Australasian Hydrographer

December 2020

AUSTRALIAN
HYDROGRAPHERS
ASSOCIATION

AHA

Australian Hydrographers Association
National Office
02 6296 3635
services@aha.net.au
PO Box 1006
Mawson ACT 2607
Australia

Editorial Team

Jacquie Bellhouse BSc CPH
(Editor-In-Chief)
Harrison Schofield BSc
Zac Ward CPH

publication.thinktank@aha.net.au

Style Editor

Grant Robinson

Design

ByFriday
1300 BYFRIDAY (1300 293 793)
design@byfriday.com.au
www.byfriday.com.au

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Acknowledgement of Country

The AHA acknowledges the Australian Aboriginal and Torres Strait Islander peoples of this nation. We acknowledge the traditional custodians of the lands on which our association is located and where we conduct our business. We pay our respects to ancestors and Elders past, present and emerging. The AHA is committed to honouring Australian Aboriginal and Torres Strait Islander peoples' unique cultural and spiritual relationships to the land, waters and seas and their rich contribution to society.

JACQUIE BELLHOUSE

Editor-In-Chief's Introduction

As 2020 works its way to a close it is perhaps a good time to reflect on what we have overcome (in such a short time) and cast our eyes to where we are heading from here.

With that last point in mind, December's edition of the *Australasian Hydrographer* is an exciting one as it is the first to be edited by our extended editorial team. I think you will agree that both its editor Zac Ward (check out his Member Profile) and sub-editor Harrison Schofield have done a brilliant job!

In this edition Zac has chosen to look back at the final two papers from our 2018 AHA Conference Series *"Continuous Water Quality Monitoring - How to survive extreme events"* and *"The Cost of Unseen Extreme Anomalies and the Link Between Coastal and Upstream Systems"* with thanks to Roman Kadluczka, Melody Wu, Manly and Sam Maddox, all from Manly Hydraulics Laboratory.

We are also fortunate enough to be able to offer the first of the papers from the AHA's inaugural e-Conference *"Irrigation Efficiency Crucial for Ensuring Sustainable Water Resource"* from a regular contributor to the *Australasian Hydrographer* Daniel Wagenaar. I hope everyone has had a chance to either attend the e-conference or review the recordings available on the AHA website.

Finally, I would like to say a short word of thanks to the AHA's outgoing committee members and a welcome to the incoming members. Thanks to both teams for volunteering your precious time to keep the AHA moving forward in these interesting times.

Jacquie Bellhouse CPH
Editor-In-Chief

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ARRAN CORBETT

From the President

It is usual at this point in the year to reflect on the challenges and accomplishments in our recent past… but I am sure you will support my decision to avoid that this year and instead focus on the future.

There is a growing sense of optimism in our Association as we head in to 2021, we have near record membership numbers, our corporate partnership is growing by the day and we are negotiating our way to holding a face to face conference in the middle of next year (standby for more information).

In Q1 2021 we will be kicking off enrolments for our new training package with new RTO partners TTC and launching the NSW Open-Channel Meter Installation course. I hope to build on this success with a focused training team to ensure our members receive the support they require to help them flourish in our industry.

From a more technical perspective, we will see the launch of the new National Industry Guideline for Non-Contact Flow Measurement. Publishing this body of work will allow the exciting field of camera discharge measurements to really gain a foothold.

I believe that we will also see a continued push towards low cost telemetry options and hopefully a resulting increase in resource monitoring granularity. This to me is why our strong relationship with our corporate partners is so important. Our members have demonstrated a willingness to field test and provide meaningful feedback, which is another area I believe that our Association can do more to support.

What I am looking forward to most is the opportunity to come out and meet with you, to hear in person what challenges and opportunities you have and do what we can to support you into the future.

Merry Christmas and Happy New Year!

Arran Corbett CPH
AHA President

AHA Member Profile: Zac Ward

Describe your current role.

My current role is ‘Supervisor – Asset Monitoring’ within the Water Corporation’s Engineering Business Unit (EBU). This sees me manage a team of 10-12 hydrographers (including trainees) across the state of Western Australia where we operate and maintain hydrometric monitoring stations for the purpose of Water Corporation environmental licenses, planning and long-term strategic asset monitoring. Being state government owned utility means that our day-to-day work is not limited to only natural surface water, groundwater and meteorological monitoring but also involves what I like to call, Urban Hydrometry. E.g. monitoring of drainage catchments, sewerage networks and other large-scale asset base such as WWTP’s, hydraulic schemes, irrigation channels, odour control structures, etc.

Figure 1. ADCP Measurement Bannister Ck.

What hydrometric (or other) qualifications relevant to your role do you have?

Certificate IV in Hydrography and a Diploma of Leadership & Management. In addition to this I have a completed various parts of a both a Journalism and IT degree however my passion seems to lie with hydrometric monitoring.

What do you consider some of your major career achievements to date?

Working at Water Corporation for over 14 years now in numerous roles I feel extremely privileged to have seen so much of this amazing state that we take for granted. However whilst I have been involved in so many important small/large scale monitoring projects the thing I take the most pride in is the ongoing Hydrographic Traineeship Program we have now been successfully running for over 20 years in different configurations.

Mentoring and training is a large part of my current leadership role and given that I myself came from the traineeship program back when I was only 20 years old I get a great sense of purpose and nostalgia seeing other young trainees progress through their formal studies/on-the-job-training to become fully fledged, articulate and analytical hydrographers. We have seen another four trainees successfully complete their respective traineeships/qualifactions over the past three years and I’m looking forward to several more in the coming months!

How did you end up in the hydrometric profession?

Funnily enough my background lies more in the creative/artistic space with my initial preferred career being one of Graphic Design. As I didn’t make the cut-off for this line of study I found myself studying both Journalism and IT at Curtin University for the first four years after leaving High School. When I came to the realisation that I didn’t fancy working in either of the industries (who actually knows what they want to do when they leave school right?!?!) I dropped out of Uni and found myself once again looking for a career change.

The only thing I knew was that I had somewhat of an aptitude for maths and I didn't want to be stuck behind a desk all day. Hence the Hydrography Traineeship at Water Corporation appeared very enticing to me. I commenced this traineeship at around 20 years old with Engineering Data Services under the section management of Allan Deanne and haven't looked back since!

Was there anyone who had a major influence?

Several staff come to mind at Water Corporation when I think of people who have provided great mentoring, guidance, direction and instrumentation information. Jacquie Bellhouse, Andrew Smith and Glen Terlick to name a few have definitely assisted me through various facets of my hydrographic journey imparting knowledge and teaching the finer points of stakeholder management, data management, Hydstra functionality and most importantly government bureaucracy (including how to navigate it).

Where has hydrometry taken you in the world?

As mentioned above I've been very privileged to travel/explore so much of WA's great landscape through hydrometry. Whether it's monitoring irrigation channels and sewers in Kununurra, monitoring WWTP's in Leonora/Laverton or bore sampling and streamflow measurement throughout the beautiful South-West Region, e.g. Harvey, Collie, Dunsborough, Margaret River. The best part of my current role is the remote management of staff across a multitude of offices from Perth, Bunbury, Albany, etc.

What has been the most memorable experience (good or bad) in your career?

Drawing back on my previous point of 'Urban Hydrometry' I think some of my worst (but also best as they make for great stories) moments have been with regards to sewer-flow monitoring. Whether it's discovering a barge sized mass of rag built up on a deployed temperature sensor, odorous gases (H_2S/CH_4) which have disintegrated solid metal brackets or housings or analysing sewer-flow data which shows increased rates/levels when it's AFL Grand Final time, it definitely puts everything into context. Water is a tricky beast that needs to be monitored and understood in all its formats, even if it is more viscous than your typical surface runoff into a reservoir/dam.

What makes our profession interesting?

I think it's the constant search for knowledge and innovation. Being inquisitive, understanding how things work and utilising real qualitative/quantitative data is such a large truth in our world. The real-world applications of science really get me excited with understanding of error-bounds and accuracies so key in our profession. I think I'm also a sucker for numbers, data and other nerd stuff.

What do you do when you are not at work?

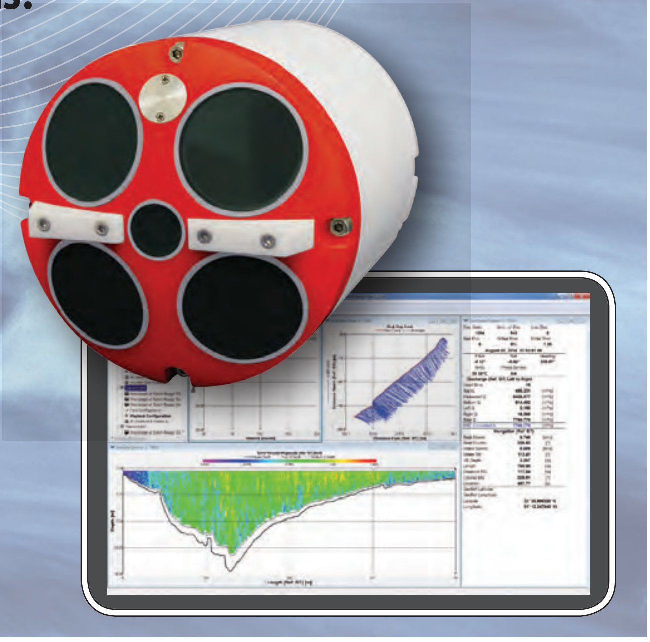
When I'm not at work most of my time is spent collecting and eventually using musical equipment. I have an extensive range of guitars, amplifiers, pedals and other electronic toys which get used at gigs and recording sessions from time to time. Playing music would definitely be my primary passion/obsession but unfortunately it's very hard to make a living out of it, particularly when you're as hopeless as me. Hey, at least it's fun and keeps me out of trouble!

How do you think hydrometric monitoring will change in the future?

Whether we like it or not automation is here to stay and only growing in popularity, especially given the expensive and risky nature of some of our more manual hydrometric monitoring tasks. With that being said we need to find a place for us as Hydrographers which both keeps us required, relevant and also adds value to data which we collect, verify, validate, calibrate, store and manage. Dashboards and SCADA outputs are great but can only be so useful if collected data and instruments are not properly understood or maintained.

Remote Operated Vehicles (ROVs) and image velocimetry appears to provide some very innovative solutions for data verification and automation. Whether it's utilising drones and LSPIV/STIV imagery or ADCPs and ADVMs, the key is to work smarter, not harder. However, we need to ensure we do not lose sight of the need for data verification, calibration and ongoing operational maintenance. After all your data measurements are only as good as your inputs and understandings.

Figure 1. ADCP Measurement Bannister Ck.



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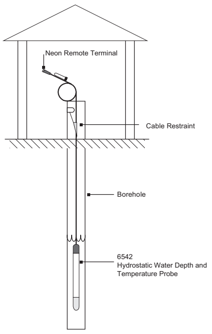
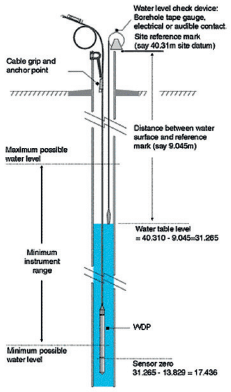
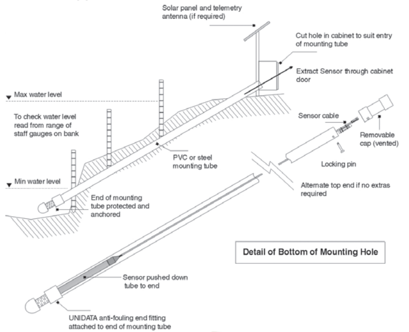
Typical Installation





Typical Installation on a stream bank



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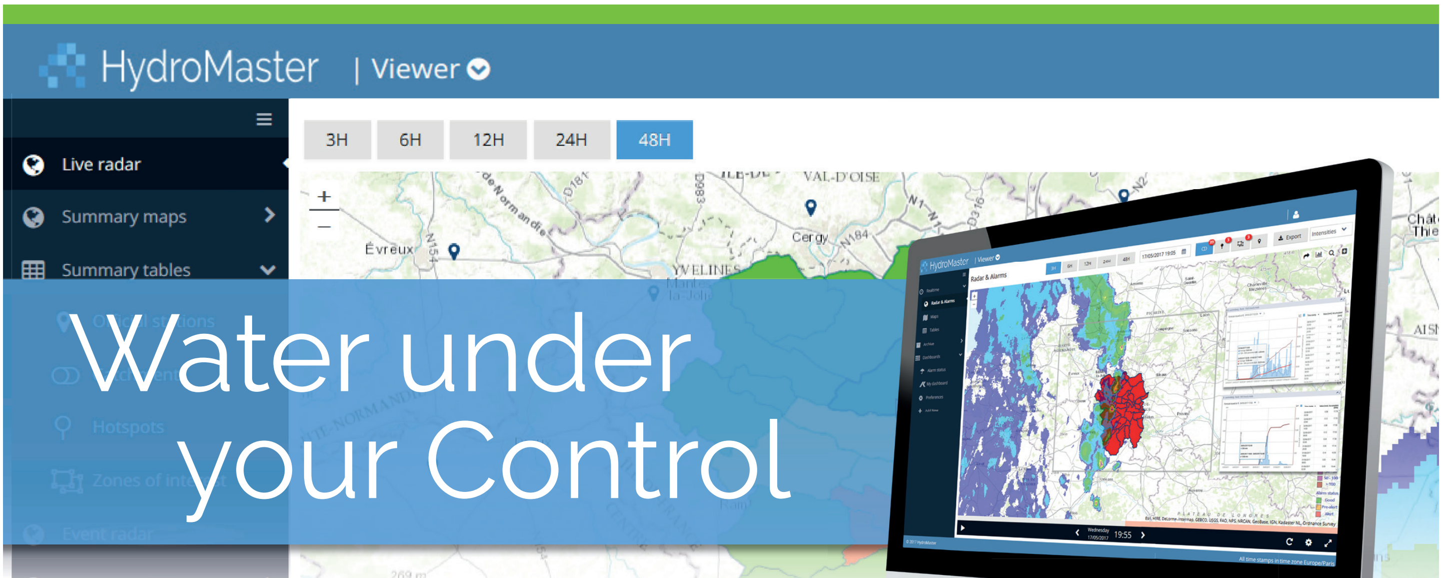

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Continuous Water Quality Monitoring - How to survive extreme events

Roman Kadluczka, Manly Hydraulics Laboratory (MHL), Sydney, NSW

Melody Wu, Manly Hydraulics Laboratory (MHL), Sydney, NSW

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

Abstract

Continuous (time series) water quality monitoring stations are established to assess variations in the quality of surface water. Near real-time water quality data and easy to understand information presentation can help water authorities and the community to make informed water related decisions. However, with an increased risk of extreme weather events in Australia, like extended drought or extreme precipitation events, both capturing water quality data and presenting information is challenging. We explore these challenges in water supply tidal pools, where the transitional zone between the freshwater and saltwater impacts the extraction of water for irrigators, industry and local water supplies, especially during critical water shortage situations.

Extreme event water quality monitoring requires sound engineering and scientific practice. The overall design of the water quality monitoring stations and sound maintenance activities are key to enable a station to adequately measure and maximise quality data capture. The station's sensor selection, frequency of the sensor calibration, and field servicing and verification program, should be based on the objectives of the water monitoring program and recognition of environmental extremes during its life.

Most of the common continuously monitored water quality parameters like temperature, pH, and dissolved oxygen usually remain within a reasonable working range during events. However, there can be drastic changes in electrical conductivity (salinity) readings during both dry and wet weather events, especially at the tidal interface. A suitable conductivity data quality coding system is required to cover freshwater, brackish water and saltwater and should be determined according to the monitoring program's objectives in consultation with the client and its end users.

Introduction

Continuous water quality monitoring stations are established to assess variations in the quality of surface water. Near real-time water quality data and easy to understand information presentation can help water authorities and the community to make informed water related decisions. However, with an increased risk of extreme weather events in Australia, like extended drought or extreme precipitation events, both capturing near real time water quality data and presenting information is challenging. This paper explores these challenges in water supply tidal pools, where the transitional zone between the freshwater and saltwater impacts the extraction of water for irrigators, industry and local water supplies, especially during critical water shortage situations. Real event monitoring data is provided to illustrate the challenges.

Example Impacts of Extreme Events on Water Temperature and Conductivity

Manly Hydraulics Laboratory (MHL) performs continuous water level and quality monitoring in most of the major river and estuarine locations along the NSW coast (Manly Hydraulics Laboratory, Report No. 2577). The *MHL Library*[1] catalogues many of the coastal river and estuarine monitoring studies completed by MHL over 26 years.

Extreme events through wet weather or drought can have significant impacts on water temperature and electrical conductivity, especially in tidal pool areas and the estuarine environment. In this paper, typical station observations are provided for a major NSW river system. The upstream distance from the river mouth to each station's site is:

- Site 1 – 20 km
- Site 2 – 29 km
- Site 3 – 37 km
- Site 4 – 51 km.

In this paper, electrical conductivity is a surrogate for salinity and refers to the conductivity compensated by normalizing measurements to what they would be if the water were 25°C.

During Wet Weather Conditions

Figure 1 shows the change in electrical conductivity (salinity) and temperature at these four stations during a flood event in June 2017. Daily rainfall data from Site 1 and level data from Site 4 is added to the figure to show the influence of rainfall events. All of these water quality stations experienced a significant drop in salinity readings during the wet weather event with Site 1 experiencing the largest drop in absolute salinity. The recorded electrical conductivity reading at Site 1 was 38,135 µS/cm at 21:00 on 7 June 2017 prior to the flood. It then dropped to as low as 1,196 µS/cm at 19:00 on 12 June 2017 during the flood phase. The difference between these two readings is close to 37,000 µS/cm or a 31 times multiplier. Subsequently, Site 1's salinity almost returned to pre-flood level on 26 June 2017 due to the saltwater re-intrusion. In contrast, there was little influence of saltwater intrusion after the flood at the further most upstream station (Site 4) such that the water remained fresh for most of the time.

Variations of around 1.5°C in temperature at Site 3 were observed during the flood. Greater variation in temperature is observed during the warmer seasons with the rainfall events (refer to Figure 2).

