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EZQ Stage and Velocity Sensor:
Test Results from The White River

1. Introduction

This report summarizes tests of the EZQ, an acoustic sensor that measure river flow velocity and water level (stage). The tests were carried out in the lab, and in the White River (Indianapolis) during 23 May-7 June 1999.

Figure 1 - EZQ River Monitor, side view. Length: 586 mm; diameter: 75 mm; weight: 1.7 kg

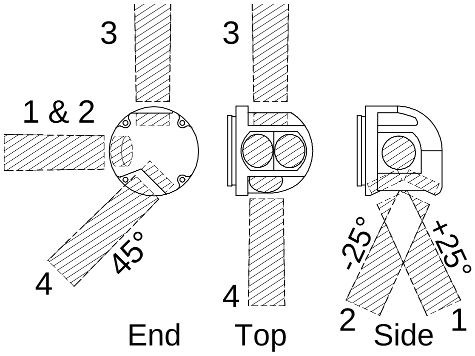

Figure 2 - EZQ beam geometry. Beams 1 and 2 measure velocity, beam 3 measures stage and the fourth beam is for future capabilities monitoring the riverbed.

The EZQ uses two beams for Doppler velocity measurements, and a third beam to acoustically measure the distance to the surface. A fourth beam, not used yet, will enable the EZQ to monitor the riverbed. Figure 1 shows a side view of the EZQ and Figure 2 shows the beam geometry.

Our main objectives in developing the EZQ are to measure velocity and stage to enable computing discharge using the index velocity method, and to provide the USGS standard SDI-12 interface. This test focussed on evaluating the velocity and stage data. The SDI-12 interface has not been implemented yet (see Section 5) and was not a subject of the test.

The EZQ measures stage by transmitting a short pulse to the surface, then identifying and locating the echo from the surface. The process uses two steps: identifying the surface echo, and measuring its position. The EZQ finds the surface as the first peak exceeding acceptance criteria—strong echoes from debris floating below the surface can sometimes fool the EZQ.

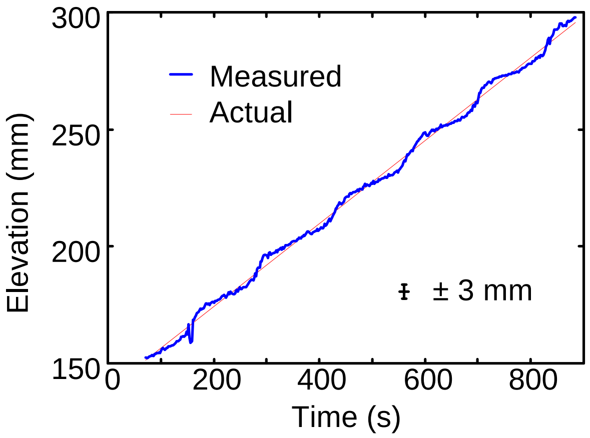

Figure 3 - Measured vs. actual water level in a small test tank. The size of a 3 mm uncertainty is given in the lower right of the plot.

2. Measuring Stage

Nortek's long experience measuring flow velocity gave us confidence we could measure the flow velocity, but prior to these tests, Nortek had no experience measuring water level acoustically. The USGS required uncertainty for water level, ±3 mm, appeared to be a challenge. Our analytical models encouraged us that we could meet the USGS requirement. Our initial effort was to convince ourselves with real data that we could routinely find the water surface, and that when we did, we could resolve it with an uncertainty of ± 3 mm.

Stage tests in the small tank

To test the resolution of our algorithm, we collected data in a small tank in which we measured the water level with a ruler (± 1 mm). We leveled the EZQ with a bubble level. On May 25, we ran a series of tests in which we changed the water level with a hose, either by siphoning water out or pouring water in. Figure 3 shows the measured water level from one run in which the water level rose at a constant rate. The *rms* difference (after removing the mean) between measured and actual levels was 2.3 mm. This test convinced us that we could resolve the distance to the surface to within 3 mm.

Figure 4 - Creating waves and wakes over the EZQ.

