Recommendations for High Quality ADCP River Discharge Measurement

Hening Huang，Ph.D., P.E.
Teledyne RD Instruments
San Diego, California, USA

Outline

Part 1: Quality Assurance (QA): Do Right Things before and during Data Collection

Recommended ADCP parameter settings to minimize discharge uncertainty

Part 2: Quality Control (QC): Accept or Reject the Collected Data

Proposed QC criteria

Part 1: Quality Assurance (QA)

Errors (or Uncertainty) in ADCP River Discharge Measurement:

- Bias error: mainly due to moving bottom
- Precision (random) error: mainly due to ADCP noise, turbulence, etc.
- Precision error is measured by Standard Uncertainty or Maximum Residual

Standard Uncertainty (relative) of Single Discharge Measurement (Modified Simpson Model, Type B):

$$u_Q = \frac{\sigma\sqrt{D_c}}{\sqrt{0.75R}} \frac{\lambda}{\sqrt{W\,H_a\,|V_a|}} \sqrt{\frac{(Z_2 - Z_1)}{H_a}} \sqrt{\frac{|V_b|}{|V_a|}} \sqrt{1 + \left(\frac{|V_b|}{|V_a|}\right)^2}$$

σ = single ping standard deviation

V_a = channel mean velocity

V_b = boat speed

D_c = cell size

W = channel width

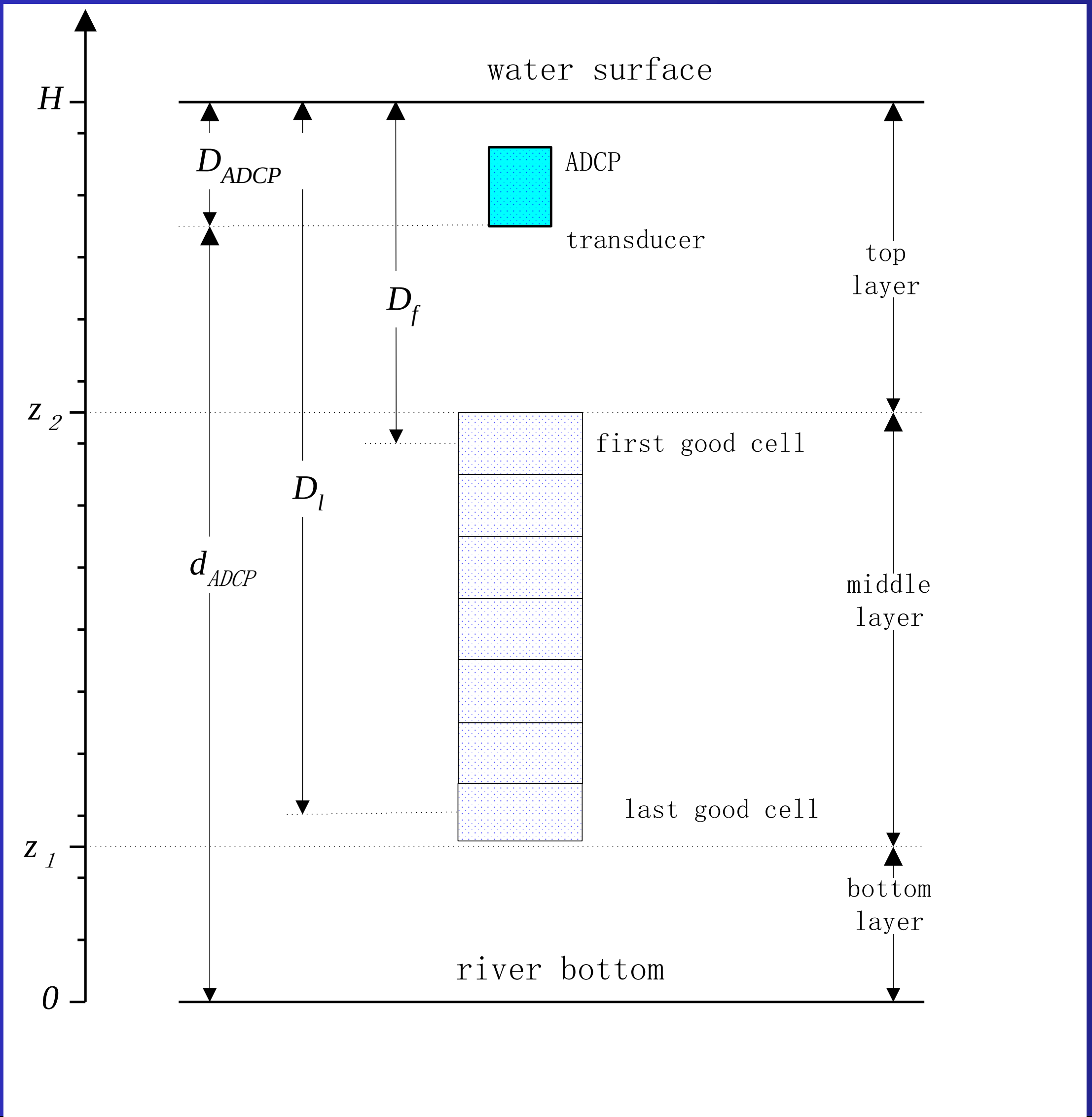
H = channel mean depth

R = ping rate

$$\lambda = \frac{H^{\beta+1}}{Z_2^{\beta+1} - Z_1^{\beta+1}}$$

Assumptions Made in the Uncertainty Model

- Ambient turbulence neglected
- 15% cell-to-cell correlation
- Power law velocity profile



Three Classes of Parameters Affecting Discharge Uncertainty

- ADCP parameters: σ, R, and D_c
- Channel parameters: W, H, and V_a
- Operation parameter: V_b

Parameters affecting Moving-Boat ADCP River Discharge Measurement Quality

Parameter	Parameter Change	Uncertainty Change	Operator Controllable?
Channel size and velocity	↑	↓	No
Turbulence intensity	↑	↑	No
ADCP performance	↑	↓	Some
Boat seed (operation)	↑	↑	Yes

