November 19, 2019



Klamath River Sonar Integration with Topobathymetric LiDAR

Technical Data Report

David (DJ) Bandrowski, P.E.
Senior Project Engineer
Yurok Tribe Fisheries Department
PO Box 1027
Klamath, CA 95548

QSI Corvallis
1100 NE Circle Blvd, Suite 126
Corvallis, OR 97330
PH: 541-752-1204

TABLE OF CONTENTS

INTRODUCTION 3
Deliverable Products 5
PROCESSING 7
Sonar Integration 7
Integration Derived Products 10
Integrated Topobathymetric DEMs 10
RESULTS & DISCUSSION 11
Mapped Bathymetry and Integrated Coverage 11

Cover Photo: An aerial upstream view from the mouth of the Klamath River.

INTRODUCTION



This photo taken by QSI acquisition staff shows a view of the Klamath River just north of the Salmon River confluence.

In September of 2019, Quantum Spatial (QSI) was contracted by the Yurok Tribe to integrate sonar data collected on the Klamath River with previously collected topobathymetric Light Detection and Ranging (LiDAR) data. The LiDAR data was originally collected for the United States Geological Survey (USGS) between June 1, 2018 and June 14, 2018. Post LiDAR processing, sonar depth measurements acquired by GMA Hydrology, Inc. (GMA) under contract with Technical Services, Inc. (AECOM) within Iron Gate Reservoir, Copco Lake, and John C. Boyle Reservoir were incorporated into the LIDAR dataset by GMA. This allowed for complete mapping of the reservoirs however, gaps in bathymetric coverage still existed in the dataset. The Yurok tribe therefore contracted QSI to integrate additional sonar collected by the US Army Corps of Engineers to fill in areas not mapped via LIDAR. As stated by the Yurok Tribe, the goal of this final sonar integration is to have a pre-dam removal foundational data set that management and the scientific community will be able to utilize to better understand the effects of dam removal, to be able to more quantitatively measure geomorphic evolution, and to be better equipped to monitor the biological and physical response of a new free flowing Klamath River.

This report accompanies the final integrated LiDAR and Sonar dataset and documents integration processing methods and analysis of the final dataset including assessment of integration coverage. Acquisition dates and acreage are shown in Table 1, a complete list of contracted deliverables provided to the Yurok tribe is shown in Table 2, and the project extent is shown in . For full information on the LiDAR acquisition as well as the GMA sonar covering Iron Gate Reservoir, Copco Lake, and John C. Boyle Reservoir please refer to the Klamath River, California and Oregon Topobathymetric LiDAR and Imagery Technical Data Report.

Table 1: Acquisition dates, acreage, and data types collected on the Klamath River

Project Site	Contracted Acres	Buffered Acres	Acquisition Dates	Data Type
Klamath Reservoirs AOI	23,620	26,732	06/11/2018 – 6/13/2018 6/8/2018	Topobathymetric LiDAR 4 band (RGB-NIR) Digital Imagery
GMA Klamath Reservoirs AOI	8.15	N/A	2/8/2018 – 8/8/2018 5/9/2018 – 5/10/2018 5/29/2018 – 5/30/2018	Multibeam Sonar Sweep Sonar
Klamath River Corridor AOI	40,908	46,004	6/1/2018 – 6/8/2018 6/10/2018 – 6/14/2018 6/8/2018 – 6/23/2018	Topobathymetric LiDAR 4 band (RGB-NIR) Digital Imagery
Yurok Tribe/USACE Klamath River Corridor AOI	N/A	N/A	7/2018 – 9/2018	Single Beam Sonar MultiBeam Sonar

Deliverable Products

Table 2: Integration products delivered to the Yurok Tribe for the Klamath River site

Klamath River Integration Products Projections: UTM Zone 10N & California State Plane Zone 1 Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 Units: Meters	
Points	LAS v 1.4 • All Classified Integrated Returns
Rasters	1.0 meter *.imgs • Integrated Bare Earth Digital Elevation Model (DEM) voids interpolated • Integrated Bare Earth Digital Elevation Model (DEM) voids clipped
Vectors	Shapefiles (*.shp) • LiDAR Tile Index • DEM Tile Index • Integrated Bathymetric Coverage Shape • Coverage by Sensor used in DEM creation

