Department of
Sustainability and
Environment

Acoustic Doppler Velocity Meters

A study to determine improvements in the reliability of Surface Water flow estimates

Victoria
The Place To Be

Project Objectives

Knitghthead for protection of instrument from vandalism

- Monitor flows at 12 challenging streamflow monitoring sites
- Improve the accuracy of moderate and high flow discharge estimates at those sites
- Virtually Increase the total number of stage – discharge observations obtained at each site. (96 per day)
- Identify variances in the stage-discharge relationship on falling and rising legs of a hydrograph.
- Reduce uncertainty in flow estimates.
- Evaluate the effectiveness of utilising Acoustic technologies to develop improved discharge monitoring.
- Develop a methodology and work procedures to identify and eliminate error sources

Study Sites.

- **Twelve sites were initially selected for the study**
  - Latrobe R @ swing Bridge
  - Latrobe R @ Kilmany south
  - Thomson R @ Bundalaguah
  - Mitchell R @ Rosehill
  - Avon R @ Stratford
  - Snowy R @ Jarrahmond
  - Macalister R @ Licola
  - Macalister R D/S Lake Glenmaggie
  - Goulburn R @ Murchison
  - Goulburn R @ McCoys Bridge
  - Murray R @ Euston
  - Gellibrand R @ Burrupa
- **Each provided one or more of the following challenges;**
  - Access difficulties during high flows
  - Subject to surge in an estuarine lake
  - Subject to variable back-up
  - Downstream from a controlled storage/s
  - Resource intensive manual stage–discharge observations required.
  - Break-out point to a flood plain.
  - Meeting Key Business Driver needs.
- **For further site detail see the accompanying background paper.**

ACOUSTIC DOPPLER VELOCITY METER

The topics discussed are;

1) Unsteady Flow Conditions,
2) The propagation of flow in space and time through a river for unsteady flows condition and the challenges due to the limitation in conventional method; namely recording stage, undertaking the discharge measurement, developing rating table,
3) ADVM (Acoustic Doppler Velocity Meter) Trial,

Unsteady Flow - Hysteresis

If flow conditions (such as depth and velocity) do vary with time at a discrete location; the flow is classified as unsteady.

$$\frac{\partial h}{\partial t} \qquad \frac{\partial V}{\partial t}$$

Hysteresis effect occurs where discharges for a given water level on the rising limb of hydrograph differ from discharge for the same level on the falling limb,

Its magnitude is significant at;

a) Sections affected by tide,

b) Where backwater effect occurs during a flood,

c) Where the flow conditions are controlled by a Lock or a Gate,

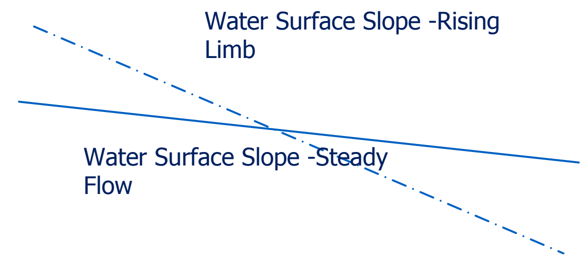
d) Where the flood plain impact on main stream is significantly variable - magnitude of the impact before and after the peak varies significantly,

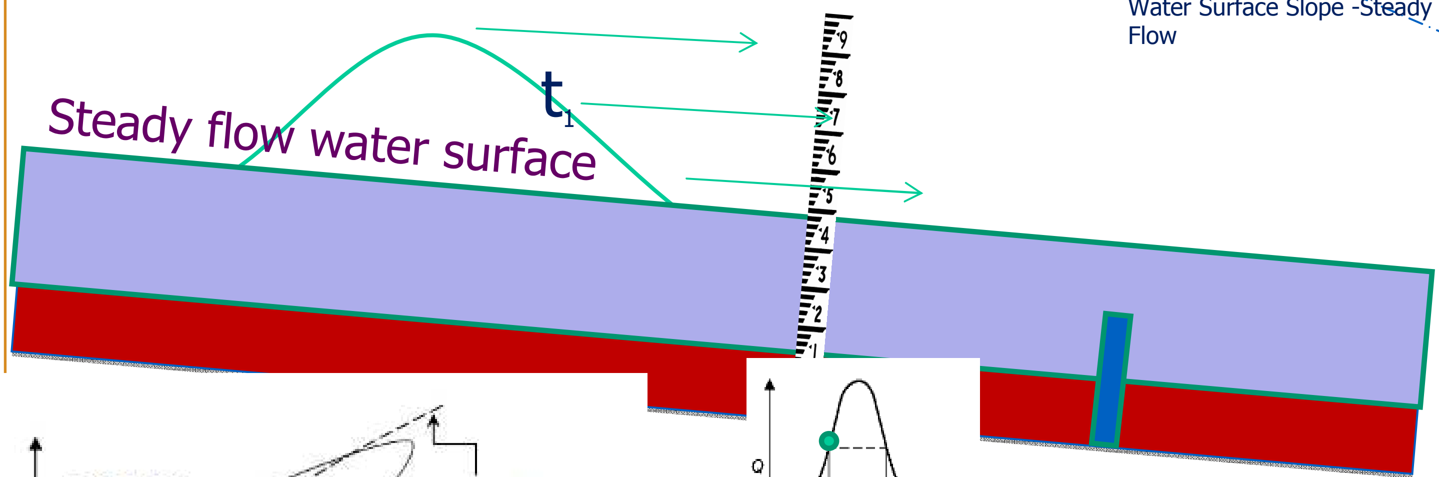
e) Where flow is regulated constantly,

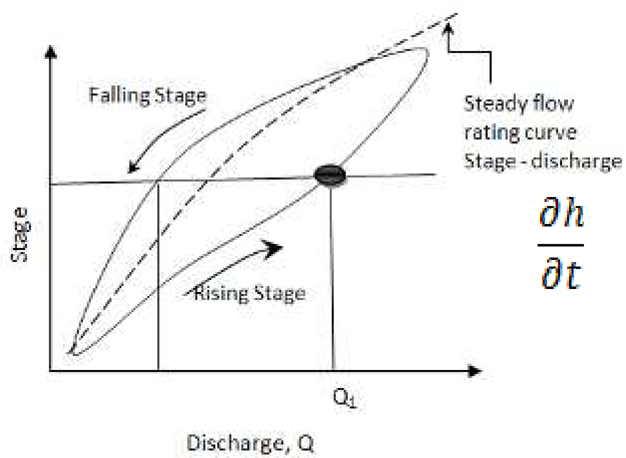
f) Where water surge occurs

Unsteady Flow-Hysteresis,

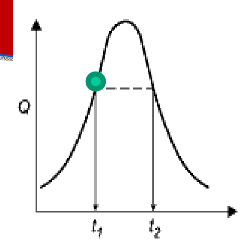
Flow conditions (such as depth and velocity) do vary with time at a discrete location, the flow is then classified as unsteady.

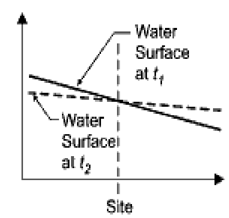






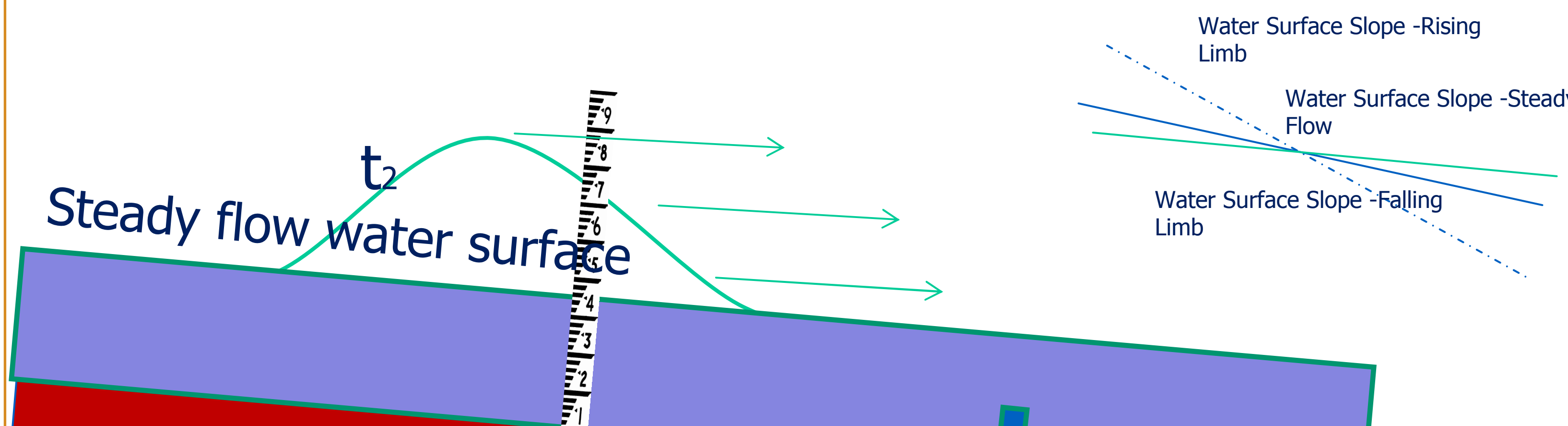
$$\frac{\partial h}{\partial t} \quad \frac{\partial V}{\partial t}$$