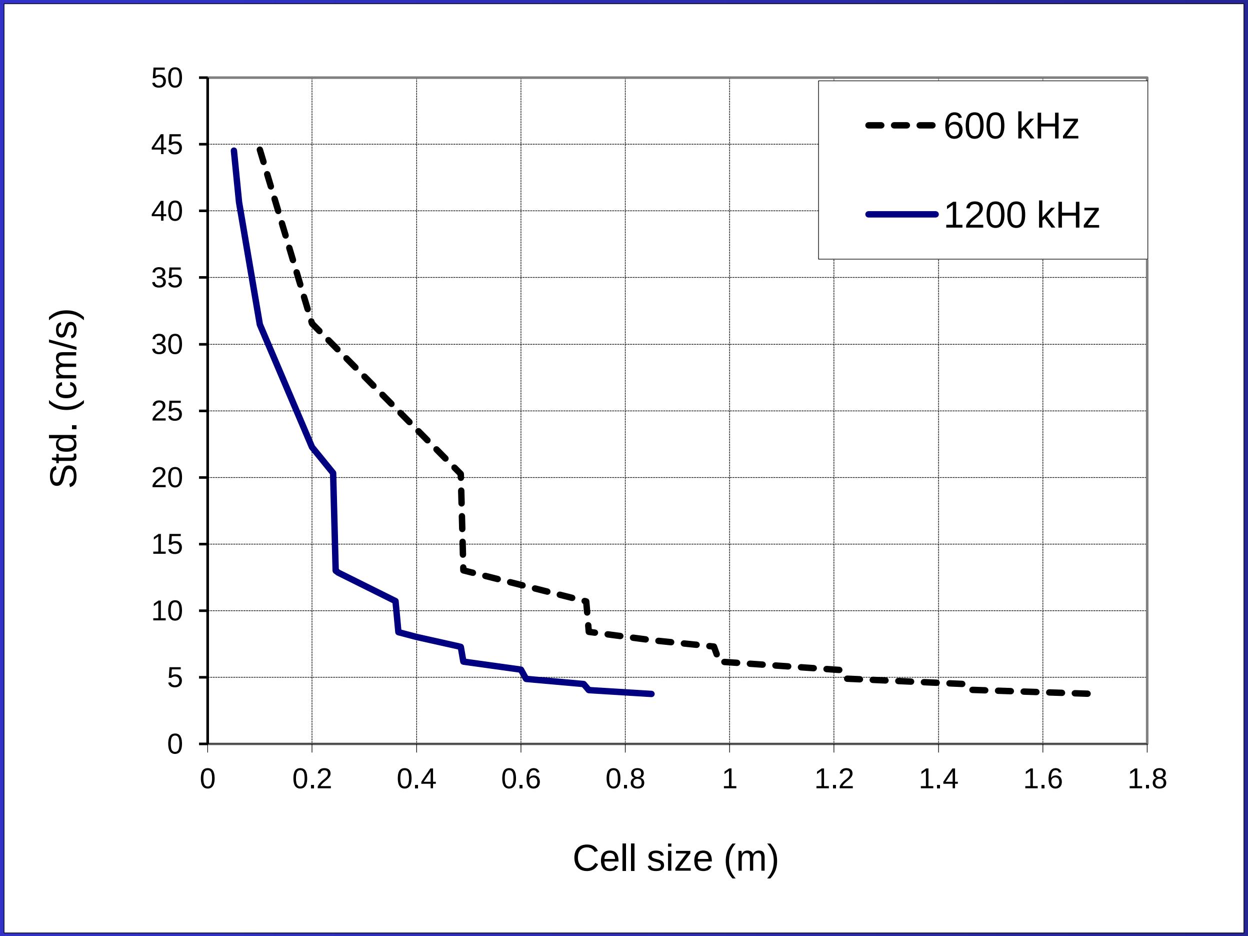
ADCP Performance Measure:

Discharge uncertainty ~ $\frac{\sigma\sqrt{D_c}}{\sqrt{R}}$

σ = single ping standard deviation
D_c = cell size
R = ping rate

σ is a function of cell size D_c

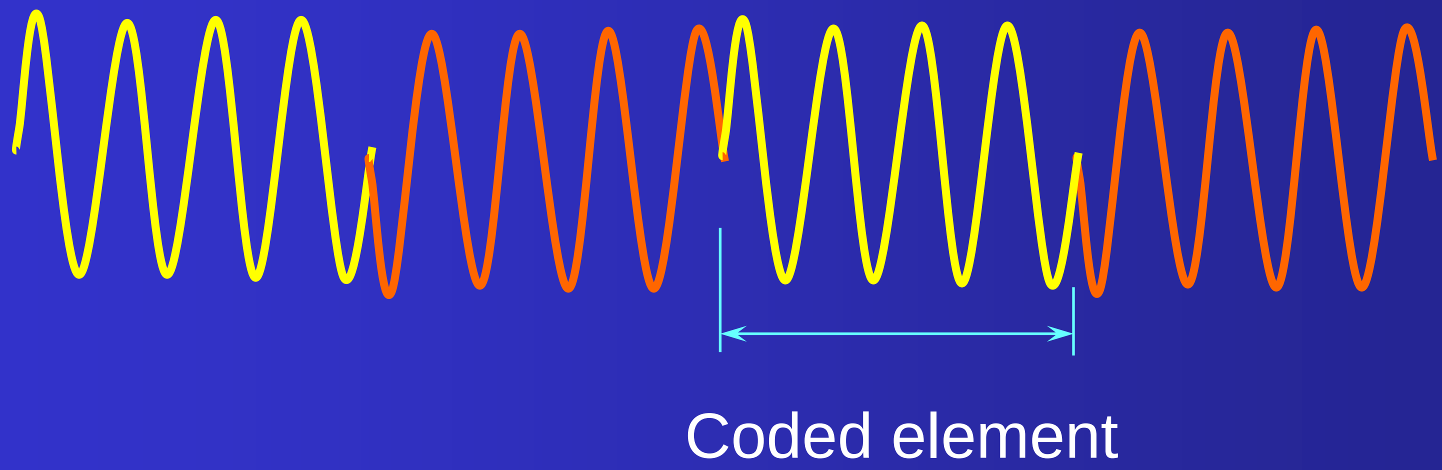
Rio Grande Mode 1 single ping standard deviation as a function of cell size (predicted by PlanADCP)



