing (m)	Easting (m)	Elevation (m)	Comment
DH6394	4487029.808	555168.142	139.898	NGS Published
DH6520	4344671.695	583591.357	17.765	NGS Published
DH6521	4322066.682	600660.298	18.460	NGS Published
DH6625	4417762.035	575711.774	65.803	NGS Published
DL9132	4474357.404	568199.098	115.746	NGS Published
DL9142	4457255.726	566217.047	97.167	NGS Published
DL9190	4387157.618	585967.041	37.020	NGS Published
DL9193	4312289.141	608034.859	8.584	NGS Published
KS2014	4333250.412	594909.156	12.601	NGS Published
KT0518	4367972.786	584517.810	27.305	NGS Published
KT1807	4399844.111	583915.690	47.886	NGS Published
LU2291	4445793.944	566086.713	95.350	NGS Published
AC9219	4262862.915	623642.507	9.805	NGS Published
AI5062	4294557.490	610582.482	13.757	NGS Published
AI5069	4278610.814	624246.418	11.904	NGS Published
DL9193	4312289.134	608034.857	8.546	NGS Published
DN4101	4252253.230	632347.444	12.144	NGS Published

Additional temporary control points set during the project are shown in Table 3. These points were only used for specific tasks on this project and are not published nor have publicly available data.

Table 3: Additional Temporary Control Points

Station ID	Northing (m)	Easting (m)	Elevation (m)	Comment
RBL1	4445479.853	563764.666	103.190	Lidar base station
CC1	4483946.586	550488.206	141.408	Clear Creek float

For additional information on acquisition, processing and accuracy for the control network, please refer to the control report (Yurok Tribe, 2024).

DATA ACQUISITION

Data acquisition began with the control survey then proceeded to multibeam once the flood levels receded and boat ramps became accessible. Airborne lidar and imagery then followed during low water. A summary of the data collected by dates is shown in Table 4.

Table 4: Acquisition Dates

Data Type	Acquisition Dates
Ground Surveys	3/31/2023 - 5/02/2024
Multibeam Sonar	4/29/2023 - 7/30/2023
Topo-Bathymetric Lidar	9/22/2023 - 10/03/2023
Ortho Imagery	9/05/2023 - 9/07/2023
Sacramento River High Flow Water Surface Profile	4/25/2023 - 4/28/2023
Sacramento River Low Flow Water Surface Profile	9/22/2023 - 10/03/2023
Clear Creek Water Surface Profile	5/02/2024
Battle Creek Water Surface Profile Check	10/11/2023

Ground Survey

Ground survey points (GSPs) were established to perform quality assurance checks on the lidar and imagery data. A ground survey plan that evenly distributed points throughout the lidar and imagery AOIs was developed and executed by the YT TSP prior to airborne data collection. GSPs were collected using Global Navigation Satellite System (GNSS) real time kinematic (RTK) survey techniques with augmentation from the CSDS RTN. Points were established using Trimble R10 or R12 receivers with observations of at least 180-epochs. The receiver was then reinitialized, and the point was remeasured as an independent check. All GSP measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the rover. Relative errors for any GSP position were limited to less than 0.03 m horizontally and 0.05 m vertically, evaluated at the 95% confidence level.

To ensure proper rover configuration and system performance, checks were made to control points documented in the prior control survey. Results are presented in Appendix A.

GSPs consisted of existing high visibility road markings and painted air targets (PATs) located on hard, flat surfaces. These points served as horizontal and vertical reference points. Non-Vegetated Vertical Accuracy (NVA) points were also collected to serve as vertical checks only. Survey control, GSP and NVA locations are shown in Figure 2. A total of 93 GSPs and 159 NVA points were collected for this project to control and validate the accuracy of the lidar and imagery datasets.

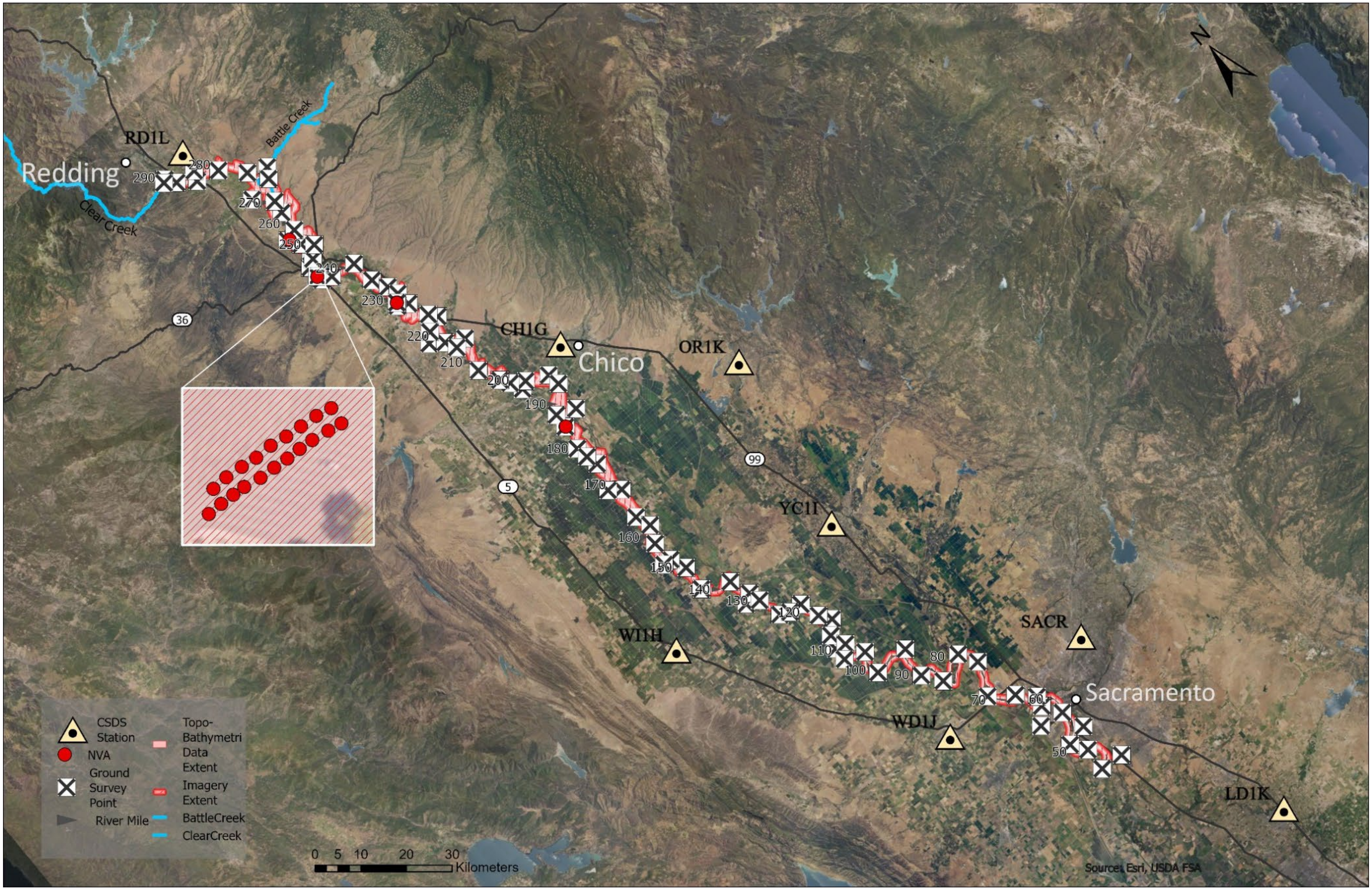


Figure 2: Reference Stations and Ground Survey Points

Airborne Topo-Bathymetric Lidar

Lidar surveys were accomplished using a Leica Chiroptera 4X (CH4X) topographic and bathymetric sensor installed in a Leica PAV100 gyro-stabilized mount. The system was deployed in the Yurok Tribe's Cessna Caravan 208 EX (N901CA) aircraft. Table 5 summarizes the settings used to meet the project specifications while Appendix B presents the classifications used for lidar data.

Table 5: Lidar Parameters

Lidar Survey Settings & Specifications	
Aircraft	Cessna Caravan 208 EX (N901CA)
Sensor	Leica Chiroptera 4X
Resolution/Density (Topographic)	~10 pts/m^2/swath
Survey Altitude (AGL)	~400 m
Survey speed	~130 knots
Swath Width	~380 m
Swath Edge Overlap	15%
Number of Flight Lines	175
Total Line Length	3292 km

The CH4X is an integrated system including a topographic laser, bathymetric laser, 4-band Leica RCD30 digital camera and inertial navigation system (INS). The digital imagery from the CH4X flights was primarily used to colorize the lidar point cloud and assist in data editing.

