# Validation of Exposure Time for Discharge Measurements made with Two Bottom-Tracking Acoustic Doppler Current Profilers

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*Abstract*-**Previous work by Oberg and Mueller of the U.S. Geological Survey in 2007 concluded that exposure time (total time spent sampling the flow) is a critical factor in reducing measurement uncertainty. In a subsequent paper, Oberg and Mueller validated these conclusions using one set of data to show that the effect of exposure time on the uncertainty of the measured discharge is independent of stream width, depth, and range of boat speeds. Analysis of eight StreamPro acoustic Doppler current profiler (ADCP) measurements indicate that they fall within and show a similar trend to the Rio Grande ADCP data previously reported. Four special validation measurements were made for the purpose of verifying the conclusions of Oberg and Mueller regarding exposure time for Rio Grande and StreamPro ADCPs. Analysis of these measurements confirms that exposure time is a critical factor in reducing measurement uncertainty and is independent of stream width, depth, and range of boat speeds. Furthermore, it appears that the relation between measured discharge uncertainty and exposure time is similar for both Rio Grande and StreamPro ADCPs. These results are applicable to ADCPs that make use of broadband technology using bottom-tracking to obtain the boat velocity. Based on this work, a minimum of two transects should be collected with an exposure time for all transects greater than or equal to 720 seconds in order to achieve an uncertainty of ±5 percent when using bottom-tracking ADCPs.**

## INTRODUCTION

The U.S. Geological Survey (USGS) as well as international agencies have collaborated to conduct field validations of acoustic Doppler current profiler (ADCP) discharge measurements. Field validations of commercially-available ADCPs were conducted by comparing discharge measurements made with ADCPs to discharge obtained by means of concurrent mechanical current-meter measurements, stable stage-discharge rating curves, salt-dilution measurements, or acoustic velocity meters. Data from 1,032 transects, comprising 100 discharge measurements were analyzed from 22 sites in the U.S., Canada, Sweden, and The Netherlands. These analyses showed that bottom-tracking broadband ADCP discharge measurements are unbiased when compared to the reference discharges regardless of the water mode used for making the measurement [2].

Analysis of exposure time for the above validation measurements indicated that in order to achieve an uncertainty of ±5 percent, ADCP discharge measurement exposure time (total time spent sampling the flow) should be 720 seconds (s) or greater, regardless of the number of transects made. However, a minimum of two transects should be made (with exposure time for all transects > 720 s) in order to minimize the possibility of directional bias in ADCP measured discharge [2].

StreamPro ADCPs are commonly used to measure flows in wadeable streams. (Note: Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.) Rehmel [4] compared discharge measurements made with a StreamPro ADCP to discharge obtained by means of concurrent mechanical current-meter measurements, other acoustic meters, or stable stage-discharge rating curves. The StreamPro-measured discharges showed no indication of bias compared to the reference discharge measurements.

Oberg and Mueller [3] validated the conclusions of [2] by showing that the effect of exposure time on the uncertainty of the measured discharge is independent of stream width, depth, and range of boat speeds. However, only one data set was available for analysis at that time. Subsequently, additional data sets have become available for analysis.

The purpose of this paper is to present the results of analyses of additional ADCP discharge measurements for validating the conclusions of [2] and [3] regarding exposure time for ADCP discharge measurements. Eight StreamPro ADCP discharge measurements are analyzed and compared to results for Rio Grande ADCPs [2]. Four special validation measurements made with both Rio Grande and StreamPro ADCPs are also analyzed for the purpose of verifying that exposure time is a critical factor in reducing measurement uncertainty. The following sections describe data collection, data analysis, and results.

## StreamPro ADCP Exposure Time

The StreamPro ADCP discharge measurements were made at eight different sites during steady flow conditions. The procedures used for data collection and analysis by [2] were followed for the StreamPro measurements. The StreamPro data sets consisted of at least 12 transects with each transect made at approximately the same boat speed.

The StreamPro 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. Measurements where the discharges changed significantly (p-value of the regression equation slope < 0.4) over the period of data collection were not considered in the StreamPro analysis. Measurements where the discharges changed significantly over time were not detrended because there were only a few transects available to establish a trend and only a few concurrent gage-height records were available to confirm the trend.

