Proposal Title: Field evaluation of an innovative bathymetric lidar for high-resolution measurement of shallow submerged channel bed topography

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PI Location and Study Location: PI: U.S. Geological Survey Geomorphology and Sediment Transport Laboratory, Golden, CO. Study: rivers located in Colorado, Arizona, and Nebraska.

Introduction:

The Federal Interagency Sedimentation Project (FISP) interreacts with various partners to develop and advance methods of accurately quantifying sediment characteristics and transport in surface waters. One of the sediment characteristics identified as a FISP focus area is bed topography and yet relatively little research effort has been directed toward this important channel attribute. High-resolution measurements of bed topography are increasingly used to support scientific investigations and resource monitoring because such data afford numerous advantages for geomorphic change detection, physical habitat characterization, and numerical modeling of flow and sediment transport. Despite advances in methods for acquiring detailed topographic data in terrestrial (e.g. SFM photogrammetry, terrestrial laser scanning) and subaqueous (e.g. multibeam sonar) environments, shallow submerged areas persist as a critical gap in our ability to measure bed topography. The goal of this study is to advance the development of a bathymetric lidar system with an unprecedented depth resolution on the order of 1 cm. This system will benefit the FISP mission and various resource management applications by providing: 1) bed topography essential for hydrodynamic modeling of river flow, sediment transport, and morphologic evolution, as well as habitat assessment; 2) information on channel cross-sectional area that would complement non-contact measurements of water surface velocity from thermal videography and thus enable a new stream-gaging methodology based entirely on remotely sensed data; and 3) a means of tracking bedforms to estimate sediment transport rates and construct sediment budgets.

Background:

Bathymetric lidar systems are capable of recording distances to both the water surface and the bed, yielding both terrestrial and submerged elevations in addition to information on water depth. Existing bathymetric lidars, however, fail to provide reliable depths and bed elevations in shallow water due to the difficulty of distinguishing between laser returns from the water surface and bed when the two surfaces are in close proximity. To overcome this 'signal separation' issue, researchers at the University of Colorado (CU) and Atmospheric & Space Technology Research Associates Lidar Technologies (ASTRALiTe) have developed an innovative bathymetric lidar based on an alternative signal processing technique known as INtrapulse Phase Modification Induced by Scattering, or INPHAMIS. Measurements collected in flumes both at the USGS GSTL in Golden, CO (Fig. 1) and the U.S. Army Corps of Engineers laboratory in Vicksburg, MS indicate that the ASTRALite lidar system can map bathymetry and resolve subtle variations in depth, as small as 1 cm. These experiments successfully demonstrated the INPHAMIS approach and indicate considerable potential for mapping shallow waters and detecting submerged objects. Building upon these laboratory experiments, ASTRALite and GSTL deployed the lidar system from a bridge over the South Platte River near Littleton, CO (Fig. 2) with encouraging results. More recently, ASTRALite has developed a topo-bathymetric system (Fig. 3) that can be deployed from an Unmanned Aerial Vehicle (UAV). ASTRALite and GSTL plan field testing of that instrument at the confluence of the Colorado and Blue Rivers in October of 2018.

Purpose and Scope:

We propose to continue our work with ASTRALite by conducting extensive field tests in a range of riverine environments to assess the potential of this new lidar to facilitate various applications relevant to the FISP and the broader scientific community. Because the performance of lidar systems is influenced by the optical properties of the water, our field tests will also examine the effects of turbidity, aeration, and water surface roughness. Because our GSTL/GCMRC research team is involved in numerous ongoing research and monitoring activities, has a wide range of established field sites, and possesses the necessary surveying and water/sediment sampling instrumentation, we are well prepared to explore, in a scientifically rigorous manner, the capabilities and limitations of the new ASTRALiTe lidar for terrestrial/shallow bathymetric mapping. The proposed research represents an important step toward transitioning this sensor to operational use in support of the FISP mission.

Technical Requirements:

We will perform field tests to: a) compare lidar-derived bathymetry with *in situ* measurements acquired by wading surveys and/or single- or multi-beam sonars for various water depths, ranges (distance between instrument and water), flow speeds, and turbidities over both static and mobile beds; b) compare lidar-derived topography with equivalent data from terrestrial ground-based lidar; c) quantify uncertainties and errors introduced by turbidity, aeration, and water surface roughness; and d) develop guidelines for deploying the new lidar system in the field and analyzing the resulting data. Our primary objective is to define the range of conditions under which the number and quality of lidar returns are sufficient to enable accurate, high resolution measurement of river bed topography. FISP funds will be used to support ASTRALiTe engineers for travel to field sites and data analysis.

Deliverables:

1) Comparison of the ASTRALiTe lidar terrestrial and bathymetric measurements with those from conventional surveying methods (wading, sonar, terrestrial laser scanning).
2) Quantitative characterization of relevant water column optical properties: absorption, attenuation, and scattering coefficients; turbidity; and concentrations of chlorophyll and CDOM. Surface water velocities and bed composition will also be recorded at each site.
3) Documentation of guidelines for deployment and analysis guidelines based on these data sets.