Figure 2 shows water level, water temperature and salinity data at Site 4, and comparative daily rainfall data from a nearby location during 2014 to 2015. Flood peak height was recorded as 7.33 m Australian Height Datum (AHD) at 13:30 on 22 April 2015, compared with the site's normal working range from around -0.4 m to 1.0 m AHD. Recorded electrical conductivity reading at Site 4 was 747 µS/cm at 02:30 on 20 April 2015 prior to the flood. It then dropped to 142 µS/cm at 03:00 on 22 April 2015 during the flood phase. Variations of around 7.8°C in temperature at Site 4 were observed during the flood presumably due to the lower wet weather flow temperature compared with the pre-flood river temperatures.

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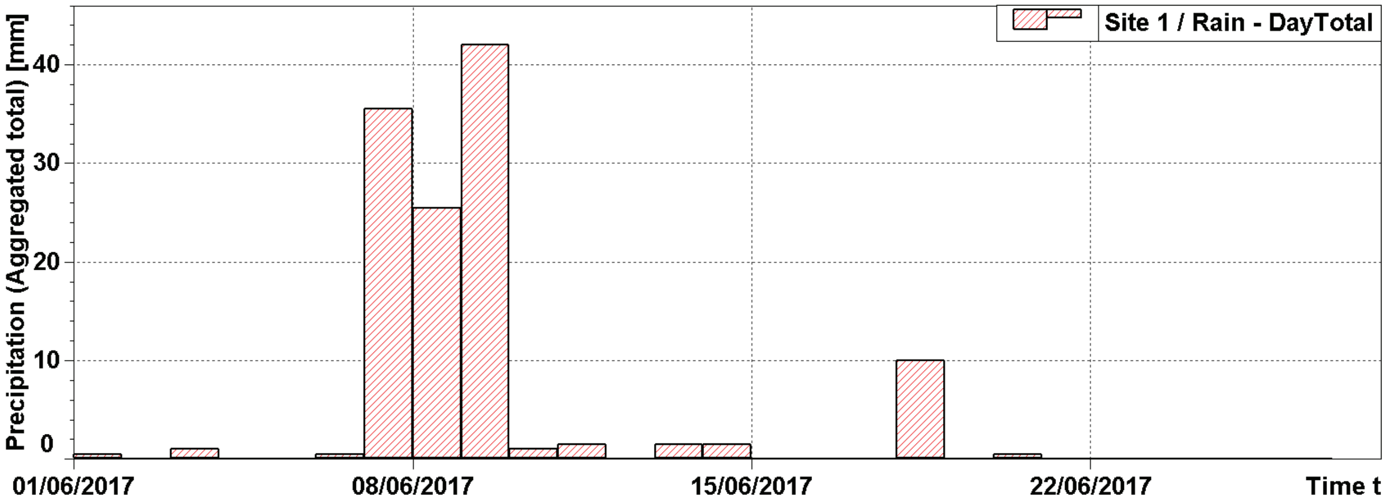
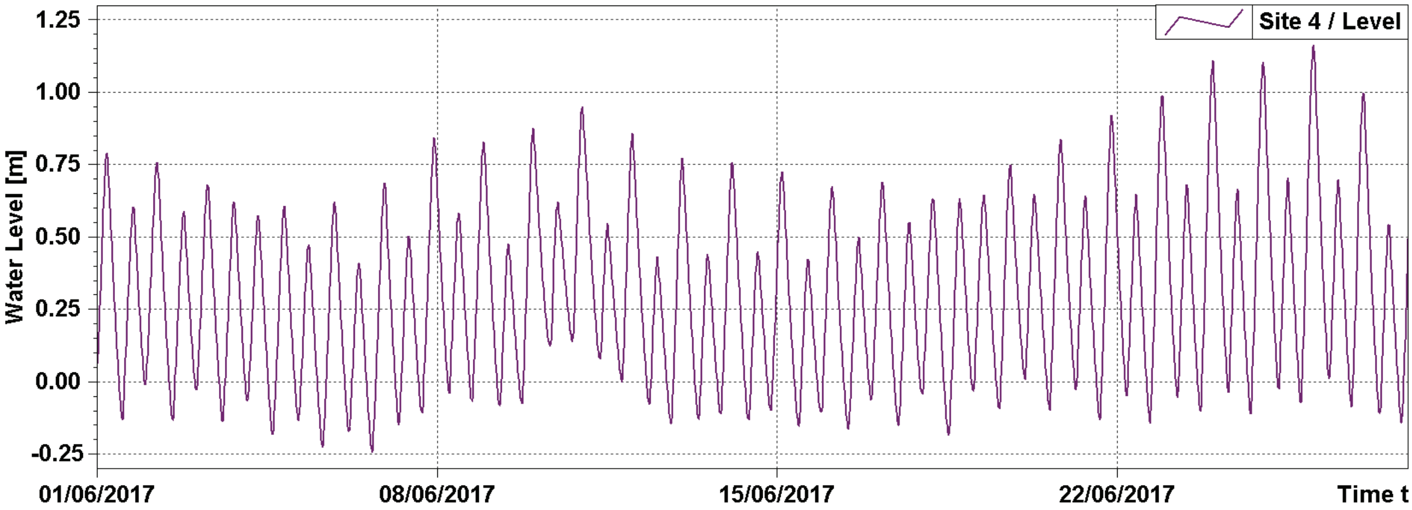
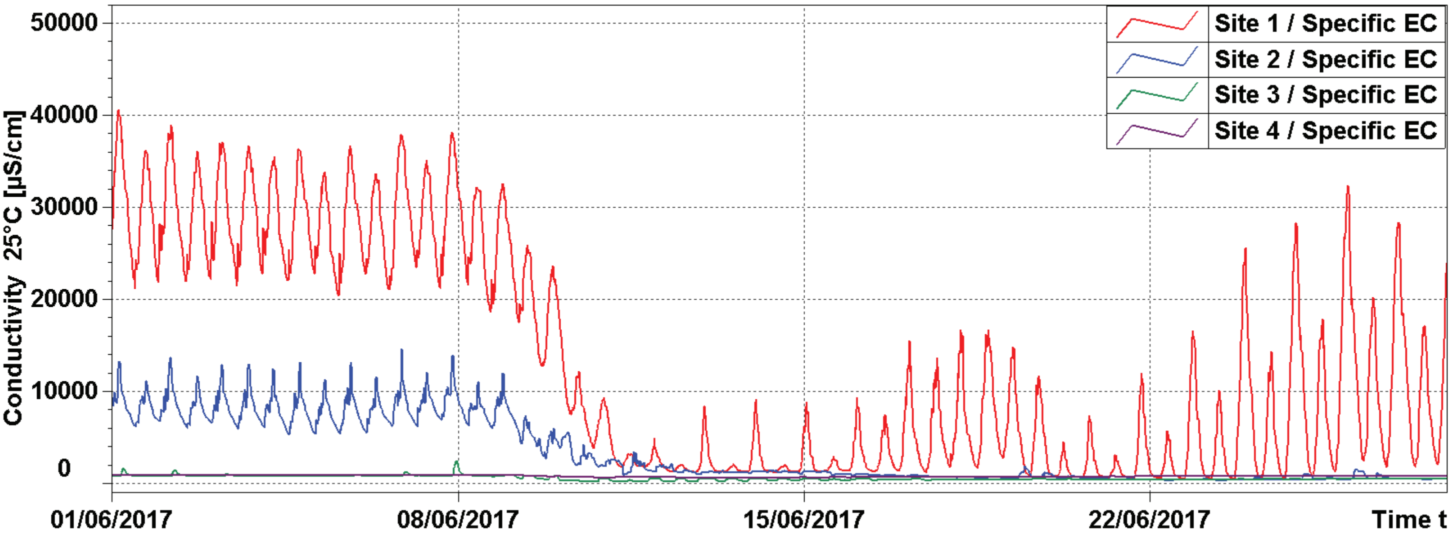
[3] www.mhlservices.net/apps/library/ accessed 8 December 2020)


Precipitation (Aggregated total) [mm]
40
30
20
10
0
Site 1 / Rain - DayTotal
01/06/2017
08/06/2017
15/06/2017
22/06/2017
Time t


Water Level [m]
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
Site 4 / Level
01/06/2017
08/06/2017
15/06/2017
22/06/2017
Time t


Conductivity 25°C [µS/cm]
50000
40000
30000
20000
10000
0
Site 1 / Specific EC
Site 2 / Specific EC
Site 3 / Specific EC
Site 4 / Specific EC
01/06/2017
08/06/2017
15/06/2017
22/06/2017
Time t

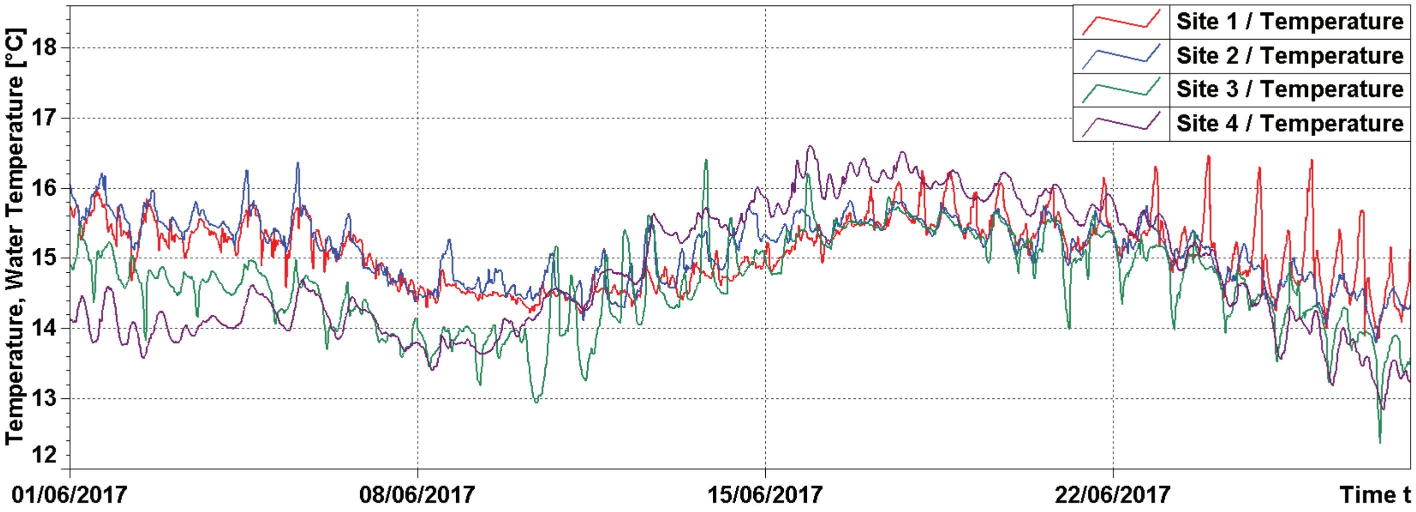


Figure 1. Change in electrical conductivity and temperature at four NSW water quality stations during flood event in June 2017 (adapted from MHL 2015).

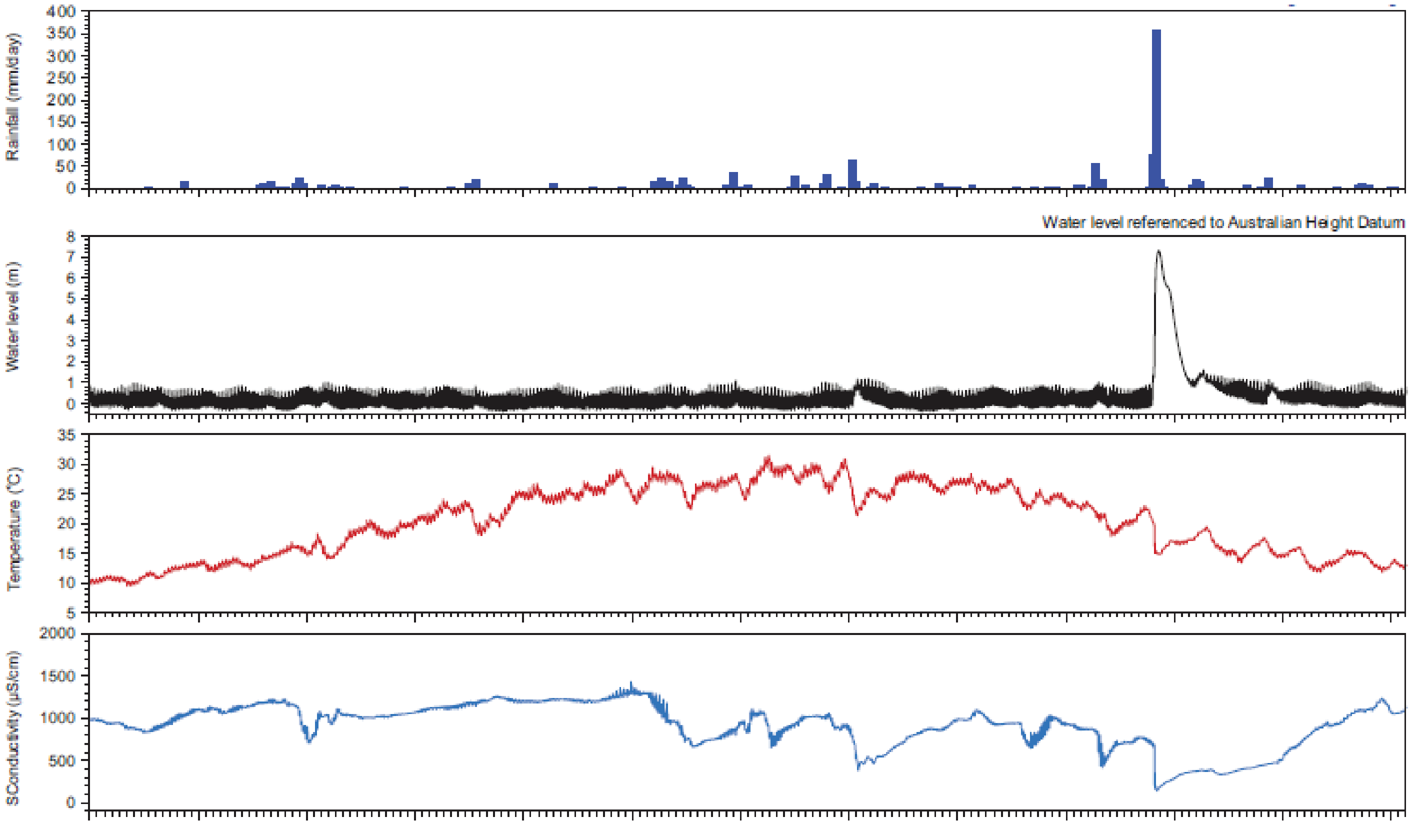


Figure 2. Water level, water temperature and conductivity data at site 4 in 2014–2015 (adapted from MHL 2015).

During Drought Conditions

During low flow conditions the dissolved solids are more concentrated and therefore salinity levels are higher. Figure 3 shows sustained high salinity levels at the four stations when there was little rain from early December 2017 to mid-February 2018. Daily rainfall data from Site 1 is included in the figure, demonstrating the dry weather effect.

Figure 3 also highlights the salinity (represented by the conductivity) level in relation to the proximity of the water quality station's location to the ocean.

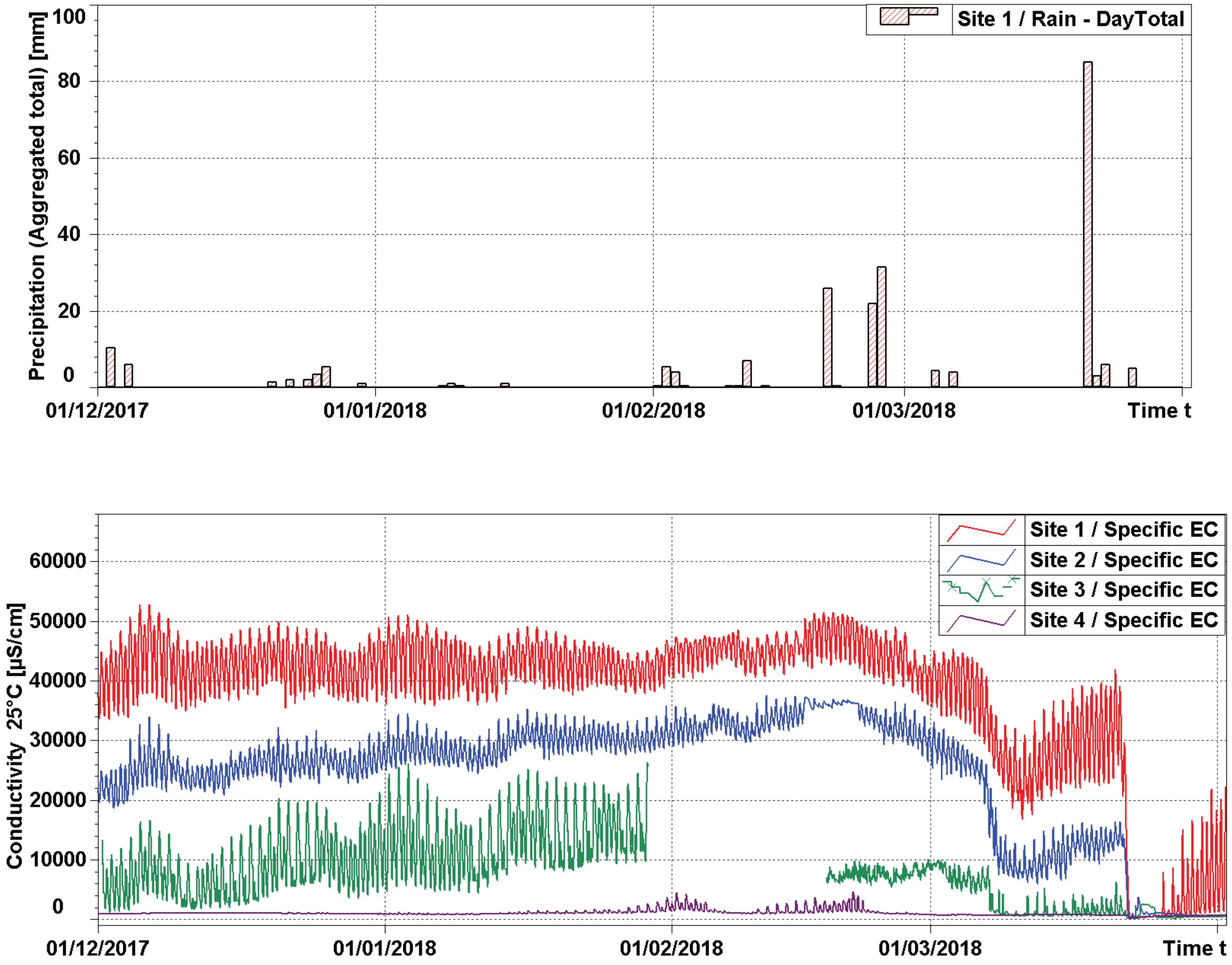


Figure 3. Sustained high salinity level at four NSW stations from December 2017 to mid-February 2018.

