ChannelMaster H-ADCP

HORIZONTAL ACOUSTIC DOPPLER CURRENT PROFILER

# Open Channel Flow and Water Level On-Line Monitoring

The compact, flexible, and affordable **ChannelMaster** is a horizontally-oriented Acoustic Doppler Current Profiler (H-ADCP) designed to collect high-accuracy water velocity, stage, and discharge data for a wide array of applications.

By leveraging Teledyne RDI's BroadBand technology, ChannelMaster allows you to obtain unmatched data quality, even in low velocities and complex flows, where a single cell cannot provide enough information.

The ChannelMaster's innovative design includes everything you need to collect high-quality data. The standard unit comes equipped with temperature, pressure, pitch and roll sensors, and a vertical beam.

ChannelMaster provides:

- Teledyne RDI's BroadBand technology, which allows for small cells and/or short averaging/sampling intervals

- Ability to measure highly accurate velocities even in difficult environments such as slow flow or rapidly changing flow

- A range of 1–128 user-selectable cells, with cell sizes from 25cm to 8m and profiling ranges from 1m to 300m (depending on system frequency)

- Standard stainless steel mounting fixture
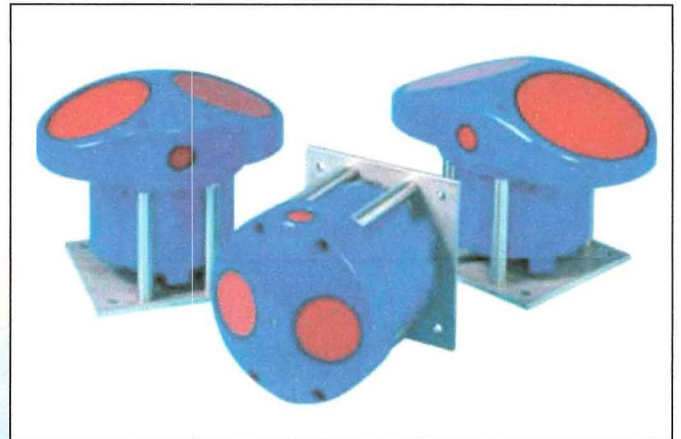
ChannelMaster Applications:

- *Rivers, streams, and irrigation canals: Monitor discharge and water level. Easily integrated with a telemetry or SCADA system.*

- *Estuaries: Measure complex currents for environmental monitoring or circulation model calibrations or verifications.*

- *Port and Harbors: Monitor currents to provide velocity information for vessel maneuvering and safety.*
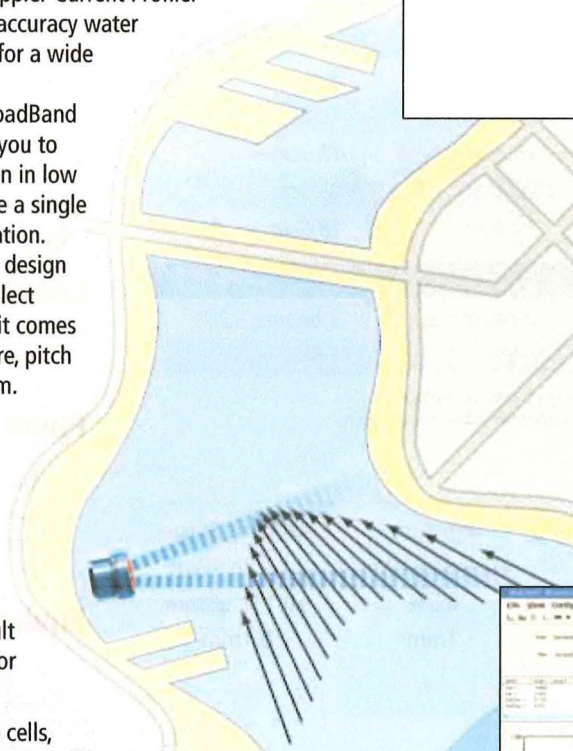
Teledyne RDI's ChannelMaster H-ADCP is installed on a riverbank or near-shore structure to acquire real-time velocity, stage, and discharge data.
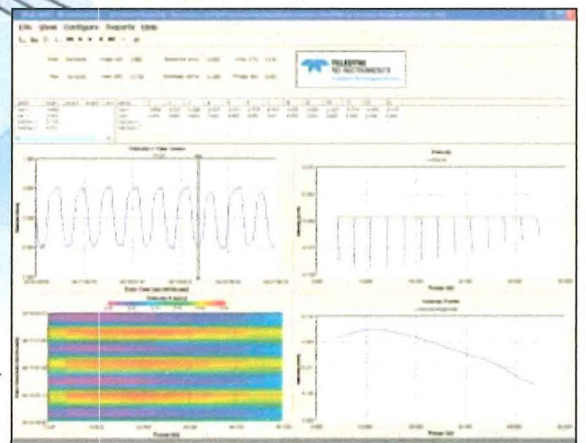
ChannelMaster H-ADCP data samples.

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RD INSTRUMENTS
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ChannelMaster H-ADCP

HORIZONTAL ACOUSTIC DOPPLER CURRENT PROFILER

Technical Specifications

Model Name	CM300	CM600	CM1200
System frequency	300kHz	600kHz	1200kHz
Water Velocity Profiling (Broadband mode)			
Profiling range	4m[a] to 300m[b]	2m[a] to 90m[b]	1m[a] to 25m[b]
Velocity range	±5m/s default, ±20m/s maximum		
Accuracy	±0.5% of water velocity relative to ADCP, ±2mm/s		
Resolution	1mm/s	1mm/s	1mm/s
Number of cells	1-128	1-128	1-128
Cell size	1m to 8m	0.5m to 4m	0.2m to 2m
Blanking distance	1m	0.5m	0.2m
Data output rate	User-programmable		
Physical Properties			
Weight in air	6.8kg	4.76kg	3.4kg
Weight in water	3.17kg	2 kg	1.58kg
Height	18.3cm	18.3cm	18.3cm
Width	32.5cm	26.4cm	18.3cm
Depth	19.8cm	19.3cm	18.9cm
Transducer			
Geometry	2 beams, ±20°	2 beams, ±20°	2 beams, ±20°
Beam width	2.2°	1.5°	1.5°

[a] Assume one good cell (minimum cell size); range measured from the transducer surface.
[b] Assume fresh water; actual range depends on temperature and suspended solids concentration.

Standard Sensors

Sensor	Temperature	Tilt (pitch and roll)	Pressure	Acoustic Stage
Range:	-4°C to 40°C	±10°	0.1m to 10m	0.1m to 10m*
Accuracy:	±0.2°C	±0.2°@2°, ±0.5°@10°	0.5%	±0.1%, ±3mm
Resolution:	0.01°C	0.01°	1mm	0.1mm

* User-programmable to 18m maximum.

Software

- **WinH-ADCP:** System setup, data acqusition, discharge calculation, data display, and summary report
- **PlanCV:** Deployment planning, predicting precision, power usage, etc.

Other Hardware & Features

- 4mb internal recorder
- 25m power and communications cable standard, longer available
- Stainless steel mounting plate
- Built-in index-velocity method flow calculator

Communications

RS-232 with SDI-12, or RS-422

- SDI-12 supports v 1.3 (concurrent).
- Simultaneous SDI-12, and internal logging supported.

