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Laboratory and Field Application of River Depth Estimation Techniques Using Remotely Sensed Data: Annual Report Year 2

Jonathan M. Nelson
US Geological Survey National Research Program
Geomorphology and Sediment Transport Laboratory
4620 Technology Drive, Suite 400
Golden, CO 80403
phone: (303) 278-7957 fax: (303) 279-4165 email: jmn@usgs.gov

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LONG-TERM GOALS

Our long term goal in this and related projects is to maximize the amount of information regarding river flow and morphology that can be deduced from remotely sensed information. In this specific project, our goal is to test and improve the river bathymetry prediction methods developed in previous ONR-funded work. This goal involves further development on computational methods as well as exploration and refinement of methods for remotely measuring water-surface elevations and water-surface velocities. In previous work, we have been able to demonstrate that inversion of the momentum equations and morphodynamics modeling can be used to detect errors and fill gaps in various remotely sensed river bathymetry data sets (i.e., such as those measured using bathymetric LiDAR and various optical correlation techniques using multi- and hyperspectral scanning, as reported in Wright and Brock (2002), Kinzel et al., (2007), Legleiter and Roberts (2005), and Legleiter et al., (2004)). In the current project, we are looking at this problem in a more expansive sense by testing measurement techniques and computational approaches that can be used in the absence of any bathymetric estimate, as would typically be the case in rivers with high suspended sediment loads and/or deep depths, which limit optical techniques. Eventually, we envision that these two different techniques can be rejoined in a manner that is accurate, efficient and capable of providing meaningful error estimates for predicted morphology.

OBJECTIVES

The specific objectives for the second year of this two-year effort were to (1) test and refine our methods for measuring detailed water-surface elevations and velocities in rivers, and (2) to develop and test a new laboratory setup for collecting detailed measuring water-surface elevation and water-surface velocities in flumes with a variety of bed configurations. The first area of endeavor was aimed at developing real world methods for collecting data required for computing bathymetry from surface information, and the second was aimed at collecting ideal (or nearly so) data sets in the lab to test bathymetric inversion techniques over a wider range of conditions than we could reasonably do in the field. As noted in our original proposal, we expected to investigate two methods for water-surface elevation measurements, one for smaller scale systems (laser-scanning) and one for larger systems (the AirSWOT methodology, see Rodriguez, 2010). However, the AirSWOT experiment planned for the

Sacramento River has been repeatedly delayed, and is still not completed as of this writing (we still hope it will occur and we will participate). Thus, while the first year of this effort was aimed at improving the computational techniques of the inversion method and obtaining/testing both laser-scanning and infrared videography equipment, the second has been directed at improving our field capabilities for measuring water-surface information and developing a new laboratory setup for collecting detailed test data sets for inversion computations. For water-surface velocity measurements in the field and lab, we use the infrared videography methodology developed by others (e.g., Dugan and Piotrowski, 2003; Dugan et al, 2013; Kinzel et al., 2011). For water-surface elevations, we have used laser-scanner methods in the field and lab, as well as newly-developed acoustic techniques in the lab, as described below.

APPROACH

In our last round of ONR research effort, we developed a simple method for estimating depth based on water-surface elevation and water-surface (or vertically averaged) velocity. This was described in our 2013 yearly report and in Nelson et al. (2012). To test that approach, we began by applying it to idealized velocity and elevation fields developed from a quasi-three-dimensional flow model (FaSTMECH, Nelson and McDonald, 1996; Nelson, Bennett and Wiele, 2003; McDonald et al, 2006, Nelson et al., in press) available in the International River Interface Cooperative (iRIC; www.i-ric.org) river modeling package developed by our group and others. This method was applied for two field sites, one on the Trinity River and another on the Kootenai. We also explored the effect of measurement errors on the predictions of bathymetry. The method was shown to work well except in the area of strong lateral friction (fixed in a new version through iterative inclusion of these effects) and in areas of nonhydrostatic flow effects (an inherent limitation in our approach). With this proof-of-concept in place, we have concentrated on making measurements required to test the approach, including both lab and field components. This was started toward the end of the first year of the current grant (we obtained the infrared camera near the end of the first reporting period), and has continued throughout the second year. Thus, our overall approach has been to develop a new method for inverting the momentum equations to relate local bathymetry to local water-surface elevation and velocity, and develop techniques to measure the requisite information in order to test the approach in both the field and laboratory.

