In Search of Techniques for Monitoring River Discharge

Ralph T. Cheng, BRR, WR

HYDRO-21 Committee

Civil and Environmental Engineering Department
University of Illinois at CU
October 10, 2001

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Additional Research Topics:

1. Topics on Flow Measurements
   (Bottom Boundary Layer, Turbulence,
   Field Scale PIV)
2. Estuarine Hydrodynamics, Nowcast System
   (3D Numerical Model, UnTRIM)
3. In-situ Sediment Measurements
   (LISST, ADCP)
4. Hydraulics in Open Channel

OUTLINE:

- Introduction
- USGS Stream Gaging
- Search for New Technology
- Proof-of-Concept Experiments
  - Skagit River, WA
  - S. Fork Shenandoah River, VA
  - California Experiment
  - Helicopter Experiment
- Future Directions

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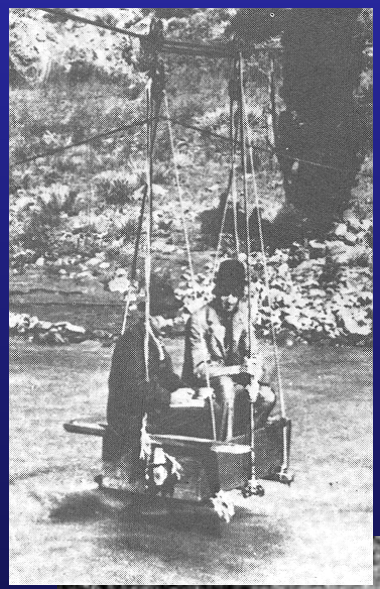
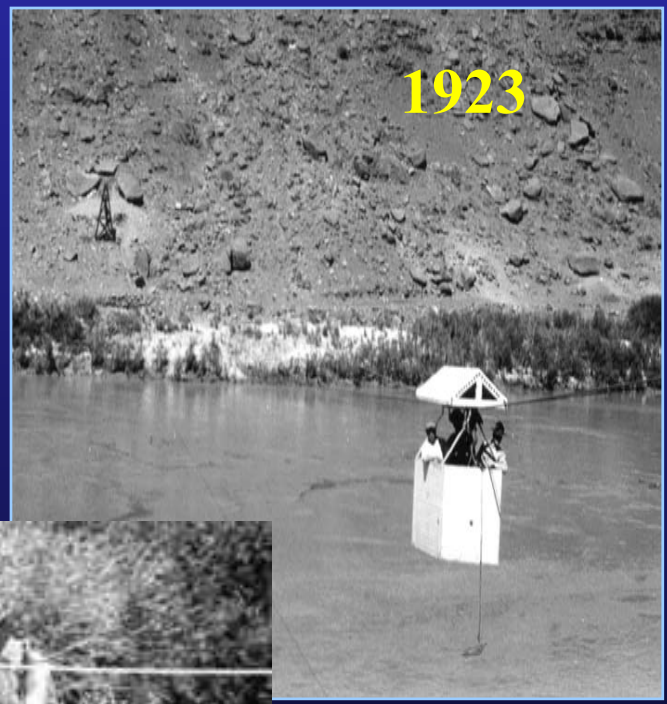
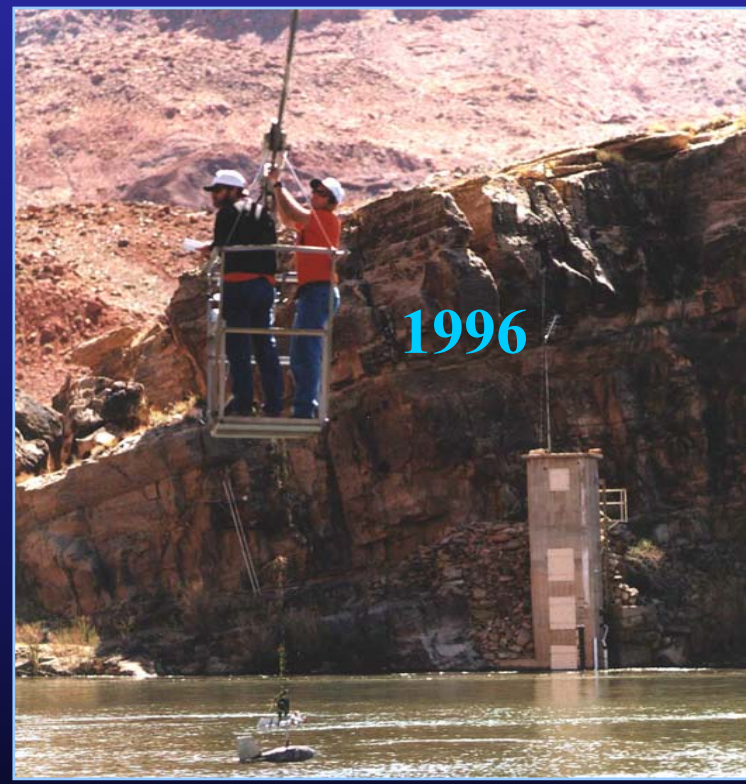
Introduction:

Defining Hydrologic Instrumentation for the 21st Century

Why: Background and Motivations







Colorado River at Lees Ferry

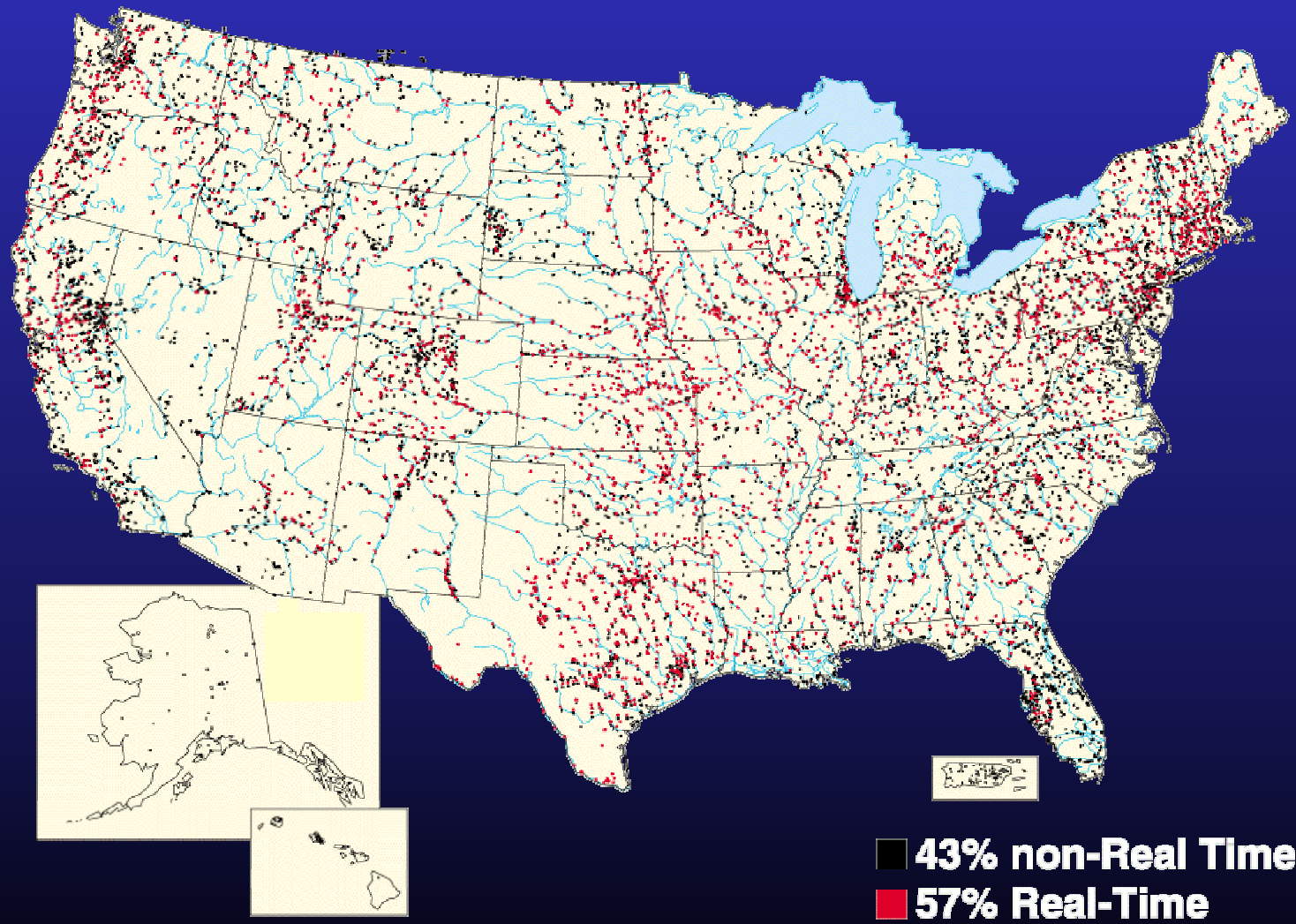
Introduction:

Defining Hydrologic Instrumentation for the 21st Century

Why: Background and Motivations

Will Stream Gaging in the USGS Look Different in the 21st Century?

USGS Sreamgaging Network



USGS

PROVISIONAL DATA SUBJECT TO REVISION

05355200-- CANNON RIVER AT WELCH, MN

Current Conditions

Flow (ft?/s)	Stage (ft)	Date	Time
3,960	7.18	07/11	13:00

Streamflow -- updated Tue Jul 11 13:00 2000 -- download presentation-quality graph

Expanding Uses of Streamflow Information

- Resource Appraisal and Allocation
- Design of Nation's Water Infrastructure
- Flood Hazard Planning and Forecasting
- Reservoir Operations
- Water Quality Management
- Instream Flows for Habitat Assessment
- Understanding Changes in Streamflow
- Recreational and Safety

Introduction:

Defining Hydrologic Instrumentation for the 21st Century

Who: **Hydro-21 Committee**

John Costa, OSW, Portland, Oregon

Ralph T. Cheng, BRR, WR, SWH

Frederick P. (Pete) Haeni, OGW, Geophysicist

Nick Melcher, Arizona Dist. Chief

Earl M. Thurman, Kansas Dist., Geochemist

Eugene Hayes, HIF

Introduction:

Defining Hydrologic Instrumentation for the 21st Century

What: Objectives

To provide vision and leadership in WRD, USGS for identifying and evaluating new technologies and methods that might have the potential to change the paradigm in WRD data collection program.

ICOM and ITAS are designated to address the immediate instrumentation needs.

USGS Stream Gaging:

WRD operates ~7000 Gaging Stations
(~$80 M Program)

$$Q = \int_{\vec{A}} \vec{V} \bullet d\vec{A}$$

Stream Gaging:

Q = Discharge;

$\vec{V}$ = Velocity; $\vec{A}$ = Area

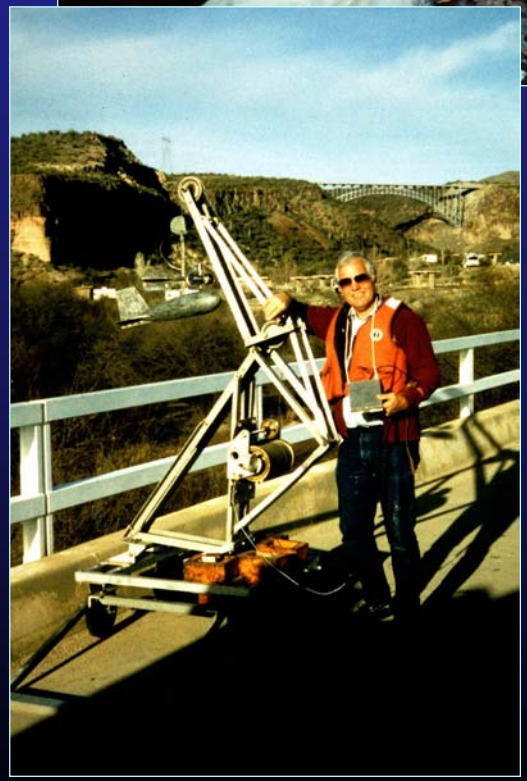
Present Shortcomings and Difficulties:

