

Analyzing ADV Data Using WinADV

Tony L. Wahl (1)

(1) Hydraulic Engineer, U.S. Bureau of Reclamation, Water Resources Research Laboratory,
P.O. Box 25007, Mail Code D-8560, Denver, CO 80225-0007; Phone: 303-445-2155;
Fax: (303) 445-6324; email: twahl@do.usbr.gov

Abstract

Since their introduction in 1993, acoustic Doppler velocity meters (ADV's) have quickly become valuable tools for laboratory and field investigations of flow in rivers, canals, reservoirs, the oceans, and around hydraulic structures and in laboratory scale models. The post-processing and analysis of ADV data present unique requirements compared to traditional current-metering equipment, due to the types of data obtained, the analyses that are possible, and the need for filtering of the data to ensure that technical limitations of ADV's do not adversely affect the quality of the results. One useful software tool for this purpose is the WinADV program, written by the author for use in the Bureau of Reclamation's Water Resources Research Laboratory, and made available to the public via the Internet since 1996. The program is designed for post-processing of real time data files (*.adv files) recorded by SonTek and Nortek ADV's, and offers powerful filtering and processing options that make it valuable for field and laboratory studies. The software has been regularly upgraded to maintain compatibility with new file formats, and also now has limited capability to analyze data collected by SonTek's Argonaut series of monostatic Doppler current meters. This paper describes the software and illustrates the application of some of its advanced features to typical hydraulic measurement situations.

Introduction

Acoustic Doppler velocity meters (ADV's) in a variety of configurations are widely used for laboratory and field measurement of 2- and 3-dimensional water velocities. The instruments are relatively rugged, easy to operate, and can be readily mounted and maneuvered within the flow field. Although the probe is inserted into the flow, the sensing volume is several centimeters away from all physical parts of the probe, so the presence of the probe generally does not distort the measurement. Velocities can be measured in any body of water containing suitable acoustic scatterers, or scattering particles may be added to the flow. Kraus et al. (1994) described the technical features and capabilities of ADV's.

To some degree, ADV's can fulfill the roles of a range of other flowmeters, including propeller-type current meters, hot-film probes, electromagnetic current meters, and laser-doppler velocimeters, depending on the methods used to collect and process the data. The primary data stream provided by an ADV is a time series of velocity vector components. The sample reporting rate can be varied from 0.1 Hz to 25 Hz on the instruments that operate at an acoustic frequency of 10 MHz, and sampling rates of up to 200 Hz are possible with some of the newer probes. Some averaging always takes place at the time of data collection, since the probes collect data internally at sampling rates higher than the nominal upper limit and average it before reporting and storing the data at the chosen sampling rate. Data processing needs can include additional averaging over time periods greater than 10 seconds, combining velocity components into resultant vectors, and computing basic statistics needed for analyses of turbulence. At times there is also a need for more sophisticated analyses. For example, power spectrum plots and

histograms can reveal periodicity and unusual distributions of velocity in the time series, and model scaling computations and adjustments for relative probe motion are commonly needed in laboratory studies to allow quick interpretation of data collected from scale models.

ADV's have several unique data processing requirements due to their method of operation and some of the inherent limitations of the acoustic Doppler measurement technique. Unlike many other measurement methods that exploit a physical property of water to obtain a velocity measurement (e.g., momentum to turn a propeller, mass flow through a magnetic field), ADV's actually measure the velocity of the scattering particles in the flow. As a result, the quality of the measurement is dependent on the presence of scatterers and their behavior within the sampling volume. To ensure that ADV measurements provide an accurate representation of the flow velocity, one should evaluate two additional parameters provided in the ADV file, the signal-to-noise ratio (SNR) and the correlation (COR). Filtering the data using one or both of these parameters can improve the quality of the measurement.