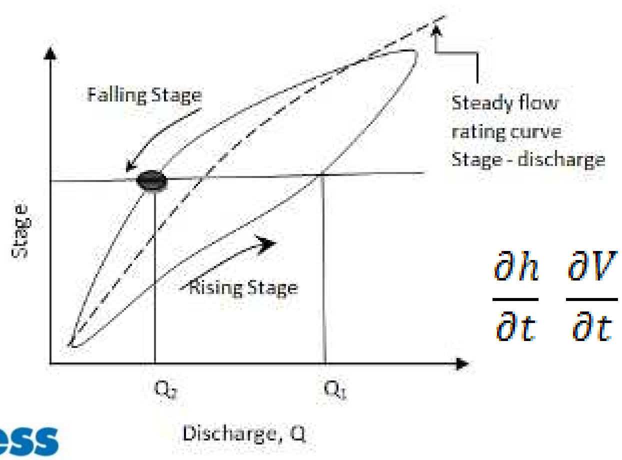




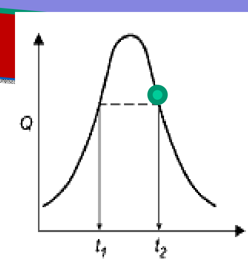
Unsteady Flow,

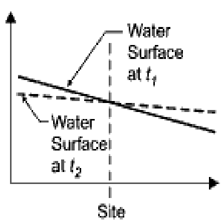
Flow conditions (such as depth and velocity) do vary with time at a discrete location, the flow is classified as unsteady.





$$\frac{\partial h}{\partial t} \quad \frac{\partial V}{\partial t}$$

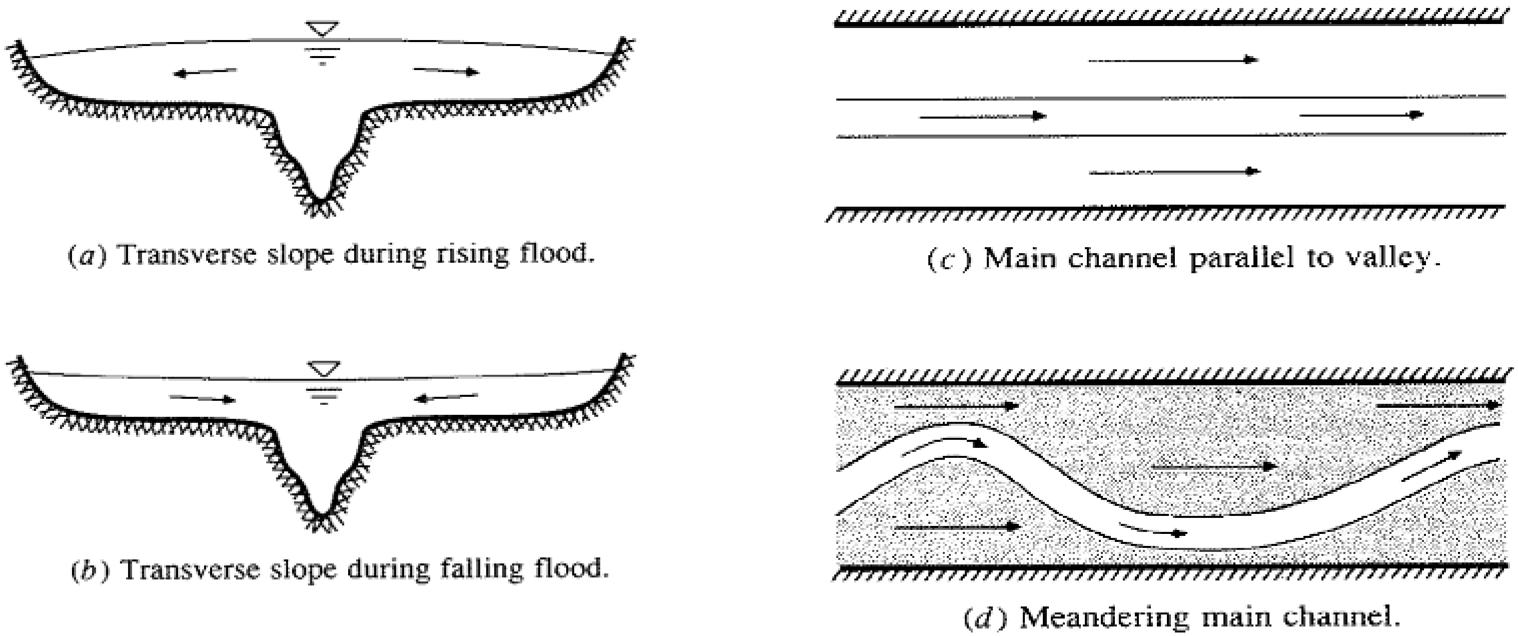




Thiess services

Victoria The Place To Be

River with a Flood Plain & Unsteady Flow,



(*a*) Transverse slope during rising flood.

(*c*) Main channel parallel to valley.

(*b*) Transverse slope during falling flood.

(*d*) Meandering main channel.

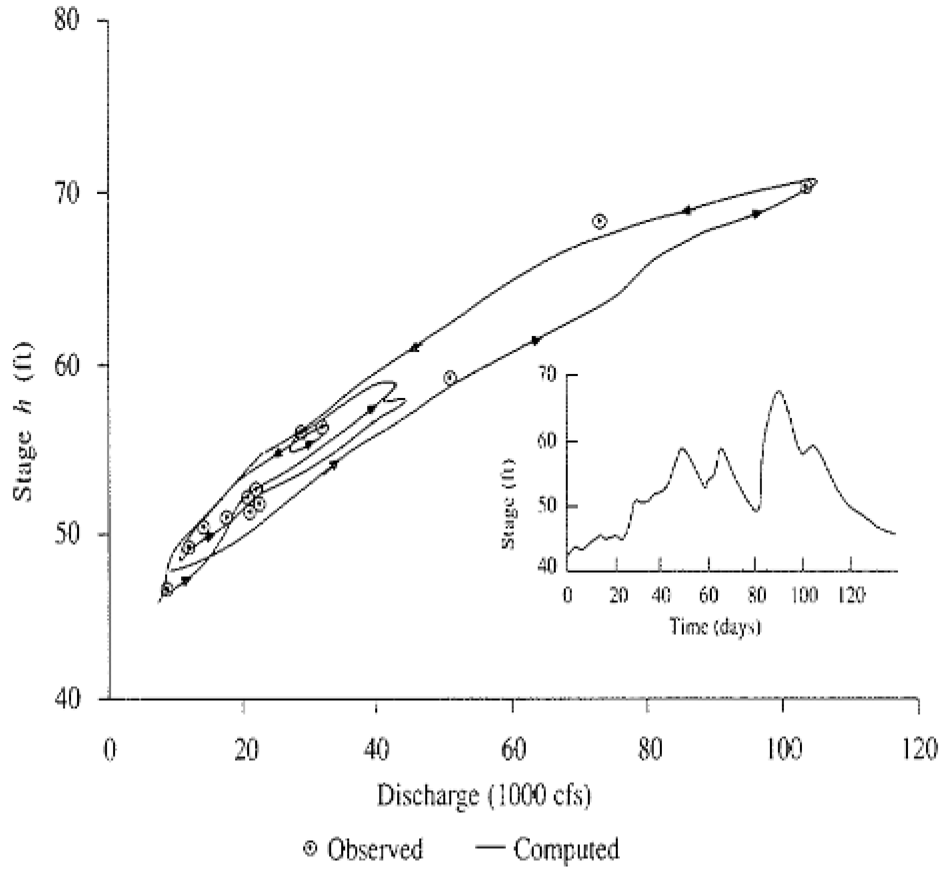
The interaction between the main channel and the flood plain or inundated valley is one of the most important factors affecting flood propagation.

The impact of a flood plain on wave celerity where the flood wave progresses more slowly in an inundated valley.