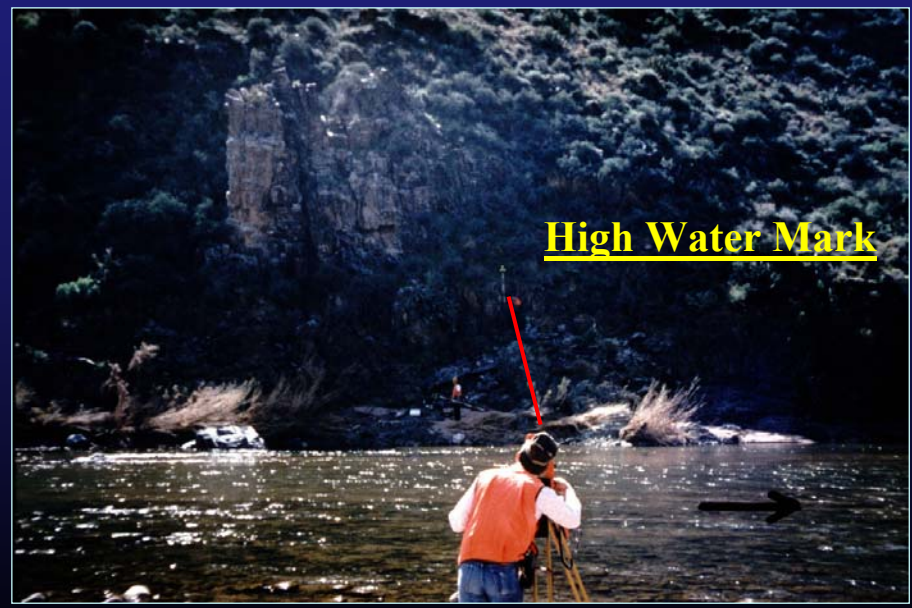
Extensive labor, Travel, Service,

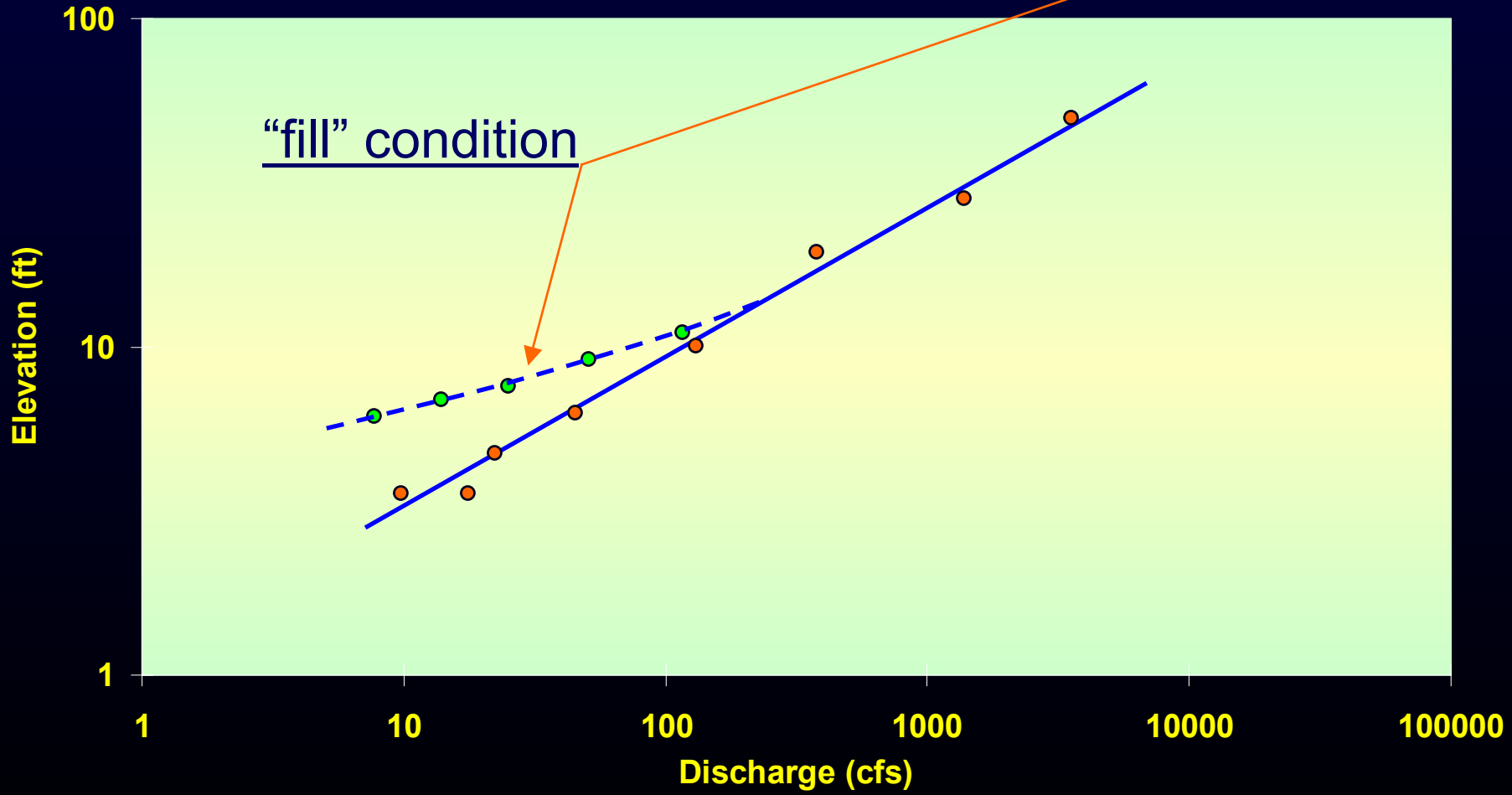
Potential Hazards

Inadequate Stage-Discharge Relations

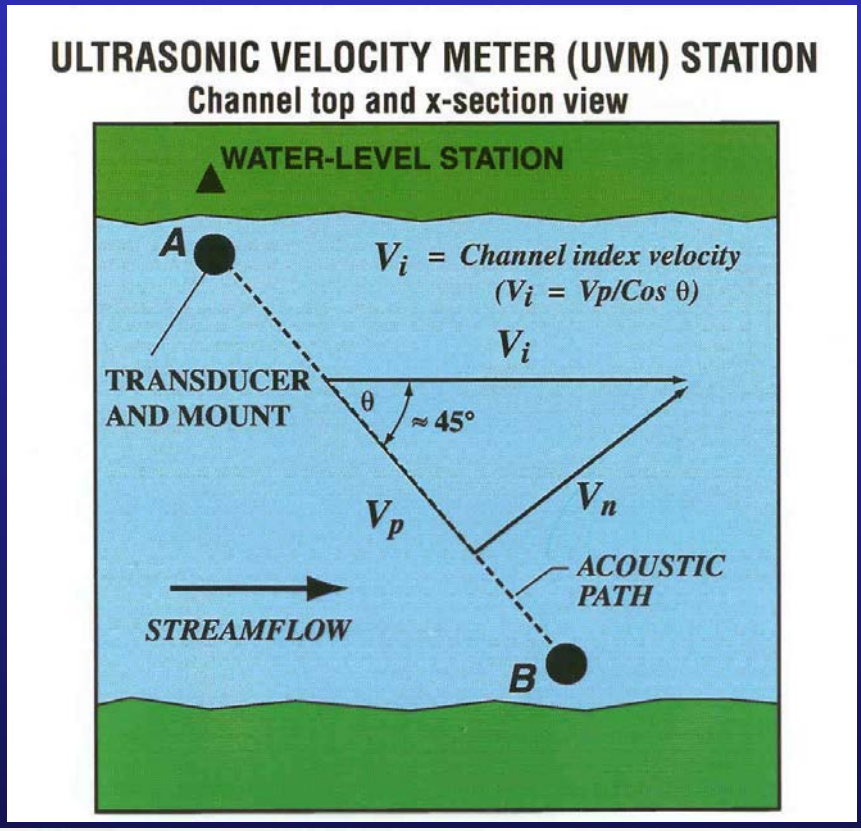
Commonly used methods for discharge measurements

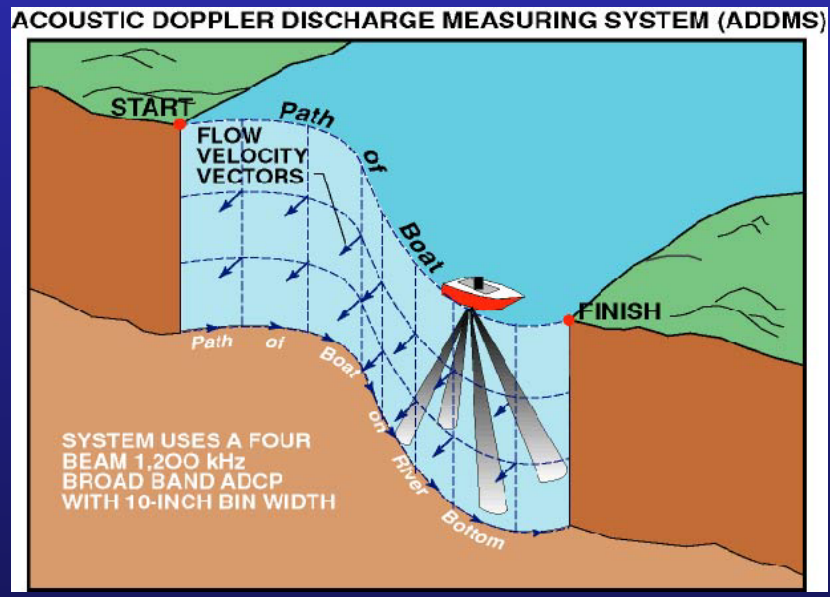


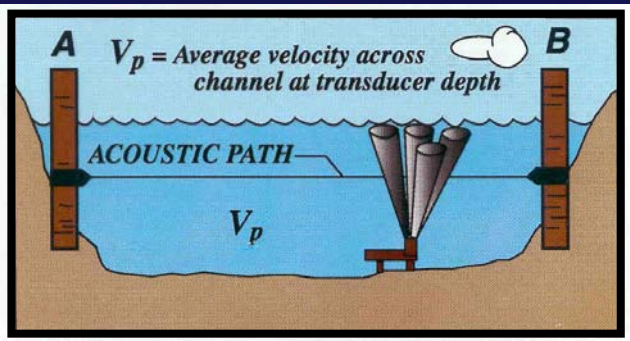


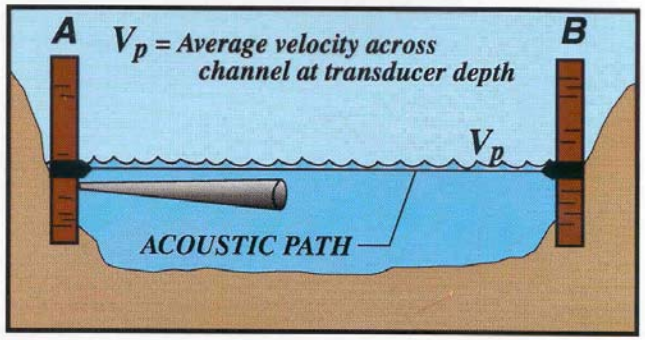

100
10
1
Elevation (ft)
"fill" condition
1
10
100
1000
10000
100000
Discharge (cfs)

Other Methods for River Discharge Measurement: UVM, ADCP,.....









Searching and Evaluation of Potential Technologies

River Discharge:
Channel X-section
Velocity Distribution

$$Q = \int_{\vec{A}} \vec{V} \bullet d\vec{A}$$

Notes:
1 = Field Tested
2 = Possible, but not tested
3 = Not Possible

Without Contacting Water!

Technology	Stage	Water Depth	Mean Velocity	Surface Velocity
HF Radar	1	3	3	1
LF Radar	2	1	2	3
Lasers	2	1*	2	2
Imaging (PIV)	2	3	3	2
Acoustics	1	3	2	2

Hydro-21 Interim Recommendations

(Stream Gaging)

- **Future River Discharge Measurement Should be by Remote or Non-Contact Methods**
- Continue Evaluation All Technologies:
  Acoustics, Laser, Radar, Imaging,
  …etc.
- Conduct Proof-of-Concept Experiments

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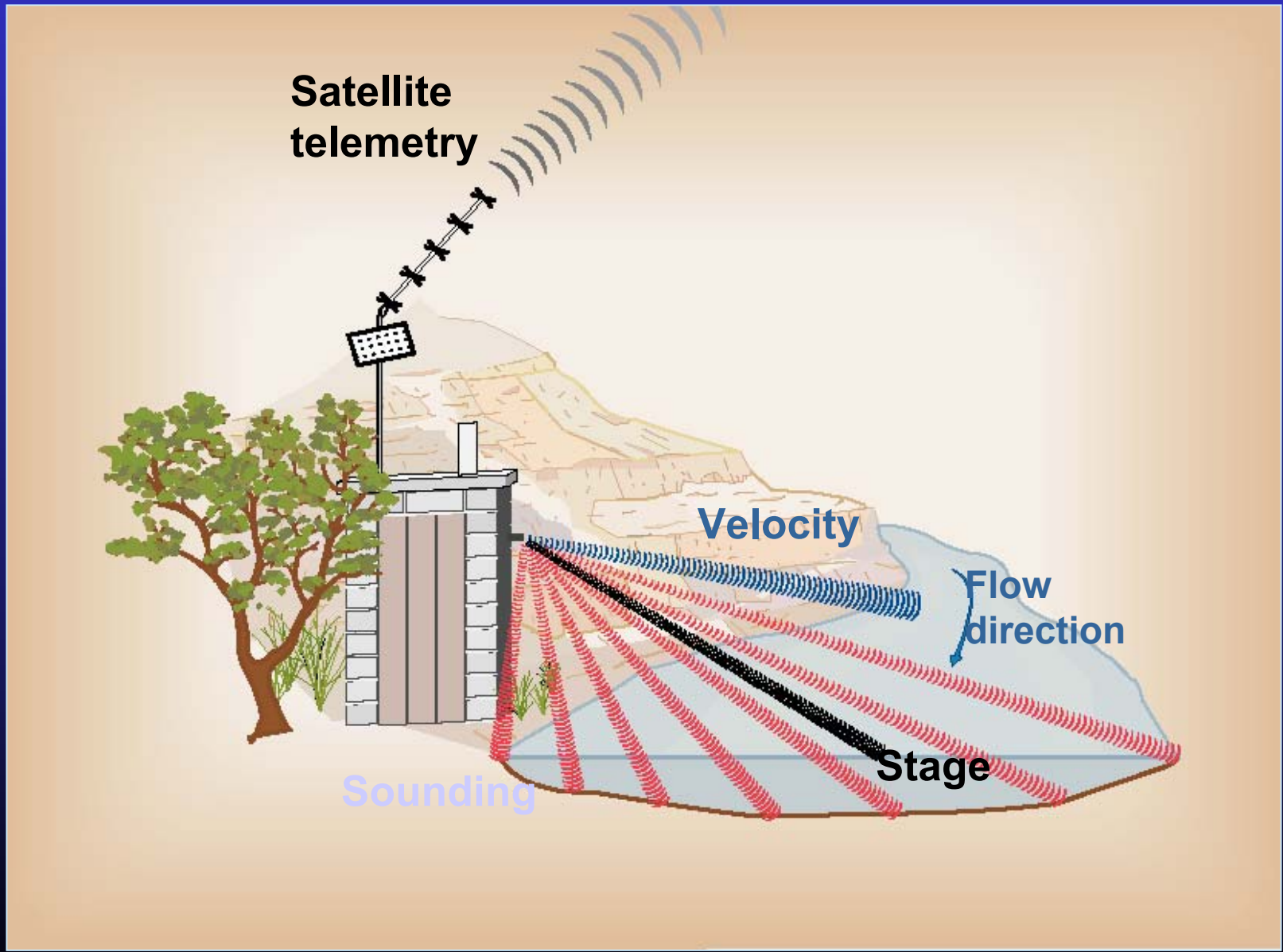
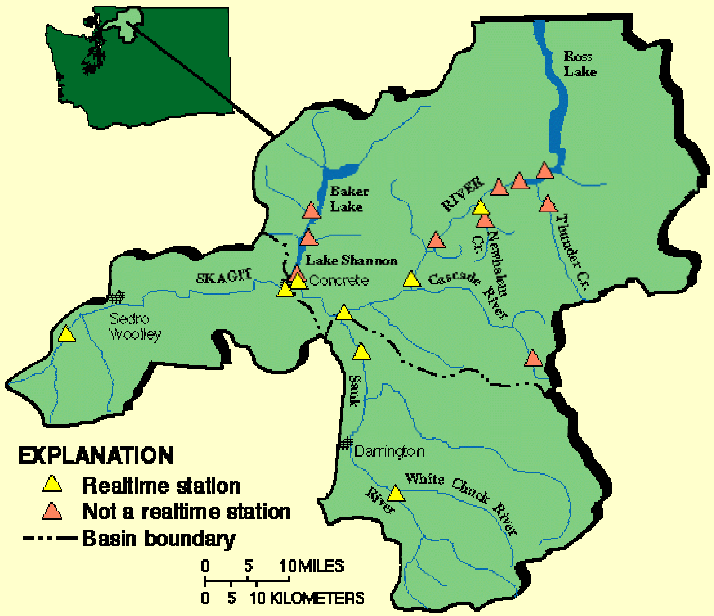
Non-Contact Measurement of River Discharge



Hydro21 Proof-of-Concept
Non-contact discharge experiment:
Skagit River at Mount Vernon, WA
April 21, 1999

Costa, J. E., K. R. Spicer, R. T. Cheng, F. P. Haeni, N. B. Melcher, E. M. Thurman, W. J. Plant, and W. C. Keller, 2000, Measuring Stream Discharge by Non-Contact Methods: A Proof-of-Concept Experiment, Geophysical Research Letter, Vol. 27, No. 4, p. 553-556.