For the StreamPro measurements, the 1, 2, 4, 6, and 8 transect mean discharges were computed sequentially from each set of 12 transect groups. Percent differences were computed by subtracting the mean discharge for the 12 transects from the 1, 2, 4, 6, and 8 transect mean discharges and dividing by the mean discharge for the 12 transect groups.

The results of these computations are plotted with the results of [2] and are shown in figure 1. The StreamPro data fall within and show a similar trend to the data from [2]. These data confirm that exposure time is a critical factor in reducing measurement uncertainty for discharge measurements made with StreamPro ADCPs. Furthermore, it appears that the relation between uncertainty and exposure time is similar for both types of ADCPs.

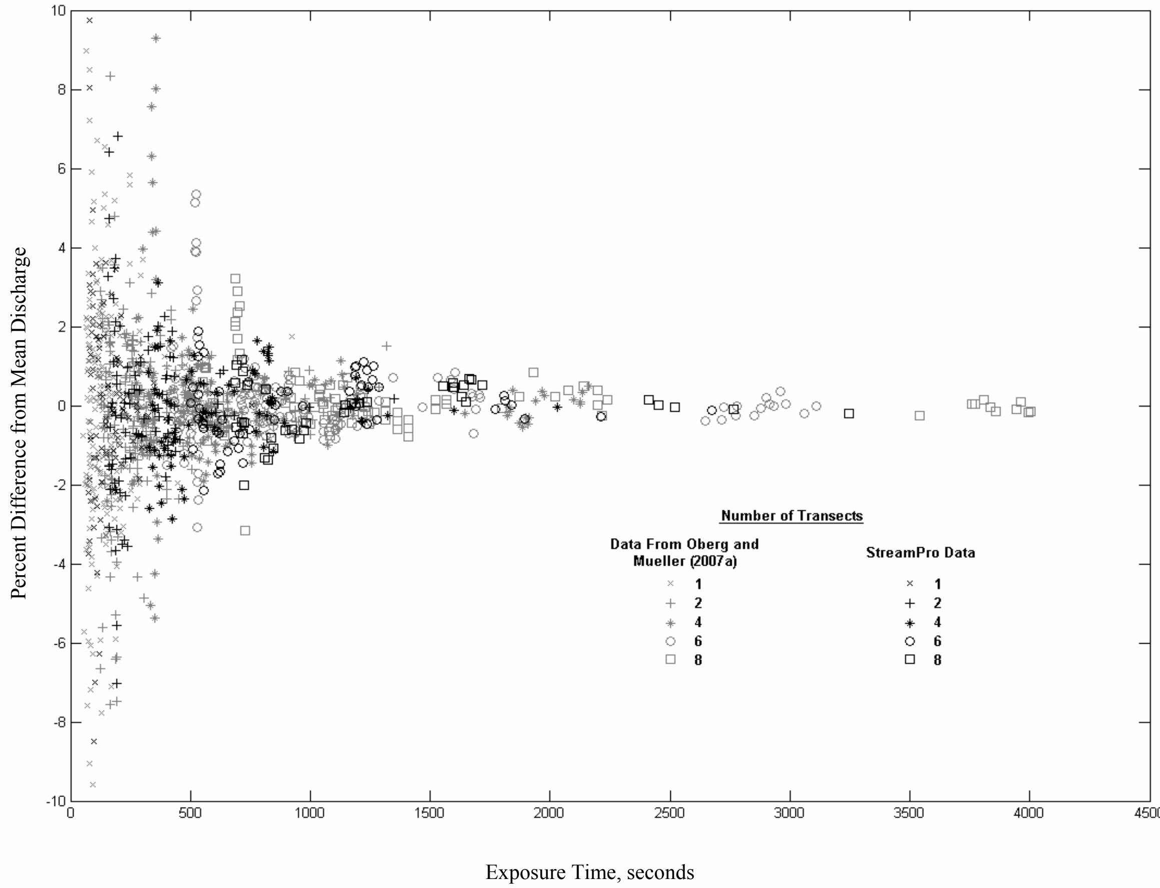


Figure 1. Relation between measured discharge uncertainty and exposure time for StreamPro and Rio Grande ADCPs.