Water Quality Monitoring Programs - Extreme Event Considerations

The overall design of a water quality monitoring station, as well as maintenance and quality assurance activities, are key to enabling a station to adequately measure and maximise quality data capture. It is also important for the provision of useful data to end-users, through extreme events.

Design of Continuous Water Quality Monitoring Stations

According to USGS (2007), major considerations in the design of a continuous water quality monitoring station, include station configuration, selection of types of monitors and sensors, site selection, locations of the sensors in the aquatic environment, the use and calibration of field meters and the actual operation of continuous water quality monitors. Selection of a well-constructed site with safe accessibility and robust sensors will increase the likelihood of a station surviving in extreme events, including flooding.

Sensors should be able withstand high water pressures experienced during a flood. For example, Site 4's normal working range of its level sensor is from around -0.4 m AHD to 1.0 m AHD, however during the April 2015 flood it experienced peak levels of 7.33 m AHD (refer to Figure 2). Other floods may create higher pressures, which are to be accounted for in station design and sensor selection.

Interestingly, some water quality sondes with depth sensors are prone to water ingress and damage. In such cases, a separate water level sensor in parallel to the water quality sonde (without depth sensor) maybe appropriate.

Station instrumentation (all electronics including logger, modem and power supply) should be housed above acceptable flood design levels. Often the 1% annual exceedance probability (AEP) flood level is used for this purpose. However as extreme events have more impact, higher flood levels and other protection methods may also need to be considered. If these design requirements are impracticable, a buoy floating system with adequate mooring cable, designed to cope with the extreme water level height, may provide an alternative solution.

A powerful battery, which can support the whole operating system for at least six to seven days during flood events, is vital for stations which rely on solar power during wet weather and overcast events. This is especially pertinent given 3G/4G modems are typically more power hungry than the previous 2G telecommunications system.

Most of the common continuously monitored water quality parameters like temperature, pH, and dissolved oxygen usually remain within a reasonable operational range during extreme events. However, as demonstrated earlier in this paper, there can be drastic changes in electrical conductivity (salinity) readings during both dry and wet weather events, especially at the tidal interface. Electrical conductivity sensors typically have range-based accuracy limits which require consideration (e.g. wide range sensor readings can be compromised in low salinity conditions) when designing stations and selecting suitable sensors.

Delivery of a Continuous Water Quality Monitoring Program

Reliable and accurate continuous monitoring of water quality parameters requires ongoing maintenance activities such as calibration of field meters, routine on-site sensor inspection, cleaning, servicing and calibration checks of sensors (USGS, 2006). Whilst selection of high-quality instruments and good station design can reduce ongoing maintenance effort, there remains a point of balance in capital and maintenance expenditure versus desired data reliability and accuracy. Noting also the need for maintenance, protection and repair activities is potentially increased during extreme events.

Decisions on maintenance activities in particular field servicing, verification and calibration intervals are best determined in line with program objectives and through informed discussion with clients and end-users. In-field maintenance visit periods can vary from weekly through to six-monthly, although typically monthly, two-monthly or quarterly visits are currently adopted in coastal NSW. Water quality sensor calibration periods can also vary, however are typically between 1 to 12 months in coastal areas. The interval is influenced by several factors including desired data reliability and accuracy, monitored water quality parameters, ease of access (including safe access requirements), data transfer methods and environmental conditions (which may damage instruments or hinder operations).

Typically, telemetered data traces are reviewed weekly in the office to confirm station operation. During major events, data traces maybe checked in 'near real time', in response to client, emergency response authorities and community requests. It is also often desirable to deploy field staff (where safe to do so) to verify station operation using grab samples at their extremes. This is particularly important where there are community safety concerns related to flooding and water quality.

Conductivity Sensor Calibration

Ensuring the performance of electrical conductivity sensors in tidal zones requires additional attention due to the large measurement range often encountered. Two standard solutions which bracket the expected environment conditions are recommended when carrying out sensor calibration. Deionized water (close to zero conductivity reading) is used to test the behaviour of the sensor post calibration. Also, the 'spot check' field verification procedure is carried out over the expected range of conductivity values for each individual station.

For example, Site 1 has a normal working conductivity range which typically varies from around 35,000 to 50,000 µS/cm, due to tidal influence, however it can drop to near zero salinity with flood events (refer to Figure 3). The sensor deployed at Site 1 has a full conductivity range of 0 to 100,000 µS/cm to cover this range allowing for extreme events. Two standard conductivity solutions of 12,880 µS/cm and 58,600 µS/cm which bracket the expected condition of Site 1 are applied during calibration. However, deionized water is also used to test the behaviour of the sensor post calibration. The on-site verification procedure is performed over the expected range which is from around 35,000 to ~ 50,000 µS/cm.

Conductivity Water Quality Data Coding

Time series water quality data codes provide data end users (modellers, planners and researchers) an indication of measurement confidence and accuracy, which is dependent on the adopted station design, instrument selection and maintenance regime. The assigned quality code is often particularly important for extreme events at the tidal interface, as the event data maybe sought to calibrate and verify models, as well as contribute to studies on the nature and prevalence of extreme events.

Current continuous electrical conductivity water quality data codes can prove inappropriate for data end-users and not reflect reasonable monitoring programs. For example, commonly adopted *absolute value* based quality codes, generally developed for freshwater environments, are not suitable to describe the extreme range of measurement that occurs within tidal and coastal areas and inland potentially brackish surface water/groundwater. According to water quality codes used in NSW, to achieve a *'Good'* coding (±20 µS/cm) in brackish water or marine conditions, implies accuracies better than ±1.0% and ±0.2%, respectively. Such accuracies for continuous monitoring can be hard to achieve, very expensive and are typically not required by end-users; which can make the quality code description misleading without understanding its basis.

A suitable electrical conductivity data quality coding system should recognise the extreme range which can occur with events to cover freshwater, brackish water and saltwater conditions. Current database coding systems can be difficult to change and constrained in code descriptions. Ideally metric descriptions should be provided for a range of quality dimensions based on end-user needs, for example completeness, timeliness, accuracy to reality, consistency and conformance (Robinson 2008). There remains more work to be done to establish meaningful continuous monitoring data quality codes to adequately cover extreme events.

Conclusion

Extreme event water quality monitoring requires sound engineering and scientific practice. Real event data demonstrates the challenges faced for continuous water quality monitoring.

The overall design of water quality monitoring stations and associated maintenance activities is key to enable a station to adequately measure and maximise quality data capture, particularly during extreme events. The station's sensor selection, calibration frequency and field servicing and verification program should be based on the objectives of the water monitoring program and recognition of extremes during its operation.

There can be drastic changes in electrical conductivity readings during both dry and wet weather events, especially at the tidal interface. Informed quality codes reflect the accuracy of the instrumentation selected, the maintenance regime and the full range of measurement experienced, including extreme events. A suitable conductivity data quality coding system is required to cover freshwater, brackish water and saltwater and should be determined according to the monitoring program's objectives in consultation with the client and its end data users.

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Manly Hydraulics Laboratory acknowledges its clients to which it provides continuous water quality monitoring to along the NSW coast, including the NSW Office of Environment and Heritage, WaterNSW and local government.


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The Cost of Unseen Extreme Anomalies and the Link Between Coastal and Upstream Systems

Sam Maddox, Manly Hydraulics Laboratory, Sydney, NSW

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

Abstract

On the morning of the 21st of August 2017 Tweed Shire Council officers awoke to find a large tidal anomaly on the Tweed River had passed through. This resulted in saline intrusion over the weir at Bray Park and into the local drinking water supply. Although this was a spring cycle in the tidal phase for the region there was no significant forecasted wave action accompanying the high tides and no foreseeable cause for Council to enable its weir topping prevention protocol. In Australia such tidal anomalies can be caused by coastally trapped waves (CTWs) which are propagating waves caused by low pressure systems that originate in the south-west of Australia and travel east. Using the NSW network of tide and river gauges this CTW event was tracked up the coast of NSW and into the Tweed area where effects of the weir inundation were felt most. A resulting outcome of this event has seen Tweed Shire Council utilise this network data and other predictive models to better improve weir overtopping procedures.

Coastally Trapped Waves (CTWs) and Resulting Tidal Anomalies

CTWs are a hybrid form of wave between barotropic shelf waves and internal Kelvin[2] waves *(Woodham, 2013)*. Consistent wind stress in the alongshore direction is the primary force causing these disturbances which then propagate along the coast as a boundary trapped wave *(B. Wang, 2015)*. CTWs are not isolated to the Australian coastline and they are a frequent phenomenon *(Brink, 1991)*. A defining characteristic of CTWs is they always travel with the coast on their left which in Australia is from south-west of the country to the north-east. In NSW this track is from the south to north coast. The propagation length and amplitude modulation of these CTWs greatly depend on the coastline bathymetry before eventually decaying through bottom friction *(Woodham, 2013)*.

Tidal anomalies are the difference between the recorded tide levels and the predicted tide levels. The predicted tide levels are constructed by analysing historical recorded levels and drawing out the astronomical constituents through harmonic analysis that force the tide at that location. In this case study we highlight the anomaly effect the CTWs have on the predicted levels in NSW, specifically the impacts in estuarine areas.

Event Tracking

On 15 August 2017, multiple strong low-pressure systems moved from off south-western Australia into the Great Australian Bight (Figure 1). This brought about consistent, strong alongshore wind stress over a sustained 48-hour period. The initial energy provided by the low-pressure fronts in conjunction with the direction they travelled created a CTW anomaly which propagated along Australia's southern coastline.

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[2] A traveling disturbance that requires the support of a lateral boundary

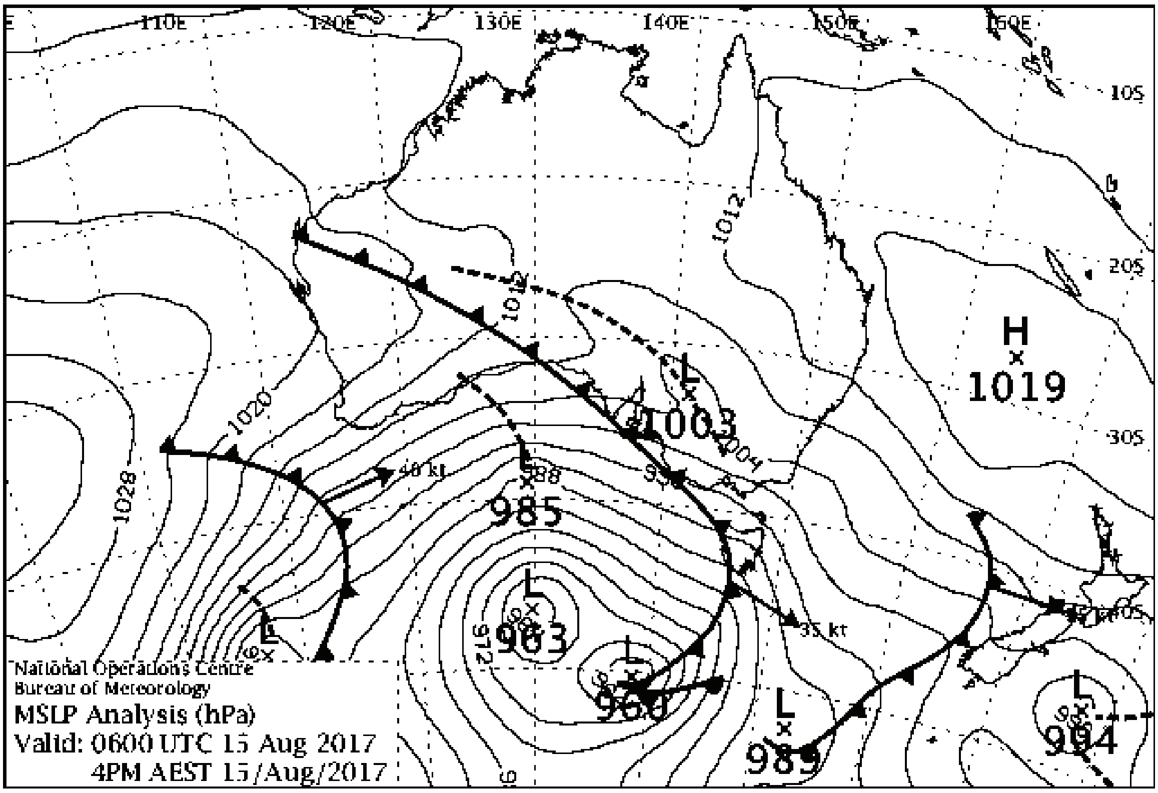


Figure 1. Australian synoptic chart on the 15th August 2017 (Source: Gary Brassington, Bureau of Meteorology).

As the anomaly reached Bass Straight on 18 August it was met with conditions that intensified the wave as it began to refract up the south-eastern coast. Aligning winds produced from the passing low-pressure system and an overland high-pressure system amplified the anomaly as it moved up the NSW coastline (Figure 2).

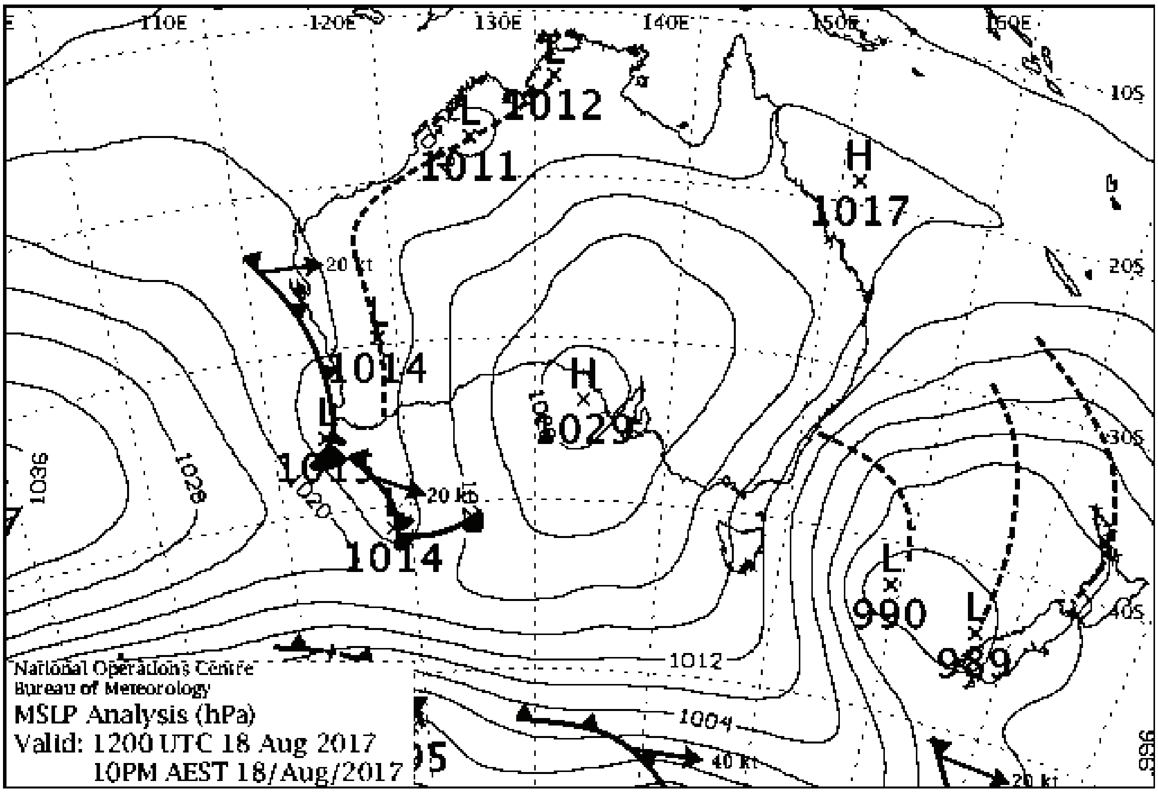


Figure 2. Australian synoptic chart on the 18th August 2017 (Source: Gary Brassington, Bureau of Meteorology).