The implementation of the acoustic Doppler measurement technique in an ADV probe is accomplished by measuring the phase change produced in the acoustic signal reflected off of scattering particles in the flow. The magnitude of the phase difference is proportional to the flow velocity. The phase difference can be positive or negative, allowing ADV's to measure both positive and negative velocities. The limits of the measurement range are the velocities corresponding to phase differences of $\pm 180^\circ$. The probe can be configured during a specific measurement session to establish the user's choice of measurement ranges. Because positive phase angles greater than 180° cannot be distinguished from negative phase angles between -180° and 0° , if the phase angle is greater than 180° it will be seen as a negative phase angle between -180° and 0° , and will be incorrectly interpreted as a negative velocity. Similarly, phase angles less than -180° (e.g., -181°) are interpreted as positive phase angles and positive velocities. As a result, when the flow velocity approaches the limits of the measurement range, it is possible for the probe to report velocities that alternate from large positive to large negative values and vice-versa. This behavior is known as *aliasing*, and erroneous velocities reported by the probe when operating in this range are called *velocity ambiguities*. Identifying and eliminating velocity ambiguities is critical to obtaining accurate results when measuring flow velocity with an ADV.

The variety of data products that can be derived from an ADV time series, the need for filtering and quality control checking of the data, and the need for scaling and adjustment of the data to account for model scale and measurement techniques makes customized data processing software a valuable asset when analyzing ADV data. To fulfill these needs, the WinADV software program was developed for use at the Bureau of Reclamation's Water Resources Research Laboratory in Denver, Colorado. Since its development in 1996, the program has been available to the public for download from the Internet, and has been periodically updated to maintain compatibility with newer ADV data formats and provide new and improved features.

The WinADV Program

The WinADV program is written in Visual Basic and compiled in a 32-bit version for Windows 95/98/NT/2000 computers and a 16-bit version for Windows 3.1 computers. The program includes an integrated online help system and is distributed with an electronic copy of a printable user's manual. The initial purpose for developing the program, and still its primary function, is to provide a means for quickly displaying the velocity time series in a format similar to that

provided by ADV data collection software (i.e., the *adv.exe* or *adf.exe* programs available from SonTek and Nortek, or the *CollectADV* program available from Nortek).

WinADV is able to load the *.adv files created by the current and past versions of the real time data acquisition software programs provided by SonTek and Nortek. The program can load files containing data collected from just one probe, or from multiple probes connected to a single data acquisition computer (up to 16 using the most recently manufactured ADV's and data acquisition software). The program cannot load the *.adv files created by remotely deployed ADV's. These files contain data from multiple bursts of ADV operation occurring at variable intervals, rather than the single, simple time series contained in a *.adv file. WinADV is also incompatible with the *.lfr file format used by the first generation of ADV instruments known as the ADVLab-1. A recent addition to the WinADV program is the ability to load data files created by the SonTek Argonaut series of monostatic Doppler current meters. These instruments produce a data stream similar to that of the ADV, i.e., a single time series of velocity components and associated signal strength and measurement quality parameters.

Three primary views of the ADV data are available: time series, histogram, and power spectrum. Each chart is provided on a separate tab of the main WinADV screen (fig. 1). The time series chart can display velocity components and magnitudes, signal amplitude, signal-to-noise ratio, and correlation score. For probes equipped with other integrated sensors, such as compass-tilt sensors, pressure transducers, or temperature measurement devices, these parameters may also be shown. In addition, flags embedded within the file to mark points of particular interest noted during data collection can be displayed on the same chart used to show the SNR and COR time series. The user may choose to display either the average or minimum values of the SNR and COR parameters, since multiple values are recorded within the ADV file (one for each acoustic beam). Several formatting options are available for the display of the time series graphs (e.g., line chart, symbols-only, bar chart, etc.)

The histogram view shows a histogram of the collected data, again with options to display one or more velocity components, signal amplitudes, SNR or COR values, or data collected from integrated sensors. The chart can be shown in the format of a probability density function or a cumulative distribution function. The histogram, like the time series and power spectrum charts, can be saved to a file, copied to the system clipboard, or printed. Figure 2 shows a histogram chart created by WinADV.

The power spectrum chart can display power spectra for the same parameters as those available on the time series and histogram charts. Power spectrum charts may be valuable



Figure 1. — Main screen of WinADV showing velocity time series, SNR and COR values, and recorded flags.

in studies involving waves or other periodic flow oscillations, and can also be used to detect unintended periodic probe motion that may have occurred during data collection. The user chooses the size of sampling window to be used for calculating the power spectrum; the number of samples used must be an integer power of 2, i.e., 2^n . If there are sufficient samples available, WinADV will compute power spectra for adjacent blocks of 2^n samples and average the spectra together before plotting. Power spectra are computed without the use of any windowing function; the objective in providing the power spectrum chart in WinADV is only to supply a means for easily identifying periodicity in the data. WinADV does not provide any more sophisticated frequency domain analysis options, since details of the computational techniques vary depending on the application.