Serial baud rates: 300–115,200 bps

Construction

Cast polyurethane with titanium hardware, mounting plate included.

Power

Voltage:	10-18VDC
Max. current:	1.5A
Power consumption:	0.1W @ 10% duty cycle (typical)

Environmental

Operating temperature:	-5°C to 45°C
Storage temperature:	-20°C to 50°C

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www.rdinstruments.com
Free 24/7 emergency support

DL25 - ADCP Extended Memory And Control

Reliable and flexible control of ADCPs in remote areas

The DL25 Extended Memory And Control (EMAC) enables long term data logging and remote control of Teledyne RDI Channel Master ADCPs. This supports deployment of these ADCPs in remote areas where large data recording requirements exist because the instrument cannot be readily accessed.

Data logging for other ADCP types used in ocean deployments can be provided by packaging the DL25 for subsea deployment.

Long Term Recording of Data

By providing an extended memory capability, long term data logging for ADCPs can be implemented. Data is stored on user-provided SD cards and so the memory capability and endurance of the recoding is only limited by the size of SD card selected.

ADCP Control

Once deployed in a remote area control of the ADCP may be required to respond to local conditions or to change the setup of the instrument. The DL25 EMAC provides the capability to interface directly to the ADCP using an easy-to-use web page display or a TCP Telnet channel accessed via radio modem or other method.

ADCP Confidence

When deployed in a remote location it is important to know that an instrument is set-up correctly and working. The DL25 EMAC enables an easy method to check that an instrument is working in-situ so that even inexperienced users can perform checks after deployment. This reduces the need for highly-trained staff to be absent for long periods to travel to remote locations and check instruments. Local support can be used for setup and over-the-phone guidance can be provided for trouble shooting.

Available Packaging

The DL25 EMAC can be packaged to suit your application.

OEM Version: PCB and embedded software only ready for integration into your data logging system

IP67 Enclosure: Rugged enclosure with industrial standard connectors suitable for dry applications in harsh environments.

Subsea Enclosure: Fully sealed enclosure with underwater connectors suitable for subsea deployment

Telemetry Package: UVS can design and supply a full telemetry package for remote area applications to suit your budget

Features

- Common ADCP commands included as "macro" style buttons
- Processing and display of recorded data via web interface
- User configurable data storage capacity
- Access to logged data files locally as well as remotely
- Large PD0 files can be downloaded in user-selectable ranges
- Logs and reports proprietary health status of device (battery, temperature, leaks, etc.)
- "Hard Break" can be sent to ADCP
- Status updates can be sent with Twitter and ThingsSpeak
- Able to record/log serial output from device in native data formats (ASCII, PD0 (binary), etc.)

Benefits

- Inexperienced users can perform checks with simple guidance
- Remote validation of data and device configuration
- Sufficient for mission lengths of several months
- Local and remote checking of logged data
- Easy management of large files and fast access to ranges of interest
- In the event of an instrument failure this feature can be used to assist to determine the root cause
- Enables ADCP to be set to sleep mode and save power. The ADCP can be woken as required
- Receive alerts via Twitter on selectable events, such as power reset, system errors, etc.
- View data on ThingsSpeak from remote locations
- Flexibility for recording from many devices

LaserFlow™ Velocity Sensor and Signature® Flow Meter: Redundant Flow Measurement

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Expertise in Flow

LaserFlow™ Velocity Sensor

Standard Features

- Non-contact velocity and level measurement
- Single or Multiple Point measurement below liquid surface
- Rugged, submersible enclosure with IP68 ingress protection
- Zero deadband from measurement point in non-contact level and velocity measurements
- Quality readings without manual profiling
- Bidirectional velocity measurement

Signature® Flow Meter

Standard Features

- Multiple parameter data logging
- Program & summary reports
- Data integrity verification
- Triggering, sampler enabling
- Compatibility with Flowlink® software
- Multiple simultaneous flow technologies
- pH and temperature input
- SDI-12 input
- RS-485 input
- RS-485 output
- Analog outputs
- Remote communication via cell phone or Ethernet

Wastewater collections personnel at a Pennsylvania municipality faced a complex flow monitoring application which required a flexible and accurate solution. The city had incurred significant expense in installing a flume at a key monitoring location, only to have the device overwhelmed during critical high flow conditions when accurate flow data was most needed. Estimated costs for replacing the flume with a larger device were not cost-effective and still carried no guarantee of proper operation during the most extreme infiltration and inflow events.

Figure 1: (Left) Aerial view of the LaserFlow manhole, Signature flow meter and flume vault locations

Figure 2: (Right) Street view of the LaserFlow manhole, Signature flow meter and flume vault locations

To resolve this challenging combination of conditions, the municipality chose to install the Teledyne Isco TIENet™ Signature flow meter to monitor multiple sensors simultaneously during changing flow conditions. Additionally, the flow meter was equipped with the optional cellular modem option to enable remote monitoring and alarming.

To monitor the flow in the flume vault during normal conditions, a TIENet™ remote 310 ultrasonic sensor was mounted using the floor mount for horizontal surfaces. See Figure 4.

To monitor the flow during the submerged flume conditions, the LaserFlow sensor was installed upstream. Additionally, the optional TIENet™ 350 Area Velocity sensor was mounted to the bottom of the LaserFlow for flow measurement during submerged conditions. This
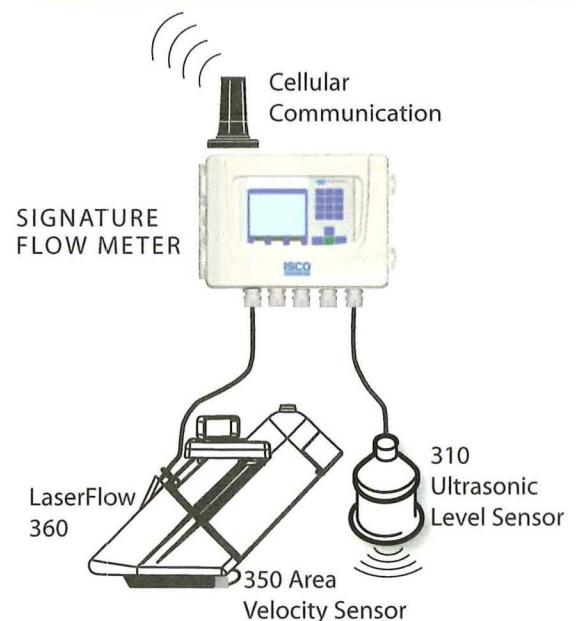

Figure 3: Multiple sensors connected to a Signature flow meter

310 Ultrasonic Level Sensor

Standard Features
- Non-contact velocity and level measurement
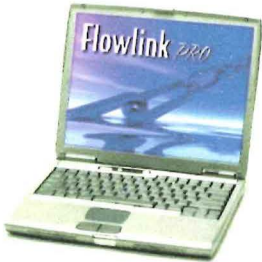- Transmits sound pulses reflected off liquid surface

350 Area Velocity Sensor

Standard Features
- Differential Pressure Level measurement
- When mounted on bottom of LaserFlow sensor, takes over flow rate measurement during submerged conditions

Flowlink Pro Software

Standard Features
- Communicates with site instruments for configuration, data retrieval and data recording
- Connects to the site Code Division Multiple Access (CDMA) or Global System for Mobile Communications (GSM) modem via cellular telecommunications service

sensor provides continuous wave Doppler to measure area velocity with a differential pressure transducer to measure level. This method allows continuous flow monitoring of the manhole during submerged conditions.