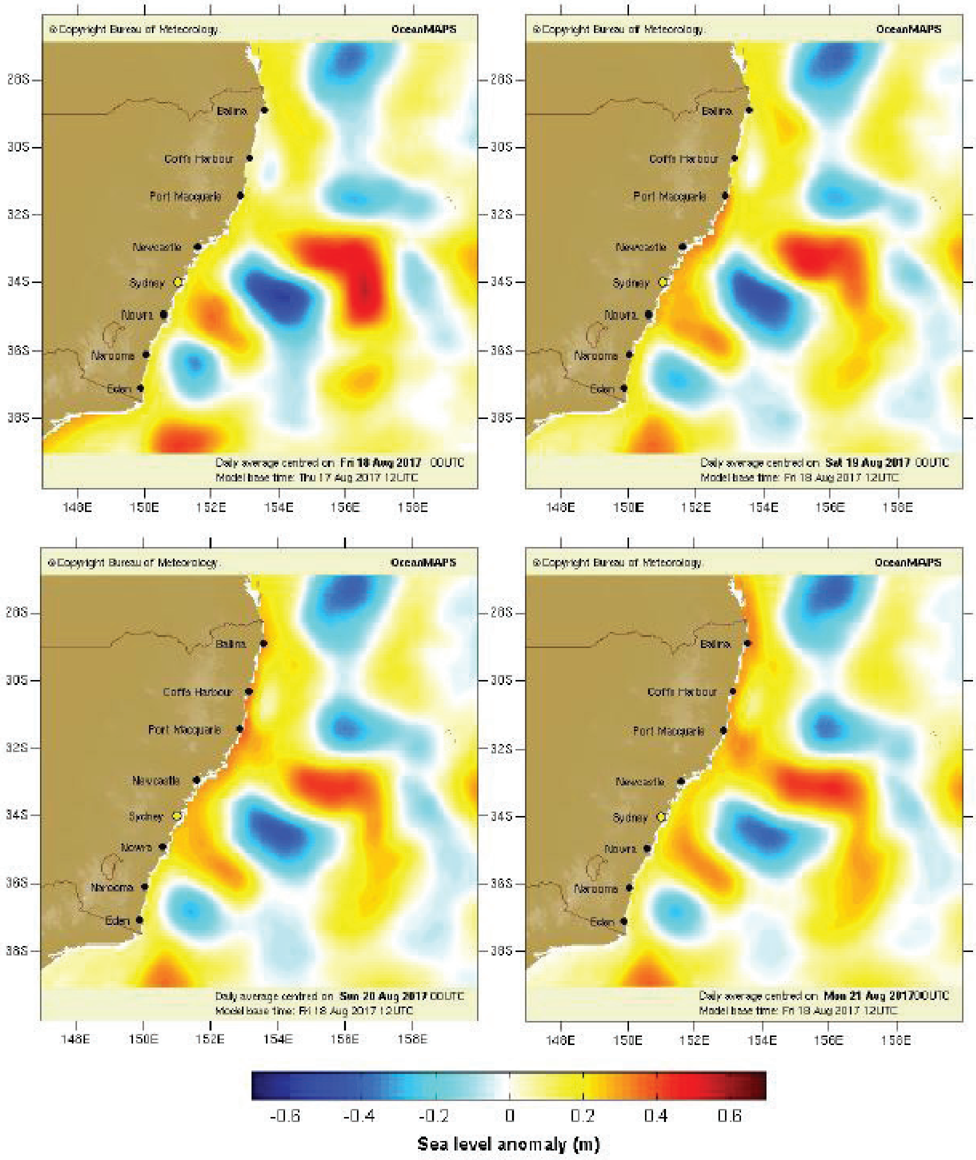


Figure 3. Model of the eastern seaboard anomaly from August 18th to 21st 2017 (Source: (MHL, 2017) Gary Brassington, Bureau of Meteorology).

Figure 3 shows the Bureau of Meteorology's (BoM) modelled CTW anomaly as it wrapped around the Bass Strait and moved up the NSW coast. The recorded residuals at different Manly Hydraulics Laboratory (MHL) tidal stations on the NSW coastline during the CTW event timeframe are shown in Figure 4. The anomaly is recorded earlier at Eden as it first moves course up the NSW coast, also of a slightly lower magnitude as modelled in Figure 3. Sydney also missed the maximum force of the CTW possibly due to the wave direction and refractive direction highlighted in Figure 5 which is a contour anomaly plot of the residual data recorded along the coast. Figure 3 and 5 show good congruency between modelled residual and recorded tides. The largest anomaly is felt from the Coffs region to the Tweed coast with the CTW recording an anomaly exceeding 0.5 m at Coffs Harbour.

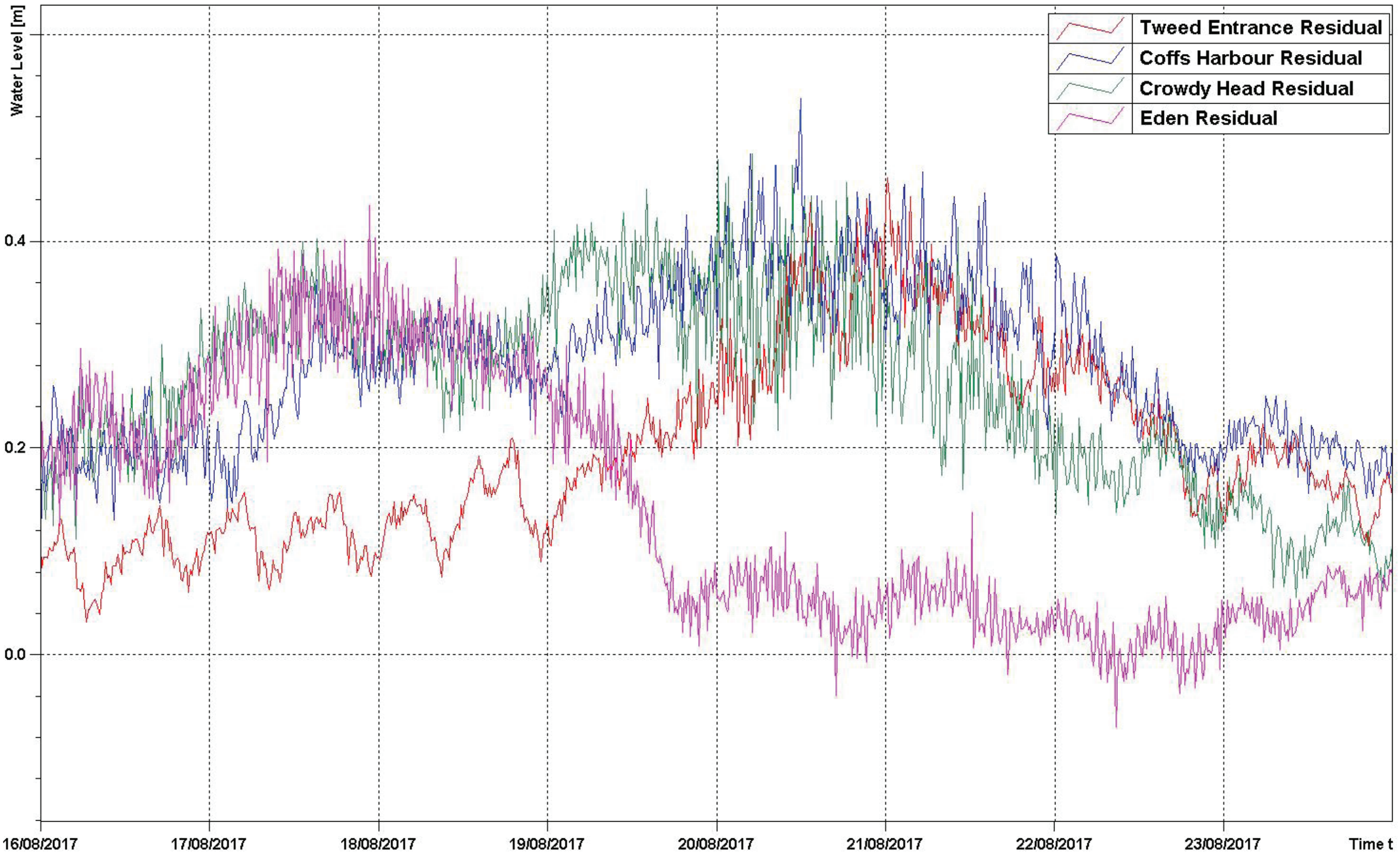


Figure 4. NSW MHL tide gauge recorded residual plot during the CTW event.

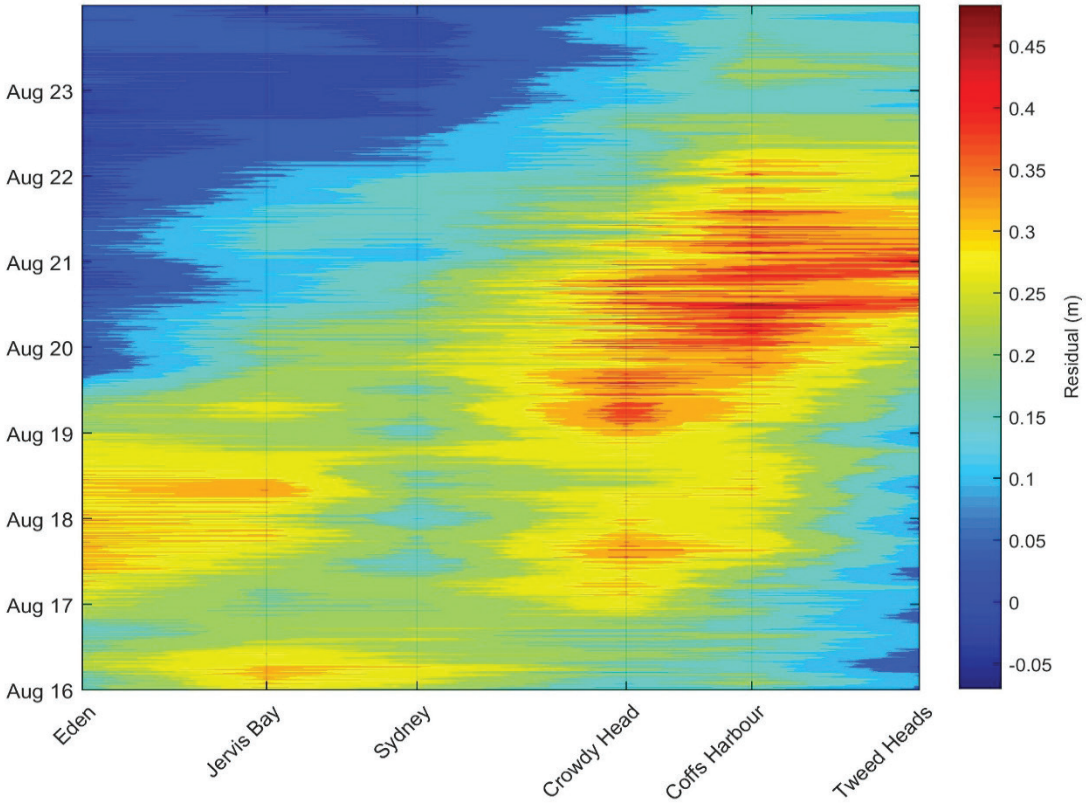


Figure 5. Residual contour plot measured at MHL ocean tide gauges on the NSW coast.

Tidal anomaly effects are readily identified at ocean gauges when compared to tidal predictions at the river gauge. The sea level change with respect to the prediction can be calculated in real-time as the recorded data downloads. Tidal predictions are complicated at river gauges by factors such as inland flows and dynamic entrance conditions which disrupt the harmonic analysis required to generate one. As a result, sudden raised sea level effects in estuarine areas become harder to identify, predict and prepare for. This case study focuses on the Tweed region of north-eastern NSW which has the largest anomaly impact, and where the culminating effects of this CTW were felt far into the estuarine zone.

The Tweed Shire

Tweed Shire Council is located in the north-eastern corner of NSW (Figure 6). It includes a coastal stretch from Byron Shire to the Tweed River Entrance. The junction of the non-tidal water catchment and the tidal reach of the Tweed River occurs at Bray Park Weir near Murwillumbah which is approximately 35 km upstream of the Tweed Entrance. The weir was constructed to secure a fresh drinking water supply to the urban areas of the shire (Figure 6). The weir crest is at a level of 1m AHD. Under normal neap low tide conditions, the weir adequately prevents the upstream movement of brackish water but under a king tide the crest may be over topped contaminating the water supply (Figure 7).

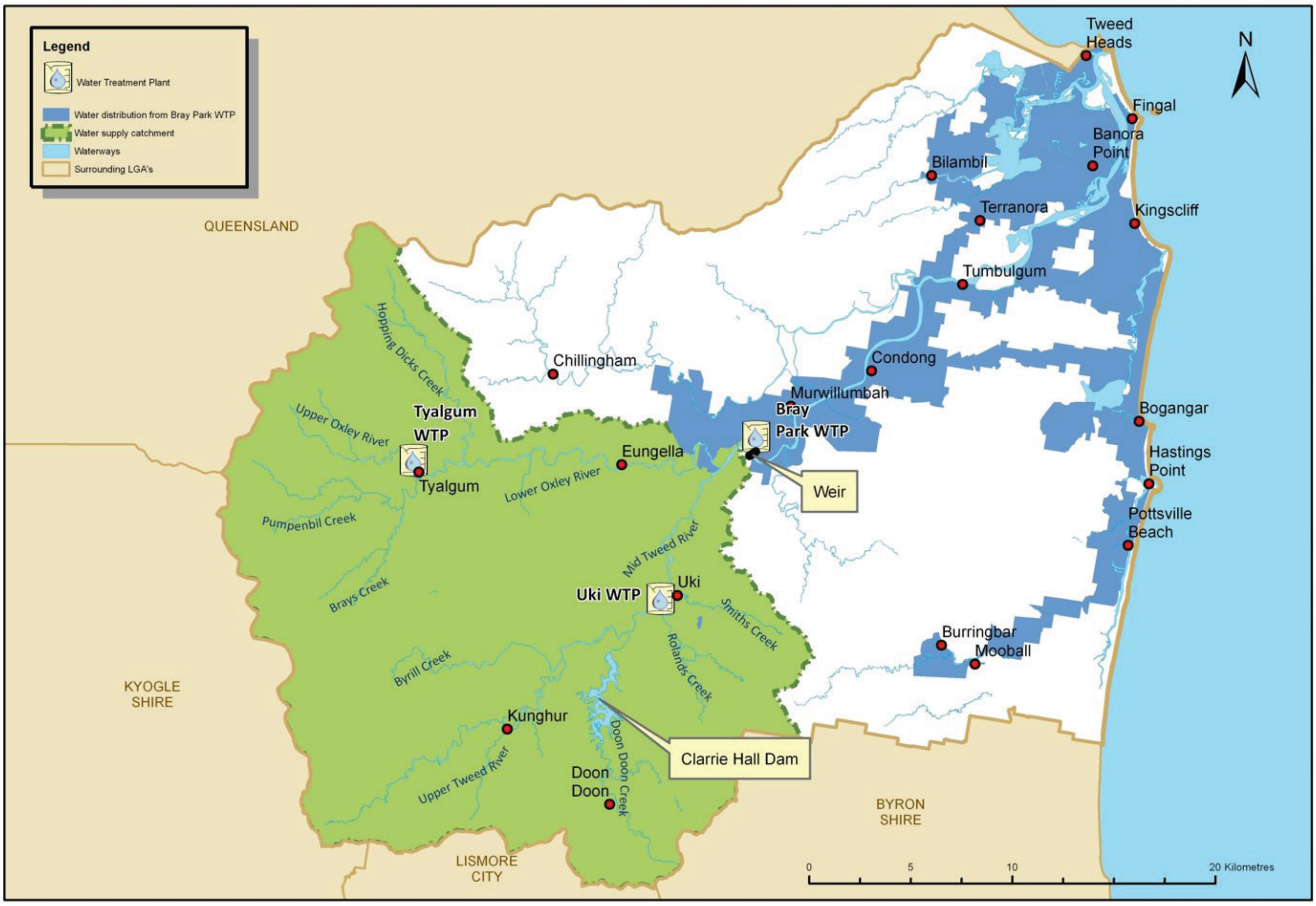


Figure 6. Tweed Shire Council area and water distribution within that area reliant on the Bray Park Water Treatment Plant (WTP) (Source: Tweed Shire Council).

Council has implemented different water supply protection controls when king tides are predicted to overtop the weir:

- Lay flat hose (150 mm diameter) — filled with water and held in place with sandbags — difficult to install and is only effective if there is no water flowing over the weir.

- Sandbags — effective with up to 300 mm flowing over the weir but are labour intensive to install and prone to disturbance by vandals (Figure 8).
- Concrete blocks — effective with up to 400 mm flowing over the weir but require heavy machinery to install (Figure 8).

Figure 7. Bray Park weir under neap low tide conditions and during king high tide. (Source: Tweed Shire Council).

Figure 8. Tweed Shire Councils overtopping prevention controls using sandbags and concrete blocks (Source: Tweed Shire Council).

The deployment of controls to protect the water supply are determined using tidal predictions. In mid-August 2017 a spring cycle was predicted, however the tidal levels were not considered sufficiently high to deploy additional protection (Figure 9). The predicted peak high of the spring cycle at the Tweed River mouth was 0.912 m AHD at 20:15 21 August 2017. There is a good correlation of tidal amplitudes between Tweed Entrance and Murwillumbah Bridge with the primary difference being the tidal phasing when analysing the forecast.

