

## Prediction of Hydrodynamics for Unidirectional Flow

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### LONG-TERM GOALS

Our long term goal is to develop an understanding of the relationship between channel geometry and three-dimensional flow features in rivers. One application of such an understanding would be the prediction of channel geometry and other channel characteristics (e.g. roughness) given observations of flow velocities and/or river surface.

### OBJECTIVES

Over the next biennium, our objectives involve applying previously developed methods to more challenging river geometries, and to exploit different measurement types. Hence, we would like to:

1. Assess the feasibility of determining channel depth utilizing velocity observations from drifters.
2. Assess the feasibility of determining frictional parameters (as a function of space) using remotely sensed observations of surface elevation.
3. Utilize the developed depth-inversion framework for the determination of flow depth in more complex rivers.

### APPROACH

Over the last biennium, we have developed methods that allow the determination of bathymetry using information about the flow velocities. These methods rely on the use of an accurate hydrodynamic model, an initial guess for the bathymetry (often a very simple geometry), and observations of flow velocities. This methodology was first applied while utilizing observations of currents in a surf zone setting, and results of the estimated bathymetry showed significantly improved skill over the prior guess. We found that multiple observation types (e.g., current observations versus wave height observations) provided more useful information than one observation type alone (even if we accounted for differences in the number of observations). We could also pinpoint the effectiveness of any given observation in correcting the bathymetry (Wilson *et al.*, 2010).

We then applied the same methodology to the estimation of river bathymetry. Our initial bathymetric guess consisted of a simple stream-wise uniform parabolic channel. We assumed that the overall flow rate in the river was known and utilized several types of observations of river velocities. The

hydrodynamic model of choice was the Regional Ocean Modeling System ROMS – a hydrostatic primitive equation model for a curvilinear boundary-following domain (Haidvogel *et al.*, 2008). We applied ROMS to several example river settings and found that it was accurate in predicting the general flow patterns including an accurate estimate for the location of a front between two counter-rotating vortex structures. Further, we found that river depth estimation was an attainable goal with multiple observation types, including surface velocities that could be obtained from radar observations and drifter-type observations of velocities (Wilson and Ozkan-Haller, 2012)

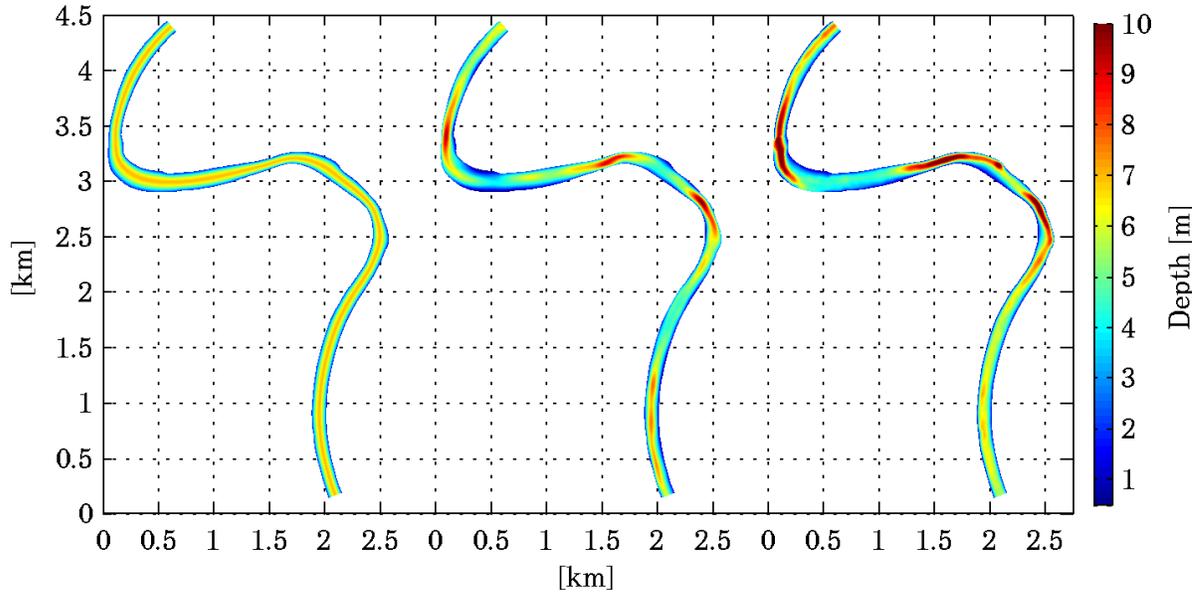
We have then extended and utilized the developed methods in more challenging situations. In particular, we are applying the techniques to different types of systems (e.g. a meandering versus an anastomosing reach) with relatively sparse observations (e.g. observations from less than 10 drifters). We are assessing performance of the method and number of required observations for a successful bathymetry inversion.

