Australasian Hydrographer

June 2020

AUSTRALIAN HYDROGRAPHERS ASSOCIATION

AHA

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Samuel Nicholson

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JACQUIE BELLHOUSE

Editor's Introduction

We are now half way through the year and I don't know about our readers but the days are blending into each other. It also feels like the many restrictions that we are being asked to live with have become business as usual.

However during this time one of the highlights, for me, has been the variety of posts on our Facebook page. It has been great to see how our members have been not just getting on with the job, but sharing the joy it brings. I hope we see a continuation of this; there is nothing better than living vicariously through others.

This quarter please find some more great articles from the 2018 AHA Conference. For a relative ADCP dunce I found Daniel Wagenaar's article "Maximize Doppler Accuracy during Extreme Events with Hydrographic Principles" quite enlightening. The article "Suspended Sediment & Turbidity Monitoring in NZ – a product of Extreme events" by Evan Baddock was also very relevant to some of my recent work in the South West of WA. For something just a little different (well for some anyway) you may also appreciate Justin Stockley's paper "The growing demand and difficulties of hydrometric measurement of extreme events in urban stormwater and sewers".

Now… I will be the first to acknowledge that this month's *From the Vault* is a little "outside the box" but I thought the very topical paper warranted a spot. Originally presented at the 1995 Sydney Hydrographic Conference, Russel Marks and Allan Deane's paper "Statistical Indicators to Assess Gauging Station Performance" will hopefully prompt a broader conversation.

Question: How does one determine a gauging station's performance, and quantify the accuracy of the derived flow?

To provide some further context, in May a meeting of the Water Monitoring Standards Technical Committee (WaMSTeC) endorsed the development of two new Guidelines by Mark Randall and AHA member Tony Polchleb. The proposed guidelines (now in development):

- National Guideline for Measurement of Surface Velocities; and
- Guideline on the determination of site/control stability and performance.

I have volunteered to help Tony with the site/control stability and performance guide, and during my reference search was kindly provided a copy of Russell and Allan's original paper. As I am really keen to hear from our various readers how they go about assessing site stability and performance I thought it might prove to be a great way to "break the ice".

And lastly thanks to ALS Hydrographics for providing some of the photos, from its recent photographic completion, for this month's cover page. According to Colin Giddens, National Project Manager Hydrographics, the idea of the competition was to highlight what it is they do and some of the fantastic places they do it in.

There were some brilliant shots provided both by Colin as well as from our members, across the globe (check out Pavel Nikolaev's site in Pevek, Chukotka), via our Facebook page. The final selection process as a consequence was quite challenging. However the symbolism of Sam Nicholson's photo was, in the end, very hard to overlook. I think it is a good representation of our slow but evident recovery from recent events. I would love to hear what you think.

And finally, I would really love to hear your thoughts on how the journal is going. Much like the AHA Committee I need your feedback in order to gauge where the Journal is hitting the mark and more importantly where or what can be done better. Even more so I always need your articles. If you have a letter to the editor (I would love to introduce a letters to the editor section on topical subjects!), completed an interesting project, developed a new measurement technique, evaluated some new equipment or have an interesting insight into our origins and history I would love to hear from you.

Best regards,

Jacquie Bellhouse
Journal Editor

ARRAN CORBETT

From the President

As we find ourselves coming through the "first wave" of COVID19 the challenge ahead for all is to find a way to return to some form of normality. Given the many restrictions that we are being asked to live with in the medium term this is no small task. Communication is critical to the success of these efforts or otherwise. Learning how to make our way safely (and responsibly) back in to regional communities to undertake field work is one such example.

In order to gain the trust of those that have been protected by their remoteness we must communicate the efforts we are making around distancing and decontamination. I for one am looking forwards to getting back out on the road, having my first draught beer in a country pub and having a chat with the motel owner after a productive day in the field. Good, clear communications will ensure that these are happy interactions.

In other news our national office has been busy putting the finishing touches in place for our Memorandum of Understanding (MoU) with the Floodplain Management Association. I am excited that we have forged this link as I see strong potential for our members to get involved in a space that can only benefit from what we bring — good quality, reliable water data. Please get involved, attend their meetings (online for now) and show them what we can do. If you are keen to be involved let me know.

And one last thing if I may... We need your feedback; we need to know where we are winning and more importantly where we can do better. The committee has asked the national office to prepare a member survey – use this as your opportunity to influence your industry.

I sincerely hope that you continue to find value in the AHA and thank you for your ongoing support.

Best regards,

Arran Corbett
AHA President

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Looking Forward VEGA

Maximize Acoustic Doppler Accuracy during Extreme Events with Hydrographic Principles

Daniel Wagenaar, Xylem Water Solutions Australia

Paper presented to 19th Australian Hydrographers Association Conference Canberra, 12-15 November 2018

Abstract

The accuracy of acoustic Doppler measurements is directly related to site selection, measurement principles and user operation. Site selection requirements for the application of acoustic Doppler instruments are based on a number of measurement site and hydraulic requirements. The requirements are very similar to what a Hydrologist or Hydrographer will use in the selection of a monitoring site in either natural or artificial channels.

Acoustic Doppler principles and standard operating procedures are essential during the data collection and post-processing process. The application of principles and well documented processes will ensure consistent and quality data sets that are measurable. Most organisations have well documented standard operational procedures that align with International Standards to ensure that the application of the methodology is consistent.

Obtaining the required knowledge and skill-set to perform, interpret and analyse acoustic Doppler measurements requires considerable exposure time to field application and data review processes. Acoustic Doppler instruments, depending on the sensors used, supply a large amount of information for the operator to interpret and analyse in real-time and during post-processing.

The application of acoustic Doppler instruments in flow measurement process requires sufficient knowledge on acoustic Doppler principles, hydraulic theory, channel and catchment characteristics, especially during extreme events. The information collected during flow measurements shown in Figure 1 needs to be evaluated in real-time and assessed against acoustic Doppler measurement principles, measurement site and hydraulic conditions.

The measurement site and hydraulic conditions at the measurement section should be assessed before and during the measurement. It is imperative that the operator has a good understanding of possible impacts on acoustic Doppler measurements and how it could affect the overall measurement accuracy.

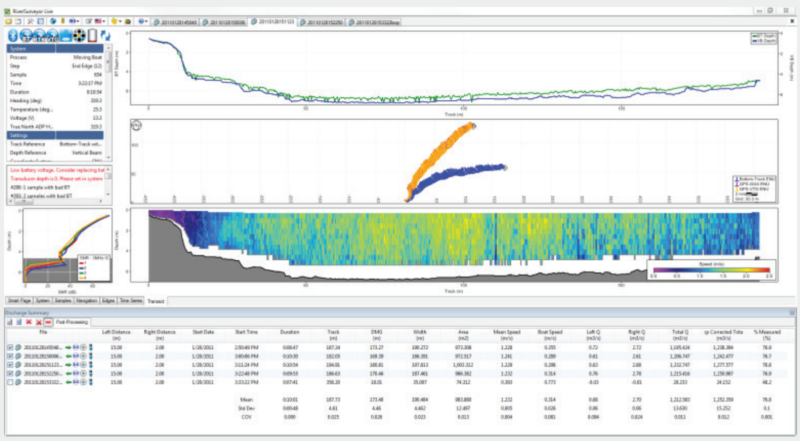


Figure 1. Acoustic Doppler Data Collection.

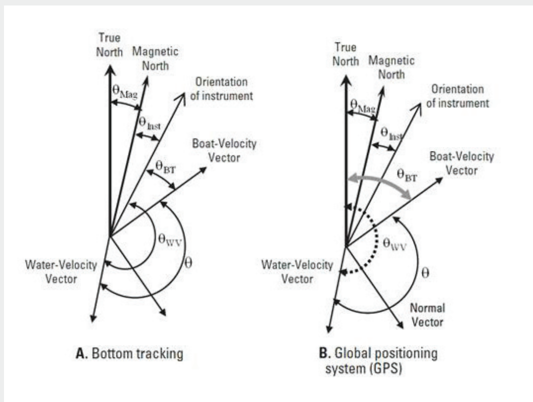


Figure 2. Compass Reference for Bottom Track and GPS.

The review and analysis of acoustic Doppler data during post-processing can be complex, especially if external references such as compass, Global Positioning System (GPS) and conductivity, temperature and depth (CTD) data are used. Multiple tier review was developed to assist operators with analysing and processing of acoustic Doppler data collected. The first tier consists of an "Initial Review" of the various references collected and associated data from external sensors shown in Figure 3. The "Initial Review" should be performed in the field to determine if the measurement quality and if additional data is required.

The second tier consists of "Detailed Review" and should be performed in the office. The "Detailed Review" process breakdown the evaluation to an individual sample. Extrapolation and other processing techniques are performed during this stage to determine a final quality score.

The multiple tier review process outcome is based on the operator's knowledge and understanding off all the facets discussed. Automated review processes such as QRev from United States Geological Survey (USGS) is highly recommended, especially during complex flow measurements that occur during extreme events. The automated review process also gives a consistent approach in how the data is analysed and processed between operators and different hydrographic offices.

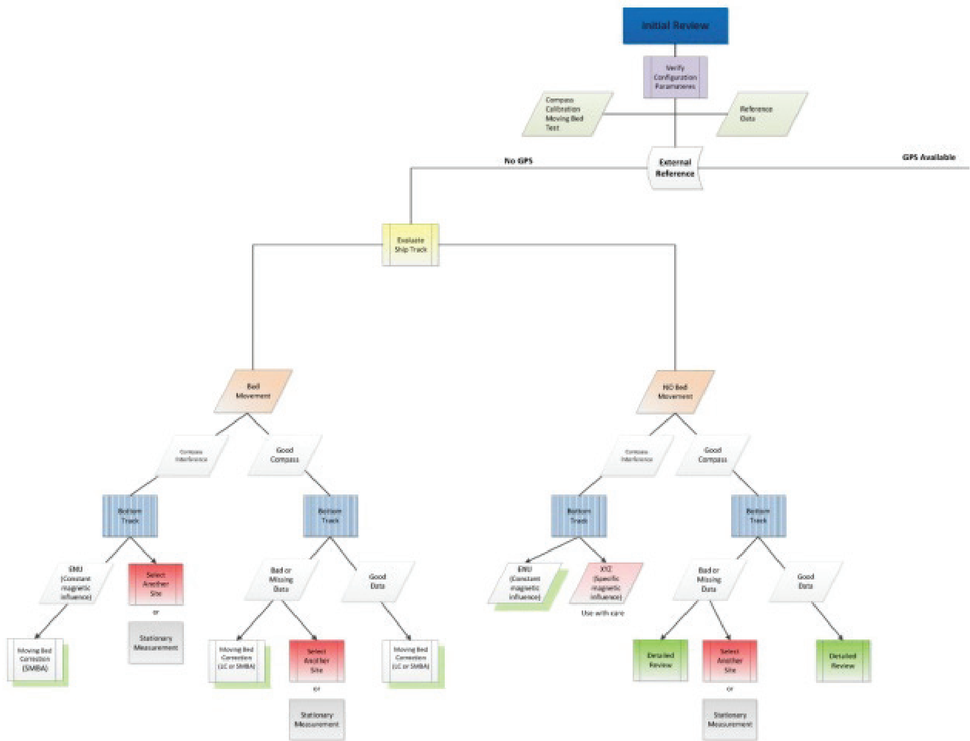


Figure 3. Initial Review Flow Diagram.

Site Selection / Hydraulic Requirements

Site selection requirements for natural channels are mainly used to define a section of channel that resembles steady uniform flow conditions as much as possible, knowing that these flow conditions seldom or never occur in natural channels and that the actual flow condition is rather classified under non-uniform unsteady flow conditions. Although flow conditions are an important aspect of site selection, sediment transport, vegetation and flooding are equally important criterion during the site selection process. These are all factors that can influence the operation of acoustic Doppler instruments and can impact/potentially reduce the accuracy of velocity and stage measurements.

The following site criteria are listed to assist the user during the site selection process in natural channels taking into account the hydraulic requirements and additional influences such as sediment transport, vegetation and flooding.

- Steady uniform flow conditions.
- Sub-critical flow conditions.
- Drawdown zone at section controls should be avoided.
- Straight length of channel with uniform cross-section and slope (10 times section width).
- Uniform velocity distribution over the width of the cross-section.
- Approach velocities with Froude number ≈ 0.5. The flow in the approach channel should be smooth and free of disturbances.
- Flow in the stream should be confined to a single well-defined channel with stable banks.
- Wide flood plains and or secondary channels during flood events should be avoided.
- Natural or artificial controls upstream of monitoring site could cause turbulent and unsteady flow conditions and should be located far enough upstream.
- Bends upstream of monitoring site could create skew flows at the point of measurement and should be located far enough upstream.
- Steep slopes upstream of monitoring site could cause turbulent and unsteady flow conditions and should be located far enough upstream.
- Roughness of the riverbed and banks must be investigated at the site to determine what impact it will have on the velocity distribution.
- Avoid prominent obstructions in a pool that can affect the velocity pattern.
- Discharge sensitivity towards the channel section.
- Aquatic plants can affect acoustic Doppler operation and areas where excessive aquatic plants are present should be avoided.
- Access to the site during flood events is important.

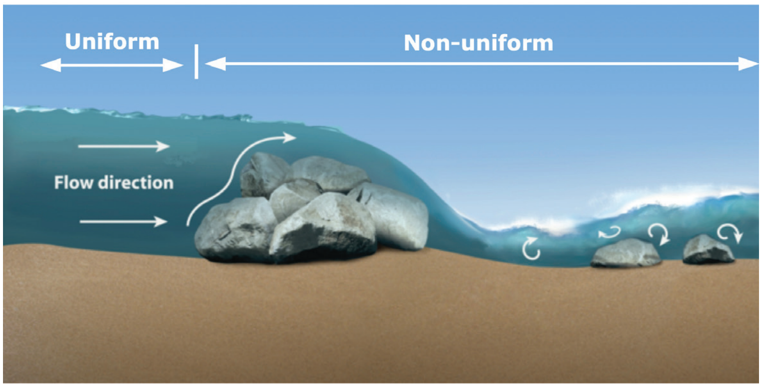


Figure 4. Uniform flow condition.

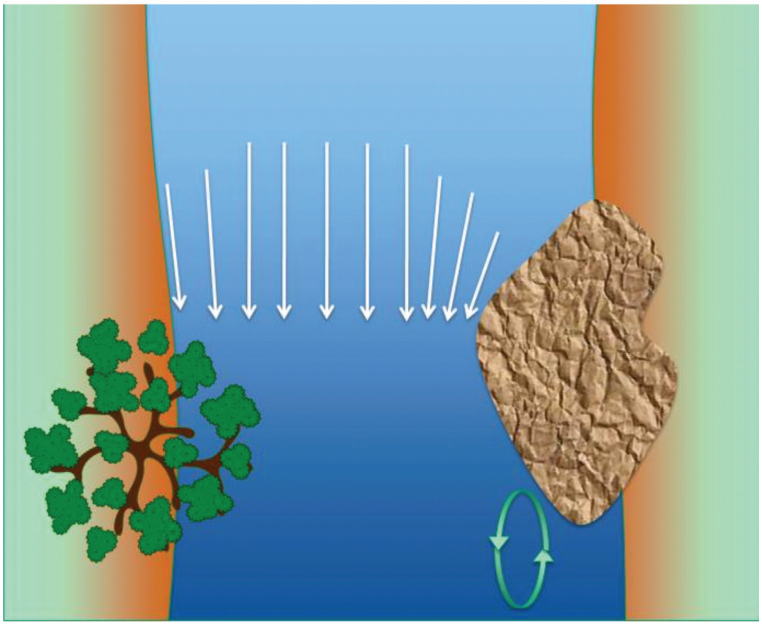


Figure 5. Prominent obstruction.

Measurement Section

The initial assessment of measurement section for both moving boat and stationary techniques are essential for the accuracy and continuity of data collection during the measurement process. The assessment of the measurement section can consist of performing a single moving boat transect or couple of stations using stationary method to verify acoustic Doppler operation.

The assessment of the measurement section can be grouped into sound speed and environmental conditions.

Sound Speed

Temperature and Salinity at the transducer face of the acoustic Doppler instrument is used to calculate the speed of sound in the water column. It is important that an accurate measurement is taken of both the water temperature and salinity at the measurement section with a reference instrument.

The percentage error in depth measurement (vertical beam and bottom track) when the temperature and/or salinity throughout the water column are different from the water surface (salinity set by user and temperature measured by ADPC temperature sensor) is supplied in Figure 6 and 7.

The percentage error shown in Figures 6 and 7 is based on water surface temperature of 20°C and salinity of 0 ppt.

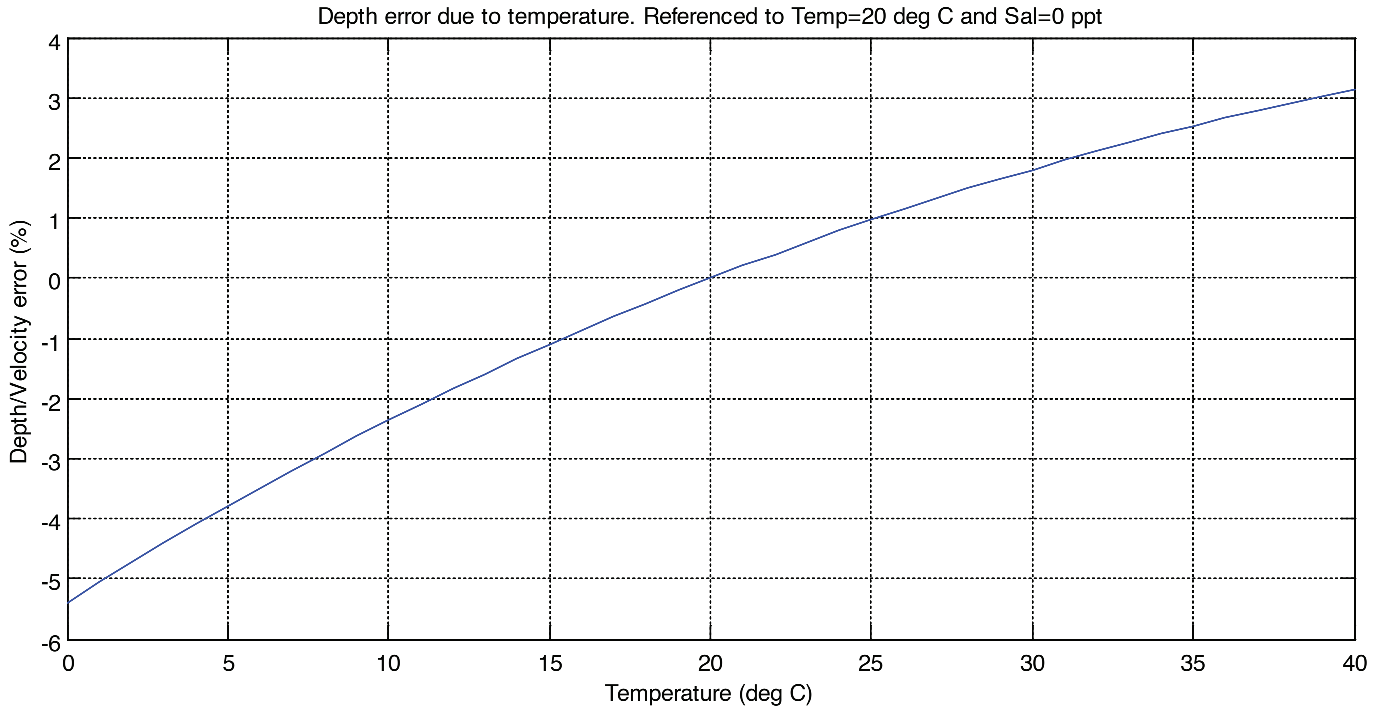


Figure 6. Depth Error due to Temperature.

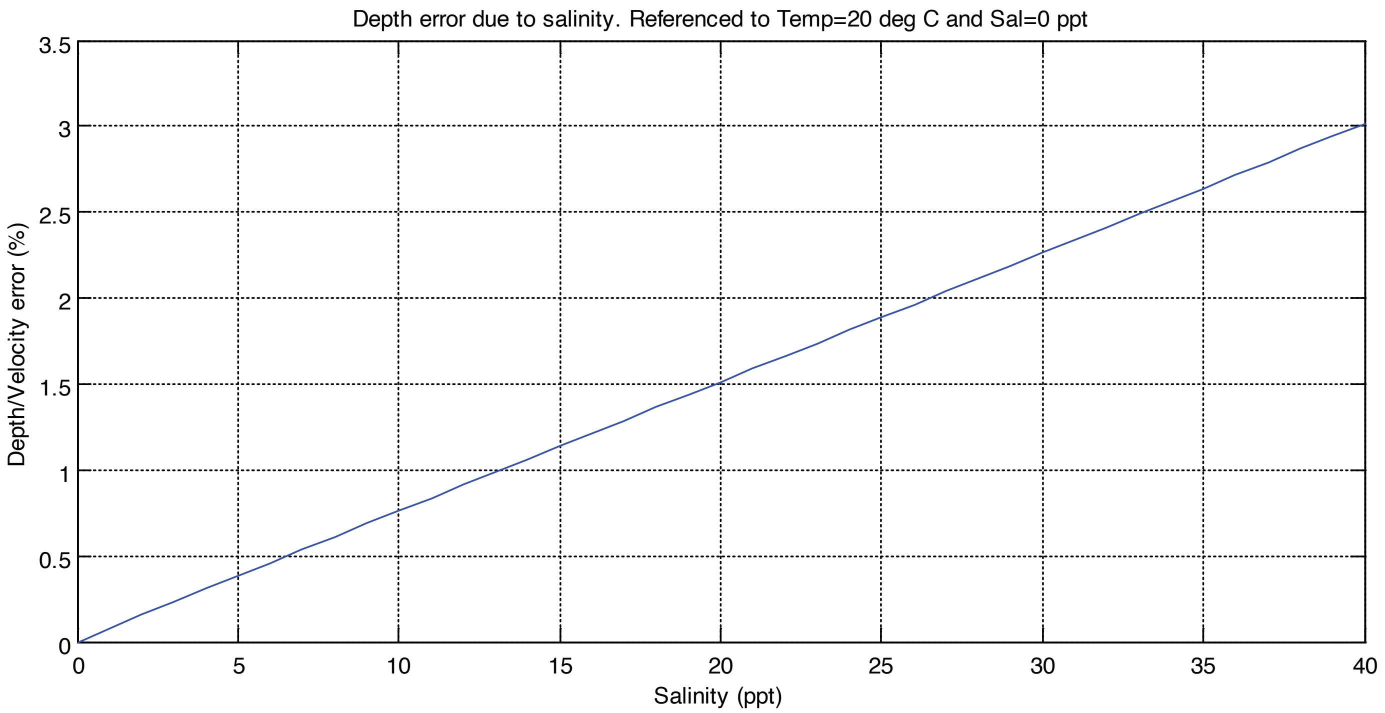


Figure 7. Depth Error due to Salinity.

It is important that Acoustic Doppler instruments equilibrate to the water temperature before a measurement is performed. In cases where there is large difference between instrument and water temperature, the operator will be required to extend the equilibration time before a measurement can commence.

Environmental Conditions

Environmental conditions have the largest impact on acoustic Doppler measurement of all the different factors that impact the accuracy and continuity of data collection during the measurement process.

The information that needs to be reviewed in detail during the initial measurement consists of the following variables:

- Individual beam profile, Signal to Noise Ratio (SNR).
- Magnetic error.
- Bottom tracking.
- Vertical and bottom track depth measurements.

Figure 8. Environmental Conditions.

Measurement Technique / Components

There are two measurement techniques that are applied for acoustic Doppler current profilers (ADCPs) in open channel flow measurements. The selection of the appropriate measurement technique and components used in discharge measurement consists of a number of factors based on environmental conditions, hydraulic conditions, measurement site, available infrastructure and health and safety.