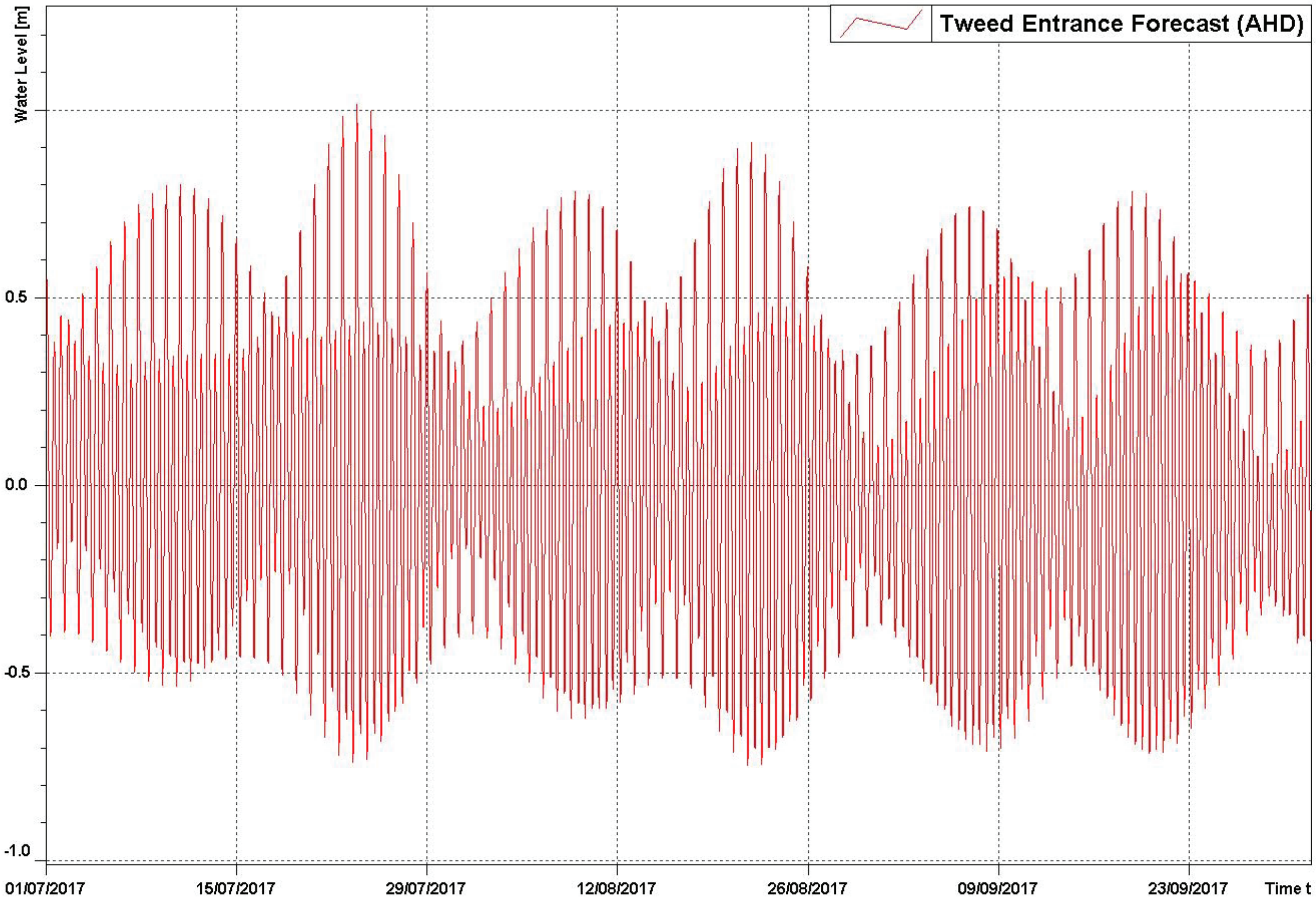


Figure 9. Tweed Entrance tidal forecast July through August 2017.

CTW Anomaly Effects on the Tweed River

MHL on behalf of the NSW Office of Environment and Heritage maintains a network of flood gauges throughout the Tweed River (Figure 10). These are installed to monitor flood heights in the area. Data is used for many purposes by government and the community including how to best act when the region is in flood. With this information connection between ocean tide and estuarine network it is possible to observe how a flooding event can influence the true tidal signal at an ocean gauge but also how an anomaly such as this August 2017 CTW effects upstream locations.

An analysis plot of Tweed Entrance, Tumbulgum and Bray Park Weir gauges show how the level rise of the non-tidal gauge behind the weir at Bray Park coincided with the high tide conditions during the CTW event (Figure 11). Essentially the spring tides have been boosted to levels far greater than any forecasted high tide for that year with the highest tide predicted 1.067 m (AHD) on 24 June, while the highest recorded during the event was 1.280 m (AHD) at 20:00 on 20 August. This equated to a peak reading at Bray Park Weir gauge of 1.225 m (AHD) at 22:15. Peak levels remained over the weir for each night high tide for the duration of each six-hour high tide for three straight days, slowly decaying each day from 20 August. By comparing the tidal anomaly residuals in the contour plot of the Tweed River (Figure 12) it is possible to track the anomaly as it moves up the river. The 0.3m anomaly had its greatest penetration up to the weir site (past Murwillumbah Bridge) on the incoming high tide push.

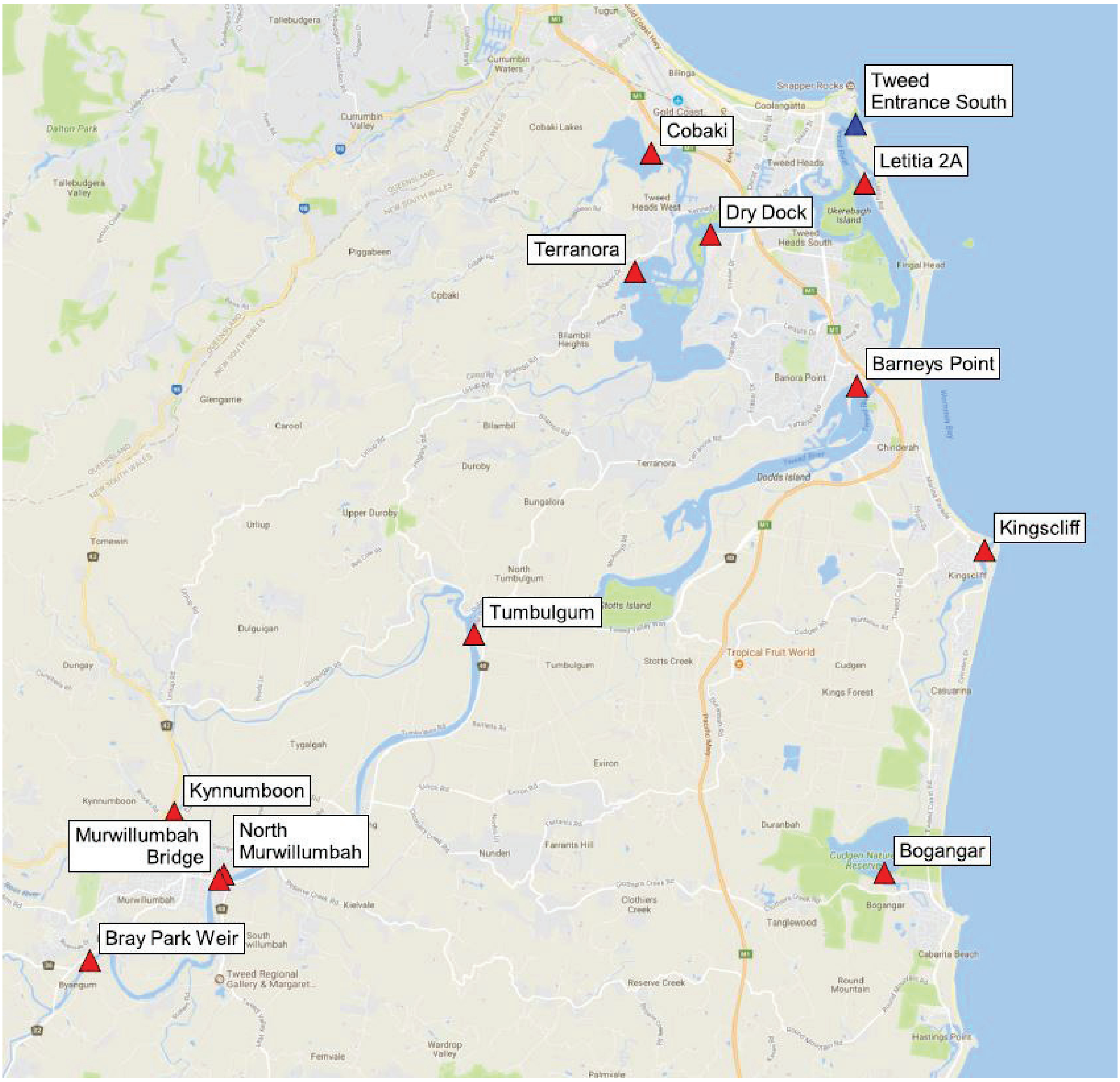


Figure 10. MHL tide and river gauge locality map for the Tweed River region.

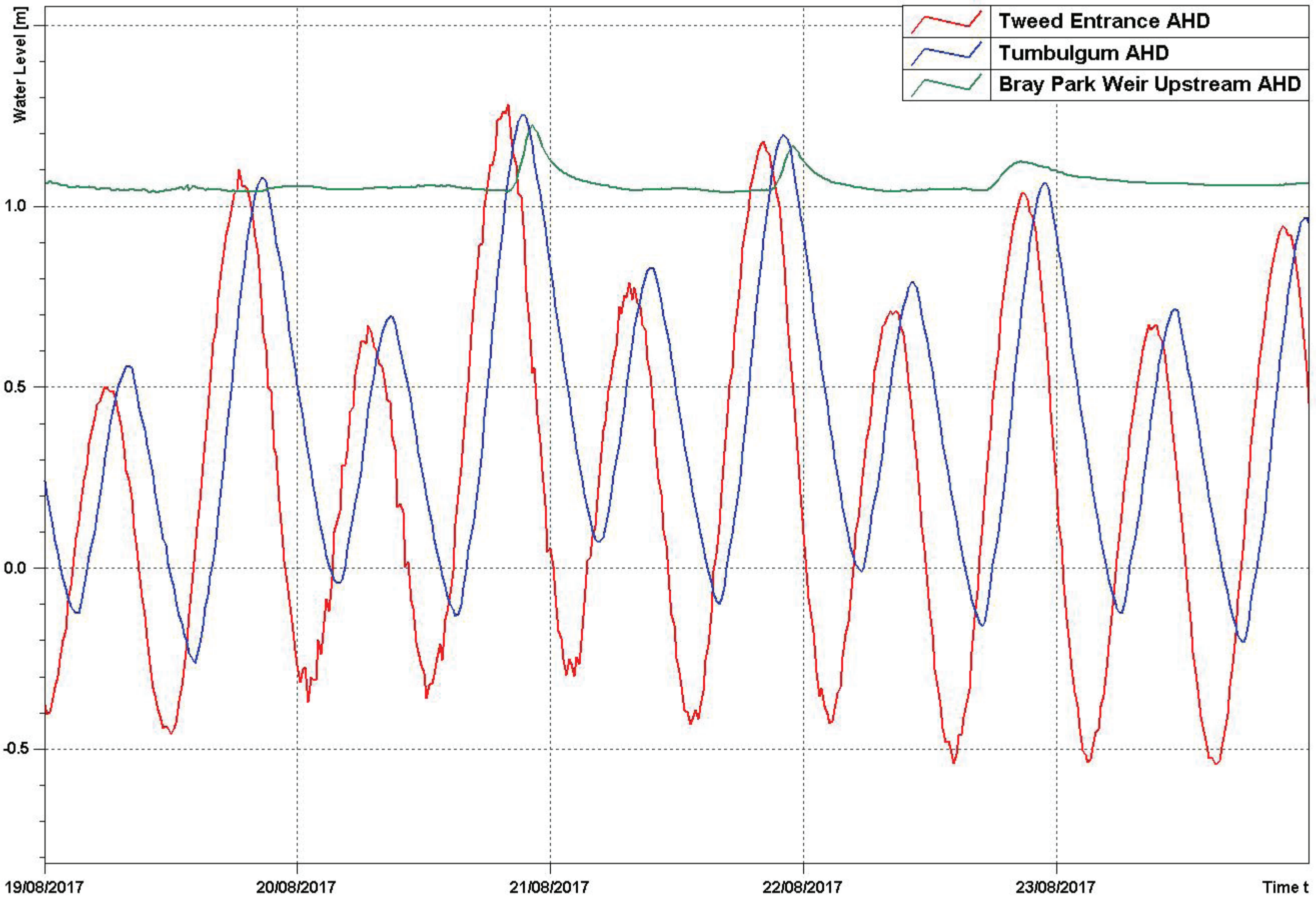


Figure 11. Tweed River tide gauge recording analysis plot.

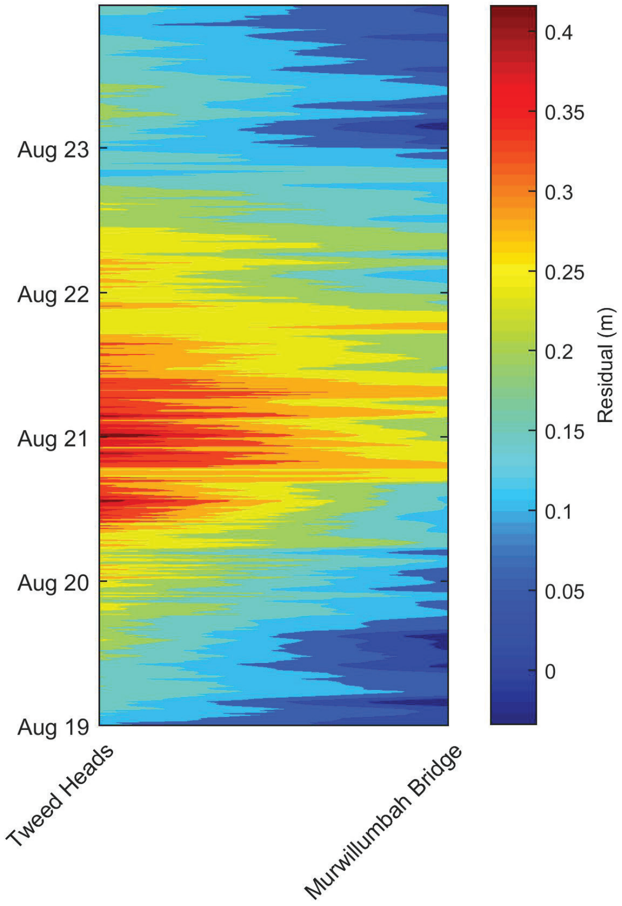


Figure 12. Tweed River anomaly contour plot tracked upstream between Tweed Entrance gauge and Murwillumbah Bridge gauge.

Effects of an Overtopping at Bray Park Weir

The human cost of this unforeseen anomaly was the sudden shut down of the Bray Park Water Treatment Plant (BPWTP). The BPWTP services a large area in the region. It has a daily average production of 27 ML with a maximum capacity of 100 ML a day. The extraction pump sits 1.4 km from the weir and uses membrane ultrafiltration to treat the water. The Ultrafiltration process is an effective barrier to solids and pathogens but not to dissolved salts.

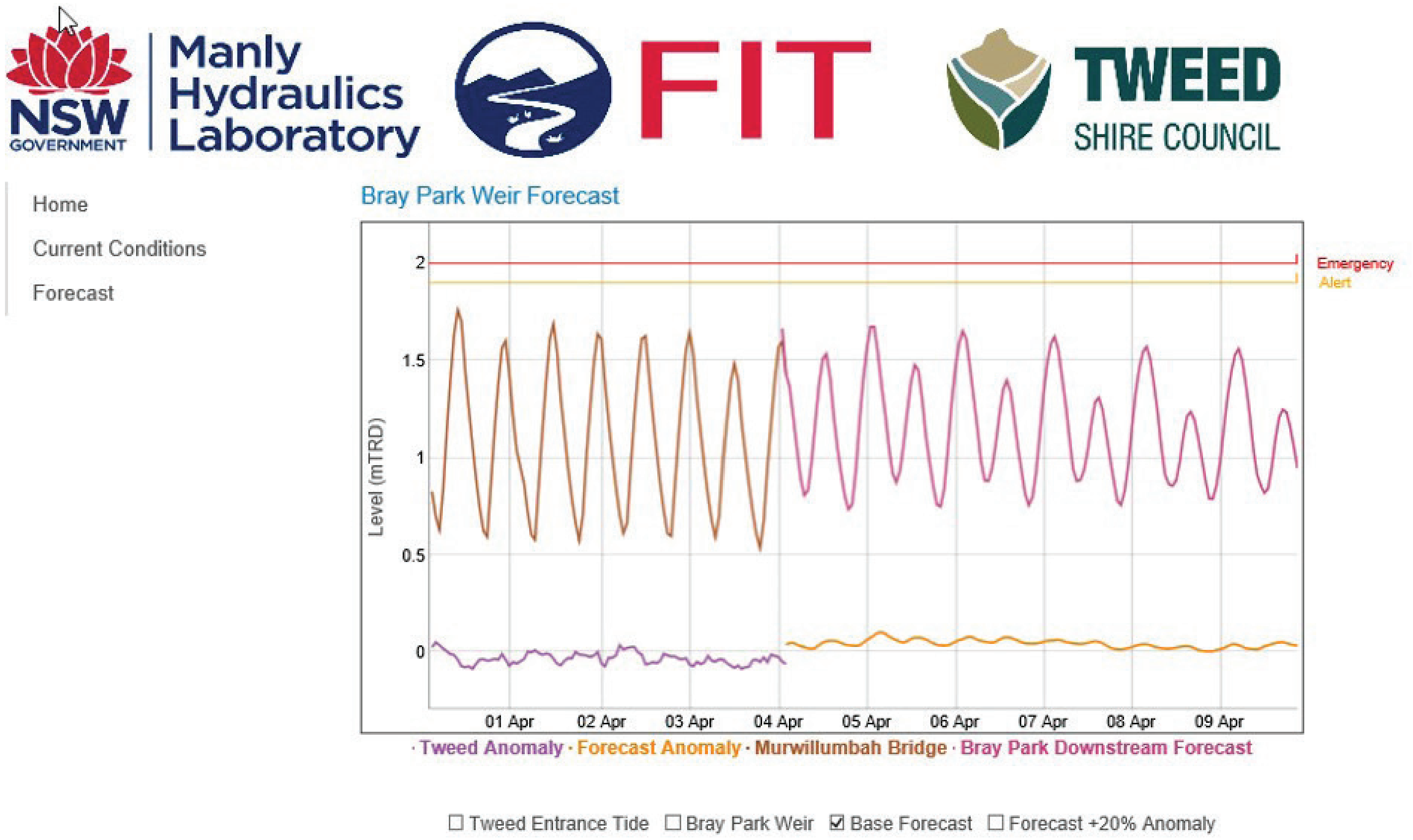
The CTW anomaly was first detected early morning on 22 August. A low-level chlorine alarm was triggered when the online analyser fell below the alert limit of <0.8 mg/L for >30 minutes. Further investigation revealed the saltwater ingress and the plant was taken offline. Council then initiated its Incident Procedure, including a comprehensive sampling program to monitor the extent of the contamination based on conductivity (Table 1). The Australian Drinking Water Guidelines provide the following Total Dissolved Solids (TDS) levels for the aesthetic quality of drinking water: <600 mg/L is regarded as good quality drinking water. 600-900 mg/L is regarded as fair quality 900-1200 mg/L is regarded as poor quality and, >1200 mg/L is regarded as unacceptable. The weir surface maintained a relatively low electrical conductivity (120 µS/cm) however due to the higher density of the brackish tidal water there was a strong conductivity depth profile with conductivities as high as 6000 µScm-1 at the bottom of the weir.