Flightlines were planned in Leica MissionPro software and are presented in Figure 3. The survey area was broken up into 8 manageable blocks (A through H from north to south), where flightlines were designed to minimize the time in turns while covering the required AOI. The sinuous nature of the river lead to multiple blocks and directions since the speed of the aircraft mandates straight lines.

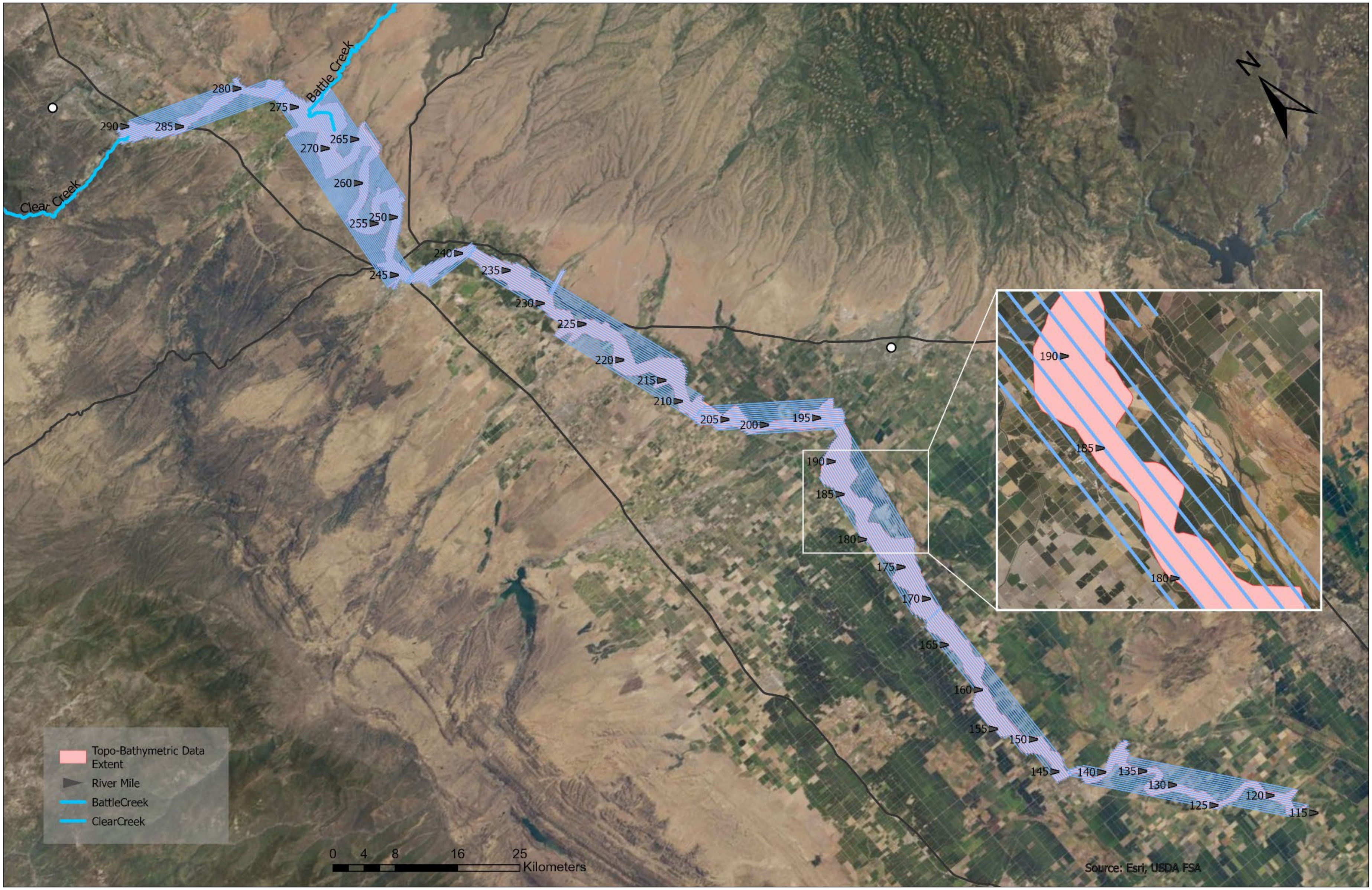


Figure 3: Topo-Bathymetric Data Flight Lines

Multibeam Sonar

Two shallow draft jet boats were deployed on the river surveying simultaneously along different reaches in order to meet project deadlines. The *GMA-Jet*, a 19-foot aluminum river sled operated by YT TSP, and the *Ospika*, a 21-foot aluminum workboat operated by Marker Offshore, shown in Figure 4.

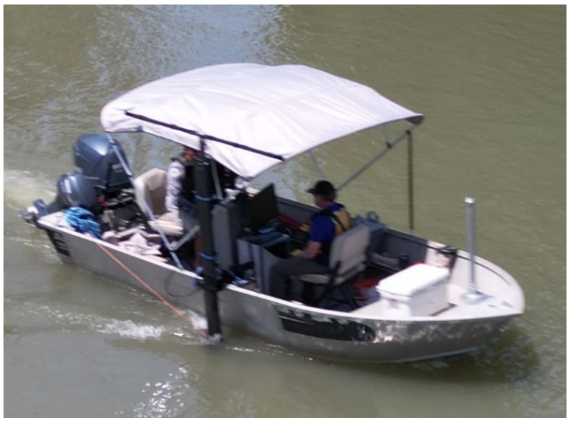


Figure 4: Survey Vessels (*GMA-Jet* left, *Ospika* right)

Each vessel used a NORBIT Compact Wideband Multibeam Sonar with integrated Applanix POS/MV inertial navigation system (iWBMSh). The sonars were configured to operate at 400 kHz and generate 256 beams for each ping. Equi-distant mode was used in the main channel, and equi-angular mode was used along the banks where the sonar swath was rotated to obtain coverage up to the waterline where possible. Swath angle was adjusted in real-time to maximize data quality and coverage. Raw data were logged using QPS Qinsy software which also provided real-time vessel navigation.

Surface sound speed was recorded using the NORBIT integrated time-of-flight sensor and profiles were taken using AML BaseX2 on the *Ospika* and a Valeport Swift sound speed profiler on the *GMA-Jet*. Profiles were taken at the start and end of each block and at approximately 2-hour intervals within a block. Additional casts were taken whenever the vessel significantly changed location or encountered any large temperature differentials. Overall, the water was well mixed, and very little stratification was noted in the field.

Prior to data acquisition, each vessel's sensor offsets were measured and entered into the survey systems. A GNSS Azimuth Measurement System (GAMS) calibration was conducted on each vessel to refine the relationship between the primary and secondary GNSS antennas with respect to the IMU reference frame. During this procedure, the vessel is in the water and navigated through a series of figure eights and other maneuvers while the POS/MV automatically calculates the GAMS parameters. Once complete, the results are compared to the measured values and stored to the system. A patch test was then completed by each vessel in the Keswick Reservoir to determine the sonar mounting angles relative to the Inertial Measurement Unit (IMU) reference frame. Results are presented in Table 6 and Table 7 for the two vessels. Latency for both systems was verified to be zero seconds.

Table 6: *GMA-Jet* Offsets

Sensor	X (+Forward) m	Y (+Starboard) m	Z (+Down) m
Primary GNSS L1 PC	-0.783	0.000	-2.265
Secondary GNSS L1 PC	1.223	-0.008	-2.271
IMU Reference Point	0.255	0.000	0.079
Sonar Reference Point	0.000	0.000	0.000
Reference Frame	**Roll °**	**Pitch °**	**Yaw °**
Sonar to IMU	-0.116	-0.001	-0.116

Table 7: *Ospika* Offsets

Sensor	X (+Forward) m	Y (+Starboard) m	Z (+Down) m
Primary GNSS L1 PC	-2.309	0.508	-2.180
Secondary GNSS L1 PC	-0.310	0.501	-2.126
IMU Reference Point	0.255	0.000	0.079
Sonar Reference Point	0.000	0.000	0.000
Reference Frame	**Roll °**	**Pitch °**	**Yaw °**
Sonar to IMU	-0.070	0.130	0.000

Static draft (the location of the sonar reference point relative to the water surface) for each vessel was measured at the beginning and end of each survey day to account for changes in vessel loading due to fuel burn or crew changes. The distance between the water surface and a known point, such as the top of the flange, was measured with the vessel at a zero roll. The fixed offset between the known point and the sonar reference point was then applied to determine the draft.