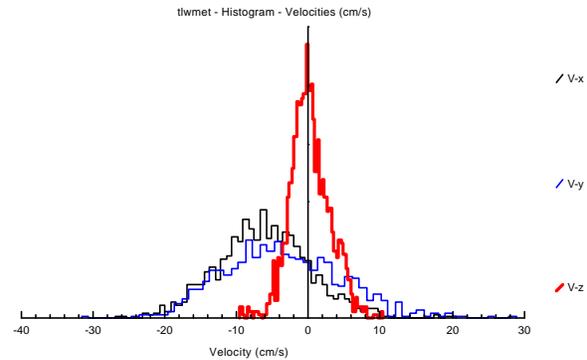


Figure 2. — Histogram chart created with WinADV and saved in a Windows metafile.

In addition to displaying the measured data in an ADV file, WinADV also provides the capability to view and print the probe and measurement configuration used to record the data. This information is similar to that provided by the *GETCTL* utility program provided by SonTek and Nortek. Information provided includes probe types, serial numbers, velocity range settings, and measured distances to the sampling volume and nearby boundaries.

WinADV provides powerful data processing options which will be discussed in more detail later in this paper. A quick summary view of the computed statistics for a single ADV file can be obtained from the main screen of WinADV by clicking on the **Stats Summary** button. Statistics for the file are displayed in a scrollable grid, just as they would be processed using the data processing options described later in this paper.

WinADV can load single data files for review, filtering, and processing, or the program can be used to quickly review or process multiple data files contained within a single subdirectory. The **View or Process Multiple Files** command leads the user to a file selection dialog box in which multiple files may be selected. If the **View** button is clicked from this page, WinADV will load the first data file and add **Next** and **Previous** buttons to the display to allow the user to browse forward and backward through the list of selected files. If the **Process** button is clicked, WinADV will process each of the selected files in sequence, using the same set of processing options on each file. Details regarding the processing options are discussed later in this paper.

Program Options

Data handling options are available in four categories:

- Sampling options to define the range or ranges of samples to be analyzed
- Filtering of data to exclude poor-quality or erroneous data
- Traversing options to define the motion of a moving probe
- Scaling to convert data to prototype scale and make simple coordinate transformations

Options settings can be saved to a *.opt file for later use with other ADV files.

Partitioning Data within a Single ADV File Using Sampling Options - Although the real time data acquisition software used to operate an ADV probe only allows the storage of a single time series of data within each file, there is a limited capability to mark multiple segments of data within a file so that the file may be processed in pieces. This is sometimes preferable to recording individual files for each sequence of data. This is most readily accomplished by marking flags in the data file using the *adv.exe* or *adf.exe* programs. Each time the F7 key is marked while recording data, the flag counter in the ADV file is incremented by one. The flag marks can then serve as indicators of the start and/or end of sampling windows to be analyzed. Through its Sampling Options screen, WinADV offers nine methods for subdividing the data file into sampling windows for viewing and analysis. When the data are processed by WinADV (to compute mean velocities, turbulence quantities, etc.), each sampling window is processed separately. The sampling window choices are:

- **All Samples** - The entire file is used.
- **All Samples (delimited by flags)** - A separate set of summary statistics is computed for each range of samples between consecutive flag markers (e.g., 1-2, 2-3, 3-4, 4-5, ...).
- **Odd/Even Flags** - Each odd-numbered flag (1, 3, 5, 7, ...) marks the start of a sampling window, and each even flag marks the end of the sampling window.
- **Even/Odd Flags** - Opposite of above; this may be useful if you get off-sequence while marking flags during data collection.
- **Use Pause and Restart Marks** – Works with recent versions of the *adv.exe* and *adf.exe* data collection programs that offer a *burst mode* of data collection in which the user can pause the recording of data to the file and then restart recording at a later time. The event marker (flag) is incremented by ten at each restart.
- **N Samples After Each Flag** - Each flag mark is considered to mark the start of a sampling window containing N samples (N specified by the user).
- **T Seconds After Each Flag** - Similar to above, except that the length of the sampling window may be specified in seconds.
- **Range of Sample Numbers** – The user can define the range of samples to be analyzed using the sample number identifier. The first sample in the file is considered sample number 1.
- **Range of Sample Times** - This is similar to the range of sample numbers, except that the range is specified using times in seconds rather than sample numbers.