Thiess services

Victoria The Place To Be

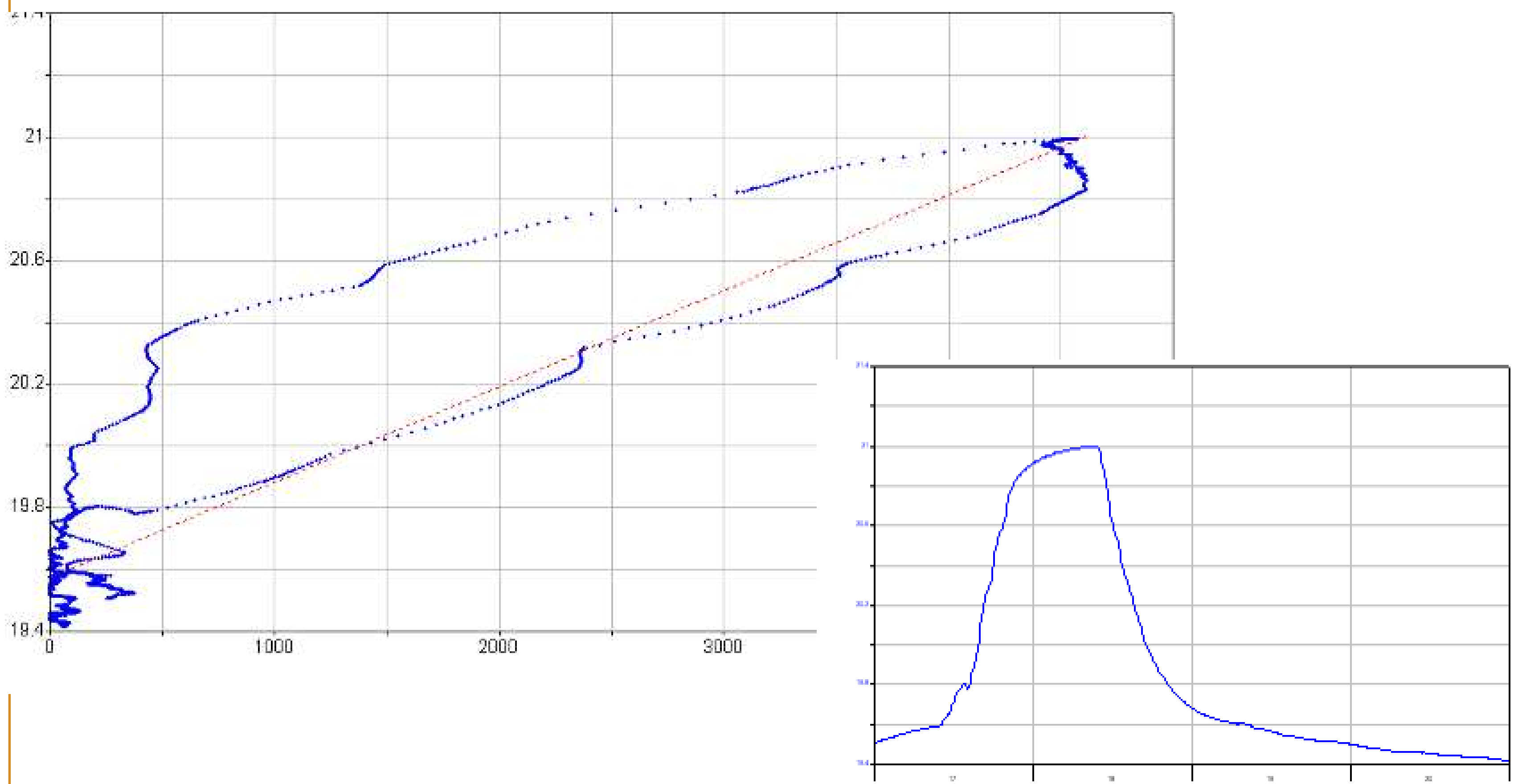
Loop Rating - Hysteresis



Looped stage discharge relation for the Red River, Alexandra, Louisiana (May 5th – June 17th 1964. Source: D. L. Fread, WATER RESOURCES BULLETIN, VOL. 11, NO. 2 AMERICAN WATER RESOURCES ASSOCIATION APRIL 1975,

