Overview

In the fall of 2017, the US Geological Survey (USGS) contracted Quantum Spatial, Inc. (QSI) to collect and process topo-bathymetric LiDAR, natural color imagery, and hyperspectral imagery for a 54-mile stretch of the Kootenai River in northern Idaho. A complex endeavor with extraordinary requirements and involving extensive collaboration, ingenuity and innovation, the project contributed significantly to our local understanding of the Kootenai River while simultaneously evaluating the large-scale commercial value of new techniques for mapping inland bathymetry.

Remote sensing is a rapidly evolving industry. The US Geological Survey (USGS) is continually active in evaluating new methodologies, sensors, and approaches to model terrain and to design base specifications and guidelines for data collection for national elevation programs such as 3DEP, the National Elevation Database (NED) and Coastal National Elevation Database (CoNED). Modeling the bathymetry of rivers is particularly challenging and requires unique technologies to model submerged terrain with the same accuracy and resolution as can be achieved for terrestrial landscapes. Historically, boat-mounted sonar surveys have provided inland bathymetry data, but this technology is fraught with shortcomings for shallow waters. New technologies such as topo-bathymetric LiDAR combined with hyperspectral imagery present an opportunity to analyze and model inland shallow water floodplains and riverine environments like never before, providing valuable new insights into water resource management and aquatic habitats. Although QSI has been perfecting this technology for shallow river systems since 2012, the USGS set out to officially evaluate it using the newest bathymetric sensors before embracing the technology for national mapping programs.

USGS’s Inland Bathymetry Research Project (IBRP) has been instrumental in this evaluation phase, focusing on a diversity of pilot rivers to test topo-bathymetric LiDAR’s ability to characterize fluvial patterns and processes and identify optimal conditions and standardized collection and processing techniques. With research and restoration activities already underway, the Kootenai River in northern Idaho was identified as a perfect pilot IBRP site for evaluating these questions. The Kootenai River flows from its headwaters through a rugged region of southwestern Canada, winding through Montana and Idaho, before meeting the Columbia River 500 miles later. The watershed drains an area of 19,000 sq mi and spans six different biomes. It supports a rich variety of flora and fauna and is a primary source of drinking water and agricultural irrigation along its course. Given this diverse reliance on the Kootenai by fish, wildlife and humans alike, it has become a hotbed of research on fluvial processes, species protection, habitat enhancement, restoration, and flood dynamics for a collection of scientists, environmental groups, tribes, and local communities.

Complexity & Innovation

With three technologies involved – LiDAR for bathymetric data, co-acquired natural color imagery for ancillary information, and hyperspectral imagery for depth and flow modeling - the Kootenai River project required great operational ingenuity on the part of QSI’s flight team to pull off. This complex combination of technology included QSI’s Riegl VQ-880-G topo-bathymetric LiDAR sensor with
an integrated 29MPixel Prosilica GT6600 digital camera, and an ITRES CASI 1500H hyperspectral imagery sensor provided by USGS. The project was among the first riverine areas of interest to test the then new 1.5 Secchi Depth Riegl VQ-880-G system settings and performance for modeling Pacific Northwest rivers. The LiDAR sensor was set to collect data at QL1 pulse density of 8 pulses/m2 for topographic surfaces, and at least 2 pulses/m2 for bathymetric surfaces; the natural color imagery was co-acquired with the LiDAR at 10 cm GSD; and the hyperspectral imagery was collected at 50 cm pixel resolution. Collecting three disparate types of data in the same time frame and deployment required outfitting and installing the hyperspectral sensor with the topo-bathy LiDAR (and camera) sensor into a single two-hole aircraft. This was accomplished through skilled technical craftsmanship by experienced QSI sensor engineers and acquisition managers with an advanced understanding of geometry and sensor mechanics. Flight plans were evaluated and optimized for flight time given the particular altitude, field of view, and swath width required to meet contract specifications for terrain resolution. Utilizing one aircraft for a single deployment to the study area increased efficiency in collecting all data in the same time frame while also significantly reducing costs.

