University of New Hampshire
University of New Hampshire Scholars' Repository

5-18-2009

Observations of River Topography and Flow Around Bridges

Thomas C. Lippmann
University of New Hampshire, Durham, t.lippmann@unh.edu

Follow this and additional works at: https://scholars.unh.edu/ccom

Part of the Oceanography and Atmospheric Sciences and Meteorology Commons

Recommended Citation

Lippmann, Thomas C., "Observations of River Topography and Flow Around Bridges" (2009). *Center for Coastal and Ocean Mapping*. 1227.
https://scholars.unh.edu/ccom/1227

This Report is brought to you for free and open access by the Center for Coastal and Ocean Mapping at University of New Hampshire Scholars' Repository. It has been accepted for inclusion in Center for Coastal and Ocean Mapping by an authorized administrator of University of New Hampshire Scholars' Repository. For more information, please contact nicole.hentz@unh.edu.

Report as of FY2008 for 2008OH76B: "Observations of River Topography and Flow Around Bridges "

Publications

Project 2008OH76B has resulted in no reported publications as of FY2008.

Report Follows

Report as of FY2008 for 2008OH76B: "Observations of River Topography and Flow Around Bridges " 1

Observations of River Topography and Flow Around Bridges

Thomas C. Lippmann

Center for Coastal and Ocean Mapping, University of New Hampshire, Durham, NH 03824

Formerly of

Dept. of Civil and Environmental Engineering & Geodetic Science, and the Byrd Polar Research Center, The Ohio State University, Columbus, OH 43210)

Rationale

This investigation was motivated by the amount of river, estuarine, and coastal infrastructure that is susceptible to extreme wave and flooding events. The high velocities and resulting shear stresses associated with high flow velocities are capable of scouring or depositing large quantities of sediment around hydraulic structures. Preventing the failure of these structures and sedimentation in inlets alone costs federal and state agencies billions of dollars annually. In addition to being costly, the manual monitoring of bridge scour - as mandated by the Federal Highway Administration - can be inefficient in states such as Ohio where the flood events that initiate the scour process occur sporadically. According to the National Scour Evaluation Database, there are 23326 bridges over waterways in the state of Ohio, of which 5273 are considered scour susceptible and 191 are considered 'scour critical'.

Previous methods for identifying bridge scour have relied on the manual (diver-based) sampling of local water depths that are generally limited to periods of low water flow. As the dynamic scour and deposition of sediments around structures is highest during periods of high flow, traditional sampling methods have limited our ability to predict quantitatively scour or deposition levels and to evaluate sediment transport models. This research is aimed at developing and testing new methods to observe riverbed topographic evolution around piles and under bridges where the structures themselves interfere with GPS based positioning. Simultaneous measurements of the velocity profiles can be used in conjunction with the observed bathymetry to make inferences about bridge scour and the effect of bridge piles on local riverbed topography.

Related to problems generated by sediment scour are issues of sediment deposition in navigational channels. On the Maumee River, OH, alone, the Army Corp of Engineers spends millions of dollars annually to dredge an average of 850,000 cubic yards of sediment. With the elimination of open lake disposal of dredged sediments, an inter-agency collaboration of government and private citizens has been formed to identify possible methods for reducing the amount of deposition by reducing the soil erosion along river bank’s. Clearly, development of new observational capabilities and a subsequent increase in observations of riverbed topography and flow around structures will improve our ability to utilize available resources in the most efficient manner.

Objectives

The objectives of this research were to

1. observe the variability of riverbed topography in an around bridge support piers on the Great Miami River near Hamilton and the Ohio River near Cincinnati.
2. develop methods to conduct detailed topographic and hydrographic surveys in and around bridges where the structure limits GPS positioning.
3. infer the affects of bridge structure on topographic variability and scour, and relate these to observed flow characteristics.

Methodology

The first survey site for this project was located in Butler County, Ohio near the Columbia Bridge over the Great Miami River at Hamilton, Ohio (Figure 1). The Hamilton, OH, field site has been identified by USGS collaborators (D. Straub and S. Jackson, USGS, Worthington, OH) to have previously experienced up to 1 *m* variability in local morphologic variability and was the subject of a previous multi-year monitoring project. The bridge is four lanes wide constructed with four monolithic concrete bridge piers. River and bank surveys were completed 2005, 2006, 2007, and again in 2008 as part of this ongoing research program. An example survey is shown in Figure 2.

Figure 1. Photo of the Columbia Bridge over the Great Miami River at Hamiltion, OH.

The surveys were conducted with the Coastal Bathymetry Survey System (CBASS), a Yamaha GP1200 Waverunner (personal watercraft) equipped with a differential GPS receiver, dual-transducer 192 KHz sonic altimeter, and custom onboard navigation system (Figure 3). As part of previous research efforts, the system has been utilized extensively in coastal marine and fresh water environments where waves and currents are present (and sometimes energetic). The system has accuracies of about +/- 7-10 *cm* in both the horizontal and vertical coordinates of the measured bathymetry. The bank survey was conducted by walking with a backpack-mounted differential GPS receiver and antenna. The bathymetric survey spans about 1.2 km along the river, and was done over 2.5 hours with about 60 cross-river transects spaced every 20 m.