## DATA COLLECTION FOR VALIDATING EXPOSURE TIME

Discharge measurements were made for the purpose of validating the relation between exposure time and uncertainty and to insure that this relation was not dependent on stream width, stream depth, or boat speed. The following criteria were used for collecting ADCP discharge measurements for this purpose: steady flow, relatively uniform flow, and suitability for ADCP discharge measurements. The ADCP was configured for the site conditions using the guidelines provided by the USGS and the instrument manufacturer. A discharge measurement using an ADCP was made using standard procedures [1] with the mean boat speed for the measurement less than or equal to the mean water speed.

For the ADCP measurements, a discharge measurement was made consisting of 8-12 transects, instead of the normal 4 transects [1]. 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.

Four data sets of this type have been collected to date (January 2008). Transects were not obtained at 1.5 times the mean boat speed for the Gunnison River near Grand Junction, Colorado data set. A table summarizing the four special validation measurements is shown below (table 1).

Table 1. Summary of validation sites.

| Validation Site | Date | ADCP Model | Frequency, kHz | Water Mode | Number of Transects | Discharge, $m^3/s$ |
|---|---|---|---|---|---|---|
| Gunnison River near Grand Junction, Colorado | Sept. 2006 | Rio Grande | 1200 | 12 | 34 | 66.5 |
| Fox River Upstream Dam at Montgomery, Illinois | Jul. 2007 | Rio Grande | 600 | 5 | 46 | 17.2 |
| Fox River Downstream Dam at Montgomery, Illinois | Aug. 2007 | Rio Grande | 600 | 12 | 38 | 316 |
| Salt Fork River near St. Joseph, Illinois | Jan. 2008 | StreamPro | 2000 | 12 | 46 | 3.77 |

## VALIDATION OF EXPOSURE TIME

The discharge measurement data sets were processed and reviewed using procedures for data review outlined by [1]. 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.

The 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. Oberg and Mueller [3] previously analyzed the Fox River Upstream Dam measurements, because at that time this was the only data set where the discharge did not change significantly (p-value of the regression equation slope > 0.4) during the period of data collection.

The Fox River Downstream Dam and the Gunnison River data sets both indicated a possible decreasing trend in discharge over time. Gage-height records collected at nearby streamflow-gaging stations during the period of data collection confirmed the decreasing trend in discharge over time. These data sets were detrended by removing the best straight-line fit from the data, returning noise about the abscissa. The noise was added to the mean of all transects from the raw data set yielding a detrended data set with the same average value as the raw data set. The Gunnison River and Fox River Downstream Dam raw stationarity plots along with the detrended stationarity plots are shown below in figures 2a and 2c. The Fox River Upstream Dam data analyzed previously by [3] were included for completeness (fig. 2b). The Salt Fork River data collected using a StreamPro ADCP are shown in figure 2d.

