Analysis of Exposure Time on Streamflow Measurements Made with Acoustic Doppler Current Profilers

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ABSTRACT

Previous work has concluded that a critical factor in reducing the uncertainty of ADCP streamflow measurements is exposure time (total time spent sampling the flow). Preliminary results of an effort to confirm this conclusion are presented herein. Forty-six transects were made with an ADCP during steady flow conditions on the Fox River at Montgomery, IL. Mean discharges were computed for 1, 2, 4, 6, and 8 transects using the Fox River data. Percent differences were computed by subtracting the mean discharge for all 46 transects from the 1, 2, 4, 6, and 8 transect mean discharges. The percent differences were plotted versus measurement exposure time and superimposed on data collected previously by Oberg and Mueller (2007). The results of this analysis confirm that exposure time is a critical factor in measurement uncertainty.

INTRODUCTION

In a typical streamflow measurement made using conventional methods (Rantz et al. 1982), the current meter is exposed to the flow field from approximately 15 to 30 min depending on depth of the flow. The resulting measurement lasts 1 hour or longer. Using an acoustic Doppler current profiler (ADCP) a complete transect (single pass across the stream) and, thus, a measurement of streamflow can be made in less than 2 min. The U.S. Geological Survey (USGS) currently (2007) requires that at least four transects be averaged for a complete discharge measurement, except in rapidly changing flow (Oberg et al. 2005). Therefore, it is possible to complete a streamflow measurement using an ADCP with less than 8 min of exposure time. Although use of four transects is common practice, little or no published research is available that suggests that four transects is the optimal approach for making streamflow measurements with ADCPs.

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Oberg and Mueller (2007) analyzed a dataset of ADCP streamflow measurements to determine the proper number of transects necessary for obtaining a desired accuracy goal. This dataset contained streamflow measurements made with an ADCP, each having 12 transects made under steady flow conditions. Stationarity of the discharges in the dataset was evaluated by linear regression of discharge with time and visually screening plots of discharge versus time. Only data sets that passed the visual screening and that had a slope coefficient with a p-value greater than 0.4 were used in their analysis.

Oberg and Mueller (2007) computed uncertainties associated with 1, 2, 4, 6, and 8 transect means as the percent deviation from the mean of 12 transects. The uncertainty at two standard deviations associated with the 4 transect mean was +/-5.4 percent, comparing well with the commonly stated accuracy of +/- 5 percent for discharge measurements. However, Oberg and Mueller (2007) found that the uncertainty of the measured discharge is more dependent on the exposure time of the instrument, than on the number of transects collected. Exposure time refers to the total amount of time spent sampling the flow. This conclusion is analogous to the sampling time requirements for current-meter measurements as specified in standards and procedures used by many agencies throughout the world (ISO 1979 and Rantz et al. 1982). Oberg and Mueller's (2007) analysis was based on using varying numbers of transects from 29 different groups of transects. They showed the relation between exposure time and the percent deviation from the mean discharge for 12 transects (Fig. 1). For a specified number of passes, as the exposure time increases, the uncertainty associated with the measurement decreases.