WORK COMPLETED

Based on research efforts over the first 9 months of the second year of our ONR grant, the following tasks are complete:

1) We negotiated and signed an agreement for free use of the proprietary code Typhoon (Derian, 2012) for research. Following testing over the last two years, we concluded that this code appeared to give the best results for developing velocity fields from mid-wavelength infrared videography in the lab and field. The advantage of this code over more standard PIV methods is related to a more flexible treatment of interrogation windows. Due to the wide variation of structure sizes in turbulent flow in rivers, use of a single, initial interrogation is undesirable for optimal results and the Typhoon algorithm yields better results.

2) We used up-looking submerged acoustic sensors manufactured by SeaTek to measure spatially distributed water-surface elevations over various obstacles in one of the laboratory flumes at the USGS Geomorphology and Sediment Transport Laboratory. These sensors were originally

developed and used for three-dimensional bedform experiments. This original use deployed the sensors over a fairly large area to measure the water-surface elevation fields over dunes. For our experiments, we required much closer spacing, so we developed a gating technique to avoid cross-talk between sensors. We deployed this array in the flume and measured water-surface elevations over various bed morphologies. While successful in detecting the water surface at sub millimeter accuracy, the up-looking approach created some significant issues (because the sensors are in the flow and have an effect on the water-surface elevation and velocity). In addition, the number of sensors we owned was insufficient to give the desired spatial resolution.

3) To deal with the issues found in (2) and described in the section below on results, we worked with a developer of ultrasonic sensors to procure 50 ultrasonic sensors that could be placed above the water surface. In collaboration with the manufacturer, we developed a technique that sampled over the sensors in three spatial patterns designed to avoid crosstalk between sensors (thereby allowing high spatial resolution). We initiated a collaboration with a graduate student from Colorado School of Mines to aid in the interfacing of sensor/hardware and software components. Work is currently ongoing on this new array and we expect to have results from it before the end of the current grant period.

4) As noted last year, experiments with a laser scanner on the Platte River in 2012 showed the potential of using near-infrared lasers for detecting water-surface elevation. A field campaign was conducted April 11-13, 2014 on the Rio Grande River in Embudo, NM to collect conventional water-surface elevation, water-surface velocity, bathymetry and topographic surveys. During this field experiment, we made remote measurements of water-surface elevation with a laser scanner and water-surface velocity using both the infrared and conventional cameras. The laser scanner provided spatially explicit water-surface elevation measurements. Thermal boils were detected with greater reliability when the infrared camera was pointed near nadir over the water surface.

5) Processing of conventional videography data was explored using the Naval Research Laboratory's ePIV software with assistance from Todd Holland and a post-doctoral student. Output from the software was handled using MATLAB scripts. The ePIV software had some difficulty with the large boils observed in the laboratory flume but was capable of tracking surface foam from video collected near the HWY 119 bridge over the St. Vrain River in Colorado by post-doc Toby Minear.

6) The commercial PIVview software was used to obtain velocity vectors from field video observations. Output contains average pixel displacements in an image sequence. MATLAB code was written to plot the output and the Image Processing module in MATLAB was used to construct a script to convert the output file from PIVview to velocities using control points in the image.

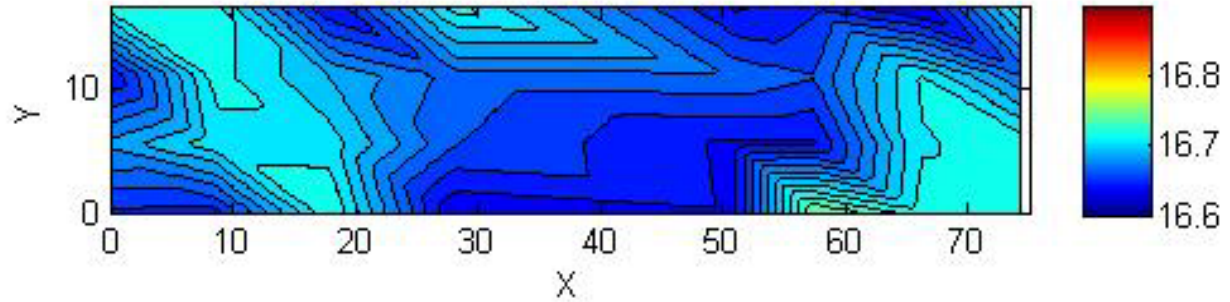
7) Additional experimentation with infrared video was conducted to track surface boils in Clear Creek, Colorado near a stream gage and also in the irrigation canal near GSTL. A jib crane and heavy duty tripod was purchased to obtain a near nadir view of the water surface and tested at Clear Creek pedestrian bridge. The crane did not yield improved image quality, but the observations were conducted during the day when thermal contrast was less than optimal. Surface turbulence at this site was also problematic. We experimented with filters to resolve

this problem, but we believe more work is required to get optimal imagery, especially when thermal contrast (air/water) is low.