Moving Boat

Moving boat measurement technique consists of performing reciprocal transects with a total measurement time exceeding 800 seconds (Australian Standards, e.g. AS 3778 or National Industry Guidelines 2013). The minimum number of transects required for a valid moving boat measurement is two transects.

Moving boat measurement technique consists of number measurement components and it is essential that each of these components is performed during the measurement process. The environmental, hydraulic conditions and measurement site conditions will determine which measurement components and or reference data sets will be used in the final discharge calculations. It is therefore essential that all the required data sets are collected to assist the operator during the real-time data review and post processing of measurement results.

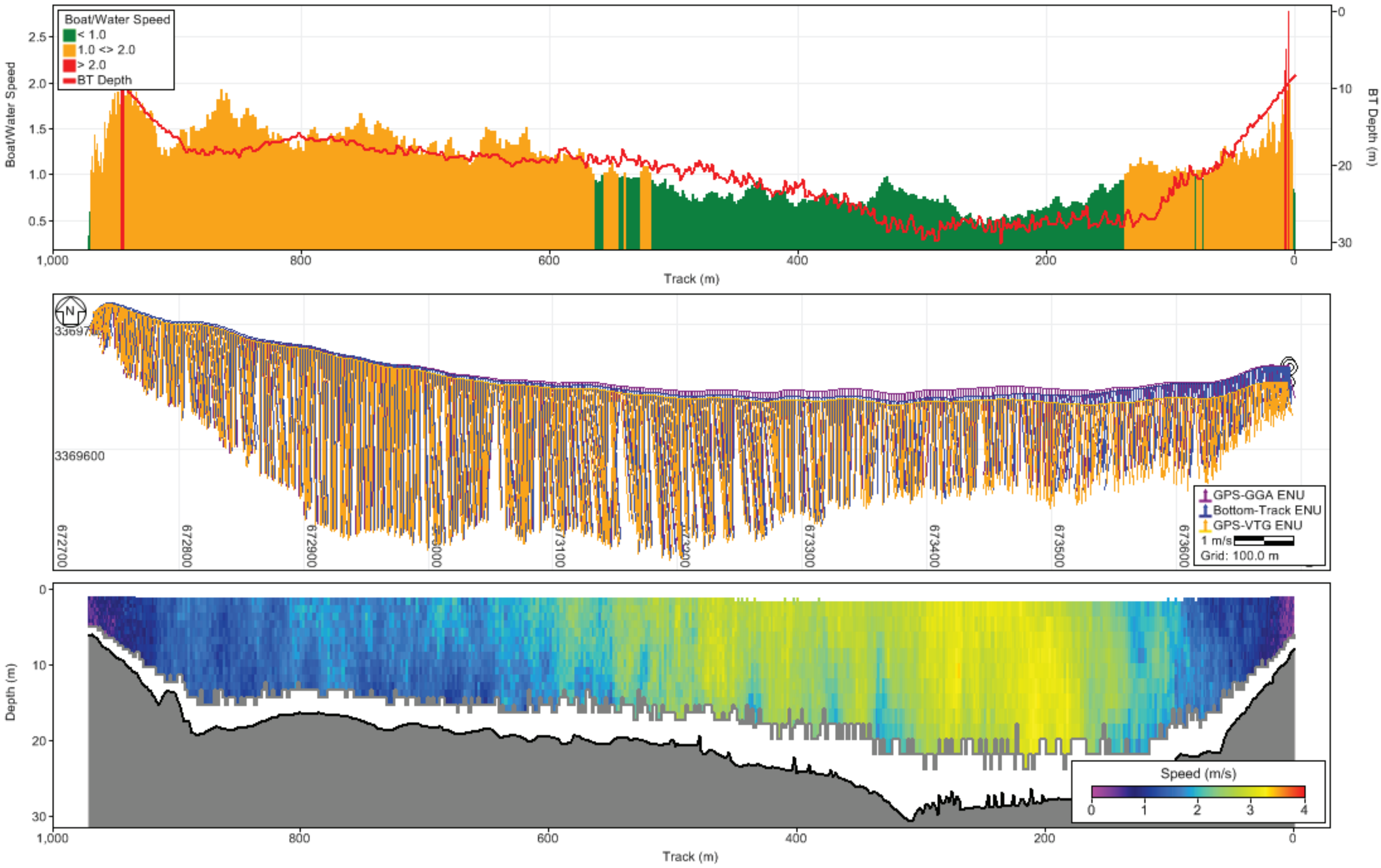


Figure 9. Moving boat measurement technique.

The measurement components for the moving boat measurement technique consist of the following key components:

- Metadata;
- System test;
- Compass calibration;
- Reference temperature / salinity reading;
- Loop moving bed test / stationary moving-bed analysis (SMBA).
- Reciprocal transects (>800 s).

The data sets collected during moving boat measurement is dependent on the ADCP instrument and if GPS is used during the measurement. The data sets that are normally available during moving boat measurement consist of the following:

- Compass;
- Pitch and roll;
- Temperature;
- Velocity (Beam, XYZ, East-North-Up (ENU));
- Track reference (Bottom Track, GPS-GGA and GPS-VTG);

- Depth reference (Vertical beam, bottom track);
- Coordinate system (Beam, XYZ, and ENU).

Stationary

The stationary measurement technique consists of measuring at a number of verticals across the measurement section. The minimum number of verticals required for valid stationary measurement is dependent on the width of the measurement section. The number of verticals required based on ISO 748:2007 is summarized in Table 1.

Table 1. Number Verticals (ISO 748)

Channel Width	Number Verticals
<0.5m	5 to 6
>0.5m and <1m	6 to 7
>1m and <3m	7 to 12
>3m and <5m	13 to 16
>5m	≥22

The stationary measurement technique consists of a number of measurement components and it is essential that each of these components is performed during the measurement process. The environmental, hydraulic conditions and measurement site conditions will determine which measurement components and or reference data sets will be used in the final discharge calculations. It is therefore essential that all the required data sets are collected to assist the operator during the real-time data review and post processing of measurement results.

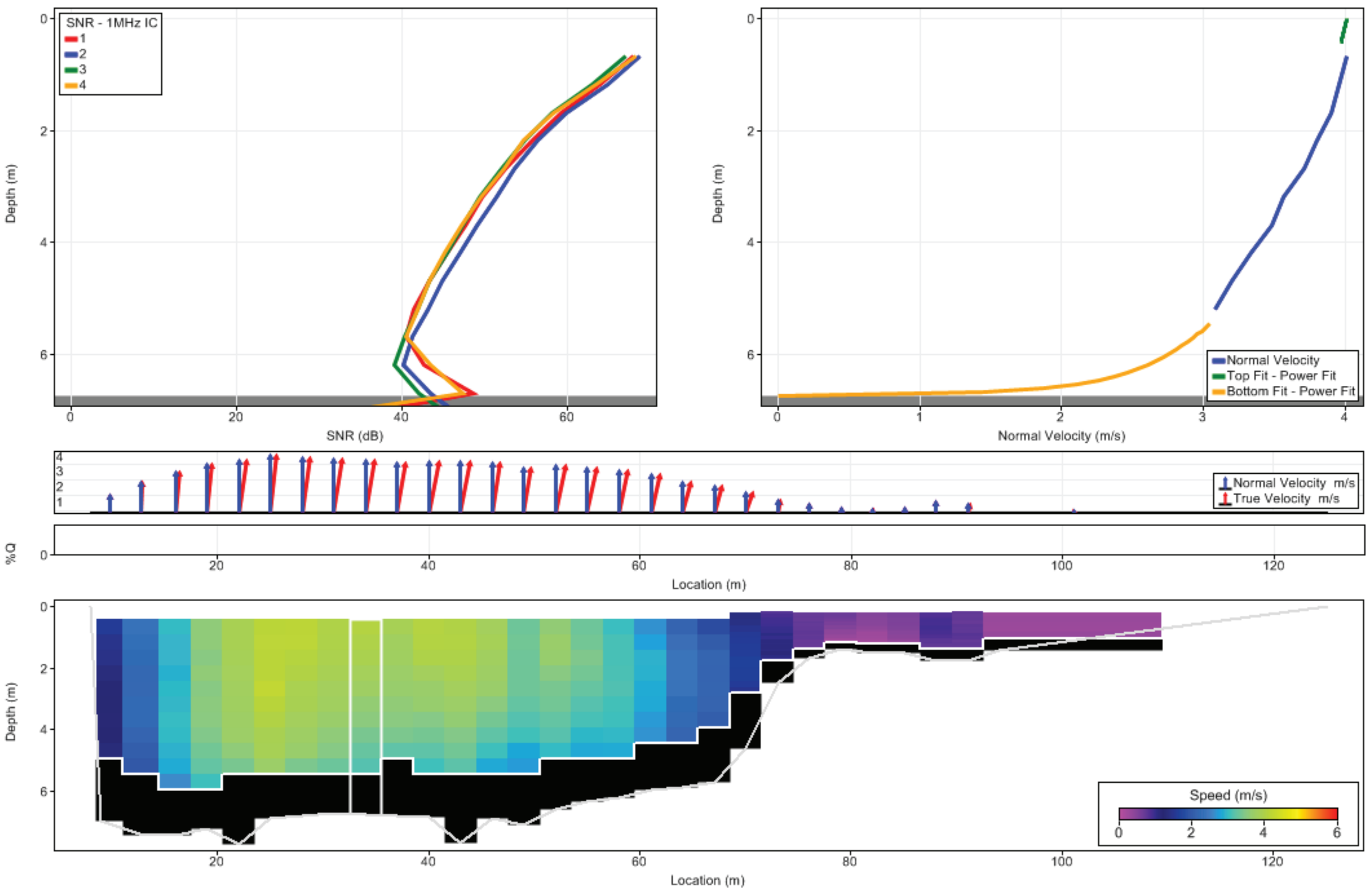


Figure 10. Stationary Measurement Technique.

The measurement components for stationary measurement technique consist of the following key components:

- Metadata;
- System test;
- Compass calibration;
- Reference temperature / salinity reading;
- Azimuth;
- GPS projection line (only if GPS is used for distance between verticals);
- Measurement at verticals.

The reference data sets that are normally available during stationary measurements consist of the following:

- Discharge method (Mid-Section, Mean-Section);
- Track reference (System, Bottom Track);
- Depth reference (Vertical Beam, Bottom Track).

Real-Time Data Review

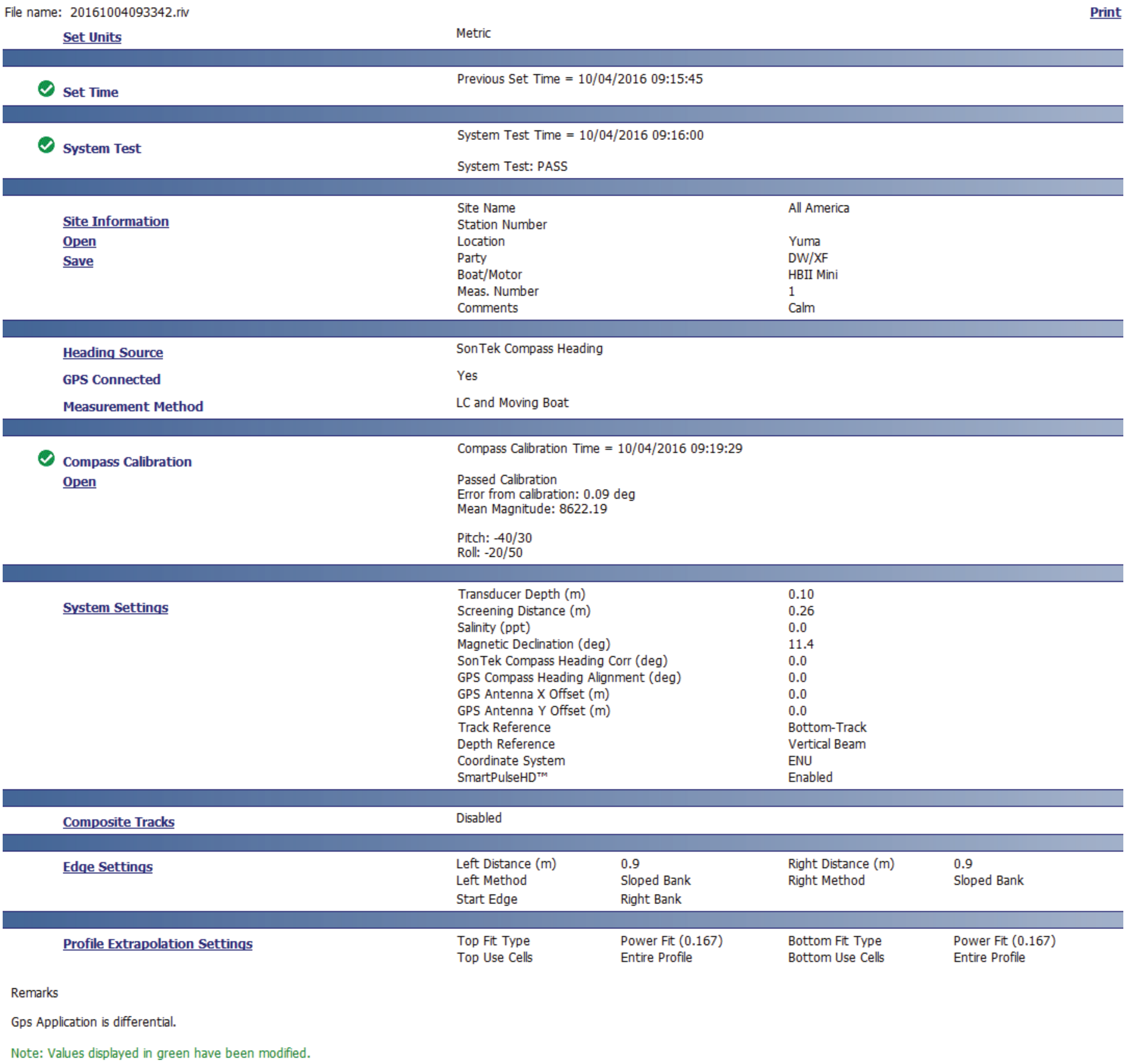
The analysis of data during the measurement process is essential to ensure accurate and reliable data sets and should start with the first measurement component and or sample collected.

SmartPage

The Metadata associated with each measurement is not only limited to measurement site and operator information, but also includes information on system tests and compass calibration. In addition to the Metadata, there are a number of settings that are associated with the environment, hardware configuration, measurement section and processing that will have direct impact on the discharge results.

The review of the metadata and user configuration under the SmartPage sections in Figure 11 is essential to ensure that accurate and reliable data is collected:

- Set time;
- System test;
- Site information;
- Compass calibration;
- System settings;



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Set Units	Metric			
Set Time	Previous Set Time = 10/04/2016 09:15:45			
System Test	System Test Time = 10/04/2016 09:16:00 System Test: PASS			
Site Information Open Save	Site Name Station Number Location Party Boat/Motor Meas. Number Comments		All America Yuma DW/XF HBII Mini 1 Calm	
Heading Source	SonTek Compass Heading			
GPS Connected	Yes			
Measurement Method	LC and Moving Boat			
Compass Calibration Open	Compass Calibration Time = 10/04/2016 09:19:29 Passed Calibration Error from calibration: 0.09 deg Mean Magnitude: 8622.19 Pitch: -40/30 Roll: -20/50			
System Settings	Transducer Depth (m) Screening Distance (m) Salinity (ppt) Magnetic Declination (deg) SonTek Compass Heading Corr (deg) GPS Compass Heading Alignment (deg) GPS Antenna X Offset (m) GPS Antenna Y Offset (m) Track Reference Depth Reference Coordinate System SmartPulseHD™		0.10 0.26 0.0 11.4 0.0 0.0 0.0 0.0 Bottom-Track Vertical Beam ENU Enabled	
Composite Tracks	Disabled			
Edge Settings	Left Distance (m) Left Method Start Edge	0.9 Sloped Bank Right Bank	Right Distance (m) Right Method	0.9 Sloped Bank
Profile Extrapolation Settings	Top Fit Type Top Use Cells	Power Fit (0.167) Entire Profile	Bottom Fit Type Bottom Use Cells	Power Fit (0.167) Entire Profile

Remarks

Gps Application is differential.

Note: Values displayed in green have been modified.

Figure 11. SmartPage.

Compass

Compass Calibration

The presence of ferrous metals, power supply, electric motors, etc. close to the compass calibration location and the operator procedure in calibrating the compass can result in the compass calibration failing. The following impacts are normally visible in the data collected:

- Increased standard deviation of magnetic field measurements from the mean magnetic field shown in rose plot (calibration was performed to fast);
- Distortion of the magnetic field, pitch and roll measurements at a certain heading (remote control boat batteries next to instrument);
- Spikes present in the pitch and roll measurements during calibration (accelerated to fast with remote control boat);
- Short time span of the compass calibration;
- Magnetic influence is unacceptable.

The compass calibration requirements along with pass and fail criteria are summarized under the following key aspects:

- Calibration duration must be between 60 and 120 seconds;
- Perform two complete rotations;
- Rotation, pitch and roll must be performed smoothly during calibration;
- Pitch and roll during calibration must exceed what is to be expected during measurement;
- Error from compass calibration must be smaller than 0.5 degrees;
- Magnetic error < 3.5%, if > 3.5% recalibrate, identify possible influences or select another site;
- Compass calibration, pass or fail.

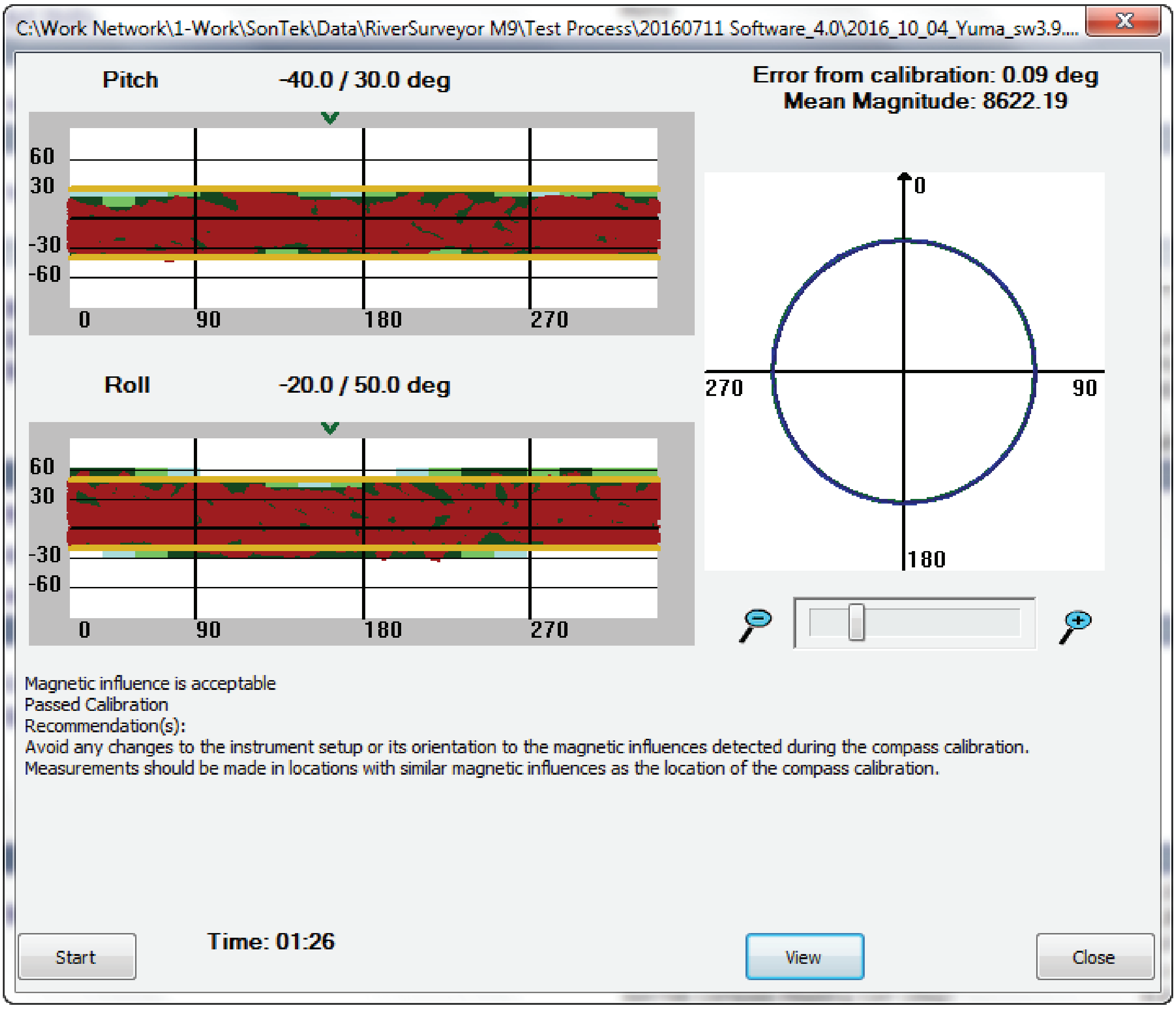

Figure 12. Compass calibration.

The compass calibration location and procedure is a key aspect for an accurate calibration. The following aspects are essential in the measurement process:

- Compass calibration must be performed inline of measurement section. This applies to both moving boat and stationary measurements;
- Calibration should be performed at the water edge or top of bank;
- During the calibration, the instrument should be rotated as smooth as possible, while inducing pitch and roll that is expected on the water surface. It is important not to perform erratic movements that could result in spikes in the pitch and roll data;
- When using a kayak, manned boat or remote control boat, both the instrument and boat must be turned during the calibration. In the case of manned and remote-control boats, the outboards must be used to rotate the boat during the calibration;
- Do not perform compass calibrations on a bridge, near vehicles or steel structures that could result in higher magnetic field;
- Remote control boat power supply, electric motors and on-board computers should be located as far as possible from the instrument.

Compass Dependency

There are a number of measurement components of the moving boat technique that are dependent on accurate and reliable compass heading. The following aspects are essential to the measurement process:

- XYZ coordinate system is NOT dependent on compass heading;
- ENU coordinate system is **not** dependent on accurate compass heading **if** final discharge is the only output required. Only θ angle between boat velocity and water velocity vector in Figure 10 is used in the final discharge calculation for bottom tracking measurements. The water velocity vectors will have a heading error, but this will not influence the magnitude because both boat velocity and water velocity vectors are referenced to the same magnetic compass, see compass dependency diagram;
- If accurate heading is required for water velocity vectors in relation to Magnetic North then ENU coordinate system is dependent on accurate compass heading in addition to accurate compass calibration;
- GPS track reference is highly dependent on accurate compass heading in addition to accurate compass calibration and magnetic declination, see compass dependency diagram;

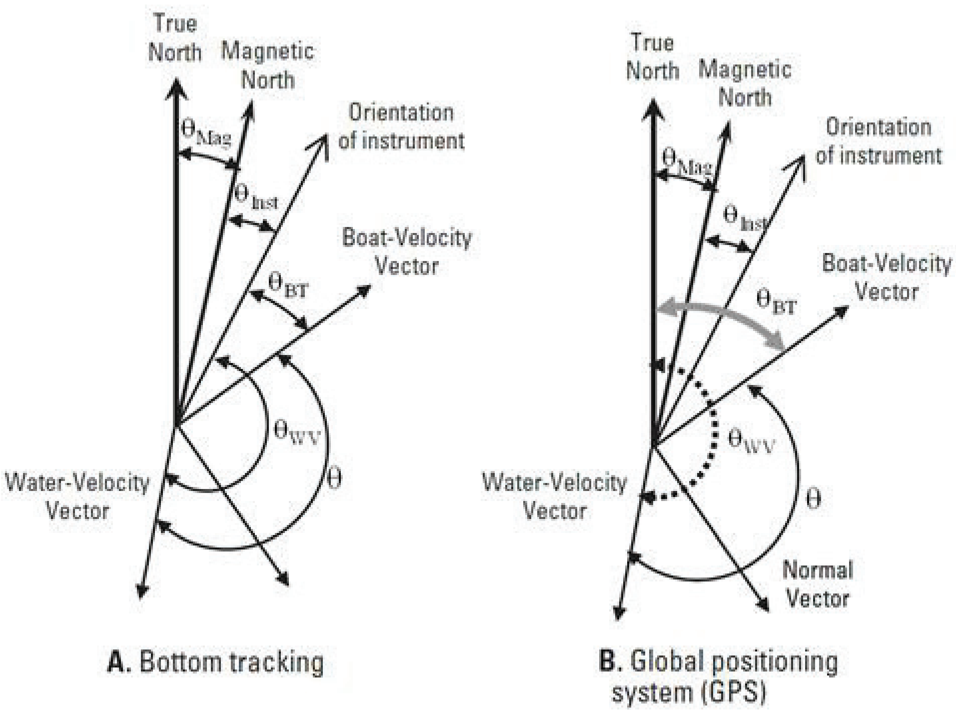

Figure 13. Compass dependency diagram.