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HYDRO-21 Committee
The 1st USGS
Proof-of-the-Concept
Non-Contact Stream Gaging

Field Experiment Coordinated by
John Costa, OSW

Skagit River, WA
April 20-21, 1999

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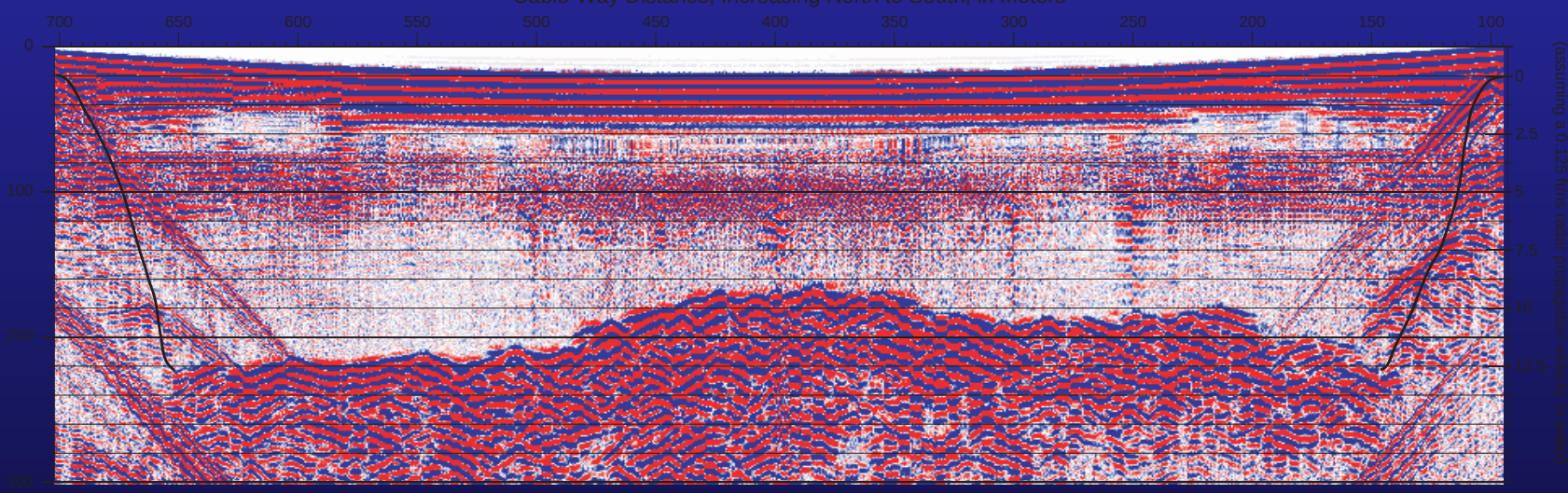
The 1st USGS
Proof-of-Concept
Non-Contact Stream Gaging

Skagit River, I-5, Washington
U.S. Geological Survey
Stream Gaging Station 12000500



100 MHz GPR river-bottom reflection record
Collected with antennas suspended from a cable car
First non-contact stream discharge measurement
Conducted April 21, 1999
Hydro 21 committee

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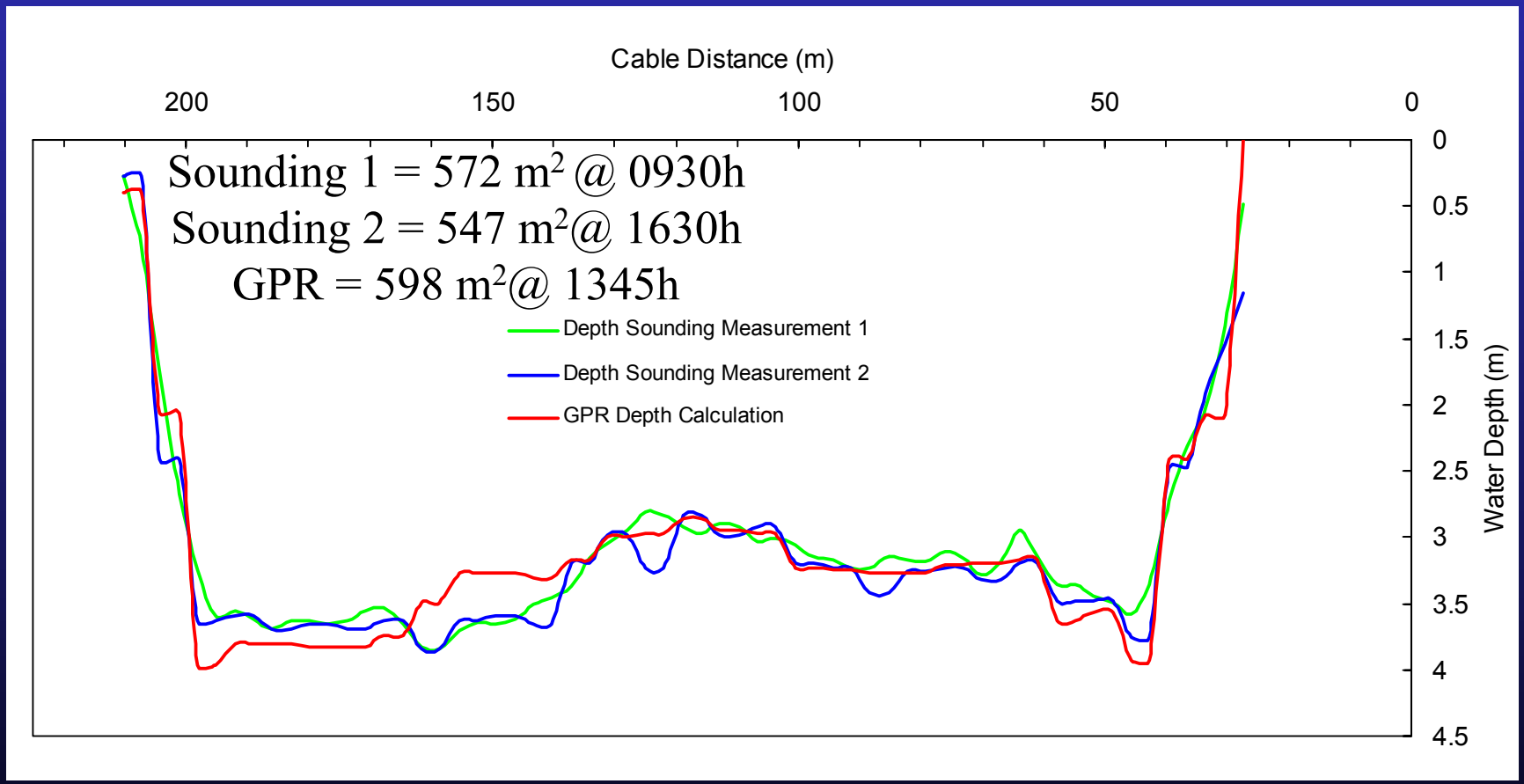
GPR Derived Cross-section Compared to Two Sounding-Weight Measurements



Assumes average radar travel-time = 0.04 m/ns

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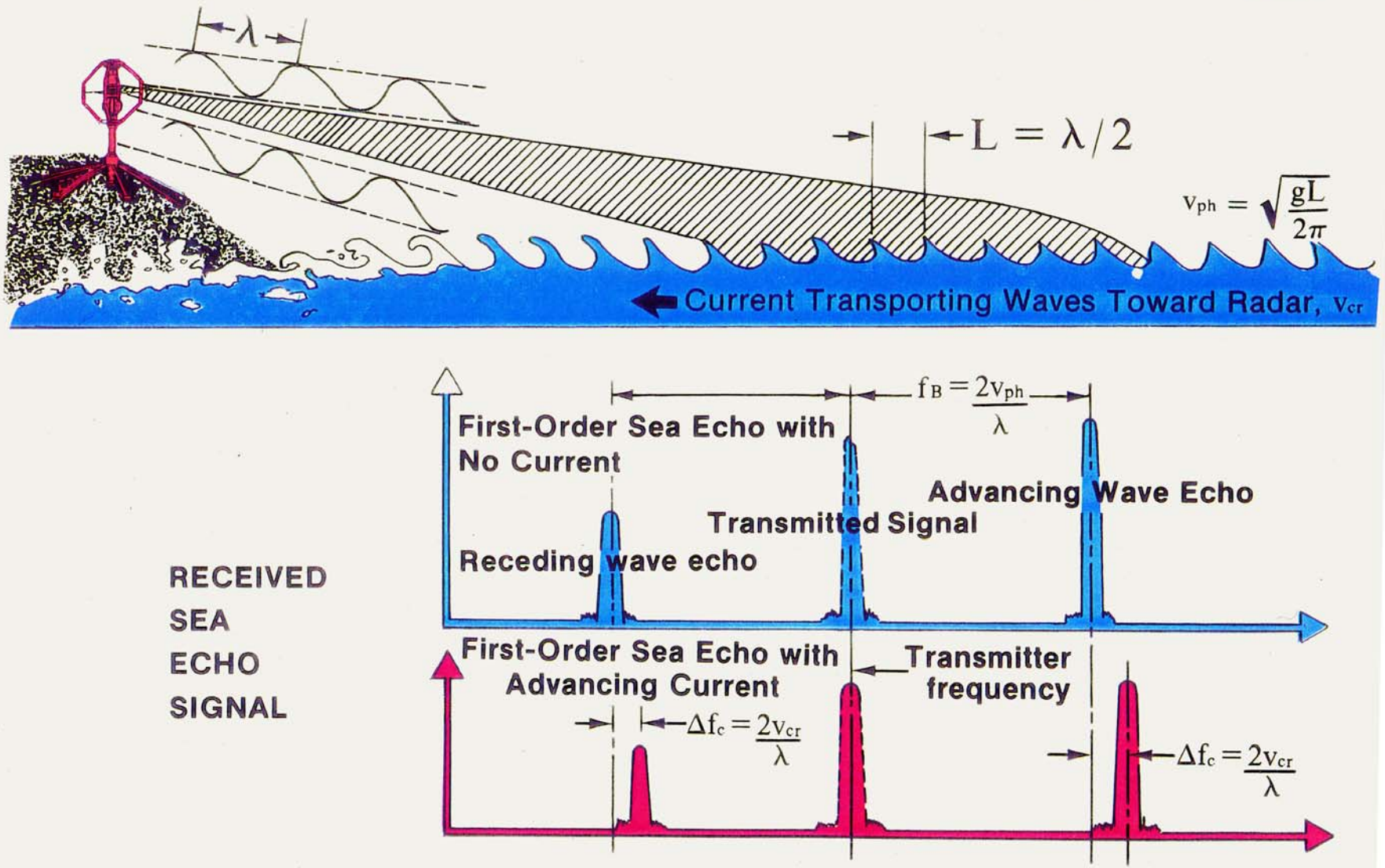
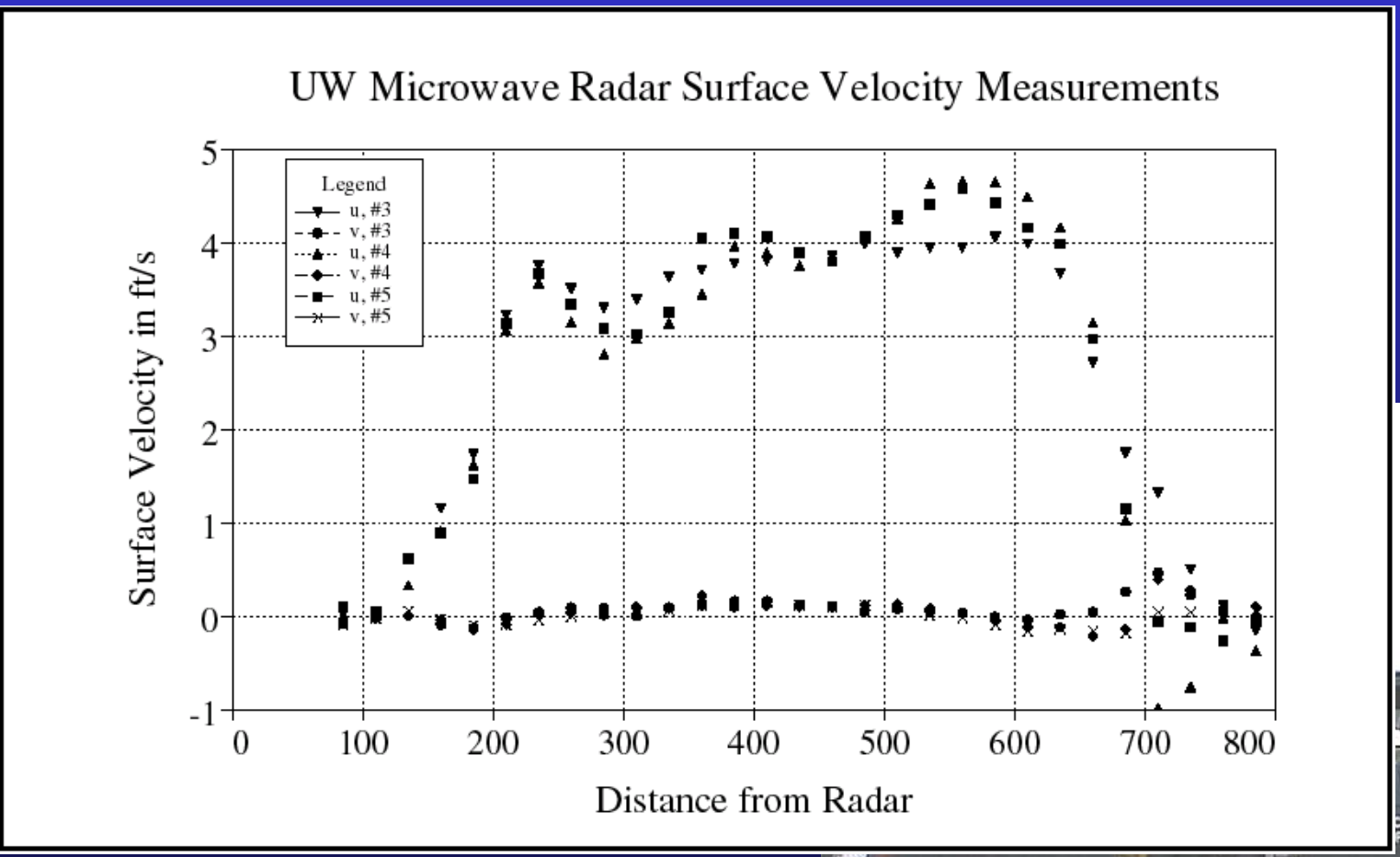
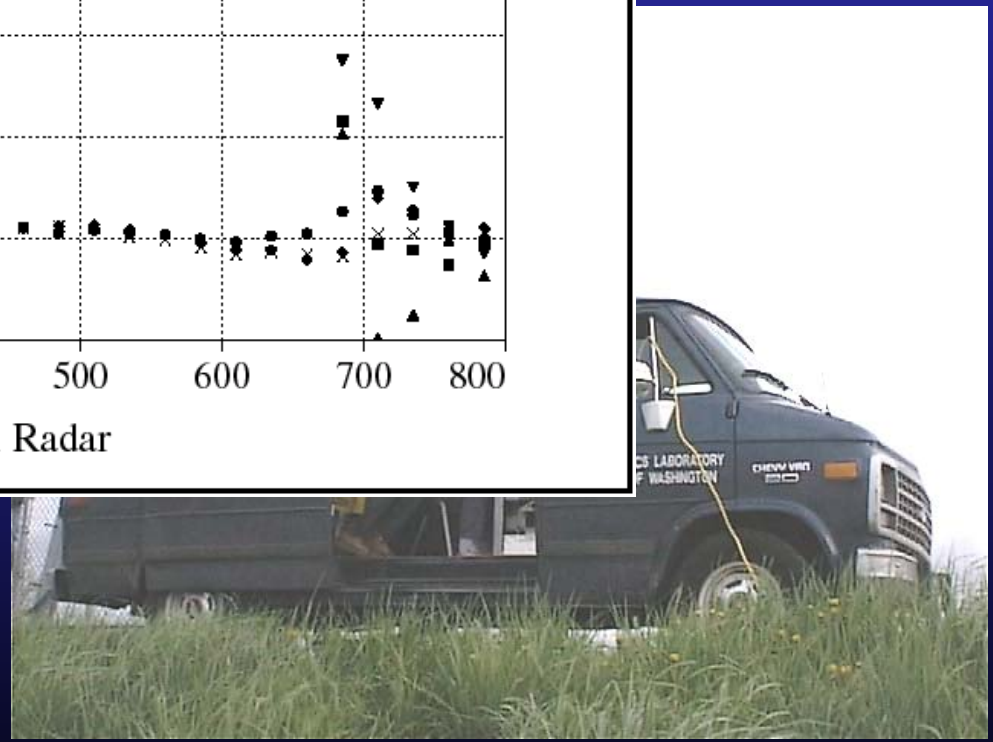
NARROW-BEAM FIRST-ORDER BRAGG SCATTER FROM THE SEA

