RD Instruments
Acoustic Doppler Current Profilers

Application Note
August 1999

High Resolution River Profiling - Modes 5 and 8

Is:

- Small Depth Cell Sizes
- Shallow Water Profiling
- Low Flow Velocity
- Low Standard Deviation

Is Not:

- General Purpose
- Robust
- Deeper Water Profiling
- Profiling in Turbulence and Shear

Profiling Modes – There are three user-selectable profiling modes: 1, 5, and 8, that are set by the WM command (e.g. WM5 for Mode 5). They are used to tune the ADCP for different flow conditions. Each mode has its own window of operation, as shown in Figure 1. In this application note, we concentrate on the characteristics and setup criteria for profiling in slow and shallow flows using the High Resolution Profiling Modes 5 and 8. Modes 5 and 8 provide have the capability to provide more precise velocity measurements than Mode 1, but they have a restricted window of operation. If your flow speed and profiling range fall outside this window, refer to the General River Profiling – Mode 1 application note for information on profiling in general conditions.

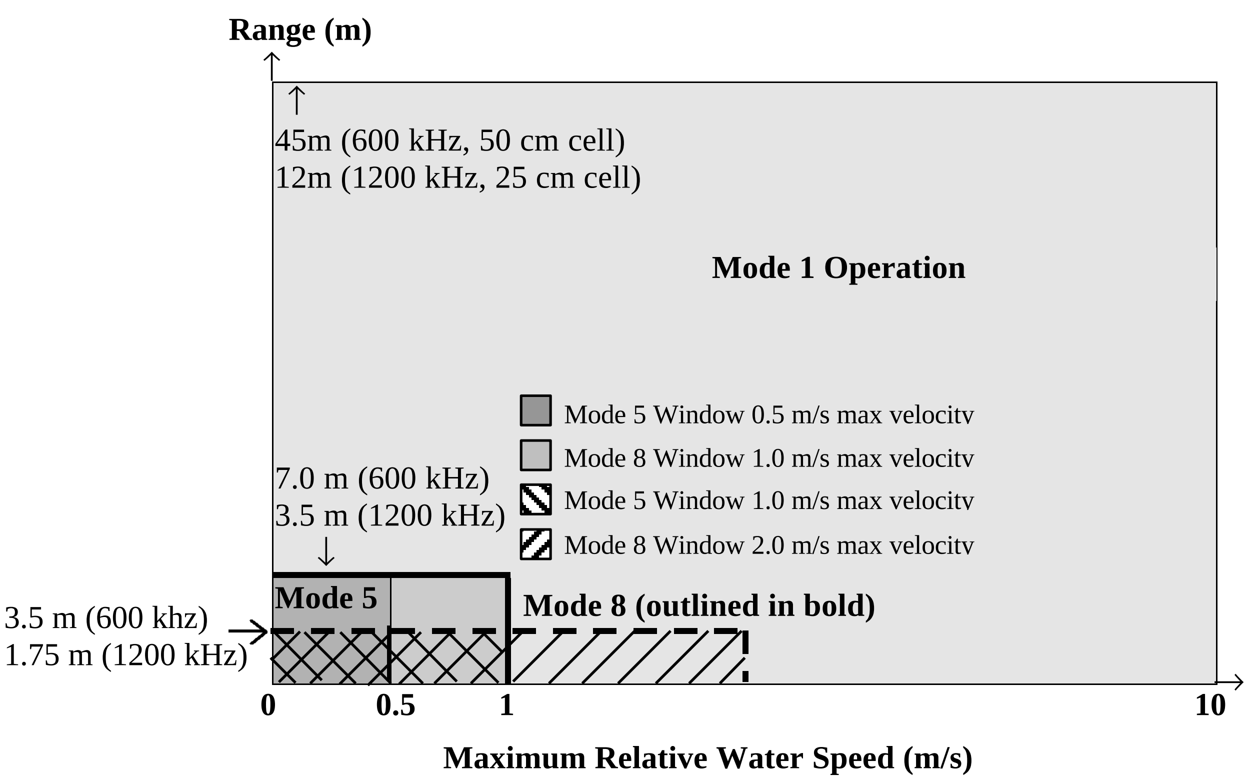

Figure 1. Operational Windows for Profiling Modes 1, 5, and 8

Mode 5 and 8 Description - Modes 5 and 8 provide high resolution profiling capability. These modes use short encoded pulses that travel to the bottom, where they are reflected, and then travel back up to the ADCP. When the signal from the first pulse is received at the transducer face, the ADCP transmits another pulse. The ADCP knows how long to wait before sending the second transmission because Bottom-Track measures the water depth. For this reason, it is important to use Bottom-Tracking when performing transects where the bottom depth varies along the track.