- Loop method will report the following warnings if the accuracy of compass heading impacts the measurement accuracy:
  - Bottom track of loop method ends downstream of starting point;
  - Difference in flow directions greater than 3 degrees;
  - Difference in flow directions greater than 95% uncertainty;
  - Potential error > 5%.

The collection of accurate and reliable compass heading data is essential for accurate measurement results, especially if ENU coordinate system and GPS Track references are used in the final discharge calculations. The following aspects are essential to the measurement process:

- The presence of ferrous metals, power supply, electric motors, etc. within the measurement section must be taken into account during the measurement site selection process;
- XYZ coordinate system is not dependent on compass heading and it is recommended that this solution is used for final discharge calculations at measurement sections where compass headings are significantly impacted. Accurate and reliable bottom tracking is required for the use of XYZ coordinate system;
- ENU coordinate system is not dependent on an accurate compass heading for final discharge calculation. If magnetic compass heading is exposed to constant influence (mounting frame, boat, etc.) within the measurement section, the final discharge will not be affected. The boat velocity and water velocity vectors will have a heading error. If the magnetic compass is exposed to localized influence (bridge pier, embankments with reinforced concrete, etc.) it is recommended to evaluate the boat velocity and water velocity vector's heading. If the vectors are distorted in the localized area, XYZ coordinate should be used instead. Accurate and reliable bottom tracking is required for the use of ENU coordinate system;
- GPS reference track must **not** be used for final discharge calculations if the compass heading was impacted. The magnetic error plot should be used to identify if a change in magnetic field occurred between the compass calibration location and the measurement section;
- Loop method must **not** be used if compass heading was impacted within the measurement section. It is recommended that the SMBA method is used instead for determining the presence of moving bed;
- Measurements performed from a bridge could be affected by either the bridge deck or pier. It is recommended that the rope (or tether) is extended. This will increase the distance between the measurement section and bridge. It is important that the rope is not too long, allowing the operator full control over the movement of the tethered platform.

Moving Bed Test – Loop

Moving bed occurs when sediment particles or bedload is transported along the channel bed. It is important to understand that bedload is not consistent across the measurement section. The catchment and site conditions that most commonly result in a moving bed include the following.

- Catchments with significant soil erosion;
- Catchments with steep slopes and flash flooding;
- Catchments affected by drought, fire, etc.;
- Alluvial channel conditions;
- Wind erosion (sand dunes, etc.).

The Loop Method is dependent on accurate compass heading and bottom tracking during the entire loop measurement. The following criteria are essential for the loop method:

- If the water velocity is less than 0.25 m/s (0.8 ft/s), the loop method may be inaccurate. Consider using a stationary test to check moving-bed condition;
- If the moving bed velocity is greater than 0.012 m/s (0.04 ft/s) and moving bed velocity/mean velocity > 1%, loop indicates a moving bed;
- Minimum duration 3 minutes;

- Difference in flow directions > 3 degrees;
- Loop correction boat track ends downstream of start point;
- Invalid bottom track > 5%, “Warning: Loop may not be accurate”;
- Invalid bottom track > 20%, “Error: Loop is not accurate”;
- Consecutive invalid track > 9 seconds, “Error: Loop is not accurate”.

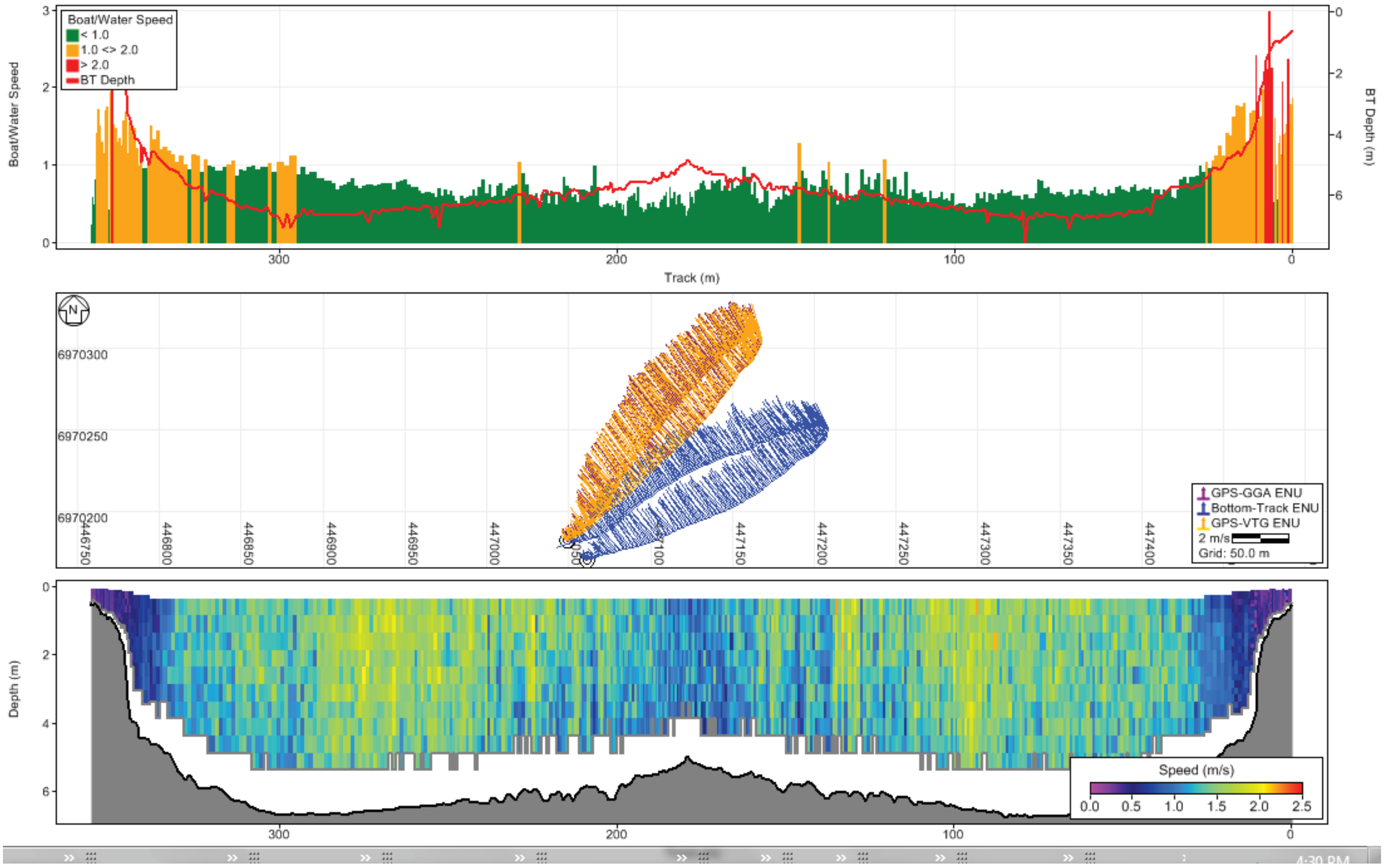

Figure 14. Loop Moving bed test.

There are several measurement techniques that can be followed to improve measurement results of the loop method,

- Make use of a fixed marker for reference, to determine the starting point of the loop method. It is important the loop measurement ends at the exact same position as the starting point. Any difference between the start and end locations will bias the results;
- It is not required to start at the bank, the operator can move away from the bank to improve the stability of the boat at the starting point;
- When the loop method starts, the operator must move immediately to the opposite bank. Excessive movement at the start location can bias the results;
- When the boat reaches the opposite bank, the operator must return immediately back to the starting point. Excessive movement while located at the opposite bank can bias the results;
- When the boat returns to the starting point, the loop method must be stopped. Excessive movement at the end location can bias the results;
- For wide measurement sections, it is recommended that the duration of the loop method should equal the width of the channel in seconds.

Vertical / Edge Measurements

Invalid edge measurements occur when the water depth is too shallow for two valid cells and/or no valid depths measurements are obtained from bottom tracking and or vertical beam. The measurement approach and site conditions that most commonly lead to invalid edge measurements are the following:

- Too shallow (less than 2 valid cells);
- Wind direction;
- Vegetation and algae;
- Underwater obstacles.

The following impacts are normally visible in the data collected due to invalid edge measurements shown in Figure 15:

- Number of cells displayed in profile plot is < 2;
- No cells displayed in profile plot, only cell start depicted with "Grey" line;
- Number of samples < 10.

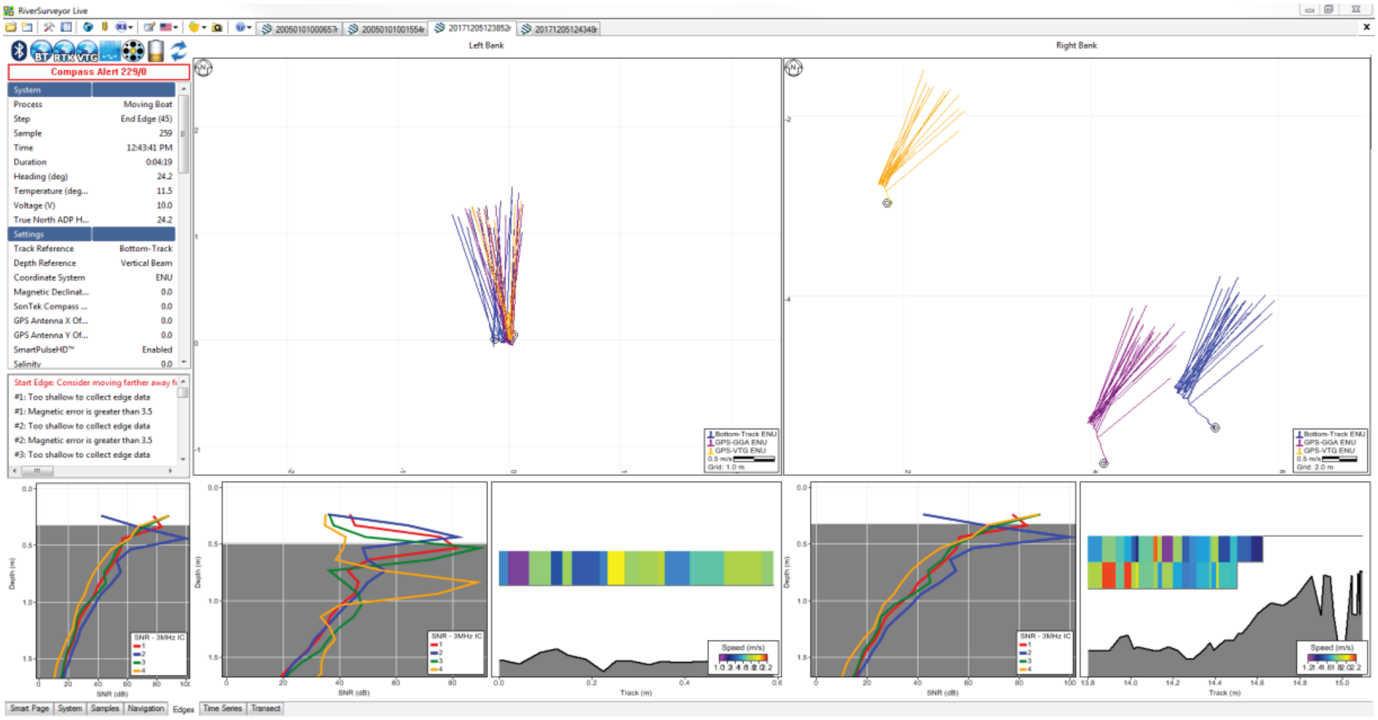

Figure 15. Edge measurements.

The collection of accurate and reliable edge measurements is essential for estimating the edge discharge in the unmeasured zone shown in Figure 16. The following criteria are essential to edge measurements:

- Minimum of 2 velocity cells;
- Minimum of 10 samples;
- Edge discharge should **not** exceed 5% of total discharge;
- Left or right bank selection;
- Sloped or vertical banks.

There are a number of measuring techniques that can be applied to enhance the edge measurements' accuracy and reliability. The following aspects can assist with improving edge data collection:

- The boat or tethered platform should be kept still during edge measurements as far as possible. This is difficult, especially if the wind is blowing and/or back flow, eddies or skewed flow on the banks are present. The use of sea anchor / drogue could assist with keeping the boat or tethered platform parallel with the edge;

- Starting the edge measurements further away from the bank decreases the possibility of collecting edge data in too shallow water. The measuring technique should be adapted based on the hydraulic and site conditions at the time of measurement. The 2 velocity cells required for edge measurements are a minimum and can be increased to 3 or 4 cells.

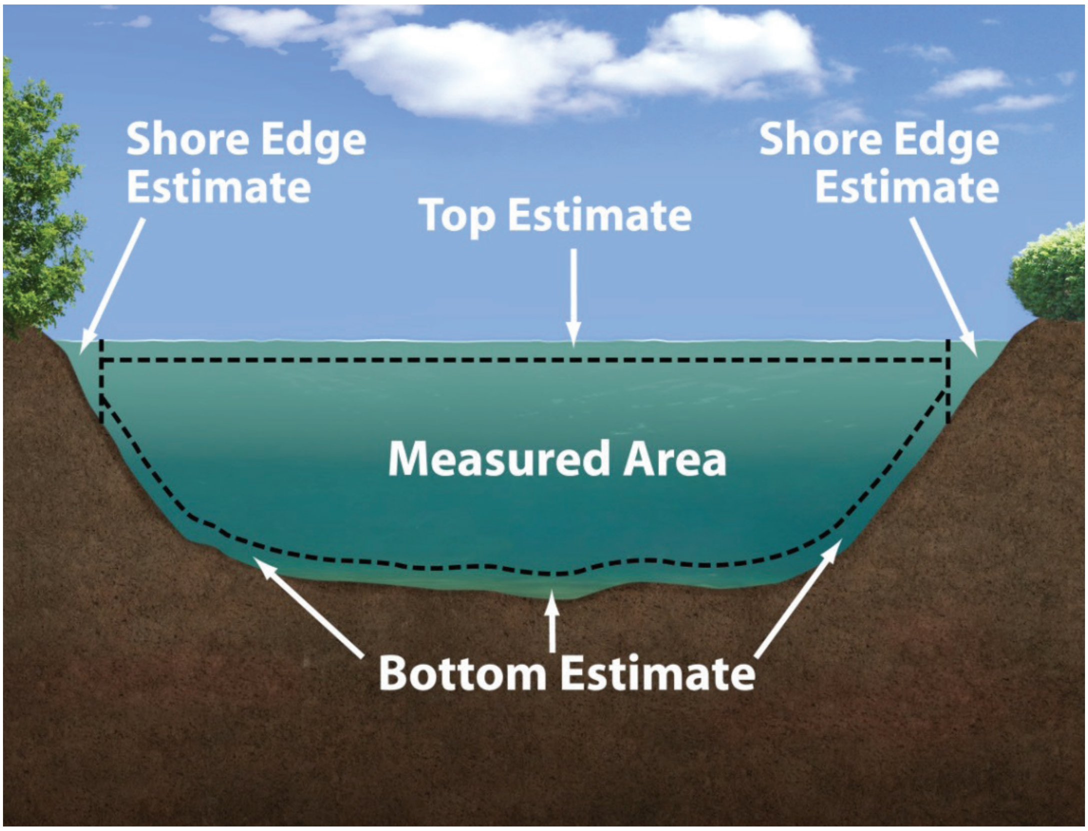

Figure 16. Unmeasured Zone.

Transects

There are a number of environmental, hydraulic and measurement site conditions that can impact the accuracy and reliability of the data during a transect measurement. The data sets collected during moving boat measurement is dependent on the ADCP instrument and if Global Positioning System (GPS) is used during the measurement. The data sets that are normally available during moving boat measurements consist of the following:

- Compass;
- Pitch and roll;
- Temperature;
- Velocity (Beam, XYZ, ENU);
- Track reference (Bottom Track, GPS-GGA, GPS-VTG);
- Depth reference (Vertical Beam, Bottom Track);
- Coordinate system (Beam, XYZ, and ENU).

Each of the data sets has defined criteria that are used to evaluate the data collected during the measurement process. The criteria associated with individual components of transects during real-time data review are summarized in Table 2.

Table 2. Transect components

Component	Variable	Criteria
Beam Profile	SNR	Beam Separation
Compass	Magnetic Error	> 3.5%
Compass	Pitch and Roll	
Depth	Cells	Minimum 2
Operation	Boat Speed	< mean water speed
Operation	Boat Speed	Not greater than 0.87m/s
Operation	Boat Speed	Steady and non-erratic
Temperature	Temperature	Greater than 2°C difference
Track Reference	Bottom Track	Samples with invalid bottom track
Track Reference	Bottom Track	Greater than 9 consecutive samples
Track Reference	Bottom Track	Presence of Bottom track velocity spikes
Track Reference	GPS / Bottom Track	GC – BC, close to zero
Track Reference	GPS / Bottom Track	D (BT) / D (GPS) (Ratio DMG, 1 best)
Track Reference	GPS-GGA	Bad GPS-GGA samples
Track Reference	GPS-GGA	HDOP is greater than 2
Track Reference	GPS-GGA	Presence of multipath. Change in altitude from the previous sample is greater than 3 m.
Track Reference	GPS-VTG	Bad GPS-VTG samples. Boat Speed is less than 0.1 m/s
Transects	Directional Bias	
Transects	Reciprocal Transects	Even number

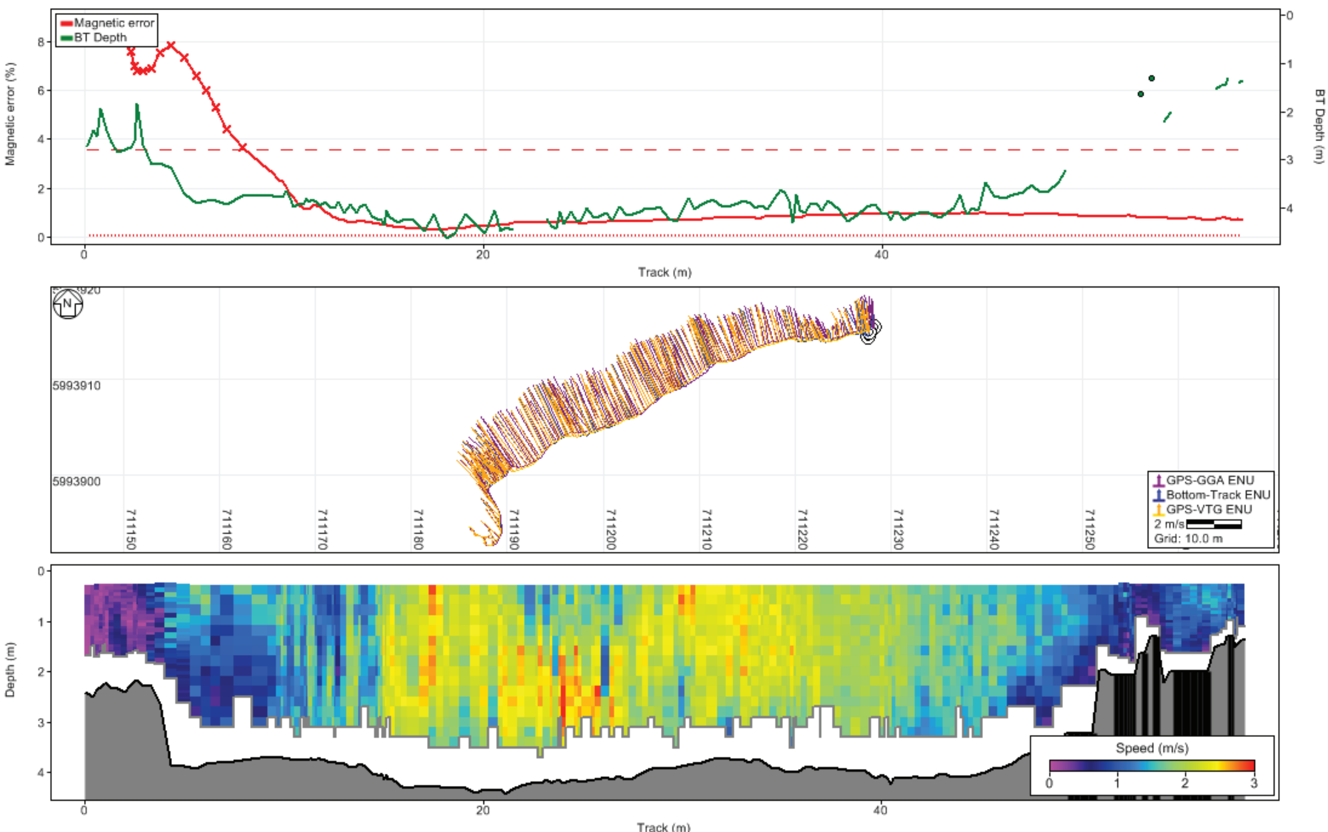

Figure 17. Moving boat transect.

Discharge Summary

The review of discharge summary shown in Figure 18 should be performed after the completion of each transect to determine if there is any variation in the following calculations based on the measurements performed:

- Width;
- Area;
- Discharge;
- Measurement duration.

It is important that the operator reviews each of the data sets outlined in the previous sections to determine if the data collected is accurate. Referencing the discharge measured against rated discharge should be performed after post-processing of measurements is finalized.

Discharge Summary

Post-Processing

File	.eft Distance (m)	ight Distanc (m)	Start Date	Start Time	Duration	Track (m)	DMG (m)	Width (m)	Area (m2)	Mean Speec (m/s)	Boat Speed (m/s)	Left Q (m3/s)	Right Q (m3/s)	Total Q (m3/s)	Corrected (m3/s)
20160606140030r.rivr	3.00	5.00	6/6/2016	2:00:31 PM	0:03:50	58.86	46.17	54.165	170.424	1.640	0.256	1.43	2.86	279.570	--
20160606140436r.rivr	3.00	5.00	6/6/2016	2:04:37 PM	0:03:13	50.95	46.29	54.292	211.876	1.594	0.264	2.71	2.02	337.710	--
20160606140757r.rivr	3.00	5.00	6/6/2016	2:07:57 PM	0:03:23	58.85	45.22	53.216	173.178	1.684	0.290	2.66	2.79	291.631	--
20160606141211r.rivr	3.00	5.00	6/6/2016	2:12:12 PM	0:03:12	53.35	45.95	53.952	176.103	1.720	0.278	2.25	2.55	302.893	--
				Mean	0:03:24	55.50	45.91	53.906	182.895	1.660	0.272	2.26	2.55	302.951	--
				Std Dev	0:00:15	3.46	0.42	0.416	16.852	0.047	0.013	0.51	0.33	21.697	--
				COV	0.000	0.062	0.009	0.008	0.092	0.028	0.048	0.226	0.129	0.072	0.000

Figure 18. Discharge summary.