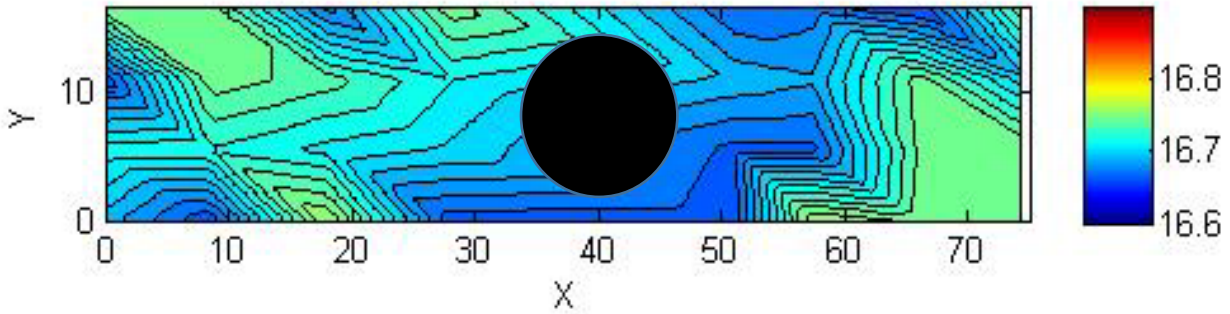
8) We have started to do some limited experimentation with UAV and videography for water-surface velocity (so far only with conventional cameras due to their lighter weight and MUCH lower cost). Some initial work using UAVs was published this year by Kinzel et al. (in press).

RESULTS

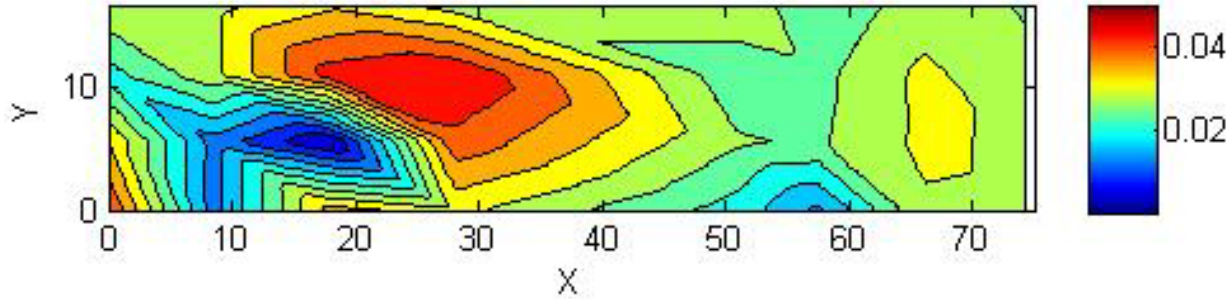
Figure 1 shows the response of the water surface to a small obstacle measured in the lab using the Seatek up-looking sensors. Because the accuracy of placement of the sensors was comparable to the signal we wanted to measure, we subtracted the background water-surface elevation to get the response due to the obstacle. In this case, that change is less than half a mm. Due to the spatial sparseness of the array, the spatial pattern shows some questionable lateral variation, but the overall effect is clear. This shows that even very small surface elevations changes can be measured in the lab, but also that we needed a denser array and that a non-invasive array (ultrasonic from above) would be better. This led to the design of a new ultrasonic array with up to 49 sensors, as shown in Figure 2. These sensors are constructed and we are now working on programming (in collaboration with a graduate student, Matthew Chee, from Colorado School of Mines) to collect this data in an optimal manner. This system pulses the ultrasonic arrays in a 12/12/12/13 pattern for a 7x7 array to avoid cross-talk and to achieve the highest possible spatial and temporal resolution. As in the case of the data shown in Figure 1, the data will be temporally averaged for the inversion calculations.