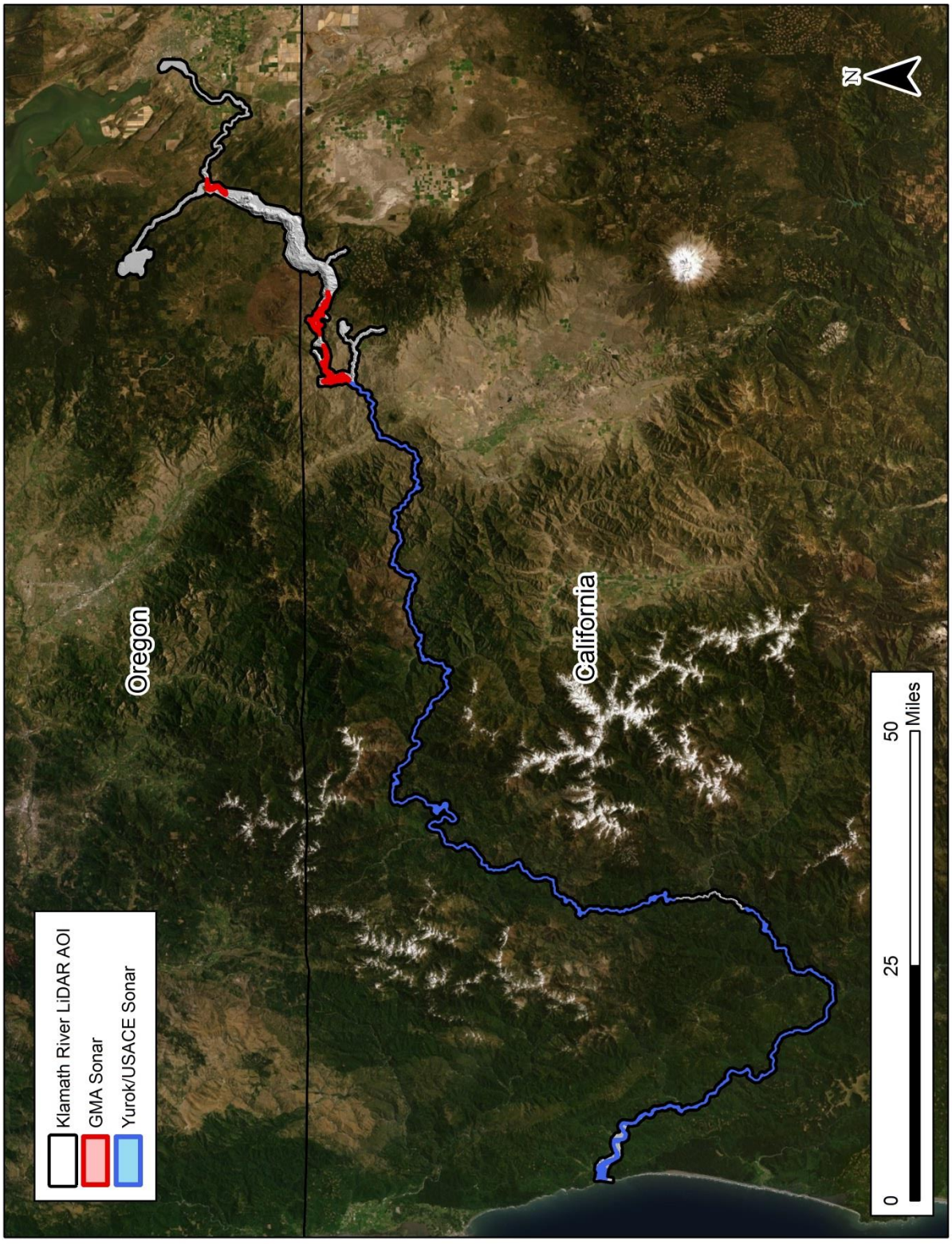
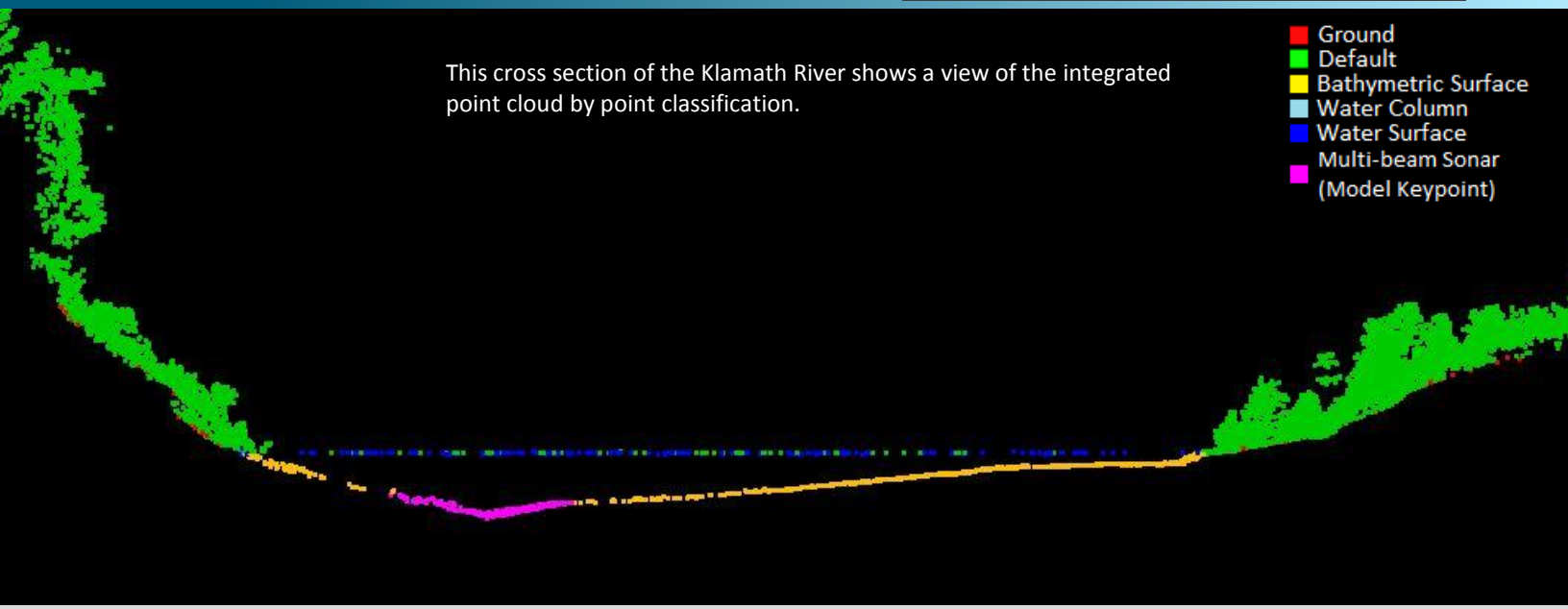