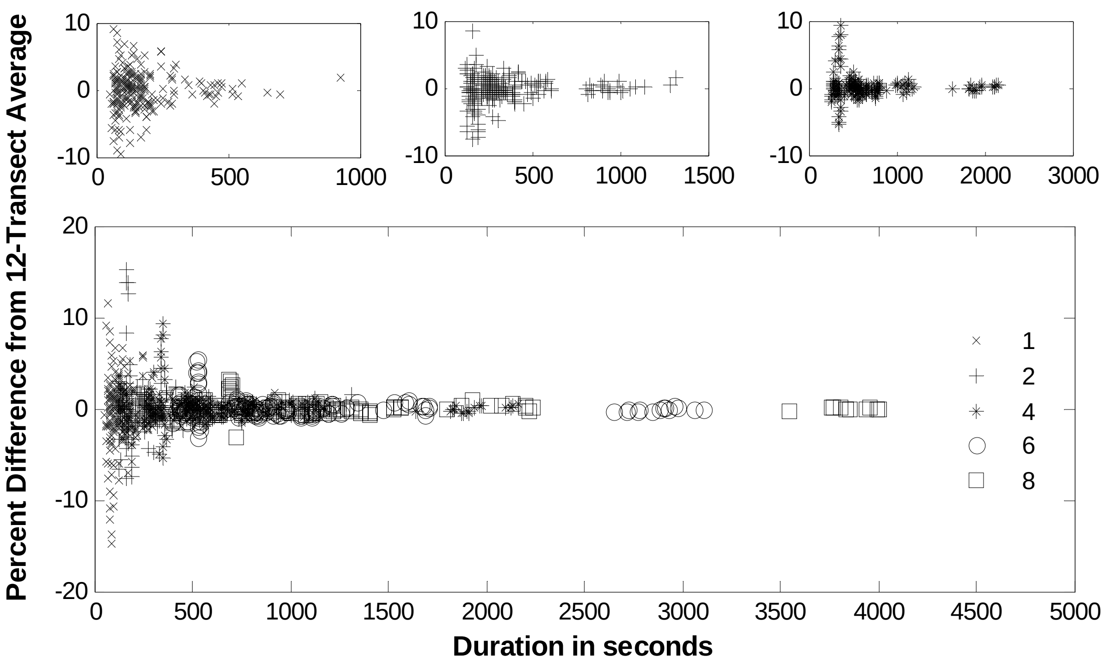

Fig. 1. Relation between measured discharge uncertainty and exposure time for ADCP measurements, from Oberg and Mueller (2007).

The uncertainty associated with ADCP measurements for instrument exposure times from 500 to 1000 s, from 1000 to 1500 s, and from 1500 to 2000 s are +/- 2.4, 1.8, and 1.2 percent, respectively. Statistical analysis of their data indicated that an uncertainty of ±5 percent in the measured discharge should be achieved by ADCP measurements with an exposure time of at least 720 s or greater, regardless of the number of transects made. However, a minimum of two transects should be made (with exposure time for all passes > 720 s) in order to minimize the possibility of directional bias in ADCP measured streamflow.

Although this analysis seems fairly robust, a number of questions remain. For example, is exposure time just a surrogate for stream width, which is also related to stream depth? Is boat speed an important variable independent of stream width? Although Oberg and Mueller (2007) presented convincing evidence that exposure time is not a surrogate for width, it was necessary to examine some of these questions. The purpose of this paper is to summarize preliminary results of the authors' attempt to validate the conclusion of Oberg and Mueller (2007) regarding exposure time for ADCP streamflow measurements.

DATA COLLECTION

In order to validate the conclusion regarding the exposure time for ADCP streamflow measurements, the following approach was used. Sites for measurements were chosen where the flow appeared to be steady. The ADCP was configured for the site conditions using the guidelines provided by the USGS and the instrument manufacturer. A streamflow measurement using an ADCP was made using standard procedures (Oberg et al. 2005) with the mean boat speed for the measurement less than or equal to the mean water speed. The measured discharge consisted of 8-12 transects instead of the normal 4 transects. After this measurement was completed, the mean boat speed was computed for all transects. Subsequently, the following measurements were made:

- 4-6 transects were obtained at 0.5 times the mean boat speed,
- 2-4 transects were obtained at 0.25 times the mean boat speed,
- 12 transects were obtained at 1.5 times the mean boat speed, and
- 12 transects were obtained at 2 times the mean boat speed.

This procedure should be repeated for several different measuring conditions using different ADCP configurations to provide a more complete validation.

Two data sets have been collected to-date (July 2007). The first data set was collected using a 1200 kHz Rio Grande ADCP using water mode 12 on the Gunnison River near Grand Junction, CO, in September 2006. (Note: Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.) The mean flow for the Gunnison River measurement was 66.5 m^3/s. The second data set was collected using a 600 kHz Rio Grande ADCP using water mode 5 on the Fox River at Montgomery, IL, in July 2007. The mean flow for the Fox River measurement was 17.2 m^3/s.

ANALYSIS OF EXPOSURE TIME DATA

The data collected were processed and reviewed using procedures for data review outlined by Oberg et al. (2005). The processing and review included screening out obvious errors in the data sets, adjusting the extrapolation methods as necessary, and correcting any problems observed in the field. Thirty-four transects from the Gunnison River measurements and 46 transects from the Fox River measurements were available for analysis. For both data sets, the discharges for each transect were within 5 percent of the mean of all measured discharges.

The Gunnison and Fox River data sets were analyzed by means of linear regression of discharge with time and visual screening of plots of discharge versus time to determine whether the measured discharges were stationary. The Gunnison River data set indicated a possible decreasing trend in discharge over time. Although the net change in discharge is only approximately 1 m^3/s, these data were not included in further analyses and are not presented in this paper. The Fox River data set showed no trend in discharge versus time (Fig. 2).