Timeline:

Months 1-3: Evaluation of topo/bathy data to be collected at the Colorado and Blue River confluence in October 2018. Months 4-6: Assessment of bathymetric surveying performance in streams with a range of turbidity and water surface roughness with bridge (Gunnison River, CO) and UAV (Niobrara River, NE) deployments. Months 7-9: Test lidar against single and multibeam sonar across a wide range of water depths under clear water, static bed conditions (boat deployment on Colorado River in Glen Canyon, AZ). Months 10-12: Summarize field testing, formulate deployment/analysis guidelines, and present results at 2019 Fall AGU Meeting or another relevant scientific conference.

Budget:

This proposal requests support from the FISP to build upon the Colorado/Blue River confluence test already planned for October 2018 by performing three additional field evaluations of the new ASTRALiTe lidar system: Gunnison, Niobrara, and Colorado River in Glen Canyon. GSTL and

GCMRC will contribute ground-truth measurements using existing USGS project funds. The cost of the three additional field tests is expected to total approximately $30,000. GSTL and GCMRC will make an in-kind contribution of travel costs for our staff to obtain ground-truth measurements using existing USGS project funds and equipment. The Niobrara River field test will coincide with a planned 185 km topo-bathymetric lidar acquisition, funded by the USGS National Geospatial Program (NGP), using a manned aircraft to deploy the Riegl VQ-880 topo/bathymetric lidar, which features a penetration of 1.5 Secchi depths. Field measurements collected for the NGP acquisition will be leveraged to provide comparison data for the ASTRALiTe UAV lidar system, which has an anticipated penetration of 2 Secchi depths. The topo/bathymetric mapping capabilities of the two lidar instruments will also be compared and evaluated.

Unique Qualifications:

The USGS performs essential monitoring and important research in shallow water environments nationwide. Support from the FISP is needed to facilitate development of a novel surveying technology and aid in transitioning the ASTRALiTe lidar sensor into a well-tested, field-ready system that can expand the scope and improve the quality of terrestrial and shallow-water bathymetric mapping. ASTRALiTe is a small business and does not have the resources required to perform rigorous field tests. Similarly, current USGS resources do not support development of original technology comparable to that resulting from private sector innovation. Funds from the FISP will be used to support development and testing of this new lidar technology by leveraging the expertise, planned field campaigns, and equipment resources of two USGS research centers, both focused on river geomorphology.

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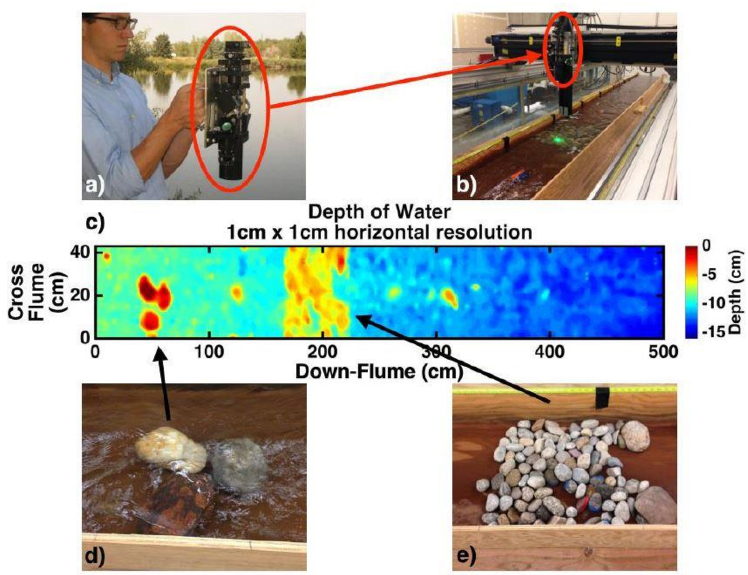

Figure 1. The handheld ASTRALiTe lidar system (a) was mounted to a scanning mechanism (b) over a flume at the USGS GSTL. This mechanism allowed the lidar system to translate up and down the flume to produce a map of water depth (c). Water depths from 0 to 14 cm were measured and verified using a ruler. Features such as individual cobbles (d) and gravel clusters (e) are evident in the depth map. This

experiment demonstrated the ability of the lidar to resolve shallow depths and detect underwater objects under turbulent flow conditions.