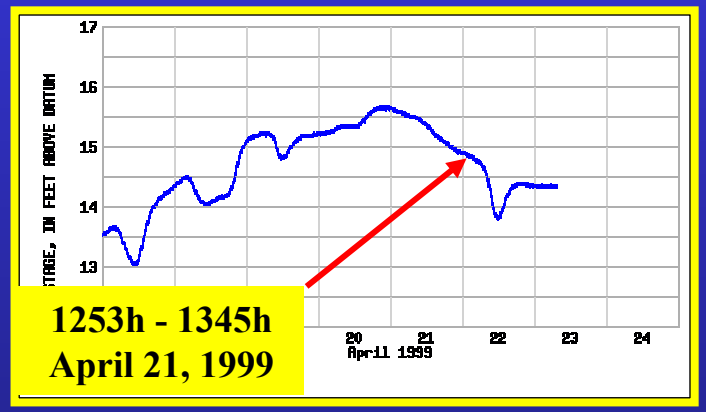






Skagit River, WA
April 20-21, 1999

HYDRO-21 Committee
The 1st USGS
Proof-of-Concept
Non-Contact Stream Gaging



Provisional Results: April 21, 1999 in k-cfs

Conventional Method (.2 & .8)	=	18.6
Stage-Discharge Rating Curve	=	17.8 - 18.2
ADCP Discharge Measurement	=	18.4
Non-Contact Discharge Measurement	=	18.5

The Non-Contact Stream Gaging *Concept* was validated! And…….

Field Experiment Coordinated by
John Costa, OSW

Skagit River, WA
April 20-21, 1999

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Radar Technologies
Contacts and White Papers

Dr. Bill Plant, Applied Physics Laboratory
University of Washington, Microwave Radar

Metratek, Inc.,
A Major Radar Contractor for Navy

CODAR Sensors, Ltd.,
Ocean Surface Current Measurements

Further tests of radar technology to measure surface velocity and water depth distributions

Metratek's Approach: Mono-static radar (March 8-9, 2000)

Test Site: South Fork Shenandoah River, VA

CODAR's Approach: Bi-static radar (June 5-7, 2000)

Test Sites: Delta-Mendota Canal & American River

Questions to be answered:

1. Would radar technology work;
2. Radar Power (FCC);
3. Installation;
4. Cost.

USGS-Metratek South Fork Shenandoah River, VA
March 8-9, 2000

Approach: Mono-static radar, emphasis is on variable frequencies

Objectives: Surface Velocity and Channel Cross-section

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Metratek Experiment

USGS-CODAR Experiment
Delta-Mendota Canal and American River
June 5-7, 2000

Approach: Emphasis is on using bi-static radar

Objectives: Surface Velocity and Channel Cross-section

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Basic Research Questions

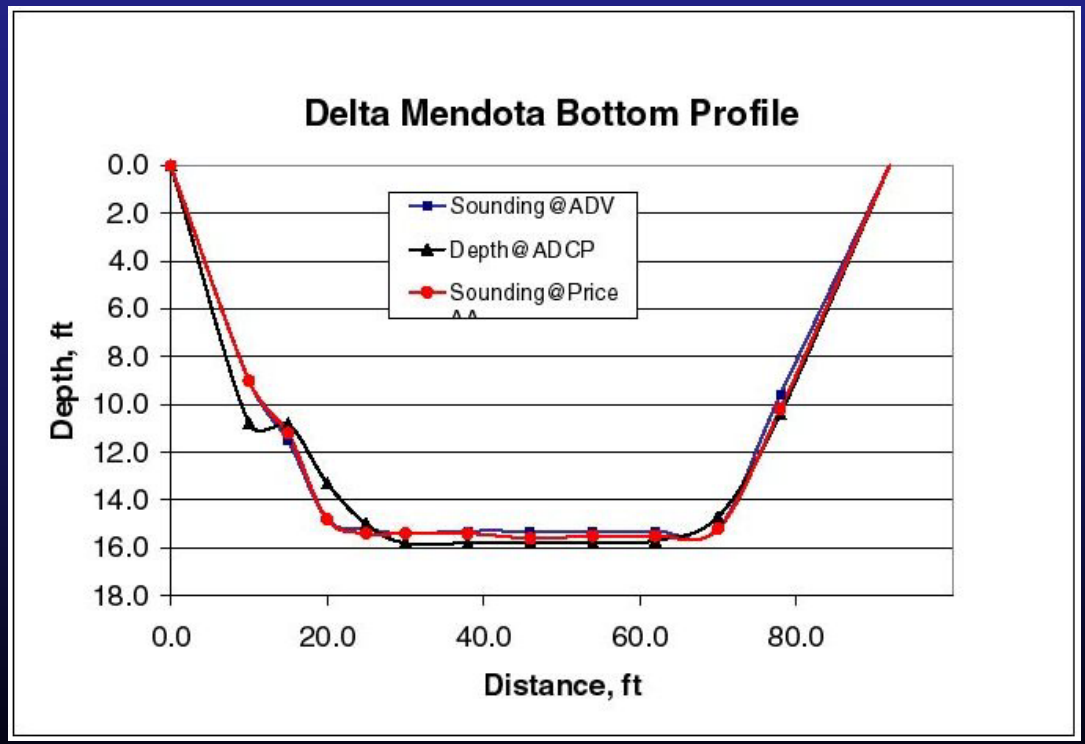
1. Can we measure water surface velocity distribution across river by radar?
2. Can we determine the water depth distribution by radar?
3. Can we use water surface velocity as an index velocity for computing river discharge?
4. What is the relation between surface velocity and water column mean velocity? ($\beta \sim 0.85 \ldots 0.92$)
5. What are the effects of Reynolds number, 3-D, secondary flow, and bed roughness?

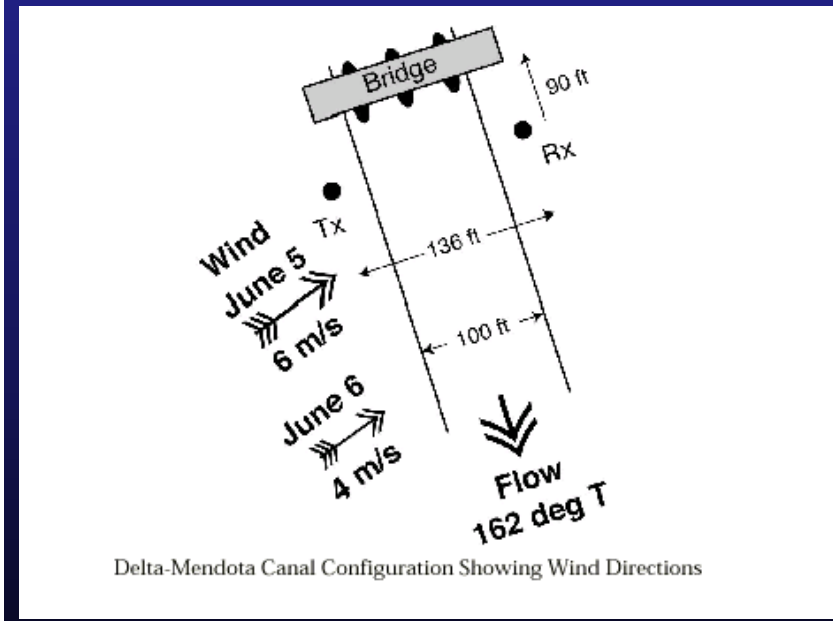
Basic theory: Logarithmic "Law-of-the-Wall (LoW)"

Basic question!

Are there conditions for the validity of LoW?

USGS-CODAR Experiment
Delta-Mendota Canal
near Tracy Pumping Plant
California
June 5-6, 2000





Delta-Mendota Canal Configuration Showing Wind Directions

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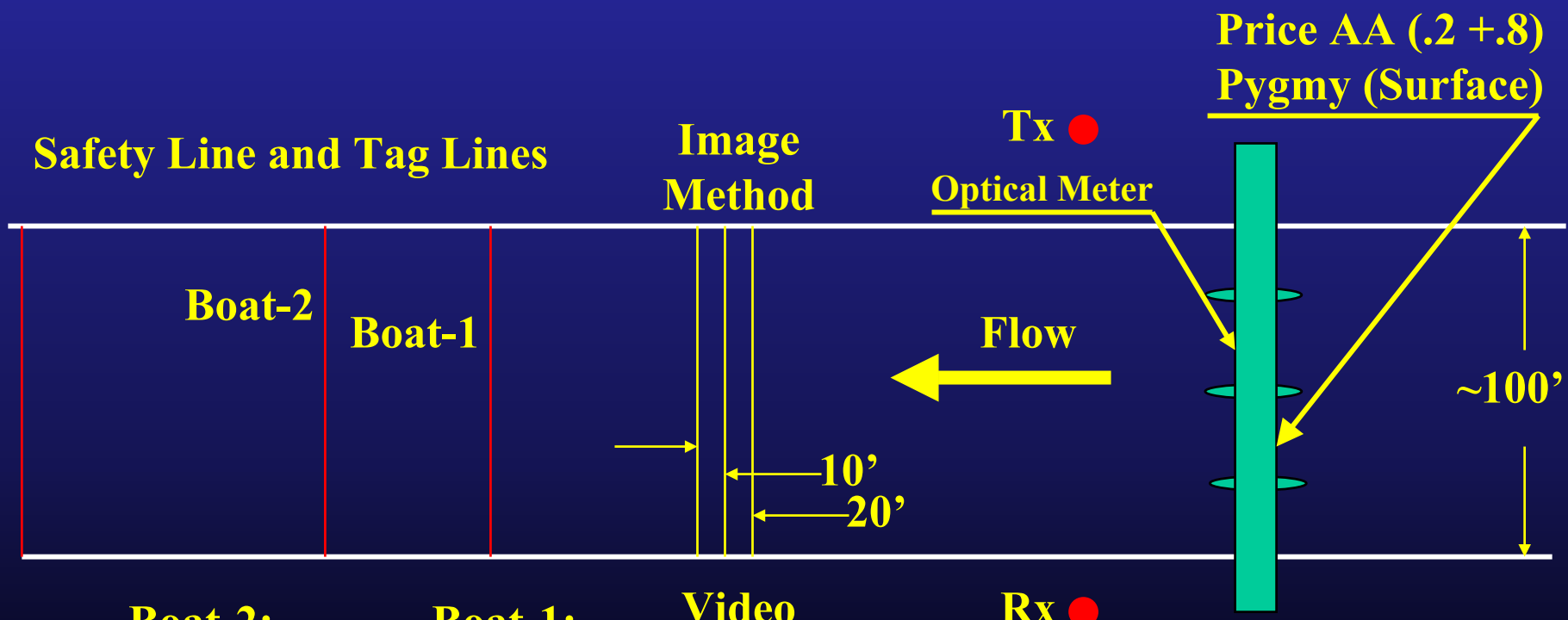
USGS-CODAR Experiment
Delta-Mendota Canal
June 5-6, 2000