Following the discharge event, data from the three flow conditions was collected using Teledyne Isco Flowlink software. The advanced technology of the Signature flow meter with its TIENet™ network capabilities enabled the municipality to obtain data from the three sensors with a single download and generate an accurate flow discharge report.
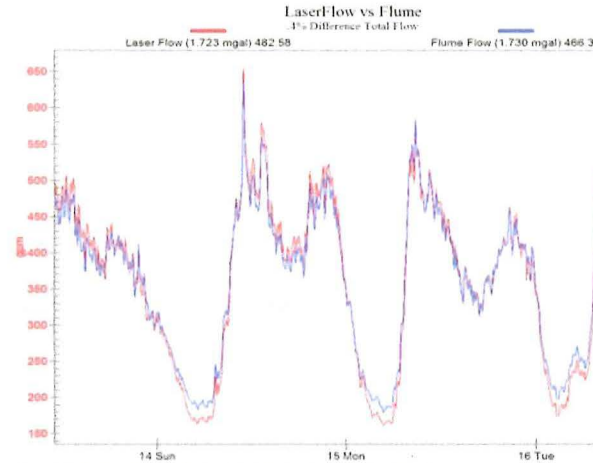

Figure 4: (Top Left) The graph displays how the advanced laser technology verifies the accuracy of the flume under normal flow conditions.

Figure 5: (Top) The TIENet™ 310 ultrasonic level sensor determines the flow rate in the flume vault.

Figure 6: (Left) The LaserFlow sensor operating under normal flow conditions.

Figure 7: (Bottom Left) The graph displays the operation of the 350 sensor during submerged flow conditions.
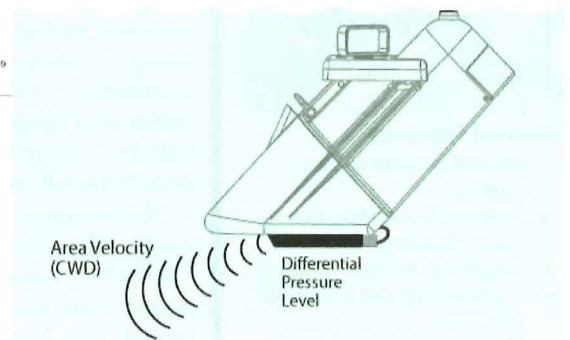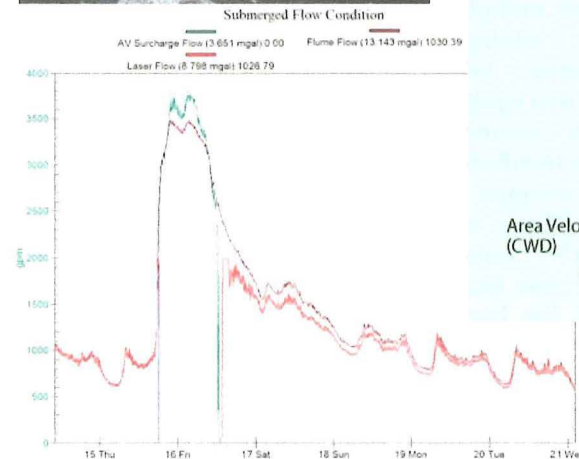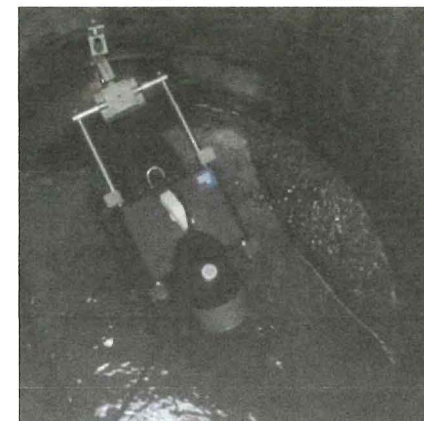

Figure 8: (Above) When water reaches the LaserFlow, the optional 350 area velocity sensor takes over flow rate measurement.

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River Discharge Monitoring Using Horizontal Acoustic Doppler Current Profiler (H-ADCP)

Hening Huang

Teledyne RD Instruments, Inc., 14020 Stowe Drive, Poway, CA. 92064, USA
(Tel: 858-842-2600, e-mail: hhuang@teledyne.com)

Abstract: H-ADCP is an effective tool for river or open channel discharge monitoring (either real-time or self-contained deployment). This note describes discharge calculation methods and alternatives for real-time discharge monitoring. Two application examples are given.

1.0 Introduction

H-ADCP (Horizontal Acoustic Doppler Current Profiler) is an acoustic Doppler instrument manufactured by Teledyne RD Instruments, Inc. for discharge monitoring in rivers, streams, and open channels. It can be used either in real-time mode through a telemetry system, or in self-contained mode. An H-ADCP measures velocity horizontal profile across a channel by its two horizontal acoustic beams (Figure 1). H-ADCP also measures water level by its up-looking acoustic beam. However, H-ADCP does not measure discharge directly. A discharge calculation method must be employed by a user to calculate discharge using the H-ADCP measured velocity and water level data. This note describes two methods, Index-velocity method and numerical method for discharge calculation. Two alternatives for real-time discharge monitoring are discussed. Two application examples are given.
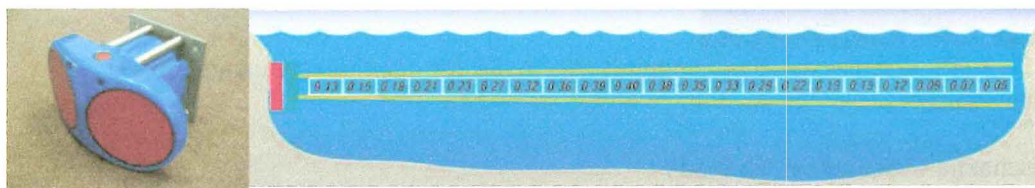

Figure 1 H-ADCP and velocity profiling. Numbers are velocities at cells.