Table 6. Summary of Implementation Plan Work Streams

Location Time	Bray Park Weir Surface 8am 22/8/2017	BPWTP Raw 9am 22/8/2017	BPWTP Treated 9am 22/8/2017	Hospital Hill Reservoir 9am 22/8/2017
TDS by calculation (mg/L)	120	1200	1350	650
Conductivity (µS/cm)	199	1933	2174	1055

Table 1. Water sampling results taken around Bray Park after BPWTP was shut down on the 22nd August (Tweed Shire Council internal report).

Significant human resource and time is spent on rectifying the effects of an overtopping anomaly such as a CTW. Council has considered several options on improving warning information along with infrastructure and procedures to overall be better equipped. One such method has been collaboration with MHL in developing an improved Tweed River level prediction tool. The tool uses aggregate sea level predictions calculated by the BoM *(Taylor, 2017)* in combination with astronomical forecasts at Tweed River Entrance and Murwillumbah Bridge; in addition analytical methods are used to calculate the anomaly height at Bray Park Weir. The model is designed to give a rolling seven-day prediction of anomaly heights at the weir (Figure 13), with increased accuracy at shorter prediction times. The model was shown to predict the August 2017 CTW event correctly six days out *(MHL, 2018)* and after extensive sensitivity testing it was released for Council's use.



☐ Tweed Entrance Tide ☐ Bray Park Weir ☑ Base Forecast ☐ Forecast +20% Anomaly

Figure 13. MHL forecast tool used by Tweed Shire Council to prepare for anomalies – example output.

Conclusions

Tidal anomalies such as CTWs are continuous phenomena due to the ever changing atmospheric conditions altering the water level heights away from calculated astronomic constituents. CTWs can occur along much of Australia's coastline and may cause adverse impacts on estuarine networks. With the evolution of increased tidal data resolution and improved prediction models it is possible to make better informed decisions to reduce CTW impacts.

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Thank you to Marty Hancock of Tweed Shire Council for access to council data and reports along with paper review.

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Irrigation Efficiency Crucial for Ensuring Sustainable Water Resource

Waleed Ali, Murrumbidgee Irrigation, Griffith, NSW, Australia

Daniel Wagenaar, Xylem Water Solutions, Newcastle, NSW, Australia

Paper presented to the Inaugural Australian Hydrographers Association 2020 E-Conference, 23-27 November 2020

Abstract

Irrigation network efficiency is a fundamental component in ensuring a sustainable water resource. It has become more pertinent with the expansion of irrigation areas, ageing infrastructure and climate change.

There are a number of aspects that drive an efficient irrigation network, with water resource planning, maintenance programs and flow monitoring networks forming the key components. The knowledge of water lost due to evaporation, leakage or unauthorised abstractions as a result of a well-designed monitoring network is invaluable, as this assists in decision making processes for future expansion or maintenance of the irrigation network.

The ability to accurately monitor flows within irrigation networks, even under stress during peak demand can highlight structures that exceed their hydraulic limit during certain flow conditions. Most importantly, it gives both the customers and operators the confidence that the flow and associated billing from water releases are accurate.

Murrumbidgee Irrigation (MI) implemented a validation process to review the flow monitoring network at strategic points over a three-month period. The process consisted of temporary installation of SonTek SL1500-3G acoustic Doppler instruments at nine predefined measurement sites. An index velocity rating was developed that is based on velocity measurements from these instruments and discharge measurements from RiverSurveyor M9 Acoustic Doppler Current Profiler (ADCP). The index velocity rating is robust against variable backwater conditions, normally encountered during peak demand.

The process implemented by MI to automate the data collection, audit and index velocity rating development is sophisticated to ensure accurate assessment of the flows. The SL1500-3G instruments send velocity and diagnostic data at fixed sample intervals via serial output over TCP/IP to an SQL database. The ADCP discharge measurements performed during the week are processed at the office, from where the information is captured into custom designed application. The application compares the data captured from the discharge measurements against the velocity data stored on the SQL database. Index Velocity rating is developed based on information entered, from where a detailed assessment is performed to determine if the index velocity rating is valid. During the verification period, field personnel have the option to request that no flow changes are made during the discharge measurements. This ensures that the flow in the channel is relative stable during the discharge measurements.

The flow results from the index velocity ratings are used to further improve the existing stage-discharge relationships at each of the flow measurement sites selected within the irrigation network.

Introduction

Murrumbidgee Irrigation (MI) is one of the largest private irrigation companies in Australia supplying water to over 3,260 landholdings within an area of 378,911 ha in the Murrumbidgee Irrigation Area (MIA). The MIA is a highly productive agricultural region where most farmers rely heavily on the water supplied by MI for their irrigation needs. During 2019/2020 season, MI's delivery network incurred water losses of ~15% which amounts to 64 GL. Improving the irrigation efficiency of the network can result in substantial water savings that can be reallocated to farmers for productive use.

MI uses flow measurements at the supply regulators to monitor flow in the irrigation network. The regulators use water levels and gate openings to compute flow and thus the accuracy relies on the calibration and maintenance of the sensors. There is a need to independently measure and validate the flows for improving the overall efficiency of the irrigation network.

Murrumbidgee Irrigation implemented a flow verification process during the 2019 / 2020 season to verify flow accuracy of the irrigation network. The flow measurement sites selected for the verification process are of strategic importance to the overall operation of the irrigation network. The following sections will cover the verification approach, instruments used and process for measuring flow.

Methods

Flow Verification Approach

The flow verification approach adopted comprises the index velocity method for continuous flow monitoring at the respective flow measurement sites. The index velocity method is not affected by variable backwater affects and is less sensitive to changes in cross sectional area, two common aspects normally encountered in open channel flow such as irrigation channels. The index velocity method requires the following two components for accurate and reliable flow computation.

- Real-Time velocity and stage measurements to capture actual flow conditions at the measurement site - Acoustic Doppler Velocity Meter (ADVM).
- Calibration discharge measurements performed during each scheduled site visit - Acoustic Doppler Current profiler (ADCP).

Stage-Area and Index-Velocity ratings were developed from synchronous velocity-stage (ADVM) and discharge (ADCP) measurements. The flow at each measurement site was computed by applying real-time velocity-stage measurements against Stage-Area and Index-Velocity ratings.

The workflow adopted for the flow verification process of Murrumbidgee Irrigation network is outlined in Figure 1.

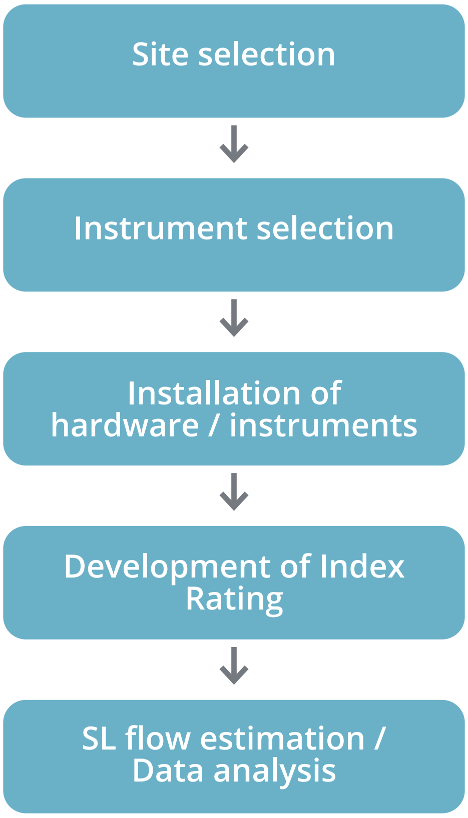


Figure 1. Workflow of MI's Flow Verification Approach.

Measurement Site Selection

The measurement site selection process is essential for accurate and reliable data collection during the verification process. The selection criteria implemented during the site selection process was based on several measurement site and hydraulic requirements provided in Table 1.

Table 1. Selection criteria for measurement sites

	Criteria	Comment
01.	Steady uniform flow with sub-critical flow conditions.	Channel cross-section surveyed using ADCP. Measurements used to document velocity distribution, channel shape and bathymetry.
02.	Uniform velocity distribution over the width of the cross-section.	Channel cross-section surveyed using ADCP. Measurements used to document velocity distribution, channel shape and bathymetry.
03.	Channel section relatively straight for 10* channel width upstream of measurement site with uniform cross-section.	Aerial Imagery used to measure reach lengths. Channel cross-section surveyed using ADCP.
04.	Distance of > 10* channel widths from any control / hydraulic structures.	Distances from control structures verified via aerial imagery.
05.	Channel bed and slopes free of aquatic vegetation, debris and sediment.	ADCP used to survey upstream and downstream of SL location. Maintenance team required to clean 2 channels.

An initial shortlist of measurement sites located on the MI main supply channels was generated based on their strategic importance and the need for accurate flow measurements. A final list of nine measurement sites were compiled from the short list based on their suitability to accurate apply the index velocity method provided in Table 2.

The measurement sites selected are located on two of the major supply channel systems in MI network, the Lake View Branch Canal (LVBC) and the Northern Branch Canal. The channel geometry, bathymetry and flow/velocity distribution were surveyed using ADCP instrument. Figure 3 shows the cross-section from the ADCP survey at one of the selected sites, Rosetto. This concrete lined channel has a uniform trapezoidal cross-section and a uniform velocity distribution as shown in Figure 3.

Table 2. The names, channel types, dimensions and max design capacities of the sites selected for flow verification

Asset ID	Name	Channel Type	Top Width (m)	Bottom Width (m)	Max Flow (ML/d)
RG-2-698	Scotts Rd	Concrete	9	3.2	395
RG-2-950	Apolonis	Concrete	7.8	2.6	310
RG-2-951	Overs	Concrete	7.9	2.6	300
RG-2-640	NBC-1	Earth	16.5	8	677
RG-2-679	NBC-Offtake	Earth	16.6	8.8	690
RG-2-949	Nericon	Concrete	8	2.6	340
RG-2-680	Temora Rd	HDPE lined	6	2.3	260
RG-2-681	Rossetto	HDPE lined	6.8	2.3	242
RG-2-621	Andreattas	Concrete	8.3	3.2	370

Figure 2. Aerial view of SL1500-3G site installation on the NBC.

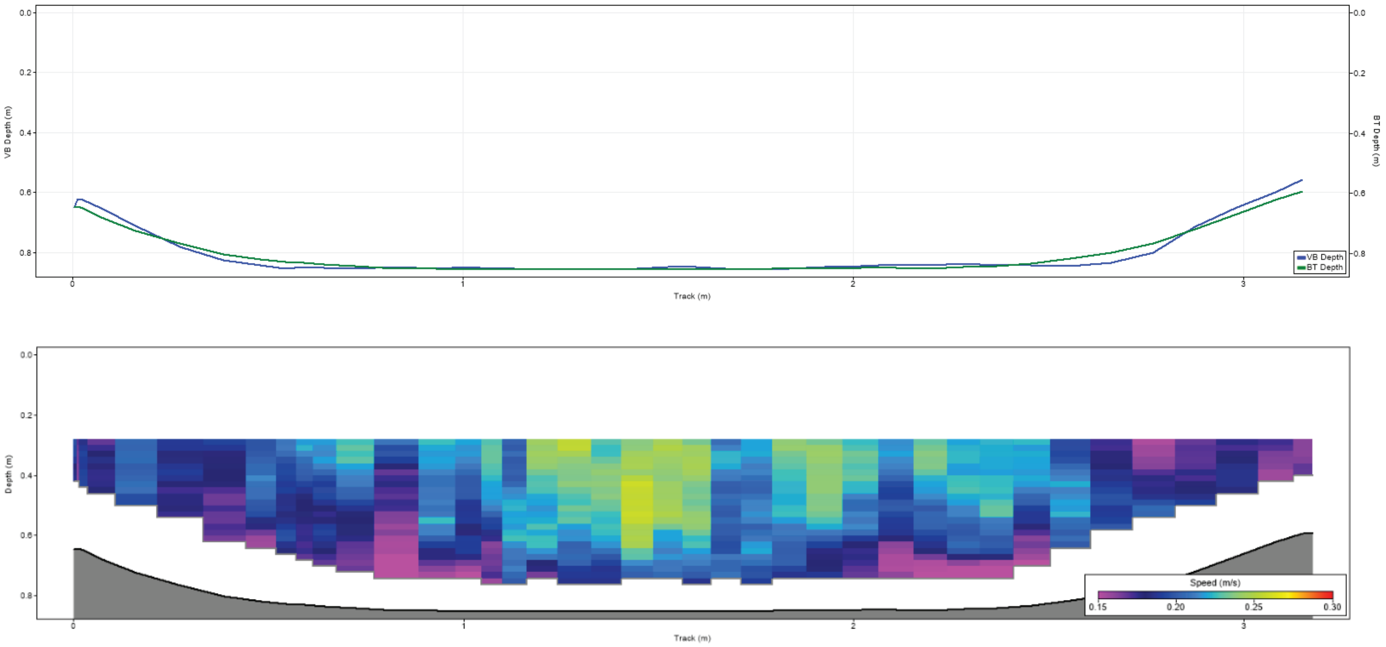


Figure 3. Channel cross-section (top) and velocity distribution (bottom) at the Rosetto site on NBC.

Instrument Selection and Integration

The instrumentation adopted for developing rating at each measurement site can be grouped under Real-Time (ADVM) and Calibration (ADCP) flow measurement devices, shown in Table 3.

Acoustic Doppler Velocity Meter (ADVM) instruments are mounted on the channel bank, with fixed orientation and elevation. Continuous velocity and stage measurements are performed and reported based on user specified sampling interval and sampling duration.

Acoustic Doppler Current Meter (ADCP) instruments are used to perform instantaneous flow measurement at a monitoring site. The flow is measured by traversing the channel comprising of reciprocal transects with the instrument deployed on either a board or remote-controlled boat.

Table 3. Acoustic Doppler measurement devices

Group	Type	Model	Measurement	Calculated
Real-Time	ADVM	SonTek SL1500-3G	• Stage • X-Velocity • Y-Velocity	• Flow • Area • Mean Velocity • Velocity Magnitude
Calibration	ADCP	RiverSurveyor M9	• Depth • X-Velocity • Y-Velocity • Bottom Tracking	• Flow • Area • Mean Velocity

Hardware Integration

i. ADVM Mounting Frame

ADVM (SL1500-3G) instruments were installed at each of the 9 measurement sites identified for flow verification, illustrated in Figure 4. The ADVM was mounted on a sliding mount secured in between two sliding rails on the side of the channel, shown in Figure 5. The sliding rails were fixed in place by a steel frame secured to a 500L road barrier filled with water. The mounting system allows for quick installation without the need for establishing permanent infrastructure or modification to the existing channel lining. The design of the mounting system makes it easy to redeploy at other measurement sites and perform maintenance on the instrumentation.

Figure 4. ADVM deployment.

Figure 5. Temporary ADVM mounting frame.

The telemetry equipment and power supply were housed inside a junction box (refer to Figure 6) which included:

- NTC-100-01 4G LTE CAT M1 Serial IOT device: to collect serial data form the ADVM and send it to MI's database in real-time
- 12V battery: to provide power the ADVM and IoT device

The junction box was mounted inside a stainless-steel frame, with a 20 W solar panel attached on top of the frame to charge the battery.

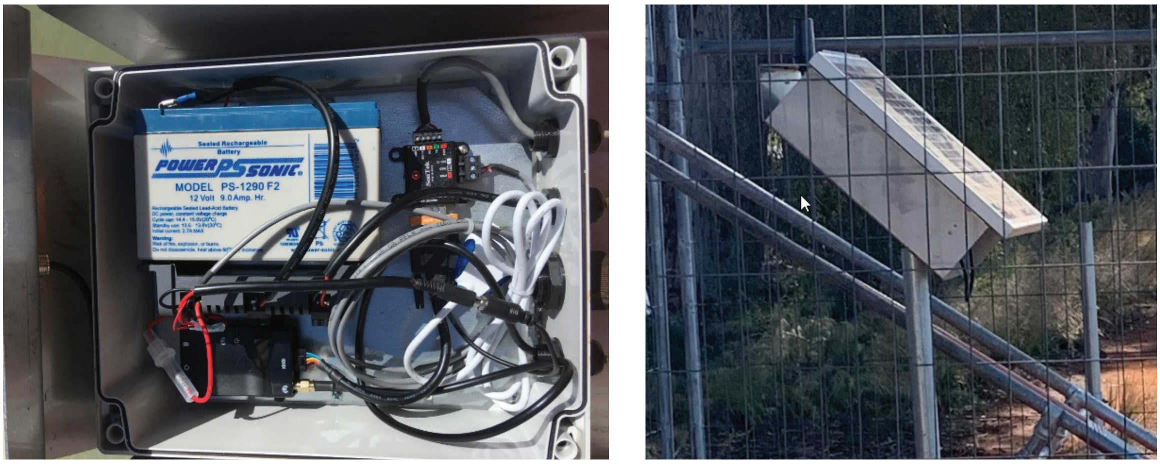


Figure 6. Junction box for housing electronics.

ii. ADCP Cableway

ADCP (RiverSurveyor M9) cableways were installed adjacent to the ADVM installations at each of the measurement sites. The cableway allows a single operator to perform an ADCP discharge measurement with an ADCP, shown in Figure 7. The use of a cableway improves the overall accuracy of the discharge measurement by achieving a more constant boat speed while traversing across the channel. A plastic mesh was used to attach the Hydro-board to the cableway at two points, thus reducing lateral movement on the Hydro-board and minimised the variance in discharge measurement results.

Figure 7. Cableway design at each measurement site for ADCP discharge measurements.

Instrument Configuration

The criteria used for the ADVM's configuration and installation were specific to each measurement site. The key aspects that were focused on during the initial configuration and installation comprised of the following in Table 4.

Table 4. Criteria for configuration and installation of SL1500-3G.