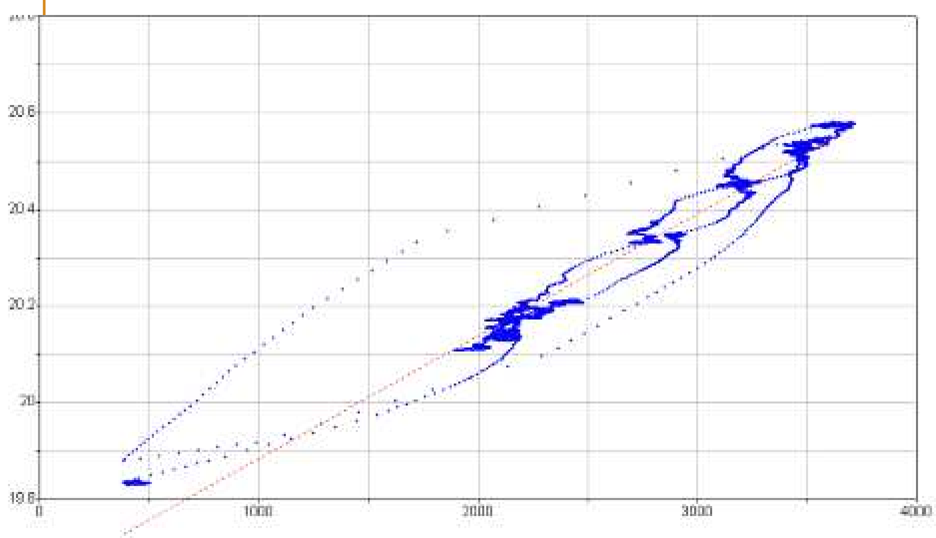
Loop Rating - Hysteresis

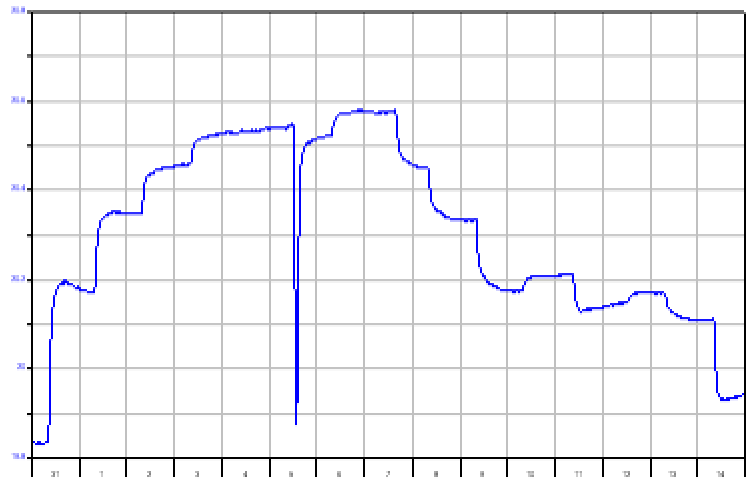
Looped Stage Discharge Relationship



Loop Rating - Hysteresis

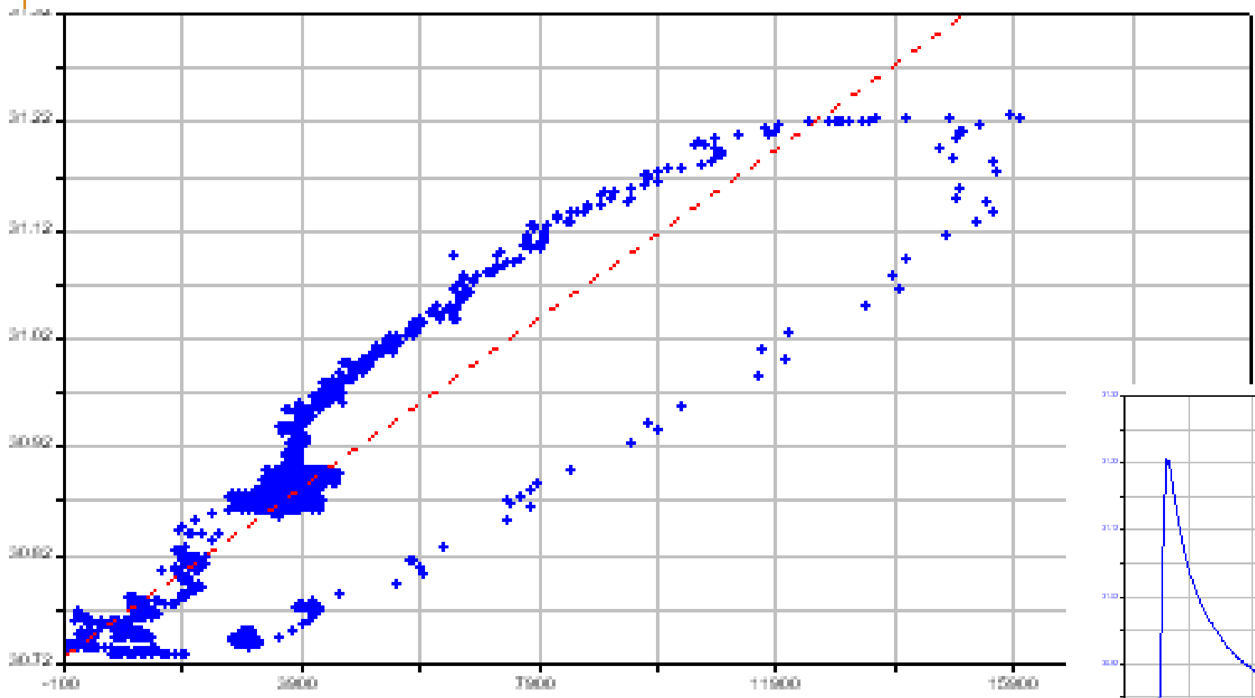
Looped Stage Discharge Relationship

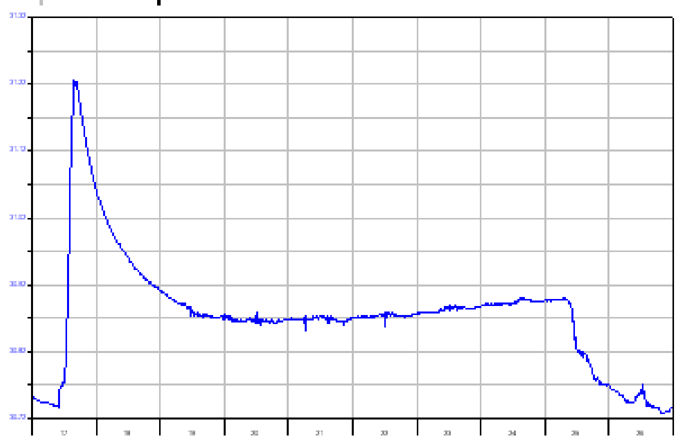




Loop Rating - Hysteresis

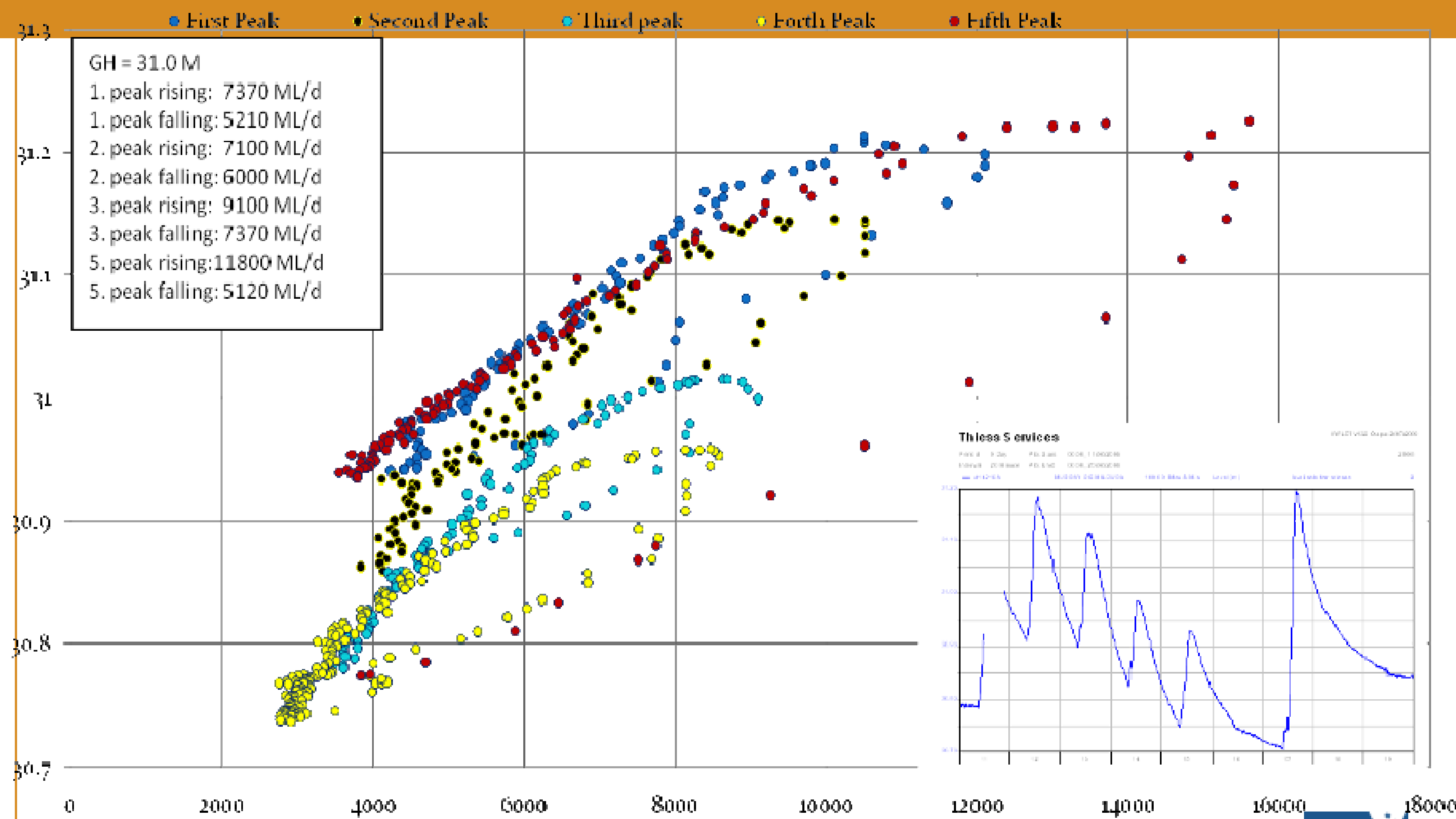
Looped stage-discharge relationship





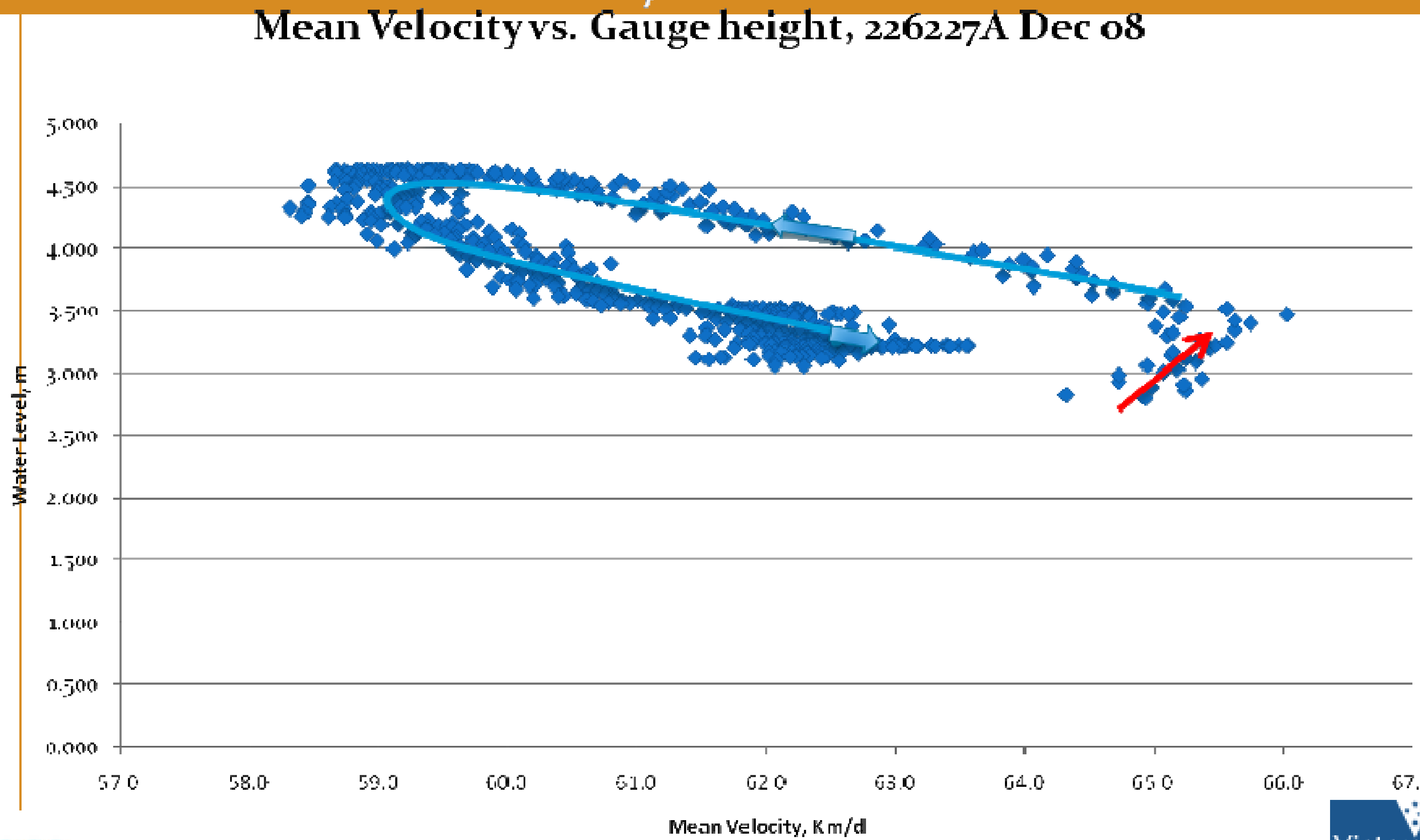
Loop Rating - Hysteresis

Looped stage discharge relationship for multi peaks, Murray River 2006



Acoustic Doppler Velocity Meter

The effects of the trees on the bank, of the junction on the velocity recorded



Indirect Discharge Calculation for Unsteady Flow,

Indirect Discharge Estimation Methods for Unsteady Flow;

a) Estimation methods based on stage measurements at a single section
Jones, Henderson, Di Silvio, Fread, Faye and Cherry, Fenton formula,

b) Approaches based on simultaneous stage measurements
Chow, Fenton and Keller formula, The stage-fall-discharge method by Hershey,

c) A dynamic rating curve approach to indirect discharge measurement; based on water level collected from two sections on the reach

Indirect Calculation Methods,

The equations in these methods are derived from the 1-D shallow water momentum equation by disregarding one or more terms;

$$\frac{\delta z}{\delta x} + \frac{1}{2g}\frac{\delta(\beta \frac{Q}{A^2})}{\delta x} + \frac{1}{g}\frac{\delta(\frac{Q}{A})}{\delta t} = -\frac{Q}{K^2}$$

Slope +Convective acceleration+local acceleration= friction slope terms

In these formulas, assumptions are made, and number of coefficients are used, such as **momentum coefficient, kinematic wave celerity,** which might be varying from the section to section, depending on physical features of reach, slope and resistance coefficient,

St Venant Equation:

$$Q = Q_o \left[1 - \frac{1}{S_o}\frac{\delta y}{\delta x} - \frac{u}{S_o g}\frac{\delta u}{\delta x} - \frac{1}{S_o g}\frac{\delta u}{\delta t} \right]^{1/2}$$