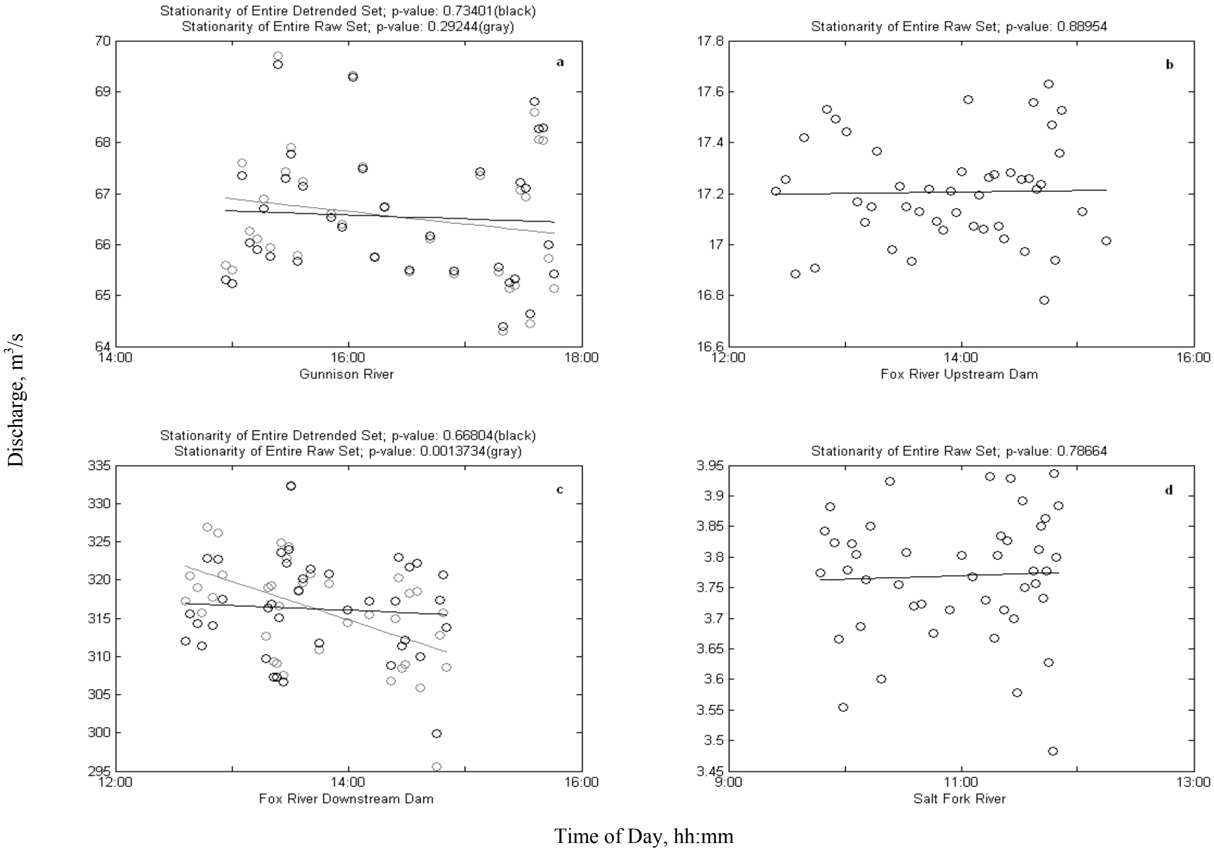


Figure 2. Stationarity of validation sites. (a) Gunnison River, Colorado (b) Fox River Upstream Dam, Illinois (c) Fox River Downstream Dam, Illinois (d) Salt Fork River, Illinois.

The exposure time was not a direct function of stream width, depth, or boat speed as is possible when using multiple sites because each of these measurements were from a single site with variable boat speeds. For the validation site measurements, the 1, 2, 4, 6, and 8 transect mean discharges were computed from each data set 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 transects from the 1, 2, 4, 6, and 8 transect mean discharges and dividing by the mean discharge for all transects (figs. 3a-d).