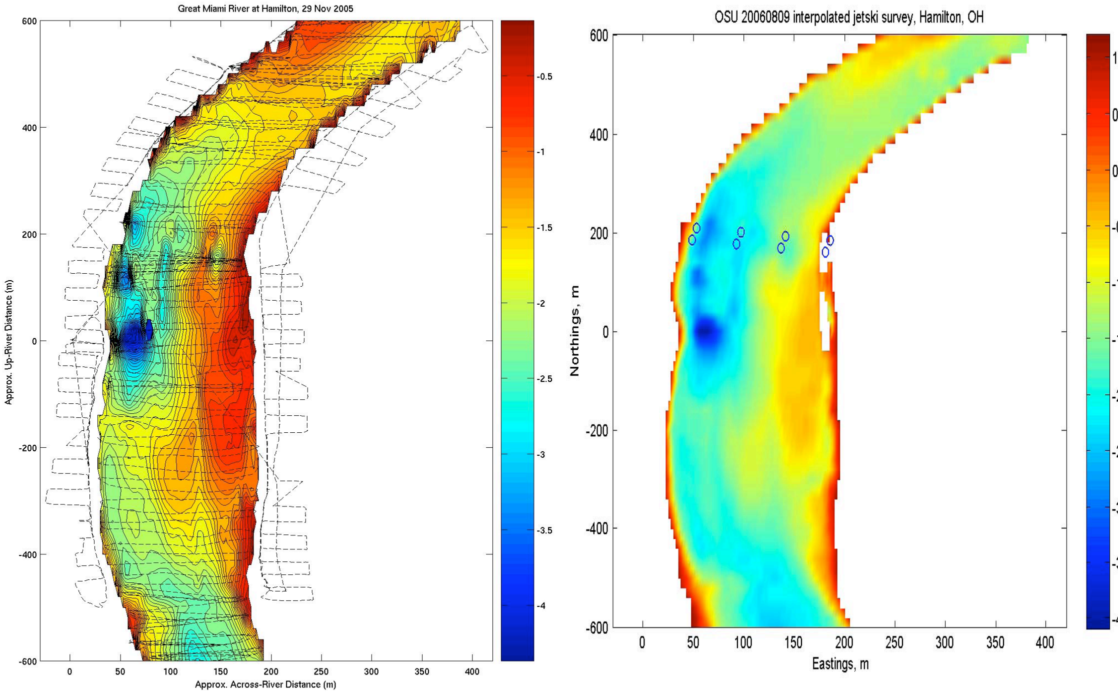

*Figure 2. (**left panel**) Bathymetric survey of the Great Miami River in Hamilton, OH, conducted using the CBASS survey system (Figure 3). The depths are shown in meters as color contours relative to the approximate mean water level at the bridge (located at about y=200 m in the figure). The horizontal coordinates are in meters relative to our GPS base position. The survey tracks are shown as dashed black lines in the figures. The riverbanks exceeding 6-8 meters above water level were surveyed with differential GPS manually (e.g., walking) but are omitted from the plot so that the river topography can be seen more clearly. (**right panel**) Interpolated river bathymetry including sonar data under the bridge using preliminary dead reckoning technique. Also shown are the locations of the bridge piles.*

Figure 3. The WaveRunner survey system is capable of measuring water depths from approximately 0.4 m to 25 m.

GPS-based bathymetry surveying near bridge structures and piles (indicated in Figure 2 for the Columbia Bridge at Hamilton) is difficult due to line of sight blockage of the GPS satellite constellation near the bridge. In past surveys this has resulted in sparse bathymetry data near the piles and under the bridge because of positional uncertainties, and thus details of the scour and topographic irregularities were not observed. Sonar data are collected for these areas; however, the lack of positional data precluded the use of the depth measurements.

Ideally multibeam or interferometric swath bathymeters would be used to measure the sub-bridge bathymetry in and around the piles. However, these systems are extremely expensive to purchase, rent, or operate, and thus are not readily available for repeated surveys over time by a wide range of interested entities (including governmental, research, engineering, and management entities). What is needed is a simpler, more cost-effective way to obtain estimates of the river topography near bridge structures where the GPS satellite are blocked. As part of this work, we will test a age-old method for estimating vessel positions based on simple inertial and geometrical ideas.

The navigational method know as dead-reckoning was developed over 500 hundred years ago by sailors and is still used today in combination with other navigational aids such as GPS and inertial systems. This method requires an initial known position and assumed trajectory. A simple form of dead-reckoning utilizes a measured velocity vector, then integrates the horizontal x and y components over a finite time scale to find the corresponding spatial position.

In this case, the initial and final positions are determined from the last known fixed GPS position before the signal dropout under the bridge and the first fixed position on the other side of the bridge, respectively. Velocity is maintained (and assumed) constant by the survey vehicle operator until a fixed position is acquired again. The vehicle is kept on a constant heading using visual landmarks by the operator to minimize spatial deviations from the assumed trajectory. A schematic of the geometry used in dead reckoning is shown in Figure 4. The distance and heading between the last two known points, (x_0, y_0) and (x_1, y_1) respectively, can be easily calculated. The times of these two points are taken from the GPS record, and the times along this line are calculated based on the desired number of points and sampling frequency. The sonar record is then interpolated to these times and depths are extracted for the specified times. Figure 5 show a detailed map of the survey tracks near and under the bridge during a preliminary field test of the technique.

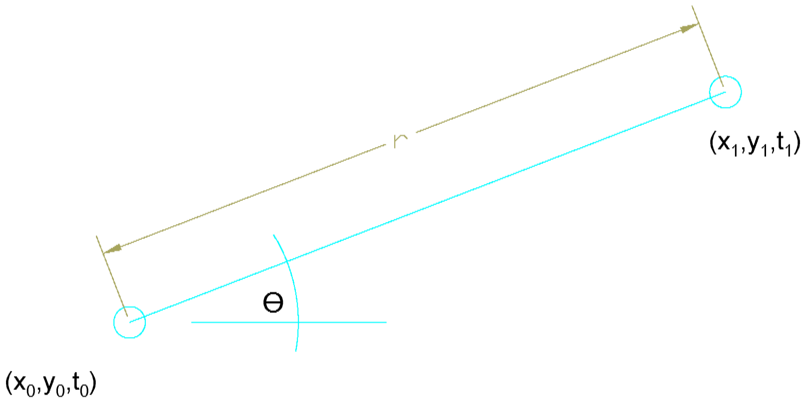

Figure 4. Illustration showing two known points along with the heading and distance between them. The speed of the survey vessel is assumed to be held at a constant velocity between known positions.

This pseudo dead reckoning technique is a viable method based on a preliminary field test conducted in the spring of 2007. Figure 6 show the interpolated elevation data under the pier (shown as a time series of observed depths). However, in this preliminary test no ground truth were available. As part of the present research, extensive tests over known river topography (obtained with the CBASS) in regions away from any structure will be conducted in order to quantify the accuracies of the dead reckoning techniques. Once verified, the technique was applied to regions close to and under bridges where GPS drop-outs occur.

This technique, with our current equipment, is limited to areas that the water surface can be assumed flat because there is no way to determine fluctuations in water surface elevation (*i.e.*, surface waves). The incorporation of an inertial system may allow this technique to be effective in the presence of waves. In most instances, it can be assumed that surface wave fluctuations are small, and associated errors will have only a minimal effect on the bottom topography.

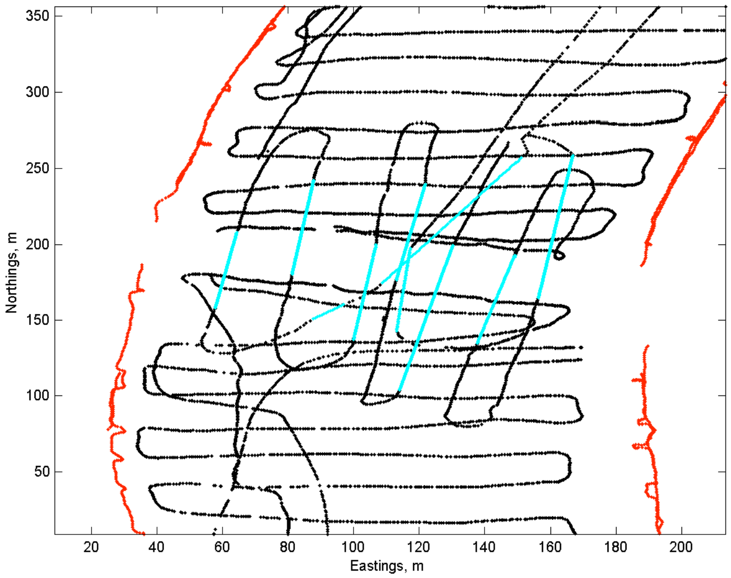

Figure 5. Close up plot of the survey tracks. Red tracks indicate walking survey, the black tracks indicate CBASS survey, and the cyan tracks indicate interpolated positions based on the dead-reckoning technique.