Kinematic wave
Diffusion wave
Dynamic wave

Thiess services

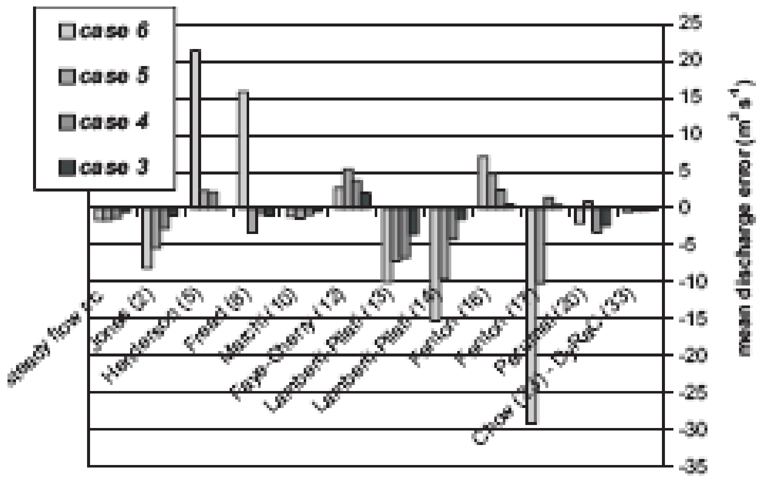
Victoria The Place To Be

Indirect Calculation Methods,

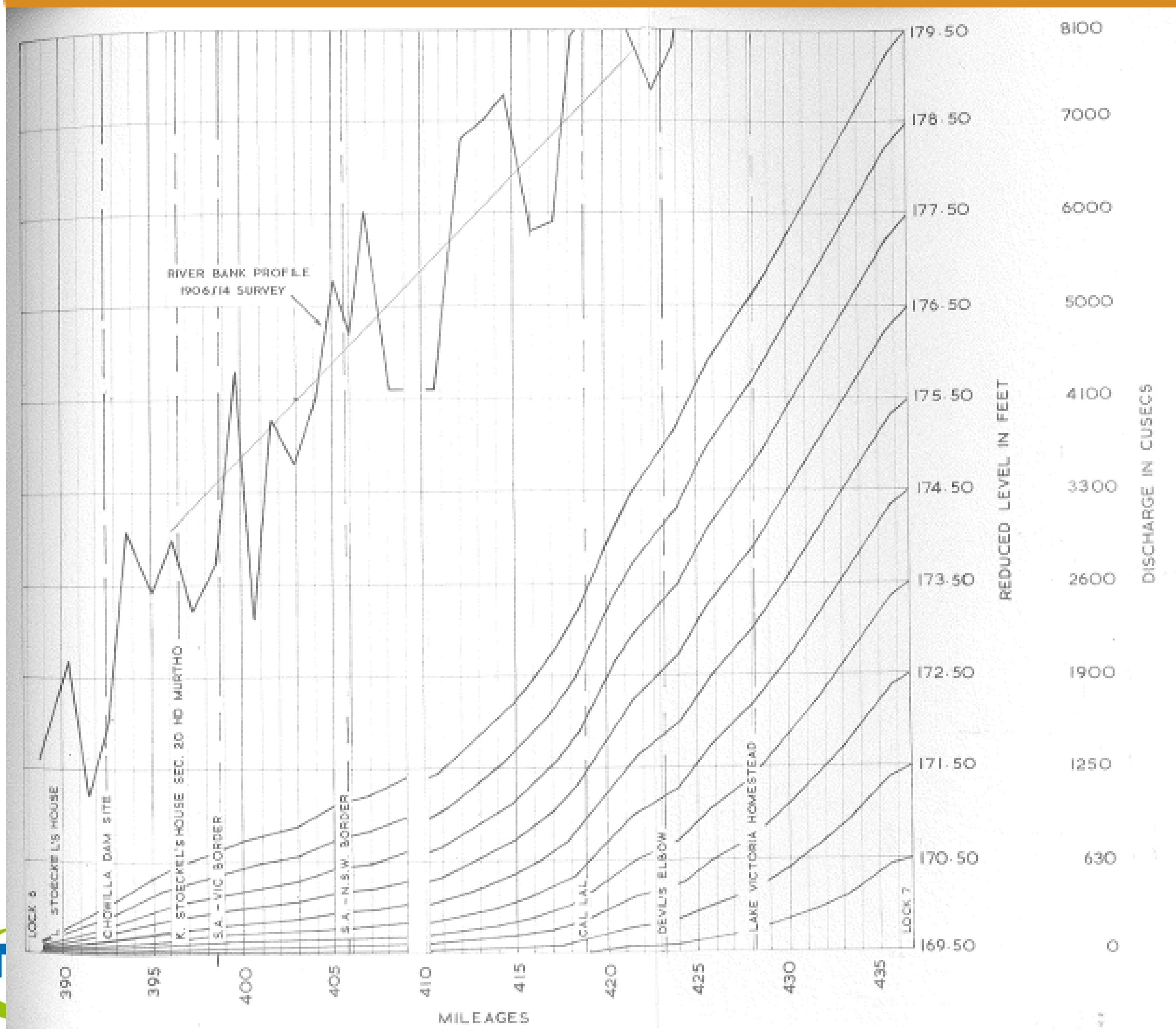
The ability of the different equations to estimate discharge depends on the channel geometry, hydraulic parameters such as roughness and flood wave characteristics;

Table 1. Characteristics of numerical experiments. In all the experiments, Manning's roughness has been set equal to 0.035 $m^{-1/3}$ s.

	Cross section geometry	Bed slope	Time to peak	Peak discharge ($m^3 s^{-1}$)
Case 1	Rectangular, 50 m width	10^{-3}	24 h	900
Case 2	Rectangular, 50 m width	5×10^{-4}	24 h	900
Case 3	Rectangular, 50 m width	2×10^{-4}	72 h	900
Case 4	Rectangular, 50 m width	2×10^{-4}	24 h	900
Case 5	Rectangular, 50 m width	10^{-4}	72 h	900
Case 6	Rectangular, 50 m width	10^{-4}	24 h	900
Case 7	Rectangular, 400 m width	5×10^{-5}	168 h	10 000
Case 8	Rectangular, 400 m width	2.5×10^{-5}	168 h	10 000
Case 9	Variable	10^{-4}	24 h	900
Case 10	Irregular	2×10^{-4}	24 h	900
Case 11	Irregular	10^{-4}	24 h	900



Indirect Calculation Methods,

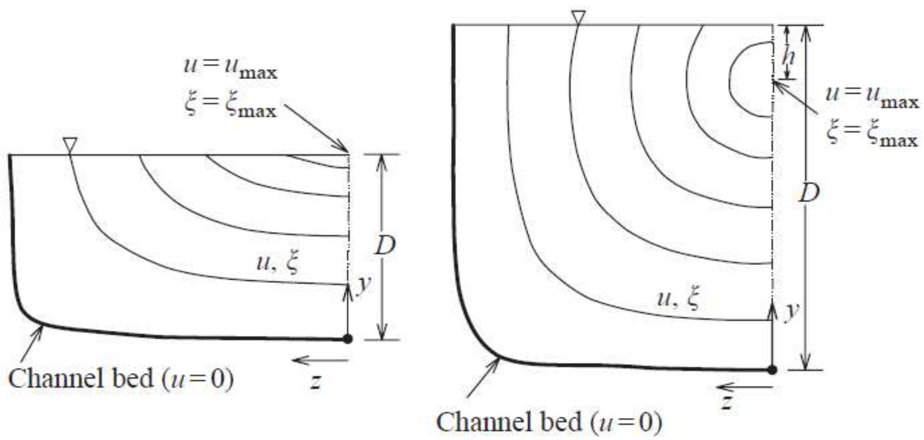


Murray River Water Surface Profiles, from Lock 7 to Lock 6,

Source: J.S. Gerny P. J. Manoel Operational Requirements of The Rufus River Gauging Station on the River Murray April 1973 SA Water

Indirect Calculation Methods,

Chui Distribution; Method of discharge estimation based on probability concept-The Concept of Maximum Entropy



(a) Pattern I ($h \leq 0$) (b) Pattern II ($h > 0$)

Figure 2 Velocity distribution patterns in open channels.

the possible patterns of distribution described in Fig. 2. Chiu (1987, 1988, 1989) derived the following velocity distribution equation:

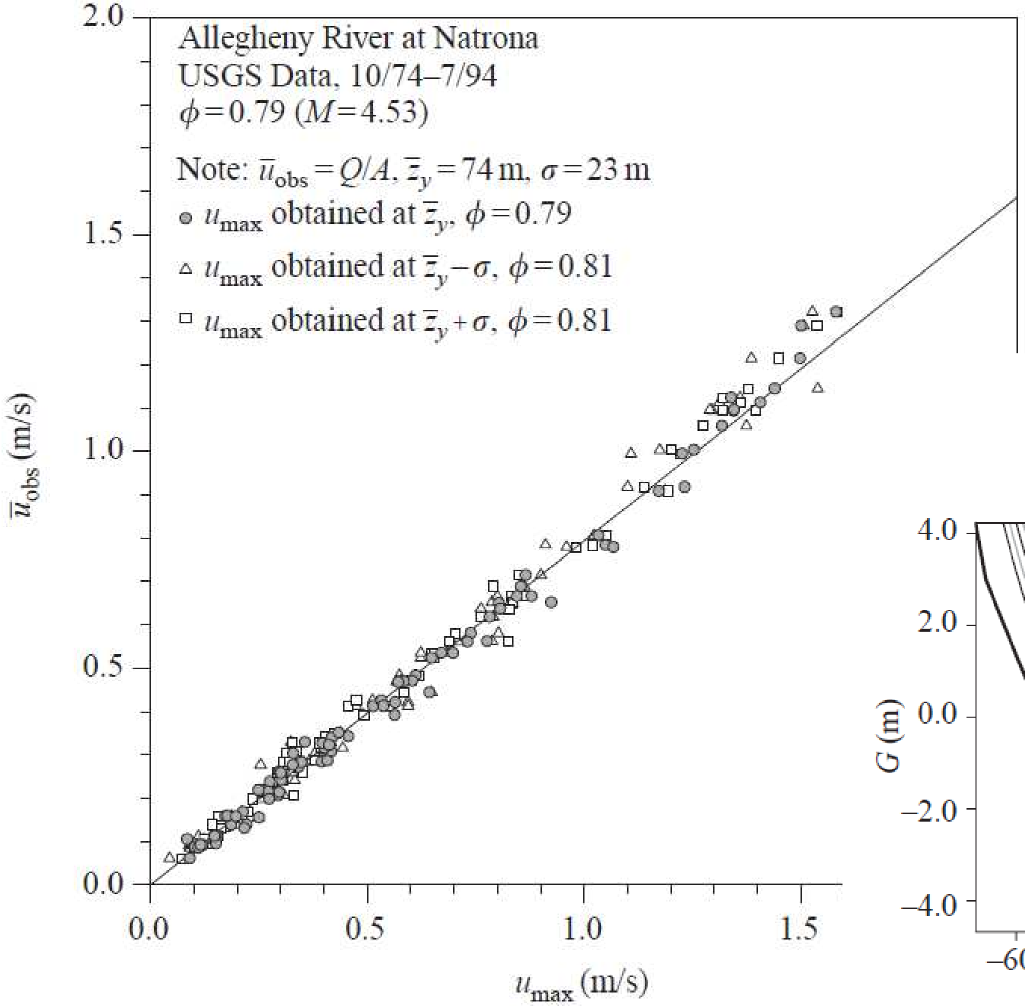
$$u = \frac{u_{max}}{M} \ln[1 + (e^M - 1)\xi] \quad (1)$$

in which u = velocity; u_{max} = maximum velocity; M = parameter; and ξ = dimensionless variable with which u develops.