The dynamic draft (settlement) curve for the *Ospika* was also measured in the Keswick Reservoir during patch testing. The vessel was operated at a fixed engine Revolutions Per Minute (RPM) for a 1-minute duration, and the elevation change measured with each RPM using the post processed vessel trajectory. A table of settlement vs. RPM/Speed was then developed and is presented in Figure 5. Dynamic draft was not required for the *GMA-Jet* as that vessel was not used for water surface profiles.

Dynamic draft is affected by the varying speed of the water passing the vessel hull. In riverine environments, the ground speed of the vessel cannot be used since the settlement will vary for the same ground speed going up or down stream. Therefore, RPM is used as a proxy for hull speed as higher RPM generally equates to a faster speed of the water under the hull.

RPM	SPEED (M/S)	SETTLEMENT
1000	1.65	-0.009
1200	1.93	-0.012
1400	2.21	-0.016
1600	2.45	-0.020
1800	2.63	-0.023
2000	2.80	-0.027
2200	2.92	-0.029
2400	3.05	-0.032
2600	3.23	-0.036

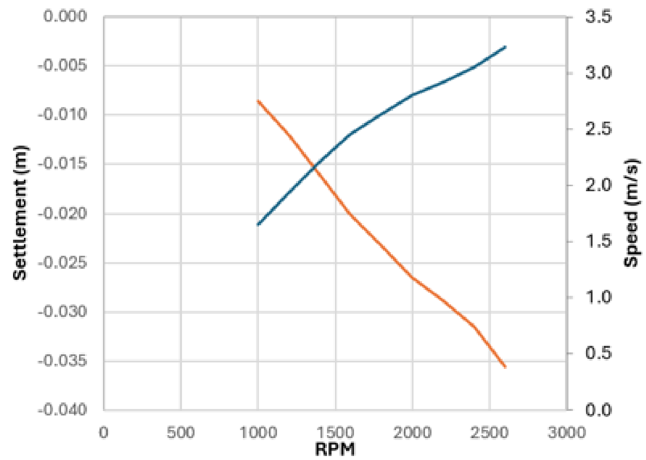


Figure 5: *Ospika* Dynamic Draft Table

The AOI was divided up into 87 roughly 2-mile long sections named according to the approximate river mile. This created a consistent naming convention and allowed the vessels to focus on smaller areas at a time, ensuring they were complete before moving on. The multibeam surveys were completed over a total of 84 boat days (43 for the *GMA-Jet* and 41 for the *Ospika*) spanning 56 calendar days.

Multibeam data were collected by the survey vessels up to approximately 2 meters water depth (at high flow). This was estimated as a conservative point where sufficient overlap would be reached with the lidar. This was not the most efficient order in which to collect the data, but unseasonably high-water levels early in the year forced the team to collect sonar before lidar.

Airborne Imagery

Digital imagery was acquired using a PhaseOne PAS 280i system installed in a SOMAG GSM 4000 gyro-stabilized mount. The PhaseOne PAS 280i is a large format nadir digital imaging sensor. The system consists of an iXM-RS280F metric camera that utilizes two 90mm Rodenstock lenses and an iXM-RS150F Near-InfraRed (NIR) that utilizes a single 150mm lens. The PAS 280i simultaneously collects Red-Green-Blue (RGB) and NIR imagery, creating a 280 MP 4-band image solution. The imaging specifications and project specific settings are shown in Table 8. Topographic Lidar was simultaneously collected during imagery acquisition with a Riegl VQ-1560 II-S installed in a SOMAG GSM 40000 gyro-stabilized mount. The additional lidar was co-collected to orthorectify the imagery; this was necessary due to the differing topo-bathymetric lidar and imagery extent. Flightlines were planned in TopoFlight Mission Planner software and are presented in Figure 6.

Table 8: Imagery Specifications and Settings

Digital Orthophotography Specifications	
Aircraft Used	Cessna Caravan 208 EX (N901CA)
Sensor	PhaseOne PAS 280i
Spectral Bands	Red, Green, Blue, NIR
Pixel Size	3.76 µm
Focal Length RGB	90 mm
Focal Length NIR	50 mm
Field of View RGB	32.9° along track X 45.7°across track
Field of View NIR	42.2° along track X 56.2°across track
Cross Track Overlap	>55%
Along Track Overlap	60%
Resolution Ground Sample Distance	<10 cm
Flight Altitude (AGL)	~2377 m
Data Format	16-bit IIQ

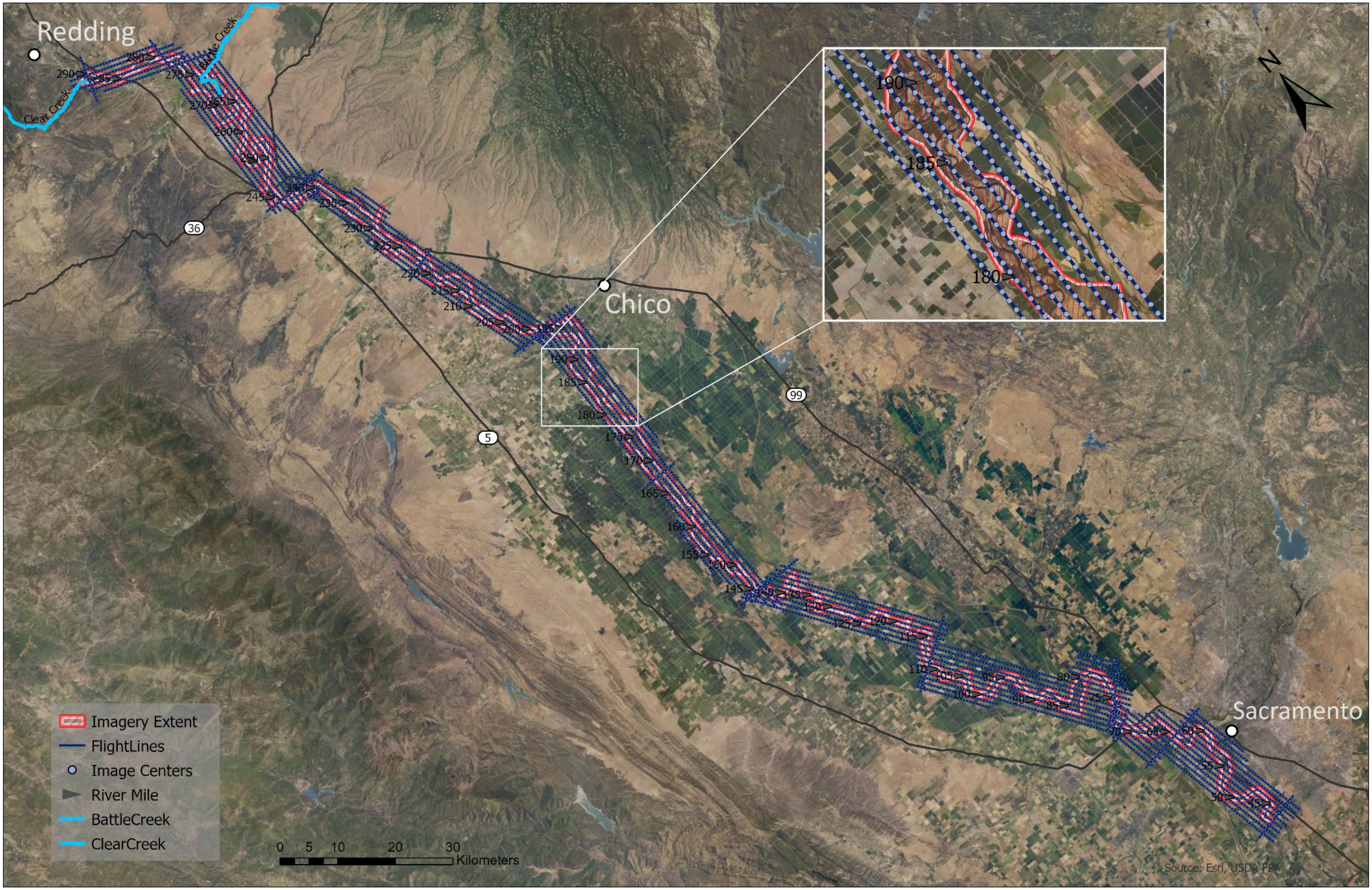


Figure 6: Imagery Flight Lines

Water Surface Profiles

Water surface profiles were measured at multiple flows along the Sacramento River, Clear Creek and Battle Creek for modelling purposes. The statement of work required the following:

- Sacramento River: From the Clear Creek confluence at approximate river mile 290 to Wilkins Slough at approximately river mile 117 (roughly 174 miles) at high and low flows defined by:
    - High flow discharge: approximately 10-15,000 cfs at upstream end of the reach based on gauge records at Keswick Dam (USGS 11370500) and Bend Bridge (USGS 11377100); and 15-25,000 cfs at the downstream end of the reach, Sacramento River below Colusa (USGS 11389500)
    - Low flow discharge: approximately 3,250 cfs at upstream end of the reach based on gauge records from Keswick Dam (USGS 11370500) and Bend Bridge (USGS 11377100); and 5,250 cfs at the downstream end of the reach, Sacramento River below Colusa (USGS 11389500)
- Clear Creek: Lower 2 miles to the confluence with the Sacramento River
- Battle Creek: Lower 6 to the confluence with the Sacramento River

A combination of techniques was used, as summarized in Table 9 along with the average and standard deviation (σ) of the USGS observed discharge over the collection period. The high flow water surface profile along the 174-mile Sacramento River reach was completed by the *Ospika* while collecting initial multibeam depths in the deeper sections of the river. This single pass required 4 days due to the relatively slow vessel speeds (typically between 7-8 knots).