2.0 H-ADCP Installation

An H-ADCP is usually installed on a pier or on a channel bank. It should be mounted with its face looking across the channel. The mounting level usually is fixed below the lowest water level. However, if the water level changes too much from dry season to wet season, it may consider mounting the unit at several different levels according to the water level changes. However, each change of mounting level will require a rating when using Index-

velocity method for discharge calculation. Figure 2 and 3 show two H-ADCP installation examples.
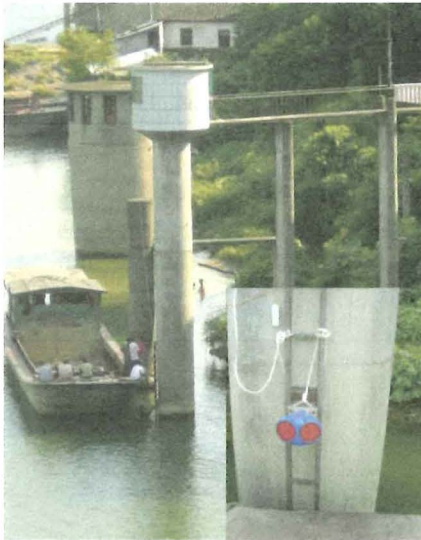

Figure 2   A 600 kHz H-ADCP at Guyi hydrology station in Xiang River, Guangxi, China

Figure 3   A 300 kHz H-ADCP at Songpu Bridge hydrology station in Huangpu River, Shanghai, China

3.0   Discharge Calculation Methods

It is important to note that H-ADCP does not measure discharge directly. An H-ADCP collects data for velocity horizontal profile and water level. Users need to employ an appropriate method for discharge calculation using the velocity profile and water level data. There are two discharge calculation methods. One is the so-called Index-velocity method. The other is the numerical method. These two methods are based on different approaches. A major difference between the two methods is that Index-velocity method requires rating or calibration, while numerical method does not. Another major difference is that Index-velocity method does not require the H-ADCP profiling range covering the majority of channel cross-section. Therefore it can be used for either small streams or large rivers with the river width much greater than the H-ADCP profiling range. Table 1 shows a comparison of Index-velocity and numerical method. Details on the two methods are described in Appendix 1 and 2 respectively.

Table 1 Comparison of Index-velocity and numerical methods for discharge calculation

	Index-Velocity Method	Numerical Method
Need rating or calibration?	Yes	No
Need H-ADCP profiling range to cover the majority of channel cross-section?	No	Yes
Is H-ADCP mounting position allowed being changed?	No. If mounting position changes, new rating has to be developed.	Yes. Calculation can account for mounting position change.

4.0 Real-Time Discharge Monitoring Solution Alternatives

Based on the system hardware configurations, there are two alternatives when using H-ADCP for real-time river discharge monitoring. Alternative 1 is show in Figure 4. This alternative employs an on-site computer. Therefore, it is usually used at large hydrology stations such as Guyi and Songpu stations (Figures 2 and 3), where on-site computers are available. Q-Monitor-H, an advanced software for H-ADCP, is recommended when using this alternative. One of the important features of the software is it can accept external water level data through a serial port for discharge calculation. The software can use either numerical model or Index-velocity method to calculate discharge. Figure 5 shows a screenshot from Q-Monitor-H.
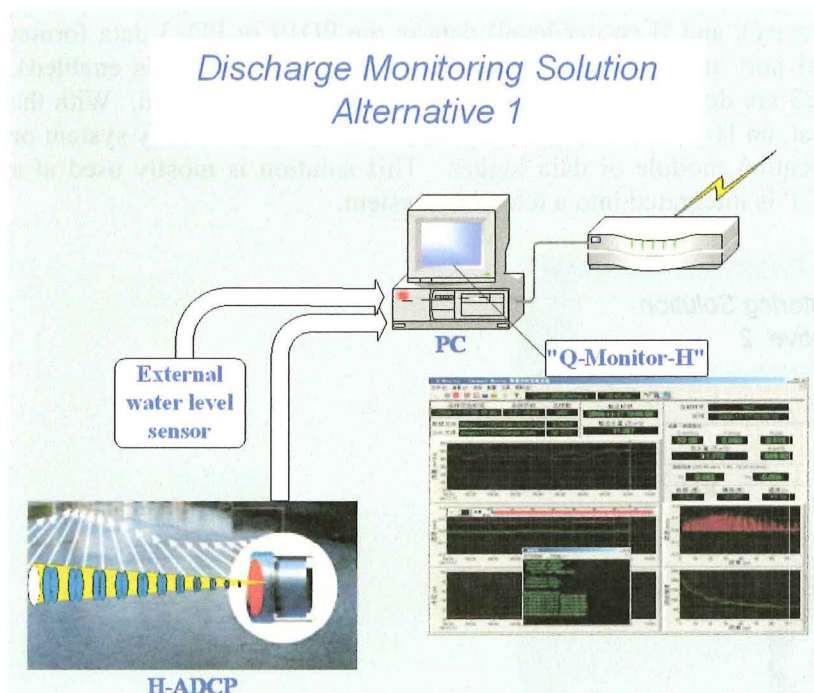

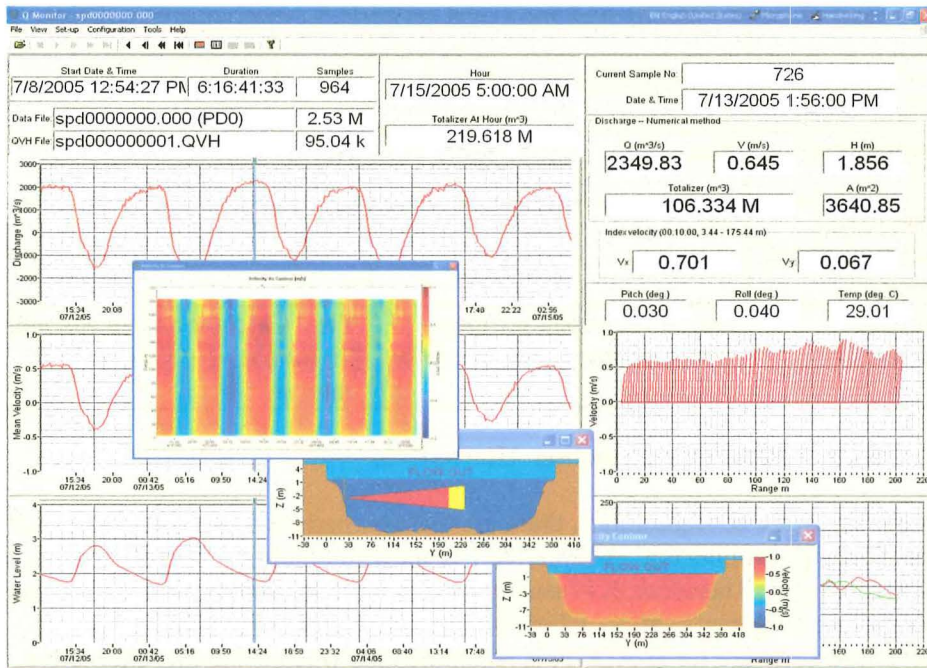Figure 4 Discharge monitoring solution Alternative 1