Data Collection Methods:



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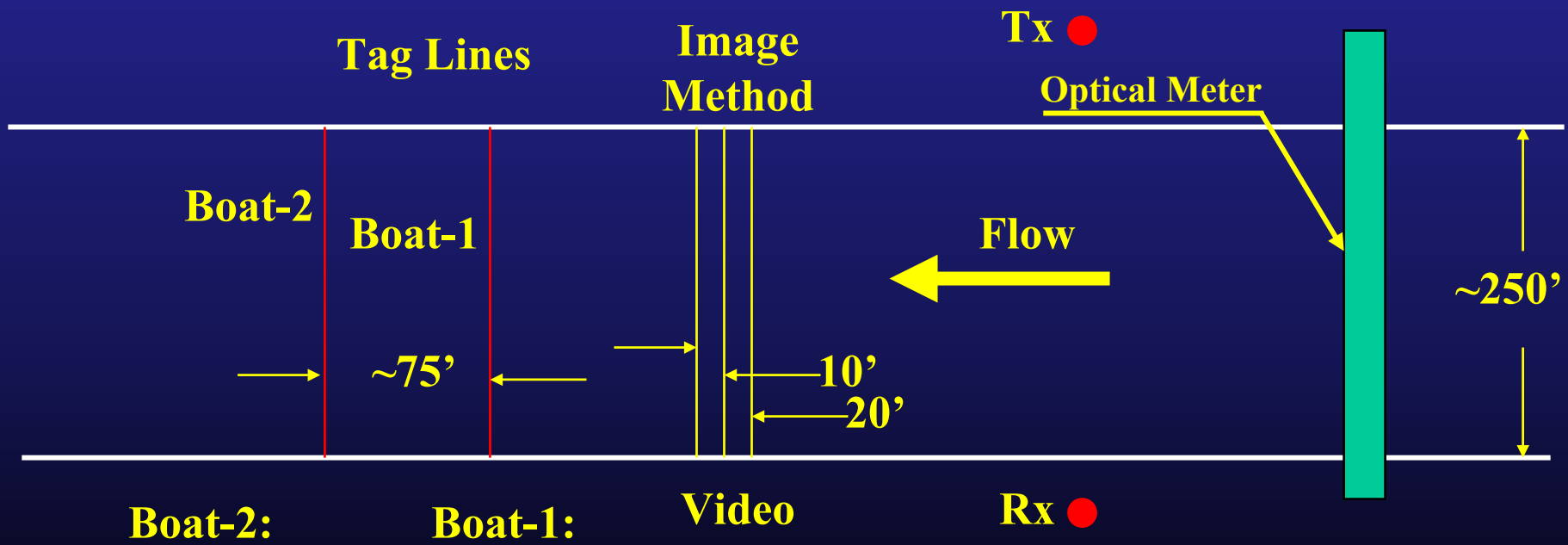
ADCP Assembly
ADV Assembly

USGS-CODAR Experiment
American River
Near Sacramento, CA
June 7, 2000

Data Collection Methods:



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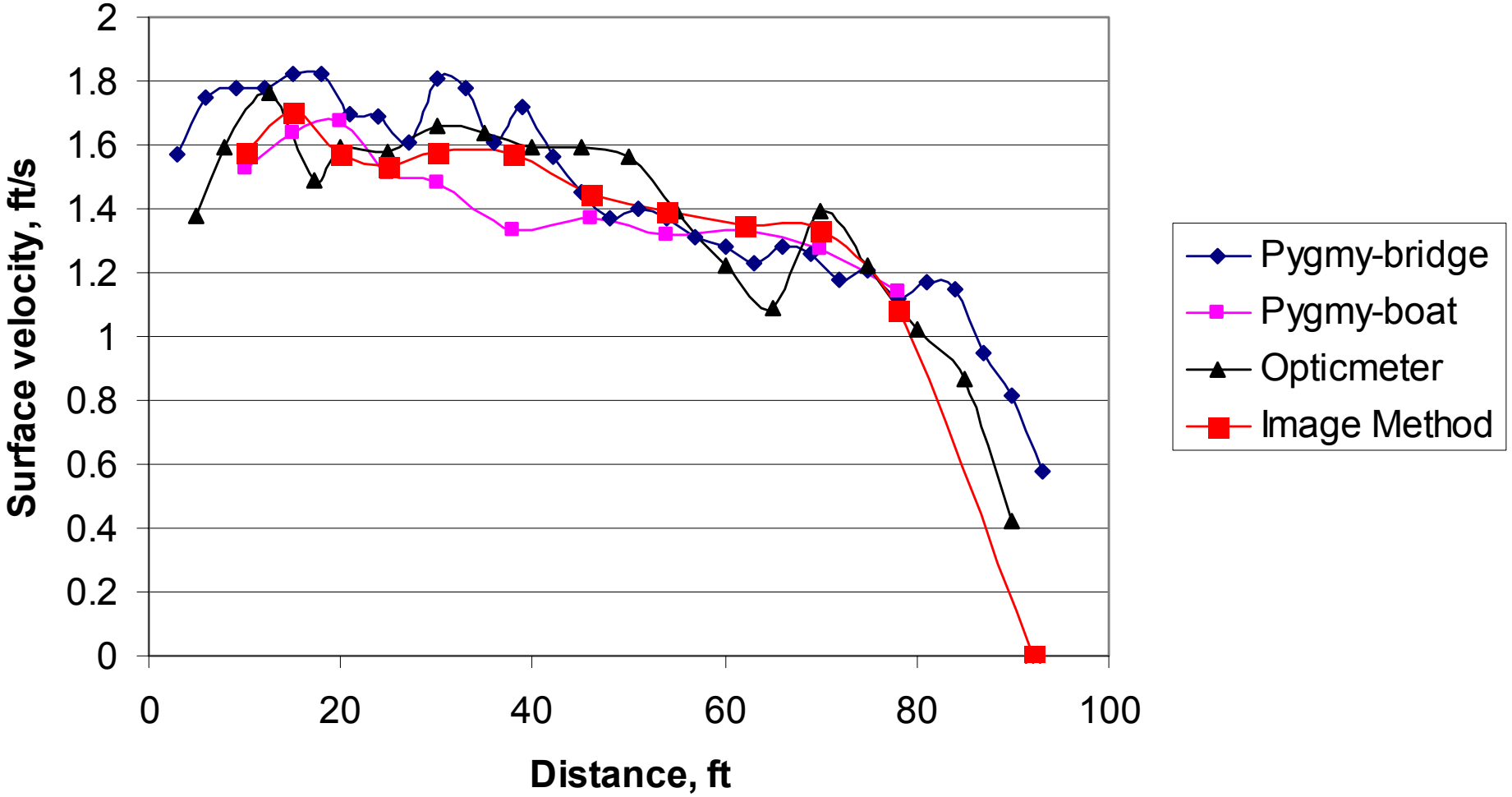
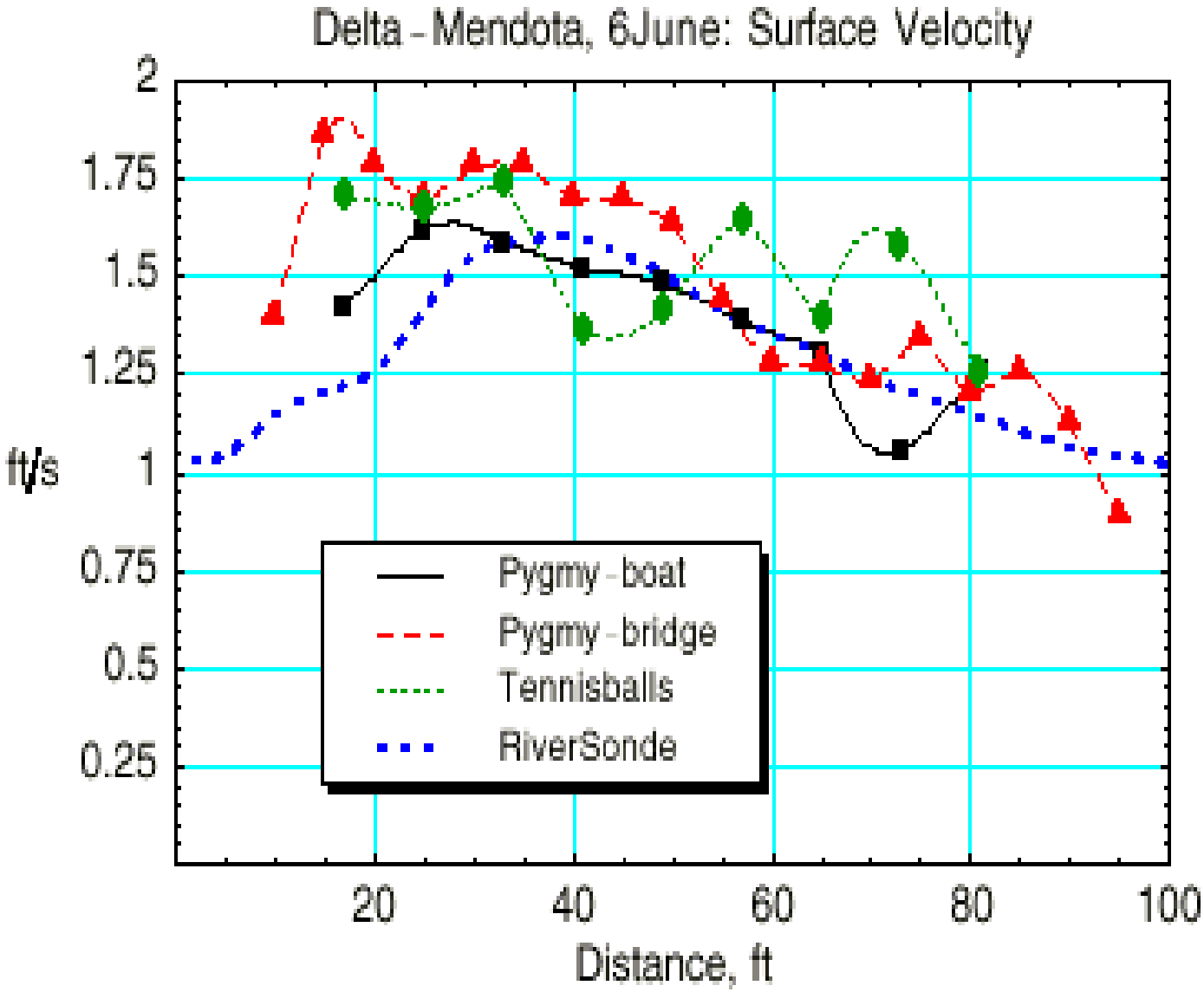
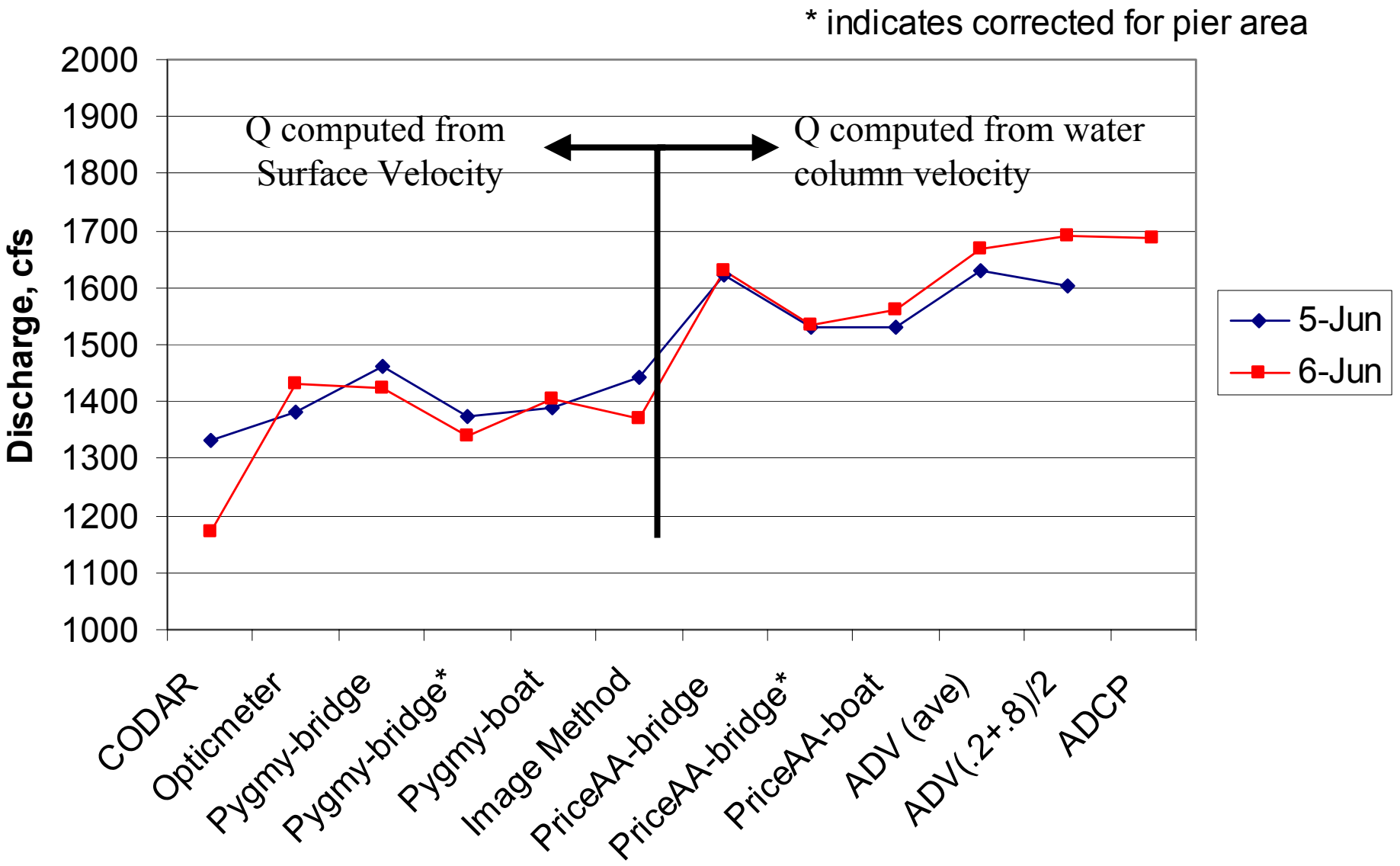
Delta Mendota, June 5:Surface velocities