Post Processing – Moving Boat

The post-processing of moving boat measurements consists of a detailed review of the measurement results. It is important to note that the acoustic Doppler principles listed in the real-time data review are applicable to post-processing as well (Figure 19).

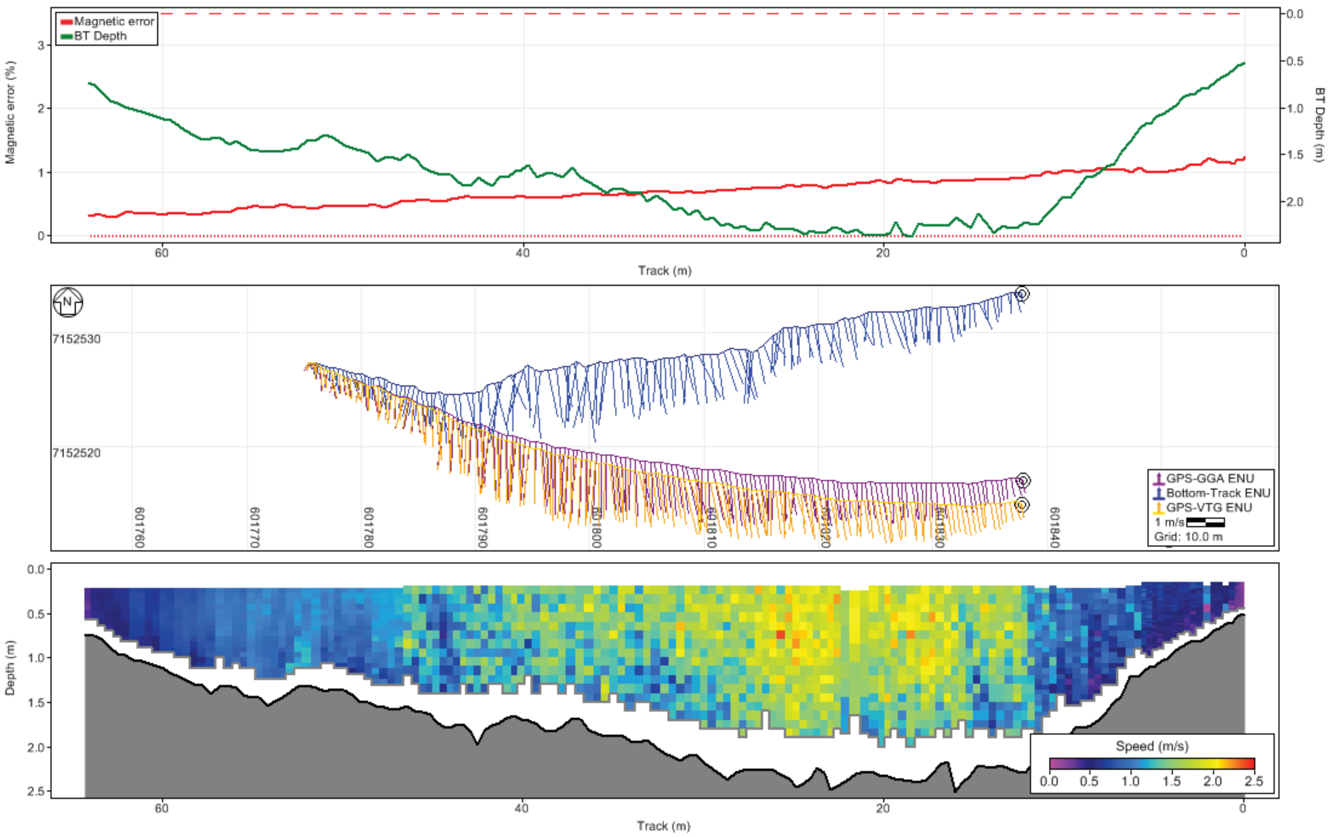

Figure 19. Moving boat measurement.

Reference Track

Selection of the appropriate reference track for the final discharge calculation is the most important aspect of the post-processing stage. The reference tracks displayed in the ADCP software is also the most prominent data set visible to the operator. The following sections discuss the process involved in selecting the appropriate reference track for the discharge calculation.

Bottom Reference Track

The bottom reference track section focusses on moving boat measurements performed with ADCP instruments that are not equipped with GPS systems (Figure 20).

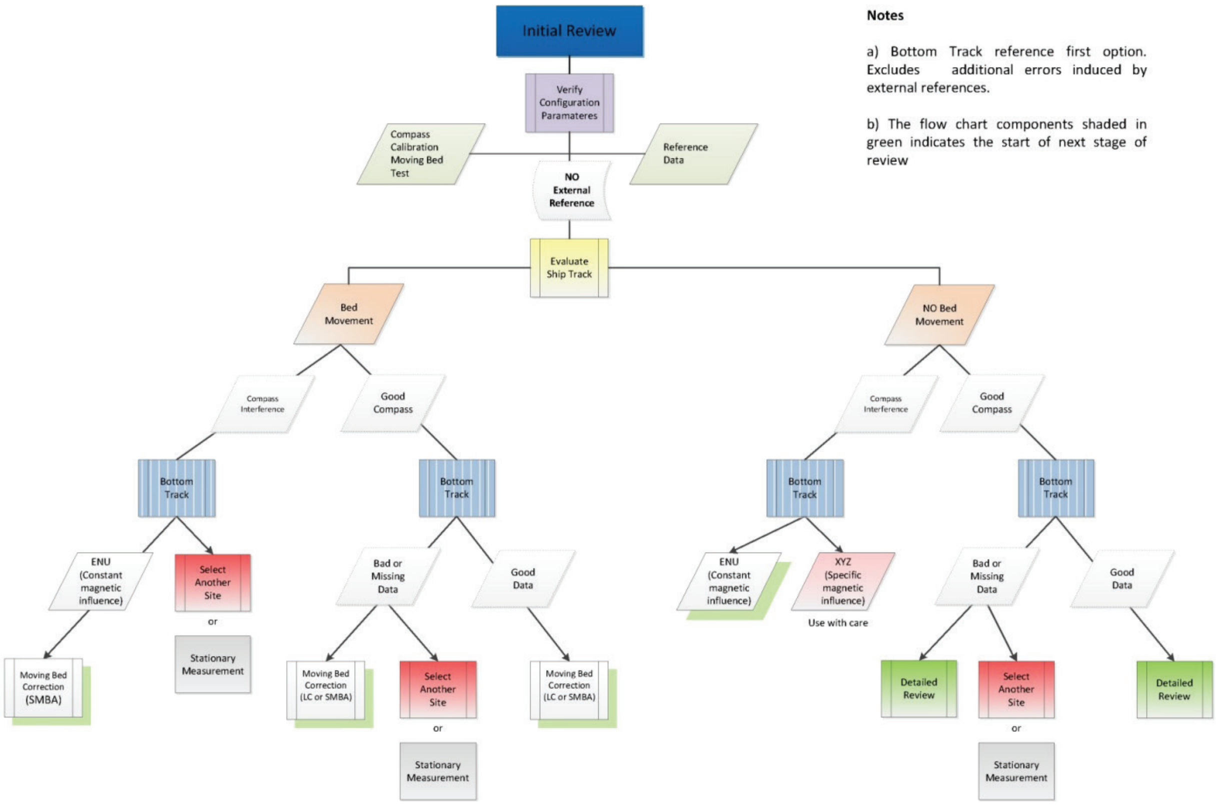

Figure 20. Bottom reference track.

GPS Reference Track

The GPS reference track section focusses on moving boat measurements performed with ADCP instruments that are equipped with GPS systems (Figure 21).

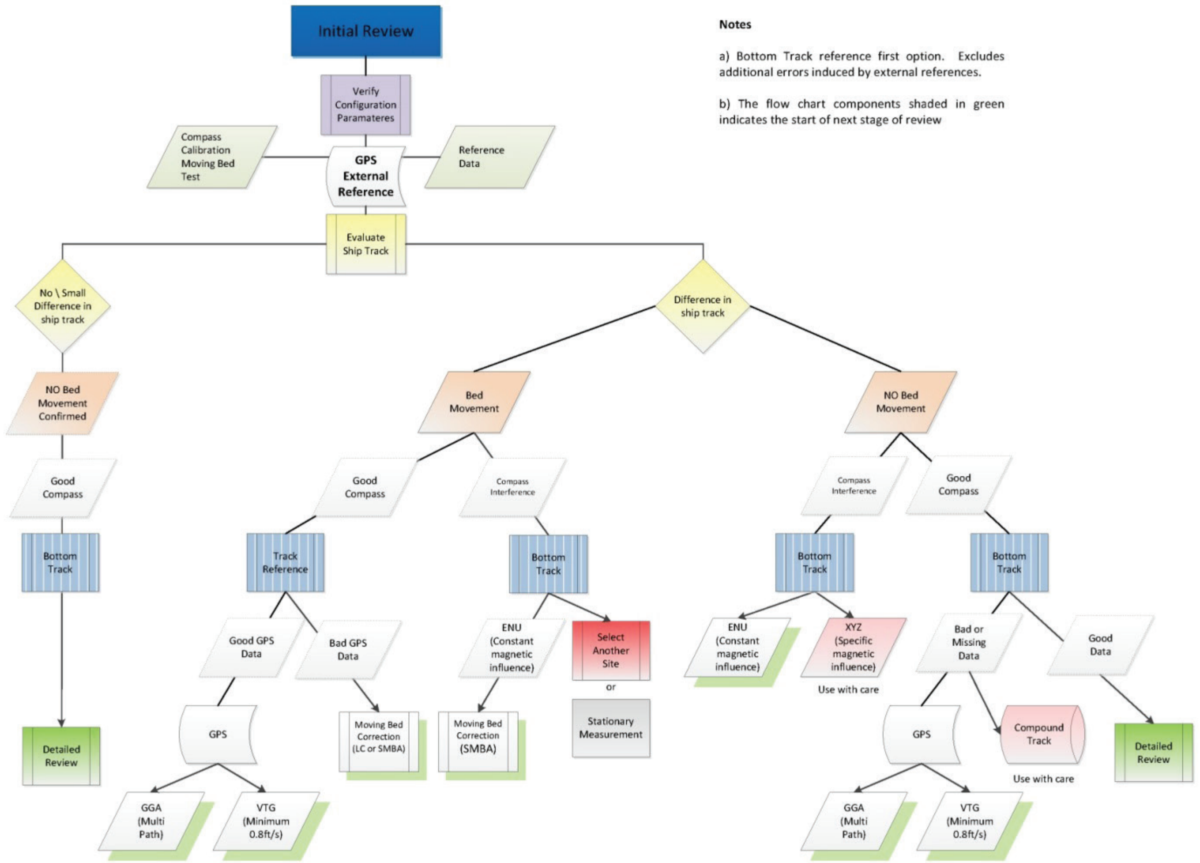

Figure 21. GPS reference track.

Detailed Review

The detailed review is focused towards key aspects of the overall measurement with specific attention on individual samples and or features in the measurement summarized in Table 3. It is essential that any anomalies are identified in the measurement as this could impact the reference track selection and or final discharge calculations.

Table 3. Detailed review

Component	Variable
Track Reference	Bottom Track / GPS-GGA / GPS-VTG
Track Reference	Ship Track / Velocity Vectors
Velocity	Magnitude contour plot
Velocity	Is flow unidirectional
Velocity	Ambiguity Velocities
Velocity	Velocities in ENU
Velocity	Vertical velocity (spikes, etc.)
Velocity	Bad or missing data
Depth	Depth reference VB or BT
Depth	Check bed contour profiles
Depth	Spikes in bed profile
Depth	Bad or missing data

Table 3. Detailed review (continued)

Component	Variable
Beam Profile	Individual Beam
Beam Profile	Reflecting riverbed
Beam Profile	Edge / Shallow areas
Beam Profile	Aeration / Obstructions
Extrapolation	Extrapolation method correct
Extrapolation	Check extrapolation parameters
Extrapolation	Compare with individual profiles
Discharge Summary	Duration
Discharge Summary	Track / DMG / Width
Discharge Summary	Area
Discharge Summary	Mean Speed
Discharge Summary	Total Q
Discharge Summary	% Measured
Discharge Summary	Std Dev / COV

Post-Processing – Stationary

The post-processing of stationary measurements requires a detailed review of the measurement results. It is important to note that the acoustic Doppler principles listed in the real-time data review is applicable to post-processing as well (Figure 22).

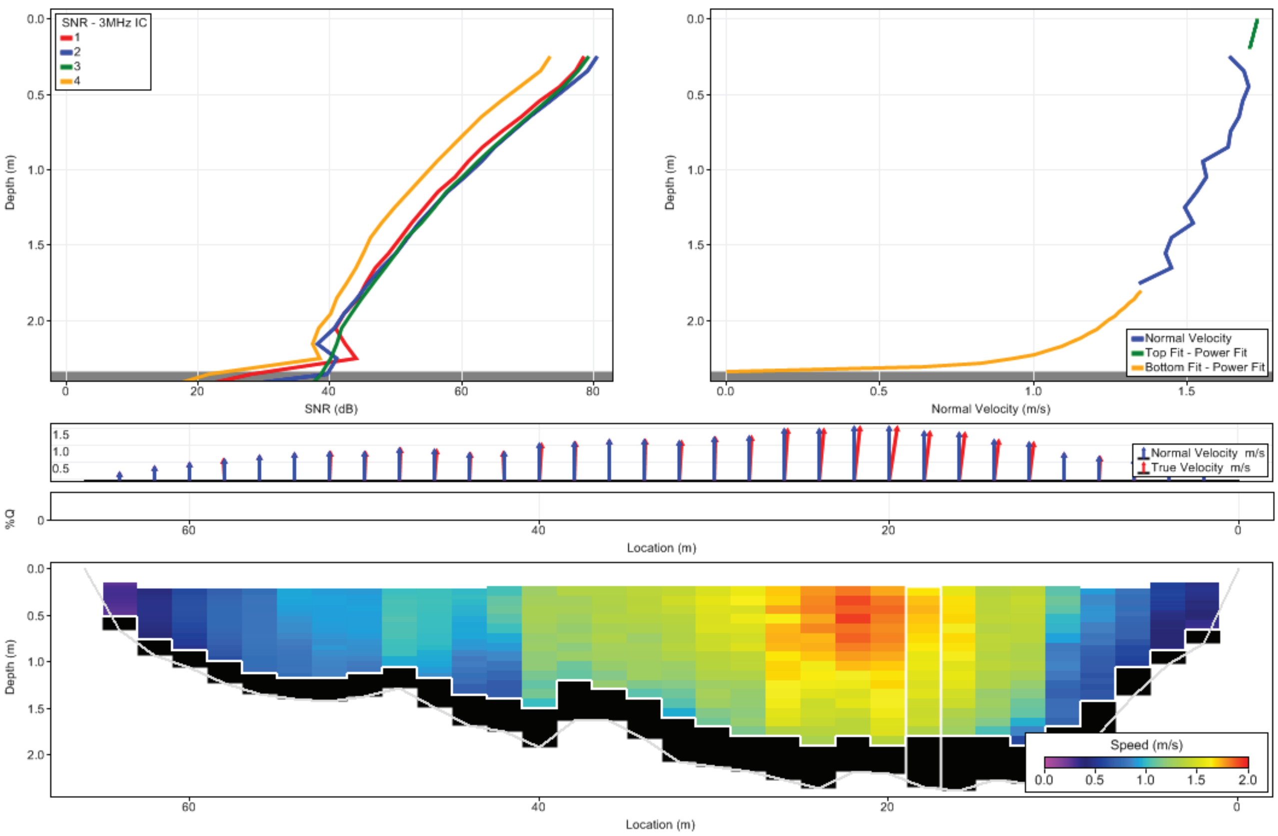

Figure 22. Stationary measurement.

Detailed Review

The detailed review is focused towards key aspects of the overall measurement with specific attention on individual samples and/or features in the measurement summarized in Table 4. It is essential that any anomalies are identified in the measurement as this could impact the reference track selection and/or final discharge calculations.

Table 4. Detailed review

Component	Variable
Track Reference	System / Bottom Track
Velocity	Magnitude contour plot
Velocity	Is flow unidirectional
Velocity	Ambiguity Velocities
Velocity	Velocities in ENU
Velocity	Vertical velocity (spikes, etc.)
Velocity	Bad or missing data
Depth	Depth reference VB or BT
Depth	Check bed contour profiles
Depth	Spikes in bed profile
Depth	Bad or missing data
Beam Profile	Individual Beam
Beam Profile	Reflecting riverbed
Beam Profile	Edge / Shallow areas
Beam Profile	Aeration / Obstructions
Extrapolation	Extrapolation method correct
Extrapolation	Check extrapolation parameters
Extrapolation	Compare between verticals
Discharge Summary	Duration
Discharge Summary	Width
Discharge Summary	Area
Discharge Summary	Mean Speed
Discharge Summary	Total Q
Uncertainty	ISO / IVE

QRev

QRev applies common and consistent computational algorithms combined with automated filtering and quality assessment of the data to improve the quality and efficiency of streamflow measurements. It further helps ensure that streamflow measurements are consistent, accurate, and independent of the manufacturer of the instrument used to make the measurement. Software from different manufacturers uses different algorithms for various aspects of the data processing and discharge computation. The algorithms used by QRev to filter data, interpolate data, and compute discharge are documented and compared to the algorithms used in the manufacturers' software. QRev applies consistent algorithms and creates a data structure that is independent of the data source (Figure 23).

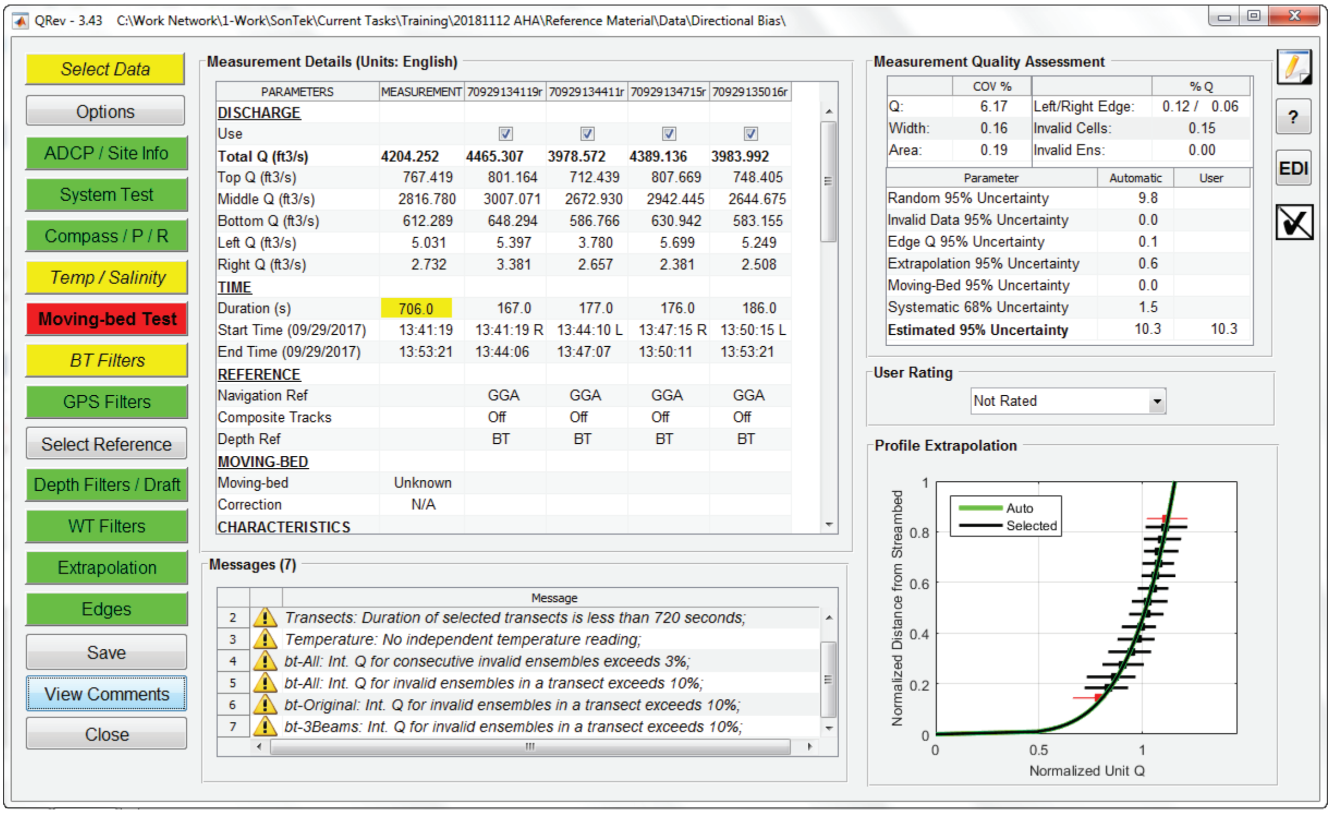

Figure 23. QRev - Moving boat processing.

Conclusion

Obtaining the required knowledge and skill set to perform, interpret and analyse acoustic Doppler measurements requires considerable exposure time to field application and data review processes. Acoustic Doppler instruments, depending on the sensors used, supply a large amount of information for the operator to interpret and analyse in real-time and post-processing.

The data analysis starts with the first measurement component and/or sample and it is important that operators review the data during the measurement process. The real-time data review supplies sufficient information to make an accurate assessment of the measurement results based on environmental, hydraulic and measurement site conditions. The QA process implemented in RiverSurveyor Live software was based on international and USGS standards, to assist operators during data collection. The acoustic Doppler principles, summarized in the "Real-Time Data Review" section are the basis of the QA process implemented.

The use of QRev for analysing and processing moving boat measurements has a number of advantages above the use of a manufacturer supplied user interface. The following are the main advantages and it is recommended that operators and organisations implement QRev in their operations:

- Consistent approach in the processing of moving boat measurements;
- Removes the potential impact of different knowledge and skill-sets in an organisation;
- Improved algorithms to resolve data sets affected by excessive influences from environmental, hydraulic and measurement site factors.

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[1] National Industry Guidelines were updated in 2019 after preparation of this paper.

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Introducing the GW50 Nitrate Sensor

The Hydrometrics GW50 Nitrate Sensor is designed and made in New Zealand. It complements our existing Greenspan range of sensors to support environmental monitoring in the extreme climatic conditions we experience in Australia. Aquamonix is the exclusive distributor of the GW50 Nitrate Sensor.

- Solid, 316 stainless steel construction
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Suspended Sediment & Turbidity Monitoring in NZ – a product of Extreme events

Evan Baddock, NIWA, Dunedin, NZ

Paper presented to 19th Australian Hydrographers Association Conference Canberra, 12-15 November 2018

Abstract

During – measuring and sampling over extreme events.

This paper provides an overview of some of the important things to know about suspended sediment and turbidity monitoring in New Zealand Rivers.

In New Zealand it is common to use turbidity to derive suspended sediment concentrations. However, estimating suspended sediment loads from continuous turbidity measurements is complicated by numerous factors including stream flow changes, type and positioning of sensors, sediment flux, and biological fouling and debris causing false readings (to name a few). There is an increasing 'confusion' on how best to conduct the monitoring, instrument validation procedures, and in particular how to use the data for various purposes.

Continuous turbidity monitoring is becoming more frequently used in our networks around the country for a variety of purposes, ranging from use as a proxy variable to determine suspended sediment concentrations through to using it as an absolute value for environmental state assessment. While New Zealand has developed a 'National Environmental Monitoring Standard' (NEMS), for turbidity, this does not seem to cover or satisfy all use cases and challenges encountered when measuring.

Obtaining consistent and robust relationships between turbidity and suspended sediment are particularly challenging and this presentation will illustrate some of those challenges, what we have learnt from them, and possibly raise some questions for discussion.

Turbidity as a surrogate for suspended sediment

Turbidity is a measure of the optical properties of water that cause light to be scattered and absorbed. Turbid water results from suspended material; for example, sediment, organic matter and dissolved constituents such as organic acids and dyes. Turbidity is often used as an inverse measure of water clarity.