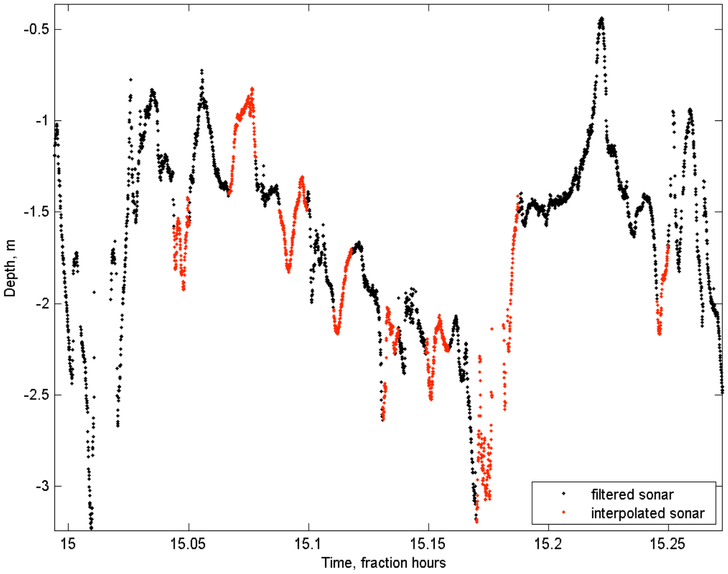

Figure 6. Sonar data from CBASS. The black points are the data from the known GPS positions and the red points are the data extracted from the sonar record based on the interpolated spatial and temporal points.

In addition to riverbed topographic observation, vertical profiles of river flow velocity were be obtained with a Sontek Rivercat Acoustic Doppler Current Profiler (ADCP) integrated into the CBASS survey system. The sensor can remotely sample three-components of velocity at about 20 *cm* range bins at a 0.2 *Hz* sampling rate. The observations were used to map the general flow field over the region surveyed around the piles and under the bridge. Flow measurement will allow inferences of the effect the bridge structure has on the local riverbed topography.

The second field site is located on the Ohio River near Cincinnati. This site is significantly different than the first with significantly larger flows spanning a deeper and wider river basin. Bathymetric observations made at this site were similar to Hamilton, except that the deeper depths of the Ohio River precluded the use of the Sontek ADCP which needs to track the bottom in order to remove vessel motion from the current measurements but could not follow the bottom over a significant range. No other ADCP was available for use in this study, and thus current measurements are limited to the Hamilton site.

Results

A bathymetric survey was conducted along a 3 *km* stretch of the Ohio River near Cincinnati over a 2 day period on 01 and 10 July 2008 (Figures 7 and 8). This region of the Ohio River is characterized by an approximately 300-400 *m* wide basin with water depths at the time of the survey ranging a few meters near the banks to 17 *m* in some parts of the channel. There are also 5 bridges that cross the river in the survey area, and a small creak that flows northward into the Ohio River in about the middle of the domain. The CBASS survey tracks are shown on the bathymetry in Figure 7, and the location of the bridges in Figure 8. The bottom topography is highly variable over the region, with shoals, holes, sandbars, and other detritus scattered along the banks. At the time of the survey, significant water hazards in the form of logs and tree limbs were observed through out the region (but did not negatively impact the surveys).

The effect of the bridge pilings on the topography is qualitatively evident in the survey (Figure 8). Below bridges 1, 2, and 3 there are significant holes and scour channels that extend several hundred meters downstream of the piles and increasing the depth by up to 5 *m* or more. Across-river transects showing the river basin profile 100 *m* both upstream and downstream of each bridge are shown in Figure 9. The location of the transects is also indicated in Figure 8. There is significant variability in the bottom profile up and down stream of bridge piles 1-3. In contrast, an interestingly, the profiles above and below bridges 4-5 show relatively minor variability in the vicinity of the bridges. It is possible the gentler slope of the river bed (shown in along-river profile in Figure 10) in this region limits the scour effects near those piles. As well, this region is upstream of the inflow tributary to the south. Although not measured herein, it was qualitatively observed how the river flow increased noticeably downstream of the river confluence.

In order to test the dead reckoning methods described earlier, repeated cross-river profiles were used to simulate conditions where navigation was lost periodically and under varying vessel speeds and river flow conditions. A total of 51 cross-river transects were arbitrarily selected through the 3 *km* river section. In each case an estimate of the mean vessel speed and direction was determined by points near the riverbanks along various transect lines. These estimates were then used to estimate the position of the vessel through time assuming a constant speed and direction. The estimated times and positions of the vessel were used with the raw sonar data to estimate water depths across the channel. An example (typical) comparison is shown in Figure 11 for the vertical and horizontal uncertainties. Overall, we observed a mean root-mean-square (RMS) error of 7.9 *cm* in water depths, and 9.1 *m* in spatial location. The mean vertical bias observed was -5.2 *cm*, most likely owing to the unknown behavior (motion and heave) of the vessel while underway. The higher spatial offsets are primarily a result of the river flows tending to carry the vessel downstream. Although pilot corrections were made, and an onboard navigation system available, it was still difficult to transit in a straight line. This offset did not seem to result in higher uncertainties in water depth estimates, a result of the (in general) relatively gently sloping bottom except near the bridge scour regions.

A summary of the RMS errors is shown Figure 12. The RMS vertical errors are plotted as a function of RMS horizontal errors. As expected, the RMS vertical uncertainty goes up as the horizontal positioning gets worse. The correlation squared is 0.68. These results show that even for positional errors of order 25 *m* or so, the RMS vertical errors are still less than 15 *cm* (and half that on average). This order of error is close to the accuracies of the CBASS (with estimated errors of order 7-10 *cm* in the vertical based on sonar and GPS errors.

Over the past 4 years we have surveyed the Great Miami River near the Columbia Bridge in Hamilton, OH. Figure 13 shows the survey from 29 November 2005 and the survey from 10 July 2008. Each plot shows the same color scale and the contour intervals are 0.25 *m*. The location of the bridge pilings are indicated on the plots. Only the bathymetry below the water line is shown (that is, now GPS walking survey data are included in the figures; and it should be noted that the river banks were not observed to migrate during the 4 year period). It should be noted that where possible the dead reckoning techniques - verified with the Ohio River data – were used to fill in the bathymetry in and around Columbia Bridge as the nearly continuous bathymetry map shows in Figures 13 and 14.