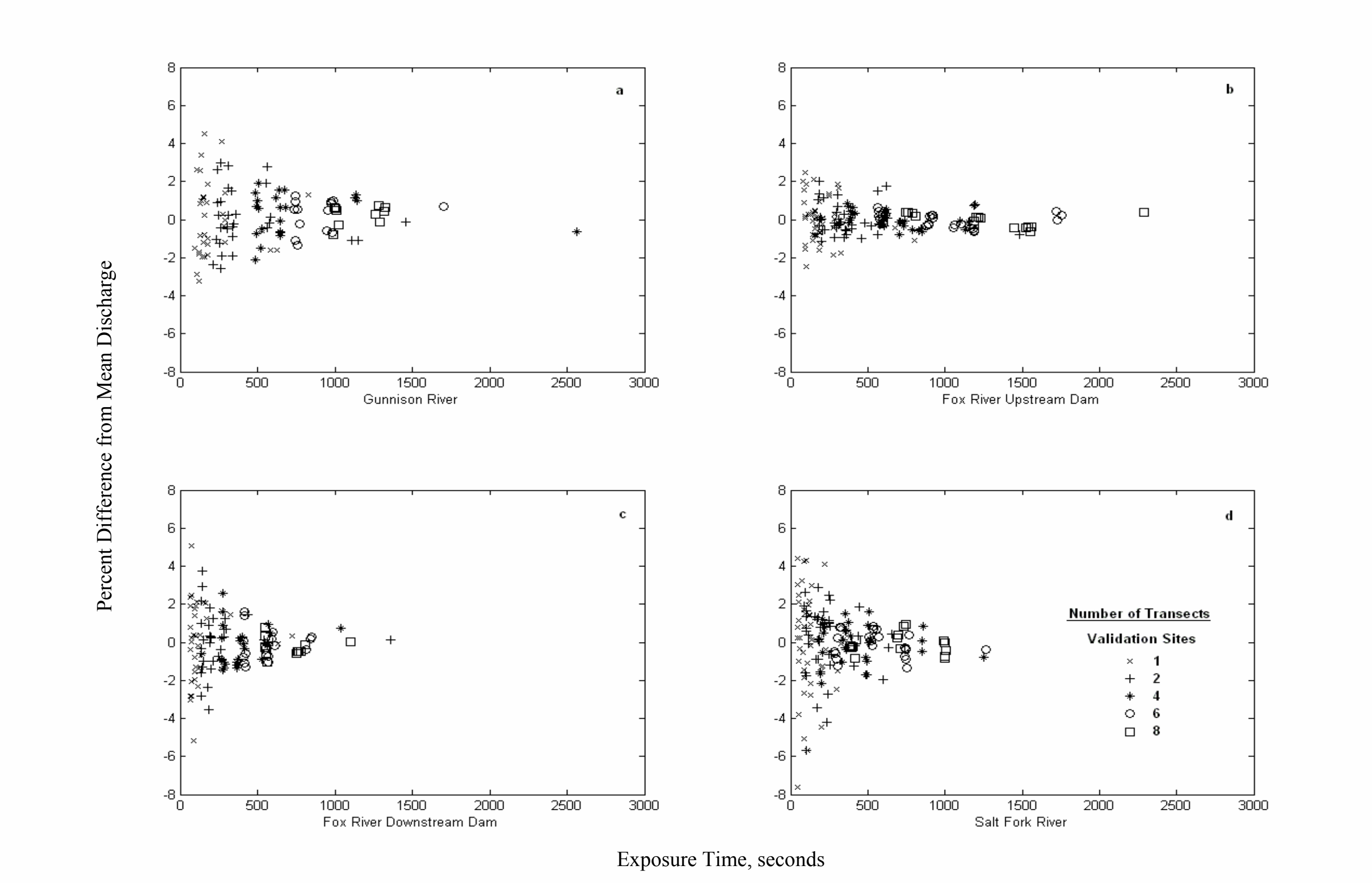


Figure 3. Relation between measured discharge uncertainty and exposure time for validation sites. (a) Gunnison River, (b) Fox River Upstream Dam, (c) Fox River Downstream Dam, (d) Salt Fork River.

The results of these computations were plotted with the results of [2] and are shown in figure 4. The data fall within and show a similar trend to the data from [2]. 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.