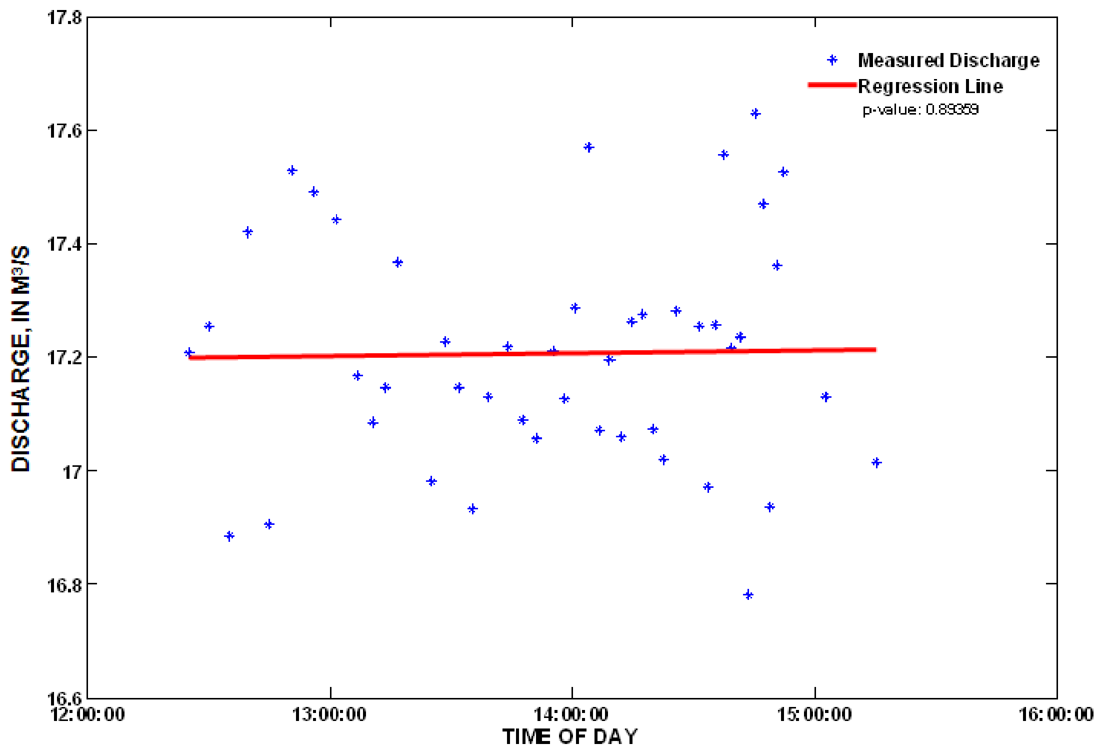

Fig. 2. Measured discharges and trend lines for ADCP discharge measurements made July 2, 2007, Fox River at Montgomery, IL.

The Fox River data were analyzed to validate the previous work. Since the data from the Fox River were from a single site with variable boat speeds, the exposure time was not a direct function of stream width, depth, and boat speed as is possible when using multiple sites. The 1, 2, 4, 6, and 8 transect mean discharges were computed from the Fox River data for each group of data having similar boat speeds. Running means were computed using sequential data for the 2, 4, 6, and 8 transect means because multiple transect measurements are measured sequentially. Percent differences were computed by subtracting the mean discharge for all 46 transects from the 1, 2, 4, 6, and 8 transect mean discharges. The results of these computations were plotted with the results of Oberg and Mueller (2007) and are shown in Fig. 3. The data from the Fox River fall within and show a similar trend to the data from Oberg and Mueller (2007). Differences in exposure time within the groups of 1, 2, 4, 6, or 8 transect means are due to changes in mean boat speed, as are longer exposure times for fewer transects in a mean. The reduced scatter in the Fox River data (Fig. 3) is most likely due to the flow conditions and water mode used to obtain the