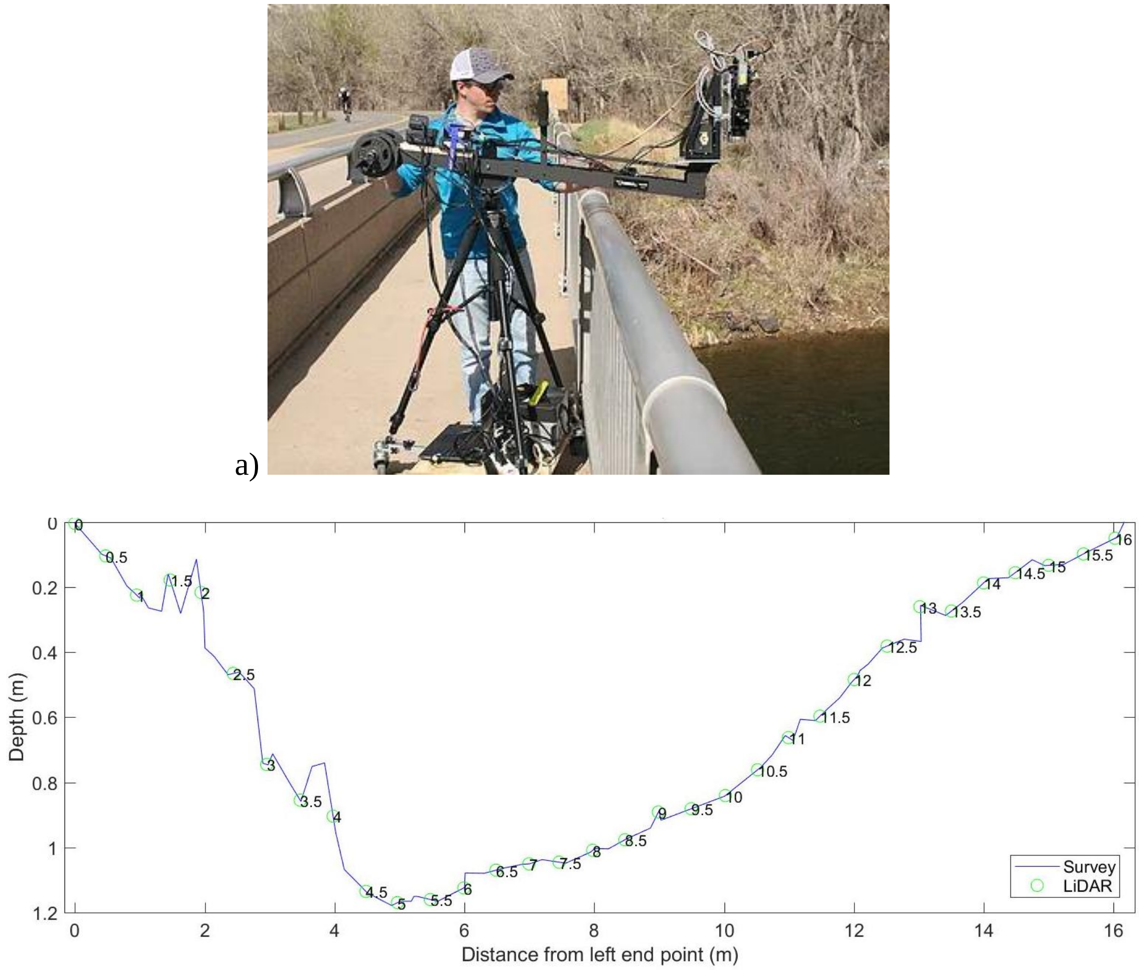

Figure 2. (a) The ASTRALiTe lidar system was mounted on a crane deployed from a bridge over the South Platte River. (b) Comparison of depths measured by the ASTRALiTe lidar and with a conventional survey. This experiment verified depth penetration and accuracy up to 1.2 m.

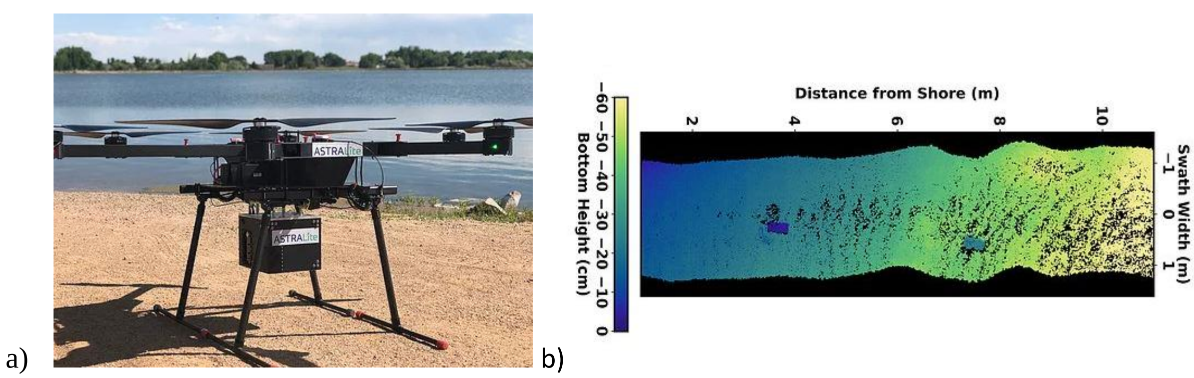

Figure 3. (a) The UAV-based ASTRALiTe Lidar system. (b) 3-D bed elevation point cloud generated from a single pass of the UAV. https://www.astralite.net/uav-lidar