Table 9: Water Surface Profile Summary

Water Surface Profile	Method	Reported Discharge
Sacramento River High Flow	Vessel float collected 4/25/2023 - 4/28/2023	Keswick Dam (USGS 11370500): Average = 8,690 cfs (σ = 70 cfs) Bend Bridge (USGS 11377100): Average = 12,330 cfs (σ = 240 cfs) Below Colusa: 13,070 (σ = 550 cfs)
Sacramento River Low Flow	Lidar water surface extracted from data collected 9/22/2023 - 10/03/2023	Keswick Dam (USGS 11370500): Average = 6,670 cfs (σ = 180 cfs) Bend Bridge (USGS 11377100): Average = 7,610 cfs (σ = 280 cfs) Below Colusa(USGS 11389500): 6,230 (σ = 240 cfs)
Clear Creek	Vessel float collected 5/02/2024	Clear Creek near Igo (USGS 11372000): 245 cfs
Battle Creek	Lidar water surface extracted from data collected 9/16/2023 & 9/23/2023	Battle Creek below Coleman (USGS 11376550): 235 cfs

The low flow water surface profiles on the Sacramento River and Battle Creek were extracted from the topo-bathymetric lidar derived water surface. This method was verified by comparison to a separate vessel float on Battle Creek as further discussed in the data processing section.

The Clear Creek water surface profile was measured with a GNSS mounted to a kayak that was floated downstream. The GNSS was configured to not only receive real-time corrections from a base station established on control point CC1, but also log raw observables internally at 1-second intervals.

The high flow discharge water surface profile on the Sacramento River was collected on days that fell slightly below the targets. This was due to adjustments in the schedule as a result of the flooding earlier in the spring.

Targets were also not met on the low flow water surface acquisition. To meet project deadlines, the lidar data collection was completed at the earliest low flow on the Sacramento. This time period had flows that were slightly higher than the targets but were nearly the lowest over the entire year. Targeted flows of 3,250 cfs were not ever reached during 2023 as shown by the plot of discharge at Bend Bridge in Figure 7.

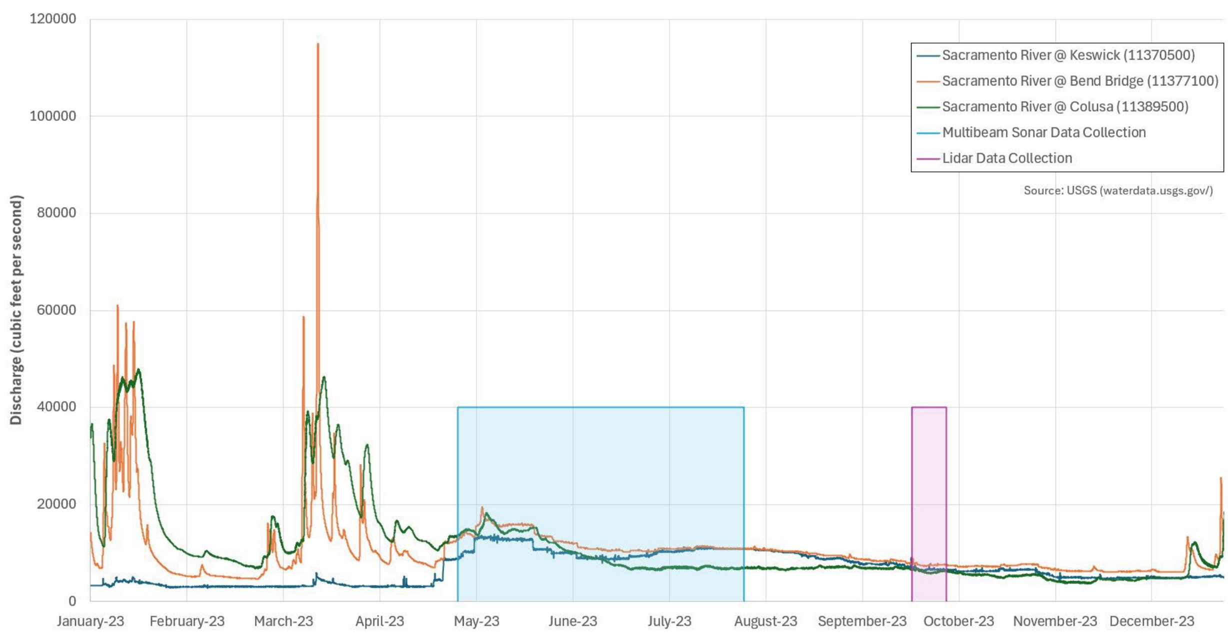


Figure 7: 2023 Discharge Plot on the Sacramento River

DATA PROCESSING

Ground Survey

Ground surveys were processed by YT TSP staff in Trimble Business Center version 2023.11 software. Raw data from the survey controllers were imported then geodetic settings, antenna heights and models were verified. The reported precisions of each point were reviewed to ensure project objectives were met and any points falling below thresholds were removed. Position checks were reviewed to ensure control network accuracy as well as proper base station and rover configuration.

The final points were then exported in text format for lidar and imagery product accuracy assessment. Points were also merged with photos and exported in report format, provided in Appendix C.

Topo-Bathymetric Lidar Data

Topo-bathymetric lidar data were initially processed in the field immediately after acquisition to develop coverage maps and validate that the data collected would meet project specifications. The penetration depth of the bathymetric lidar varied considerably based on conditions from zero in highly turbid areas to over 3 m. Areas with poor penetration were reflown in an attempt to avoid returning with the sonar for infill. Final processing to a partially classified point cloud was completed by Hexagon then delivered to YT TSP for integration.

To begin the initial field processing, the aircraft trajectory was determined. The CH4X contains a Novatel SPAN INS with a Novatel LCI IMU. The GNSS receives data on GPS L1, L2, L2C, L5, and GLONASS L1, L2 signals. Trajectory processing combines data from the sensor integrated GNSS and IMU with data from the project base station to compute accurate position and orientation of the sensor during the flight. Novatel Inertial Explorer was used to combine the GNSS and IMU processing in a tightly coupled solutions for high accuracy Differential GNSS/IMU post-processing solutions.

The DGNSS/INS solutions file was combined with the sensor calibration values and raw sensor data in Leica Survey Studio (LSS) to produce georeferenced LAS unclassified point clouds. A calibration flight was completed prior to the project to determine the relative orientation between the scanner, INS, and GNSS systems. This calibration is applied to the raw sensor data, in combination with the DGNSS/INS solution file to produce the georeferenced LAS v1.4 unclassified points clouds.

Once lidar data were verified, tiles were generated and imported into TerraSolid TerraScan software in a 500 m x 500 m tiling scheme. Initial classification of the LAS point cloud was then completed by Hexagon using TerraScan software. The LSS automated classifications were reviewed and improved using additional macros. After these automated routines were complete, technicians manually inspected an editable TIN model for each respective tile to further correct any misclassification of points. After ground classification was complete, a combination of automated classification macros and manual editing by technicians was used to classify the bathymetric points. The resulting classified tiles were delivered to YT TSP on a series of hard drives for final processing and integration.

YT TSP reviewed the delivered data and completed additional processing using TerraScan version 23.017 and LAStools 2024.01 software to enhance the ground classification. Initial ground points were filtered then used as a seed surface to increase detail and density, particularly in areas of vegetation where multiple lidar returns were present. Further processing was done to clean up the ground classification along the banks and also remove noise throughout the dataset.