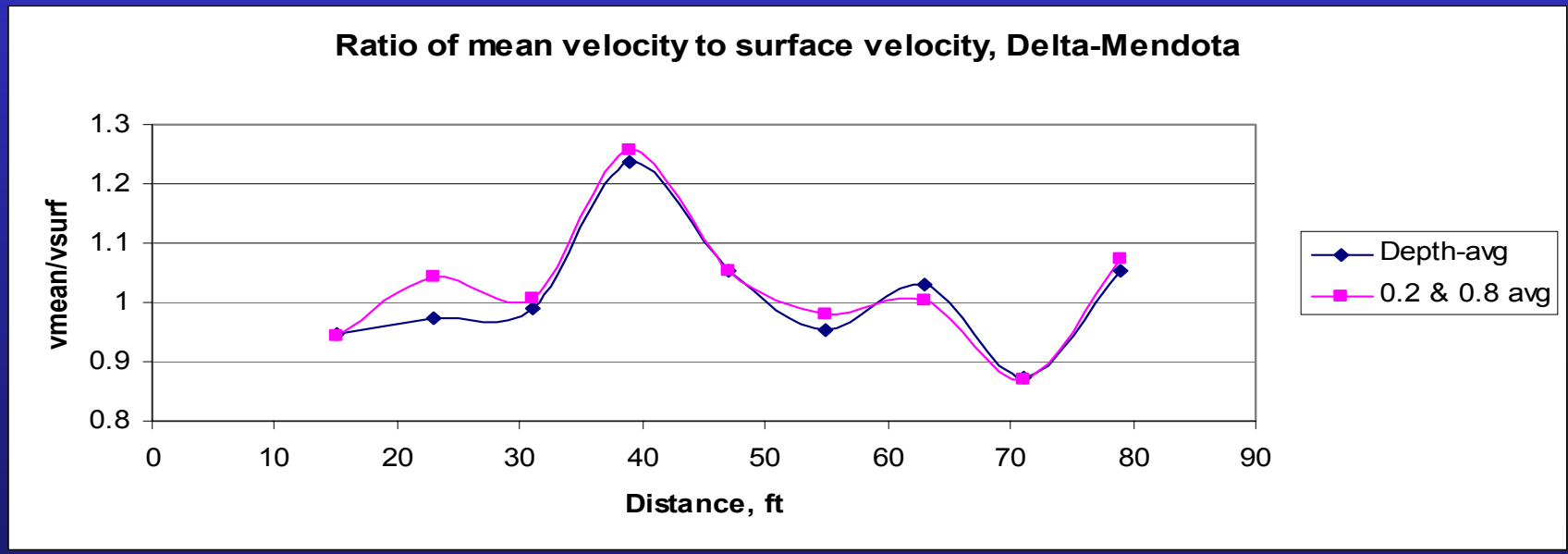


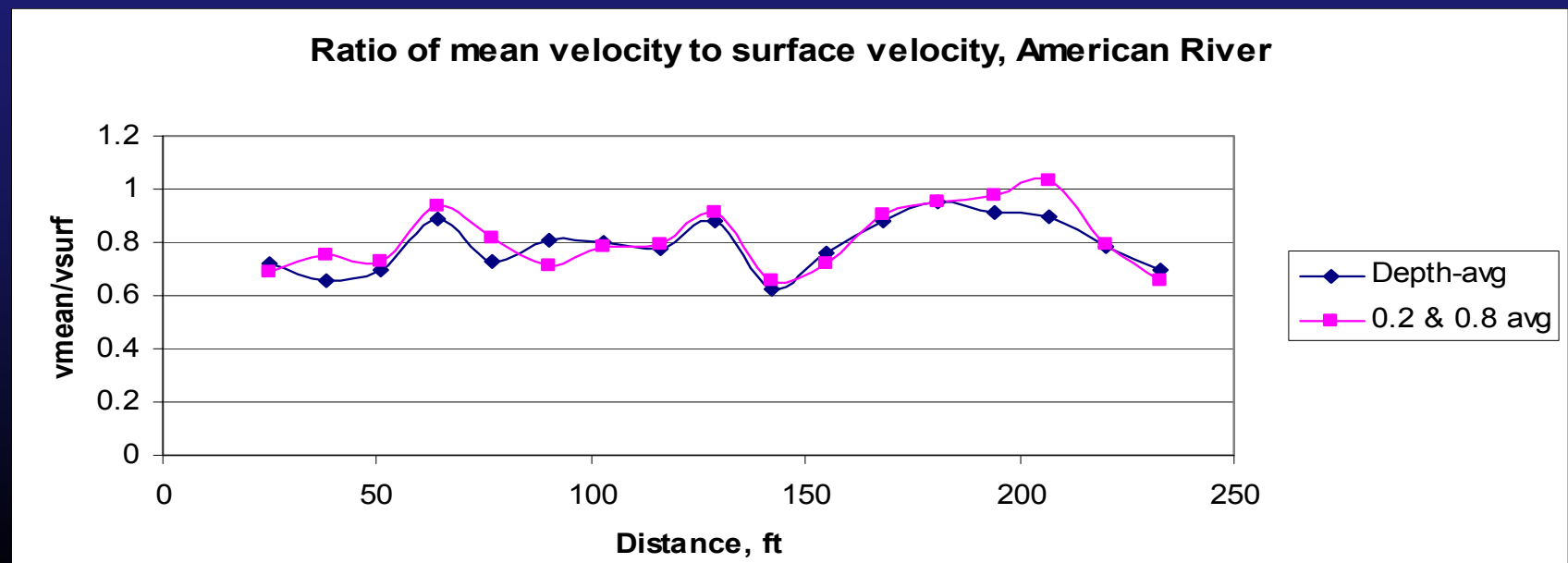
Cumulative Delta-Mendota Velocity Profile Comparisons for June 6 Morning

Discharge at Delta Mendota

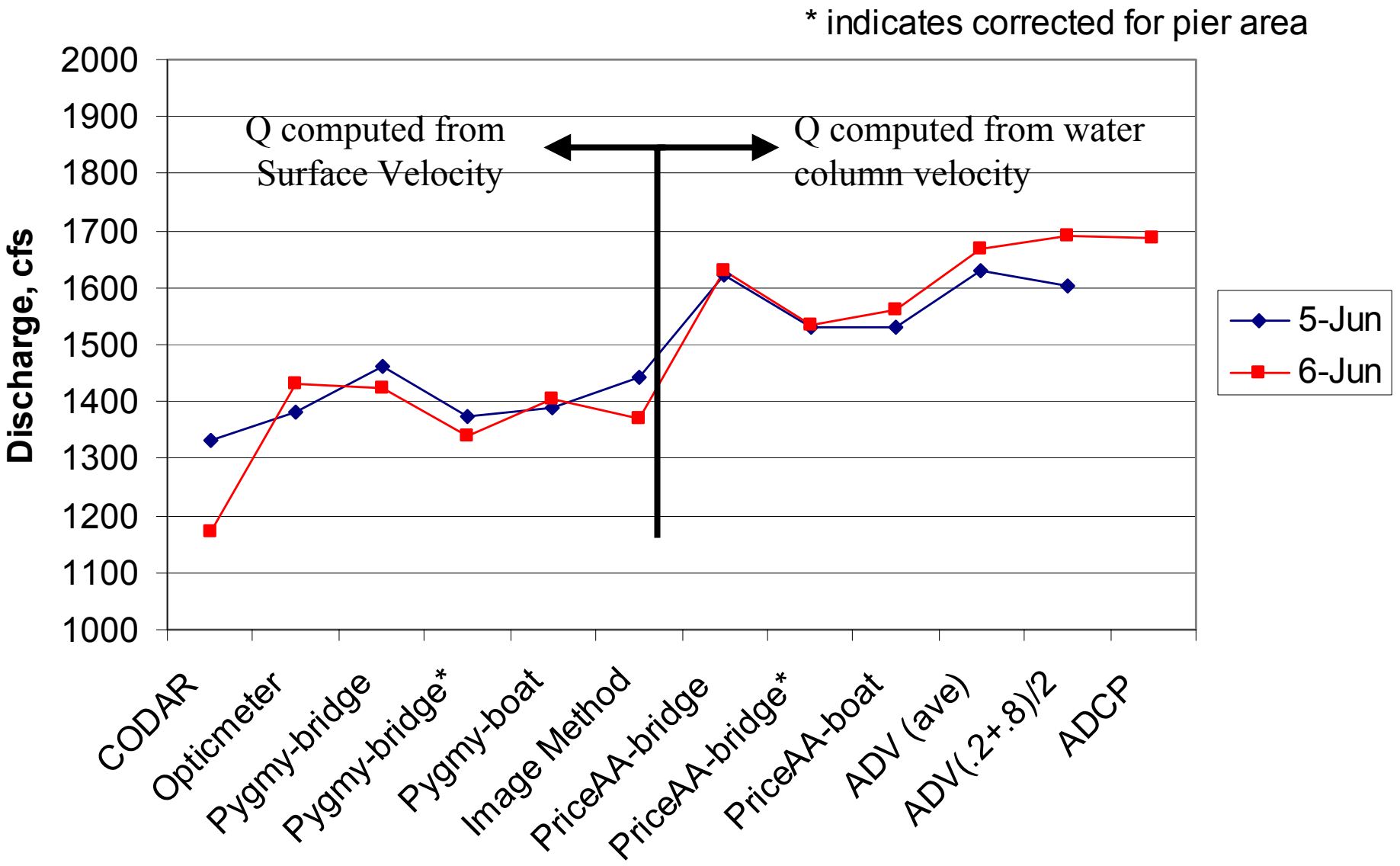


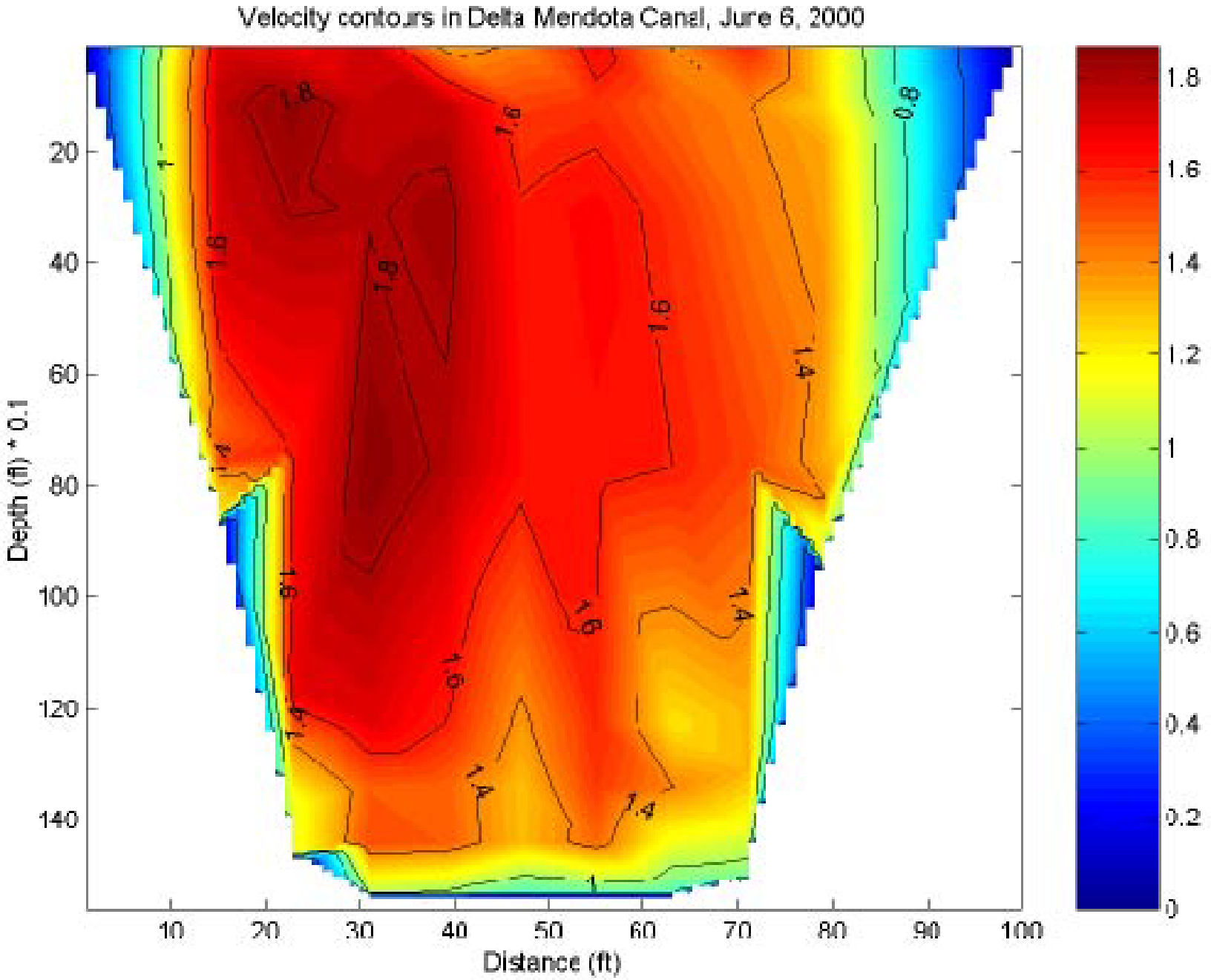
Measured Ratio of Mean Velocity to Surface Velocity