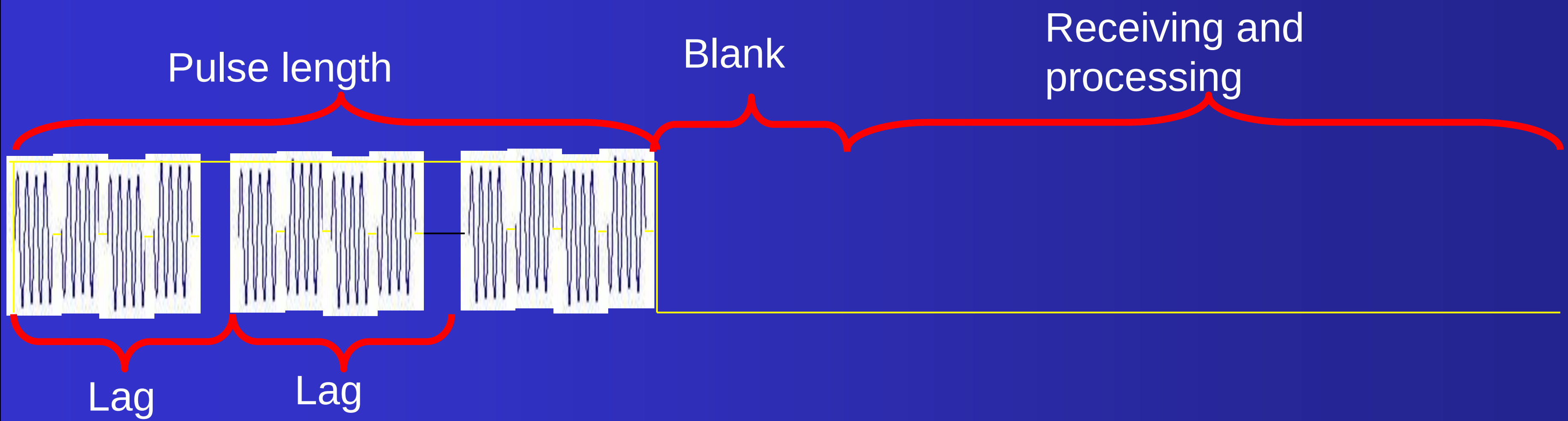
Note that big drops at certain sizes. Why?

Broadband ADCP coded pulse

Coding： phase shift 180 degree



Mode 1 (Broadband) Ping



A cell contains at least 2 coded pulses (CP). The number of CP increases with increasing cell size. However, it has no change (constant) within a certain cell size range until the cell size reaches a critical size. As a result, the single ping standard deviation has a big drop.

Number of Coded Pulses (WV175)

1200 kHz ADCP

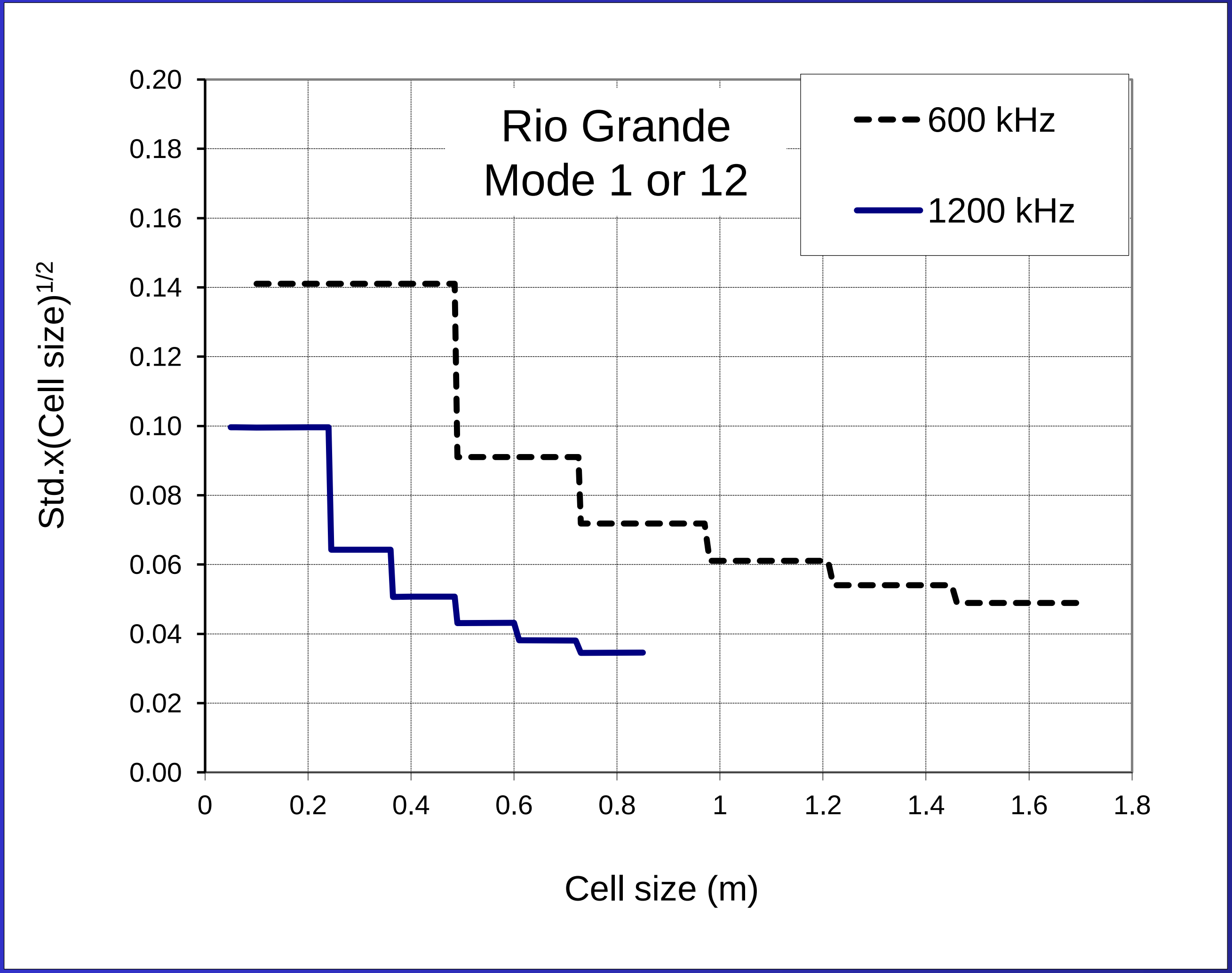
Cell Size Range (cm)	5-24.5	24.5-37	37-49.5	49.5-62	62-74.5	74.5-87
Number of CP	2	3	4	5	6	7