Figure 1: Location map of the Klamath River spanning Oregon and California



Sonar Integration

Upon receipt of the USACE data, QSI imported the sonar into the existing bathymetric LIDAR using Bentley Microstation and Terrasolid software. The single beam data was assigned a point source ID of 2, and the multibeam sonar were assigned a point source of 3 and 4 depending on reach. The previous sonar was assigned a point source ID of 1 and all sonar data has the user byte assigned to 2 in order to facilitate distinguishing the data source in future analysis.

The goal of the integration was to provide seamless, full bathymetric surface coverage; however, the temporal difference between acquisition timeframes must be considered during surface creation. LiDAR data for the Klamath River was collected June 1 – June 14 2018 while the Yurok/USACE Sonar collection occurred between July and September 2018. While the two datasets aligned nicely for a majority of the river, surface deviations between the two technologies was present in select locations due to variable environmental factors such as tidal sediments, water clarity, turbidity, and bottom surface reflectivity.

In order to provide the most seamless and manageable dataset, in areas where there was good LiDAR coverage the LiDAR data was used for the raster DEM creation. The sonar was utilized for DEM creation in all areas > 9 square meters where LiDAR coverage was lacking. The raster models were then inspected for any anomalies resulting from this approach. Manual editing of the point cloud was performed as necessary with the aim to remove or minimize artifacts to the surface due to temporal differences or data offsets. All sonar data remains in the dataset however are classified differently to distinguish the data used in seamless model creation. All sonar used in model creation was classed to class 8, while the sonar overlapping the LiDAR is classified as class 0. The previously collected sonar covering the Klamath River reservoirs is classified to classes 80 and 81. A shapefile indicating which

sensor technology was used for DEM creation and the associated acquisition timeframe has been provided as separate deliverable.