A



B



C

Figure 1. Water-surface elevation in cm measured in a flume with up-looking acoustic sensors (mean U about 5 cm/s, depth 20cm). A. No obstacle. B. With obstacle. C. Difference.

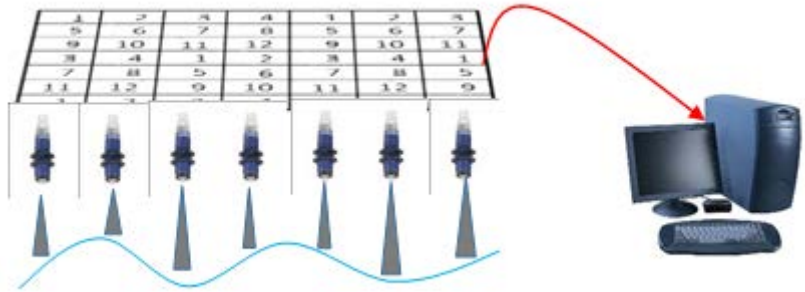


Figure 2. Schematic depiction of new array of ultrasonic sensors now under construction for the laboratory water-surface elevation measurements.

Figure 3 shows examples of water-surface elevations (A) and water-surface velocities (B) measured in the field using laser scanners and infrared videography, respectively. Similar measurements have been carried out at 5 different field sites, including the Platte, Rio Grande, Clear Creek, St. Vrain, and an irrigation canal near our laboratory. Through this measurement program, we have learned a fair amount about the applicability of both techniques, as follows:

Infrared videography for water-surface velocity

(1) The quality of results from the infrared videography method depends critically on high thermal contrast between the air and water.

(2) Off-nadir measurements are poor at angles greater than about 45 degrees and optimal results are produced near nadir (i.e., straight down).

(3) Issues with apparent "reflection" of mid-wave thermal radiation or other interference are still significant. We have tried various methods to reduce this and have made some improvements, but this needs further work to optimize image quality before processing.

(4) At this point, the best processing appears to be found using the Typhoon code (Derian, 2012) and we have an agreement in place to allow continued use of this proprietary product. We continue to test other algorithms and this may change in the future.

Laser scanning for water-surface elevation:

1) The dirtier the water and rougher the surface, the higher the rate of data return from the terrestrial laser scanners. Even in very clear water, returns are obtained, but they may be insufficient for inversion calculations with high resolution. We plan to use a full waveform resolving laser scanner to see if we can improve on this result with different processing of the returned waveforms.

2) Both infrared and visible wavelength scanners appear to work well for measuring water-surface elevations.

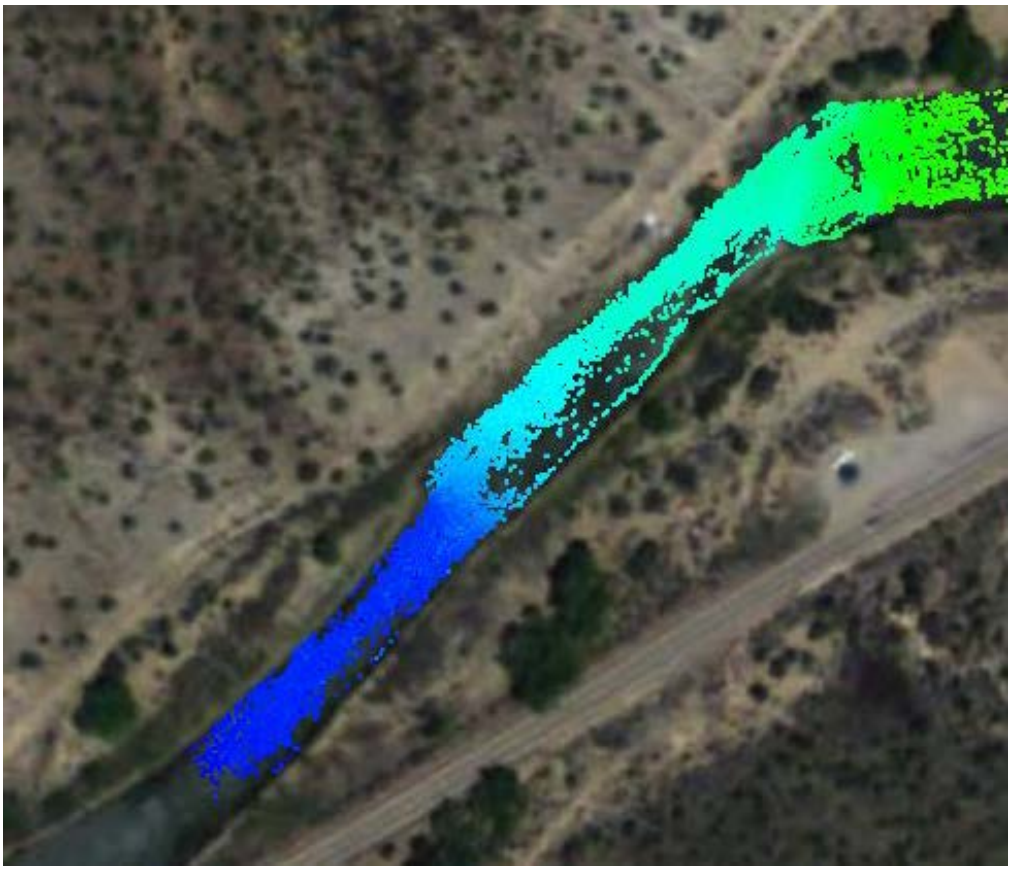
3) The errors in laser scanned elevations become large at near-hroizontal angles over long distances, so it is difficult to scan long reaches from a single location (the example shown in Figure 3A used 12 laser scanner base positions to get the best possible results)