Once sampling windows are established, the user will note changes in the appearance of the time series, histogram, and power spectrum charts. The time series chart will show only the data contained within the defined sampling windows, while the histogram and power spectrum charts will operate on only a single sampling window at one time. The user can browse forward and back through the available sampling windows.

A powerful feature for controlling and adjusting sampling windows in ADV files is to use the sampling options based on flag marks in combination with the flag editor provided in WinADV. The flag editor allows the user to create a custom set of flag marks for a data file and save them separately in an ASCII file for later recall (WinADV does not alter the original file). Using the flag editor and the flag-based sampling windows, multiple sampling windows could be established in a single ADV file, even if no flag marks were made when the data were recorded.

Data Filtering Options - Data filtering is an important aspect of the analysis of ADV data. The signal-to-noise ratio and correlation scores are good indicators of some of the possible problems encountered while using an ADV, and WinADV offers filters based on their values. Filters are also available to address problems that cannot be detected by analysis of the SNR and COR values. WinADV's filters can be applied separately or in combination.

The SNR parameter indicates the relative density of acoustic scatterers in the flow and the resulting strength of the signal received compared to the noise level of the instrument. ADV manufacturers recommend an SNR value of at least 5 when measuring average flow velocities, and 15 or higher when measuring instantaneous velocities and turbulence quantities. If possible, problems with low SNR should be corrected during data collection. Although it is not specifically recommended by ADV manufacturers, filtering based on the SNR value may be useful in some situations, such as when only a short segment of a data file is affected. WinADV offers a filter based on the SNR value, with a user-selected cutoff level.

The correlation parameter, COR, is an indicator of the relative consistency of the behavior of the scatterers in the sampling volume during the sampling period. ADV's collect data at a higher sampling rate than the sample reporting period, and the COR parameter indicates the consistency of the multiple measurements that take place within each sampling period. The value varies from 0 to 100, and ADV manufacturers have typically recommended filtering to remove any samples with correlation scores below 70. WinADV offers such a filter, with the option to adjust the cutoff value. In the author's experience, samples with correlation values much less than 70 can sometimes still provide good data, especially when the signal to noise ratio is high and the flow is relatively turbulent (a condition that seems to lead to generally lower correlation scores).

The problem of overranging of ADV probes was mentioned earlier. When the flow velocity is too high relative to the velocity range setting of the instrument, aliasing of the data occurs, creating velocity ambiguities. Figure 3 shows velocity ambiguities recorded in the flow in a laboratory flume. The velocity of this flow was correctly measured during the first 23 seconds of the measurement period shown. When the discharge was increased slightly, the probe overranged and the reported velocities changed sign. Near the end of the period shown, the velocity was reduced and positive velocity spikes began to occur as the flow reentered the measurable range. It is critical to note that the SNR and COR values do not give a clear indication that there is a problem, and would not be useful for filtering. Clearly, other filtering strategies are needed if this type of problem is to be eliminated from the analyzed data.

WinADV's velocity cutoff filter can be helpful when dealing with data files containing velocity ambiguities. The user may specify a cutoff value for one of the three velocity components and whether to keep data above or below the cutoff. This filter is successful in data files in which the overranging is consistent and produces clear and dramatic changes in the reported velocity, as shown in figure 3. This filter is less successful when overranging is more severe (i.e., velocity is well above the value that first causes overranging), or when the flow is very turbulent and overranging occurs differently from sample to sample (i.e., different acoustic beam overranging each time).