Stage tests in the White River

On May 26, we collected data on the White River to test algorithms for finding the water surface and to characterize effects of disturbances at the water surface. We collected raw backscatter data during normal, undisturbed flow, then we created waves and wakes over the EZQ with a small boat (Figure 4). Figure 5 shows the backscatter in the water during this time. The surface appears as an obvious line across the figure at a depth of around 800 mm. A sharp increase in backscatter corresponds to the first waves that hit the site.

Figure 6 shows the corresponding computed stage plus a quality parameter that measures the shape and size of the echo from the surface. The parameter is largest when the surface is undisturbed and gets smaller under the effects of the waves and wakes.

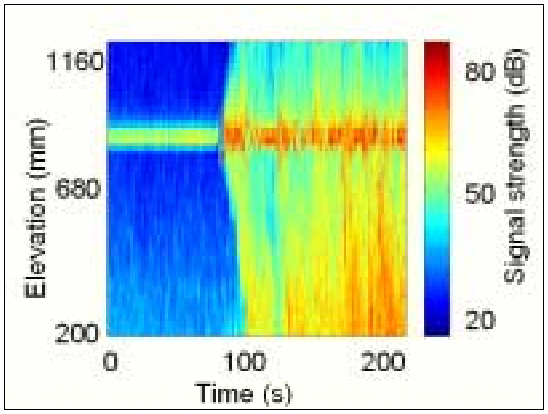

Figure 5 - Backscatter during first stage tests. At around 100 s, backscatter increased as boat wakes and waves began to hit the site.

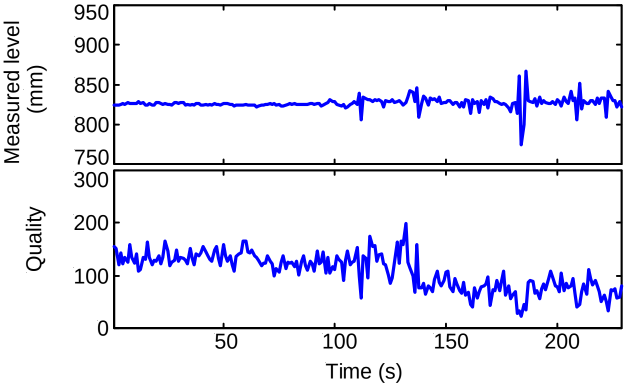

Figure 6 - Water level measured while a boat creates waves and wakes over the EZQ. The quality factor measures the shape of the surface echo.

The water level in Figure 6 contains oscillations associated with the waves. Because the EZQ samples often enough to resolve these motions, it can efficiently remove them through averaging. These tests convinced us that we could find the surface and that we could resolve it on time scales short enough to enable us to efficiently filter out surface waves. We then implemented stage detection into the EZQ. The algorithm consisted of a crude method for identifying the surface echo plus an effective method for resolving the water level once we find the surface. Our algorithm processes and averages roughly 230 pings over 10 s. We later improved the method for identifying the surface, but we did not implement it into the EZQ until after this series of tests were complete.

3. White River: 11 days of Stage and Velocity Data

Test Site

The White River test site is under an interstate freeway (Figure 7), between two bridge supports. An Affra Acoustic Velocity Meter (AVM) is permanently mounted at the site, and a Sontek Argonaut SL Doppler Current Meter (DCM) was temporarily mounted, approximately collocated with the EZQ. The EZQ was mounted at a depth of about 1 m, and the DCM was mounted about 20 cm below the EZQ. The AVM has an acoustic stage sensor, located on the other side of the river from the EZQ. The DCM had

Figure 7 - The White River test site is directly under the Interstate 79 bridge on the east (right)side of the river.

no means for measuring the water level.

The EZQ did not have an internal tilt sensor, so we had no means to verify the angle of the vertical stage-sensing beam. We did our best to level the EZQ, but lack of a tilt sensor means that the beam could have been as much as 5° from vertical. While we expect the effectiveness of the stage sensor to be directly related to the orientation of the beam, our tests earlier in the week suggested we could still find the surface reasonably effectively. Before we left the EZQ to collect data, we did verify that it was finding the surface.