It is also a popular proxy indicator for continuously monitoring suspended sediment concentration because of its dependence on the concentration of sediment particles suspended in the water and because it is relatively simple to measure with in situ instruments (within limits).

The sensor types vary from transmission-type sensors, which capture the attenuation of a light beam along a path between the light source and receiver, and back-scattering sensors, which measure the intensity of light scattered back towards the source.

When calibrating sensors to stock Formazin solutions, different sensors can return different results. As a result, turbidity records from different sensors are not necessarily comparable, resulting in a need for standardisation.

The use of different standards between field-deployed instruments and laboratory instruments further complicate the understanding of sensor performance and calibration.

For suspended sediment applications, the range over which sensors operate reliably needs to be considered. High concentrations during floods can be missed because of over-ranging or sensor saturation.

It is important to understand the range of uses to which the data can be put, and ensure that data collected for one purpose can be used as widely as possible in the future. Key to planning, maintaining and recording turbidity is the understanding of and ensuring stationarity of record.

Continuous turbidity monitoring

The advantage over discrete sampling is we now see the whole picture (figure 1 below), all parts of the rising and recession of the streams flood events. Of course, this in itself is fraught with difficulties in dealing with flooded rivers, debris, loss of equipment and possible unreliable data results.

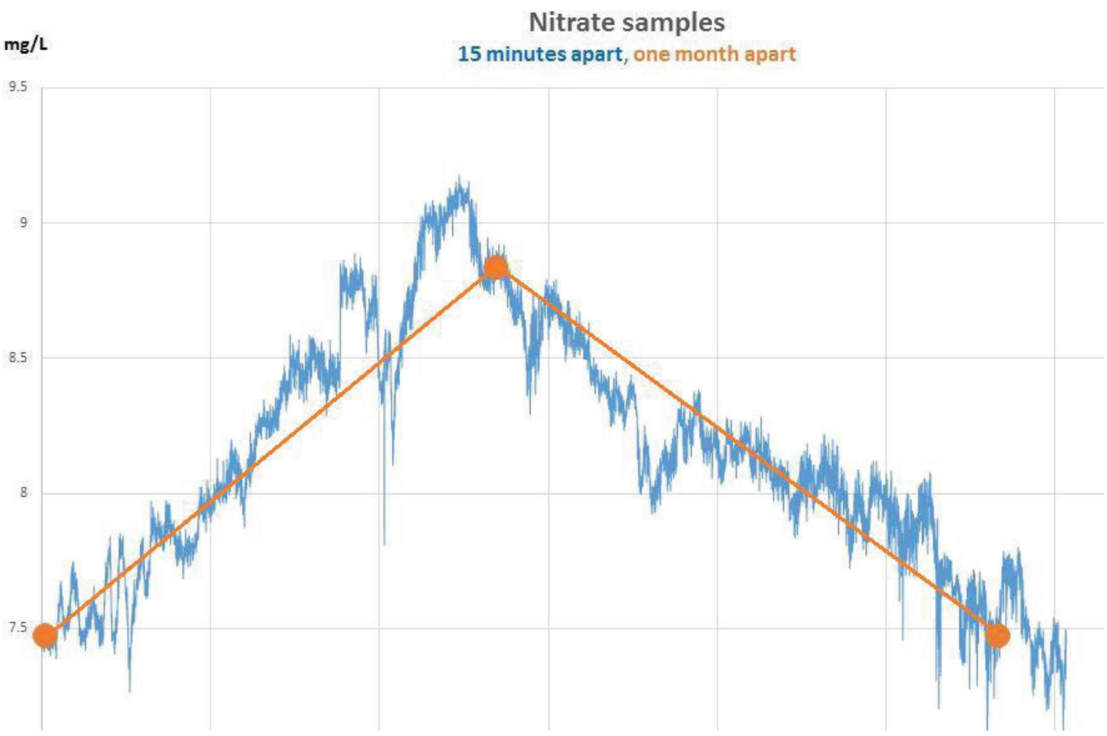

Figure 1. Discrete one month samples compared with 15min continuous data.

The latest generation of sensors claim to do all we want, but are they really delivering? Nephelometric Turbidity Units (NTU) vs Formazin Nephelometric Units (FNU), optical or ultrasonic, 90-degree light beam or not? Can we indeed compare sensors one to another in the same river let along between rivers!

There are still many questions to answer and best practice to decide on as we install, use and look over the data generated.

One big question is, are our sensor calibration methods reliable and comparable?

- Use manufacturer's recommended calibration procedures;
- Perform an office or laboratory calibration before deployment in the field;
- Calibrate in field with standards of known quality;
- Carry spare sensors and/or sondes;
- Latest movement is toward lab/office calibration and replace sensors in the field where needed;

Table 1. Sensor calibration criteria

Measured property	Calibration criteria
Temperature (˚C)	> ± 0.2˚C
Specific conductance (μS/cm)	The greater of ± 5 μS/cm or ± 3 %
Dissolved oxygen (mg/L)	> ± 0.3 mg/L
pH	> ± 0.2
Turbidity (turbidity unit)	The greater of ± 0.5 or ± 5% (this is NZ NEMS Standard).

USGS Standards T&M 1-D3

USGS Techniques and Methods guidelines and findings for continuous water quality monitors have these main points for field procedures:

- Don't "over calibrate" optical sensors;
- If recalibration needed, it's usually a problem with the standard;
- New wipers are more robust and do a better job;
- Sensors stay cleaner in water flowing with velocity;
- Swapping the sensors out so any calibrations are carried out in the lab;
- Using StablCal formazin standard gives best results using 2-4 point calibration (0-1000).

The NZ NEMS Standard

The current NEMS standard around turbidity states the following:

- ± 3 FNU for values less than 20 FNU; or
- ± 15% for values greater than or equal to 20 FNU and less than 750 FNU relative to primary reference;
- >750 FNU: undefined;
- Units of Measurement = Formazin Nephelometric Units (FNU) Resolution 0.1 FNU;
- Primary reference measurement;
- Annual zero-point validation: ± 1 FNU;
- Monthly verification samples/measurements;
- Annual verification sample collected during a runoff event in which turbidity range exceeds 100 FNU.

NEMS Calibration frequencies have been established as follows:

In situ sensor: Calibration shall occur when verification confirms that the in-situ sensor is not conforming to the accuracy of the Standard (NEMS NZ QC 600) and/or as per the manufacturer's specifications.

Sensor calibration shall be undertaken as detailed in the instrument reference manual and confirming to the ISO 7027 Standard. In brief, this involves:

- Securing fresh stock solutions of Formazin that cover the full FNU range of the instrument;
- Measuring the FNU of these stock solutions accurately with an already calibrated laboratory instrument that meets the ISO 7027 Standard; and
- Measuring their FNU with the field instrument.

Sensor validation shall include:

- Measuring a clear-water (zero turbidity) sample;
- Checking that the agreement between the laboratory and field instruments is within tolerance levels.

Once per year, the field sensor shall be removed from its mounting hardware, cleaned thoroughly, and used to measure the turbidity of clear distilled water (i.e. in a black plastic container) with near-zero turbidity, as measured with a calibrated portable or laboratory instrument.

The comparison shall provide sensor values within ± 1 FNU.

Turbidity and suspended sediment challenges

Things to keep in mind:

- Sensor differences will cause sample measurements to vary;
- Two identical turbidity sensors can give different readings in “real” samples;
- Sensors **should** give the standard value in the standard within the uncertainty;
- Formazin is the reference standard;
- Formazin and StablCal are universal standards;
- Polymer bead standards are sensor specific.

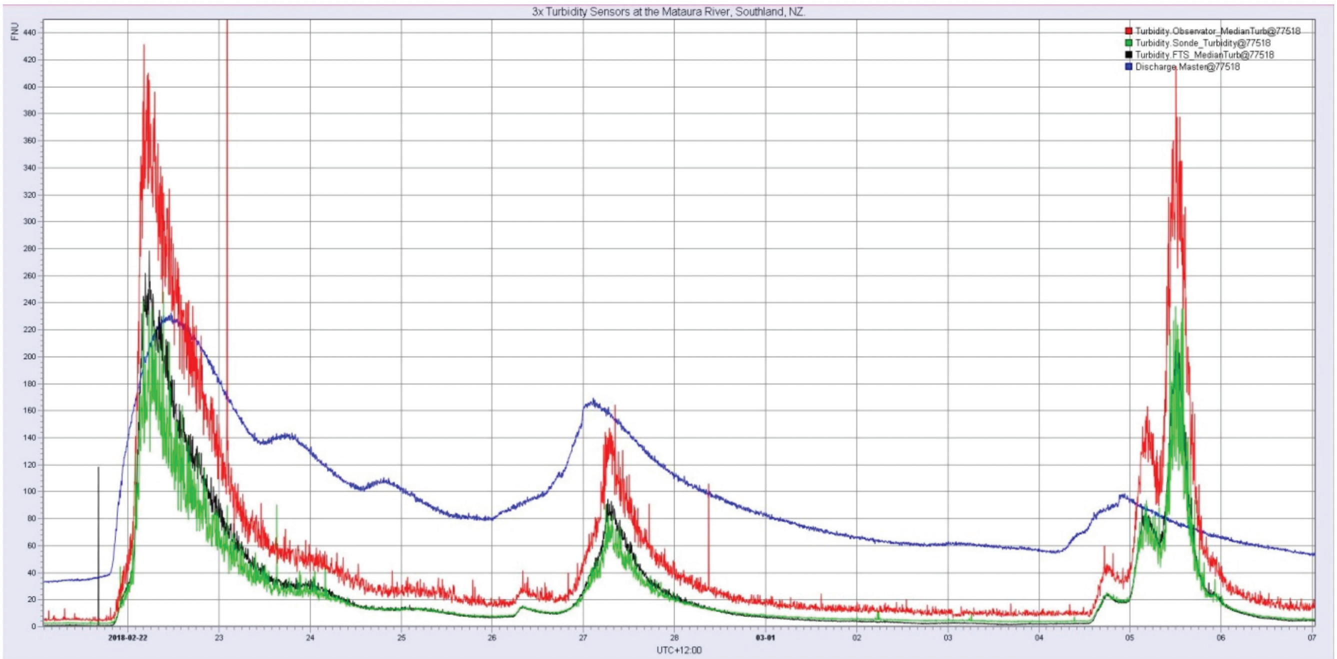

Figure 2. Three different Turbidity sensors giving three results in the same river.

The challenge, as seen in the graph above, is making our data comparable. Our NEMS standards now require FNU sensors at a scale to cover the natural range found in a particular river and to follow the standard protocol mentioned above.

Conclusion

The NEMS review team is addressing a range of issues in the current document. As the different organisations use these sensors and practices more we aim to resolve the issues going forward, so we can indeed compare data between rivers, between sensors, between brands and between organisations, including:

What are people's experiences with different turbidity readings from the same make and model of sensor? What's the best way of overcoming – or accounting – for this given sensor may need to be removed temporarily (e.g. servicing) or replaced?

1. Should turbidity sensors be calibrated in-situ or in the lab? Are people using formazin for calibration? If not, what and why?
2. Sensor calibration frequency – should this be determined by validation results vs fixed time interval (e.g. manufacturer's guidelines are 12 monthly for DTS-12 sensors)?
3. Sensor validation requirements – regular (monthly?) plus targeting higher flow/turbidity conditions – e.g. in-situ via a hand-held sensor or black disk visual clarity, or collection of a water sample for lab measurement?
4. What is the most appropriate method to adjust data collected pre- and post-calibration?

References

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The growing demand and difficulties of hydrometric measurement of extreme events in urban stormwater and sewers

Justin Stockley, Xylem Analytics, Perth, WA

Paper presented to 19th Australian Hydrographers Association Conference Canberra, 12-15 November 2018

Abstract

Measurement of water level and discharge in urban stormwater and sewers during intense rainfall events presents many challenges for the hydrographer. Faced with fast peak response times, complex flow conditions, interactions with groundwater and surface water bodies as well as safety issues, there has been demands on technique and technology to enable the collection of accurate data.

The functional design criteria of stormwater drains and sewer networks now incorporate allowances for climate change in many countries. With aging infrastructure, sea level change and more intense rainfall events, there is a growing demand for accurate measurement methods as well as active monitoring systems that can notify relevant emergency services in real-time.

This paper looks firstly at the impact of climate change on the hydraulic operation of storm and sewer systems, drawing on case studies to highlight the increasing demand for accurate data. The difficulties faced by the hydrographer when measuring data during peak events is also addressed as well as the typical technologies employed. Finally, hydrometric data collection in cities is faced with operational demands which drive real-time decision making and responses to extreme events. Case studies are provided along with emerging technologies that are enabling data collection and transmission.

Introduction

Measurement of water level and discharge in urban stormwater and sewers during intense rainfall events presents many challenges for the hydrographer. Faced with fast peak response times, complex flow conditions, interactions with groundwater and surface water bodies as well as safety issues, there has been demands on technique and technology to enable the collection of accurate data. This paper broadly covers some case studies highlighting these issues and attempts to share the experiences garnered from monitoring work undertaken in urban environments over the period 2004 to 2012.

1. Hydrographic Data Collection in Wastewater Systems

Wastewater systems are inherently extreme environments posing a multitude of challenges for hydrographers. Extreme events within these systems are difficult to forecast and not necessarily driven only by rainfall. For example, downstream blockages in pipes can turn a routine visit into an extreme event very quickly.

As cities become more urbanised, many more stormwater drains become covered to maximise land use and thus many of the challenges of measuring water in wastewater systems are also faced by those tasked with measuring stormwater flows.

1.1 Safety Challenges

1.1.1 Confined Spaces

Covered conduits are confined spaces and the danger they pose to those that work in and around them is well understood. Table 1 data below is based on the personal experience of the author and is provided as an indicator (and reminder) that hazardous confined spaces can occur in the least expected location.

Table 1. Hydrogen Sulphide Gas Data from Author's Confined Space Experience

Location	Approximate Number of Manholes Measured	H_2S Gas Maximum Measured
SYDNEY	100	20
SINGAPORE	1500	50
HONG KONG	400	200
ABU DHABI	5	20
CHESTER, UK	5	25
PERTH	80	**1200**

1.1.2 High Flow Events in Sewers and Covered Drains

High flow events in sewers can be caused by a variety of factors such as rain water infiltration into pipes as well as dry weather downstream blockages.

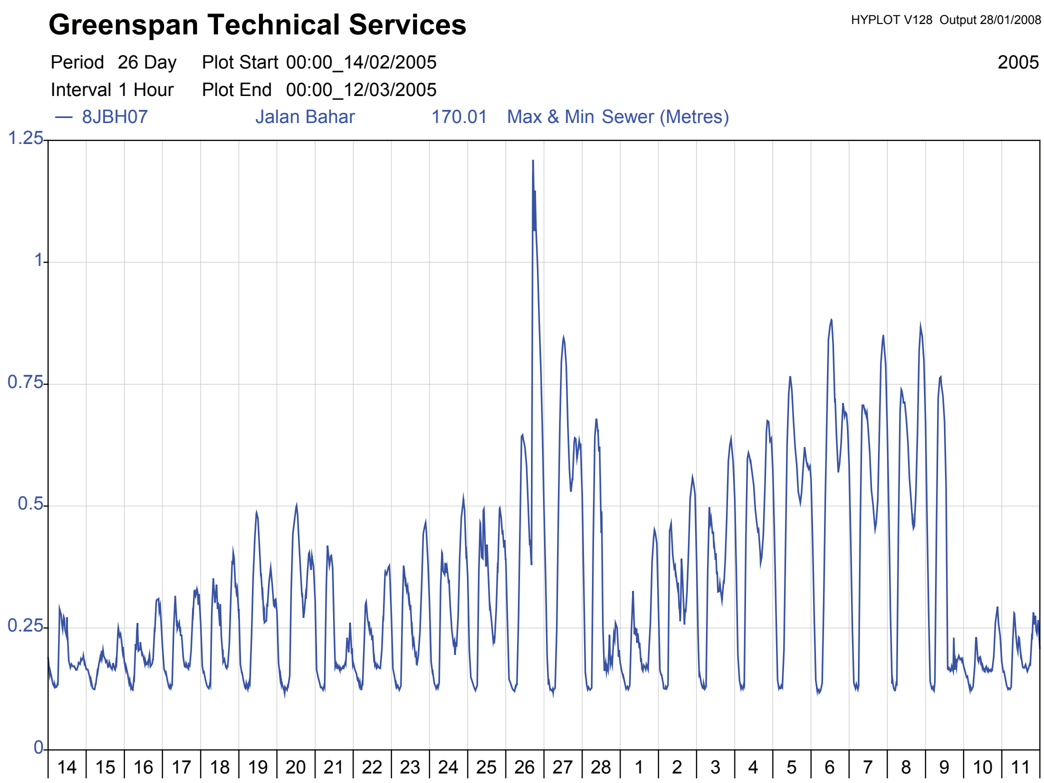


Figure 1. Time series plot of water level showing effect of downstream trash screen debris build up and subsequent clean*

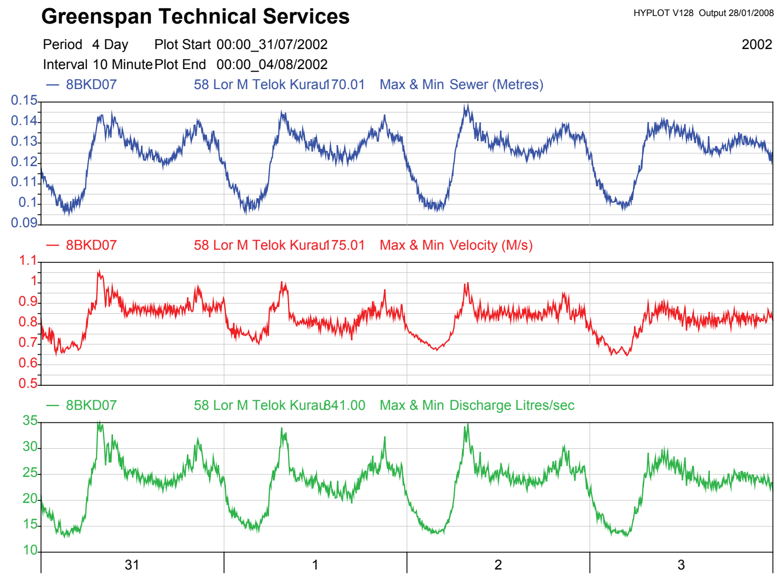
Acknowledgment: Greenspan Singapore PTE LTD for the use of data plots.

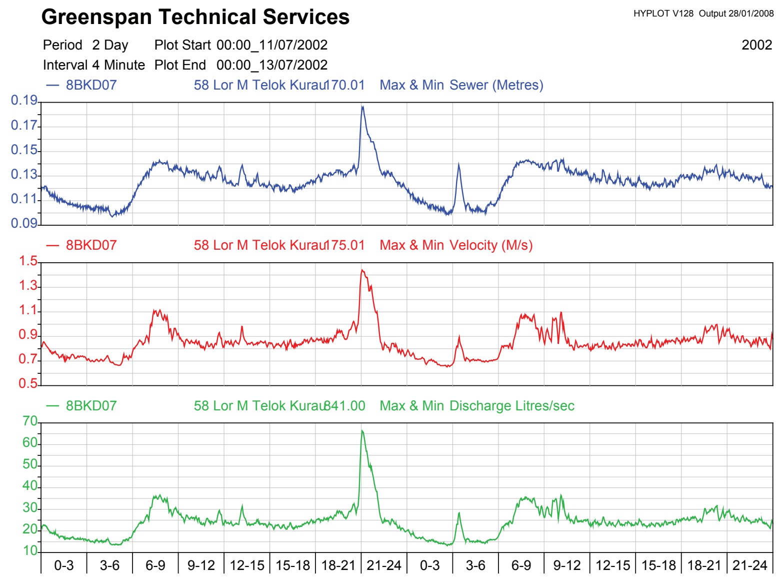
1.2 Measurement Challenges

Tables 2 and 3 below detail the extreme variability that can be encountered when collecting data in sewers. Given a backdrop of inherent variability, instrumentation and configuration often needs to be customised based on the situation.

Table 2: Inherent Variability in Sewer Discharge Data Examples

**Acknowledgment: Greenspan Singapore PTE LTD for the use of data plots.*

<table>
<tr>
<td>


</td>
<td>Typical residential hydrograph in a sewer with a diurnal daily pattern.</td>
</tr>
<tr>
<td>


</td>
<td>Residential hydrograph with response from rainfall.</td>
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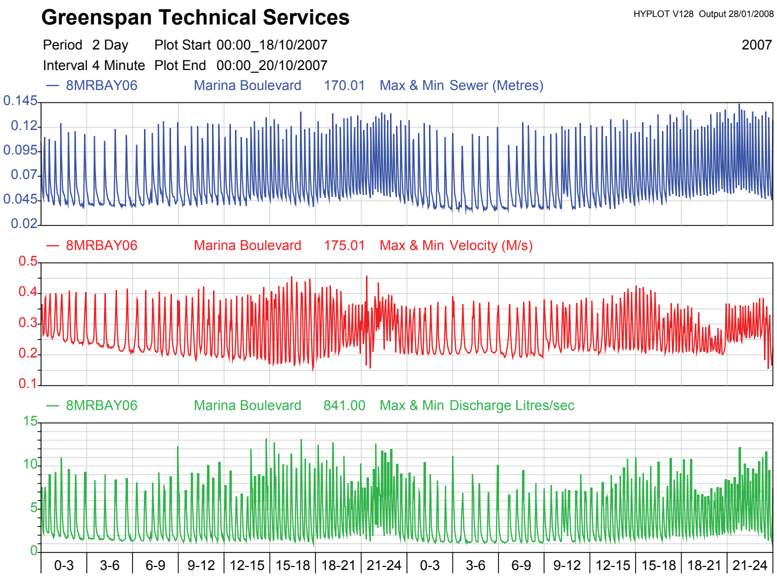

</td>
<td>Hydrograph from a location downstream of a pumpstation.</td>
</tr>
</table>

Table 3: Inherent Variability in Sewer Discharge Data Examples

**Acknowledgment: Greenspan Singapore PTE LTD for the use of data plots.*

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<tr>
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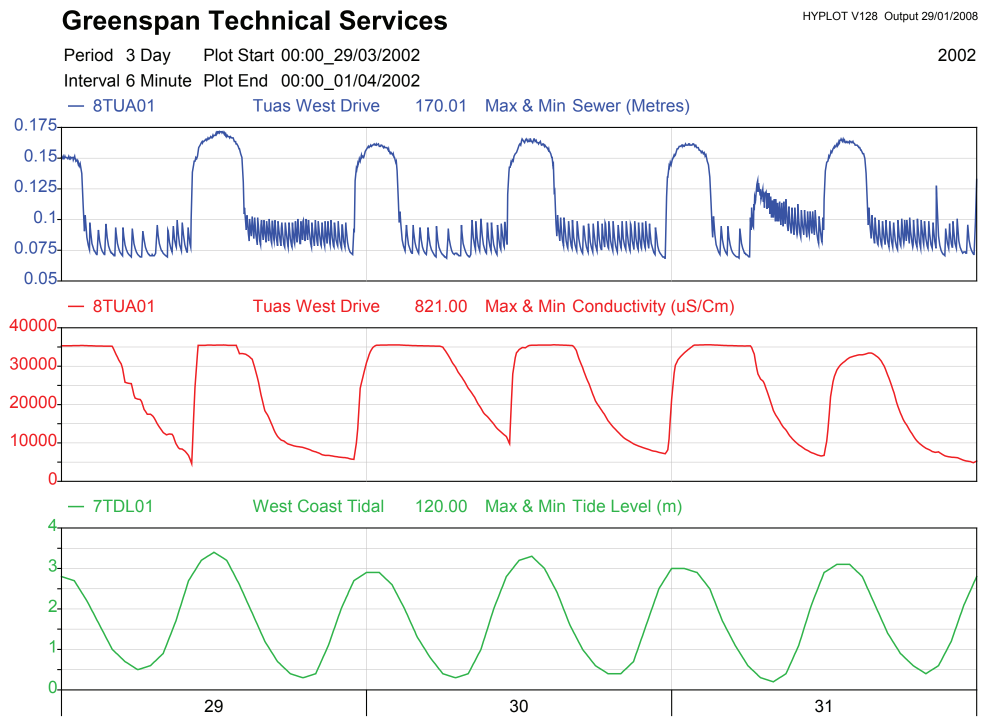
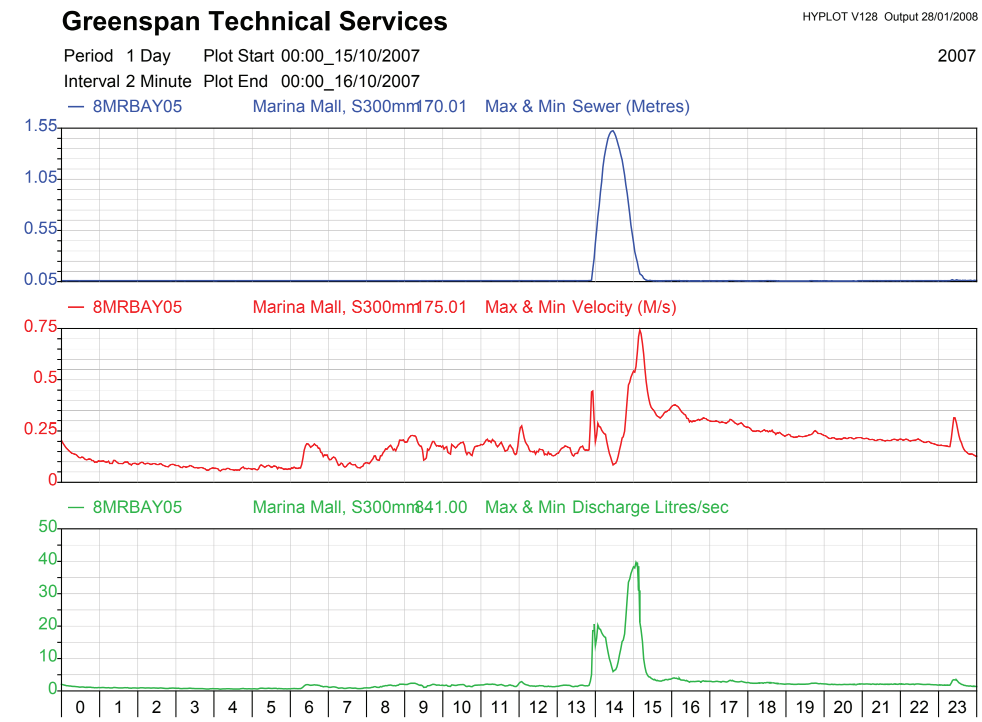


</td>
<td>Site affected by sea water ingress into collection pipe.</td>
</tr>
<tr>
<td>


</td>
<td>Site with significant response to rainfall.</td>
</tr>
</table>

Case Study 1: Monitoring during Extreme Events in Manholes

High water events in sewer manholes cause a multitude of problems such as overflows whether via constructed bypasses into natural water courses or into public property. Developing monitoring systems in order to provide real-time alerts as high water level events occur faces many challenges including:

1. High humidity and corrosive (explosive) gas environments;
2. Data transmission issues due to instrumentation being covered by manholes;
3. Verifying and validating data in flooded manholes.