Aspect	Criteria
Cell Size	The number of cells and cell size was dependent on the channel shape and width. The measurement volume range of the instrument was restricted to exclude 10% of total width from the opposite bank. The number of cells and cell size in relation to the channel cross section is shown in Figure 8.
Number of Cells	
Sampling Interval	Sampling interval was selected based on the rate of change of the flow hydrograph.
Sampling Duration	Sampling duration was selected based on sampling interval and power supply.
Elevation	The instrument elevation was determined based on historic water levels, ensuring the instrument is located approximately 0.6 of the water depth from the water surface.

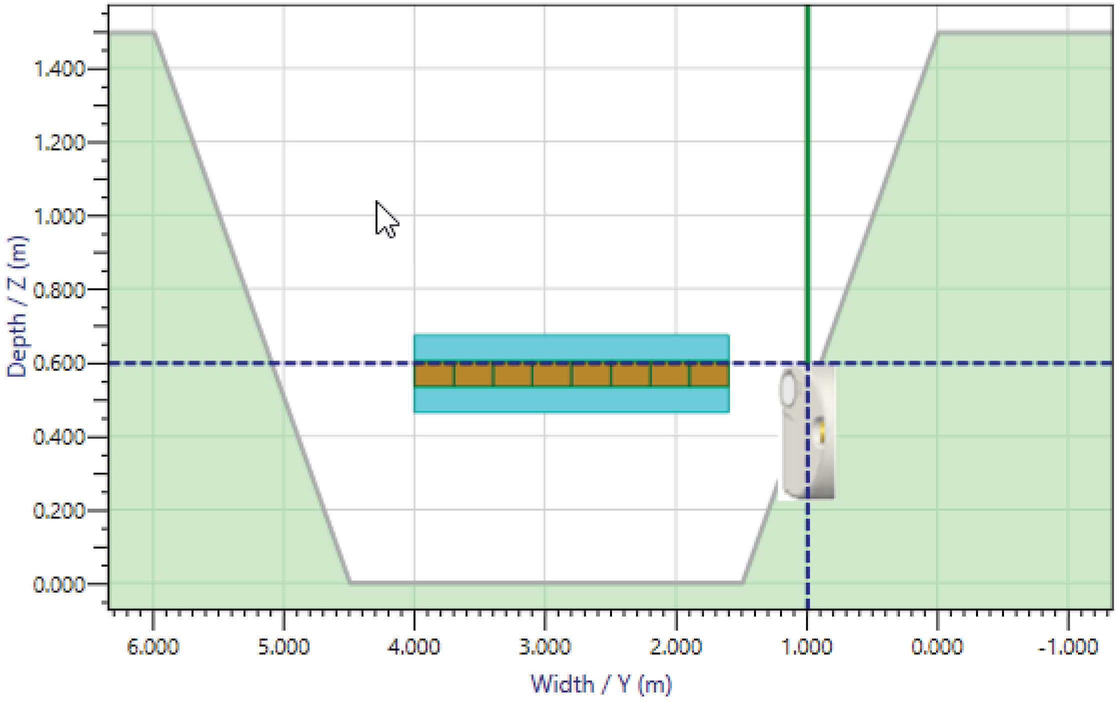


Figure 8. Measurement Volume in Relation to Channel Cross Section.

Instrument Maintenance

The operation of the ADVM was verified during each scheduled visit to ensure the instrument is functioning properly. The steps followed to verify operation is provided in Table 5.

Table 5. Maintenance steps performed on instrument.

Step	Procedure
Beam Checks	Beam checks recorded and analysed by field hydrographer at every site visit to ensure acoustic beams are not being obstructed within the measurement volume.
Internal clock check	The instruments clock time checked for drift during site visits.
Clean instrument	Every month ADVM's were raised form the water and cleaned with a light brush to remove any sediment or biofouling if present.
Clean frame/ mount	The sliding rails and ADVM mount were inspected during site visits to ensure no debris was impacting measurements.
Format recorder	The data from the internal recorder was downloaded and the recorder formatted periodically.

Data Transmission / Storage

All the ADVM instruments were configured with a sampling interval of 300 s and a sampling duration of 240 s. The sampling interval is dependent on the rate of change of flow hydrograph and the application of ADVM in irrigation or storm water channels, a five minute interval is regarded as the maximum to accurately record changes in flow conditions. The sampling duration is dependent on the sampling interval and power supply provided at the measurement site. A longer sampling duration averages the small scale turbulence affects in the channel and therefore improving the standard deviation of the measured velocity.

The instruments measure continuously during the 240 s sampling duration and the average of each measured variable is stored against every five minute sampling interval. A total of 32 variables are available through ASCII output.

At the end of each sampling interval the data is stored internally as well as providing an output via the RS232 serial port to the NTC Cat M1 modem in the form of ASCII characters.

The modem sends this data as packets via TCP/IP to a Virtual Machine (VM) hosted on MI’s server. A Python application running on the VM parses the ASCII characters, transforms them into a table based on predefined rules and uploads the records to MI’s SQL database. The data flow from the ADVM to MI's SQL server is illustrated in the Figure 9.

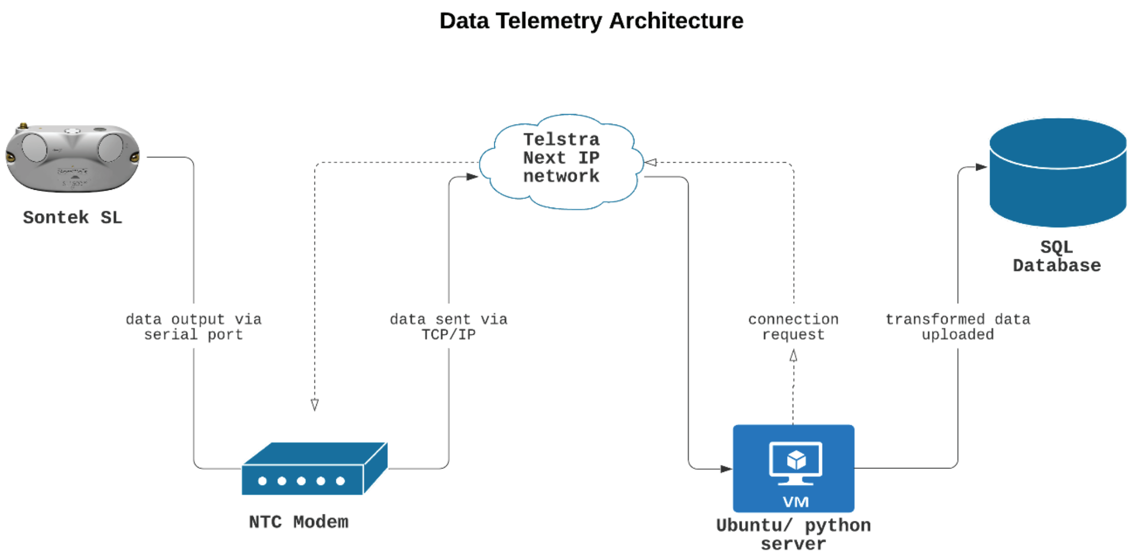


Figure 9. Flow Chart of Data Flow from the SL1500-3G (ADVM) to MI's SQL Server.

The Python application identifies the source of the data based on the unique IP address associated with the SIM card installed in the modem at each location.

Technologies used:

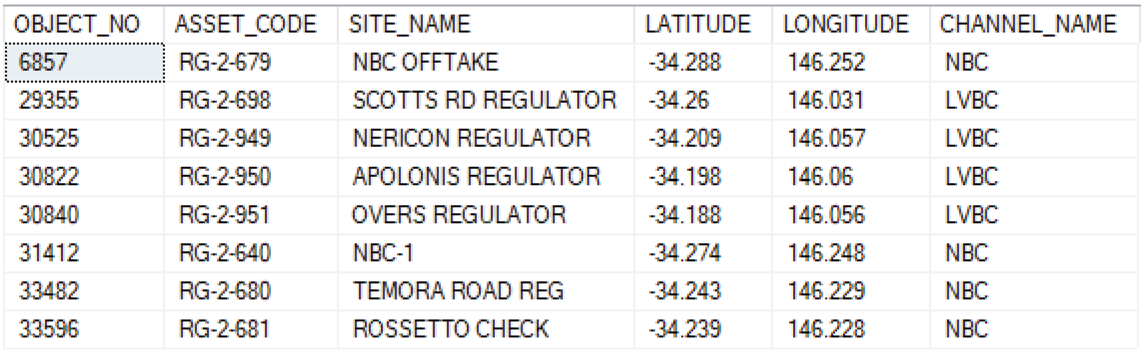
- *Python*: a general-purpose programming language used for data engineering and analysis tasks in this project.
- *SQL Server*: a relational database management system that was used for storing and managing data in this project.

Database Structure

The SQL database developed for the flow verification process contains of four tables to store the index-velocity and discharge data, shown in Table 6. The ADVM sites are treated like objects in the SQL database and are given a unique OBJECT_NO shown in Figure 10. The objects table is used to store the details of each site such as channel name, location coordinates and unique keys used to identify the sites.

Table 6. SQL Database Tables.

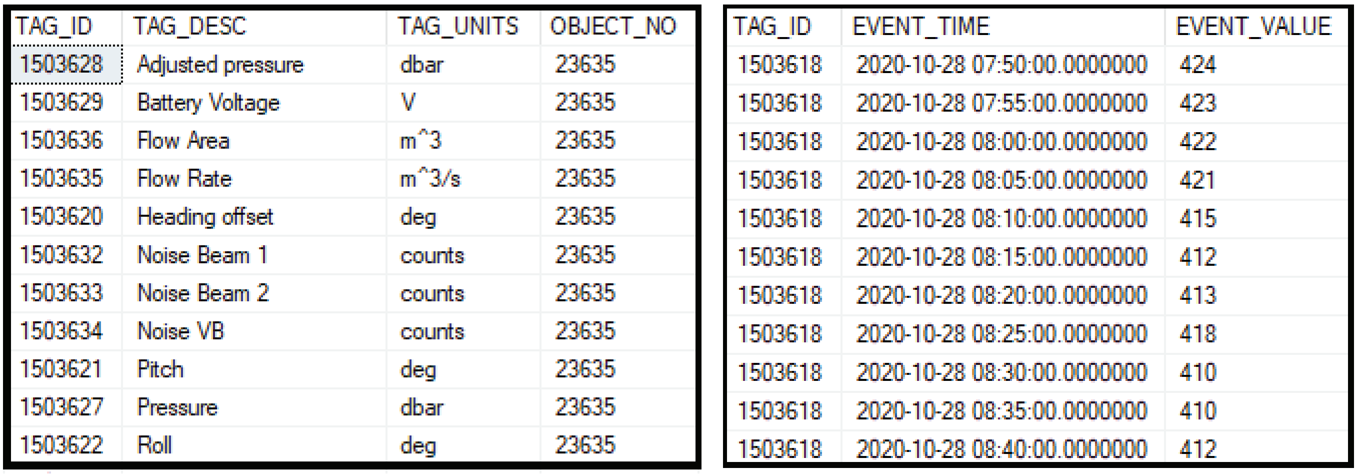
Table	Description
Objects	Information on the unique locations
Tags	Tag Ids for unique parameters for each object
Events	Timestamped values for the parameters
Survey-Compilation	Contains discharge summary for each ADCP measurement



OBJECT_NO	ASSET_CODE	SITE_NAME	LATITUDE	LONGITUDE	CHANNEL_NAME
6857	RG-2-679	NBC OFFTAKE	-34.288	146.252	NBC
29355	RG-2-698	SCOTTS RD REGULATOR	-34.26	146.031	LVBC
30525	RG-2-949	NERICON REGULATOR	-34.209	146.057	LVBC
30822	RG-2-950	APOLONIS REGULATOR	-34.198	146.06	LVBC
30840	RG-2-951	OVERS REGULATOR	-34.188	146.056	LVBC
31412	RG-2-640	NBC-1	-34.274	146.248	NBC
33482	RG-2-680	TEMORA ROAD REG	-34.243	146.229	NBC
33596	RG-2-681	ROSSETTO CHECK	-34.239	146.228	NBC

Figure 10. Structure of the Objects Table in MI's database.

A unique TAG_ID value is used to reference each output attribute for each ADVM object shown in Figure 11 (left). As data are received from the instrument, they are uploaded to the Event table shown in Figure 11 (right) where the EVENT_TIME column represents time when the ADVM starts sampling, the EVENT_VALUE column shows the measured value and TAG_ID column identifies the type of measured attribute.

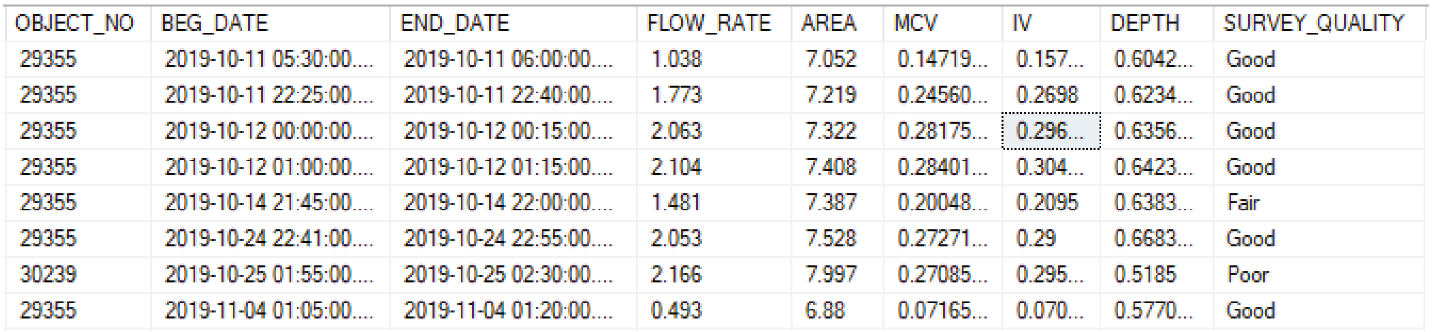


TAG_ID	TAG_DESC	TAG_UNITS	OBJECT_NO
1503628	Adjusted pressure	dbar	23635
1503629	Battery Voltage	V	23635
1503636	Flow Area	m^3	23635
1503635	Flow Rate	m^3/s	23635
1503620	Heading offset	deg	23635
1503632	Noise Beam 1	counts	23635
1503633	Noise Beam 2	counts	23635
1503634	Noise VB	counts	23635
1503621	Pitch	deg	23635
1503627	Pressure	dbar	23635
1503622	Roll	deg	23635

TAG_ID	EVENT_TIME	EVENT_VALUE
1503618	2020-10-28 07:50:00.0000000	424
1503618	2020-10-28 07:55:00.0000000	423
1503618	2020-10-28 08:00:00.0000000	422
1503618	2020-10-28 08:05:00.0000000	421
1503618	2020-10-28 08:10:00.0000000	415
1503618	2020-10-28 08:15:00.0000000	412
1503618	2020-10-28 08:20:00.0000000	413
1503618	2020-10-28 08:25:00.0000000	418
1503618	2020-10-28 08:30:00.0000000	410
1503618	2020-10-28 08:35:00.0000000	410
1503618	2020-10-28 08:40:00.0000000	412

Figure 11. Tags Table (left) - Events Table (right).

The data collected from ADCP discharge measurements were compiled and uploaded to the Survey-Compilation table. A new row is appended to this table after each completed discharge measurement. The survey-compilation table contains a summary from each ADCP discharge measurement and the corresponding IV and stage measurements from the ADVM. Each data entry is referenced to the OBJECT_NO of the measurement site as show in Figure 12.



OBJECT_NO	BEG_DATE	END_DATE	FLOW_RATE	AREA	MCV	IV	DEPTH	SURVEY_QUALITY
29355	2019-10-11 05:30:00....	2019-10-11 06:00:00....	1.038	7.052	0.14719...	0.157...	0.6042...	Good
29355	2019-10-11 22:25:00....	2019-10-11 22:40:00....	1.773	7.219	0.24560...	0.2698	0.6234...	Good
29355	2019-10-12 00:00:00....	2019-10-12 00:15:00....	2.063	7.322	0.28175...	0.296...	0.6356...	Good
29355	2019-10-12 01:00:00....	2019-10-12 01:15:00....	2.104	7.408	0.28401...	0.304...	0.6423...	Good
29355	2019-10-14 21:45:00....	2019-10-14 22:00:00....	1.481	7.387	0.20048...	0.2095	0.6383...	Fair
29355	2019-10-24 22:41:00....	2019-10-24 22:55:00....	2.053	7.528	0.27271...	0.29	0.6683...	Good
30239	2019-10-25 01:55:00....	2019-10-25 02:30:00....	2.166	7.997	0.27085...	0.295...	0.5185	Poor
29355	2019-11-04 01:05:00....	2019-11-04 01:20:00....	0.493	6.88	0.07165...	0.070...	0.5770...	Good

Figure 12. Survey-Compilation Table.