Figure 8 shows the flow structure in the river near the measurement site. Flow structure in the river is relatively simple. The strongest flow is in the center of the river, but the flow is otherwise relatively uniform across the river.

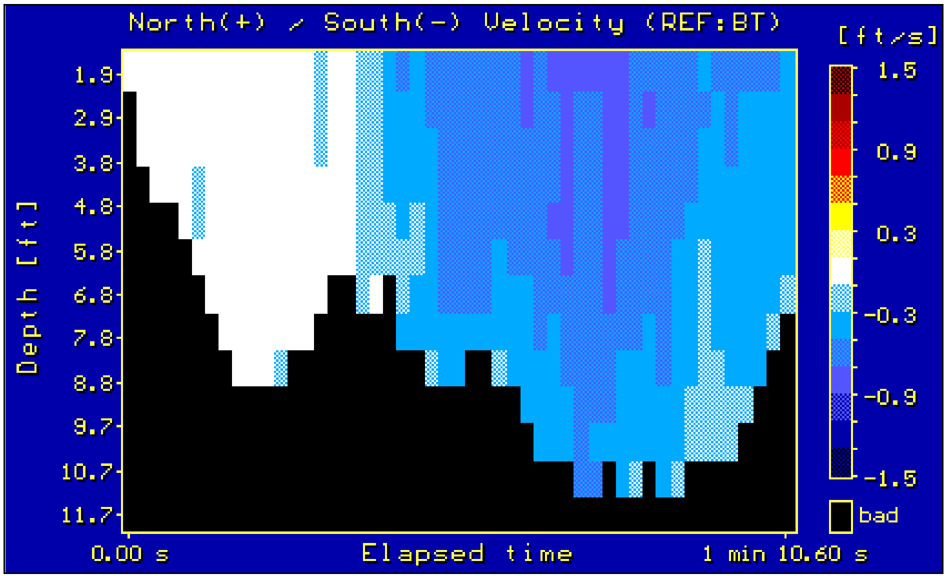

Figure 8 Moving-boat survey of flow in the White River. Flow is to the south. The main flow is between the two bridge supports. Weak flow on the left is blocked by debris between a bridge support and the riverbank.

We deployed the EZQ and the DCM on May 27 in the White River near the AVM. Both the EZQ and the DCM recorded data internally, and the AVM data were recorded on an external data logger. The EZQ and DCM recorded 1-min intervals, and the AVM used 2-min intervals. We collected data for 11 days during 27 May-7 June.

Stage Data Processing and Comparison

Both the EZQ and AVM data found the surface most of the time, but numerous spikes in the data indicated that both sensors missed the surface at times. The spikes were easily removed by identifying sudden changes in water level. We filled in gaps by interpolation. Figure 9 compares the resulting stage data for both the EZQ and the AVM.

We removed the mean difference in the comparison between the EZQ and the AVM. This is a reasonable approach because instruments are typically installed at uncertain depths. Users will obtain installation offsets by referencing readings to an external water level datum.

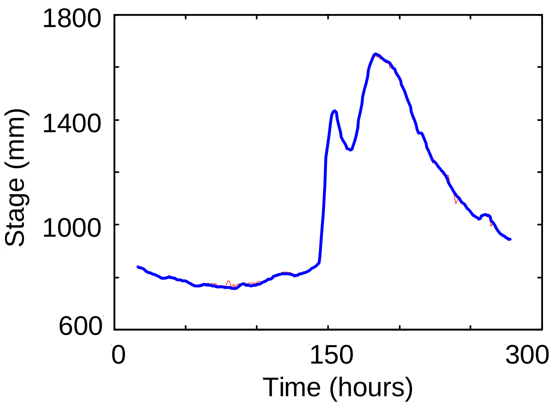

Figure 9 - Stage measured by EZQ (heavy line) and AVM (thin line). the AVM line is barely visible behind the EZQ line.