Figure 5 A screenshot of Q-Monitor-H software

Figure 6 shows Alternative 2. This alternative does not require an on-site computer. H-ADCP velocity and water level data are processed and discharge is calculated internally in real-time by an Index-velocity model built-into the H-ADCP firmware. H-ADCP outputs Q (discharge), V (mean velocity), and H (water level) data in the PD19 or PD23 data format (ASCII data on the serial port and records PD0 data internally, if recording is enabled). Details on PD19 and PD23 are described in the ChannelMaster H-ADCP manual. With the PD19 or PD23 data format, an H-ADCP can be easily integrated into a telemetry system or connected to a communication module or data logger. This solution is mostly used at a remote site where H-ADCP is integrated into a telemetry system.
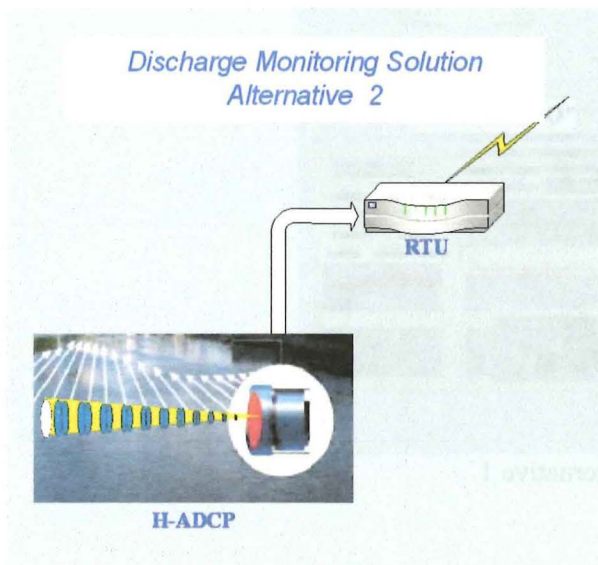

Figure 6 Discharge monitoring solution Alternative 2

Table 2 shows a comparison of the two alternatives for real-time discharge monitoring.

Table 2 Comparison of the two alternatives for real-time discharge monitoring

	Alternative 1	Alternative 2
Hardware configuration	H-ADCP and on-site computer	H-ADCP only
Require a on-site computer	Yes	No
On-site complete data display	Yes	No
On-site QVH data display	Yes	No
QVH data serial port output for telemetry	Yes	Yes
Accept external water level sensor data	Yes	No
Discharge calculation methods	Selectable two methods: • Numerical method (no calibration is required) • Index-velocity method with five rating models	Index-velocity method with linear rating model
Recorder capacity	Depends on PC memory capacity	4 Mb
Draw data (PD0 format) recording	Yes. Raw data stored in on-site computer	Yes. Raw data stored in the internal loop recorder

5.0 Application Examples

5.1 Imperial Irrigation Canal at Trifolium Check 13 Site, California, USA: Index-Velocity Method and Numerical Method

The Imperial Irrigation canal at Trifolium Check 13 site, California, USA is a trapezoidal concrete lining canal. It had a bottom width of 3.05 meters and a slope of 1:1.5. The water depth over the canal bottom was around 1.4 meters. The canal flow changed dramatically during a day from near zero to over 3 m^3/s.

The field test was conducted on December 9, 2003. A 600 kHz H-ADCP was mounted on a temporary mounting (Figure 7). The mount was placed on the right bank, at a position 64 meters upstream of the check structure. The H-ADCP was configured at an averaging interval of 37.4 seconds. The sampling interval was the same as the averaging interval. Other settings are: cell size = 0.5 meters, number of cells = 20, and blank distance = 0.5 meters. The H-ADCP was continuously collecting data from 12:34:20 to 16:18:43. A total of 361 ensemble data sets for velocity profile and water level were obtained. Concurrently with the H-ADCP measurement, a StreamPro moving-float ADCP was used to measure discharge. The StreamPro ADCP was attached to a pulley system (Figure 8). A total of 31 transects were made from 12:30 to 16:30. Each transect took about 2.5 to 4 minutes to complete and generated a discharge measurement. Details on the field test can be found in Huang (2004).

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Figure 7 H-ADCP prior to deployment at the California canal site

Figure 8 Set-up of H-ADCP and moving-float ADCP at the California canal site

Figure 9 shows the cross-section of the canal and position of the acoustic beams. The white area is the blank, red area is the valid cells used for discharge calculation (by either Index-velocity or numerical method), and yellow area is the cells not used for discharge calculation.
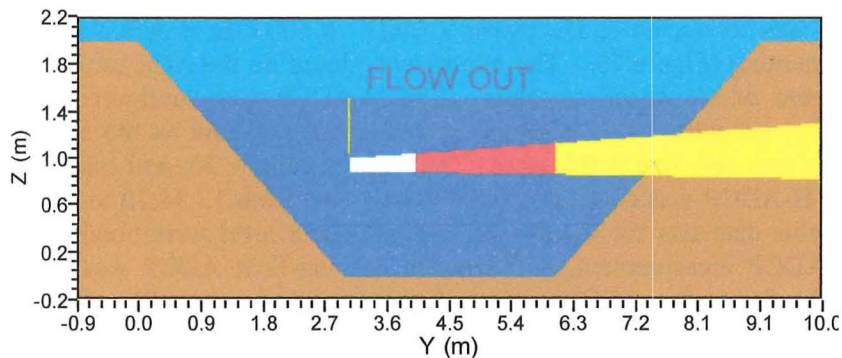

Figure 9 Canal cross-section and position of acoustic beams at the California canal site

Index-velocity method and numerical method were employed to calculate discharges respectively. The three-minute average velocity of the first four cells is taken as Index-velocity. Figure 10 shows the StreamPro ADCP measured channel mean velocity vs. the

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Index-velocity. Regression using the IVR-Creator software results in the following rating equation for the site:

$$V_m = 0.8635 \times V_I \qquad\qquad (1)$$

where V_m is the channel mean velocity, V_I is the Index-velocity, both in m/s. The correlation coefficient for the rating is 0.9972, bias 0004 m/s, and standard deviation 0.0075 m/s.
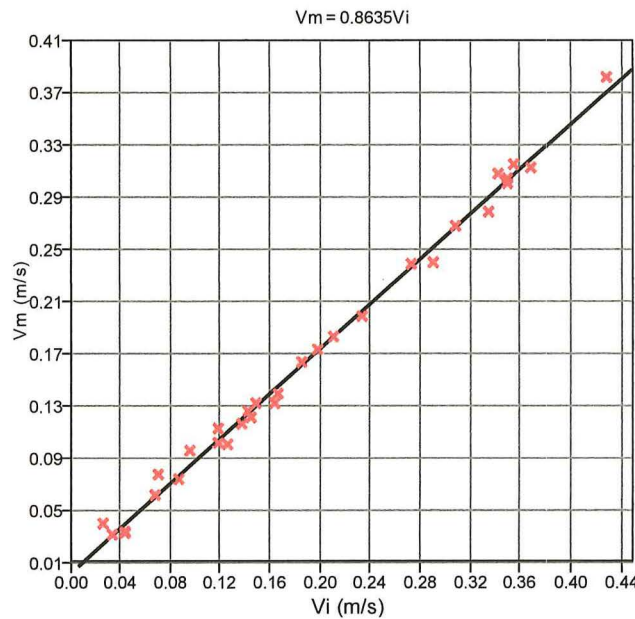

Figure 10 StreamPro ADCP measured channel mean velocity vs. the Index-velocity at the test site in California, USA

Figure 11 shows time series (187-second moving averaging) of discharge generated from Q-Monitor-H software using Index-velocity method and numerical method respectively. The StreamPro measured discharges are also shown in the plot. It can be seen from Figure 11 that the discharges calculated from both methods agree well with the StreamPro measured discharges.