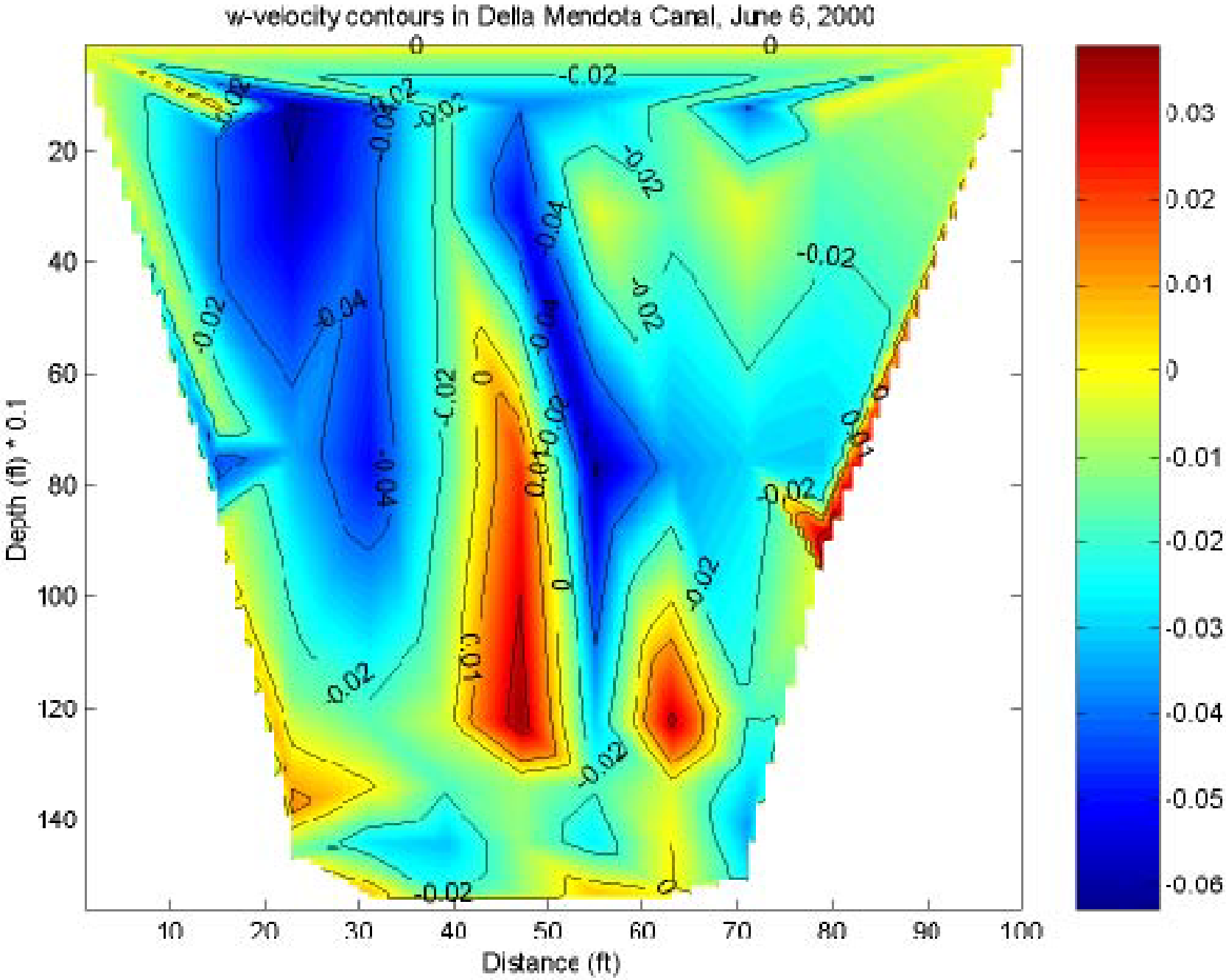


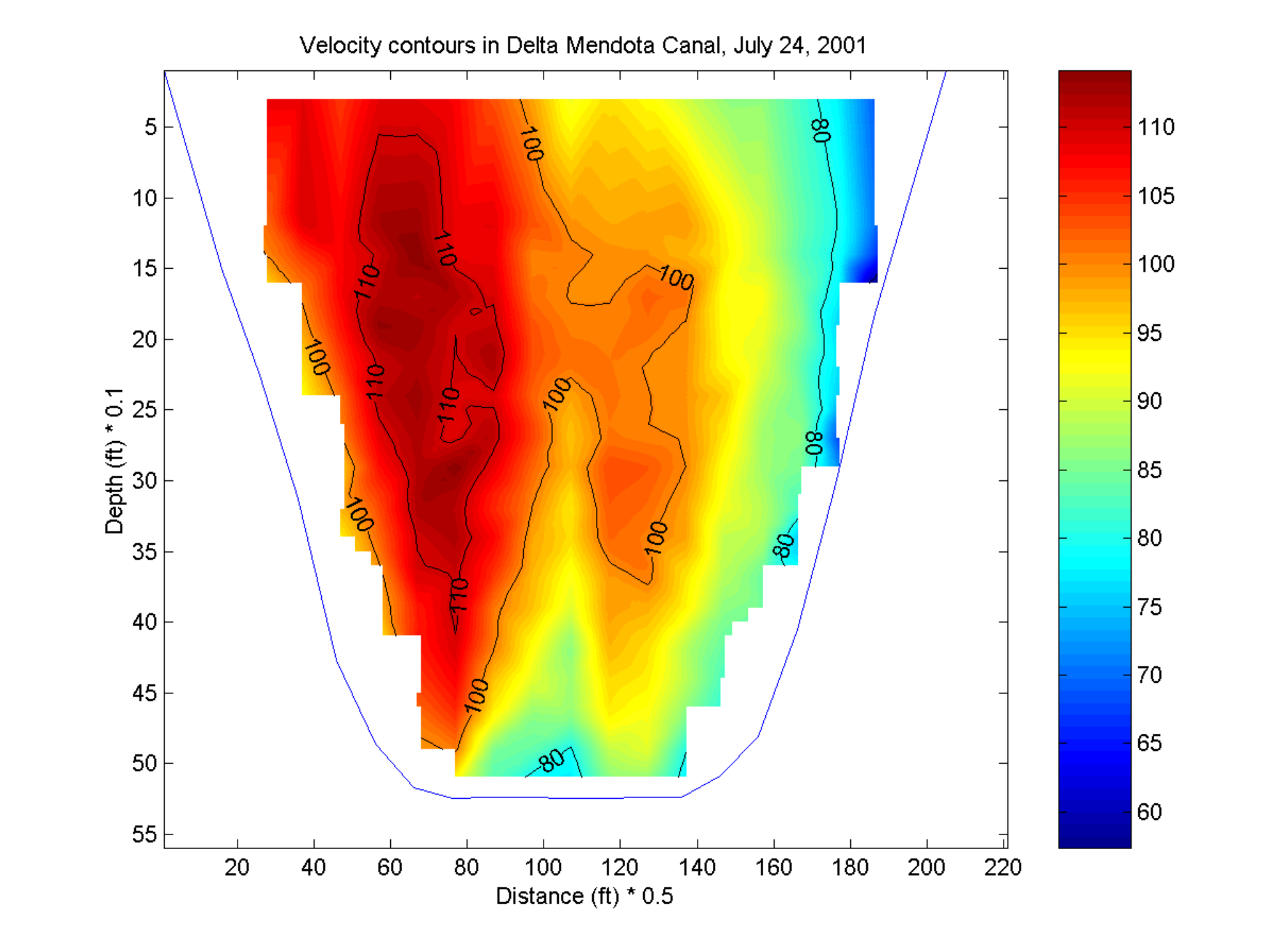


Discharge at Delta Mendota




Velocity contours in Delta Mendota Canal, Jure 6, 2000
Depth (ft) * 0.1
Distance (ft)
20
40
60
80
100
120
140
10
20
30
40
50
60
70
80
90
100
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0


w-velocity contours in Della Mendota Canal, June 6, 2000
Depth (ft) * 0.1
Distance (ft)
20
40
60
80
100
120
140
10
20
30
40
50
60
70
80
90
100
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06


Velocity contours in Delta Mendota Canal, July 24, 2001
Depth (ft) * 0.1
Distance (ft) * 0.5
5
10
15
20
25
30
35
40
45
50
55
20
40
60
80
100
120
140
160
180
200
220
110
105
100
95
90
85
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60
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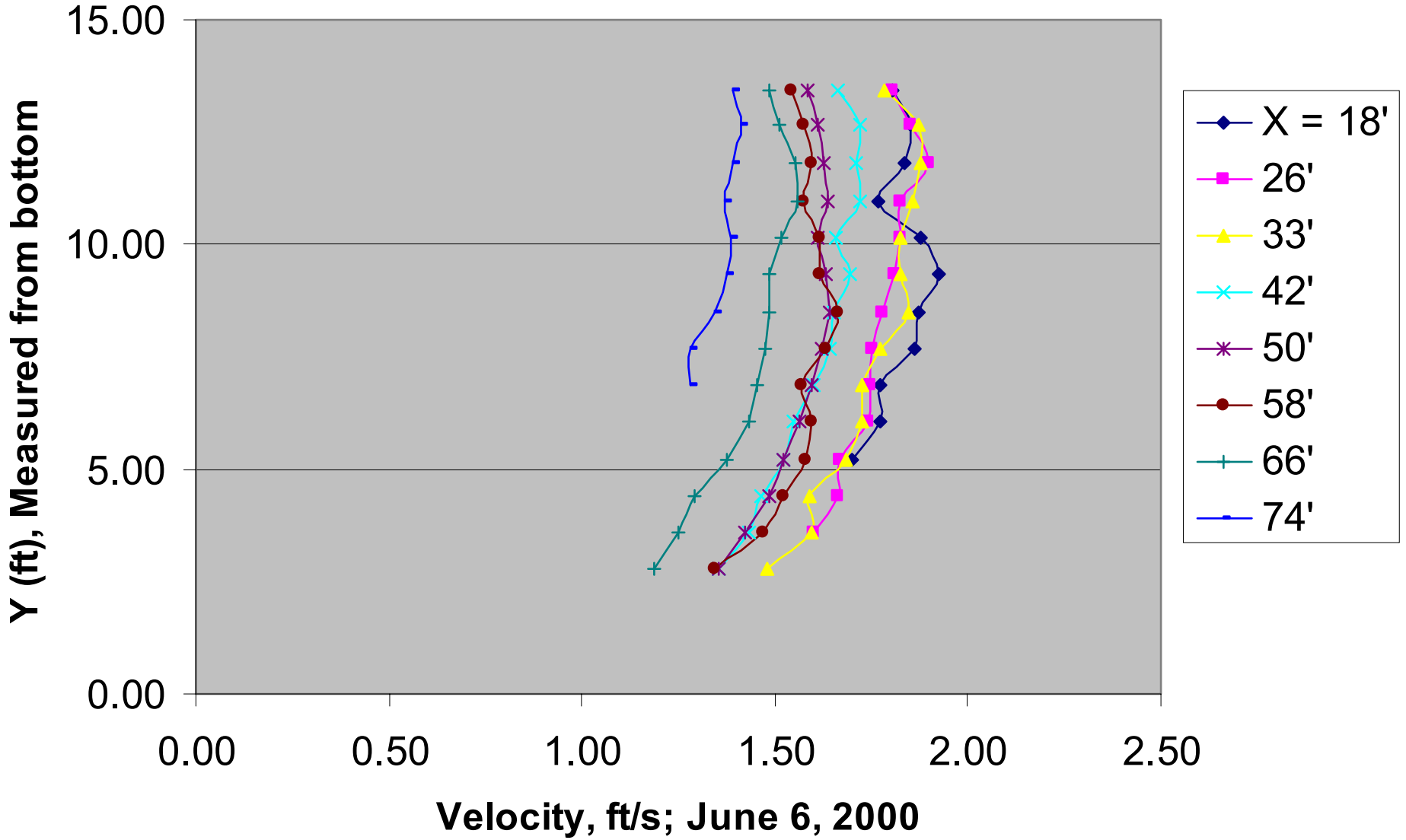
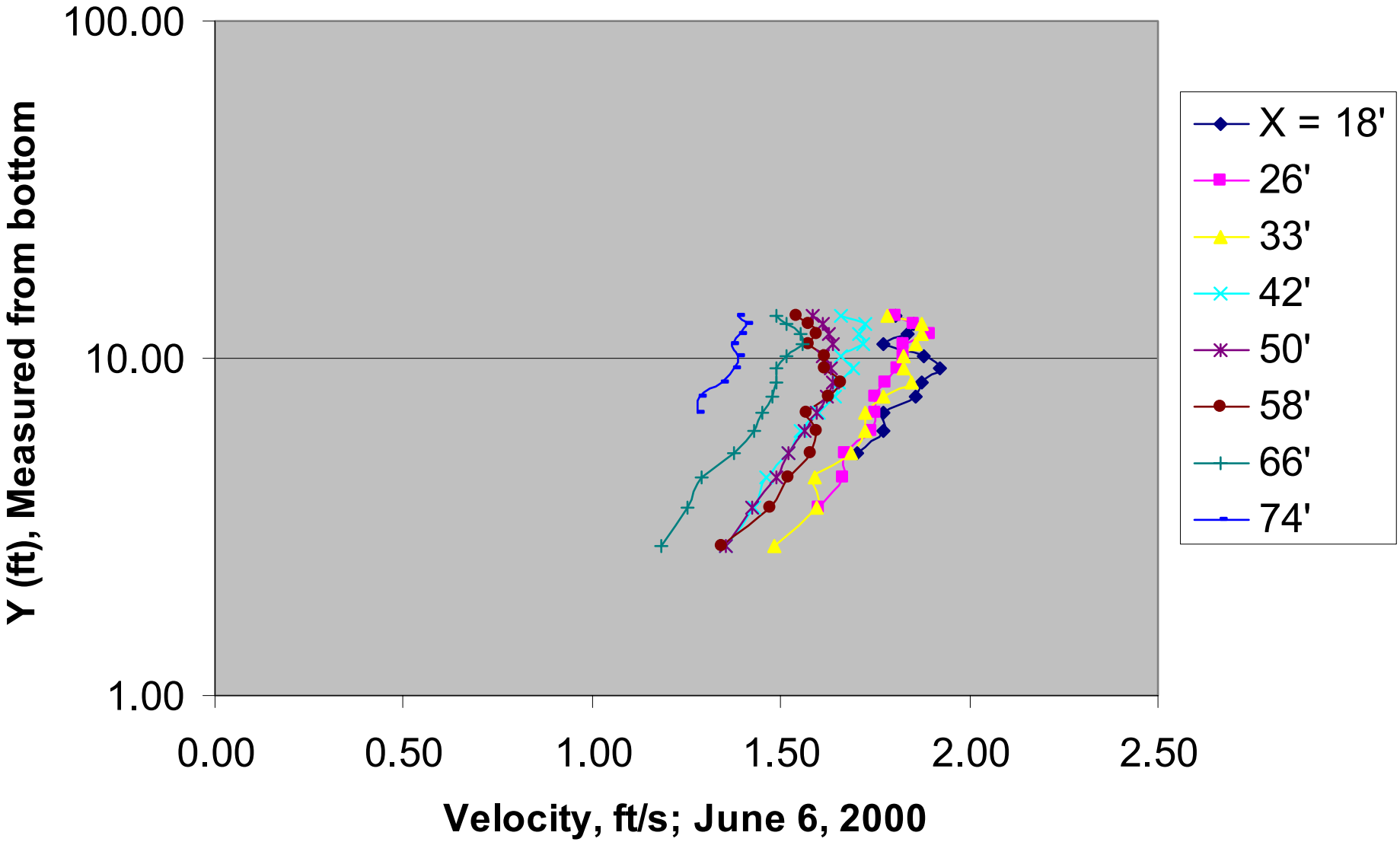
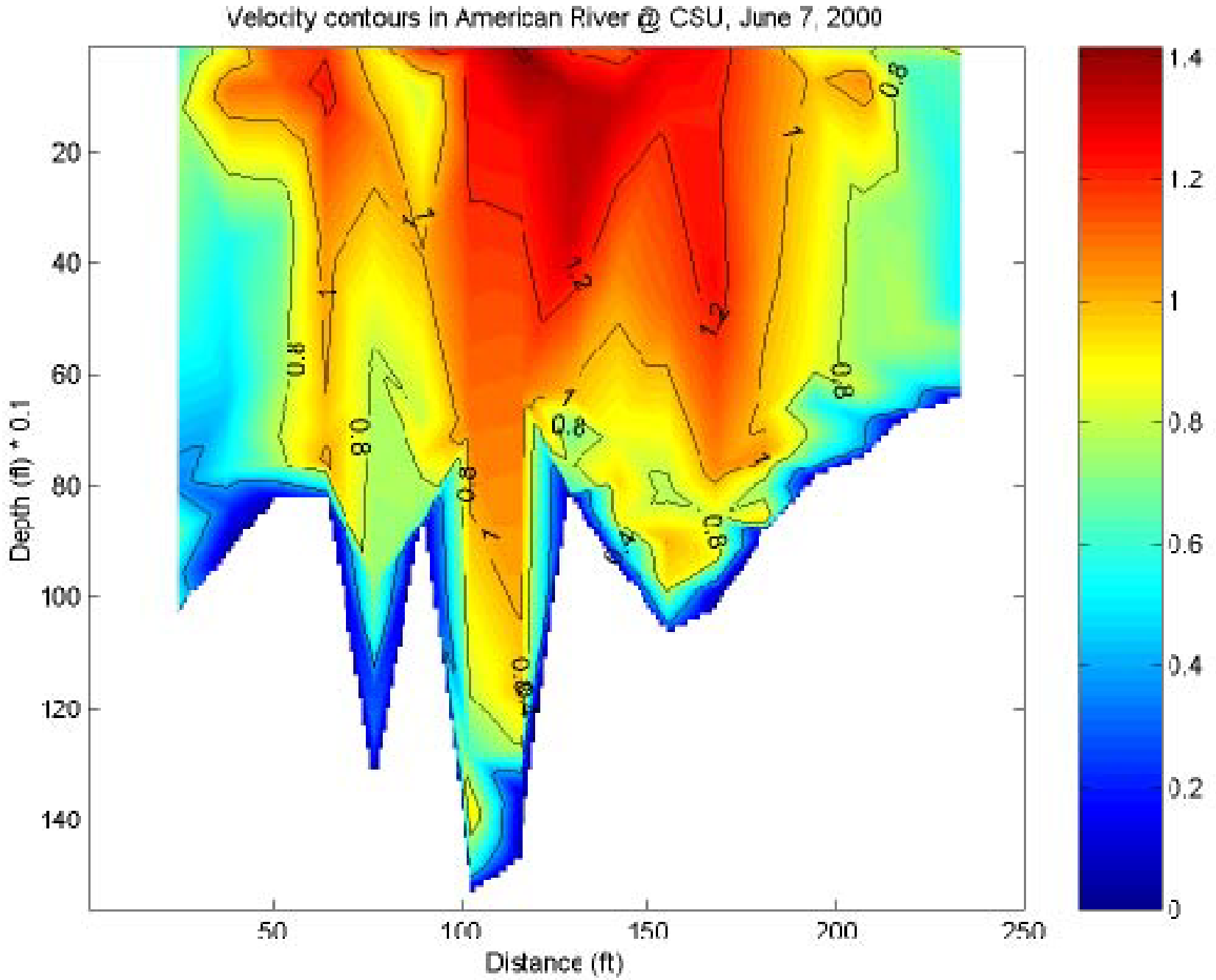
100
100
100
100
100
100
80
80
80
80