## **WORK COMPLETED**

We have so far extended the depth inversion methodology to include an iterative step to improve the resulting predictions further. We have also developed an analytical simplified model that we can use to quickly analyze dependencies on the prior bathymetry estimate and the nature of the co-variances. A publication based on this work is now in press. We subsequently moved to utilizing drifter observations from two deployments at the Kootenai River that were collected as part of ONR-funded work by PIs MacMahan and Reniers (among others).

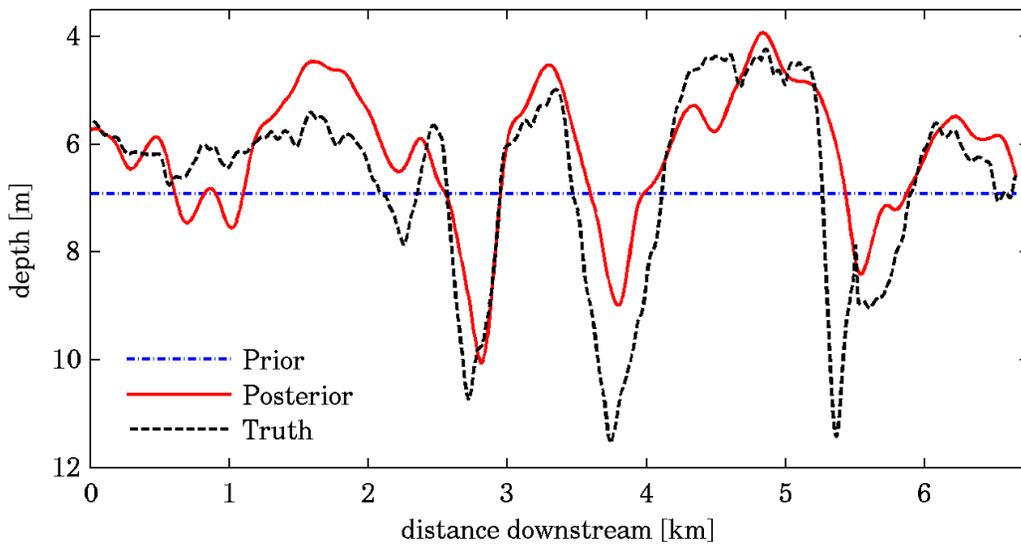
## **RESULTS**

Application of the depth inversion methodology to a meandering reach of the Kootenai River is shown in Figure 1. The initial guess bathymetry is made up of a parabolic channel and does not reproduce the general features of the measured bathymetry, which include several bars and pools. We assimilate 10 drifter tracks from observations gathered in August 2009 during relatively low flow conditions. The posterior estimates show improvements in several metrics (normalized RMS error and correlation coefficient), and the resulting bathymetry estimate has a ~1m rms-error (corresponding to ~20% normalized error) and correlation coefficient of 0.8.