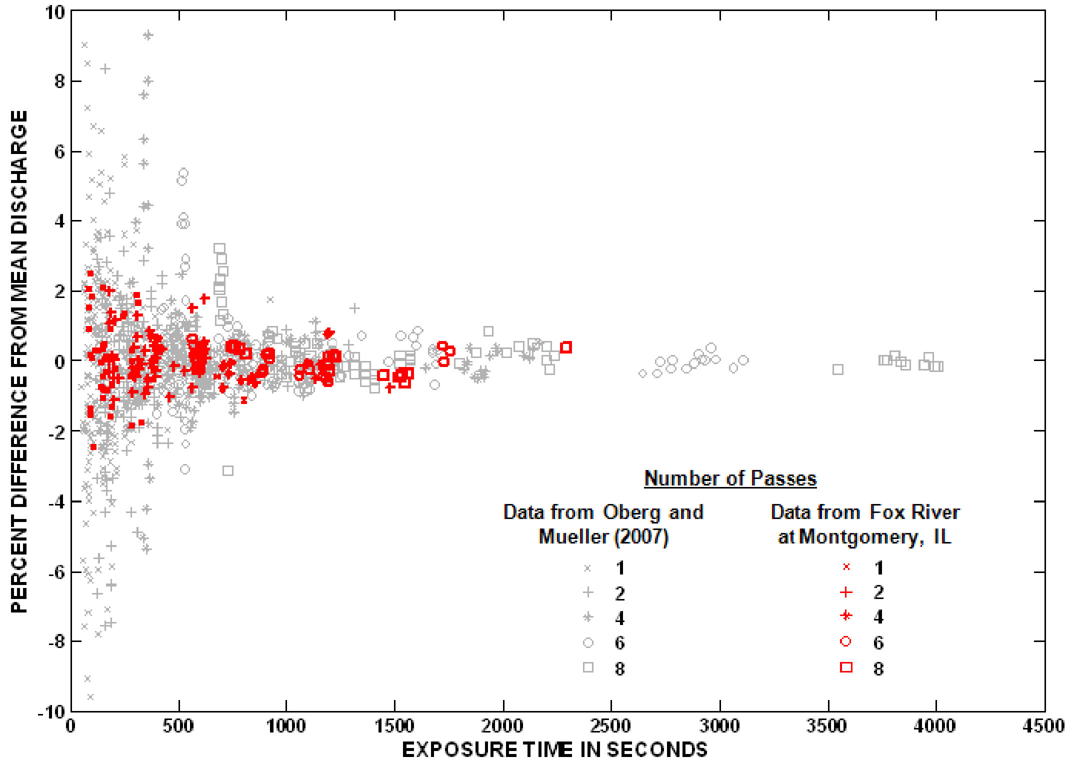

Fig. 3. Relation between measured discharge uncertainty and exposure time for ADCP measurements. Symbols in red are data from Fox River at Montgomery, IL; symbols in gray are from Fig. 5 in Oberg and Mueller (2007).

measurements. The results of this analysis provide additional confirmation of the conclusion from previous work, namely that reductions in the uncertainty of streamflow measurements made with ADCPs are more dependent on exposure time than on the number of transects made per ADCP streamflow measurement. Although only one new data set is presented, it seems apparent that the effect of exposure time on the uncertainty of the measured discharge is independent of stream width, depth and a range of boat speeds. As stated by Oberg and Mueller (2007), a minimum of two transects should be made, with an exposure time for all transects greater than or equal to 720 s, in order to achieve an uncertainty of ±5 percent.

Future work on this topic should include:

1. Analysis of the Gunnison River data to determine whether the small time trend in discharge is statistically significant or can be removed.
2. Collection and analysis of data from different sites and for different measurement conditions to further confirm the dependence of uncertainty on exposure time.
3. Theoretical and empirical analysis of temporal /spatial sampling with ADCPs.

SUMMARY AND CONCLUSIONS

Previous work using data collected for the purpose of validating streamflow measurements using ADCPs has concluded that a critical factor in reducing the uncertainty of ADCP streamflow measurements is exposure time of the instrument. An approach for validating this conclusion is presented. Two validation data sets were obtained using measurements on the Gunnison River near Grand Junction, CO, and the Fox River at Montgomery, IL. However only results from the Fox River measurements were used in data analysis due to an apparent time trend in the Gunnison River discharges. Mean discharges were computed for 1, 2, 4, 6, and 8 transects using the Fox River data. Percent differences were computed by subtracting the mean discharge for all 46 transects from the 1, 2, 4, 6, and 8 transect mean discharges. The percent differences were plotted versus exposure time and superimposed on data collected previously by Oberg and Mueller (2007). The results of this analysis indicate that exposure time is a critical factor in measurement uncertainty.

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