600 kHz ADCP

Cell Size Range (cm)	10-48.5	48.5-73.5	73.5-98.5	98.5-123.5	123.5-148.5	148.5-173.5
Number of CP	2	3	4	5	6	7

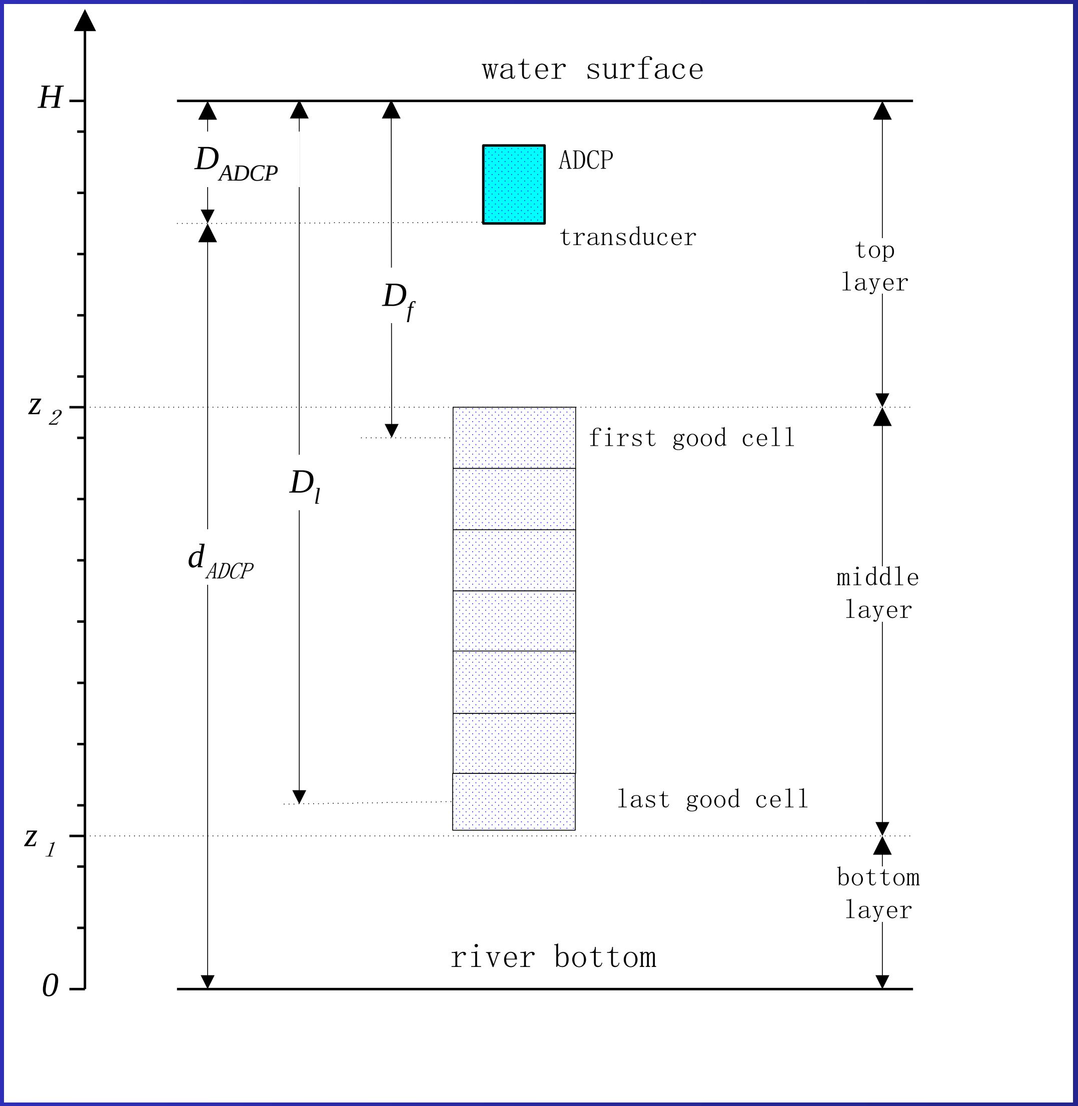
Then, The Magic!