Velocity Profiles Measured by an ADCP
15.00
10.00
5.00
0.00
Y (ft), Measured from bottom
0.00
0.50
1.00
1.50
2.00
2.50
Velocity, ft/s; June 6, 2000
X = 18'
26'
33'
42'
50'
58'
66'
74'

Velocity Profiles Measured by an ADCP




Velocity contours in American River @ CSU, June 7, 2000
Depth (ft) * 0.1
20
40
60
80
100
120
140
50
100
150
200
250
Distance (ft)
1.4
1.2
1
0.8
0.6
0.4
0.2
0

Summary of Results:

1. Surface velocity can be measured by Micro-wave or HF Radar

2. Ground Penetrating Radar (looking vertically down) can be used to map channel x-section

3. Using radar from an oblique angle can probably "see" the bottom, and detect changes of bottom; but it is questionable that we can resolve the depth distribution

Airborne Radar System

Objectives:

- **Fast response for discharge measurements in flood zones**
- **Discharge measurements in areas that are difficult to reach**

System setup:

Microwave radar and GPR on a helicopter

Helicopter based radar system for discharge Measurement September 13, 2000

Velocity due to Down Wash

River Surface Velocity

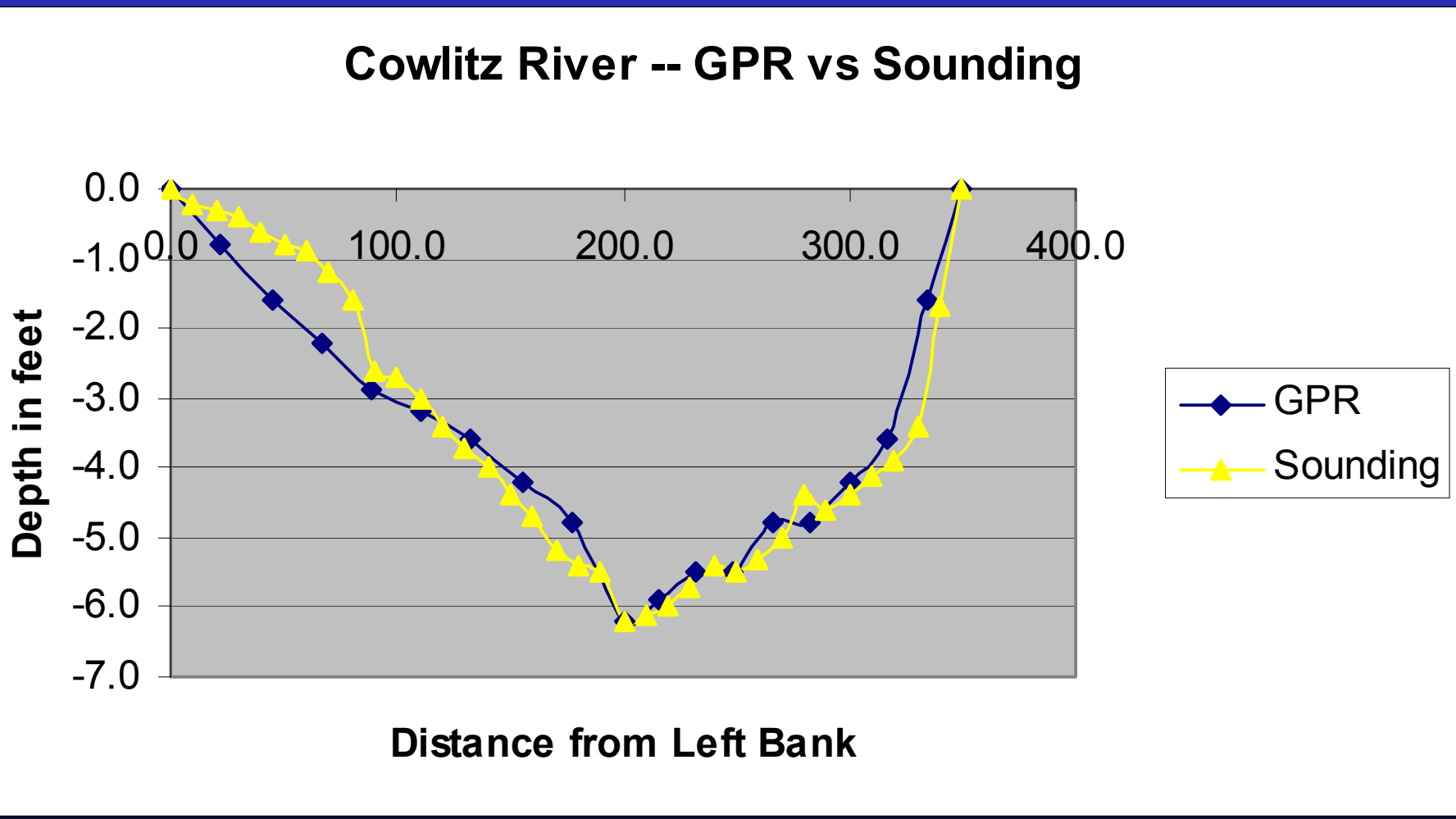
Velocity!

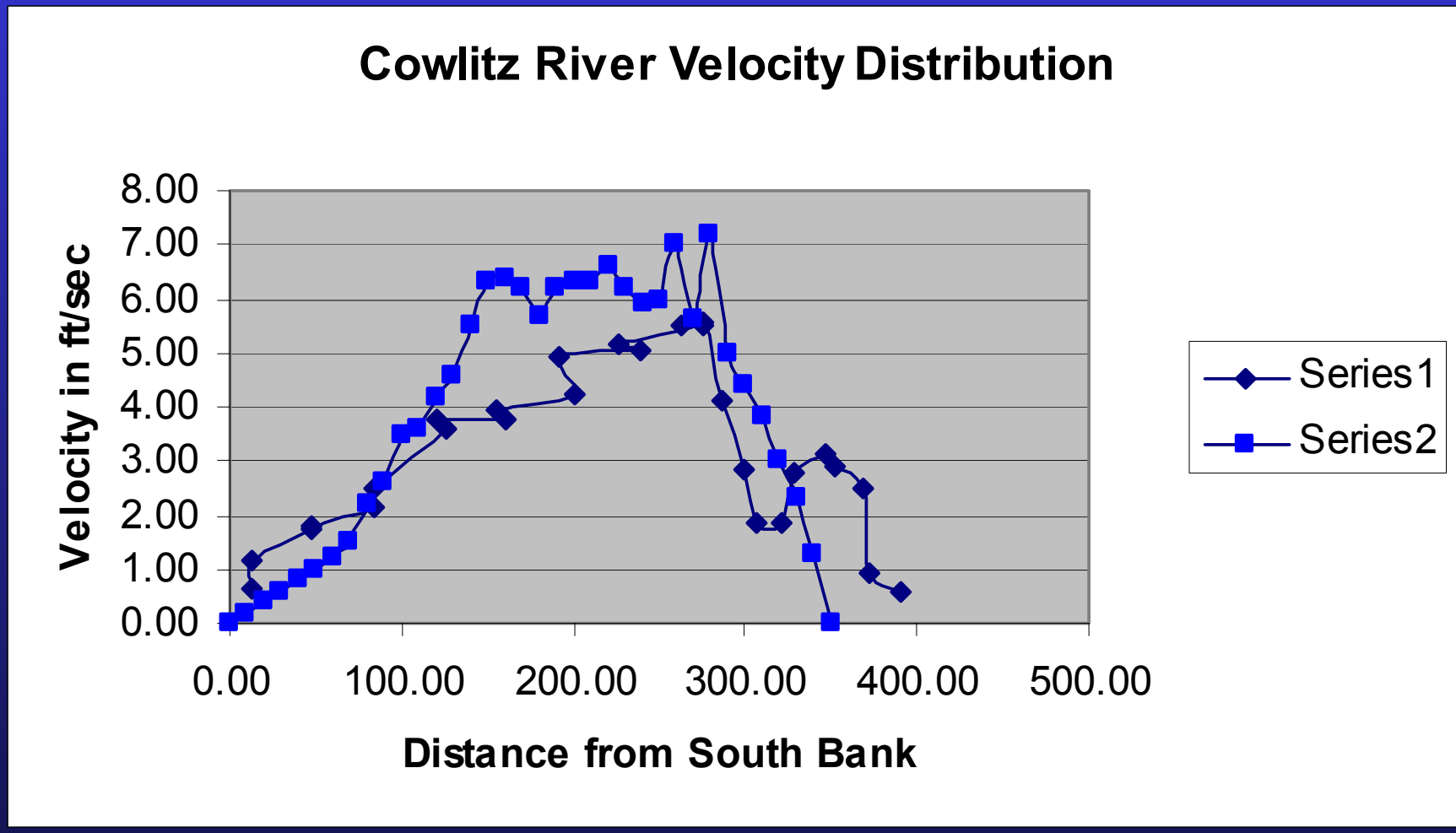
Velocity!

Depth!

Water Velocity = ½ (← + ← + → + ←) = ←

Quick Time Video!


Cowlitz River -- GPR vs Sounding
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
Depth in feet
0.0
100.0
200.0
300.0
400.0
Distance from Left Bank
GPR
Sounding



Computed Discharges: 1st Run: 6384 and 2nd Run: 3444 cfs

Conventional Discharge Measurement: 4960 cfs

Interim Conclusion: Airborne System holds promise!

Where do we go from here?

Continue Searching for Technologies

⇩

Conduct Basic Research:
Properties of Open Channel Flow

⇩

Evaluate Results of
Proof-of-Concept Experiment

⇩

Refine Helicopter
GPR-Microwave Radar-experiment

⇩

Future Directions
Recommendations

USGS
science for a changing world

Future Directions and the USGS Recommendations

Ralph T. Cheng, BRR, WR

HYDRO-21 Committee

¶ The USGS has launched a systematic effort in search for technologies that have the potential to change the paradigm for future water resources monitoring programs.

¶ Hydro-21 activities are continuing, your comments and suggestions are welcome!

USGS science for a changing world