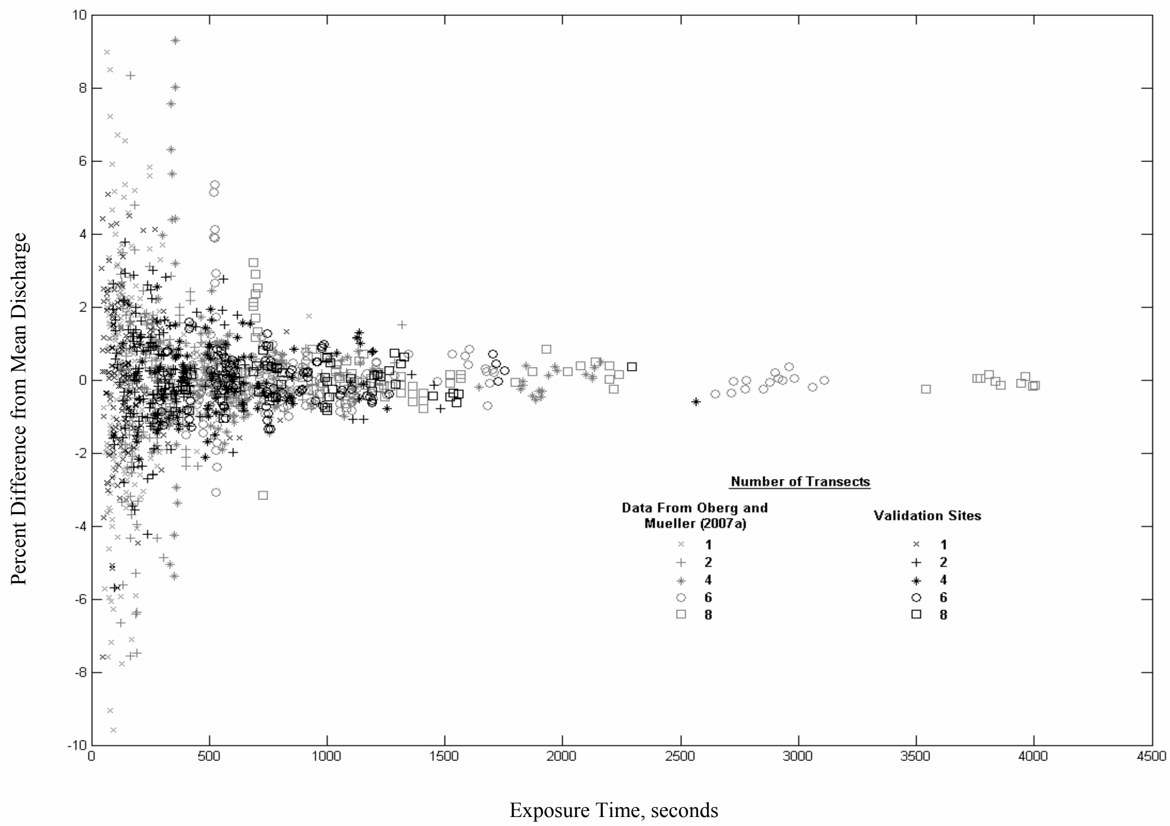


Figure 4. Relation between measured discharge uncertainty and exposure time for StreamPro and Rio Grande ADCP validation sites.

The results of this analysis validate the conclusions from previous work, namely that the reduction in the uncertainty of discharge measurements made with ADCPs is more dependent on exposure time than on the number of transects made per ADCP discharge measurement. It seems apparent that the effect of exposure time on the uncertainty of the measured discharge is independent of stream width, depth, and range of boat speeds. As stated by [2], these results indicate that for ADCP discharge measurements made with bottom-tracking as a reference, 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.

An attempt was made to normalize the exposure time for ADCP discharge measurements in the measured discharge uncertainty and exposure time plots. One physically meaningful parameter for this kind of analysis is stream width divided by boat speed. However, by definition, stream width divided by boat speed equals exposure time. Normalizing exposure time by this parameter did not produce more meaningful results. Other parameters attempting to normalize the exposure time did not provide further insight into data analysis.

Future work on this topic could include:

1. Collection and analysis of data from different sites and for different measurement conditions using Global Positioning System (GPS) to further confirm the dependence of uncertainty on exposure time.
2. Theoretical and empirical analysis of temporal/spatial sampling with ADCPs.

## SUMMARY AND CONCLUSIONS

Previous work by [2] using data collected for the purpose of validating discharge measurements using ADCPs has concluded that a critical factor in reducing the uncertainty of ADCP discharge measurements is exposure time of the instrument. Rehmel [3] validated the conclusions of [2] by showing that the effect of exposure time on the uncertainty of the measured discharge is independent of stream width, depth, and range of boat speeds. The results of analyses of additional ADCP discharge measurements verify the conclusions of [2] and [3] regarding exposure time for ADCP discharge measurements.

Eight StreamPro ADCP measurements fall within and show a similar trend to the Rio Grande ADCP data from [2]. These measurements verify the conclusions of [2] that the exposure time is a critical factor in reducing the uncertainty of ADCP discharge measurements made with StreamPro ADCPs. Furthermore, it appears that the relation between uncertainty and exposure time is similar for both Rio Grande and StreamPro ADCPs.

Four special validation measurements made with Rio Grande and StreamPro ADCPs fall within and show a similar trend to the Rio Grande ADCP data from [2]. Two data sets showed a decreasing trend of discharge over time. The trend was removed from the data before further analysis. These measurements verify the conclusions of [2] that the exposure time is a critical factor in reducing the uncertainty of ADCP discharge measurements made with Rio Grande and StreamPro ADCPs. Furthermore, these measurements from single sites with variable boat speeds verified that the exposure time was not a direct function of stream width, depth, or boat speed as is possible when using multiple sites.

The physically meaningful parameter for normalizing exposure time, stream width divided by boat speed, did not produce more meaningful results. As stated by [2], 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. These results are only applicable to bottom-tracking ADCPs with broadband technology.

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