It should be pointed out that the Index-velocity rating (Eq. 1) was developed using the StreamPro measured discharge data at the site. Therefore, the discharges calculated from the rating equation must agree well with the StreamPro discharge data. On the other hand, the numerical method is independent method and is not calibrated using the StreamPro discharge data. Therefore, the agreement between the discharge calculated from the numerical method and the StreamPro measured discharge validate the numerical method.
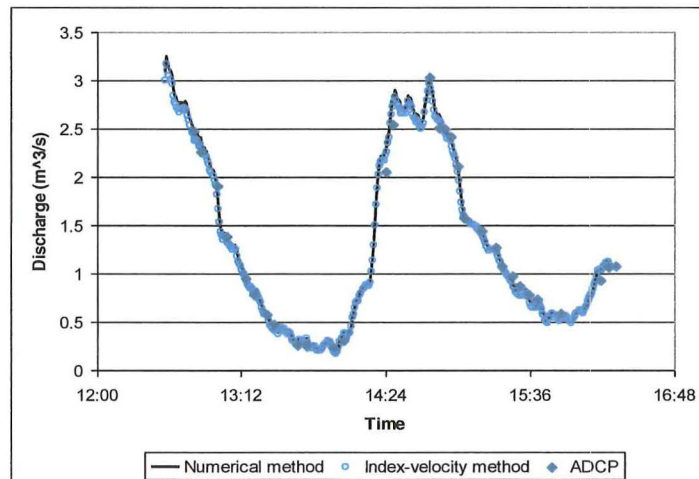
Figure 11 Time series of discharge calculated from Q-Monitor-H software using Index-velocity method and numerical method respectively with comparison to StreamPro ADCP measured discharges at the California canal site

5.2   Huangpu River at Songpu Bridge Site, Shanghai, China: Index-Velocity Method

The Huangpu River reach at Songpu Bridge site is affected by tides. The river width is about 400 m and the mean depth is about 10 m. The hydrology station house is connected to the right bank by a pier, about 30 m from the bank (Figure 12).
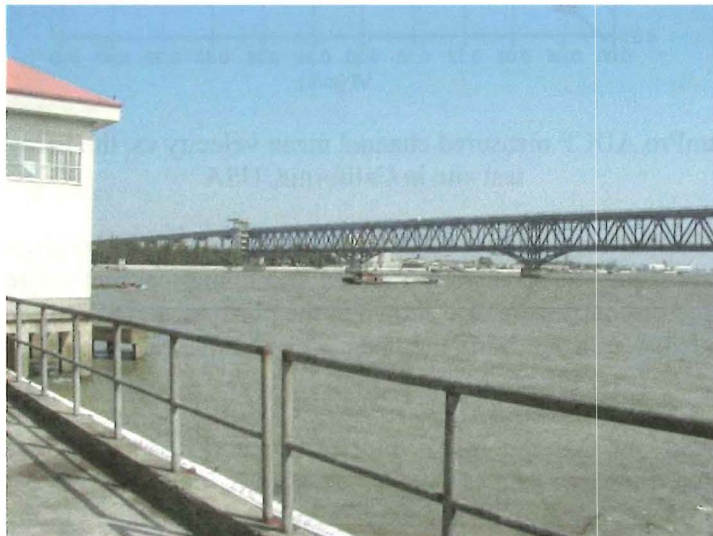

Figure 12 Huangpu River at Songpu Bridge Site, Shanghai, China

The field test was conducted on September 27 to 28, 2001. A 600 kHz H-ADCP was temporarily mounted on the outside piles of the station house. Figure 13 shows the river cross-section and the position of the H-ADCP acoustic beams. The H-ADCP was configured at an averaging interval of 1.72 seconds. The sampling interval was the same as the averaging interval. Other settings are: cell size = 2 meters, number of cells = 70, and blank distance = 0.5 meters. The H-ADCP was continuously collecting data from 13:30, September 27 to 10:00 September 28. A total of 44,201 ensemble data sets for velocity profile and water level were obtained. Concurrently with the H-ADCP measurement, traditional current meter method was employed to measure discharge. Velocities at five verticals, one using a cableway and four using anchored boats, were measured for 25 hours at

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an interval of 10 to 30 minutes. A total of 63 current meter discharge data were obtained. In addition, a 600 kHz Rio Grande moving boat ADCP was used to measure discharge and 21 ADCP discharge data were obtained.
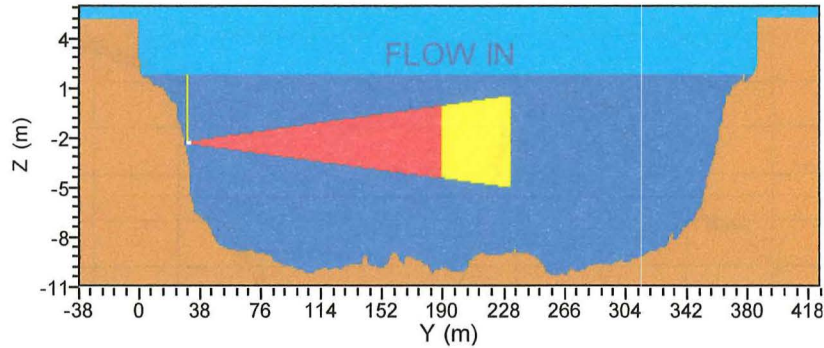

Figure 13 River cross-section and position of H-ADCP acoustic beams
at the Shanghai Huangpu River Songpu Bridge station site

Only Index-velocity method was employed to calculate discharge at this site. The three-minute average velocity of the 10th to 35th cells (20 to 70 m range) is taken as Index-velocity. Figure 14 shows the current meter measured mean velocity vs. the Index-velocity.
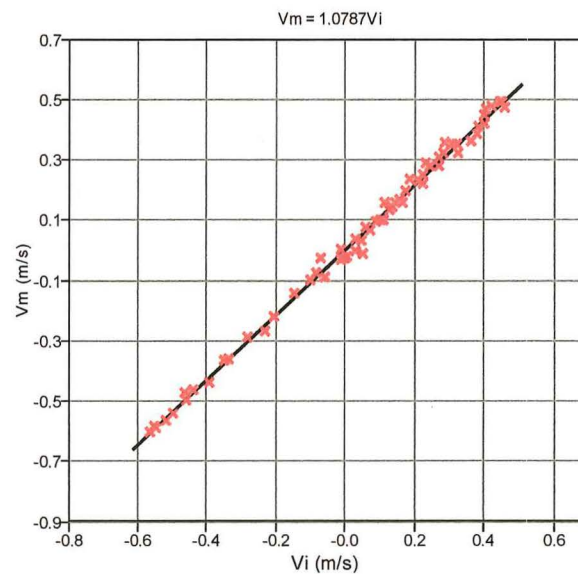

Figure 14 The current meter measured mean velocity vs. the Index-velocity at the Shanghai
Huangpu River Songpu Bridge station site

Regression using the IVR-Creator software results in the following rating equation for the Songpu Bridge station site:

$$V_m = 1.0787 V_I \tag{2}$$

The correlation coefficient for the rating is 0.9978, bias 0003 m/s, and standard deviation 0.0215 m/s.