$\sigma\sqrt{D_c}$ = constant within a cell size range

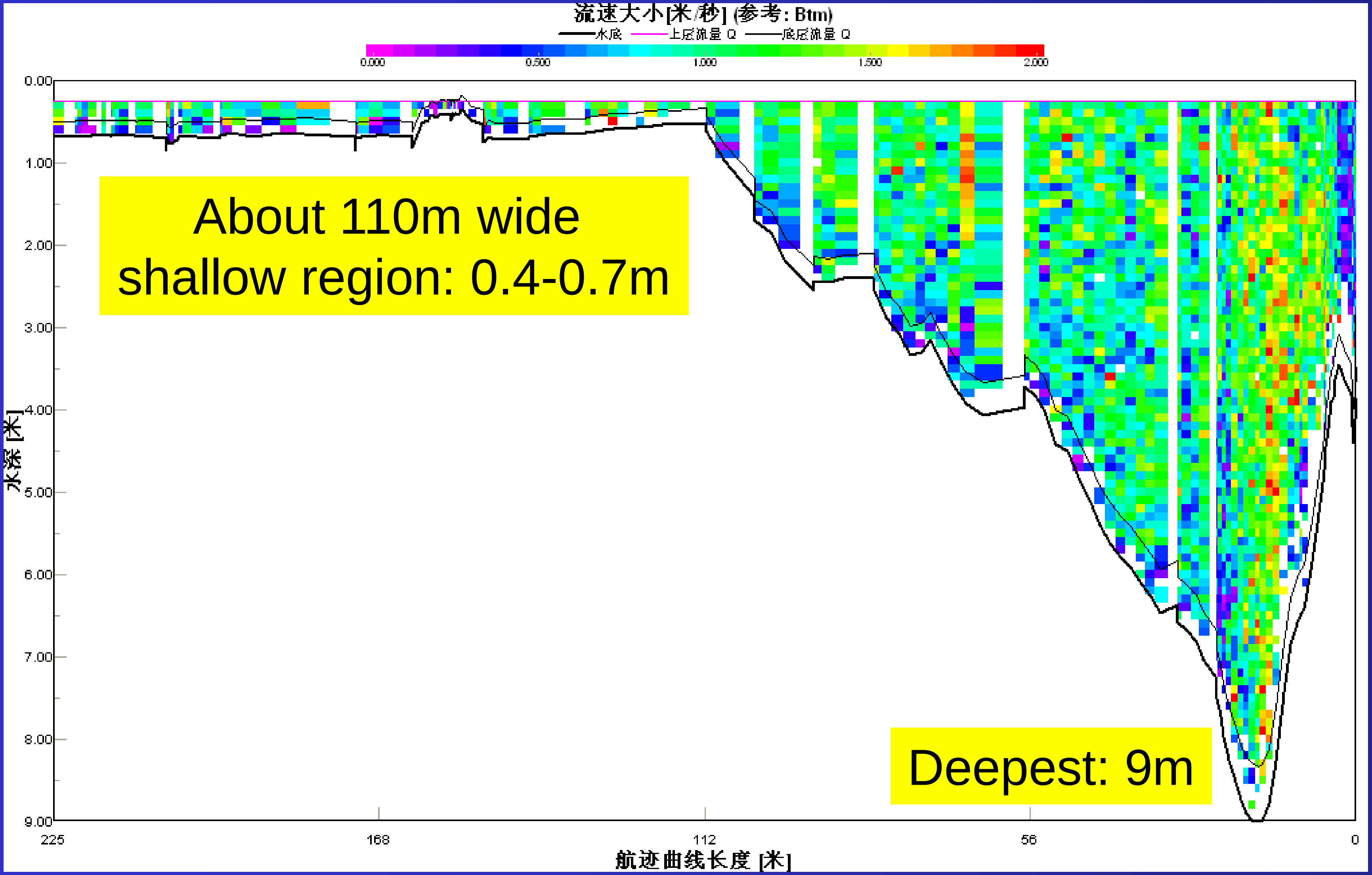


Benefits of Small Cells

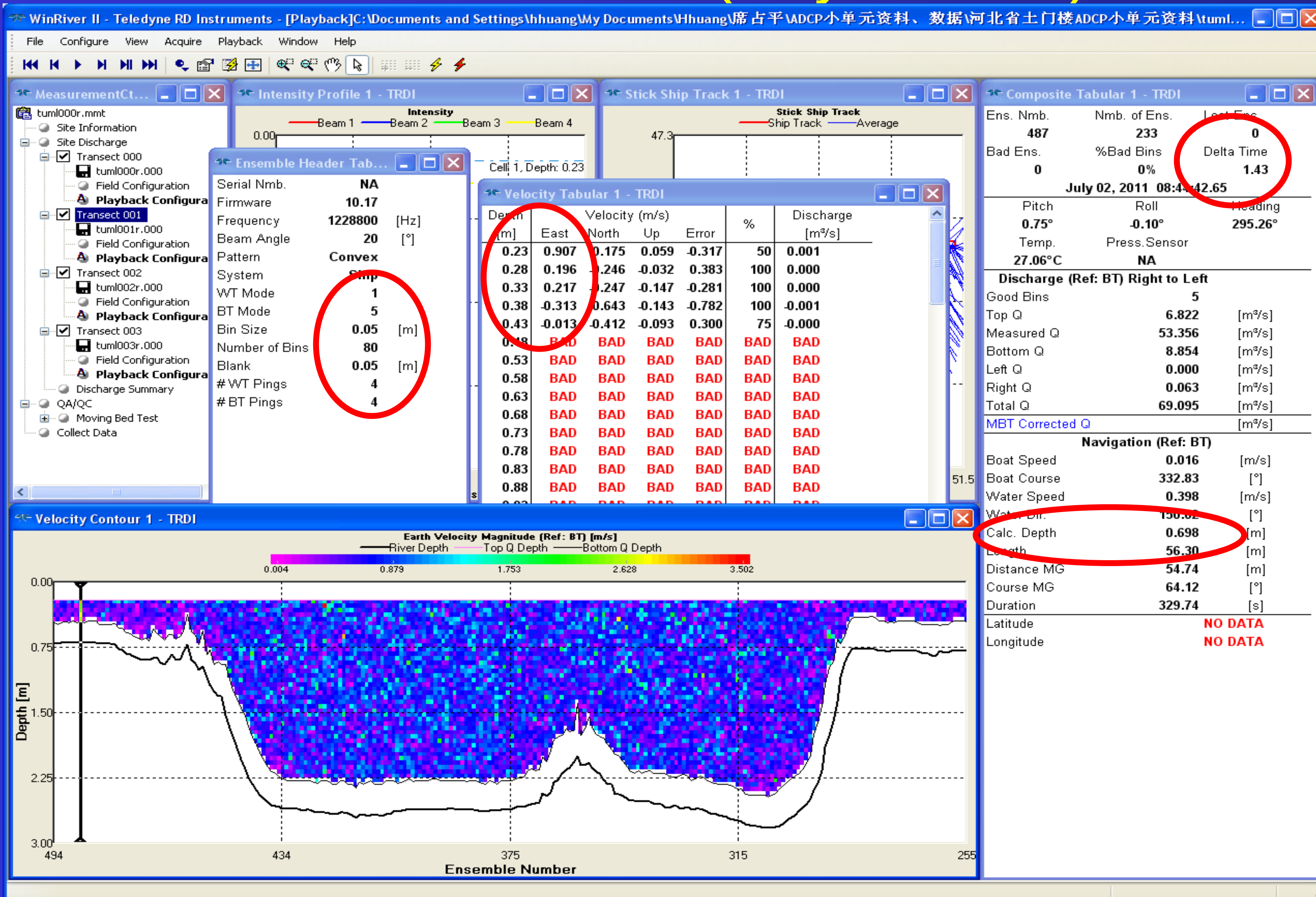
- Smaller surface/bottom unmeasured layer
- i.e., larger measured middle layer
- 1200 kHz works in 0.5m
- StreamPro works in 0.2m
-



A Yellow River Site (1200 kHz): WS10, WN98, WF5, WP2, BP2 (June 4, 2003)



A Hebei Site (1200 kHz): WS5, WN80, WF5, WP4, BP4 (July 2, 2011)



Hebei Site Discharge Data

	All Cells		1st Cells Removed	
Transect	Total Q m^3/s	Delta Q %	Total Q m^3/s	Delta Q %
tuml000	68.212	-1.01	68.558	-0.84
tuml001	69.163	0.37	69.325	0.26
tuml002	68.456	-0.66	68.414	-1.05
tuml003	69.809	1.3	70.27	1.63
Average	68.91		69.142	
Std Dev.	0.722		0.852	
CV	0.01		0.01	

Difference in Q: 0.34%!