Multibeam Sonar Data

Once sonar data collection was complete, YT TSP and Marker Offshore processed data from their respective boats in QPS Qimera version 2.5.3 software. Processing at this stage was segmented into the same 2-mile-long sections of the river the data were collected in.

To enhance real-time positioning and orientation accuracies, raw data from the POS/MV were post-processed in Applanix POSPac MMS version 8.9 software. GNSS reference station data were used from existing NGS CORS and CSDS stations using Applanix SmartBase methodology. Applanix SmartBase uses a network of reference stations to estimate atmospheric, orbital and clock errors which are then used to correct for errors at the rover location at each epoch. This post-processing method is applying the Virtual Reference Station (VRS) concept to extend the maximum baseline lengths for integer ambiguity resolution.

The resulting Smoothed Best Estimate of Trajectory (SBET) files were applied to georeference the raw soundings in Qimera. Sound speed profiles were then applied, then preliminary surfaces developed. A combination of manual and automated filtering and editing techniques were then employed to remove noise from the dataset.

The cleaned Qimera QPD format files from both boats were then combined over the entire AOI into one large project and a final gridded surface was generated at 1 meter resolution using Combined Uncertainty and Bathymetry Estimator (CUBE) algorithms. A single project wide surface was developed to eliminate any edge effects that may have been introduced by gridding the smaller sections individually.

Digital Imagery

Digital imagery was processed in iXProcess version 1.2 and went through multiple processing steps. Images were color balanced, levels adjusted, and finally corrected for geometric distortion. The RGB and NIR images were then combined into Color Infrared (CIR) format and exported from PhaseOne IIQ format to industry standard tiff format. An image exterior orientation file including position and orientation for each image was produced using the SBET produced in POSPac MMS version 8.9 and SmartBase methodologies. The images were then imported into Agisoft's Metashape version 2.1.1 photogrammetric software where analytical aerial triangulation was performed using ground control, automatically generated tie points, and camera calibration information.

Finally, aligned images were orthorectified using the co-collected lidar-derived ground model to remove displacement effects from topographic relief inherent in the imagery. The resulting orthorectified image frames were mosaicked, and seamlines were reviewed and edited as needed.

Water Surface Profiles

Several techniques were used to collect the water surface profiles throughout the project, depending on the timing of the acquisition and the size of the river. The following sections outline the processing steps for each to generate an export file with date, time, northing, easting and water surface elevation. These data were then viewed and edited in a continuous profile in Caris HIPS version 10.4.20 software. The final data were then exported to separate ESRI 3D point feature SHP files.

Clear Creek

Raw GNSS data collected using the kayak float were processed in Trimble Business Center (TBC) version 2023.11 software. Data from the real time solution using RTK had several gaps and areas of poor accuracy since the telemetry from the base station was occasionally blocked by the topography. The raw observables from the base and rover were used in a Post-Processed Kinematic (PPK) solution to generate accurate positions. The antenna height above water was applied to the solution then the values were manually reviewed and edited to create a single continuous track down river.

Battle Creek

Initially, the Battle Creek profile was collected using the same methodology as Clear Creek, but there were significant gaps in both the RTK and PPK profiles due to dense overhead vegetation. To develop a continuous profile, the derived water surface points from the bathymetric lidar were used. The derived water surface is a set of synthetic points created in LSS during raw bathymetric lidar data processing. These points are generated from topographic laser channel of the system and used as the surface to begin refraction correction of the bathymetric laser data.

A rough centerline was digitized along Battle Creek which was then used to extract the derived water surface points from the bathymetric lidar data set. The extracted points were then gridded and thinned to a 5 m spacing. The thinned dataset was then reviewed and edited for erroneous data. To validate the accuracy of this method, data along Battle Creek collected with a GNSS in open areas with good accuracy were compared to the derived water surface points. The average difference between the two methods was computed to be 0.03m with a standard deviation of 0.02m in the lower section of the creek (lidar surface lower than GNSS surface).

The lidar water surface was extracted from data collected on 9/16/2023 & 9/23/2023 when the reported discharges at Battle Creek below Coleman (USGS 11376550) were fluctuating between approximately 229 to 248 cfs resulting in a gauge height variation of less than approximately 0.03m around an average of approximately 0.31m above NAVD88. The kayak float data were collected on 10/11/2023 when the reported discharges were fluctuating between approximately 243 to 258 cfs resulting in a gauge height variation of less than approximately 0.02m around an average of approximately 0.33m above NAVD88. Although within expected uncertainties, the difference in average gauge height between the two collection periods was in a consistent direction as the difference between the water surface derivation methodologies, further validating the results.

Sacramento River High Flow

Data from the post-processed vessel trajectory (as discussed in the multibeam processing section of this report) were corrected to the water surface by both a static and dynamic draft. Static draft is the height of the vessel reference point above or below the water surface measured at the start and end of the survey day to account for changes in loading due to fuel burn. Dynamic draft (or settlement) is the change in the height of the reference point of vessel relative to the water surface due to the hull speed. As settlement is a function of speed through the water, it is difficult to determine in a dynamic current environment. It is best approximated by the engine RPM, which was documented during the collection of the water surface profiles. The dynamic draft correction was applied to the elevation data using a table of RPM vs. dynamic draft correction developed during the initial calibrations in Keswick Reservoir at the start of the project.

Sacramento River Low Flow

The low flow profile was extracted from the bathymetric lidar derived water surface points in a similar manner to Battle Creek. Sacramento River lidar data were collected over approximately 2 weeks resulting in some changes in water level between flights as discharge fluctuated in the river. These misalignments between the derived water surface points were edited out of the final dataset in Caris HIPS as much as possible, but some fluctuations of up to 15 cm remain in some cases.

PRODUCT DEVELOPMENT

LAS Point Cloud

A tiled LAS point cloud was developed for the project area covering the topo-bathymetric lidar extent. Tiles are 500 m x 500 m in size and are clipped to the defined project area. The LAS files are named by the bottom left-hand corner using the first four digits of the easting value followed by digits 2 through 5 of the northing value. The integration and product development workflow is shown in Table 10. Detailed classification descriptions are provided in Appendix B.

Table 10: Data Integration Workflow

Data Integration Step	Description
Convert and classify data	Convert ASCII sonar and conventional survey data to *.LAS v1.4 PDRF 8. Add classifications for sonar and topo-bathymetric lidar.
Terrain Development and Inspection	Develop terrain using appropriate point classifications. Add additional breaklines to sonar and lidar datasets to force correct interpolation of features. Visual inspect terrain for correct interpolation.
Data Accuracy Assessment	Query the terrain dataset with lidar, Conventional and Sonar QAQC GSCPs. Develop statistics based on standards set in place by the American Society for Photogrammetry and Remote Sensing Edition 2, Version 1 (ASPRS, 2023).
Final Products	Develop and review final products requested by client.

Terrain Model

A raster digital terrain model at 1-m resolution was developed for the project area. Ground (2), Bathymetric Lidar High Confidence (40), Bathymetric Low Confidence (66), and MBES Binned (81) classes were used as the basis for the terrain. Integration of the data sets was performed by technicians with automated and manual techniques to develop a continuous surface. In areas where topo bathymetric lidar data (40 & 66) overlapped with the multibeam sonar data (81) and the two data sets were not in agreement, priority was given to the data set that created the most comprehensive surface at the location.

Breaklines were developed as needed to enforce correct terrain interpolation. Additional water's edge breaklines were developed around ponds, lakes, and side channels and were used to hydroflatten the terrain model.

Data Voids

The water's edge breaklines delineate disconnected waters such as ponds, lakes and side channels. These areas contain sparse or no bathymetric data. Where bathymetric data were sparse and unable to produce a continuous surface, these polygons were used as breaklines to hydro flatten the terrain model. The bathymetric data that was present in these polygons was considered low-confidence and were moved to their ignored class to exclude them from the surface.

Orthoimagery

The orthorectified imagery was produced at 10 cm resolution and was tiled into 500 m x 500 m tiles. The tiles are delivered as TIFF files. Additionally, the imagery was mosaicked and exported as both JPEG 2000 and TIFF files. The mosaicked imagery is split into five segments, designated by the closest river mile, as shown in Figure 8.