In Singapore, a simple unit which was comprised of a Remote Telemetry Unit (RTU) and three floats (typically used to control pumps) was deployed at 1000 locations. The unit sends a heartbeat SMS weekly and during high water level events. SMS are sent out as each float is triggered as water rises in the manhole and a subsequent return to normal state SMS is also sent.

Typical installation showing RTU and floats.

Figure 2. High Water Level Alarm System installed in Manhole
**Acknowledgment: Greenspan Singapore PTE LTD for the use of photos.*

This project served as a good example (as a precursor) to the many predictions regarding the internet of things (IOT) in so far as monitoring systems are projected to expand in volume and serve in real-time. It also highlighted some of the challenges of such large scale monitoring systems, namely:

I. Handling and making use of large amounts of data. During a widespread event, a massive quantity of SMS is generated by the 1000 instruments and needs to be processed (IOT and Big Data);

II. Making use of such a large amount of data in a meaningful way (Data Dissemination, Data Visualisation);

III. The costs associated with data transmission with current technologies are twofold:
   A) Telecom companies update their own services and close off previously available services (e.g. the closure of GPRS network) resulting in hardware needing to be replaced.
   B) The costs of running 1000 units using SMS transmission and public cellular contracts: Average Monthly Telco Bill: SGD 6,000 resulting in approximately SGD 80,000 in annual Telco expenses using current technologies.

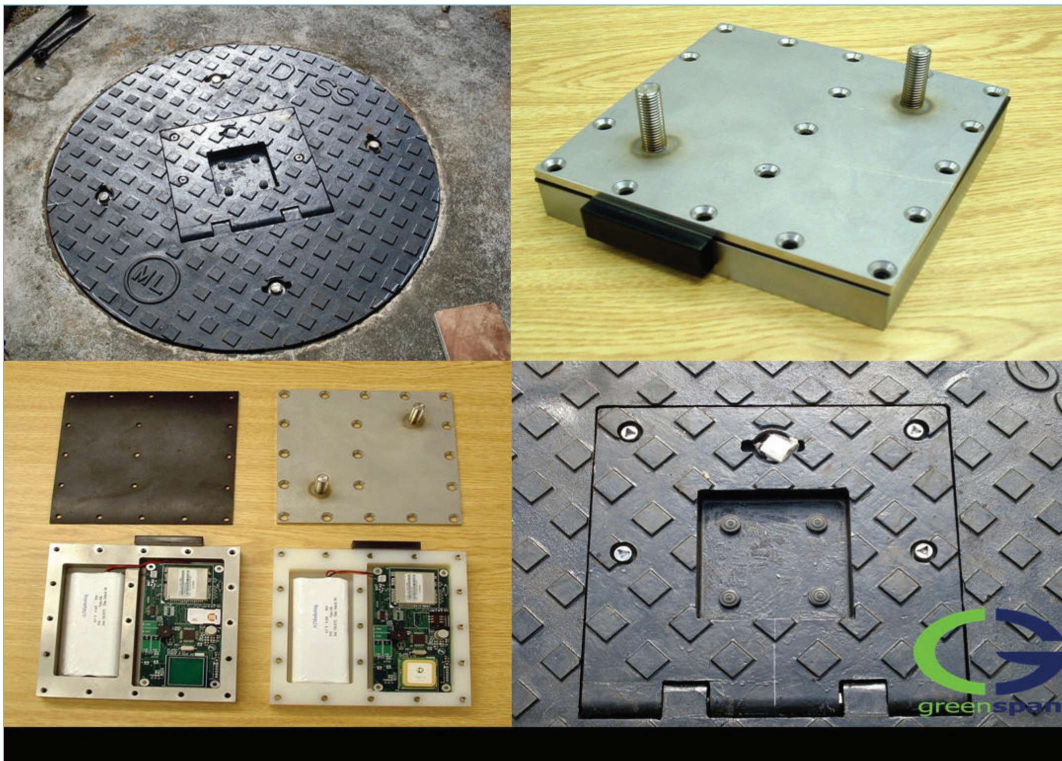
IV. Verifying data and QA/QC of data prior to archive and further analysis.

This example highlights some of the challenges that technology is attempting to address in many fields, not just hydrometrics[2].

[2] Acknowledgment: Greenspan Singapore PTE LTD for the use of data.

Singapore Case Study 2: Monitoring the safety of Extreme Environments

As data transmission technology improves, hydrographers (who are highly knowledgeable with a wide variety of instrumentation as well as site information) are well placed to realise innovative solutions to the many challenges posed of monitoring not just hydraulics but also the infrastructure associated with drainage. The below example was a simple tilt sensor that sent an alarm message should access to highly dangerous or critical manholes be accessed.



Tilt sensor and RTU hardware.

Tilt sensor in place on manhole.

Figure 3. Manhole Opening Alarm System.

**Acknowledgment: Greenspan Singapore PTE LTD for the use of photos.*

2. Hydrographic Data Collection in Stormwater Systems

Historically, stormwater drains within urban areas were designed to convey surface water runoff quickly and safely from impervious surfaces into collection channels and out to rivers, lakes or the sea. With increasing urbanisation the rapid conveyance of surface water runoff from upstream drainage zones puts large pressures on downstream capacities and storages. Given the land and infrastructure costs of amplifying stormwater drains, water sensitive urban design has been widely adopted to control surface runoff closer to the source and minimise downstream impacts.

Water sensitive urban design features can take many forms, however they have presented new challenges to hydrographers in terms of the collection of data, in particular during extreme events where the change in hydraulic conditions are often amplified as compared to natural systems.

Three case studies are described in this paper looking at the measurement challenges facing hydrographers as they are called on to measure data.

Case Study 1: Hydrometric monitoring challenges around a small scale pilot study incorporating many of the concepts of water sensitive urban design.

Dry weather surface runoff and in particular the first flush from rainfall events contains the highest pollutant loads in urbanised areas. As part of water sensitive design, treating it at upstream sources through natural processes is a core design criteria. As such, water from the traditional drain is diverted to a series of small ponds referred to as cells which are planted with specific species of plants. In order to validate the effectiveness of these structures, field data is critical. Given the complexity of the hydraulics within such a system, a multitude of instruments was required to accurately collect performance data.

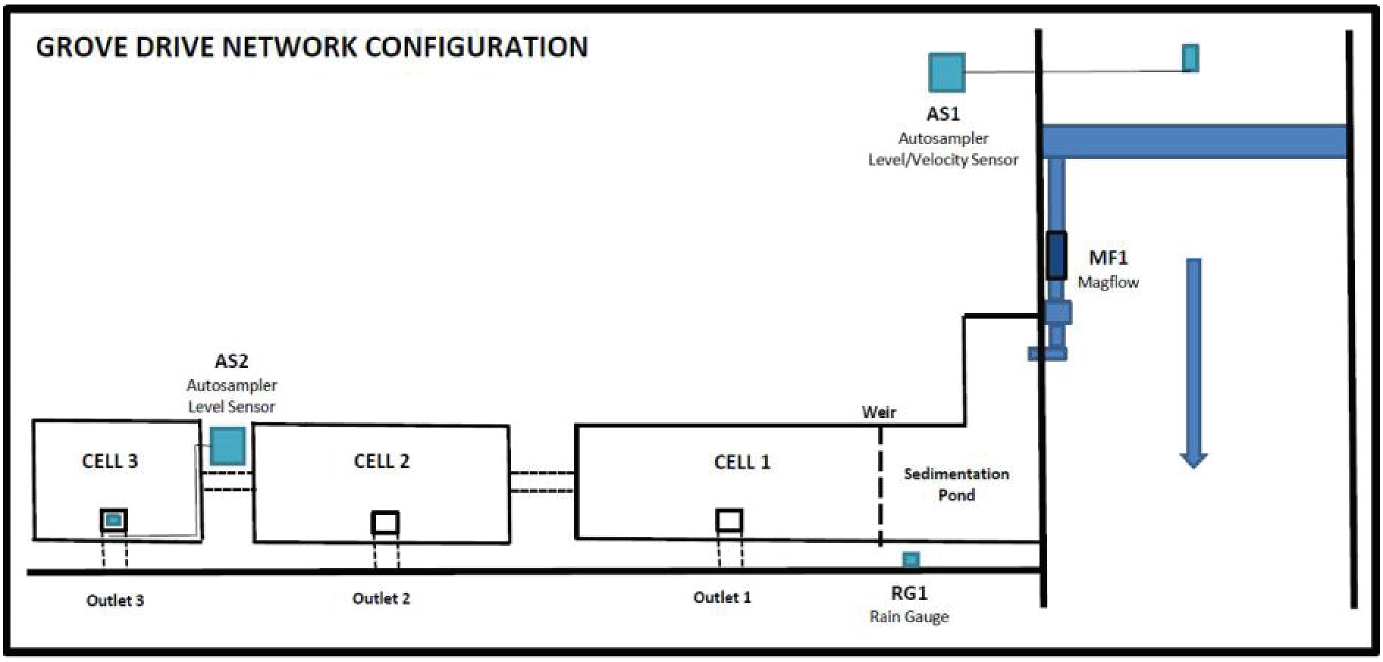


Figure 4. Site Plan of Constructed Wetland to naturally treat urban runoff.

Table 4: Location photos as indicator of scale

**Acknowledgment: Greenspan Singapore PTE LTD for the use of photos.*

	Stormwater drain.
	View of Cell 3 looking towards Cell 1.

The difficulties of measuring discharge data during high flow events in this case was overcome using a combination of instrumentation including an area velocity sensor, magflow sensor as well as a weir with stage measurement.

Case Study 2: Hydrometric monitoring challenges around a large scale example of water sensitive urban design application.

Figure 5. Before and after Kallang River restoration at Bishan Park.

Table 5: Dry weather and wet weather conditions at restored river

	Dry weather conditions.
	River during high rainfall event.

The changing nature of urban drainage has implications of the importance of hydrometric data during extreme events and dissemination to stakeholders.

Monitoring Challenges

The key monitoring objectives of collecting discharge data for system evaluation was coupled with a need for a peak water velocity real-time warning system. Given the redesign and launch of the urban park, any monitoring instrumentation and ancillary structures were to be low impact and within the chief architects overall vision and approval. Given the river now had been integrated into the urban park, reliability and robustness of any instrumentation was paramount as the system was utilised both for evaluation as well as a warning system.

Given this backdrop, discharge was determined through the area-velocity method using a radar surface velocity and water level monitoring system. Pictures in Tables 6 and 7 detail the installation at one of the five stations.

Table 6: Hydrometric instrumentation installation within national park

	Radar velocity and water level measurement system.
	Lamp post used for solar panel, power supply, data logger and modem housing.

Table 7: Hydrometric instrumentation installation within national park

**Acknowledgment: Greenspan Singapore PTE LTD for the use of photos.*

	Lamp post enclosure locked.
	Lamp post with power supply and data logger enclosures.

Case Study 3: Extreme velocities in stormwater systems.

The Kai Tak transfer scheme in Hong Kong diverts stormwater flows into a storage tunnel during storm events.

Essentially, during rainfall events and subsequent higher water levels, flow is diverted down into a storage tunnel.

The schematic is provided below showing the upstream culvert (1), the interceptor and transfer structure (2), the bypass storage tunnel (3).

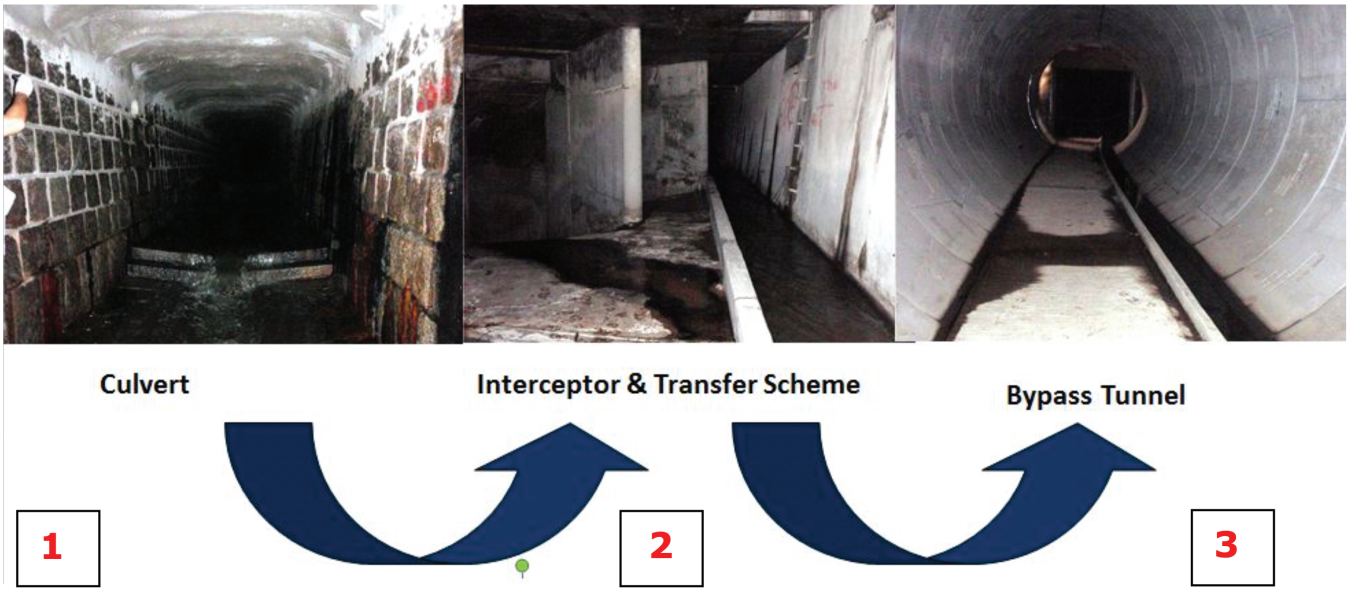


Figure 6. Interceptor Schematic.

Acknowledgement: Greenspan Singapore PTE LTD for the use of photos.

During the measurement exercise, two different types of Doppler measurement technologies (Pulsed Doppler and Continuous Wave System) were used at one location. The challenge for hydrographers is that the location is too dangerous to access during wet weather events and complete calibration and verification measurements and as such, there is a heavy reliance on the continuous monitoring instrumentation.

For this measurement exercise, for the pulsed Doppler used, there are two velocity beams that are emitted at 45 degrees. Whilst for the continuous wave sensor, the Doppler beam is emitted at 20 degrees.

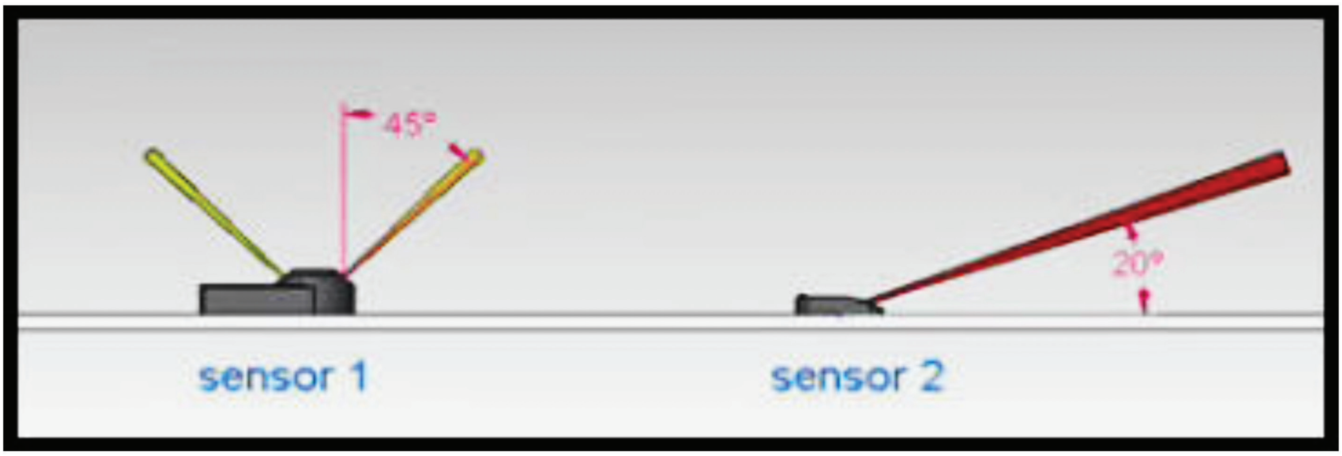


Figure 7. Beam measurement angles for pulsed Doppler sensor (1) and continuous wave sensor (2).

Additionally, the penetration distance of the pulsed Doppler velocity sensor is 6 m versus 1.5 m for the continuous wave sensor. There is also a price difference with pulsed Doppler significantly more expensive than a continuous wave Doppler.

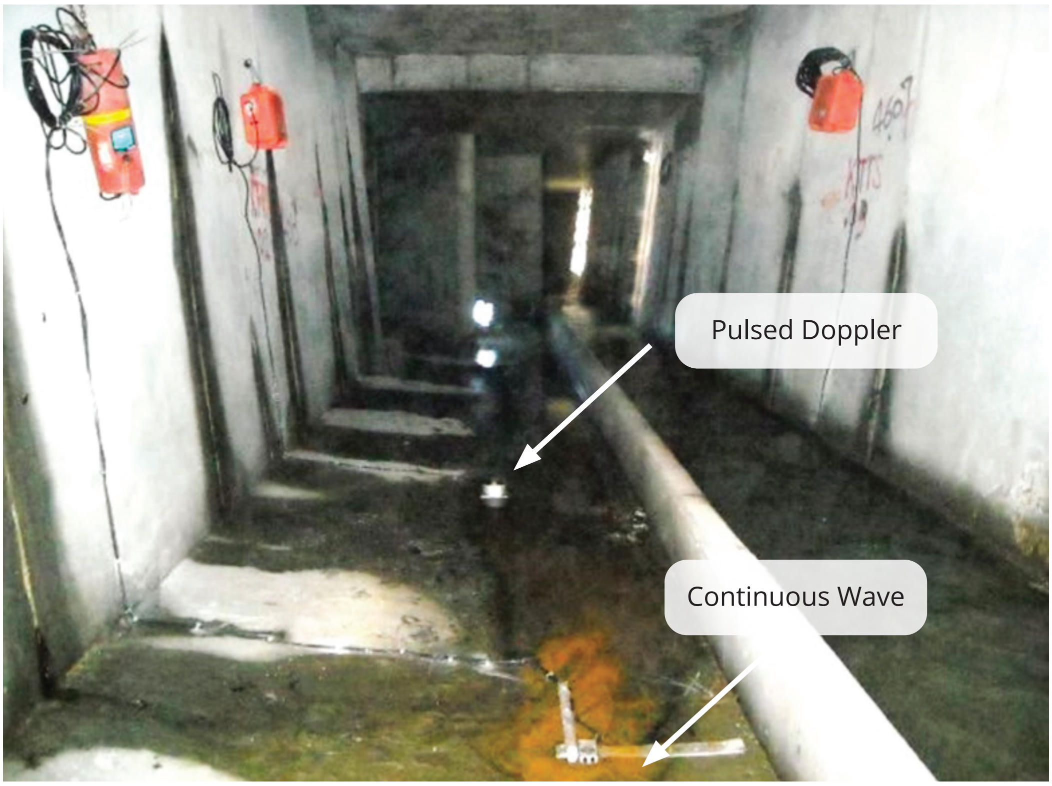
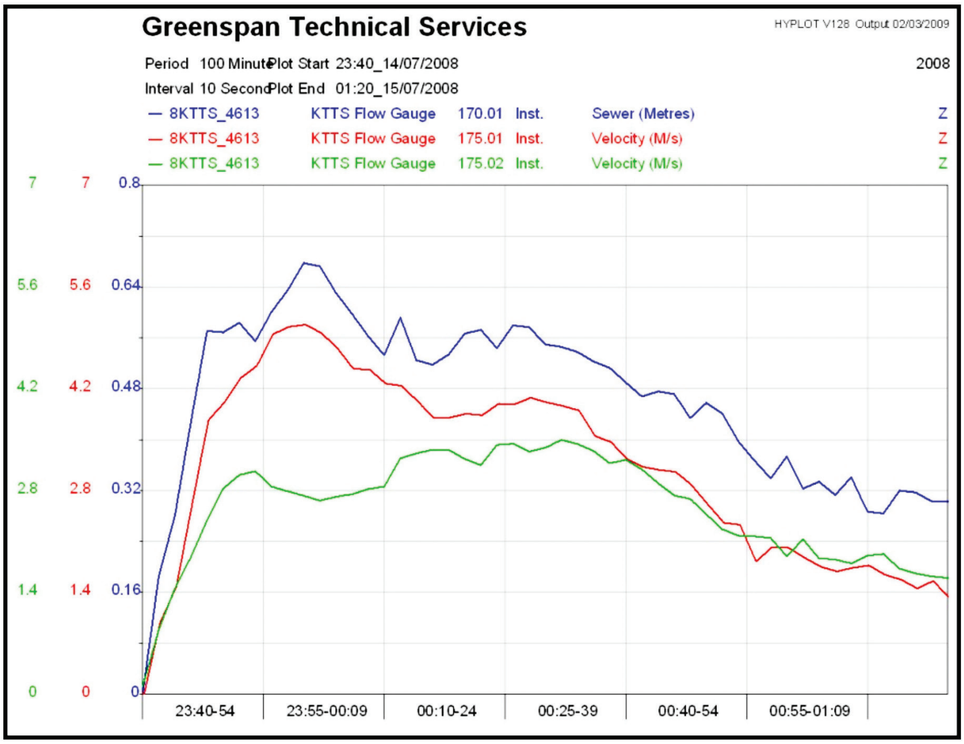


Figure 8. Installation photo of two Doppler sensors.