A second filtering method that is sometimes successful with data files containing velocity ambiguities is the *spike detection* filter. This filter was developed at the New Zealand Institute for Water and Atmospheric Research (NIWA) by Nikora and Goring (personal communication). It is based on the concept that there should be a physical upper limit to the change in flow

velocity (i.e., the acceleration) that can occur in a flow, and any measurements that indicate higher accelerations should be excluded from the analysis. This filter successfully removes velocity ambiguities, but only if they are of short duration. If overranging causes velocity ambiguities to persist for several sample periods, then they will not all be detected as spikes. The spike detection filter also successfully removes other erroneous data points whose origin may have been low signal strength or inconsistent scatterer behavior (i.e., low correlation). To make the filter dimensionless, the acceleration threshold is specified in g 's.

To reduce the chance of velocity ambiguities tainting the data collected with an ADV, it is best to record data at the highest normal sampling rate (i.e., 25 Hz for 10 MHz ADV's), whenever there is the possibility of encountering velocities that might overrange the probe. At lower sampling rates (e.g., 0.1 Hz), velocity ambiguities may occur for just a portion of the sampling period, and the erroneous data will be averaged in with valid data before the sample is reported to the user and recorded in the ADV file. This makes it more difficult to visually identify and automatically filter out ambiguities.

Velocity ambiguities sometimes occur in two situations where users do not expect them. First, large velocity components directed toward or away from the transmitting transducer of an ADV can cause overranging even when the total velocity magnitude is well below the nominal range setting of the probe. This is due to the geometric arrangement of the transmitting and receiving acoustic transducers, which causes the velocity range normal to the transmitting transducer face to be about one third of the range in the plane parallel to the transducer face. The stated nominal range setting is most closely associated with flow in the plane parallel to the transmitting transducer face. Second, the range setting of an ADV probe can sometimes change during the boundary-adjustment phase of configuring the probe at the start of each measurement. This occurs when the probe detects nearby acoustic boundaries that might cause interference with operation of the probe. To overcome this interference, the lag times of the acoustic signals transmitted by the ADV are reduced, causing a reduction of the velocity range that may lead to overranging of the probe. The fact that the velocity range was reduced is not noted in the information provided by the *GETCTL* utility. However, WinADV can read the lag time settings of the probe from the header of the ADV file and compare them to the standard lag time settings for the chosen velocity range. If they do not match, WinADV computes a new nominal velocity range and displays the chosen range and the actual range in the upper middle portion of the main WinADV screen, just below the **Probes** button. If unexpected overranging is occurring, the user should check to see if the velocity range was reduced.

The final filtering option offered in WinADV is the filtering of samples marked with a communications error flag. This is only an issue with data

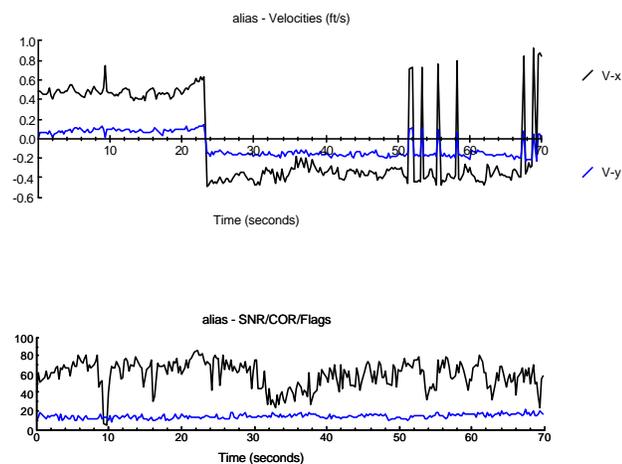


Figure 3. — Example of velocity ambiguities and aliasing caused by overranging of an ADV probe.

files collected from field-type ADV probes over a serial interface, using the *adf.exe* program. Momentary loss of communications over the serial cable can lead to corruption of individual samples, which are then marked in the ADV data file with flag 999. If the user chooses to filter out communications errors, WinADV gives the option of replacing the filtered samples with interpolated data. This allows the computation of power spectra, which require a continuous record. The interpolation feature is only available with respect to filtering of communications errors, not for filtering by the other methods discussed above.