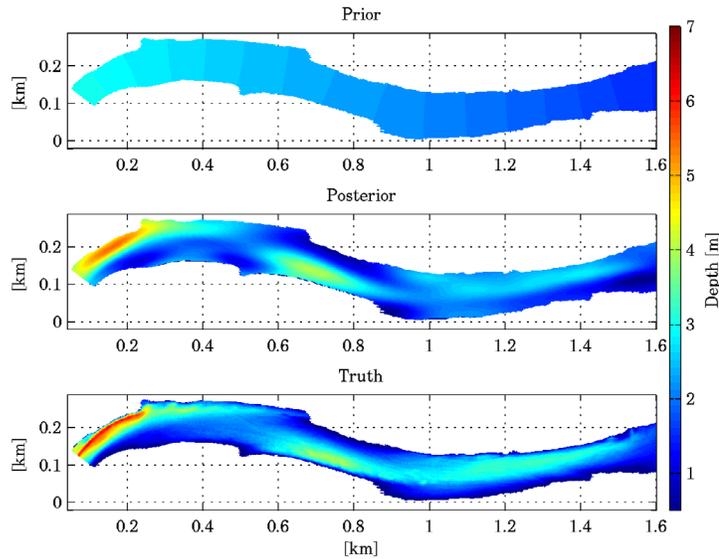
**Figure 1: Prior bathymetry estimate (leftmost panel), posterior bathymetry after the assimilation of 10 drifter tracks (middle panel), and true measured bathymetry (right panel).**

Results for the depth at the centerline of the river further show the improvement in the bathymetry estimate (see Figure 2). The prior estimate essentially has zero correlation at the centerline, but the posterior estimate correctly places bumps and holes, leading to a correlation value of 0.62. There is a consistent under-prediction in the deepest parts of the pools. This is likely related to the implicit linearity of the method. Previous work suggests that an iteration scheme (using the posterior estimate for the new prior and repeating the estimation method) would prove helpful in this case.



**Figure 2: Centerline bathymetry for prior (blue), posterior (red) and truth (black).**

A second application of the method involves the more challenging case of an anastomosing reach of the Kootenai River with a larger bed slope and shallower water depths. 11 drifter tracks were utilized and a prior guess consisting of a down-stream sloping channel was used. We note, however, that a parabolic channel with no down-stream slope produced quantitatively similar results. We found (see Figure 3) that the depth inversion step improved the correlation coefficient for the bathymetry estimate from 0.06 for the prior to 0.69 for the posterior. The centerline estimates show an even higher correlation (0.78), and result is a 0.37m rms-error (26% normalized error).



**Figure 3: Prior bathymetry guess (top), posterior estimate after assimilation of 11 drifter tracks (middle) and true bathymetry (bottom). The assimilation step results in significant improvement of the estimate over the prior.**

We further investigate the sensitivity of the results to parameters inherent in the ensemble-based method. So far, we have considered sensitivities to perturbation and localization length scales, ensemble size, and number of observations. We found that the bathymetry estimates are remarkable insensitive to the values chosen for these parameters. For example, an ensemble size of only 50 members results in a correlation coefficient of 0.66 for the anastomosing reach. This value increases only somewhat to 0.72 when 400 ensemble members are used. Further, the results are also insensitive to the assumed observational error for the drifter observations. Finally and surprisingly, bathymetry estimate with even just one drifter track result in an improved bathymetry estimate compared the prior estimate, reducing errors by 25% and improving the correlation coefficient by 0.23. Hence, the method is robust to parameter values.

## IMPACT/APPLICATIONS

As part of this study we are developing methods to estimate the depth of river channels given information about the flow velocities in the river. The potential application of this work is primarily related to problems related to navigation up river channels.

## RELATED PROJECTS

The data that the COHSTREX MURI group obtained on the Snohomish River has been utilized here to validate the numerical model and aid in the assessment of depth inversion techniques. Data gathered on the Kootenai River, ID by groups led by MacMahan and Reniers is also utilized. Finally, the methods developed and tested herein are also applied to surf zone and navigational inlet situations as part of the ONR-MURI project DARLA.

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- Wilson, G., H.T. Ozkan-Haller and R.A. Holman, Data assimilation and bathymetric inversion in 2DH surf zone model, *J. Geophys. Res.*, 115, C12057, doi:10.1029/2010JC006286.

## PUBLICATIONS

- Wilson, G., H.T. Ozkan-Haller and R.A. Holman, Data assimilation and bathymetric inversion in 2DH surf zone model, *J. Geophys. Res.*, 115, C12057, doi:10.1029/2010JC006286.
- Wilson, G., and H.T. Ozkan-Haller, Ensemble-based data assimilation for estimation of river depths, *Journal of Atmospheric and Oceanic Technology*, in press.