IMPACT/APPLICATIONS

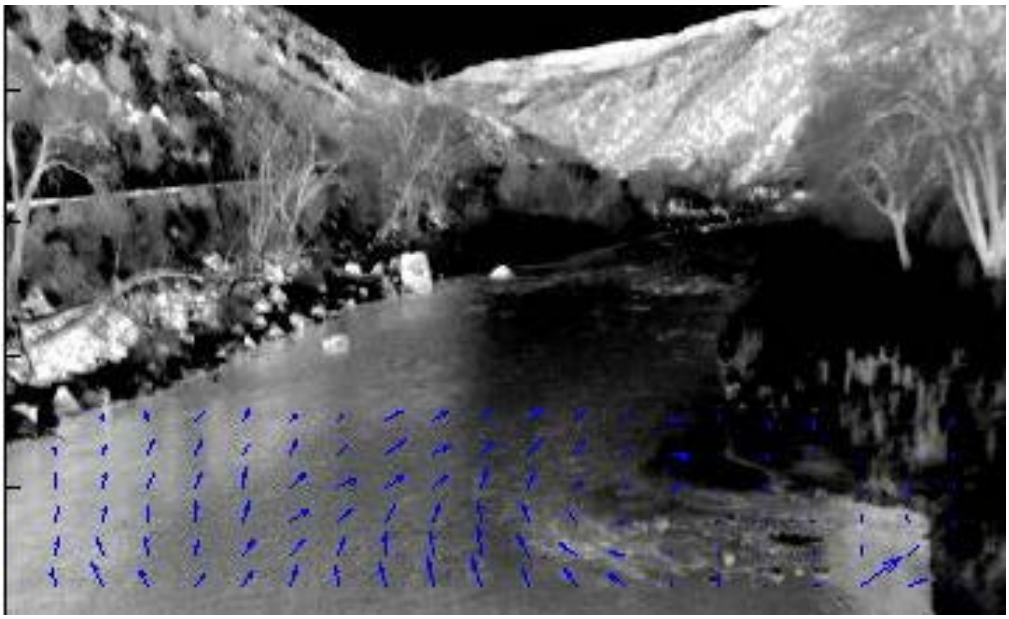
The research work carried out under this project is also playing a significant role in USGS developments for practical applications of non-contact gauging. In addition, we have added the inversion model code to the iRIC modeling interface, so it will be freely available to the public in the next major release.

RELATED PROJECTS

We continue to tie this work to other research projects, including work on the Kootenai, Platte, Sacramento, and Russian Rivers. In addition, we are working closely with NASA and personnel at the USGS California Water Science Center on the application of the AirSWOT water-surface topography testing program on the Sacramento and hope to have access to those data sets sometime later this year or early next.



A



B

Figure 3. Examples of laser-scanned water-surface elevations (A) and water-surface velocities (B) from the Rio Grande near Embudo, New Mexico.

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