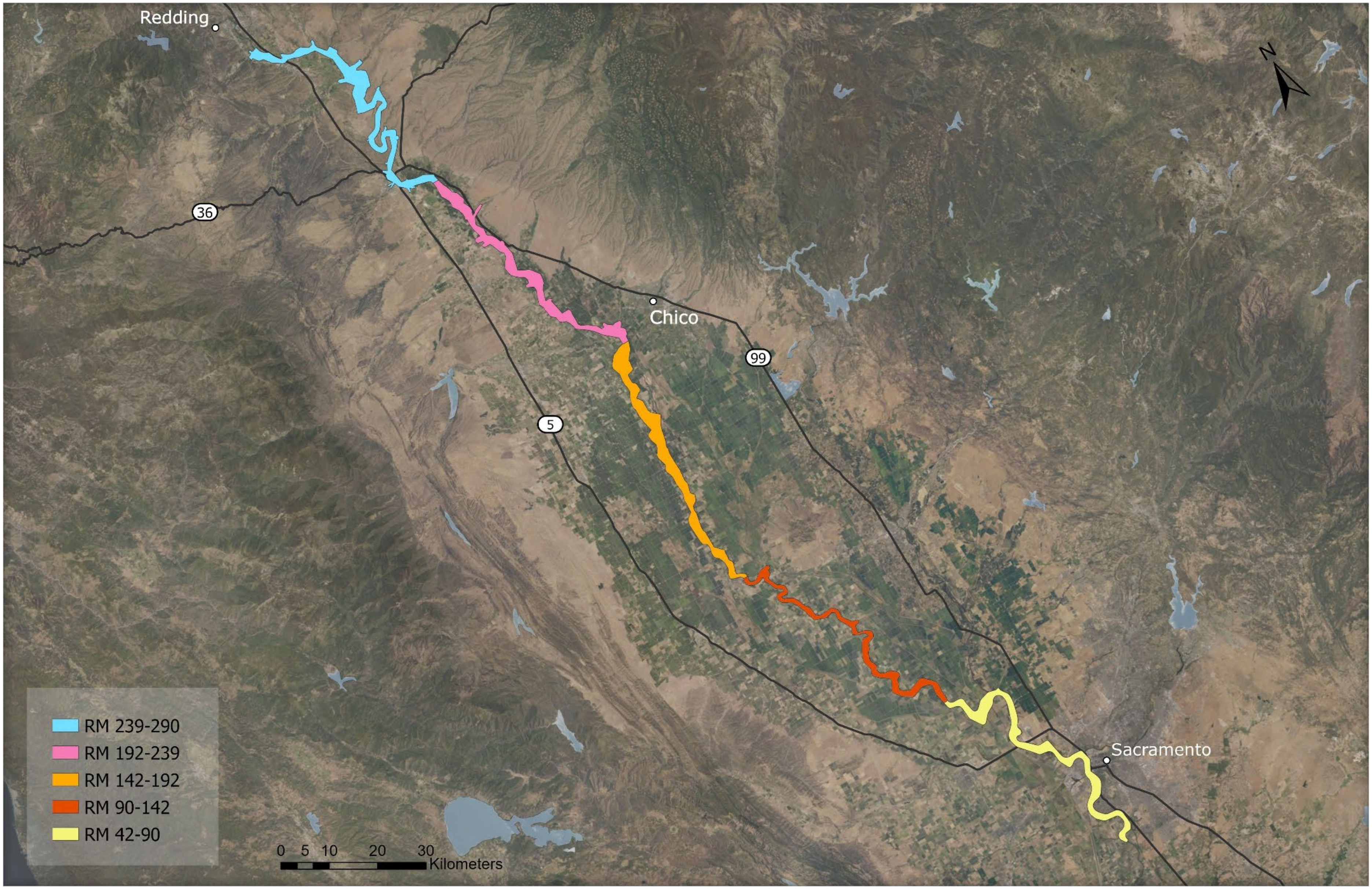


Figure 8: Orthoimagery Segments

Deliverables

The deliverables generated for the Sacramento River project are shown in Table 11. The deliverables were provided electronically on an external hard drive, accompanying this report.

Table 11: Survey Data Deliverables

Electronic Data Deliverables Horizontal Datum: NAD83 (2011) Epoch 2010.0 Vertical Datum: NAVD88 (GEOID18) Projection: UTM Zone 10N (EPSG:6339) Units: Meters	
Point Cloud Data Package	Tiled Point Cloud ● Classified Point Cloud (*.las)
Terrain Surface Data Package	Tiled Terrain Model ● 1-m DEM (*.tif) ● 1-m Hillshade (*.tif)
	Mosaiced Terrain Model ● 1-m DEM (*.tif) ● 1-m Hillshade (*.tif)
Imagery Data Package	Imagery Mosaics ● 4-Band orthorectified image mosaics (*.jp2) Tiled Imagery ● 4-Band orthorectified imagery (*.tif)
Vector Data Package	● Topobathy-Lidar Extent (.shp) ● Imagery Extent (*.shp) ● Tile Index (*.shp) ● Breaklines (*.shp) ● Data Voids (*.shp) ● Water Surface Profiles (*.shp)
Accuracy Assessment Data Package	Ground Survey Points ● Aerial Targets and Vertical Accuracy Points (*.csv) Accuracy Reports ● Statistical Analysis Summary (*.txt)

ACCURACY ASSESSMENT

Horizontal and vertical accuracy assessments of topo-bathymetric lidar and imagery products follow the guidelines set forth in the American Society for Photogrammetry and Remote Sensing Edition 2, Version 1 (ASPRS, 2023). Absolute accuracy is evaluated using the Root Mean Square Error (RMSE) values for the digital data and the mean reported ground survey accuracy values.

Absolute Vertical Accuracy

Absolute vertical accuracy was assessed using NVA reporting that compares point data collected in areas with open sky, where a lack of vegetation exists and on surfaces with level slopes (<10°) to the triangulated irregular network (TIN) surface generated by the survey data. The accuracy test was performed using 159 check points. The vertical accuracy of the topo-bathymetric lidar data expressed as the Vertical Product Root Mean Square Error ($RMSE_V$) is 0.063 m and was calculated using the following ASPRS equation (ASPRS, 2023):

$$RMSE_V = \sqrt{{RMSE_{V1}}^2 + {RMSE_{V2}}^2}$$

Where:

$RMSE_{V1}$ = $RMSE_Z$ of the tested product.

$RMSE_{V2}$ = The mean vertical accuracy of the ground surveys, reported by the field surveyor.

The results of the absolute accuracy assessment are shown in Table 12. The full accuracy assessment report including the minimum and maximum error, the standard deviation, and the residual errors at each check point can be found in the Accuracy Data Package.

Table 12: Non-Vegetated Vertical Accuracy Assessment (NVA)

Non-Vegetated Vertical Accuracy (NVA)	
Samples	159
Mean (m)	0.031
$RMSE_{v1}$ (m)	0.047
$RMSE_{v2}$ (m)	0.042
$RMSE_v$ (m)	0.063

Orthoimagery Accuracy

Image accuracy was assessed using air targets that were withheld from initial aerial triangulation. These checkpoints were identified in the adjusted orthoimagery and the displacement from targets centers was recorded for statistical analysis. The horizontal accuracy was assessed using independent, evenly distributed air targets. The horizontal accuracy test was performed using ninety-three (93) check points. The horizontal accuracy of the imagery expressed as the Planimetric Root Mean Square Error ($RMSE_H$) is 0.089 m, and was calculated using the following ASPRS equation (ASPRS, 2023):

$$RMSE_H = \sqrt{{RMSE_{H1}}^2 + {RMSE_{H2}}^2}$$

Where:

$RMSE_{H1}$= $RMSE_{XY}$

$RMSE_{H2}$= The mean accuracy of the ground surveys, reported by the field surveyor.

The results of the horizontal accuracy assessment are shown in Table 13. The full accuracy assessment report including the minimum and maximum error, the standard deviation, and the residual errors at each check point can be found in the Accuracy Data Package.

Table 13: Orthoimagery Horizontal Accuracy Assessment

Orthoimagery Check Point Accuracy Assessment			
	Air $Targets_x$	Air $Targets_y$	Air $Targets_{xy}$
Samples	93		
Mean (m)	0.033	0.021	0.074
$RMSE_{H1}$ (m)	0.065	0.058	0.087
$RMSE_{H2}$ (m)	----	----	0.018
$RMSE_H$ (m)	----	----	0.089

Relative Bathymetric Accuracy

To assess the relative accuracy of the bathymetric lidar and multibeam sonar a comparison was conducted at discrete locations along the Sacramento River. Locations were randomly selected in areas where there was overlap between the sonar and lidar. The results are presented in Table 14 with the full accuracy assessment report including the minimum and maximum error, the standard deviation, and the residual errors at each check point found in the Accuracy Data Package.