If the ADCP is used in a fixed deployment where the range to the bottom remains constant, using Bottom-Track is not necessary. The ADCP can be configured to profile to the fixed range by using the ambiguity velocity command (WZ) and disabling Bottom Track. Refer to the WorkHorse High Resolution Water-Profiling Addendum for more details on using Modes 5 and 8 in fixed deployments.

For Modes 5 and 8, two pulses are processed to create the velocity estimate. The standard deviation for Mode 5 and 8 is very low because there is a relatively long lag between the two pulses. Mode 5 estimates the velocity based on the Doppler shift, and its algorithm is sensitive to ambiguities. Therefore, this mode is highly sensitive to conditions with high shear, turbulence, and fast ADCP motion. Mode 8 makes the estimation based on a proprietary scheme. Mode 8 has no ambiguity problems, and therefore it can operate in areas that Mode 5 cannot. However the method of estimating velocity used by Mode 8 has a higher standard deviation as compared to Mode 5 operation. The standard deviation of Mode 8 is about 10 times greater than Mode 5 for the same size depth cell size and water speed.

Windows of Operation - Modes 5 and 8 have a reduced window of operation compared to Mode 1. The flow speed must be less than 0.5 m/s for Mode 5 and less than 1 m/s for Mode 8 to obtain reliable data. The profiling range for the High Resolution Modes is limited to about 7 m for the 600 kHz and 3.5 m for the 1200 kHz.

Mode 5 Window - Mode 5 is ideal in shallow water (7 m and less for the 600 kHz, 3.5 m and less for the 1200 kHz) with water speeds less than 1-2 m/s. Mode 5 is not good for areas where there is shear, turbulence, background noise, or fast ADCP motion. If high shears, turbulence, background noise, or fast ADCP motion occurs, the ADCP will not collect data.

Mode 8 Window - Mode 8 is ideal for shallow water (7 m and less for the 600 kHz, 3.5 m and less for the 1200 kHz), with water speeds less than 2 m/s. In contrast to Mode 5, Mode 8 can operate where there may be moderate levels of shear, turbulence, background noise, or ADCP motion. Mode 8 can be used in fixed measurements or slow-moving platform measurements where the water velocity flows are very low. Note that if the shears, turbulence, background noise, or ADCP motion is too great, the ADCP will not collect data.

Comparision of Water Modes 5 and 8

Mode 5 advantages compared to Mode 8:

- Mode 5 gives a lower single-ping standard deviation than Mode 8 for the same size depth cell (about 10 times less).

Mode 8 advantages compared to Mode 5:

- For the same size depth cell, Mode 8 is capable of profiling in shallower water than Mode 5 (compare the minimum profiling ranges in Tables 1 and 2).
- Mode 8 has the capability to measure higher velocity values than Mode 5 (up to about 100 cm/s for Mode 8 compared to 50 cm/s for Mode 5).
- Mode 8 works in dynamic water environments that have water velocities changes up to 100 cm/s (e.g., turbulence, eddies, shear), while Mode5 is limited to dynamic conditions with water velocity changes less than 50 cm/s.

Performance Specifications – The following tables summarize the expected performance of the 600 and 1200 kHz Rio Grande ADCP for Modes 5 and 8 as a function of cell size. The standard deviation of these modes varies with water speed, boat speed, bedform roughness, channel depth, and turbulence, while the maximum profiling range varies with water speed and boat speed. These relationships are discussed in more detail later in the section titled Effect of Relative Water Velocity on Profiling Range and Standard Deviation. A relative speed of 0.5 m/s is assumed for the Mode 5 specifications, and a relative speed of 1 m/s is used for the Mode 8 specifications. The profiling range values are referenced from the transducer face. To determine the maximum and minimum water depths, add the transducer depth. The minimum profiling range specifications assume one good depth cell and a smooth bottom.

Table 1. Mode 5 Profiling Specifications

Freq.	Blanking	Bin Size	Single-Ping Std Dev.	Range to First Depth Cell	Profling Range (m)	
					Min.	Max
600 kHz	WF25	WS10	0.5 cm/s	0.35 m	0.9 m	7 m
	WF25	WS25	0.3 cm/s	0.50 m	1.6 m	7 m
	WF25	WS50	0.2 cm/s	0.75 m	2.2 m	7 m
1200 kHz	WF25	WS05	0.6 cm/s	0.30 m	0.8 m	3.5 m
	WF25	WS10	0.4 cm/s	0.35 m	0.9 m	3.5 m
	WF25	WS25	0.3 cm/s	0.50 m	1.6 m	3.5 m

Note: Specifications assume water temperature is 10°C and salinity is 0 ppt.