Clearly there are changes that have occurred over this period, including shifting sand bars, holes, and the depth and location of scour pits. The data from each survey were smoothed onto a similar spatial grid and subtracted to quantitatively evaluate the riverbed changes that occurred (Figure 14). Evident is the appearance of a migrating sand bar oblique to the river bank to the north of the bridge. This feature is (likely) due, in part, to multi-year construction of the upstream tressel in Hamilton. Also evident are substantial reworking of the river bed to the south of the bridge, but in a less coherent manner appearing somewhat random in evolution. What is striking is that the largest changes occur right under the bridge where the scour has eroded the river bed by nearly a meter in places, a 25% change in water depth in some locations. Without the dead-reckoning techniques, it is not likely this change would have been observed.

Our final goal, was to make spatial maps of the depth-averaged flow field in and around the bridge piers to demonstrate how the flow measurements could be coupled with bathymetry observations to examine in more detail the sediment transport impact by fluid-bed-structure interactions (such as scour processes). The Sontek Rivercat ADCP was deployed on the CBASS simultaneously while conducting a survey of the Great Miami River. In order for ship-board ADCP measurements to be made, the motion of the vessel must be removed. This was done with the Rivercat by tracking the apparent motion of the assumed stationary bottom as the vessel passes by. A comparison of the bottom finding algorithms from the Rivercat bottom tracking and the CBASS are shown in Figure 15. The accurate bottom tracking allowed the Rivercat to be closely synced to the CBASS GPS and sonic data streams. Shown in Figure 16 are the estimated vessel speeds and directions from the Rivercat bottom tracking and independently from the CBASS differential GPS. Although there is reasonable agreement between these data streams, the differences resulted in significant uncertainty in the velocity estimate. As such velocity profiles were averaged over 40 *m* along-river by 10 *m* across-river regions.

The depth, time, and spatially averaged mean flow pattern observed on 10 July 2008 is shown in Figure 17. The flow vectors indicate a downstream flow of about 1 *m/s* over most of the domain, with a slight increase towards the center of the channel and a general trend of the flow following contours of the sand bars and channels. In general the general flow pattern was captured; but a close relationship to the observed bathymetry or changes over time were not found.

Significance and Additional Benefits

This research has shown that coincident observations of mean flow patterns and riverbed bathymetry can be obtained simultaneously. We have also shown that simple and relatively inexpensive dead-reckoning navigational techniques can be used to estimate river bathymetry accurately (within about 15 *cm* uncertainty) around bridges and other structures where GPS navigation is temporarily lost. The coupled observation of detailed flow and riverbed evolution around bridge structures will improve our understanding of the scour process. Engineers and river managers can make use of the developed observational techniques to further their observational programs, and to make predictions of riverbed evolution to improve structural design, streamline mitigation procedures, and reduce response times to predicted high flow events by focusing resources to projected high scour regions. The observations may also be used to select locations for future sampling sites, and to identify those sites where scour is expected to be problematic for future structural integrity. Our field methods represent new ways to monitor and evaluate bridge scour, and together these results will highlight potential areas of concern.

This project provided funds for two senior level Honors undergraduate students who assisted in the collection of the data, developing experience in field methodology for survey related projects, and assisted in the analysis of the observations. The students were trained in the use of GPS and sonar equipment used in state-of-the-art survey systems, and gained experience conducting surveys on natural rivers around bridges and structures. The students learned about sediment transport around bridges, and the influence of flow-structure interaction on the surrounding topography. A research engineer (Gabe Smith) lead the field work and data processing, and thus gained valuable experience and training in leading students in field experiments.

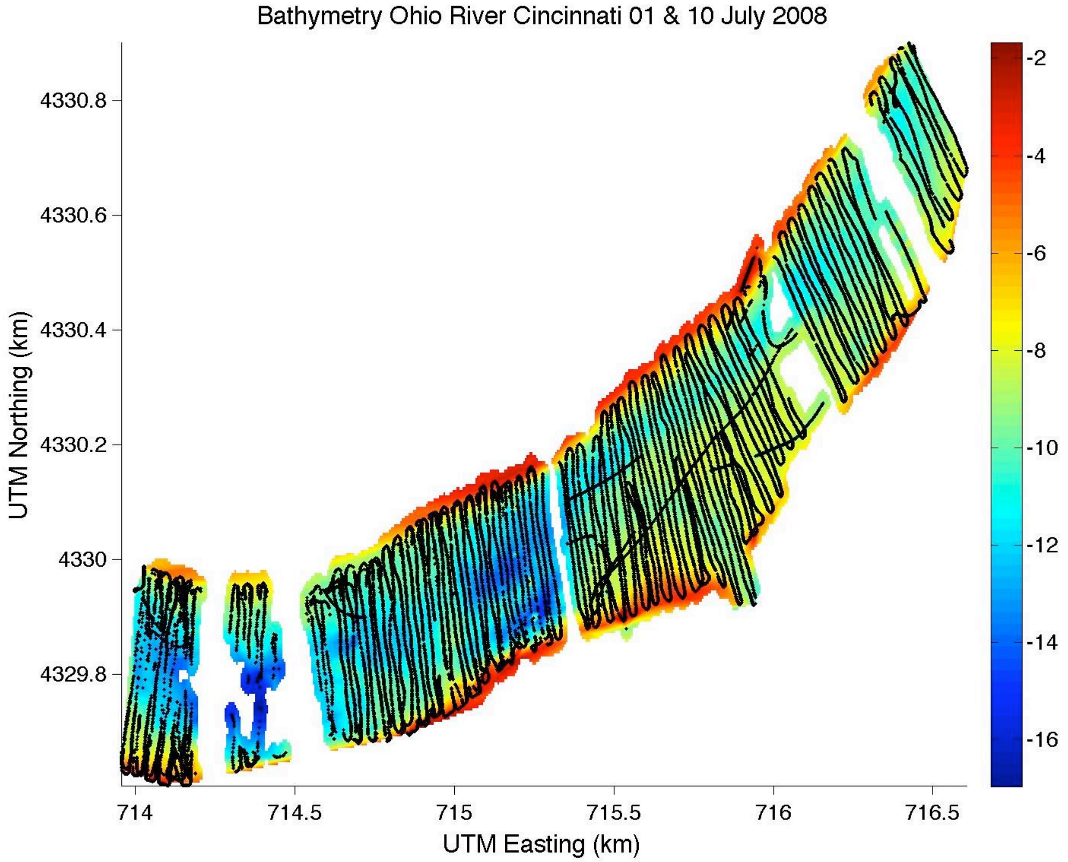

Figure 7. Bathymetric survey of the Ohio River at Cincinnati, OH, conducted over 2 days (01 & 10 July 2008) and showing the CBASS track lines.