Table 14: Multibeam to Lidar Comparison

Non-Vegetated Vertical Accuracy (NVA)	
Samples	40
Mean (m)	0.049
$RMSE_v$ (m)	0.071

Results indicate very good agreement between the two datasets. Qualitative assessment of the relative agreement between the sonar and lidar was also constantly reviewed during integration, with representative cross sections provided in Appendix D.

REFERENCES

ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 2, Version 1.0. – August 23, 2023)

https://publicdocuments.asprs.org/PositionalAccuracyStd-Ed2-V1

Sacramento River Topographic and Bathymetric Data Acquisition Control Survey Report, Yurok Tribe Fisheries Department (September, 2024)

APPENDICES

Appendix A Ground Survey Position Checks

Name	PID	Difference			Comment
		dN	dE	dH	
HPGN D CA 03 BG	AC9219	-0.010	0.001	0.100	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.002	-0.002	0.070	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.016	0.001	0.060	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.013	0.004	0.066	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.014	0.011	0.061	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.023	0.005	0.056	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.004	0.004	0.069	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.016	0.005	0.046	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.009	0.003	0.040	Check in from WD1J
HPGN D CA 03 BG	AC9219	-0.007	-0.005	0.440	Check in from WD1J
F 859 RESET	AI5062	-0.025	-0.007	0.387	Check in from WD1J
F 859 RESET	AI5062	-0.023	-0.006	0.410	Check in from WD1J
RIVER	AI5069	-0.008	-0.010	0.066	Check in from WD1J
RIVER	AI5069	-0.004	-0.002	0.065	Check in from WD1J
RIVER	AI5069	-0.005	-0.007	0.055	Check in from WD1J
RIVER	AI5069	0.003	-0.018	-0.007	Check in from WD1J
RIVER	AI5069	-0.002	-0.019	0.021	Check in from WD1J
TYNDALL	AI5072	-0.039	-0.011	0.306	Check in from WD1J
TYNDALL	AI5072	-0.041	-0.016	0.320	Check in from WD1J
5 SHA 11.70	DH6394	0.031	-0.013	-0.003	Check in from RD1L
5 SHA 11.70	DH6394	0.029	-0.014	-0.007	Check in from RD1L
5 SHA 11.70	DH6394	0.030	-0.016	-0.006	Check in from RD1L
5 SHA 11.70	DH6394	0.023	-0.012	-0.001	Check in from RD1L
5 SHA 11.70	DH6394	0.020	-0.018	0.003	Check in from RD1L
WILKENS	DH6502	-0.011	0.019	0.054	Check in from YC1I
WILKENS	DH6502	-0.009	0.022	0.073	Check in from YC1I

Name	PID	Difference			Comment
		dN	dE	dH	
WILKENS	DH6502	-0.011	0.019	0.054	Check in from YC1I
WILKENS	DH6502	-0.009	0.022	0.073	Check in from YC1I
MICHIGAN	DH6625	0.013	0.022	0.030	Check in from CH1G
MICHIGAN	DH6625	0.009	0.009	-0.003	Check in from OR1K
BEND BRIDGE	DL9142	-0.004	0.008	-0.037	Check in from RD1L
BEND BRIDGE	DL9142	0.004	0.013	-0.061	Check in from RD1L
BEND BRIDGE	DL9142	0.022	-0.006	0.004	Check in from RD1L
BEND BRIDGE	DL9142	0.010	-0.001	-0.008	Check in from RD1L
ORDBEND	DL9190	0.005	-0.001	0.055	Check in from CH1G
ORDBEND	DL9190	0.010	0.005	0.023	Check in from CH1G
PELGER	DL9193	-0.014	0.027	0.050	Check in from YC1I
PELGER	DL9193	-0.010	0.024	0.038	Check in from YC1I
PELGER	DL9193	-0.014	0.018	0.068	Check in from YC1I
PELGER	DL9193	-0.014	0.019	0.062	Check in from YC1I
EGOC	DN4101	-0.003	0.010	0.102	Check in from SACR
EGOC	DN4101	-0.003	0.006	0.094	Check in from SACR
HPGN CA 03 04	KS2014	0.012	-0.016	0.098	Check in from WI1H
HPGN CA 03 04	KS2014	0.027	-0.015	0.101	Check in from WI1H
HAMILTON	KT1807	0.014	-0.017	0.017	Check in from CH1G
HAMILTON	KT1807	0.017	-0.014	0.023	Check in from CH1G
HAMILTON	KT1807	-0.003	-0.001	0.038	Check in from CH1G
HAMILTON	KT1807	0.001	-0.001	0.030	Check in from CH1G

Appendix B LiDAR Point Classification

Classes shown in **bold** are used in the final terrain model.

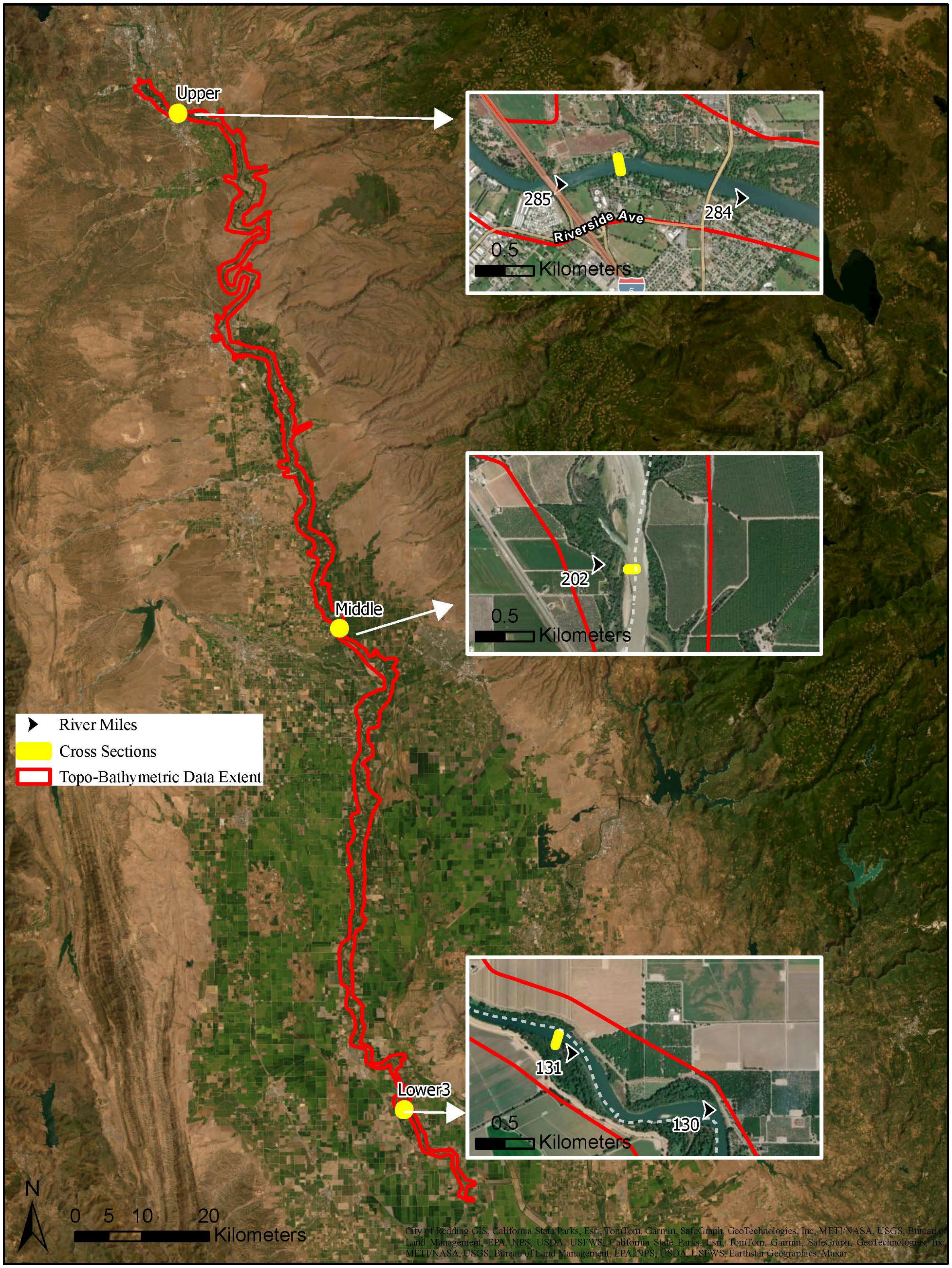
Classification Number	Classification Name	Classification Description
1	Unclassified	Processed, unclassified topographic data
2	**Ground**	**Topographic laser returns that are determined to be ground using automated and manual algorithms**
7	Low Noise	Topographic lidar returns below the ground surface determined to be noise
9	Water	Topographic laser returns that are determined to be water using automated and manual cleaning algorithms
12	Overlap Points	Topographic laser returns where overlap between flightlines occurred
17	Bridge Deck	Topographic laser returns that are determined to be a bridge using manual classification methods
18	High Noise	Topographic laser returns above the ground surface determined to be noise
20	Ignored Ground	Topographic laser ground points that were buffered along break lines
35	Bathy Lidar Extraneous	Manually rejected bathymetric lidar points
40	**Bathy Lidar High Confidence**	**Bathymetric laser returns that are determined to be riverbed using automated and manual algorithms**
41	Bathy Lidar Water Surface	Bathymetric laser returns determined to be water surface
42	Bathy Lidar Derived Water Surface	Synthetic points for bathymetric lidar refraction correction
43	Bathy Lidar Submerged Objects	Bathymetric laser returns determined to be submerged objects
64	Bathy Lidar Shallow Returns	Bathymetric laser returns determined to be noise by LSS
65	Bathy Lidar TWE1	Bathymetric laser returns determined to be noise by the turbid water routine in LSS
66	**Bathy Lidar Low Confidence**	**Bathymetric laser returns that are determined to be riverbed using automated and manual algorithms**
67	Bathy Lidar TWE2	Bathymetric laser returns determined to be noise by the turbid water routine in LSS
69	Ignored Points	Manually rejected topographic and bathymetric laser returns
81	**MBES Binned**	**Multibeam sonar points generated by CUBE algorithms**