The Kootenai project also involved close collaboration among USGS scientists, University of Wyoming (UW) fluvial geomorphologists, River Design Group (RDG) restoration engineers, and QSI’s team of project managers, acquisition managers, flight team, ground crew, and LiDAR technical experts. With a short 7-day allowed acquisition window of September 24-29, coordinating and collecting all ground and airborne data among multiple partners in the proper order while also working within the confines of weather was no small feat. To help understand drift patterns and larval fish dispersal, the hyperspectral imagery had to be collected during a specific window after special release of a red tracer dye into the river. However, given concerns the dye would impact water clarity, the LiDAR had to be collected first. All ground operations – measurements for turbidity (USGS and QSI); setting hyperspectral targets for ground control (QSI); release of the dye (UW); setting LiDAR terrestrial and submerged QA points and waveform targets (USGS & QSI); and collecting verification depth profile and cross section data (USGS) - had to be carefully timed and orchestrated with respect to each other and to the airborne flights. Finally, RDG, a river restoration architect-engineering firm, was in the midst of a channel bed dredging operation upstream of the Kootenai project site. To curtail any impact on turbidity from sediment disturbance, they agreed to halt all operations for a 48-hour period before and during the LiDAR collection. With ideal river conditions in the forecast, a hold on sediment dredging, and a multi-agency ground team at the ready, the QSI acquisition team set to work quickly and collected over 20,000 acres of topo-bathymetric LiDAR data and orthoimagery within a two-day window (25-26 Sept), then 12,851 acres of hyperspectral imagery precisely two days later (28 Sept).

Once the data were collected, QSI and ITRES analysts set to process the LiDAR and orthoimagery in parallel on a tight schedule for delivery by mid-December. With three different but interdependent workflows involving multiple subtasks and coordination among two firms, keeping the post-processing workflow efficiently coordinated and on schedule was challenging. QSI processed all LiDAR data and natural orthoimagery, but to match office expertise with respective datasets, these were carried out in two different offices (LiDAR in Corvallis, OR; imagery in Lexington, KY). Given their co-acquisition, these two datasets shared commonalities including flight and survey control parameters which factored into preliminary calibration and had to be communicated within and among teams for consistent treatment of the data. Moreover, the LiDAR-derived digital elevation model (DEM) produced by the Corvallis office enabled orthorectification of the natural color imagery by Lexington analysts. With many
subtasks involved in topo-bathymetric LiDAR processing, including correction for light refraction through water, an evaluation of the impact of water clarity and surface reflectivity on results, and treatment of the waveform data, the LiDAR processing was quite involved. And finally, ITRES ran preliminary processing and quality control on the hyperspectral data, worked with the LiDAR-derived DEM provided by QSI for the orthorectification step and using their proprietary geometric correction software, and then passed the imagery to QSI for final processing and quality assessment.

All data were expected to meet requirements for data quality, resolution, accuracy and deliverables set forth in USGS’s LiDAR Base Specifications v1.3 and the National Ocean and Atmospheric Administration (NOAA)’s bathymetric modeling standards. This was also a requirement for meeting predictive model input requirements (see below). Achieved LiDAR resolution was 11.29 points/m² for bathymetric surfaces mapped, and 8 points/m² for combined topographic surfaces (for entire area of interest). The LiDAR elevation data was accurate to within 5.6 cm of true ground (Accuracy at 95% confidence interval), exceeding USGS vertical accuracy requirement for non-vegetated vertical accuracy (NVA) of 18 cm or less. These values were also corroborated by independent assessments from USGS-collected field data. Water clarity at the time of collection resulted in depth penetration of up to 3.1 meters (~10 ft). These results collectively attested to the capacity for topo-bathymetric LiDAR to accurately model inland bathymetry.

Finally, to evaluate the full value of topo-bathymetric LiDAR in extracting useful information for river channel bathymetry, QSI processed the full waveform data from the topo-bathymetric sensor and delivered to USGS along with raw discrete return swath files. Using the Kootenai dataset, our innovative research and development staff worked closely with Riegl to improve upon the information that can be extracted from the full waveform data. Inland bathy point targets were placed on the river bottom to test automated target identification. Preliminary results indicate that better signal processing of the waveform is possible, where meaningful returns are better filtered from noise, represent deeper targets, and maintain higher fidelity to the inherent information present in the data. As Riegl incorporates these results into their RiProcess software, we expect to see improved automated processing of bathymetric LiDAR.

Future Value

The Kootenai River project has led to several societal and economic benefits on both a local and global scale. Results from the study have furthered our understanding of river ecology for the Kootenai River and similar systems while also advancing our understanding of topo-bathymetric LiDAR base specifications and requirements for widespread commercial use.

Local natural resource and planning managers of the Kootenai River watershed have gained a valuable understanding of flood risk and management strategies, as well as erosion and sedimentation patterns. High-resolution flood maps from bathymetric data are invaluable in improving our understanding of the impact of floods, flood risk, and inundation patterns to improve community preparedness and resiliency for the Kootenai River watershed, a USGS Water Mission Area priority area under the Flood Inundation Mapping Program. For dammed rivers such as the Kootenai, a better understanding of sedimentation; instream and dam-related sediment movement patterns; erosion; slope failure; geophysical impacts on water quality and fish habitat; and stream bed evolution each have important societal benefits.