Figure 15 shows time series (172-second moving averaging) of discharge generated from Q-Monitor-H software using the site specific rating model Eq. (2). The current meter and

ADCP measured discharges are also shown in the plot. It can be seen from Figure 15 that the discharges calculated from the site specific rating model Eq. (2) in general agree well with the current meter and ADCP measured discharges.
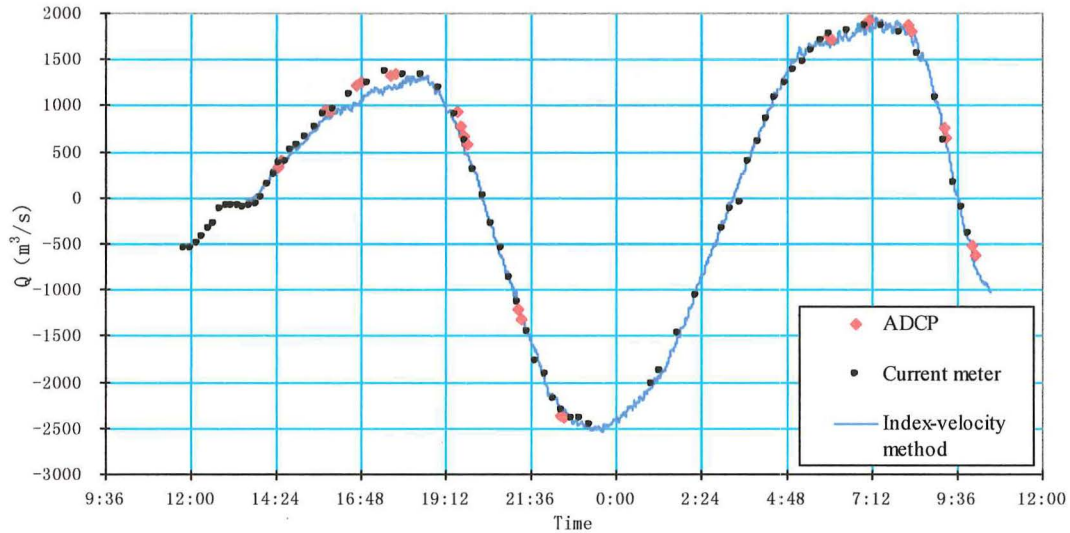

Figure 15 Time series (172-second moving averaging) of discharge generated from Q-Monitor-H software using the site specific rating model Eq. (2), compared to current meter and ADCP measured discharges at the Shanghai Huangpu River Songpu Bridge tation site

6.0 Conclusion

H-ADCP is an effective tool for real-time river discharge monitoring. It is important to note that H-ADCP does not measure discharge directly. A discharge calculation method, either Index-velocity method or numerical method, must be employed. A major difference between the two methods is that Index-velocity method requires rating or calibration, while numerical method does not. Another major difference is that Index-velocity method does not require the H-ADCP profiling range covering the majority of channel cross-section. Therefore it can be used for either small streams or large rivers with the width much greater than the H-ADCP profiling range. On the other hand, the numerical method in principle requires H-ADCP profiling range covering the majority of channel cross-section. Two alternatives may be used for real-time discharge monitoring. Each alternative has its advantages and disadvantages. Users can select one of the two alternatives to meet their site conditions and requirements.

Appendix 1 Index-Velocity Method for Discharge Calculation

Index-velocity method was developed by United States Geological Survey (USGS) and has been used by USGS for over 20 years (e.g., Morlock et. al. 2002; Rantz, 1982a and 1982b). The principle of Index-velocity method is to establish a rating for the relationship between the channel mean velocity and Index-velocity. Water level may be also a parameter for the rating. The Index-velocity is an average velocity measured at a local area in the channel cross-section. The mostly used Index-velocity is a horizontal line velocity measured by an acoustic velocity meter such as an H-ADCP. Index-velocity method can be used for a channel with its width much greater than the H-ADCP profiling range.

Discharge is calculated by:

$$Q = AV \qquad\qquad\qquad (A-1-1)$$

where: V = channel mean velocity, A = wetted area in channel cross-section. The wetted area is a function of cross-section geometry and water level. For a given site, it is a function of water level only (the so-called stage-area rating):

$$A = f(H) \qquad\qquad\qquad (A-1-2)$$

where: H = water surface level referring to a local datum. The stage-area rating is usually presented as a table or curve for a site.

A general form of Index-velocity rating (that is, the mean velocity V as a function of the Index-velocity and stage) is as follows:

$$V = f(V_I,\ H) \qquad\qquad\qquad (A-1-3)$$

where: V_I = Index-velocity, f =velocity rating model.

In most cases, channel mean velocity is a function of Index-velocity only:

$$V = f(V_I) \qquad\qquad\qquad (A-1-4)$$

The development of an Index-velocity rating at a site involves two steps. The first step is to collect data for discharge and Index-velocity at the site. While an H-ADCP samples velocities (Index-velocities), discharge measurements are conducted concurrently using a traditional velocity meter method or the moving boat ADCP method. The channel mean velocities are calculated from the measured discharge Q and wetted area A. The wetted area is calculated from the stage-area rating. The field data collection needs to cover the typical range from low to high flows at the site.

The second step is to create a relationship between the channel mean velocity and Index-velocity by regression analysis of field data. The regression procedure involves (1) the selection of an appropriate rating model (i.e., rating equation), and (2) the determination of coefficients in the model by the least-square method. The rating model should be selected to be the best fit to the field data. It also needs to comply with the hydraulics at the site.

A number of analytic models may be used for index-velocity rating (Table A-1-1). The most common one is linear model. But it can also be non-linear or compound that may consist of two or more rating equations (represented by two or more discrete curves).

Table A-1-1 Rating models for Index-velocity rating

Rating model	Mathematical expression	
Linear (one parameter)	$V = b_1 + b_2 V_I$	
Second-order polynomial	$V = b_1 + b_2 V_I + b_3 V_I{}^2$	
Power law	$V = b_1 V_I{}^{b_2}$	
Compound linear	$V = b_1 + b_2 V_I$	$V_I \leq V_c$
	$V = b_3 + b_4 V_I$	$V_I \geq V_c$
Two parameter linear	$V = b_1 + (b_2 + b_3 H) V_I$	

Note: b_1、 b_2、 b_3、 b_4 are rating coefficients.