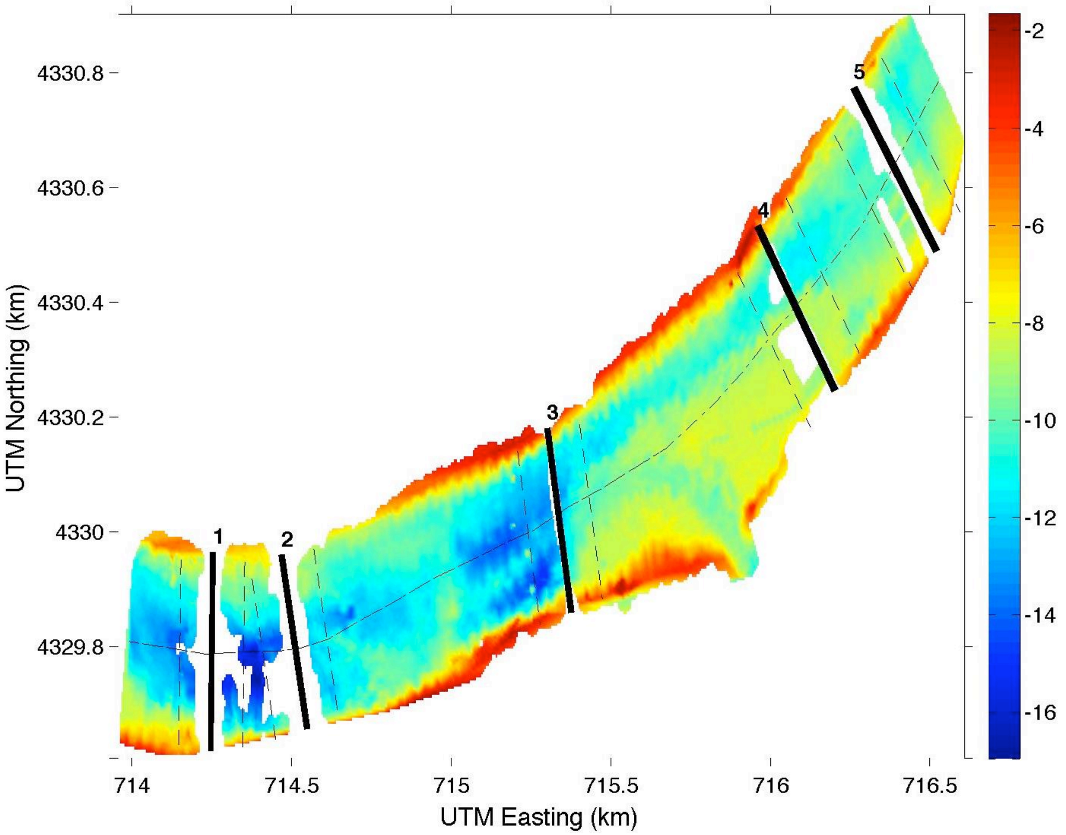

Figure 8. Bathymetric survey of the Ohio River at Cincinnati, OH, showing the location of 5 bridges and the location of cross-river and along-river transects shown in Figure D. The color scale is depth in m relative to the approximate mean water level near bridge number 4.

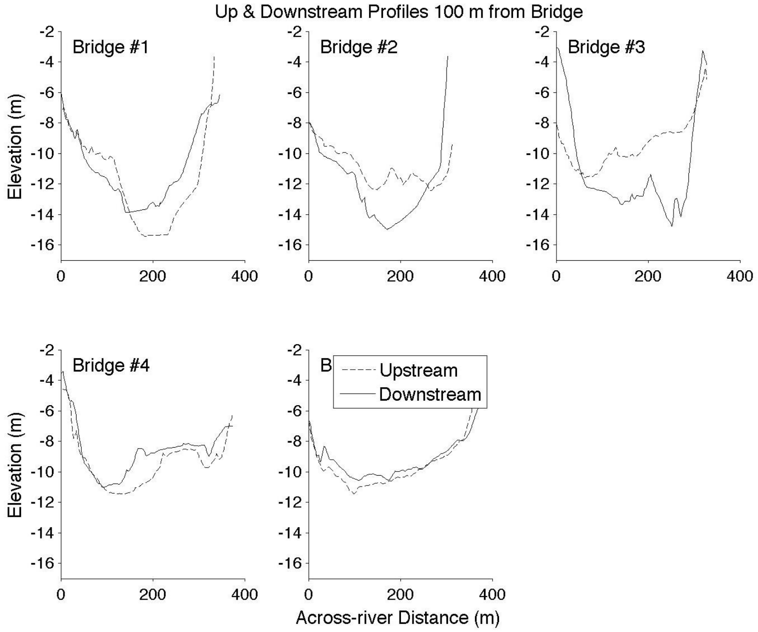

Figure 9. Across-river profiles 100 m upstream and 100 m downstream of each bridge location. The across-river coordinate is arbitrary distance along the transect (in meters).

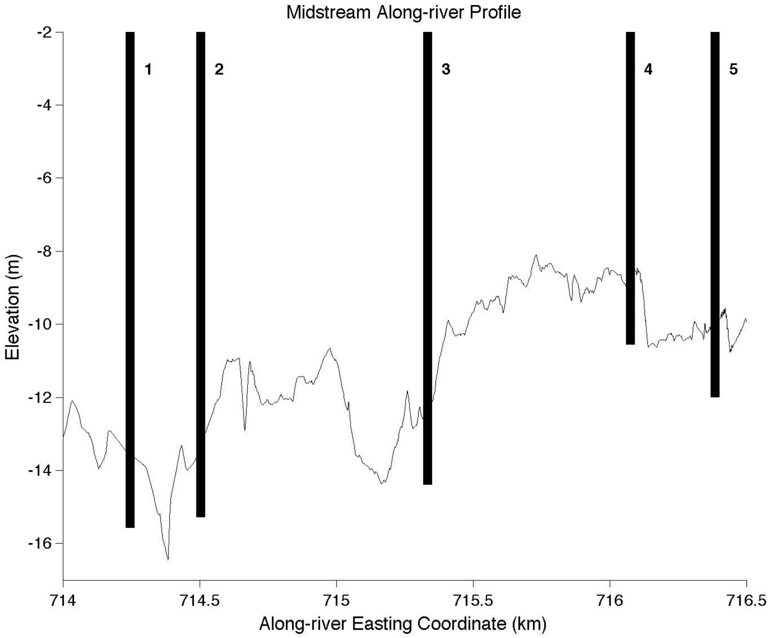

Figure 10. Along-river transect at about the mid stream location. Also shown are the location of the bridge piers.

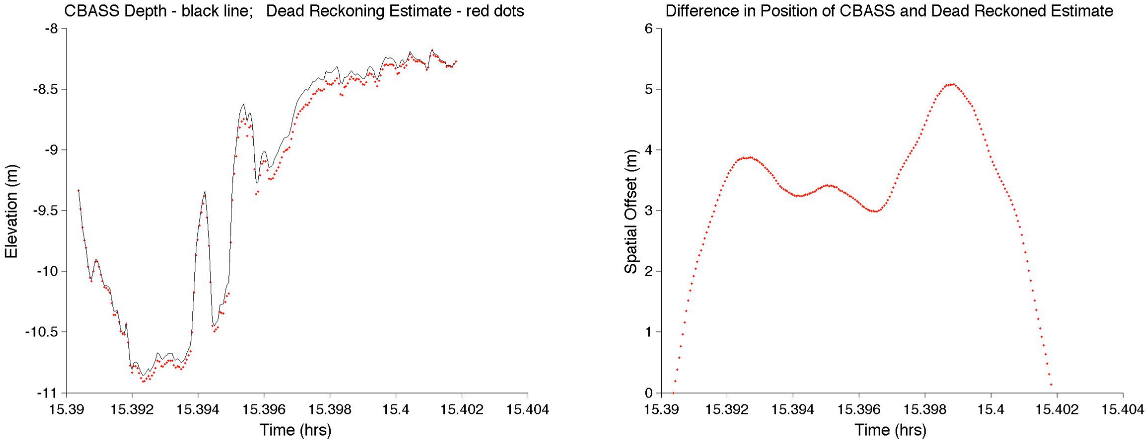

Figure 11. Comparison of dead-reckoned across-river profiles compared to CBASS measurements. The vertical comparison is on the left, and the horizontal positioning error is on the right.