Acknowledgment: Greenspan Singapore PTE LTD for the use of photos.

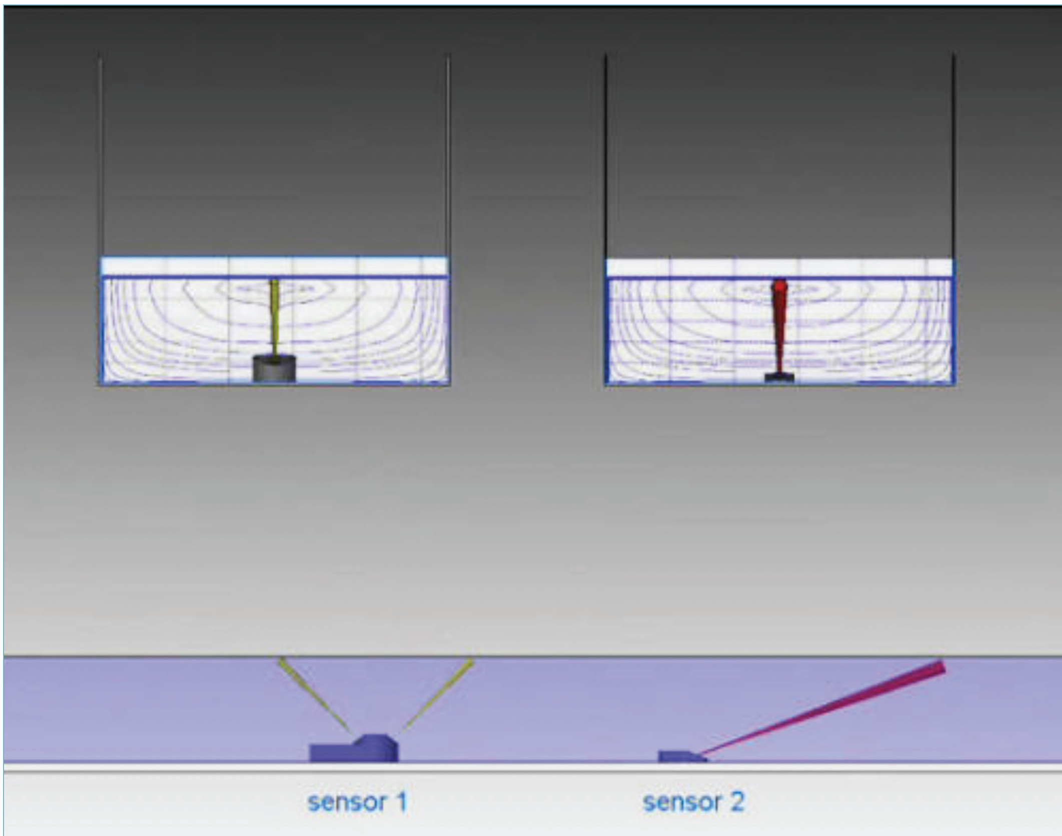
Data collected indicated that between the two sensors, data correlated very well until approximately 0.4 m; however as water level increased there was a significant difference between the two sensors.



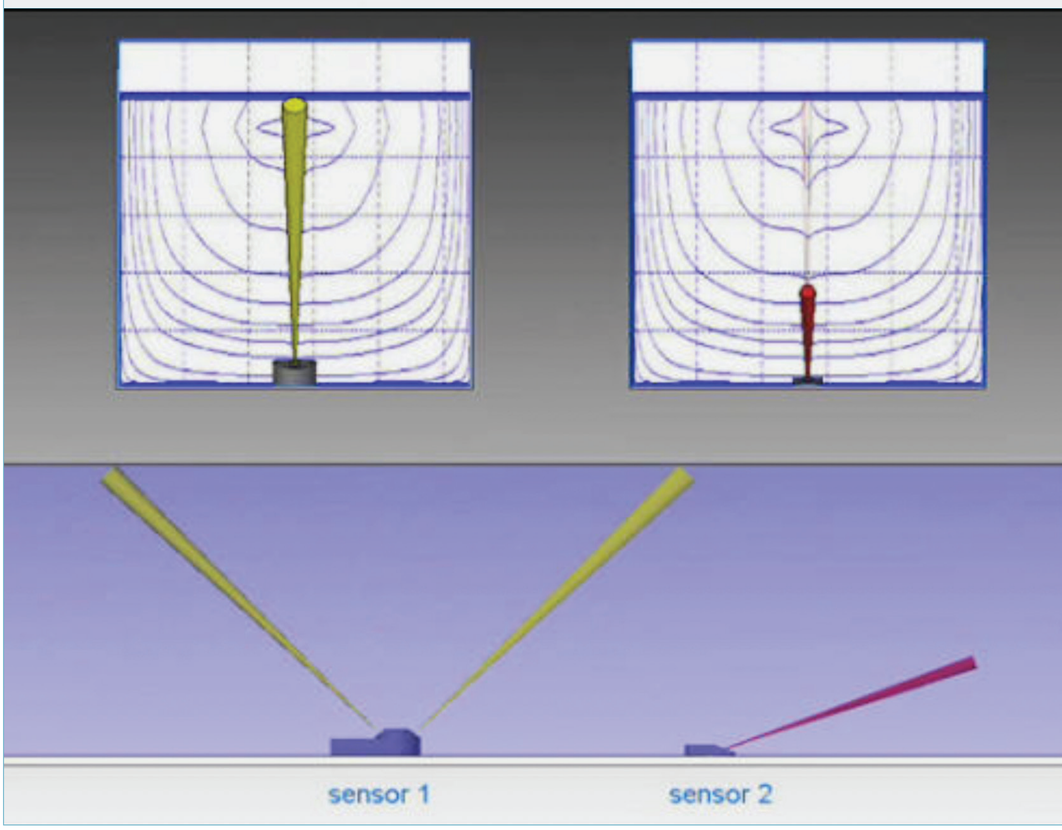
Hydrograph showing good correlation between the pulsed Doppler (red) and continuous wave (green) during low water levels but large difference during high water events.

Figure 9. Hydrograph of water level and measured velocity from two Doppler systems.

The reason for the difference can be shown in the below diagrams.



Shallow water, both sensors are measuring the same vertical profile.



Deeper water, the pulsed Doppler continues to measure the entire vertical profile.

Figure 10. Beam measurement area during low and higher water levels.

Acknowledgement: Greenspan Singapore PTE LTD for the use of diagrams.

Given the difficulties with accessing sites in urban drains, it is important for hydrographers to understand the instrument measurement methods in order to propose the correct instrumentation at the best price for the monitoring assignment. If the water is very shallow, this data comparison indicated very good correlation between the pulsed doppler and the continuous wave. Conversely, in higher water level conditions significant differences were found which can be visualised as a function of the way a sensor takes its measurement.

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From the Vault: Statistical Indicators to Assess Gauging Station Performance

Allan Deane, Regional Resource Measurement Services Officer, Perth South Region, Water Authority of Western Australia[3]

Russell Marks, Principal Hydrographer, Greenbase Consulting Pty Ltd[4]

Paper presented to 9th Australasian Hydrographic Workshop, Sydney, 27-31 March 1995

Abstract

The accuracy of hydrographic data has important consequences in the use to which the data is being put. Data accuracy and reliability is directly related to the performance of individual gauging stations, however, an objective measure of performance has long eluded hydrographic practitioners.

The Perth South Region of the Water Authority of Western Australia has developed and is trialling a set of statistical indicators to assess the performance of its streamflow gauging stations. These indicators are relatively easy to apply and have provided assessment and ranking which is compatible with more subjective assessments by station operators. The indicators are based on analysis of conventional factors related to rating curves and recording equipment. To date the approach has proved valuable in demonstrating to stakeholders the need and type of action required at particular gauging stations to improve data accuracy and reliability.

Introduction

One of the enduring issues for hydrography has been the problem of objectively assessing the performance of streamflow gauging stations (gauging stations). It has long been recognised that the solution to this problem will assist hydrographers managing the gauging network, firstly; by providing an indication of the accuracy of flow data being produced from any gauging station; secondly; by providing a means of quantifying the resources (inputs) required to produce data of a specified quality (outputs); and thirdly; by providing a means to allocate additional resources to particular gauging stations to improve the quality of data produced.

Confidence limits on the data produced from gauging stations are seen as essential to reliable hydrologic studies (Katergaris & Hardgraft, 1994). With the introduction of quality systems gaining pace in hydrography the solution to the above problem is seen as an imperative for hydrographers.

In response to customer demand and in the pursuit of quality management, the Water Authority of Western Australia's (Water Authority) Perth South Region, in consultation with Greenbase Consulting Pty Ltd, has developed and is currently trialling a statistical approach to assessing gauging station performance.

This paper describes the development of two statistical indicators which can be derived from the rating curve and the flow record. The indicators are: Accuracy of the Derived Flow (ADF); and Station Performance Index (SPI). These indicators are based on Rating Sensitivity, Rating Uncertainty and Stage Uncertainty, and are linked to Accumulated Flow Weighted Yield values.

[3] Now Retired.
[4] Currently the semi-retired Chairman of Greenbase Pty Ltd.

Assessment Factors

Stage Uncertainty

Stage Uncertainty (Refer to Figure 1) is the error associated with the precision of the stage recording device.

Uncertainties in stage values are usually systematic and dependent upon the instrument used to detect the water level at the gauging station. The water level transducer widely used by the Water Authority is the Unidata optical shaft encoder, which is generally accepted as having an accuracy of ±2 mm irrespective of the stage value.

Rating Sensitivity

Rating Sensitivity (Figure 1) is well documented in hydrographic and hydrologic literature. Suffice to say, that it is the slope of the tangent to the rating curve at the flow value in question. As such, sensitivity is inversely related to flow.

In the Water Authority the units of Rating Sensitivity are percent per millimetre (%/mm). The design criterion adopted is to achieve a sensitivity of <1%/mm at the 20th percentile of Yield.

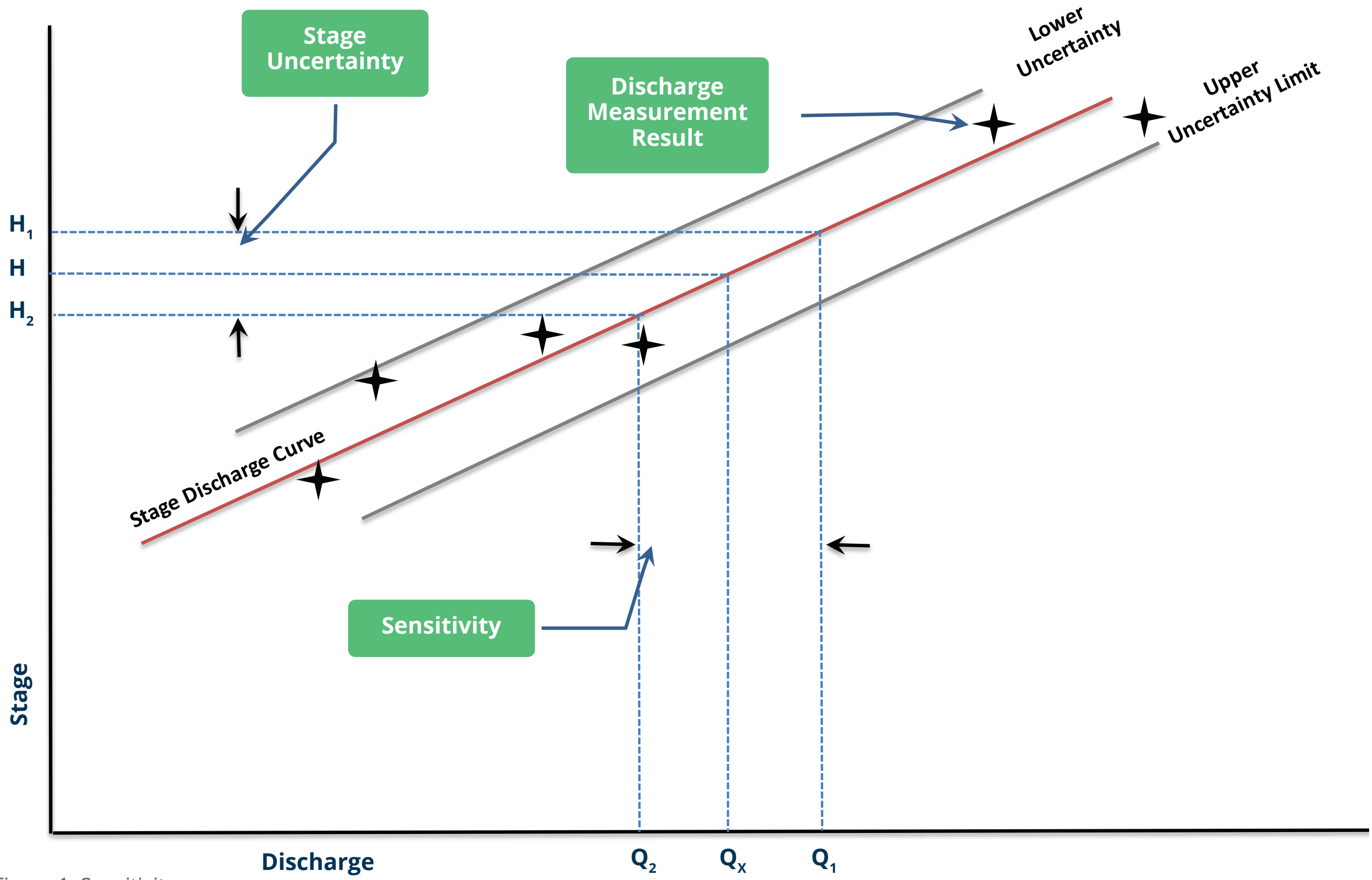

Figure 1. Sensitivity.

Example 1

The following are two points on a rating curve: [Stage 10.059, Flow 0.037] and [Stage 10.070, Flow 0.050]. Sensitivity at flow 0.037 is therefore:

$$\text{Sensitivity@ } Q_x = \frac{Q_1 - Q_2}{Q_x} * 100\% * \frac{1}{(H_1 - H_2) * 1000}$$

$$\text{Sensitivity@ } 0.037 = \frac{0.050 - 0.037}{0.037} * 100\% * \frac{1}{(10.070 - 10.059) * 1000}$$

$$\text{Sensitivity@ } 0.037 = 3.19\% \text{ /mm}$$

It can be seen therefore that errors introduced by rating sensitivity are significantly impacted by the accuracy of the stage measuring device (Stage Uncertainty).

Sensitivity is an important factor in determining accuracy of instantaneous flow values but becomes statistically less significant in determining daily, monthly and annual accumulated flows. For accumulated flows the key issue becomes the stability of the controlling feature and consequently the rating curve. Nevertheless sensitivity remains a factor in assessing overall performance.

Rating Uncertainty

Rating Uncertainty (Figure 2) is the uncertainty associated with a flow value derived by interpolation from the rating curve. The rating uncertainty is calculated independently of any uncertainty in the stage value from which the flow value is derived.

In simple terms, it can be determined from the spread of discharge measurement results at the stage value in question. The competent hydrographer however, will take into consideration other factors, such as the physical feature controlling the relationship, particularly for ratings or sections of ratings which have no discharge measurements. Inevitably this introduces a subjective element to the assessment.

Uncertainty is expressed as a percentage either side of the rating curve (±%).

The uncertainty, at a particular flow value, is determined by:

I. Estimating the lower limit and the upper limit of the interpolated flow value; and

II. Calculating the difference between the two in relation to the flow value itself.

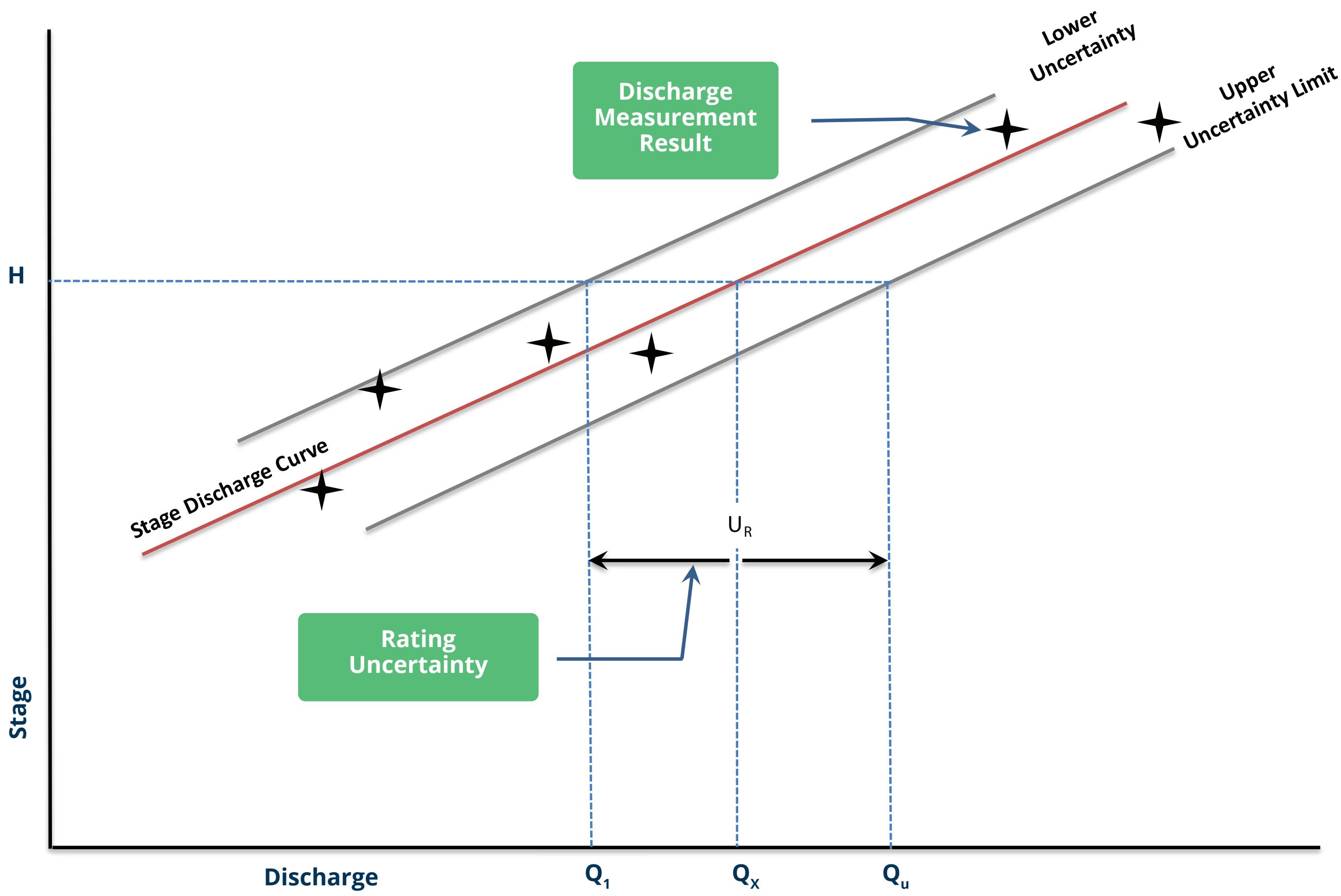

Figure 2. Rating Uncertainty.

Example 2

The 10th percentile of yield for the same gauging station as in Example 1 occurs at stage 10.059, flow 0.037. From an examination of the spread of discharge measurements at stage i0.059, the lower limit of flow was estimated to be 0.035 and the upper limit was estimated to be 0.040. The Rating Uncertainty is therefore:

$$\text{Uncertainty@ } Q_x = \pm \frac{1}{2} * \frac{Q_u - Q_l}{Q_x} * 100\%$$

$$\text{Uncertainty@ } 0.037 = \pm \frac{1}{2} * \frac{0.040 - 0.035}{0.037} * 100\%$$

$$\text{Uncertainty@ } 0.037 = \pm 6.76\%$$

Percentile of Yield

The Percentile of Yield is described as the percentage of total flow volume generated from discharge rates equal to or less than the specified instantaneous values.

Example: If 10% of the total flow past a· given gauging station is generated below say Stage 10.059 (0.037 m^3/s) then Stage 10.059 (0.037 m^3/s) is said to be the 10th percentile of yield for that station.

Accuracy of Derived Flow (ADF)

The accuracy of a flow value (Figure 3) derived from a rating curve can be deduced from the stage uncertainty sensitivity, and rating uncertainty values.

(Note: When calculating the stage uncertainty it is assumed that the stage transducer is correctly calibrated.)

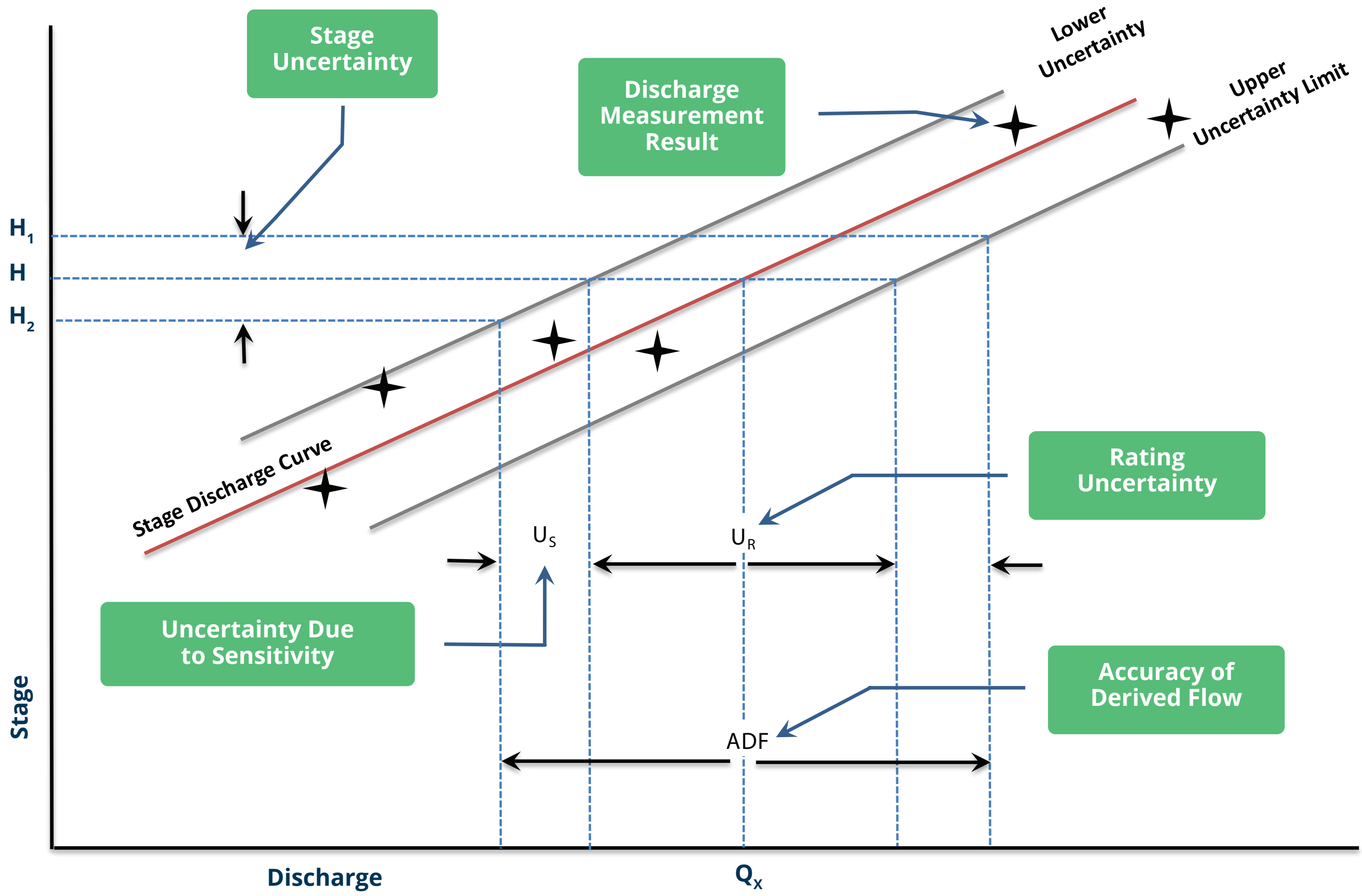

Figure 3. Accuracy of Derived Flow (ADF).