Recommended Cell Sizes for Rio Grande and StreamPro Mode 1 or 12

ADCP Model	Recommended Settings	Minimum Cell Size
WHRZ1200	WS5 or WS?= 1.05 x (max depth)/N	5cm
WHR600	WS10 or WS?= 1.05 x (max depth)/N	10cm
StreamPro	WS2 or WS= 1.05 x (max depth)/(20 or 30)	2cm

N = number of cells: 20 to 50

The other ADCP Parameter: *R*

Effective ping rate: R_e=(number of pings)/Δt

Δt = ensemble time

Discharge uncertainty ~ $1/(R_e)^{1/2}$

- Single ping ensemble slows down effective ping rate
- Multi-ping ensemble increases effective ping rate. i. e., WP4, BP4 may double effective ping rate as compared to WP1, BP1; reduces discharge uncertainty about 30%.

Operation Parameter

Boat speed: V_b
or transect duration: $T=W/V_b$

Discharge uncertainty ~ V_b/V_a

Recommendations:

- Transect time ≥ 3min
- $V_b/V_a \leq 1$ not required

Additional Recommendations (1): Blank Distances

ADCP Model	Blank Setting
WHRZ1200	WF5 (5cm)
WHR600	WF25 (25cm)
StreamPro	WF3 (3cm)

Note: Near-Zero bank for 1200 kHz ADCP introduced in 2001, named ZedHead

Additional Recommendations (2)
Ambiguity Velocity for Rio Grande Mode 1

Maximum Relative Velocity （m/s）	WV Setting
5	WV175 (default)
6	WV210
7	WV245
8	WV280
9	WV315
10	WV350
15	WV525
20	WV700

$$WV\ ? = 350 \times \text{Maximum relative velocity (m/s)}$$

1200 kHz Rio Grande Mode 1: WinRiver II Defaults and Recommended Expert Settings for Fast, Shallow (0.5-2m) Streams

Parameter	WinRiver II Default Setting	Recommended Expert Setting
Blank	WF25 (25cm)	WF5 (5cm)
Cell size	WS25 (25cm)	WS5 (5cm)
Number of water pings	WP1	WP4
Number of bottom pings	BP1	BP4
Number of shore pings (ensembles)	10	5

Part 1 Summary

- Transect duration: at least 3min no matter how small a stream is
- Use cells smallest possible for any Modes
- Use multi-ping ensemble output
- Use a towing system such as “Flying Fox” or “Traveler” to keep float speed slow and steady
- Use Mode 5 or 11 if flow condition allows

Part 2: Quality Control (QC)

Existing QC criteria (accept or reject):

(1) 4/8-transect policy (USGS before Oct 2011):

- Make at least 4 transects
- If 4-trasect RMR ≤ 5%, accept!
- Otherwise, make 8 transects, RMR=any value OK

RMR = Relative Maximum Residual:

$$RMR = \frac{\max |Q_i - Q_{mean}|}{Q_{mean}}$$

Existing QC criteria (accept or reject):

(2) 720s-duration policy (USGS after Oct 2011):

- Make at least 2 transects
- Total duration ≥720s (12min), accept!
- No criterion for RMR or Uncertainty

A Paradox in ADCP Method for River Discharge Measurement

- ADCP is an advanced technology. The ADCP method should be more accurate than the current meter method.

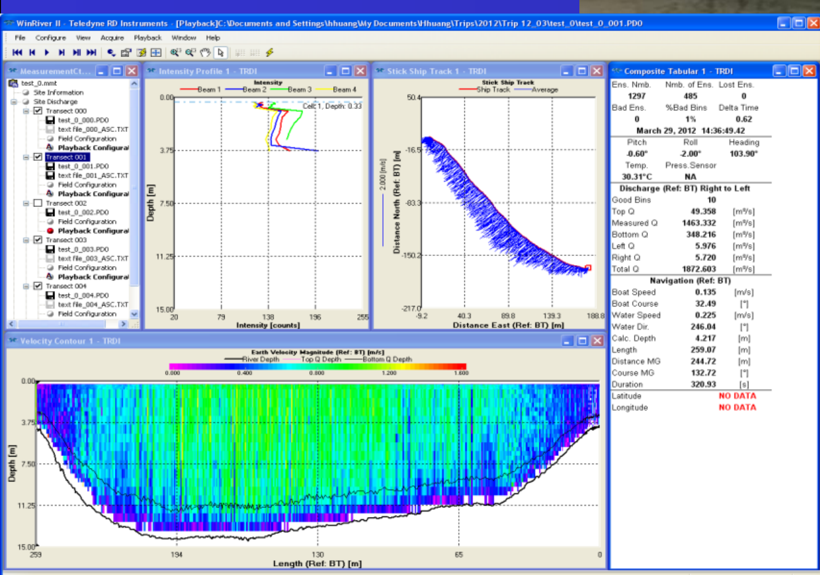
- However, the ADCP method requires *at least four* measurements, whereas the current meter method requires *only one* measurement.

- Thus, the ADCP method is *not* as accurate as the current meter method.

The paradox is not resolved. But it leads to following questions:

- Do we have to make 4 transects?
- Is making 2 transects enough?
- If 2 transects are permitted, what is the corresponding QC criterion?

Thailand Choa Praya River RiverRay Test
March 29, 2012



Two Transects May Be Enough!

Example: Measured discharges at Choa Praya River, Thailand (RiverRay ADCP, March 29, 2012)

Raw Data File Name	Duration	Q (m^3/s)	Residual (%)
test000	0:05:19	1873.236	-0.62
test001	0:05:21	1872.603	-0.66
test003	0:04:56	1900.961	0.85
test004	0:05:44	1893.112	0.43

The Q difference in first two transects is only 0.633 m^3/s!