Classification Number	Classification Name	Classification Description
85	MBES Binned Ignored	Multibeam sonar points, not used in the surface.
151	Bathy Lidar Unclassified	Bathymetric lidar returns on land unclassified by LSS
152	Bathy Lidar Unclassified	Bathymetric lidar returns on land classified by LSS as ground
157	Bathy Lidar Low Noise	Bathymetric lidar returns below the bathymetric surface determined to be noise
160	Bathy Lidar High Confidence Ignored	Bathymetric lidar points rejected by manual and automated routines from high confidence
161	Bathy Lidar Low Confidence Ignored	Bathymetric lidar points rejected by manual and automated routines from low confidence
168	Bathy Lidar High Noise	Bathymetric lidar returns above the bathymetric surface determined to be noise

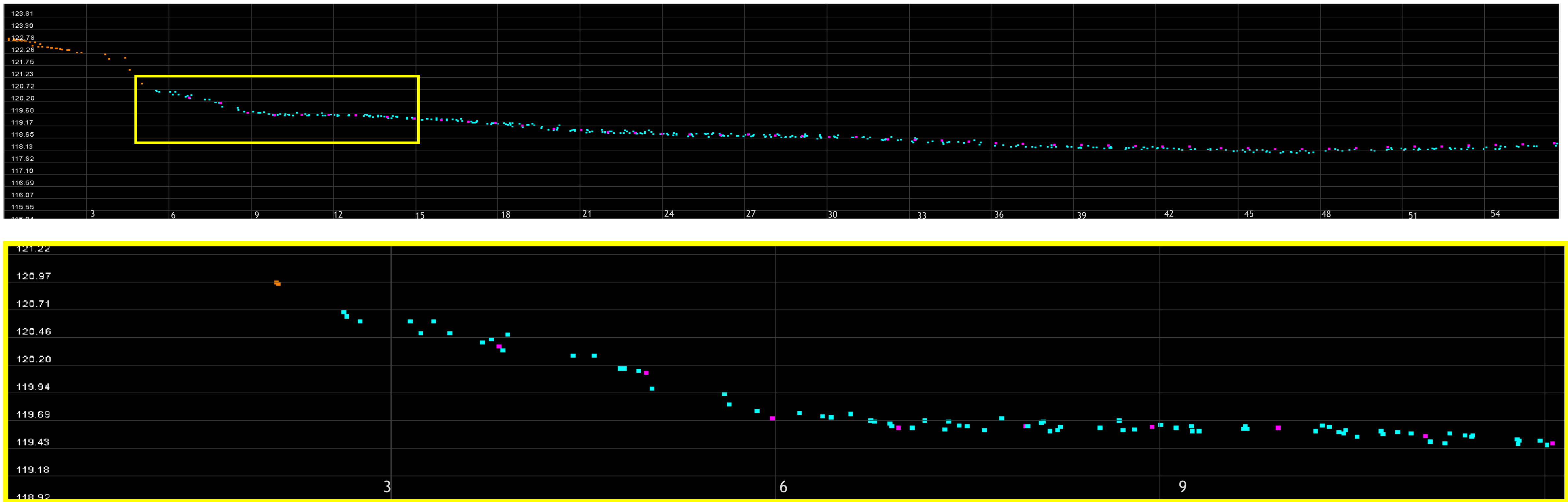
Appendix C Ground Survey Points

Project Information		Company Information		Coordinate System	
Project Title	Sacramento River TopoBathy	**Company**	Yurok Tribe	**Name:**	World wide/UTM
		Address		**Zone:**	10 North
Description:	Lidar and Imagery Ground Control	**City/State**	Klamath, CA	**Datum:**	NAD83(2011)
Modified:	10/24/2023 12:46:37 (UTC:-7)	**Postal Code**		**Units:**	Meter
Time zone:	Pacific Standard Time	**Country**	USA	**Global reference datum:**	NAD83(2011)
Comment 1:		**Phone**		**Global reference epoch:**	2010
Comment 2:		**Email**		**Geoid:**	GEOID18 (Conus)
File Name:	D:\Active_Projects\Sacramento_River_TopoBathy\C-Process\TBC\GroundControl\SacR-TopoBathy_GroundControl.vce				

Appendix D Representative Cross Sections



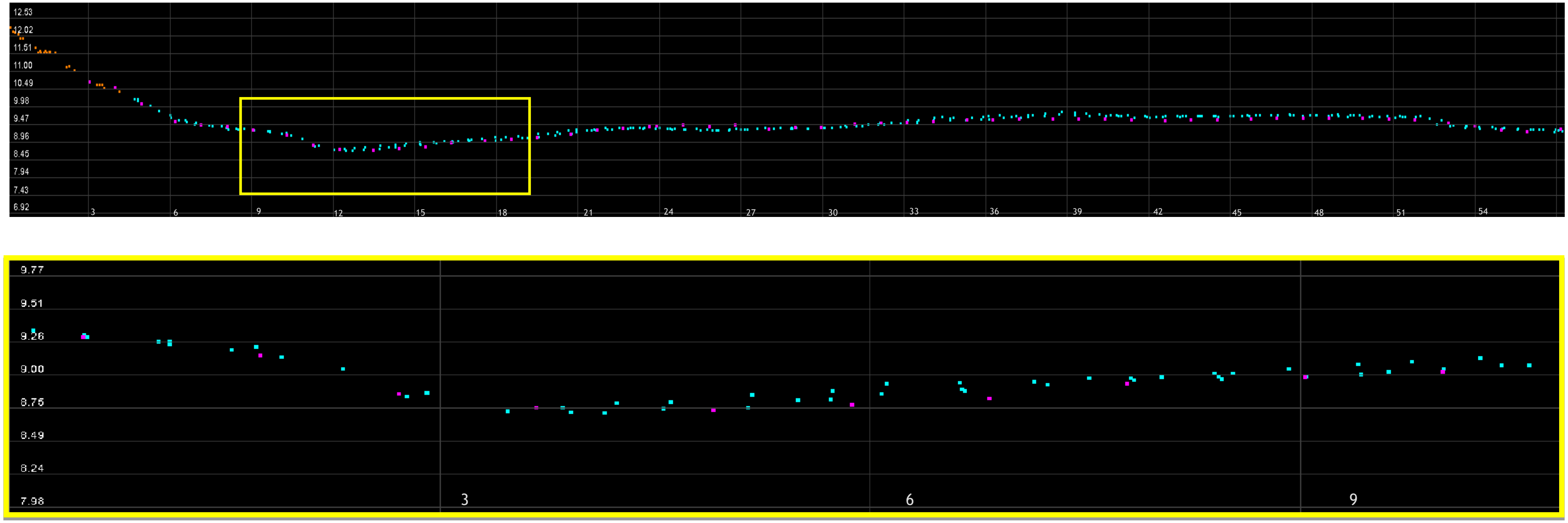
Upper Cross Section- RM 284



- Multi-Beam Sonar
- Bathymetric Lidar
- Ground

Middle Cross Section-RM 202

Lower Cross Section-RM 131



Multi-Beam Sonar

Bathymetric Lidar

Ground