Put simply, if the stream was to flow for a day at a constant discharge, the ADF value would represent the accuracy of the quoted flow value.

Example 3

Using the same information as in the previous examples and assuming the water level transducer is accurate to ± 2 mm, the ADF at the 10th percentile of flow is given by:

$$ADF = \pm\sqrt{((\text{Stage Uncertainty} * \text{Sensitivity})^2) + \text{Uncertainty}^2}$$

$$ADF = \pm\sqrt{((2\ mm * 3.19\%)^2) + (6.76\%)^2}$$

$$ADF = \pm\ 9.29\%$$

Station Performance Index (SPI)

The concept of the Station Performance Index arises from the desire to rank stations according to their performance in providing accumulated flow data.

To achieve this, flow weighted yield for each station is derived and flow values (and stage values) corresponding to the 10th, 20th, 50th, 80th and 90th percentile of yield are extracted.

ADF values for the 10th, 20th, 50th, 80th & 90th percentiles are then calculated.

Each ADF value is then weighted by a proportion of the total yield. It is assumed that the ADF for the 10th percentile represents the first 15% of yield (i.e. the mean between 10 & 20); the 20th percentile represents the next 20% of yield; the 50th percentile represents the next 30% of yield; the 80th percentile represents the next 20% of yield; and the 90th percentile represents the remaining 15% of yield. The sum of the weightings equals 100%.

The SPI is then calculated as the sum of the weighted ADF values.

Example 4

Continuing with the previous example, ADF values for the 10th, 20th, 50th, 80th & 90th percentiles are respectively: ±9.3%, ±7.9%, ±7.3%, ±7.1%, ±6.0%. The Station Performance Index is derived as follows:

$$SPI = \pm\ [(0.15 * ADF_{10^{th}}) + (0.2 * ADF_{20^{th}}) + (0.3 * ADF_{50^{th}}) + (0.2 * ADF_{80^{th}}) + (0.15 * ADF_{90^{th}})]$$

$$SPI = \pm\ [(0.15 * 9.3) + (0.2 * 7.9) + (0.3 * 7.3)\ \text{-t}\ (0.2 * 7.1) + (0.15 * 6.0)]$$

$$SPI = \pm\ 7.5$$

Initial Assessment of Gauging Stations

Using the assessment factors described above the Water Authority evaluated all gauging stations in its Perth South Region (66) in 1993 (Deane *et al*, 1993).

Each gauging station was assessed and the ADF determined for the 10th, 20th, 50th, 80th & 90th percentiles of Yield, an example of the assessment is shown in Table 1.

The results of the ADF analysis were then used to determine the SPI for each site. Stations were then ranked according to the SPI and the results tabulated. The results are shown in Table 2.

Table 1. Results of ADF analysis

616023 WATERFALL GULLY - MT CURTIS
APPRAISAL OF CURRENT STAGE-DISCHARGE RELATIONSHIP

Current Curve: 005 | **Application:** 28/4/82 - 2/5/99

Last Reviewed: April 91 | **Cease To Flow:** 10.000 mSL

Percentiles of Volume		Sensitivity	Uncertainty	ADF	Target ADF
10th	10.202 mSL	1.24%/mm	±16.0%	±18.5%	±10.0%
20th	10.233 mSL	1.08%/mm	±13.0%	±15.2%	±10.0%
50th	10.308 mSL	0.81%/mm	±11.0%	±12.6%	±10.0%
80th	10.400 mSL	0.63%/mm	±9.5%	±10.8%	±10.0%
90th	10.445 mSL	0.56%/mm	±6.5%	±7.6%	±7.6%

Assessment of Gaugings:

Total Gaugings for Station: 50 | **Gaugings in Last 5 years:** 8

No since Current Curve defined: 15 | **Time Since Last Gauging:** 6 mths

No above 10th %ile: 41/50, 14/15

No above 20th %ile: 35/50, 11/15

No above 50th %ile: 23/50, 8/15

No above 80th %ile: 7/50, 4/15

No above 90th %ile: 2/50, 0/15

No within ±2% of curve: 2/15

No within ±4% of curve: 3/15

No within ±7% of curve: 9/15

No outside ±7% of curve: 6/15

Comments:

(i) Weir controls all flows.

(ii) Instability caused by siltation and approach velocities.

Gauging Priorities

10.200 & above ESSENTIAL. Increment 0.025 mSL.

Table 2. Stations ranked by SPI

Rank	GS No	Name	ADF at Percentile of Yield 10th	20th	50th	80th	90th	SPI
1	616045	Mt Lawley Main Drain	101.0%	89.7%	50.9%	10.7%	6.9%	51.5
2	616018	Craignish	63.1%	36.6%	7.5%	5.3%	5.2%	20.9
3	614077	Marri Park	32.5%	23.6%	18.6%	15.1%	14.2%	20.3
4	616043	Palm Place	28.3%	31.2%	21.5%	10.0%	7.6%	20.1
5	616038	Ballajura Drain	27.3%	23.6%	15.7%	12.6%	12.4%	17.9
6	614017	Warren Catchment	26.4%	21.3%	18.7%	12.7%	9.8%	17.8
7	614013	Peel Drain	20.0%	21.4%	17.5%	15.5%	8.4%	16.9
8	614031	Jacks Rocks	34.2%	17.6%	14.0%	6.7%	4.7%	14.9
9	616022	More Seldom Seen	16.2%	15.8%	15.2%	12.8%	12.0%	14.5
10	614024	Jones Catchment	33.1%	18.4%	10.6%	7.2%	6.4%	14.2
11	614062	Bates	25.3%	22.2%	11.1%	6.6%	6.0%	13.8
12	616023	Waterfall Gully	18.5%	15.2%	12.6%	10.8%	7.6%	12.9
13	616007	Rushy Ck	17.2%	14.1%	9.7%	9..9%	8.8%	11.6
14	616031	Araluen	12.3%	11.7%	11.1%	11.2%	11.1%	11.4
15	616010	Hairpin Bend	20.5%	12.9%	7.6%	8.9%	9.8%	11.2
16	616232	Kumbaduru	19.2%	13.5%	8.9%	8.4%	8.0%	11.1
17	614020	Higgens Catchment	22.3%	16.4%	7.9%	6.3%	5.1%	11.0
18	614068	Nth Dandalup Townsite	11.7%	11.3%	10.9%	10.6%	10.6%	11.0
19	614069	McMahon Rd	10.9%	10.7%	10.4%	10.4%	10.3%	10.5
20	614074	Serpentine Pipehead	11.0%	10.6%	10.4%	10.3%	10.3%	10.5
21	614070	Lanstal Park	10.8%	10.5%	10.1%	10.2%	10.2%	10.3
22	614079	Lyon Road	17.5%	12.2%	8.7%	7.0%	6.4%	10.0
23	616046	Hartfield Park	20.1%	12.2%	9.0%	5.4%	4.8%	10.0
24	614019	Hansens Catchment	18.4%	14.1%	7.7%	5.4%	4.9%	9.7
25	614018	Bennetts Catchment	21.6%	10.7%	7.3%	6.4%	5.5%	9.7
26	616014	Furfaros Orchard	19.9%	12.2%	6.5%	6.6%	4.5%	9.4
27	614021	Lewis Catchment	16.7%	13.8%	8.4%	4.8%	3.0%	9.2
28	614071	Hammond Rd	12.1%	11.1%	7.6%	6.8%	6.3%	8.6
29	616025	Rocky Valley	8.0%	5.3%	13.0%	6.3%	7.5%	8.5
30	616153	Kargotich	11.6%	10.3%	7.8%	6.6%	6.1%	8.4
31	616015	Littlefield Road	12.6%	14.1%	7.1%	4.0%	3.3%	8.1
32	616026	31 Mile Brook	14.3%	10.8%	8.4%	2.7%	4.9%	8.1
33	616012	Trewd Road	17.1%	10.3%	6.3%	4.5%	3.7%	8.0
34	616009	Slavery Lane	14.8%	12.4%	6.6%	4.1%	3.1%	8.0

Table 2. Stations ranked by SPI

			ADF at Percentile of Yield					SPI
Rank	GS No	Name	10th	20th	50th	80th	90th	
35	616056	Light St	12.4%	7.9%	7.3%	7.1%	6.0%	8.0
36	616178	Jane Brook	12.7%	11.2%	8.3%	3.9%	3.0%	7.9
37	616027	McKenzie Grove	16.0%	9.9%	6.7%	5.0%	2.9%	7.8
38	614005	Kentish Farm	13.5%	10.2%	6.4%	5.1%	4.8%	7.7
39	616047	Austin Ave	12.0%	8.6%	9.5%	3.3%	3.6%	7.6
40	616044	Abbey Rd	11.9%	10.3%	6.1%	5.0%	3.9%	7.3
41	614030	Dog Hill	14.5%	8.4%	2.1%	5.8%	7.2%	6.7
42	616002	Darkin Pine Plantation	6.6%	9.4%	6.0%	6.9%	2.9%	6.5
43	616040	Susannah Bk	10.0%	7.0%	4.7%	5.2%	3.6%	5.9
44	614059	Skeleton Road	7.9%	9.4%	5.0%	3.9%	2.4%	5.7
45	616216	Poison Lease	6.4%	5.6%	5.1%	5.2%	5.7%	5.5
46	616021	Seldom Seen	7.8%	6.4%	4.9%	4.5%	4.4%	5.5
47	614078	Thomas Rd	6.1%	5.2%	4.4%	6.2%	6.3%	5.5
48	614028	Hopelands Road	9.9%	7.7%	4.5%	3.9%	1.9%	5.4
49	614072	Serpentine Falls	7.1%	3.5%	5.4%	5.5%	5.4%	5.3
50	616189	Ellen Bk	6.9%	4.3%	6.9%	2.3%	1.7%	4.7
51	616042	Brixton St	9.9%	6.9%	3.1%	2.3%	2.6%	4.6
52	616013	Ngangaguringuring	10.6%	6.9%	3.2%	1.7%	1.2%	4.5
53	614073	Gooralong Bk	7.7%	5.9%	4.3%	2.1%	1.7%	4.3
54	614037	O'Neil Road	4.7%	3.9%	2.3%	5.3%	6.0%	4.1
55	616041	Vardi Rd	6.7%	6.6%	3.3%	1.7%	1.9%	3.9
56	614033	Below Main Dam	5.2%	3.8%	3.2%	3.2%	3.2%	3.6
57	614035	River Road	6.2%	3.6%	3.4%	2.6%	1.7%	3.4
58	616065	Gleneagle	2.6%	2.3%	2.8%	1.9%	2.2%	2.4
59	614036	North Road	2.6%	2.5%	2.3%	2.2%	2.1%	2.3
60	616066	Kangaroo Gully	2.5%	4.2%	2.3%	1.1%	1.0%	2.3
61	616003	Kalamunda Road Bridge	No Flow Duration					
62	616004	Meadow Street	No Rating					
63	616039	Millars Road	No Rating					
64	616048	Canning Dam	No Rating					
65	616058	Cobiac	No Rating					
66	616061	Mundaring Weir	No Rating					

Actions at Gauging Stations

In the absence of specific direction from customers (utilisers of the data) a nominal SPI of 10 was chosen as the indicator of whether or not a site required attention.

Where the SPI was above 10 the ADF results were re-examined and actions initiated to improve the SPI. These actions are site specific to take into account the individual site characteristics and customer requirements. Some actions, such as replacing weir plates, target Sensitivity while other actions, such as replacing floatwells, enlarging stilling pools, etc., target Rating Uncertainty.

Discussion

The results obtained using the SPI compared favourably with subjective assessments of the gauging stations by operating staff and the problems identified were generally known. The advantage of using the SPI method was in providing statistical measure as opposed to a purely subjective measure. An additional outcome of the analysis has been to enhance the general awareness among hydrographic staff of the performance of various stations and the relationship between station operation and customer expectations.

The SPI has been used to demonstrate the need to take action at specific stations to improve data quality.

A number of actions at stations have been approved and are currently being implemented. In addition rating review procedures have been modified to systematically produce regular ADF and SPI assessments as part of all rating reviews.

As the specific initiatives are implemented continued monitoring of the assessment factors is expected to reflect positive changes in the SPI and hence accuracy and value of the data. In time the results should provide a better indication of the effectiveness of the ADF and SPI as indicators of station performance.

Limits of Application

The method described has been developed for use at gauging stations from which flow results are derived by means of conventional stage/discharge relationships.

It is stressed here that these indicators are indicators only and do not necessarily reflect the uncertainty of any specific flow result: Their intended use is primarily directed at producing indicators to guide hydrographic management decisions.

(Note: HYDSYS, in conjunction with the Water Authority, are currently developing more detailed statistical methodologies for the analysis of rating curves in order to apply uncertainty values to published data.)

Conclusion

The Accuracy of Derived Flow and Station Performance Index have highlighted differences in the performance of various gauging stations. Initial indications are that they will provide the Water Authority with a valuable statistically based decision support tool.

The method is one approach which can be simply and easily applied by hydrographic staff to support and plan management actions, guide resource allocation and progress quality improvements.

Addendum

It has been 25 years since this paper was presented to the 9th Australasian Hydrographic Workshop in Sydney.

In WA the Water Corporation, DWER and some private Hydrographic entities continue to use the ADF and SPI statistical indicators (or variants of them) to assess the performance of their gauging stations.

As demonstrated by the below examples this form of assessment has proven extremely useful in:-

I. Communicating, to the users, the ongoing performance of its streamflow gauging stations;

II. Determining potential areas for improvement be it:-

   a. Gauging priorities; or

   b. Asset upgrades/improvements.

III. Informing cost benefit assessments for the ongoing operation;

IV. Supporting applications for capital funding (for site enhancements/repairs).

Case Study 1: Samson Dam Environmental Release Trial.

The *"Samson Brook Environmental Water Provisions Review"* was commissioned in July 2014 to demonstrate if the Water Corporation of WA could reduce the current base-flow levels through the Samson System (located in the South West of WA) without adversely impacting on the ecological processes within the reach. Further details on this project are available in Bellhouse *et al*, 2019.

The aim of the trial was to provide sufficient evidence to the Department of Water and Environmental Regulation (DWER) that a permanent reduction in the summer base-flow component of the Samson Brook EWP could be sustained without adversely impacting on the ecological processes within the reach.

In order to demonstrate the trial is required to quantify the minimum flow rate required in order to:-

- Maintain the connection between pools along the Samson Brook Reach;
- Maintain dissolved oxygen along the Samson Brook Reach above 5 mg/L.

Flow Monitoring was commissioned at a total of six sites along the Samson reach. This included at two existing compliance flow monitoring points.

In 2019 as the trial was just about to commence its second stage (the reduced release portion) the ADF and SPI statistical indicators for the sites were reviewed (aided by a specifically designed spreadsheet developed by Russell Marks, Greenbase Pty Ltd) to ensure that the flow monitoring results were meeting the data needs of the trial.

An example of a Station Performance Indicator worksheet is shown in Figure 4 whilst the overall results are summarised in Table 3.

ΣΔ GREENBASE Pty Ltd
ACN 109 129 982 ABN 21 109 129 982
PO Box 145 WILLETTON WA 6955

Version: 20075406243016

STATION PERFORMANCE INDICATOR

Site: 6215W001 Samson Brk at 1st Below Pipehead Section #1

Stage Uncertainty ± 8 mm

Station Rating		Discharge Measurements					
Stage	Q	DM No	Date	Stage	Q	$Q^{0.4}$	Incl
49.500	0.0000	1	17/06/2015	49.701	0.056	0.316	Y
49.540	0.0041	2	29/08/2017	49.750	0.061	0.327	Y
49.584	0.0105						N
49.624	0.0201						N
49.664	0.0335						N
49.700	0.0560						N
49.736	0.0944						N
49.812	0.2097						N
49.908	0.5862						N
50.045	1.8933						N
50.129	3.1671						N
50.209	4.9752						N
50.454	15.0000						N
							N
							N
							N
							N
							N
							N
							N
							N
							N
							N
							N

% ile	Flow	Stage	S%	UH	Left Bound	Right Bound	UQ	ADF
10th	0.075	49.719	1.4%	11.6%	0.035	0.084	32.5%	34.50%
20th	0.096	49.737	1.2%	9.9%	0.045	0.108	32.5%	33.97%
50th	0.166	49.787	1.0%	7.9%	0.075	0.186	33.5%	34.43%
80th	0.461	49.882	1.0%	7.7%	0.198	0.526	35.5%	36.32%
90th	0.651	49.918	1.1%	8.4%	0.267	0.755	37.5%	38.43%

Station Performance Index 35.33%

Tramlines	0.470	1.120				
Stage	Left Q	Right Q	$LeftQ^{0.4}$	$RightQ^{0.4}$	LeftDiff	RightDiff
49.500	0.000	0.000	0.0000	0.0000		
49.540	0.002	0.005	0.0821	0.1162		
49.584	0.005	0.012	0.1196	0.1692		
49.624	0.009	0.022	0.1548	0.2190		
49.664	0.016	0.037	0.1899	0.2688		
49.700	0.026	0.063	0.2334	0.3303		
49.736	0.044	0.106	0.2876	0.4070		
49.812	0.099	0.235	0.3958	0.5602		
49.908	0.276	0.657	0.5971	0.8451		
50.045	0.890	2.121	0.9544	1.3508		
50.129	1.489	3.547	1.1725	1.6594		
50.209	2.338	5.572	1.4046	1.9880		
50.454	7.050	16.800	2.1841	3.0912		

Figure 4. Station Performance Indicator Tool developed by Greenbase Pty Ltd.

Table 3. Station Performance Assessment results Samson Brook Environmental Water Provisions Review

Station ID	Station Name	Derivation Date	SPI Value & Rating ID	Comment
W8000969	SAMSON BROOK AT BELOW DAM	21/08/2019	09.4% Rating 013-06/18	Based upon >25 DMs[5] well spread across all flow percentiles
W8002559	SAMSON BROOK AT BELOW PIPEHEAD DAM	19/08/2019	12.5% Rating 003-02/19	Based upon 8 DMs well spread across 10th-80th flow percentiles
6215W003	SAMSON BROOK AT S-WEST HWY BRIDGE	20/08/2019	16.2% Rating 000-01/16	Based upon 8 DMs reasonably spread across 5th-70th flow percentiles
6215W000	SAMSON BROOK AT SCARP ROAD BRIDGE	20/08/2019	21.0% Rating 000-01/16	Based upon 6 DMs well spread across 20th-80th flow percentiles
6215W002	SAMSON BROOK AT PADDOCK EAST L30	20/08/2019	26.6% Rating 000-01/16	Based upon 6 DMs reasonably spread across 5th-65th flow percentiles
6215W001	SAMSON BROOK AT 1ST BELOW PIPEHEAD	20/08/2019	35.3% Rating 001-01/16	Based upon 2 DMs only at 10th and 20th flow percentiles

Following a review of the Station Performance Assessment results by the client the following recommendations were made:-

- **6215W001:** Assessment of the ADFs indicates a better dispersion of gaugings are required between the 10th to the 50th %iles. Given the trial is looking at the impact of lowering the baseflow releases improving the accuracy of the derived flow in the low flow zones should be the particular focus.
- **6215W002:** Further discharge measurements are required in the 20th %ile. Improving the ADF above the 80th %ile is a nice to have but it is not considered essential. It is recognised that gauging opportunities in this portion of the flow regime are rare.
- **6215W000:** Assessment of the ADFs indicates a better dispersion of gaugings are required between the 10th to the 50th %iles. It is however acknowledged that the flows in this reach are reflective of the transfers between the main dam and pipehead and as such they are unlikely to linger in the lower zones. This is therefore a really nice to have but is considered a lower priority.
- **6215W003:** The SPI is reasonable, given the location of the site at the end of the study reach (and hence represents the lower most management point) some improvement is preferable. The measurement team are requested to focus on improving the ADF between the 20th and 80th ranges.

In addition to the above recommendations the measurement team also investigated the installation of temporary ADCPs at a number of the key sites in addition to completing more targeted gauging's.

Reviews of the ratings and maintenance of the ADFs and SPIs are ongoing. As a consequence the project has since observed improvements in the accuracy of the derived flows.

[5] Discharge measurements.

Case Study 2: Wungong Catchment Trial – Vardi Rd Gauging Station.

The aim of the Wungong Catchment Trial was to demonstrate improved water yield in a water supply catchment via enhanced silvicultural management. The Wungong catchment was selected because of its less than pristine state, discrete size, accessibility and extensive hydrologic monitoring history.

For the trial outcomes to have creditability it was essential the hydrologic data collected was of a high and known quality in order to quantify impacts of the treatments on the quantity, quality and variability of streamflow.

Competent hydrographic teams from Hydro-SMART and the then Western Australia Department of Water (DoW) were employed to work jointly on this project. In total and extensive network of 21 streamflow stations and 24 pluviographs were operated during the trial.

One of the trial sites, the Vardi Rd Gauging Station, had been providing reliable and reasonably accurate flow record for its 80.84 km^2 catchment since May 1981.

The site is well constructed and equipped conventional float-well configuration, with a stable low crest crump weir installed on a rock bar base.

However a decade prior, to the site becoming part of the trial, very few gaugings had been obtained. To rectify this during the early years (2005 to ~2008) considerable effort was expended on verifying, or redefining, the station's rating relationship. The gauging efforts prioritised utilising a range of tools including a range of station performance statistics.

By late 2008–early 2009, a range of evidence indicated an apparent 3% to 5% (flow negative) shift in the relationship, compared to the original. The clearest evidence of this shift appeared in the low to mid flow ranges of 'catchment yield' (or mid Percentiles of Yield).

Accurately identifying the magnitude of change pushed the limits of confidence for conventional hydrographic assets, instruments and practices, brought into question the 'calibration' evidence for current meters and the validity of applying of the gauging results.

One piece of evidence that supported the apparent change, was the slightly eroded or ‘corroded' condition of the crump weir surface, in comparison to its original condition.

In order to improve the confidence in the resultant flow data a range of evidence including the ADF statistics was presented in order to secure capital funding for site improvements. The primary enhancement the resurfacing of Weir confines back to its original condition and finish.

As a consequence of this work the final flow data gathered at this station during the trial was generally assessed (utilising statistical indicators including the ADFs and SPI) as being in the confidence range ±3% to ±4%.

Figure 5. Vardi Rd Gauging Station Weir prior and post resurfacing.

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