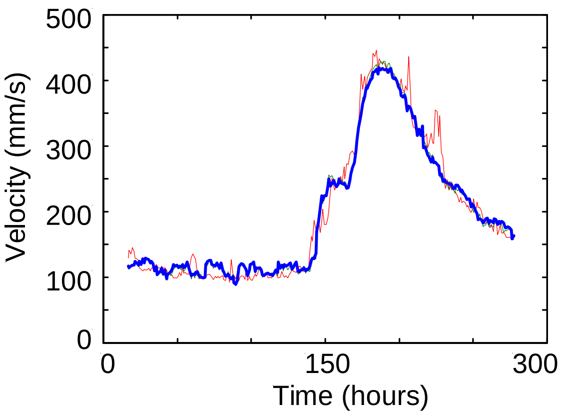

Figure 10 - Velocity measured by EZQ (heavy line), DCM (thin line) and AVM (thin line).The DCM line is barely visible behind the EZQ line.

Velocity Data Processing and Results

We processed the EZQ and DCM velocity data by averaging it into hourly intervals. No effort was required for spike removal. The AVM data held both spikes and dropouts. Large spikes were easily removed and missing values were filled in with interpolation. We were unable to remove smaller spikes from the AVM data, and these spikes generally biased the data to larger velocities.

The AVM data were unscaled for the installation angle. Absolute scaling is unnecessary because the index velocity method relies instead on velocity-discharge rating curves. The EZQ data had a coordinate transformation error that caused readings to be high by about 15%. We corrected this error in post-processing. We scaled the AVM data empirically by making the mean ratio of AVM to EZQ velocity equal to one.

Figure 10 compares all three velocity time series. The EZQ and DCM data lie nearly one on top of the other. The AVM data departs more from the others. Given the quantity of the small spikes in the AVM data, it appears unlikely that the large AVM departures (i.e. at 210 and 225 hours) are real.

4. Discussion

The short-term velocity fluctuations in the EZQ and DCM data are likely the result of turbulence-like flow structures in the river rather than instrumental uncertainty. The short-term variation in both the EZQ and the DCM velocities is far higher than what we would expect based on instrumental uncertainty.

Figure 11 compares two short records of raw data from the EZQ and the DCM. The two show substantial similarities in flow structure. Because instrumental uncertainties would not correlate from one instrument to another, we must conclude that the fluctuations represent real variations in the flow itself. The small differences in the flow could result either from the small separation between the two instrument measurement volumes, or from instrumental uncertainties.

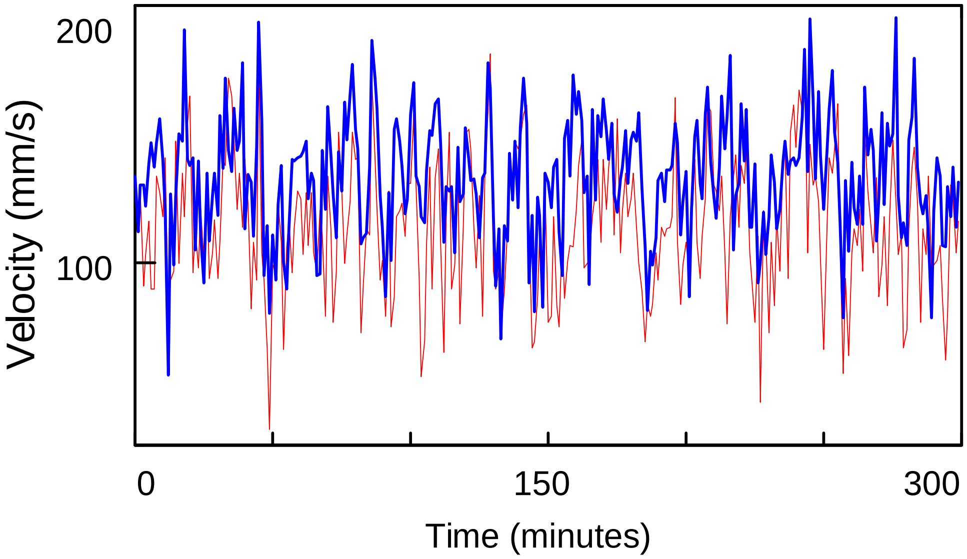

Figure 11 - Comparison of raw EZQ (heavy line) and DCM (light line) velocity during a 300-minute time segment.