Table 2. Mode 8 Profiling Specifications

Freq.	Blanking	Bin Size	Single-Ping Std Dev.	Range to First Depth Cell	Profling Range (m)	
					Min.	Max
600 kHz	WF25	WS10	8.2 m	0.35 m	0.6 m	7 m
	WF25	WS25	5.2 m	0.50 m	0.9 m	7 m
	WF25	WS50	3.7 m	0.75 m	1.4 m	7 m
1200 kHz	WF25	WS05	11.0 m	0.30 m	0.5 m	3.5 m
	WF25	WS10	7.8 m	0.35 m	0.6 m	3.5 m
	WF25	WS25	5.0 m	0.50 m	0.9 m	3.5 m

Note: Specifications assume water temperature is 10°C and salinity is 0 ppt.

Setting the Ambiguity Velocity – The ambiguity velocity for Modes 5 and 8 is set using the WZ command. A value of 5 cm/s (WZ05) should be used for most applications to allow for the deepest possible profiling range. The ambiguity velocity set in WZ is the minimum ambiguity velocity used in the ADCP processing. Modes 5 and 8 adjust the actual ambiguity velocity to higher values than that specified in WZ based on the depth of the water measured by bottom tracking. For shallower depths, shorter lags are required between the two individual pulses. The shorter lag corresponds to higher ambiguity velocity values, so the actual ambiguity velocity is adjusted upwards.

The ambiguity velocity value set in WZ for Modes 5 and 8 is different than the ambiguity velocity set using WV for Mode 1. For Mode 1, the ambiguity velocity is set to the value of the maximum expected radial velocity. In contrast, the ambiguity velocity set using WZ in Modes 5 and 8 sets the maximum allowable lag between the two individual pulses which in turn sets the maximum allowable profiling range. Both Modes 5 and 8 use this as the upper allowable profiling range, and use bottom tracking to tune the actual ambiguity to higher values for shallower depths. For this reason, it is best to use Modes 5 and 8 with bottom track enabled when making measurements from a moving boat.

In Table 3, the maximum lag settings are given for ambiguity values of 5 and 10 cm/s. These lags represent the maximum profiling ranges in ideal conditions. In practice, these ranges are reduced to the values shown in parentheses. The standard deviation values are also give for the ambiguity values. We see that as the ambiguity value increases, the standard deviation increases slightly. This is because the lag between the pulses decreases as the ambiguity velocity increases. Shorter lags give velocity estimates with a higher degree of uncertainty.

Table 3. Example Ambiguity Velocity Values and Associated Maximum Lags

WZ– Command Setting	**Maximum Lag in meters (Actual Maximum Profiling Range)**		**Standard deviation (cm/s)**				**Maximum Relative Water Velocity**	
	600 kHz	1200 kHz	600 kHz		1200 kHz			
			Mode 5	Mode 8	Mode 5	Mode 8	Mode 5	Mode 8
WZ05 (minimum)	8 m (7.5m)	4 m (3.5m)	0.3	5.2	0.4	7.8	0.5 m/s	1 m/s
WZ10	4 m (3.5 m)	2 m (1.75 m)	0.5	6.6	0.7	10.5	1 m/s	2 m/s

NOTE. WZ05 is the recommended ambiguity velocity setting for moving boat applications with Bottom-Track enabled. As Bottom Track detects the range to bottom, it will automatically adjust the amibiguity velocity to higher values for shallower depths. The result is that Modes 5 and 8 will work at higher relative water velocities in shallower water depths. For example, a 600 kHz system using Mode 5 will work in a maximum relative water velocity of 0.5 m/s for 8 m water depth, and a maximum velocity of 1 m/s in 4m water depth.

If WZ is set to a value less than 5 cm/s, the ADCP will revert to the last valid WZ value. In some cases, this value will be the default setting as given in Table 4. If the WZ value is in question, use BBTALK and type the command **<WZ?>** to determine the actual WZ value.

Table 4. Ambiguity Velocity Defaults

Instrument	**Ambiguity Velocity Default**
WorkHorse Rio Grande	WZ05
WorkHorse Sentinel and Monitor	WZ10
BroadBand	WZ10

Profiling Range Considerations of Mode 5 and 8 – If you are using bottom tracking, and the range to the bottom becomes deeper than the maximum allowable lag set by the WZ command, you may not be able to profile to the full range expected. Refer to Figure 2 for a plot of the Mode 5 and 8 profiling range as a function of water depth. This figure assumes a 600 kHz ADCP and an ambiguity setting of WZ05. In the following, we will describe three regions of the plot.