Table 3: ASPRS LAS classification standards applied to the Klamath River dataset

Classification Number	Classification Name	Classification Description
0	Not Classified	Sonar data collected by the Yurok Tribe/USACE excluded from model creation to create a seamless dataset
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and anthropogenic features
2	Ground	Laser returns that are determined to be ground using automated and manual cleaning algorithms
7	Noise	Laser returns that are often associated with birds, scattering from reflective surfaces, or artificial points below the ground surface
8	Model Key Points	Sonar data collected by the Yurok Tribe/USACE
9	Water	Laser returns that are determined to be water using automated and manual cleaning algorithms
20	Ignored Ground	Ground and Bathymetric classified points ignored for hydro-flattened model creation.
40	Bathymetric Bottom	Refracted Riegl sensor returns that are determined to be water using automated and manual cleaning algorithms.
41	Water Surface	Green laser returns that are determined to be water surface points using automated and manual cleaning algorithms.
45	Water Column	Refracted Riegl sensor returns that fall within the water's edge breakline which characterize the submerged topography.
80	Sonar Bathymetric Bottom	Sonar data collected by GMA (collected with a multi-transducer sonar sweep system)
81	Sonar Bathymetric Bottom	Sonar data collected by GMA (collected with a multibeam sonar system)

Table 4: LiDAR and Sonar Integration processing workflow

LiDAR Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and CORS GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	POSPac MMS v7.1 SP3
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.4) format. Convert data to orthometric elevations by applying a geoid correction.	RiProcess v1.8.2 TerraMatch v.16
Apply refraction correction to all subsurface returns.	RiProcess v1.8.2
Import raw laser points into manageable blocks to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.16
Using ground classified points per each flight line, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calculate calibrations on ground classified points from paired flight lines and apply results to all points in a flight line. Use every flight line for relative accuracy calibration.	TerraMatch v.16 RiProcess v1.8.2
Classify resulting data to ground and other client designated ASPRS classifications.	TerraScan v.16 TerraModeler v.16
Import all Sonar data into LiDAR point cloud with point classification 0.	TerraScan v.17 TerraModeler v.17
Classify sonar to class 8 in areas greater than 9m that were unmapped by the LiDAR system.	TerraScan v.17 TerraModeler v.17
Manually review the integration. Remove or minimize artifacts to the surface due either to temporal differences or noise in the data.	TerraScan v.17 TerraModeler v.17
Generate integrated bare earth models as triangulated surfaces. Export all surface models as .imgs at a 1m pixel resolution.	TerraScan v.17 TerraModeler v.17 ArcMap v. 10.2.2

Integration Derived Products

Because hydrographic laser scanners and multi beam sonar penetrate the water surface to map submerged topography, this affects how the data should be processed and presented in derived products from the integrated point cloud.

Integrated Topobathymetric DEMs

Bathymetric bottom returns can be limited by depth, water clarity, and bottom surface reflectivity. Water clarity and turbidity affects the depth penetration capability of the green wavelength LiDAR with returning laser energy diminishing by scattering throughout the water column. Additionally, the bottom surface must be reflective enough to return remaining laser energy back to the sensor at a detectable level. Likewise, the sonar collection is limited by obstructions within the river channel and proximity to the shoreline, due to safety procedures for crew and equipment. It is therefore not unexpected to have no bathymetric bottom returns in turbid, non-reflective, or obstructed or unsafe areas.

As a result, creating digital elevation models (DEMs) presents a challenge with respect to interpolation of areas with no returns. Traditionally DEMs are “unclipped”, meaning areas lacking ground returns are interpolated from neighboring ground returns (or breaklines in the case of hydro-flattening), with the assumption that the interpolation is close to reality. In bathymetric modeling, these assumptions are prone to error because a lack of bathymetric returns can indicate a change in elevation that the sensors can no longer map due to increased or decreased depths. The resulting void areas may suggest varying depths, rather than similar elevations from neighboring bathymetric bottom returns. QSI created a final water polygon with bathymetric coverage to delineate areas with successfully mapped bathymetry from LiDAR and Sonar integration. This shapefile was used to control the extent of the delivered clipped topobathymetric model to avoid false triangulation (interpolation from TIN’ing) across areas in the water with no mapped bathymetry.

Mapped Bathymetry and Integrated Coverage

For the Klamath River project, high resolution topobathymetric LiDAR data collection was coupled with sonar data collection in order to maximize the detail and coverage of bathymetric mapping. These complimentary technologies provide the ideal method for mapping the Klamath River, due to the ability of the LiDAR sensor to map near-shore shallow depths where sonar collection may be deemed unsafe. Likewise, in known deep areas such as the 3 reservoirs or turbid areas of the river channel, the sonar system allows for continuous coverage throughout the breadth of the river. However, due to environmental factors of the Klamath River including depth, turbidity, and conditions for safe sonar collection, some remaining areas lacking bathymetric bottom returns are to be expected.