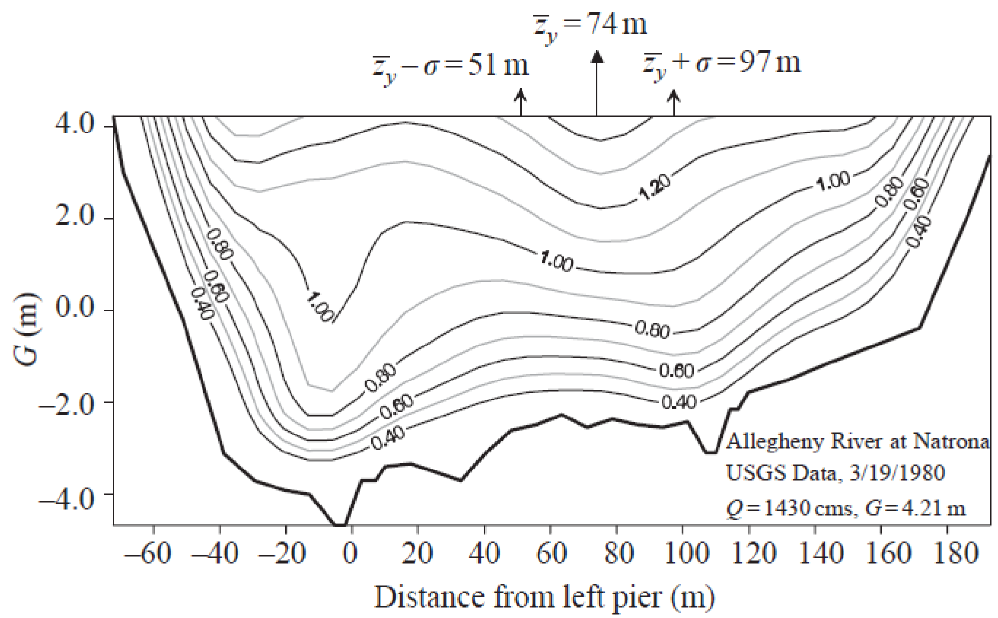
An efficient method of discharge estimation based on probability concept

Source: CHAO-LIN CHIU, Professor, Department of Civil and Environmental Engineering, University of Pittsburgh, YEN-CHANG CHEN Journal of Hydraulic Research Vol. 41, No. 6 (2003), pp. 589–596

Indirect Calculation Methods,

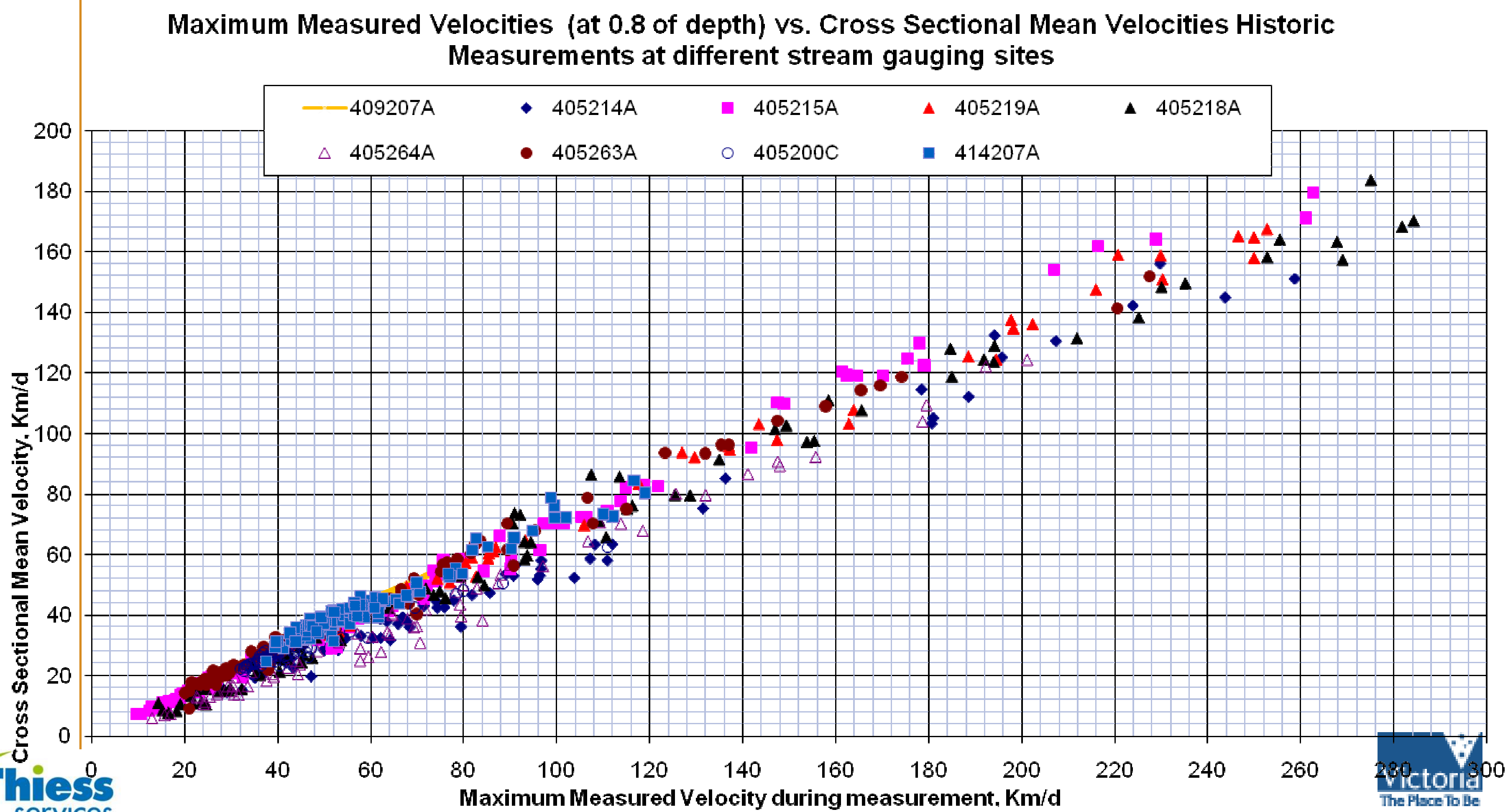


The location of



Indirect Calculation Methods,

The relationship between maximum measured velocities and mean velocities for nine different stream gauging sites in Victoria, the measurements undertaken between 1974 - 2007



Thiess services

Victoria The Place To Be

ADVM Deployment

The strong relationship between point or line velocity and mean velocities in a cross section is promising.

- Installation for fit for purpose,

a)The cost effective - monostatic Doppler current meter; the same transducer is used as both transmitter and receiver ,

b)Practical and simple and cost effective installation and housing, dismantling the instrument after the flood, reduce the risk of vandalism due to exposure of the instrumentation,

c)Deployment during flood; mobilisation of the team and flood warning from BoM

- Identifying the limitation of instrument, requirements for deployment, error sources due to environmental conditions,
- Work procedures for QA

Thiess services

Victoria The Place To Be

Deployment

ADVM - Error Sources

“All measurements have errors even after all known corrections and calibrations have been applied…. The actual errors are rarely known; however, upper bounds on the errors can be estimated.”

AS 3778.2.4—2001 ISO/TR 5168:1998 Australian Standard™ Measurement of water flow in open channels Part 2.4: General—Estimation of uncertainty of a flow-rate measurement [ISO title: Measurement of fluid flow—Evaluation of uncertainties] Pg : 6

Error Sources:

a) Systematic Error

b) Random Error

If so, what are these error sources for ADVM?

What measures should we take to eliminate these error sources (as much as possible), when deploying and operating them and analysing their data?

Thiess services

Victoria The Place To Be

Acoustic Doppler Velocity Meter

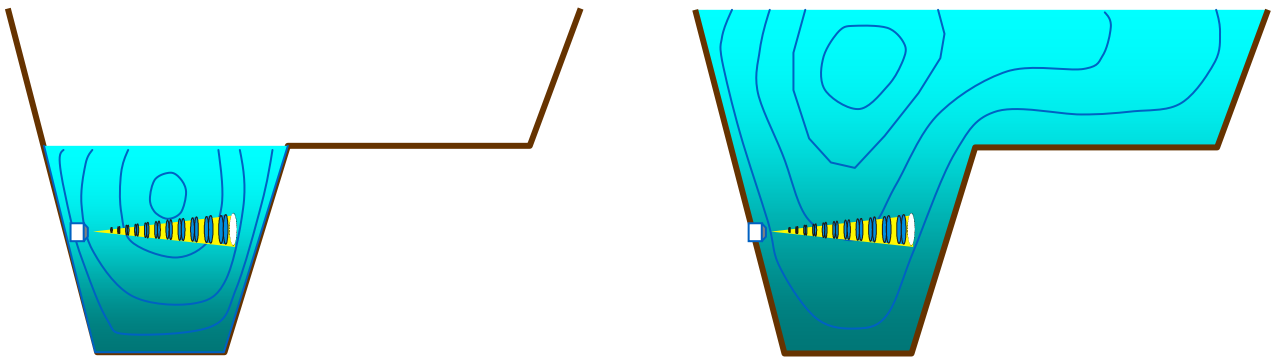
Q = A * V;