Although Excel spread sheet may be used for regression analysis to determine the coefficients in a rating equation, its use requires a quite bit of knowledge of Excel and it is time consuming. IVR-Creator, a commercially available software specially designed for Index-velocity rating development is recommended. IVR-Creator does linear and nonlinear regression analysis using a least-square method. It accepts field data for channel cross-section geometry, discharge, water level (stage), and Index-velocity. IVR-Creator has five built-in rating models as shown in Table A-1-1. Figure A-1-1 shows a screen shot of the IVR-Creator software. IVR-Creator is very easy to use and saves a lot of time. It is a useful tool for Index-velocity rating development.
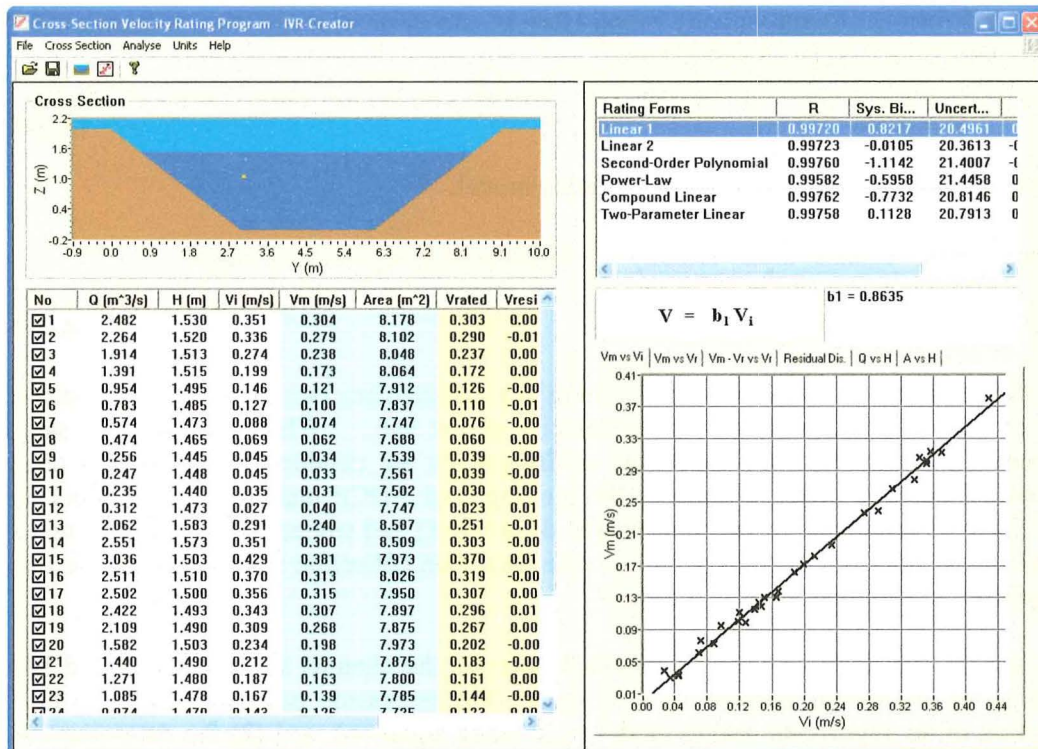

Figure A-1-1 Screenshot of the IVR-Creator software

Appendix 2   Numerical Method for Discharge Calculation

A numerical method for discharge calculation using H-ADCP data was developed by Wang and Huang (2005). The method employs power law for open channel velocity vertical profile to obtain velocity distribution in the wetted area in channel cross-sect ion. Discharge is then calculated by integration of the velocity distribution. In principle, the numerical method does not require calibration. Below is a summary of the numerical method. Details on the method can be found in Wang and Huang (2005).

Figure A-2-1 shows a sketch of H-ADCP set-up and grid for numerical calculation. An H-ADCP is mounted on a bank at an elevation Z_{adcp} (measured at the surface of the vertical transducer, $Z=0$ is a local datum). X-Y is the H-ADCP instrument coordinate. The H-ADCP is mounted with its orientation perpendicular to the channel mean flow direction. That is, X is parallel to the mean flow direction and Y is pointing to the cross-section direction. The effective velocity profiling range of H-ADCP should cover the majority of the channel cross-section.
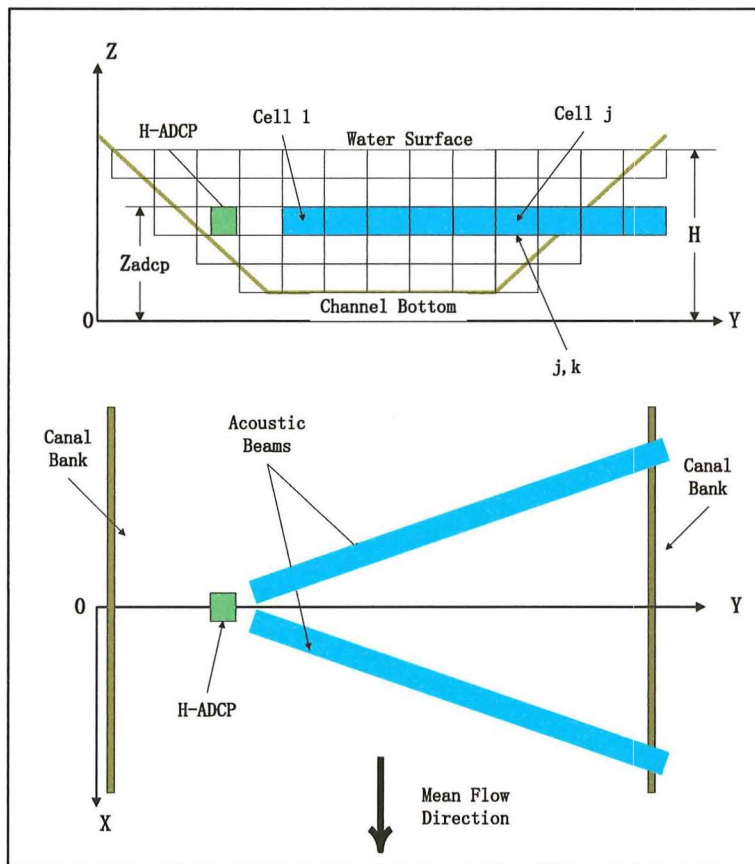

Figure A-2-1 Sketch of H-ADCP set-up and grid for numerical calculation

Let $V(y,z)$ be the velocity component perpendicular to the channel cross-section. Discharge Q can be calculated from the following:

$$Q = \iint_{s} V(y,z)\,dxdy \qquad\qquad (A\text{-}2\text{-}1\,)$$

where s is the wetted area of the cross-section.

Assume the velocity distribution follows a power law:

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$$V(y,z) = \alpha(y) \cdot (z - z_b)^\beta \qquad\qquad (A\text{-}2\text{-}2)$$

where z_b is the channel bottom elevation, $\alpha(y)$ is the velocity distribution coefficient as a function of y, β is an empirical constant. β depends on channel roughness and flow regime. $\beta = 1/6$ is suggested by Chen (1991) for open channel flows. $\alpha(y)$ can be resolved from Eq. (A-2-2):

$$\alpha(y) = \frac{V(y, z_{adcp})}{(z_{adcp} - z_b)^\beta} \qquad\qquad (A\text{-}2\text{-}3)$$

where $V(y, z_{adcp})$ is the velocity measured by H-ADCP at cell located at (y, z_{adcp}).

A numerical scheme was developed to implement the above flow calculation model. The channel cross-section is first divided into a grid with square or rectangular elements. The width of an element is usually one tenth of the maximum depth at the channel. Velocity at each element is calculated from Eq. (A-2-2). Finally, a Gaussian numerical integration is applied to Eq. (A-2-1) to calculate discharge. A Windows-based software named Q-Monitor-H (written in C^{++}) was developed by HydroAcoustic Soft Corp. to implement the discharge calculation model with the numerical scheme. Q-Monitor-H can be used to set up H-ADCP, acquire and display data, and calculate discharge in real-time. Data can be displayed and discharge can be calculated in playback too.

Appendix 3   References

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