QSI created a bathymetric coverage and void polygon following data integration, in order to clip DEMs to avoid false interpolation, and also to assess overall mapped percentage of the Klamath River. The void polygon was created by triangulating LiDAR and Sonar bathymetric bottom points with an edge length maximum of 4.56 meters. This ensured all areas of no returns > 9 m^2, were identified as data voids, and all areas with returns were identified as covered areas. In total, approximately 73.75% of the river was successfully mapped. Of the remaining unmapped areas approximately 75% is located above John C. Boyle Reservoir, a section of the river not targeted for sonar data collection (Figure 2**)**.

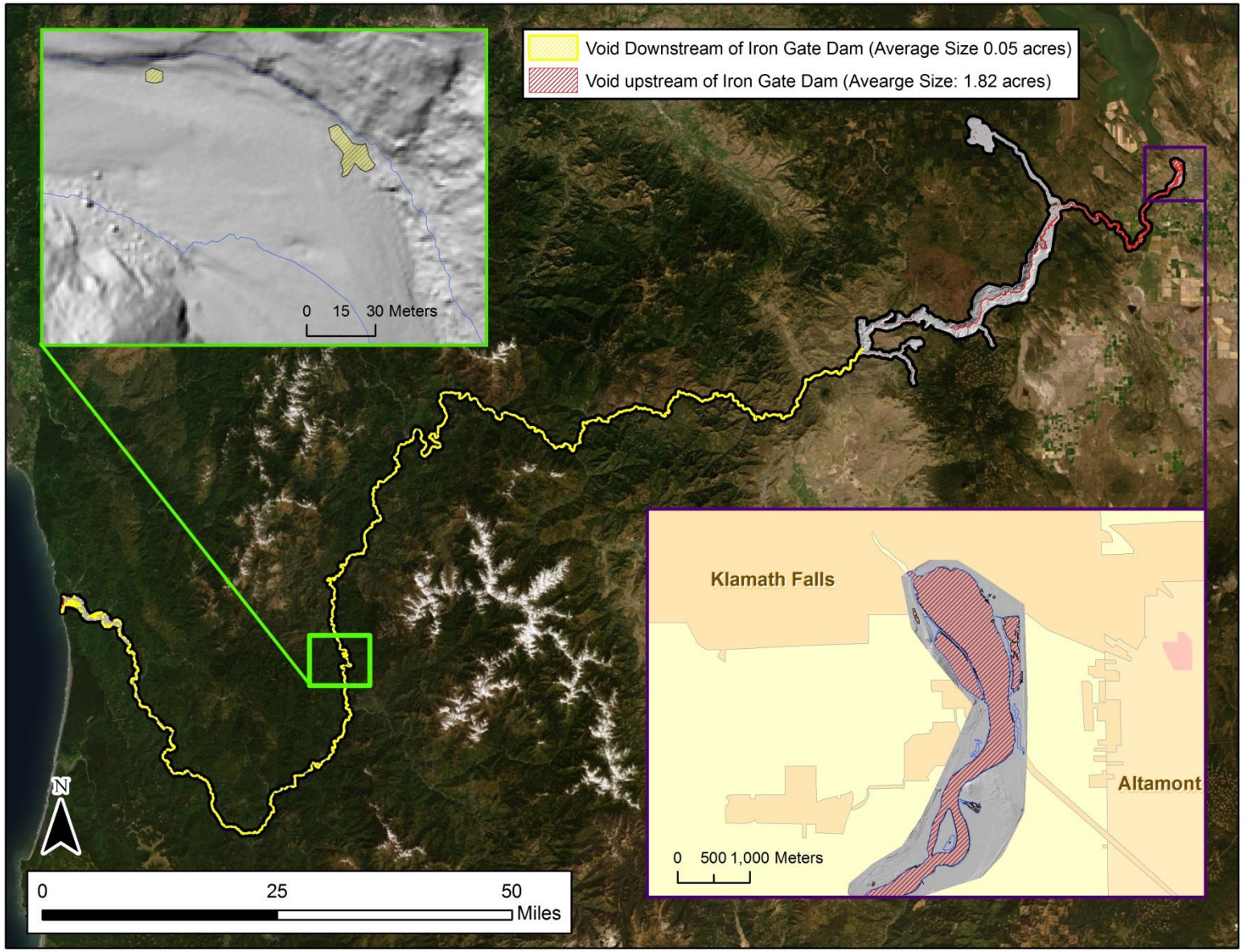


Figure 2: A map showing that of the ~25% of unmapped areas along the river, 75% of voids are located above Iron Gate Dam