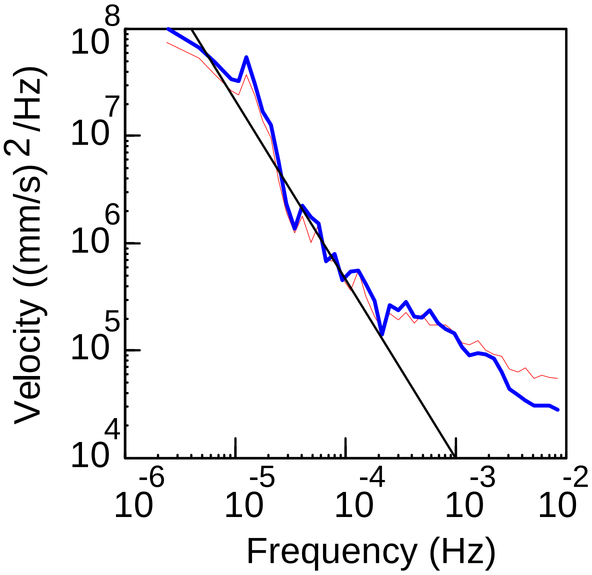

Figure 12 - Velocity spectra from the EZQ (heavy line) and DCM (thin line). The straight line has a -5/3 slope.

Figure 12 presents velocity spectra of the EZQ and the DCM. The lower frequency part of the spectrum follows a -5/3 slope, much like isotropic turbulence (which, of course, it is not). At higher frequencies, the EZQ spectrum becomes less steep, but not flat (the DCM appears to flatten at the highest frequencies). A flat spectrum indicates the sensor has reached the noise level.

Figure 13 A-C shows that velocity and stage were roughly proportional most of the time, but that at the start of the June 2 storm event, the velocity lagged behind the stage. This behavior is reasonably consistent with the equations of fluid motion. In steady conditions, rivers are in turbulent equilibrium: energy dissipated through loss of pressure head balances creation and dissipation of turbulent kinetic energy. Flow velocity remains steady because turbulent friction balances the pressure gradient. When the water level rises suddenly, the pressure gradient increases, and the velocity in turn accelerates in response to the increased pressure gradient. In time, the increased velocity creates greater turbulence, which creates greater friction, and the flow returns to equilibrium.

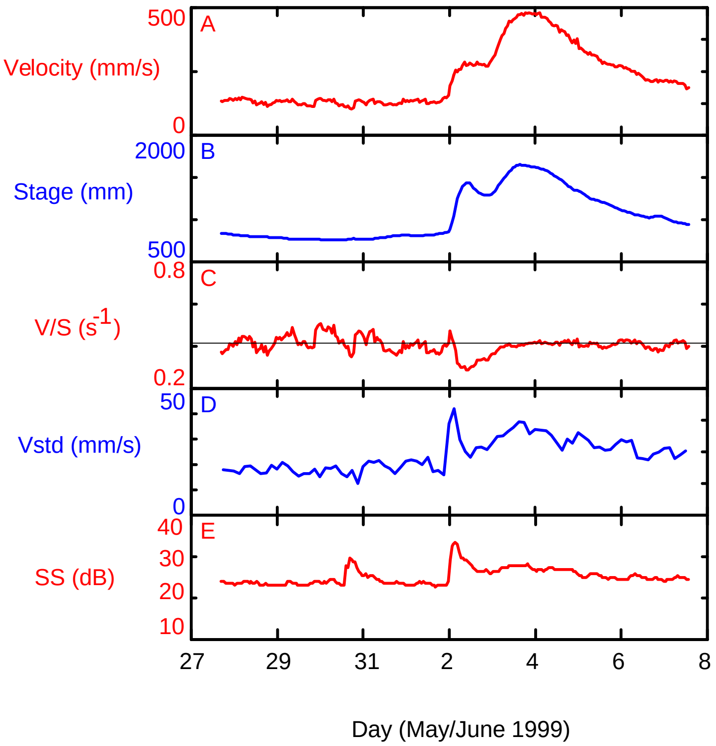

Figure 13 - Watching the river flow. Stage and velocity rose suddenly during the June 2 storm event. V/S is the ratio of the velocity to stage. Vstd is the standard deviation of velocity, a measure of turbulent fluctuations in the flow. SS is the EZQ's signal strength, a measure of backscatter.