Features for Scale Modeling – The user can select the geometric scale of a Froude-scaled model, and WinADV will calculate the corresponding velocity scale ratio from the relation $\lambda_V = \lambda_L^{0.5}$, where λ_V and λ_L are the velocity and length scale ratios, respectively. WinADV uses a separate scaling ratio for each component direction. This allows the use of a negative scale factor to reverse the sign of one or more of the measured velocities, a feature that is valuable when the ADV probe can only be oriented at 180° from the desired direction.

The maximize coverage of a model area while minimizing data collection effort, probes are often installed on traversing systems. To properly interpret these data, the motion of the probe must be added to the velocities that are measured relative to the probe. The traversing options in WinADV allow the user to specify the velocity of the probe in each component direction (using the same coordinate system as the measured velocities), and optionally to plot the velocities versus the probe position, rather than the sample time. In addition, a traversing period can be specified if the probe is making multiple passes (i.e., reversing direction and returning to the starting point), a situation described as a bouncing traverse. The traversing period entered into WinADV is the travel time from one end of the traversing system to the other (not the time for a complete lap). During the return-travel period, WinADV reverses the signs of the probe velocities. Figure 4 shows an example of data collected with a traversing system.

Data Processing Options - The processing module of WinADV operates on an entire ADV file, or on the individual sampling windows defined in it by the user. Data files are exported in ASCII files compatible with most spreadsheets. Processing can be carried out on a single file or on multiple files contained in a single subdirectory. Output options include histogram, power spectrum, and time series data export, as well as calculation and export of summary statistics.

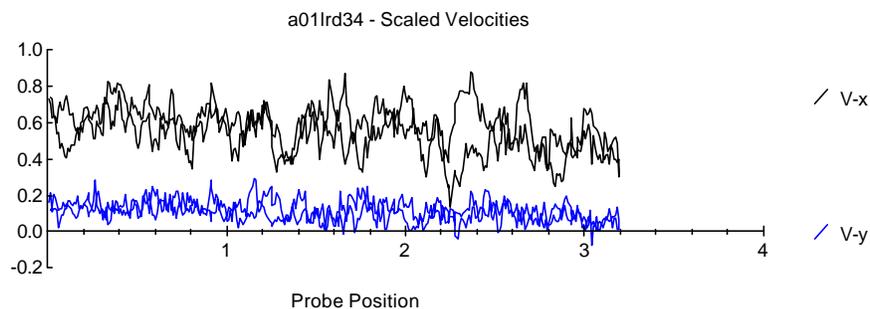


Figure 4. — Data collected from a 2-D side-looking ADV traversing a 1:12 scale fish screen model. One pass was made up and down the length of the screen at a speed of 0.76 cm/s. Velocities are in meters/sec and probe position in meters at prototype scale. V_x (the larger of the two displayed velocity components) is parallel to the screen face, and V_y is normal to the screen face. This figure was created in WinADV.

Histogram and power spectrum data export are relatively straightforward, with the program simply producing the data needed to recreate the histogram and power spectrum plots shown in WinADV. Time series data export produces a time series file that has been modified by the sampling and/or filtering operations available in WinADV. Unfiltered and filtered time series data export options are available, with the data written to ASCII files with the name *advfile.vu* and *advfile.vf*, where *vu* and *vf* indicate unfiltered and filtered velocities, respectively, and *advfile* is the base name of the ADV data file. In addition to the velocity data, signal-to-noise ratios, correlations, and signal amplitude data are exported.

Summary statistics for the filtered and unfiltered time series data are exported into files with the default names of *Filtered.Sum* and *UnFilter.Sum*. These files accumulate data from multiple processing sessions, with the results from the most recently processed files added as new rows at the bottom of the file. A partial list of the computed statistics includes:

- Mean, standard deviation, skewness and kurtosis of velocity components
- Covariances of velocity components
- Span of 95% confidence intervals on velocity components (i.e., difference between upper and lower endpoints of the confidence interval)
- Mean velocity magnitudes, correlations, signal-to-noise ratios, and signal amplitudes
- Mean values of external sensor data stored in the file, such as pressures, temperatures, etc.

Details of the computational formulas for all of WinADV's statistical parameters are given in the online help system and printable electronic user's manual distributed with WinADV.

