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Acoustic Doppler Current Profiler Applications Used in Rivers and Estuaries by the U.S. Geological Survey

The U.S. Geological Survey (USGS) has collected streamflow information for the Nation's streams since 1889. Streamflow information is used to predict floods, manage and allocate water resources, design engineering structures, compute water-quality loads, and operate water-control structures. The current (2007) size of the USGS streamgaging network is over 7,400 streamgages nationwide. The USGS has progressively improved the streamgaging program by incorporating new technologies and techniques that streamline data collection while increasing the quality of the streamflow data that are collected.

The single greatest change in streamflow measurement technology during the last 100 years has been the development and application of high frequency acoustic instruments for measuring streamflow. One such instrument, the acoustic Doppler current profiler (ADCP), is rapidly replacing traditional mechanical current meters for streamflow measurement (Muste and others, 2007). For more information on how an ADCP works see Simpson (2001) or visit *http://hydroacoustics.usgs.gov/*.

The USGS has used ADCPs attached to manned or tethered boats since the mid-1990s to measure streamflow in a wide variety of conditions (fig. 1). Recent analyses have shown that ADCP streamflow measurements can be made with similar or greater accuracy, efficiency, and resolution than measurements made using conventional current-meter methods (Oberg and Mueller, 2007). ADCPs also have the ability to measure streamflow in streams where traditional current-meter measurements previously were very difficult or costly to obtain, such as streams affected by backwater or tides.

In addition to streamflow measurements, the USGS also uses ADCPs for other hydrologic measurements and applications, such as computing continuous records of streamflow for tidally or backwater affected streams, measuring velocity fields with high spatial and temporal resolution, and estimating suspended-sediment concentrations. An overview of these applications is provided below.

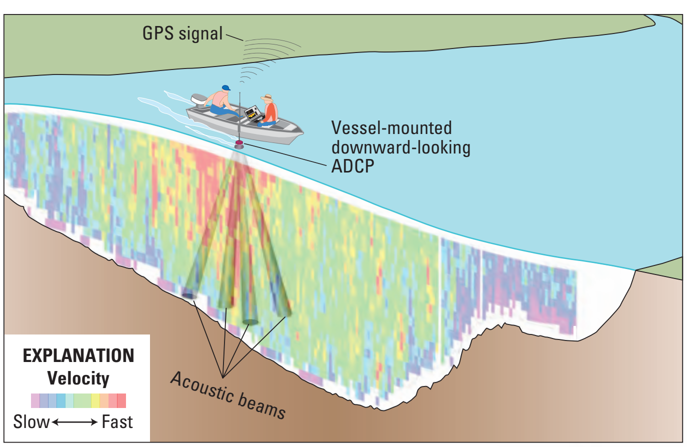

Figure 1. An ADCP attached to a manned boat for use in measuring streamflow.

Streamflow Measurements

The first attempt to use an ADCP to measure streamflow was made in 1982 on the Mississippi River by Christensen and Herrick (1982) as part of work conducted for the USGS. In 1985, the USGS purchased an ADCP and developed software for making streamflow measurements (Simpson, 2001). Since then, ADCPs have proven to be useful tools for measuring streamflow throughout the country. For many measurement conditions, the ADCP samples more of the flow (spatially), as compared to traditional mechanical current-meter measurements, resulting in more detailed streamflow information. Typically, it takes 45–60 minutes to make a mechanical current-meter streamflow measurement using the two-point method (Rantz and others, 1982), a 40-second velocity sampling interval, and approximately 25 vertical measurement sections. An ADCP streamflow measurement can be made at the same section in 15–20 minutes. This increase in efficiency results in cost savings with improved safety conditions, and more detailed streamflow data. ADCP streamflow measurements have been shown to have an uncertainty of 4.5 percent or less (Oberg and Mueller, 2007). Traditional current-meter measurements with a 40-second sampling interval and approximately 25 vertical measurement sections and uniform flow are estimated to have an uncertainty of about 5.5 percent (Pelletier 1988).

Side-mounted ADCP on U.S. Geological Survey work boat (photograph by James Duncker, USGS).

An example of how personnel from the USGS Indiana Water Science Center were able to make more streamflow measurements with fewer personnel using ADCPs during a recent flood in central Indiana is given in table 1. Because ADCPs can be used to make streamflow measurements within minutes, they often are used to measure unsteady flows, such as tidally affected streams, or unsteady flows near dams or other control structures (Simpson, 2001). ADCPs also are able to measure extreme low-flow conditions that could not have been measured by using conventional methods.

Table 1. Resources used to measure a flood in central Indiana with mechanical current meters and with ADCPs.