Proposed QC Criteria

Residual-Based Permissible Precision Limits

Number of Transects	RMR (%)
2	≤1.8
4	≤5.0
6	≤7.9
8	≤10.5

Advantages and Benefits of the Proposed QC Criteria

- Comply with ISO GUM uncertainty analysis framework:

  RMR criteria equivalent to: $U_{95} \leq 4.3\%$

- Consistent with existing 4/8-transect policy

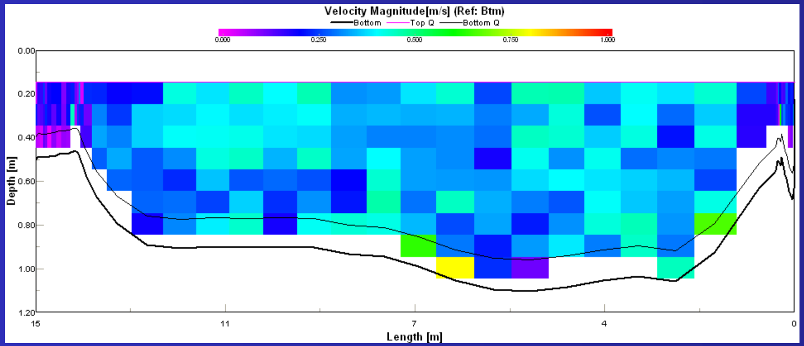
- Allow for 2 transects: save labor/time and energy, reduce CO_2 emission!

Thank you !