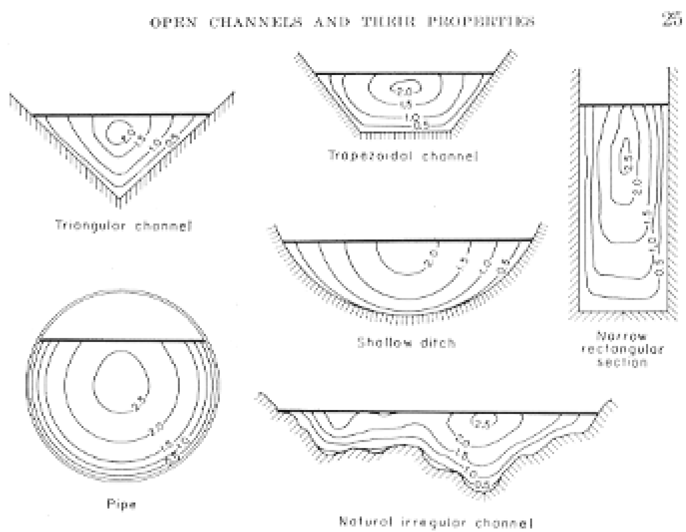
Q is discharge; A is section area; V is cross sectional mean velocity.
Velocity functions of gravitational (slope) and frictional (counteracting) forces,

Changes in area can be observed by surveying,
Changes (along the reach and along the reach over time) in hydraulic parameters such as slope, friction need to be measured;

ADVM - Error Sources

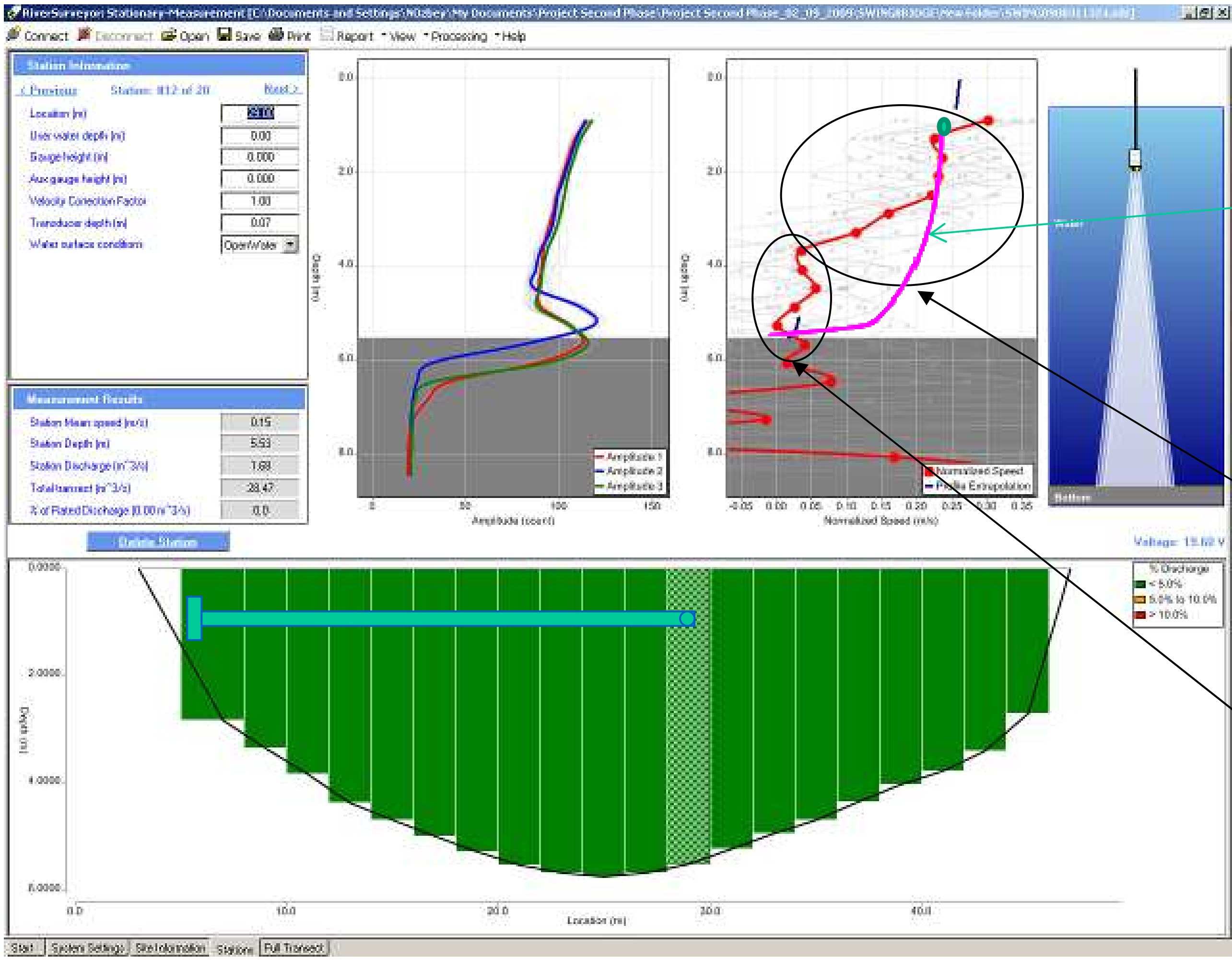
Field conditions vs. theoretical considerations;





ADVM Error Sources

Field conditions vs. theoretical considerations



Theoretical velocity distribution estimated from one point velocity

Approx: 20% difference between theoretical and calibrated flows.

Velocity is rising with depth as expected within the layer close to the surface

Velocity is not rising with depth substantially as it is expected within the bottom layer