Flood/method	Number of streamflow measurements during 10 days	Average time per streamflow measurement, in minutes	Number of hydro-graphers
January 1991/Current meter	52	96	11
July 2003/ADCP	62	18	6

In 2007, 21 percent of all USGS streamflow measurements were made with ADCPs, this includes 71 percent of all streamflow measurements made from a boat, cableway, or bridge. During this same period, approximately 250 ADCPs were used for making streamflow and velocity measurements in USGS water science programs.

Index-Velocity Method

With ADCPs, measuring and computing continuous records of streamflow can be conducted in challenging environments. Until the advent of ADCPs, it was difficult or impractical to accurately compute streamflow records on tidally affected rivers or rivers affected by backwater. Two-beam ADCPs can be attached to a fixed structure, such as a pile or bridge pier, and used to measure velocity horizontally for a portion of a channel cross section (fig. 2). The measured velocity at a fixed point in the cross section can be used to compute continuous streamflow records. When a site is subject to periods of vertically stratified bidirectional flow, an ADCP can be mounted at the bottom of the streambed in a vertically oriented or “up-looking” position, and velocities can be measured at multiple points or “bins” throughout the water column (fig. 3).

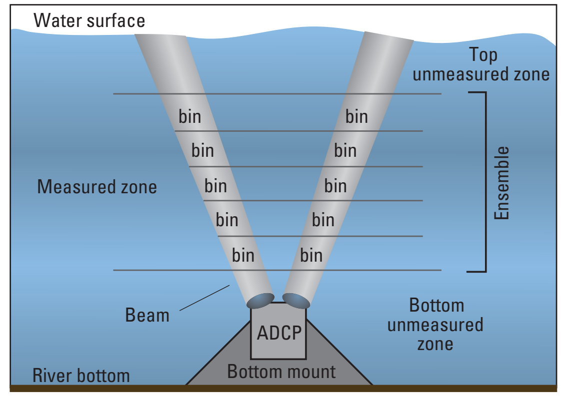

Figure 3. Schematic diagram of a bottom-mounted ADCP (Wall and others, 2006).

Measured velocity and stage or water-surface elevation data are used with the index-velocity method (Ruhl and Simpson, 2005) to compute continuous records of streamflow. In the index-velocity method, two ratings (or relations) are developed and maintained—a stage-area rating and an index-velocity rating. The stage-area rating is developed by surveying a stable cross section in the stream near the permanently mounted ADCP. The channel area for a given stage then can be determined from the surveyed cross section. An index-velocity rating (fig. 4) is developed by using the relation between the measured mean cross-sectional velocity at the surveyed cross section and the simultaneous index velocity measured with the permanently mounted ADCP.

Continuous records of stage and index velocity are converted to a channel area and mean velocity using the respective ratings. The channel area then can be multiplied by the mean velocity over time to compute a continuous record of streamflow as illustrated in figure 5.

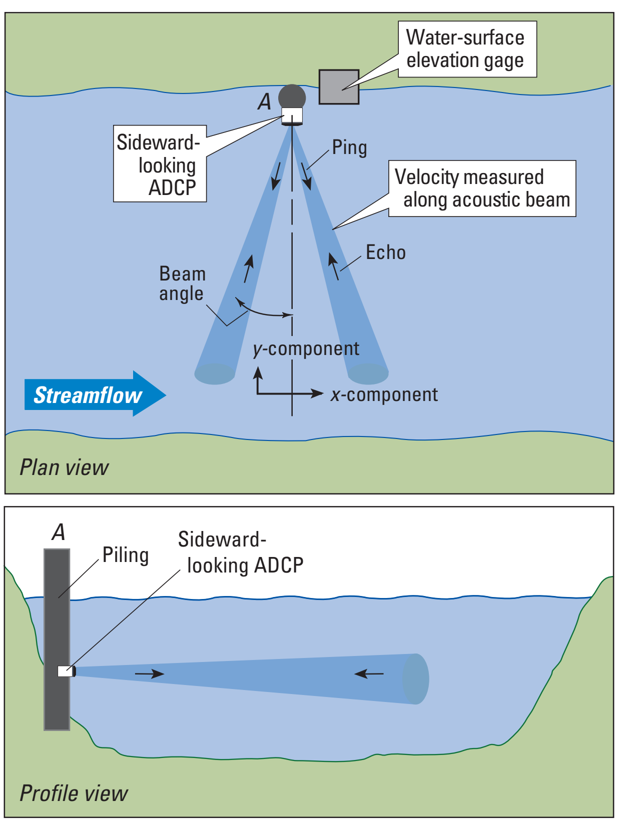

Figure 2. Installation of a fixed ADCP for use in measuring index velocity (Ruhl and Simpson, 2005).