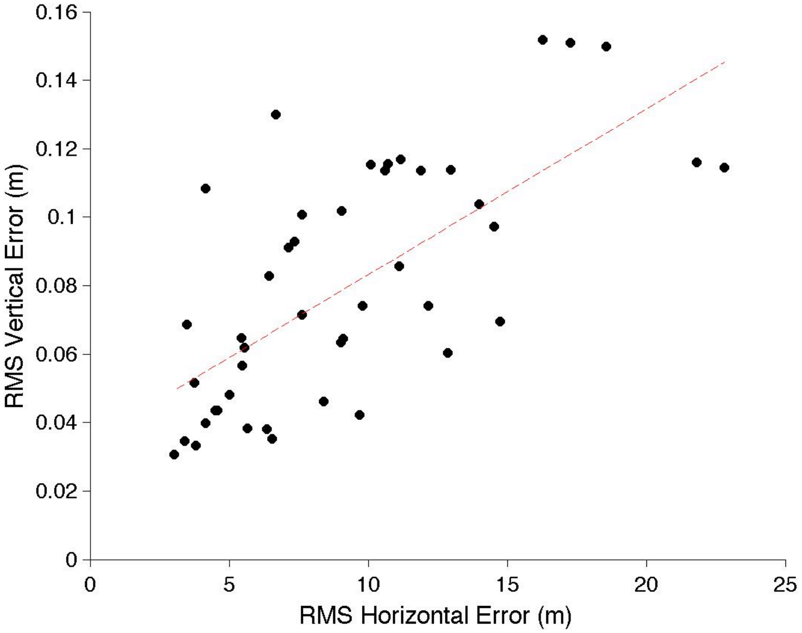

Figure 12. Scatter plot of the RMS vertical errors along 51 transects as a function of RMS horizontal errors. The correlation squared is 0.68, and mean vertical bias is -5.2 cm.

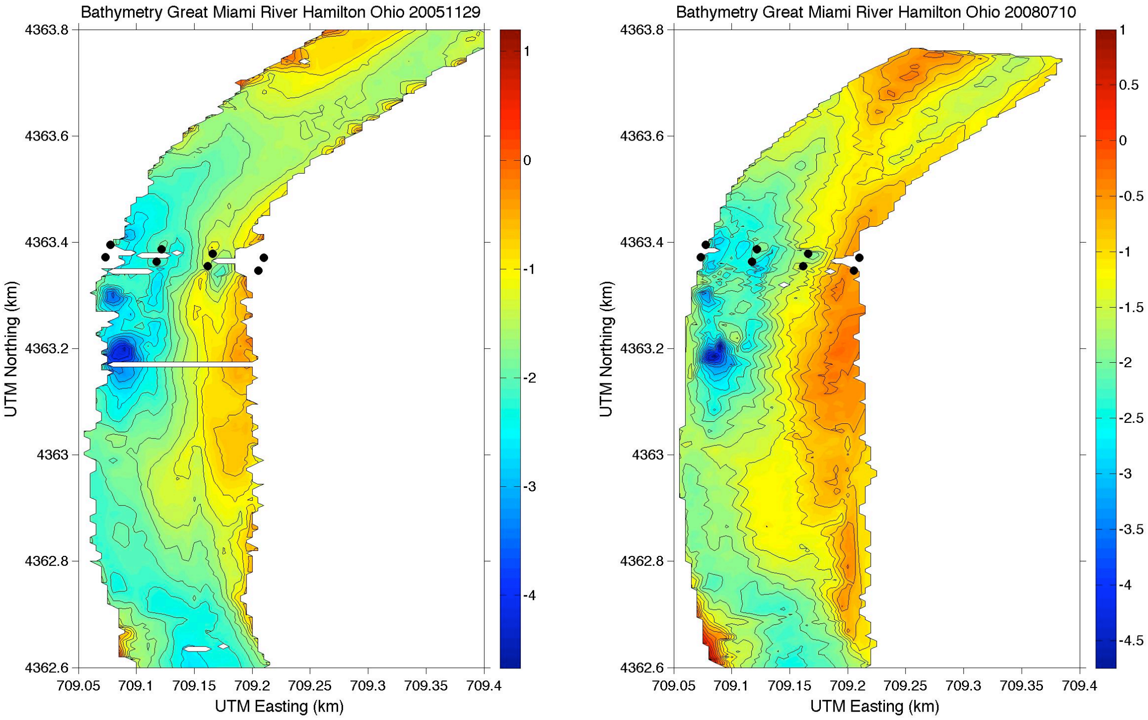

Figure 13. Bathymetry observed along the Great Miami River near Hamilton Ohio on 29 November 2005 and again on 10 July 2008. The location of the bridge piles supporting the Columbia Bridge are indicated with the black dots. The coordinate system is UTM Northings and Easting in km. The color scale indicates the water depth relative to the water level at the bridge. Contour intervals are 0.25 m.