Automated Data Processing with WinADV

WinADV offers several tools for simplifying the analysis and processing of ADV data. The processing of multiple files in a single subdirectory can automate data processing when all of the files are to be processed identically. Saving options settings in **.opt* files is helpful when different processing options are needed due to variations in probe setup, such as having to install the probe at different orientations, etc. Truly automated data processing can be achieved through the use of saved options files and the WinADV command-line interface. The command-line interface allows the specification of an ADV file to be loaded on program startup, along with an associated options file and instructions to carry out unattended processing of the data. Complete syntax for the command-line interface is given in the help file and user's manual.

An example application of automated processing is the use of WinADV to process the data collected from the Bureau of Reclamation's model studies for the fish screen structures at Durango Pumping Plant. Eight different orientations of a traversing table were used, with varying directions of probe motion and varying probe positions relative to the prototype fish screen coordinate system. In addition, data were collected at three different elevations in the model, and filtering was used to eliminate data with low correlation values. Collection of the data was automated by starting and stopping the ADV probe using the same signals that controlled the traversing system. The eight data collection configurations were designated LLD, LLU, LRD, LRU, RLD, RLU, RRD, and RRU, and these designations were used in the file names of the ADV files (e.g., *B04LLD31.ADV* indicates test flow condition *B04*, with data on the left-hand (*L*) screen at the left-downstream (*LD*) traversing table position, with the probe at

prototype elevation 31. Only four options files were necessary for processing these data, *LD.opt*, *LU.opt*, *RD.opt*, and *RU.opt*. A single data file could be processed with the DOS command

```
winadv32 B04LLD31.ADV LD.opt -pfsumfiltered.sum -pvf
```

which instructs WinADV to load the ADV file and options file, compute summary statistics on the filtered data (-pfsum) and save them in *filtered.sum*, and export the time series data (-pvf). To further automate this process, the DOS **for** command can be used:

```
for %f in (LD LU RD RU) do winadv32 B04L%f31.ADV %f.opt -pfsumfiltered.sum -pvf
```

This command would process all data files collected at prototype elevation 31. Incorporating similar commands into DOS batch files can further automate data processing. Figure 5 shows an example of data collected and processed using this technique.

Conclusions

The WinADV program is a valuable tool for filtering, analyzing, and processing data collected from acoustic Doppler velocity meters. The program can be used to analyze ADV files recorded using the real time data acquisition programs provided by ADV manufacturers. The software is available for 32-bit and 16-bit Windows-based computers and can be downloaded by the public from the Bureau of Reclamation's Internet site at <http://www.usbr.gov/wrrl/twahl/winadv.html>.

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Disclaimer

References to commercial products in this paper are for informational purposes only and do not constitute endorsement by the author or the U.S. Bureau of Reclamation.

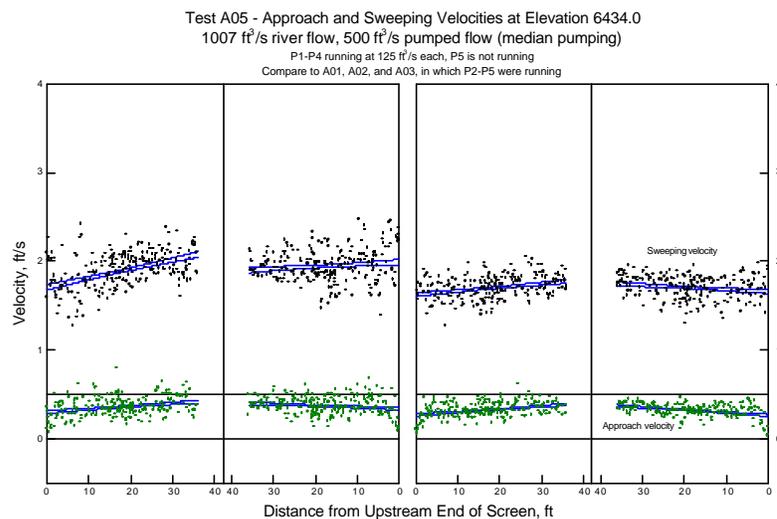


Figure 5. — Example of velocity data collected using a traversing system and processed by WinADV. The data were collected using eight separate traverses of portions of the model fish screen.