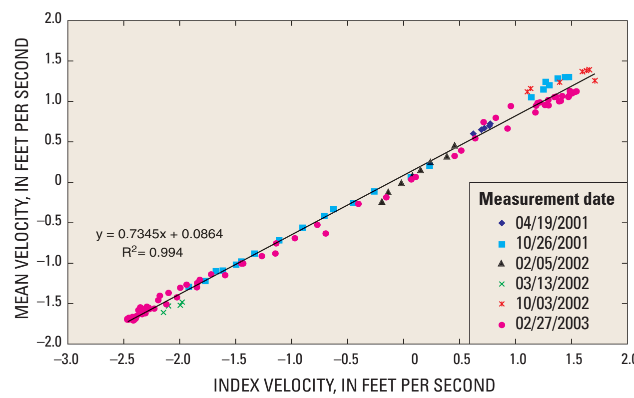

Figure 4. An example index-velocity rating (Hittle, 2005).

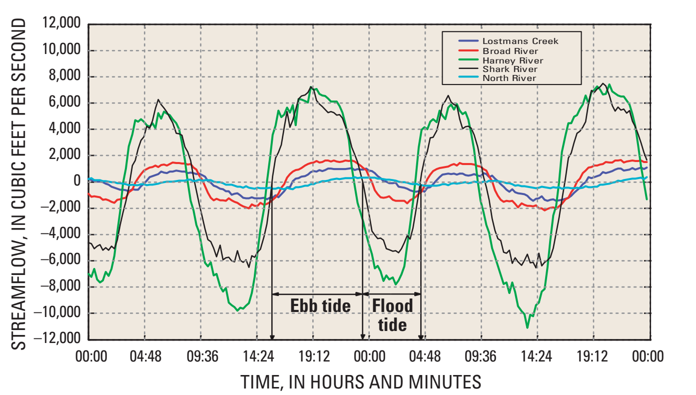

Figure 5. Typical instantaneous streamflow cycle for five stations along the southwest coast of the Everglades National Park (Levesque, 2004).

Measuring Velocity Fields

The USGS has used two-dimensional horizontal water velocity measured by an ADCP to map velocities in a stream or estuary as shown in figure 6. This figure illustrates how Dinehart and Burau (2005) used successive surveys with an ADCP and a differential global positioning system (DGPS) to analyze the flow dynamics of a section of a tidal river.

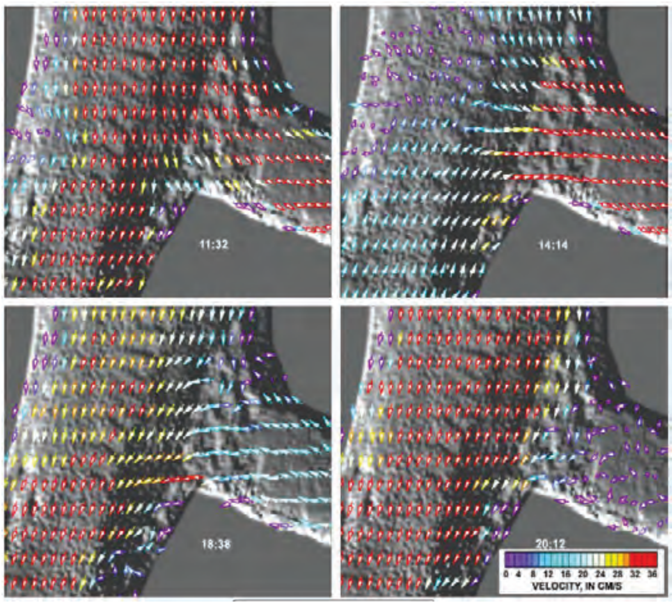

Figure 6. Visualization of two-dimensional velocities measured with an ADCP (Dinehart and Burau, 2005; cm/s, centimeter per second).

The application of multidimensional numerical hydraulic models is often facilitated with velocity data collected with ADCPs and a DGPS. Wagner and Mueller (2004) used ADCPs to collect depth-averaged velocity data to both calibrate and validate a two-dimensional (2-D) flow model of the Ohio River near Olmsted, Illinois. A single ADCP dataset for model calibration or validation, consisting of repeated ADCP measurements at 15 cross sections, could be collected in 1–2 days. Collecting the equivalent data using current meters would have required more than 1 week. Depth-averaged velocity measured by means of an ADCP and DGPS are shown in figure 7, along with simulated velocities from the 2-D model.

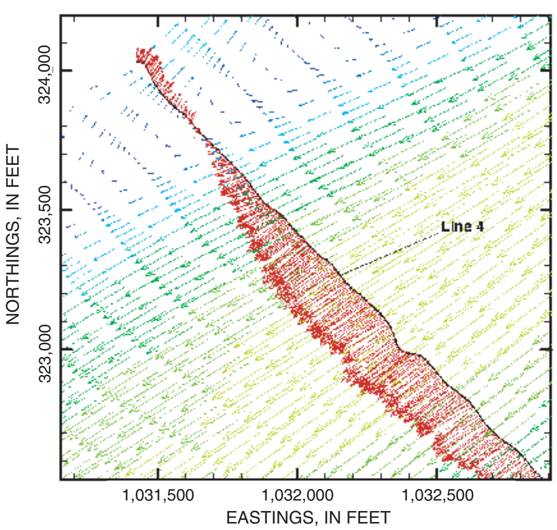

Figure 7. Velocities measured with an ADCP, which are overlaid (red) on velocities calculated by using a model (Wagner and Mueller, 2004).