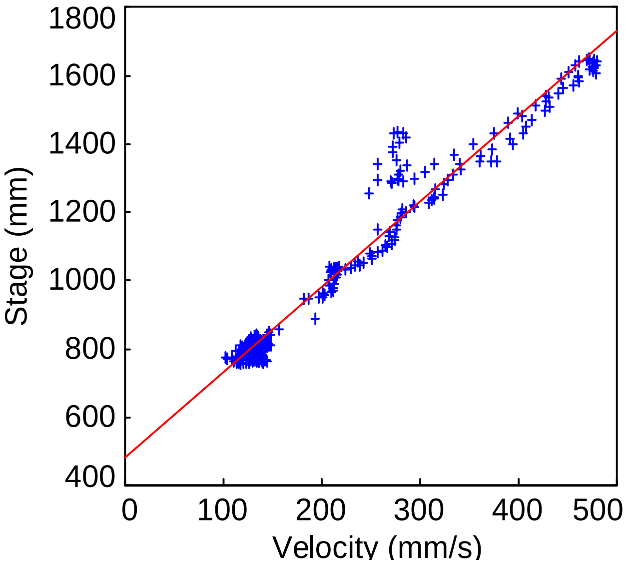

Figure 14 - Stage-velocity relationship. The points that fall well above the line correspond to the beginning of the storm event on June 2.

Figure 13 D shows that turbulent fluctuations suddenly increased at the onset of the storm event. A rule of thumb is that turbulence is typically 10% of the mean velocity. This relationship holds reasonably well in the White River (using velocity standard deviations as a measure of turbulent fluctuations). However, the turbulent fluctuations increased anomalously as the water level rose at the beginning of the storm event. The anomalously-high turbulent fluctuations disappeared into the background just as the stage began to level out at its initial peak.

Not too surprisingly, the signal strength (backscatter; Figure 13 E) also increased suddenly at the beginning of the storm event, roughly in parallel to the turbulence. The increase was almost certainly associated with increased suspended sediment, but we cannot quantitatively estimate the increased concentration. An interesting backscatter increase on 30 May appeared associated with reductions both in velocity and velocity standard deviation.

The stage-velocity relationship (Figure 14) approximates a straight line, except at the beginning of the storm event. Given constant riverbed geometry, this relationship should stay near the same line—long-term departures should indicate the need to resurvey the riverbed.

5. Epilogue

EZQ bugs, fixes and upgrades

The EZQ we used in this test was an early production model. It was missing the tilt sensor because the fixture for holding it next to the sensor head had not yet been completed. The SDI-12 electrical interface was complete, but the SDI-12 command interface has not been written. The tilt sensor fixture is complete now and a standard part of the EZQ. The SDI-12 command interface is scheduled for completion later this year, and it will be available for all EZQ systems via firmware download.

One of the reasons for tests like this is to discover problems. In this test, we discovered a coordinate transformation problem that introduced a 15% scale factor error. This error has been corrected in the EZQ firmware.

We concluded that we can measure the distance to the surface accurately when we find the surface, but we feel that we miss the surface too often. We are confident that we will find the surface more often when the stage sensor is aligned vertically—the signal strength is a strong function of angle for near-vertical alignment. Since the tests, we implemented an improved method for identifying the surface, one which should better discriminate surface echoes.

Alignment will be far easier with EZQs that include a tilt sensor. We expect typical users to install the EZQ, measure the tilt, then remove, adjust and reinstall the EZQ. EZQ mounts will be designed to make readjustment a simple one-time effort.

AVM upgrades

The AVM manufacturer has released a new firmware version that should substantially reduce velocity spiking in the AVM.

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