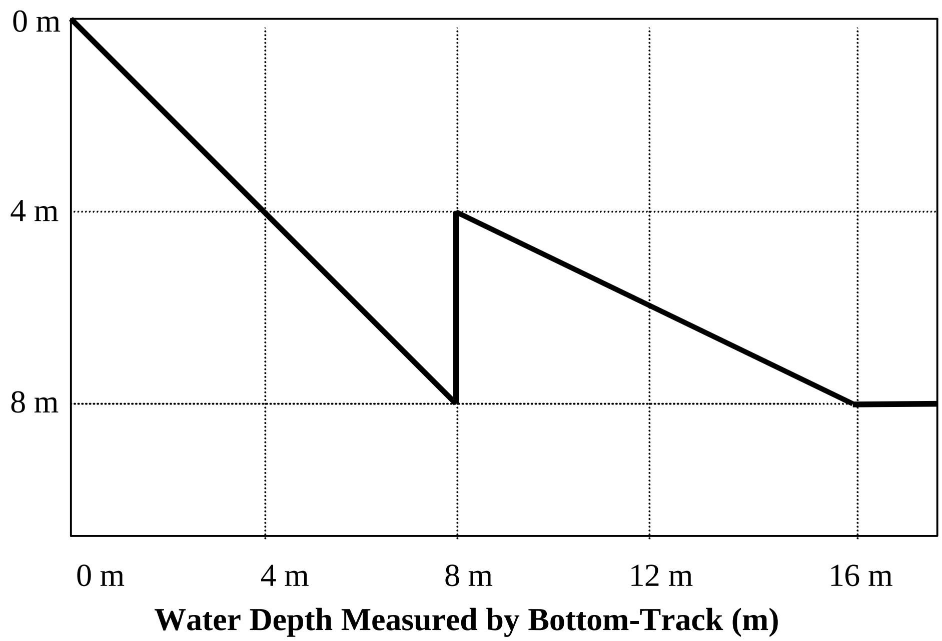

Figure 2. Mode 5 and 8 Profiling Range vs. Depth (600 kHz ADCP and WZ05)

1. ***Water Depth Less than Maximum Allowable Lag*** – The maximum allowable lag is set by the WZ command. For WZ05 and a 600 kHz ADCP, this lag is 8 m. This value represents the maximum profiling range. As the water depth increases from 0 to 8 m, the actual profiling range increases, and the ADCP profiles to the full depth range.
2. ***Water Depth Greater than Maximum Allowable Lag but Less than Twice the Maximum Allowable Lag*** – Once the water depth becomes greater than the maximum allowable lag, the ADCP will shorten its profiling range to one half the actual depth.
3. ***Water Depth Greater than Twice the Maximum Allowable Lag*** – When the water depth has become greater than two times the maximum allowable lag, the profiling range stays at the maximum profiling range set by the WZ command.

***Effect of Relative Water Velocity on Profiling Range and Standard Deviation*-** The relative water velocity (combination of water and boat velocities) has two main effects on the ADCP's profiling capability in Modes 5 and 8.

- The profiling range decreases with increasing relative water velocity.
- The standard deviation increases with increasing relative water velocity.

These relationship are shown in Table 3 where the standard deviation and profiling range are given for the 600 and 1200 kHz WorkHorse Rio Grande. We can see for the 600 kHz system using Mode 5 that as the relative water velocity increases from 50 cm/s to 200 cm/s, the profiling range decreases from 7.0 m to 2.3 m, and the standard deviation increases from 0.3 to 1.4 cm/s. Modes 5 and 8 are so sensitive to the relative water velocity because of the long lag used between their pulses.

To make a velocity measurement the ADCP forms the correlation between the scattered energy seen by one pulse with that of the energy returned in the second pulse. The correlation between these pings must meet some threshold in order for the ADCP to make the velocity estimate. This means that each ping must scatter off some of the same scatterers. If the water velocity is high, the scatterers move more quickly, and the number of scatterers seen by both pulses will go down resulting in decorrelation effects. As the water velocity increases, a velocity value is reached at which Modes 5 and 8 will not work at all. This velocity threshold is lower for Mode 5 (about 1 m/s) than Mode 8 (about 2 m/s).

With longer profiling ranges, a longer lag is used between the individual pulses. This longer lag means that the water must be moving more slowly in order to meet the required correlation threshold. This is why the profiling range is reduced for higher relative water velocities.

Table 3. Mode 5 and 8 Standard Deviation vs. Relative Velocity and Profiling Range

Frequency (kHz)	Relative Water Velocity (Water + ADCP)	Maximum Profiling Range (m)		Standard Deviation (cm/s)	
		Mode 5	Mode 8	Mode 5	Mode 8
600 kHz (25cm Cell Size)	50 cm/s	7.0	7.0	0.3	3.0
	100 cm/s	6.9	7.0	0.5	5.2
	200 cm/s	2.3	6.3	1.4	16.5
1200 kHz (10cm Cell Size)	50 cm/s	3.5	3.5	0.4	4.7
	100 cm/s	3.5	3.5	0.7	7.8
	200 cm/s	-	3.3	-	24.7