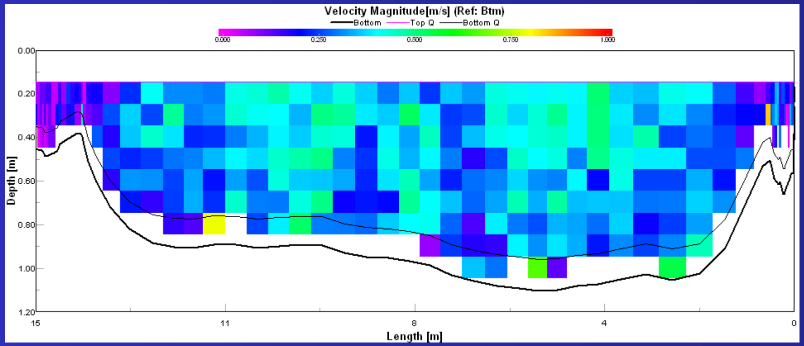
StreaPro ADCP Tests in California

Float speed

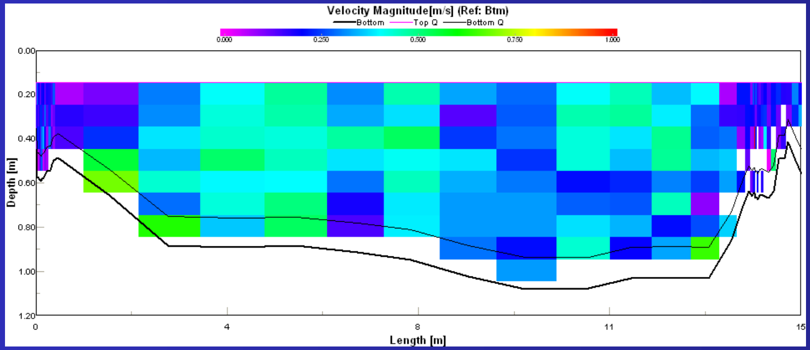
Vb = 37 cm/s



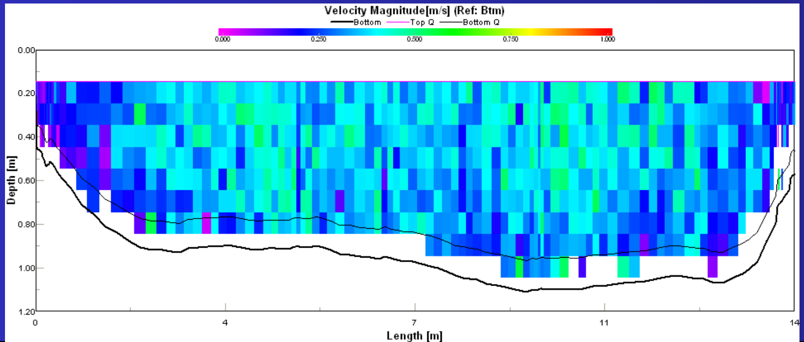
Vb = 62 cm/s



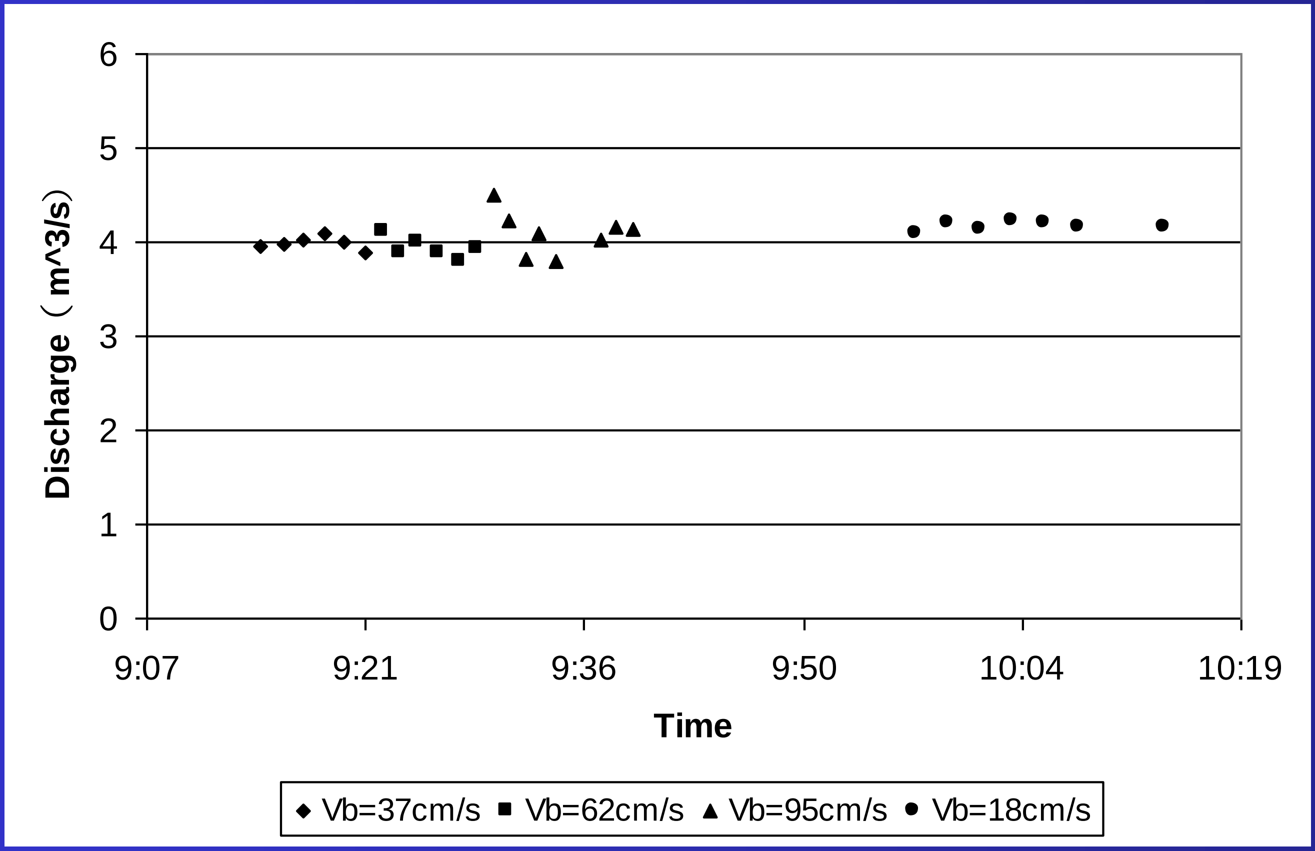
Vb = 95 cm/s



Vb = 18 cm/s



StreaPro ADCP Test Results



Statistical Analysis Results for StreamPro ADCP Test Data

Data Group	Number of Transects	Mean Channel Velocity （cm/s）	Mean Float Speed （cm/s）	Velocity Ratio V_b/V_a	Maximum Residual （%）
1	6	31	37	1.19	2.69
2	6	32	62	1.94	4.72
3	8	34	95	2.79	10.02
4	7	32	18	0.56	2.04

USGS Study on Measurement Duration

Oberg and Muller （2007）J. of Hydraulics, ASCE, Vol133, No.12

Policy change in October 2011：minimum 2 transects, total duration greater than 720s (12min)

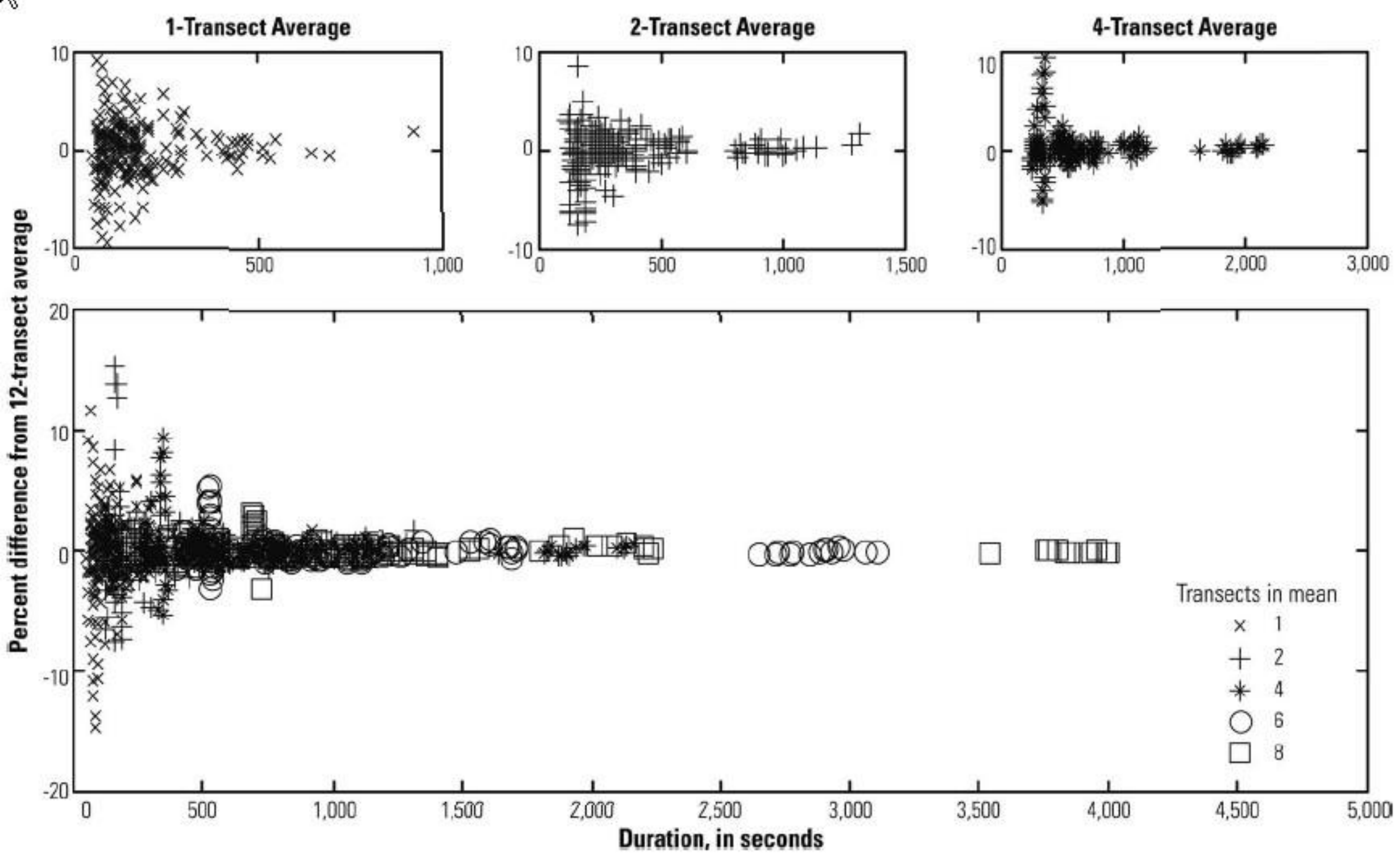


Fig. 5. Relation between measured discharge uncertainty and duration of measurement