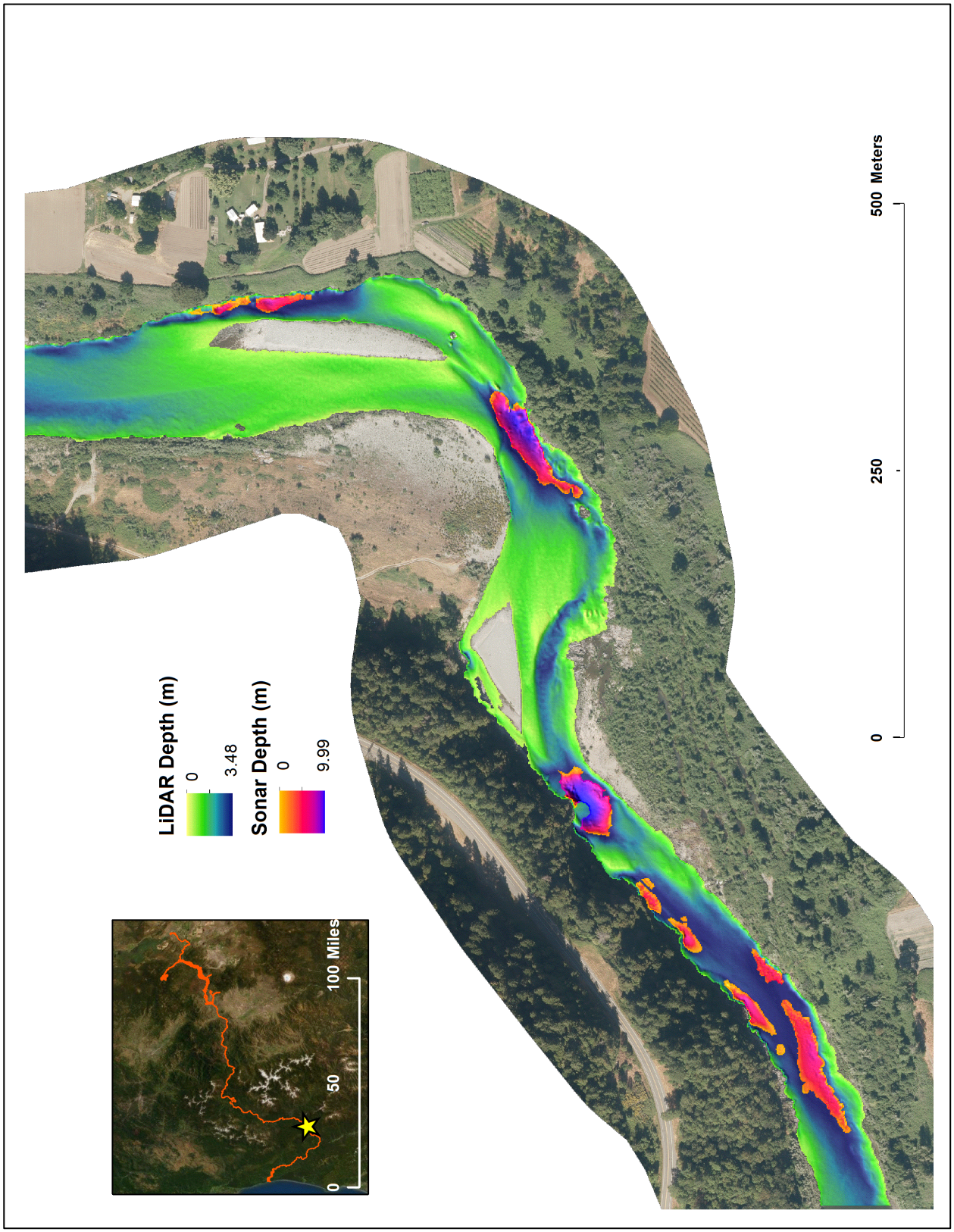


Figure 3: This image displays several of the many locations where sonar was utilized to map deep pools beyond the penetration capabilities of the bathymetric LiDAR.