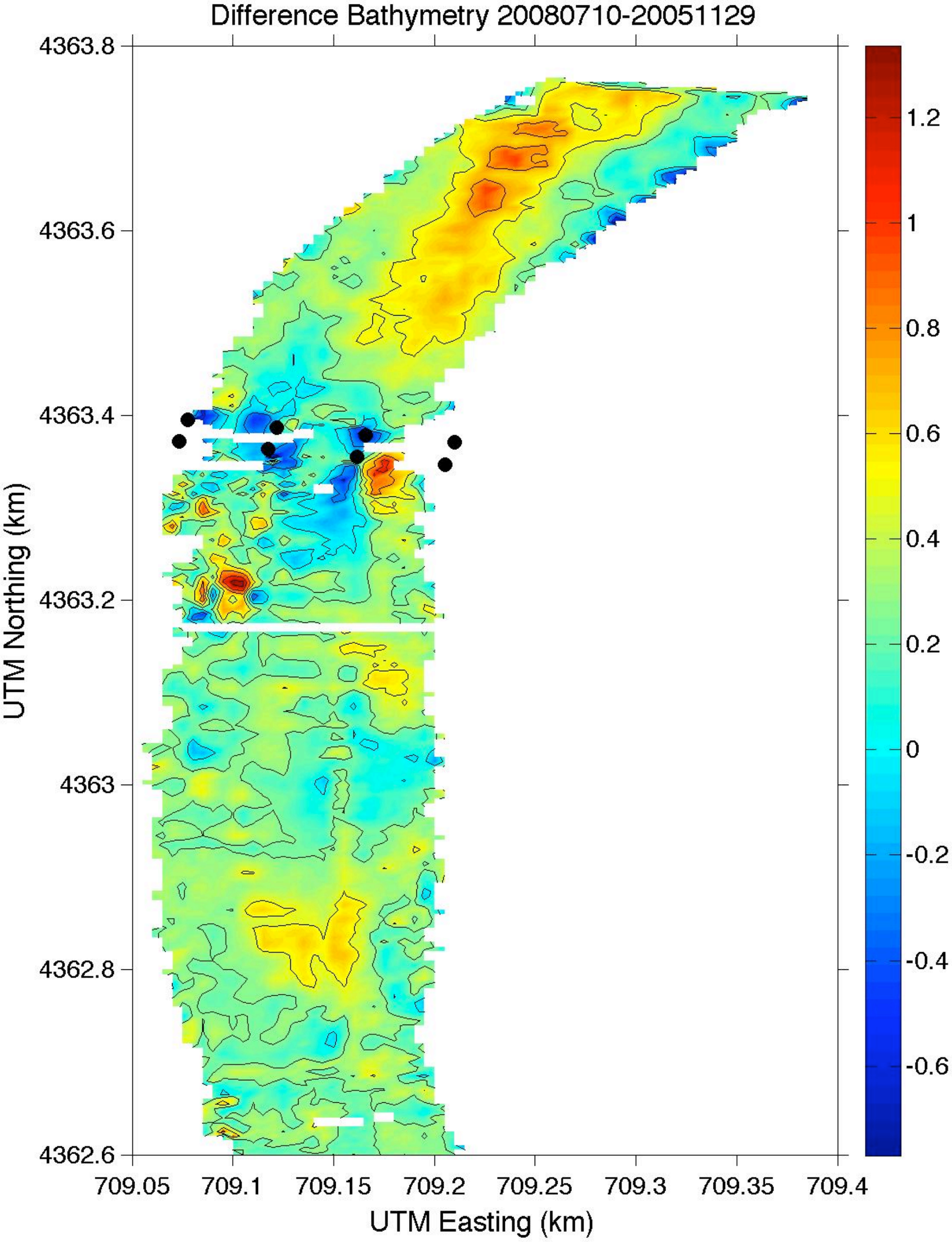

Figure 14. Difference in bathymetry between the 29 November 2005 and 10 July 2008 surveys. Clearly evident is the large wedge of accreted sand to the north of the bridge and the substantial scour around the bridge piles over the 31 month period between surveys. South of the pier also experience substantial rearrangement of sediments but what appears to be a generally random pattern.

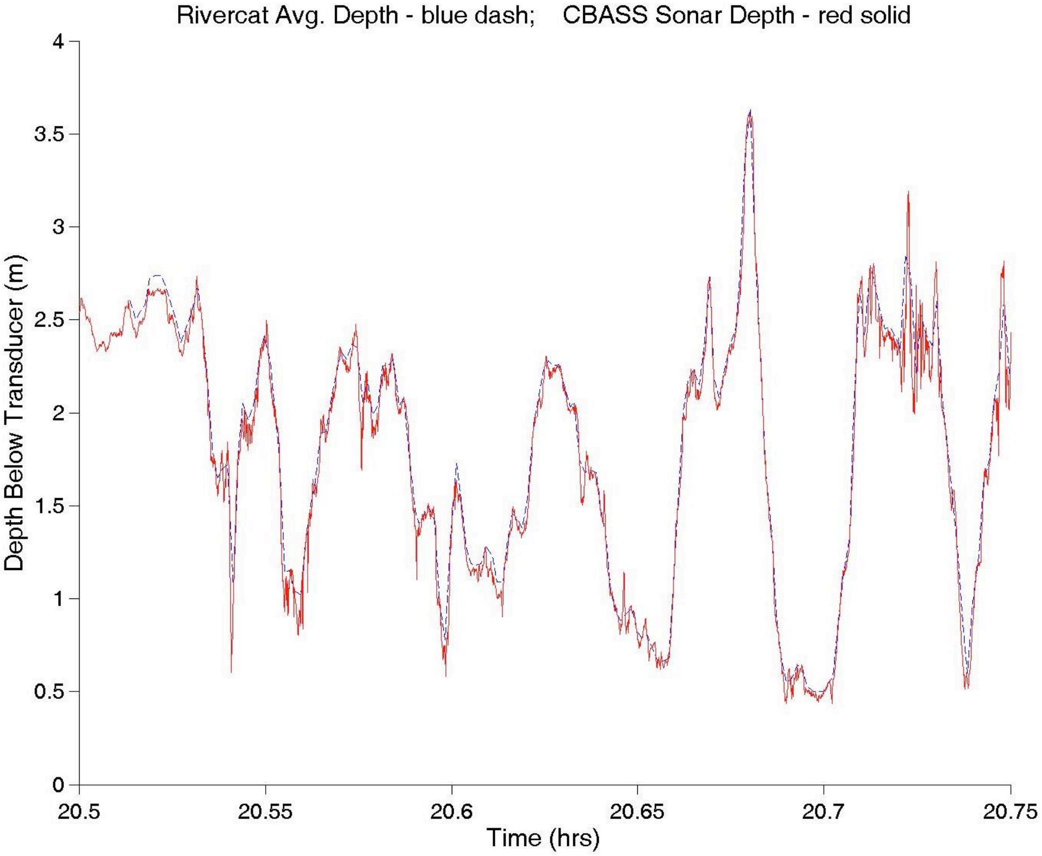

Figure 15. Comparison of the Sontek Rivercat ADCP's bottom tracking depth estimate compared with CBASS. The temporal agreement is due to shifting the time series into alignment, necessary to synchronize the two data streams so that the bathymetric map can be populated with velocity estimates.