Estimating Suspended Sediment

For each of the acoustic beams, the ADCP measures the acoustic intensity of signals backscattered to the ADCP by suspended particles in water. After correcting for the effects of temperature and voltage supplied to the ADCP and signal attenuation in the water column, the intensity of the acoustic backscatter is mainly a function of the suspended particles in the water. If the bulk of the suspended particles is composed of suspended sediment, then the backscatter intensity is mainly a function of suspended sediment and can be used as a spatial indicator of suspended-sediment concentration (fig. 8). USGS researchers are investigating and developing new methods for using acoustic backscatter as a surrogate for suspended-sand concentrations, as illustrated in figure 9.

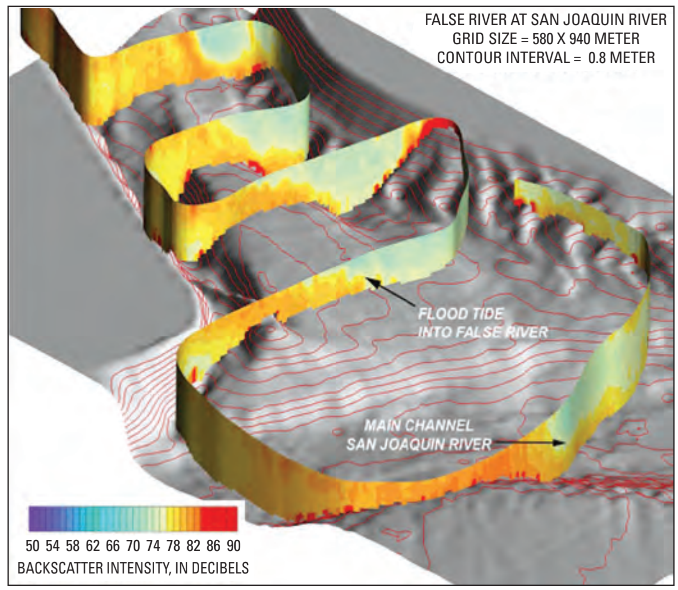

Figure 8. Backscatter intensity as an indicator of suspended-sediment dynamics along a boat track (Gray, 2005).

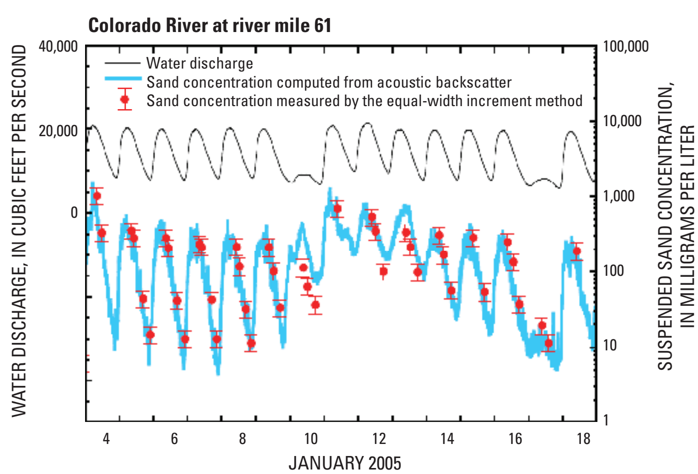

Figure 9. Comparison of estimated and measured suspended-sand concentration (Topping and others, 2007).

Summary

The emergence of hydroacoustic instruments, especially ADCPs, has allowed the USGS to adapt the technology for a variety of hydrologic measurements. The USGS uses ADCPs to make accurate streamflow measurements. Often these measurements can be made more efficiently than when using conventional methods. ADCPs permanently mounted in streams and tidal rivers are being used to compute continuous records of streamflow, and research is being conducted to use the same instruments and installations to estimate suspended-sediment concentrations. Calibration and validation of numerical models of flow and transport are facilitated by the rapid measurement of velocity fields using ADCP and DGPS technology. The USGS is leading the way in the implementation of the ADCP for riverine applications. As the technology evolves, the USGS tests ADCPs, develops new methods for measurement and analysis, and prepares guidance for ADCP applications to assure that high-quality data are collected.

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ADCPs are used on a variety of measurement platforms. *(A)* Manned boats (photograph by Paul Baker, USGS). *(B)* Tethered boats. *(C)* Remotely controlled boat.

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