Index Rating

Indexing to eliminate the systematic error,

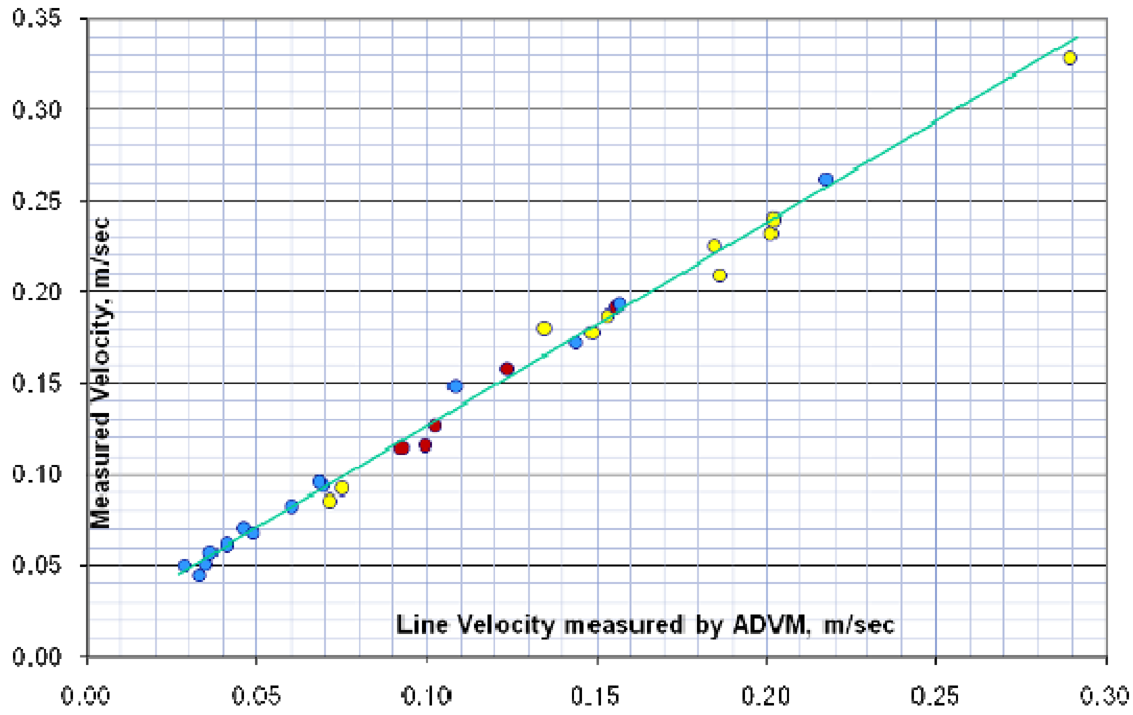
$$Q=A*V$$

Stage-Area Rating

A = f(h) from survey

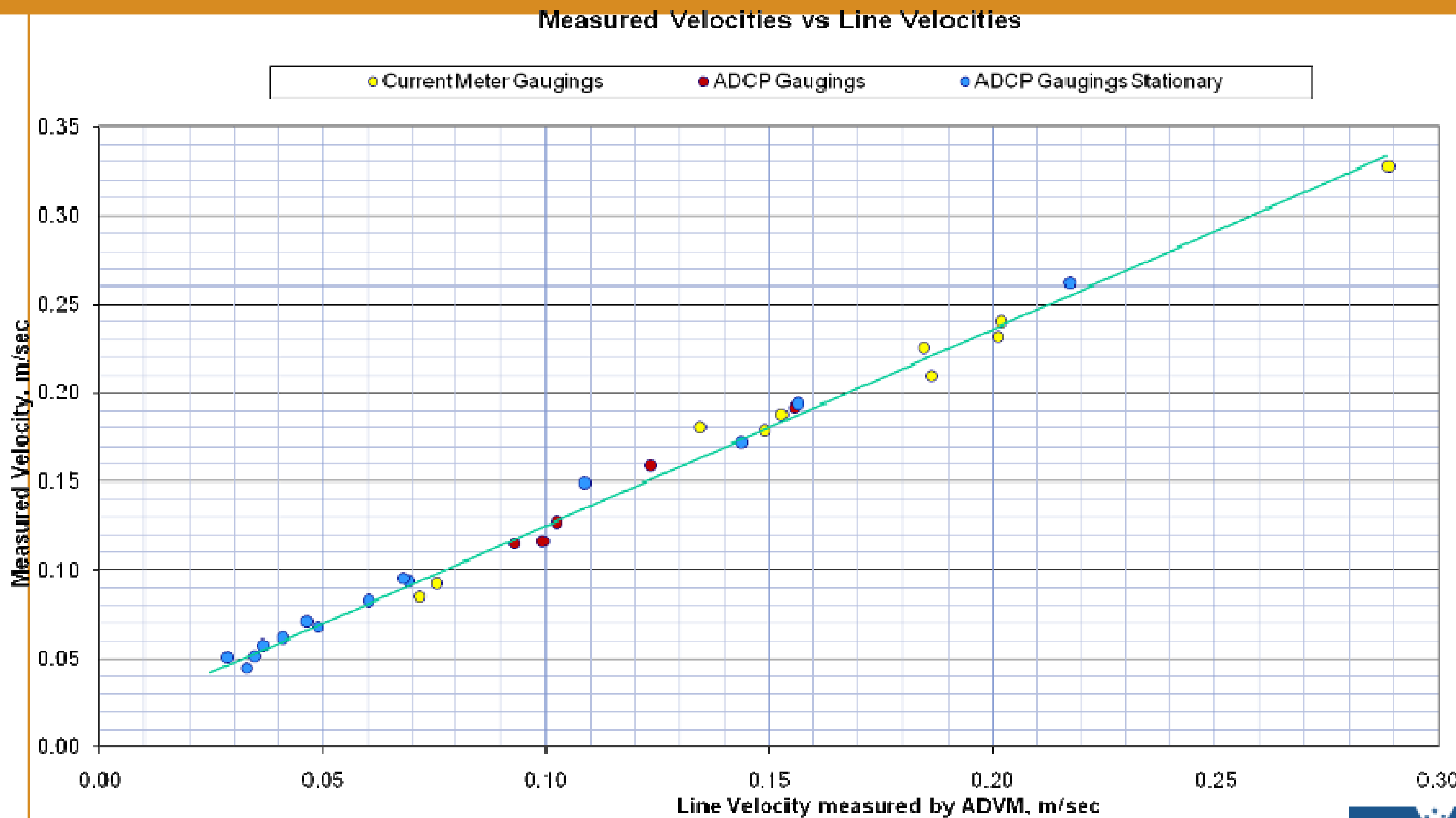
Index Velocity Rating

$$V_{mean} = f(V_{index})$$

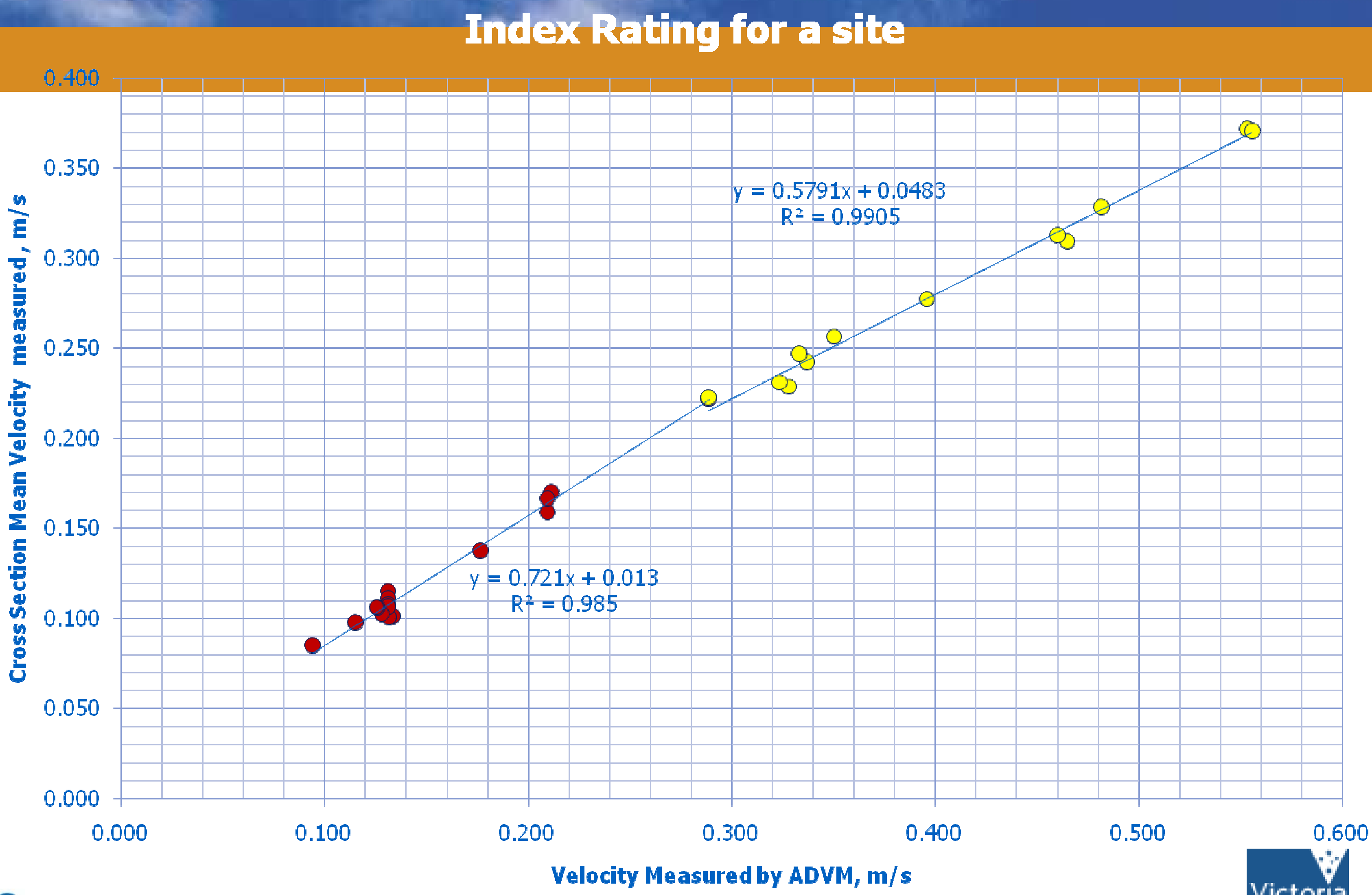


ADVM - Error Sources

Index Rating for a site



ADVM - Error Sources



Thiess services

Victoria
The Place To Be

ADVM – Random Error Sources

ADVM measures velocity by looking at the reflections of an acoustic pulse from particles in the water.

a)The magnitude of the reflection is called signal strength, which varies with the amount and type of suspended material (called scatterers) and the distance from the transducers.

b)Each velocity sample recorded by the ADVM is the average of a number of pings.

c)ADWM pings once per second over the period of time specified by the averaging interval.

d)The system records the standard error of velocity based on data from individual pings.

e)Standard error is the standard deviation of the velocity measurement from each ping, divided by the square root of the number of pings.

f)Standard error is a direct, statistical measure of the accuracy of the mean velocity data.

g)Measured standard error includes instrument-generated noise and real variations in velocity.

Thiess services

Victoria The Place To Be

ADVM – Random Error Sources

The averaging interval, sampling interval;

- Choosing an averaging interval which is long enough to eliminate instrument noise and real variations in flow,
- It is not recommended to use Averaging Interval settings of less than 60 seconds,
- 840 seconds averaging interval was chosen in our project,
- 60 seconds is used to transfer the data into logger,
- Diagnostic test embedded in the instrument is used to evaluate the reliability of data.

Thiess services

Victoria The Place To Be

Acoustic Doppler Velocity Meter

The technology was developed for military purpose for vessels and submarines,

It has been used for hydrographic purpose in USA since mid 80’s,

It is an emerging technology for Australia, introduced in the last 4 to 5 years,

Using them at very challenging sites, comparing the results with data collected by different techniques and technologies,

Taking measures to eliminate the error sources, in deployment, usage and data analysis, and developing stringent work procedures to reduce the uncertainty in data collected by Acoustic Instruments,

These are the areas Acoustic Doppler provides reliable solutions .

Thiess services

Victoria The Place To Be

Acoustic Doppler Velocity Meter

Benefits:

1) Accurate flow is collected when flow is unsteady at significantly lower costs. Conventional methods were very expensive but are even more costly today and require many teams of experienced hydrographers to undertake flood measurements. Personnel safety is enhanced also,

2)The estimated flow for a high flow can now be quantified, providing the data to the user with an improved confidence interval; talking to the scientist in a scientific language,

3)Access the real time flow data during a flood,

4)Salt and sediment load transportation is estimated with higher accuracy; see Swing Bridge Study

Thiess services

Victoria The Place To Be

Future Actions & Conclusion

Future Initiatives

- Continue to improve Acoustic Doppler Velocity Meter indexing at all sites
- Implement salt wedge and suspended load monitoring at Latrobe R @ Swing Bridge as an addendum to the primary study.
- Commission a study into the statistical analysis of ADVM results and comparison of data collected traditionally and that collected utilising the ADVM.
- Asses the effectiveness of long-term operation of ADVM's at each study site.
- Identify additional sites requiring ADVM technology in Victoria
- Optimise the application of ADVM technologies across Victoria

Conclusion

Initial studies indicate that Acoustic Technology offers an opportunity to enhance discharge accuracy and reduce streamflow data uncertainty more effectively than traditional processes.

Scientific analysis of the data derived from acoustic technologies will enable hydrologists to make informed decisions about future deployment of them.

Employment of ADVM's reduce resource commitments during times of high demand (streamflow) and enhance operator safety.