Improved understanding of fish habitat and local ecology contributed to the Kootenai River Habitat Restoration Program and other ongoing fisheries research studies in the region. The LiDAR and hyperspectral data from this project have also provided invaluable information and insight into the ecology of the Kootenai River, including aspects of flow dynamics, connectivity, and channel characteristics that define habitats for recreational, threatened and endangered fish species (sturgeon, burbot). The surface models from this study will enable modeling and imaging of geomorphology, substrates, and river bed evolution patterns critical to restoration.
planning. Moreover, the hyperspectral imagery and dye dispersion patterns reveal drift and flow dynamics helpful in understanding thermal dynamics, tracking pollutants, tracing nutrient drift patterns, and following the passive migration of larval fish. Armed with new data, biologists and natural resource managers have gained insight into the speed and distribution of fish as they move downstream to Kootenay Lake in British Columbia. And, with a new understanding of the river’s geomorphology, fisheries biologists and restoration professionals can now make more targeted efforts toward helping restore in-stream habitat for fish.

“The data will support our existing habitat restoration projects and could be useful for future restoration project design, implementation and biological assessment work.” — Susan Ireland, Fish and Wildlife Department Director, Kootenai Tribe

For the Kootenai and other river systems, access to better data also contributes to better predictive modeling of natural processes. The data from this study have contributed accurate channel-geometry data as input to flow, sediment transport, and river-bed evolution models developed by the USGS (e.g., iRIC modeling system), US Army Corps of Engineers (e.g., HEC-RAS) and US Bureau of Reclamation (e.g., 2RH-2D).

The Kootenai River project has contributed in significant ways to the geospatial field, as the larger lessons learned from the project have greatly redefined the marketplace for LiDAR mapping. It has led by example in presenting the capacity for topo-bathymetric LiDAR to ‘fill in the gaps’ in topographic modeling for underwater landscapes. By contributing to USGS’s Inland Bathymetry Research Project, the Kootenai River project has fed valuable information into the 3D Nation Requirements and Benefits Study, led by USGS and NOAA. 3D Nation aims to unify all national elevation efforts and provide a consistent set of standards and guidelines across geographies and land forms. The initiative also aims to evaluate and integrate the technology, systems, data, and services for coastal (e.g., CoNED - Coastal National Elevation Database) and inland bathymetry elevation mapping with that for the well-established terrestrial 3D Elevation Program (3DEP). The Kootenai River project has been instrumental in providing the first official insight on inland riverine bathymetric mapping requirements and solutions. As exemplified by the success of the project, the USGS has determined that when collected under optimal water clarity, topo-bathymetric LiDAR can be a cost-effective and more accurate method for surveying large areas when compared to traditional modeling with cross sections.

USGS has a proven, long term relationship with the private sector to support national mapping programs that it manages, such as 3DEP. We are one of a select number of Geospatial Products and Services (GPSC3) contractors who serve USGS geospatial programs. The success and lessons learned from the Kootenai River pilot project by a private sector geospatial contractor such as QSI has and will continue to lead to additional follow-on topo-bathymetric LiDAR projects. Given the vast number of river miles in the US, the geospatial profession should expect to see a significant investment of funds to collect topo-bathymetric LiDAR in the coming decade, providing opportunities for the continued growth and advancement of the LiDAR geospatial profession. For Quantum Spatial, current USGS follow-on projects that have spawned from Kootenai’s success and lessons learned include topo-bathymetric LiDAR collection contracts on the Klamath River in northern California and the Niobrara River in Wyoming, but this is only the beginning. The Kootenai project has aided greatly in informing the base specifications and collection criteria for these new sites of interest.

Client Satisfaction

Despite its complexity, unique requirements, and challenges, QSI delivered all products for the Kootenai River project on time (December 19, 2017). All data deliverables were accepted after USGS evaluation and validation without the need for re-work by QSI, then disseminated to local stakeholder groups to inform their efforts. In the Task Order Evaluation, QSI received a qualitative rating of Excellent, and highest marks (10 out of 10) for overall data quality and timeliness. As Jeff Danielson, Inland Bathymetry Research Project lead and CoNED Applications Project Chief, remarked after evaluating the data: “The Kootenai River topo-bathy LiDAR provided almost complete bank-to-bank coverage of braided and shallow bathymetry areas at a high-spatial density that will help fill critical data gaps in 2D and 3D hydrological modeling applications.”

Category A: Airborne and Satellite Data Acquisition, Kootenai River Project