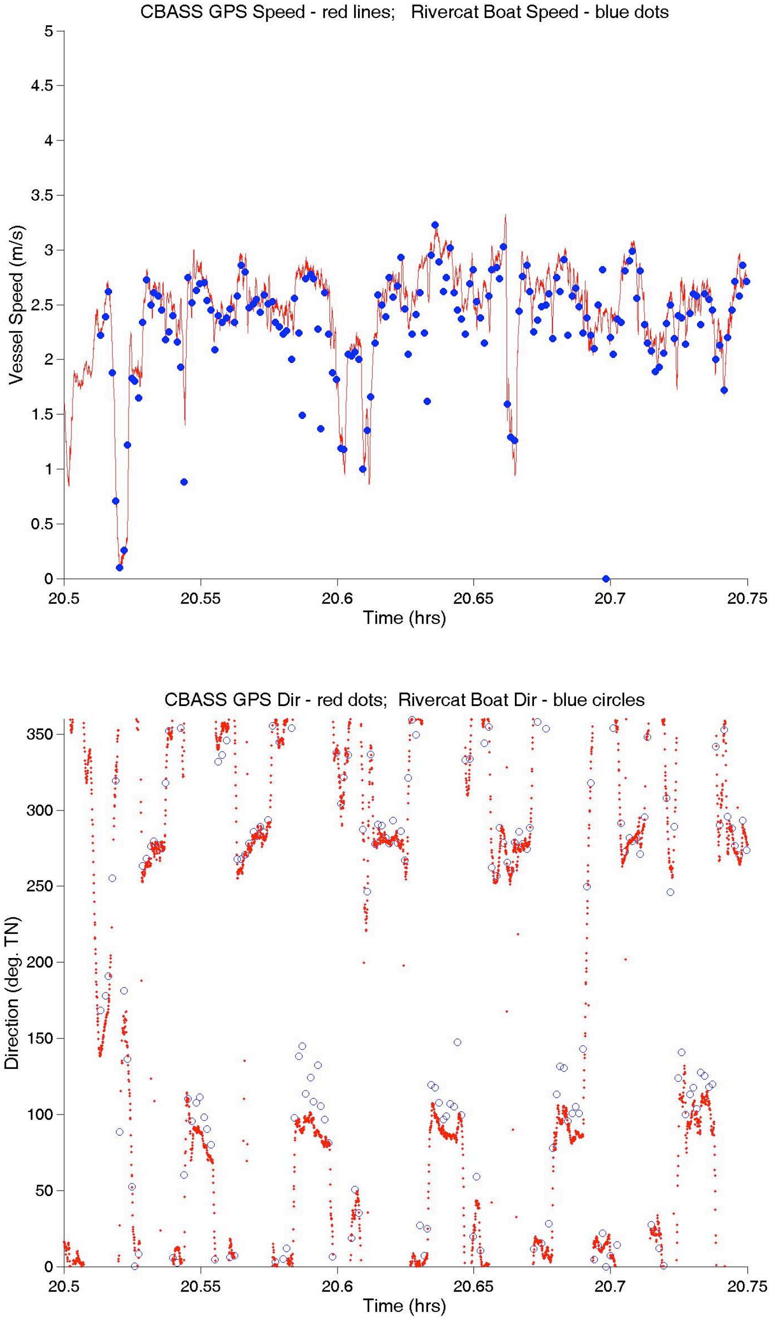

Figure 16. Time series comparison of the vessel (CBASS) speed (upper panel) and direction (lower panel) between the Sontek Rivercat bottom tracking algorithm and the CBASS differential GPS estimates. Although reasonable agreement is apparent, the differences contribute to substantial uncertainties in the velocity estimates.

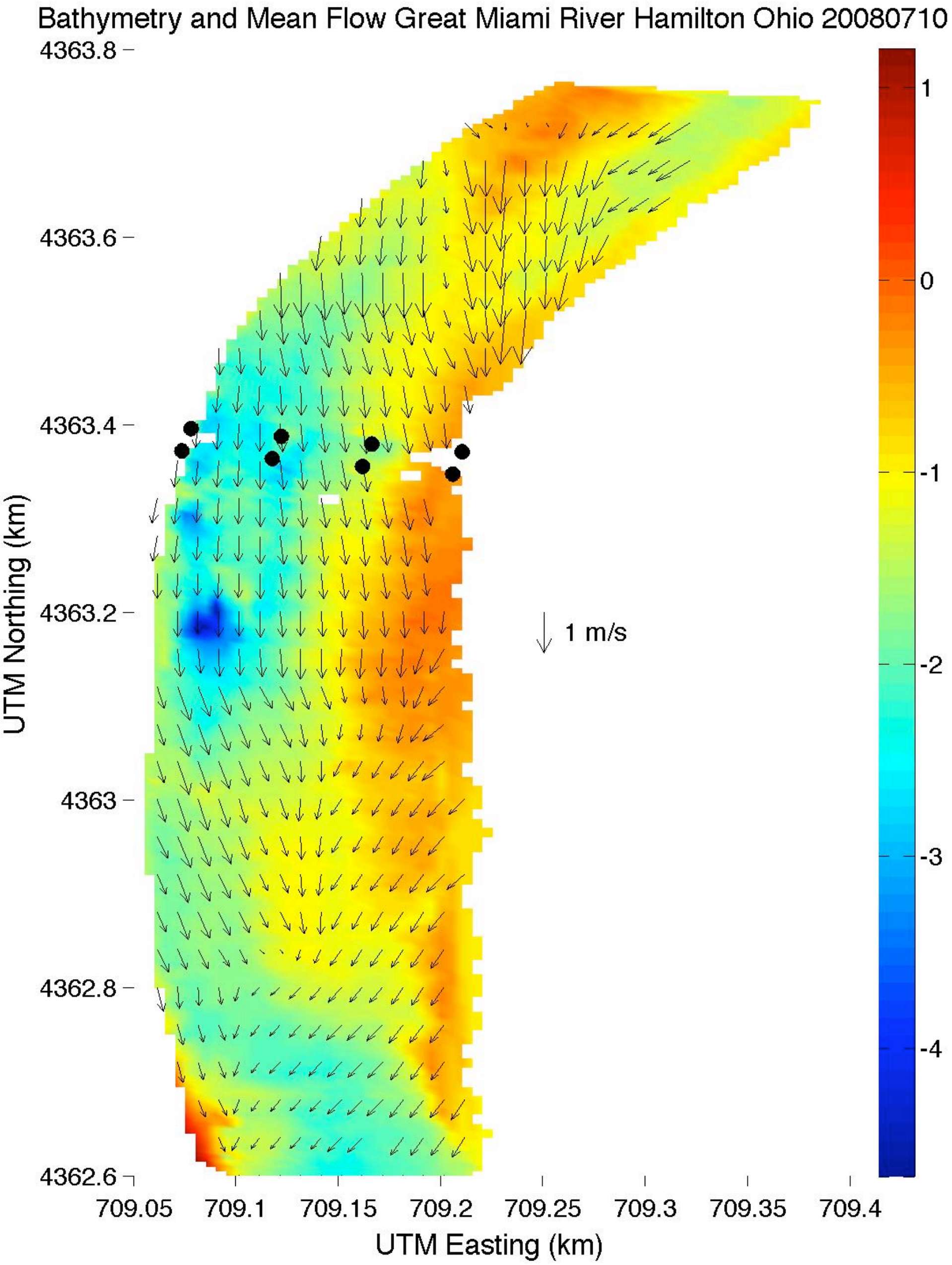

Figure 17. Observed depth-averaged flow field on 10 July 2008 with the Sontek Rivercat mounted on the CBASS. The flow vectors are overlayed onto the bathymetry measured on that day. General flow patterns can be grossly related to the variation in bathymetry, primarily in directional changes as the flow follows contours of the bottom..