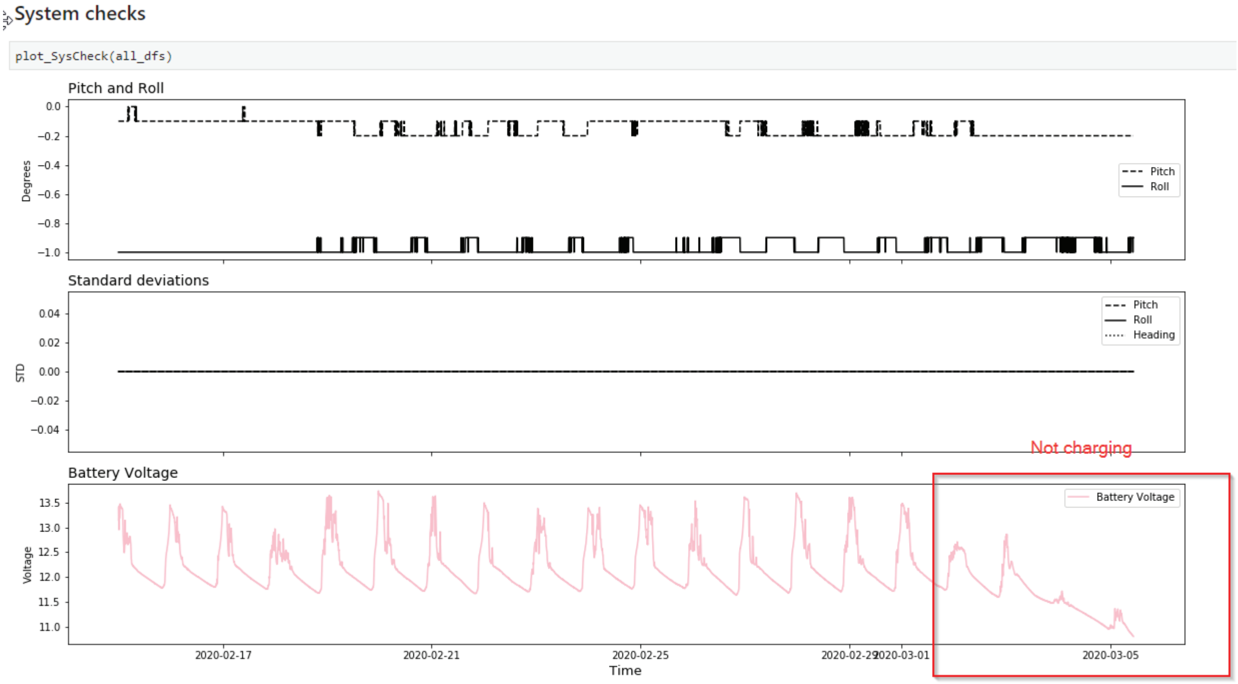
Data Monitoring and Error Reporting

The selected timeframe of three months for instrument deployment at a measurement site ensured that a range of flow conditions were monitored during this period. Real-time telemetry and diagnostic data provided from the ADVM were assessed with Python applications and SQL database to monitor the state of the instrument.

A Python program was created to monitor the transmitted data samples, which were expected from each site every 300 s (based on the sampling duration). If an instrument failed to transmit a sample for three successive sampling durations, an email alert was sent to the Hydrological Team. The team would then send field personnel to inspect the instrument.

Additionally, some attributes of the ADVM were also monitored to detect issues with the instrument. The following attributes were analysed:

- Pitch and Roll: These attributes were monitored to detect any changes to the instrument's alignment. Any changes in positioning could impact the index rating.
- Battery Voltage: Voltage was monitored to ensure the battery powering the ADVM was being charged by attached solar panel. Figure 13 shows an instance where the battery failed to charge due to cloudy weather and failed to supply the required power to the instrument. An alert was received which allowed the field hydrologist to extract the battery and charge it.
- Signal to Noise Ratio (SNR): The ratio signal strength of the acoustic beams and the ambient instrument noise was monitored over time to track any changes which could be a result of a failing transducer, excessive biofouling on transducer or beams being obstructed. Figure 14 shows the instrument at RG-2-681 within the acceptable range of SNR > 3.



System checks

```
plot_SysCheck(all_dfs)
```

Figure 13. Pitch/Roll and Battery Voltage Plots.

Figure 14. Signal Amplitude and Noise Levels at the RG-2-681.

Identification of Flow Ranges to Target

The Events table in the SQL database also contains gate flow data from pre-existing regulators at the selected sites. The historical data was used to identify the range of flows at each site and thereby the flow values at which ADCP discharge measurement would need to be done for developing robust ratings. The red crosses mark the flow rate/bins where ADCP discharge measurements where completed.

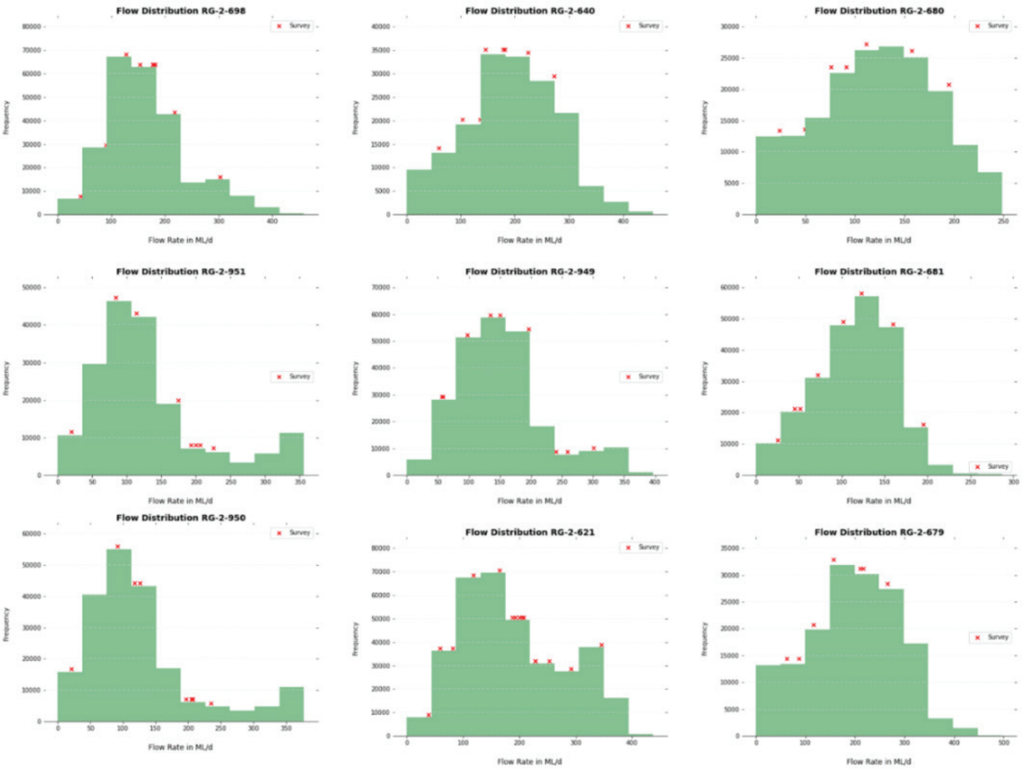


Figure 15. Distribution of Flow Rate through the Regulators at Selected Measurement Sites.

Flow verification process

At the measurement site, the field hydrographer requested the channel operators to set the regulator to a constant flow mode. This ensured a steady flow in the channel while an ADCP discharge measurement was made as shown in Figure 16. After completing the measurement, the data was uploaded to MI's shared network drive from the field.

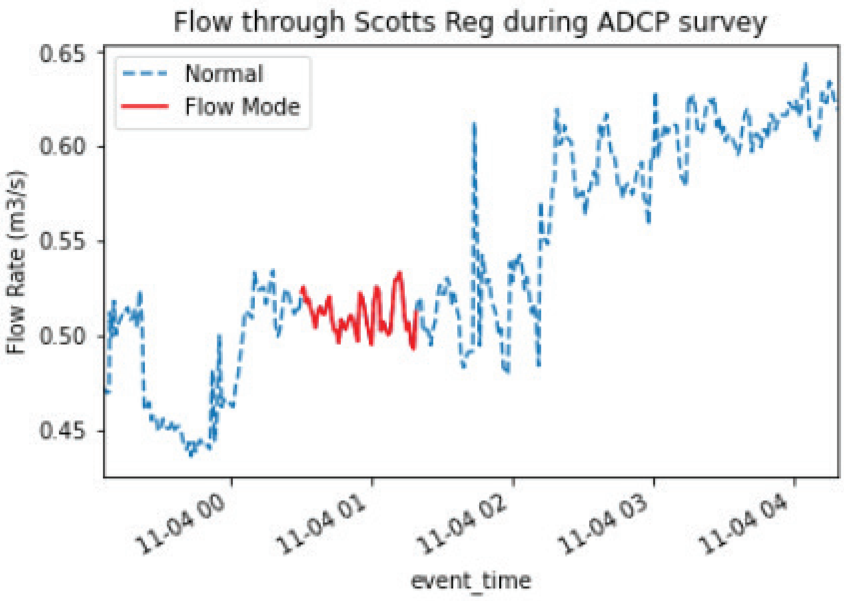


Figure 16. Flow Rate at Scotts Rd Regulator during Standard Operation and Constant 'Flow Mode'.

A standard set of guidelines were followed for collecting discharge measurement data for accurate calibration of the rating.

- The total duration of discharge measurements >= 800 s.
- RTK GPS for track reference
- Bottom Track depth reference
- Reciprocal transects

Only discharge measurements with COV < 5% in flow rate measurement were used for rating calibration.

After completing the measurement, the data was uploaded to MI's shared network drive from the field. At the office the discharge measurements were reviewed using the RiverSurveyor Live and QRev software. The discharge summary was input into a custom Python application to develop the index-velocity and stage-area ratings. The application required the following inputs:

- Site's ID / OBJECT_NO
- Start and end times of measurement
- Total discharge (Q) measured (m^3/s) (m^3/s)
- Area (A) measured (m^2)

After receiving these inputs, the Python application executes the following steps:

1. Mean channel velocity is calculated from measured flow rate and area.
2. The Site ID is used to locate the site's ADVM data in the database.
3. The start and end times are used to extract the average depth and index velocity (X-velocity) measured by the ADVM during the ADCP discharge measurement.
4. The compiled ADVM and ADCP data is uploaded to the Survey-Compilation table shown in Figure 10.
5. If the database contains a backlog of more than one discharge measurement for the site, the ratings are developed and displayed.

Two ratings were developed to compute continuous flow, the Stage-Area rating and the Index-Velocity rating shown in Table 7.

Stage-Area Rating was used to model the relationship between the measured depth by the ADVM and the cross-sectional area of the channel. The rating can be described by the following equation:

$$A = w_a * D + c_a$$

Where A is the cross-sectional area, D is the depth measured by the ADVM, w_a is the area rating coefficient and c_a is the area rating intercept.

Index-Velocity rating is used to model the relationship between the index-velocity measured by the ADVM and the mean channel velocity. The rating can be described by the equation:

$$V = w_v * I$$

Where V is the mean channel velocity, I is the index velocity and w_v in the index rating coefficient.

MI developed a standard procedure for performing ADCP discharge measurements and developing ratings to ensure consistent and accurate results, with the workflow provided in Figure 17. The process involves 3 components: desktop analysis, field survey and the automated parts of MI's custom application. The real-time flows at the regulator were monitored along with the previously identified flow targets, to select the measurement site where further discharge measurements are required.

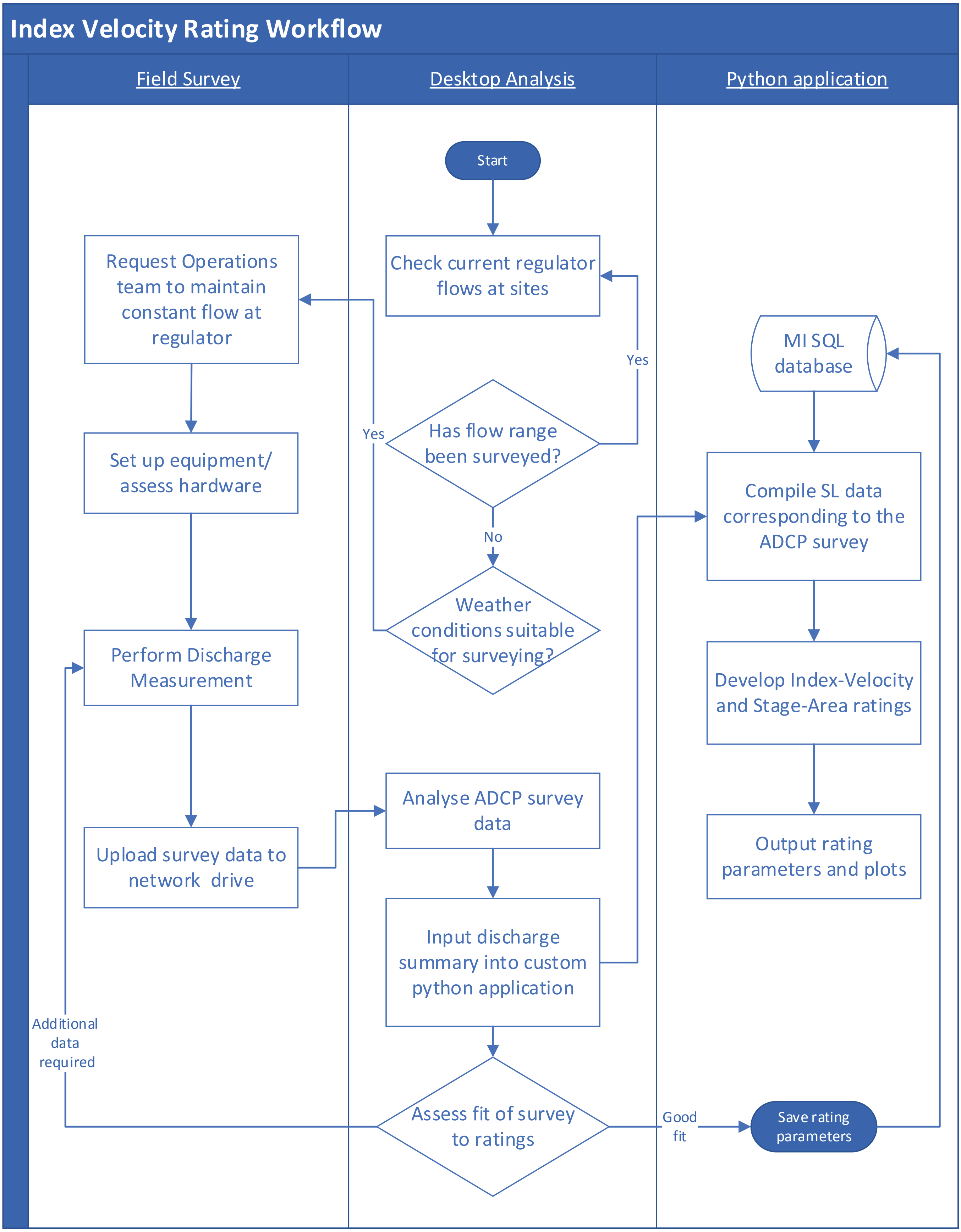


Figure 17. Workflow for Index Velocity Rating Development.

Table 7. Index Velocity Rating Method and Parameters.

Rating name	Method	X- variable	Y-variable	Comments
Index-Velocity Rating	Linear Regression	Multi-Cell X Velocity (Index Velocity)	Mean channel Velocity	Intercept set to zero to force the rating through the origin.
Stage-Area Rating	Linear Regression	Depth	Area	Intercept fitted.

The ratings were visualised and analysed after each discharge measurement to validate the measurements. If the data fit the rating, the parameters of the rating were saved to the database, otherwise additional discharge measurements were requested from the field.

Data Analysis

Discharge measurements collected over the defined flow range at each measurement site during the three month measurement period greatly enhanced the rating development. A graphical and statistical analysis of the ratings was performed to determine the applicability of each individual rating developed.

By default, the Python application fits a simple linear regression model to develop the rating. The Figure 18 shows the type of scatter plot used to visualise the ratings for each site. The visualisation along with the residual analysis was used to assess the rating. A statistical measure, the coefficient of determination (R^2) was used as an applicability of fit measure. In figure 18, the plot shows that the model fits well and the R^2 of 0.998 means that the result is acceptable.

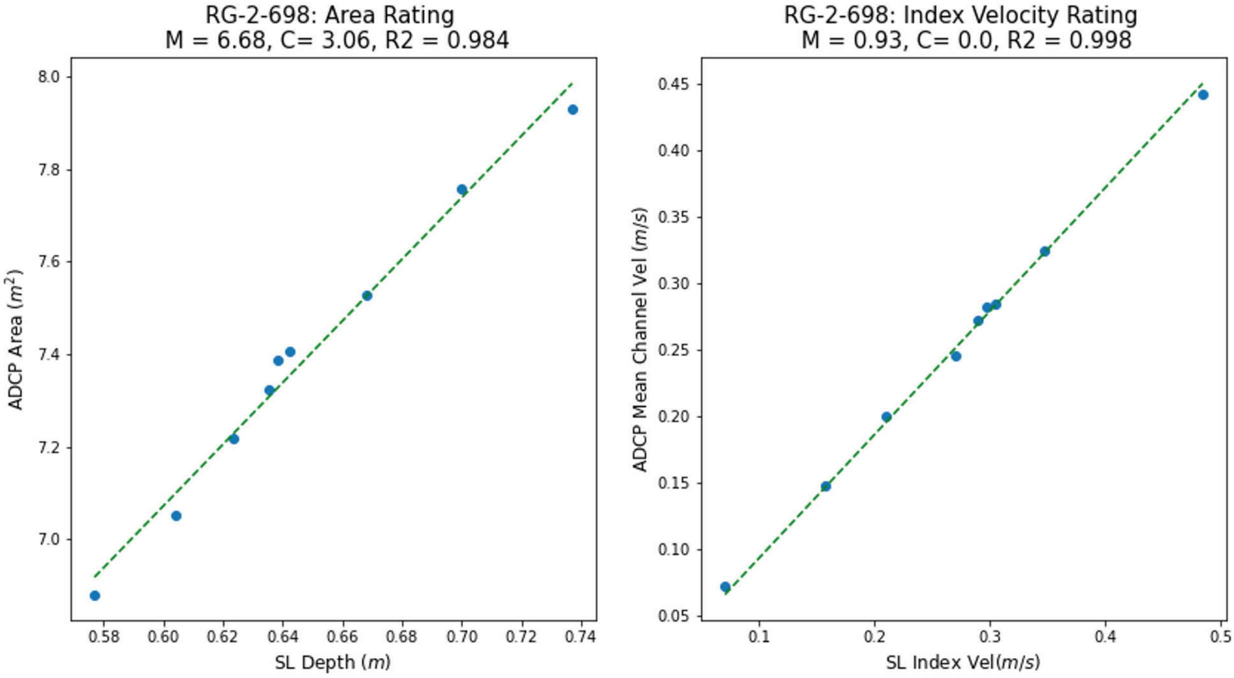


Figure 18. Scatter Plot to Analyse Stage-Area and Index Velocity Ratings.

The visual and statistical tests were repeated for all 9 measurement sites. The ratings developed for all the measurement sites are collated graphically in Figure 19.

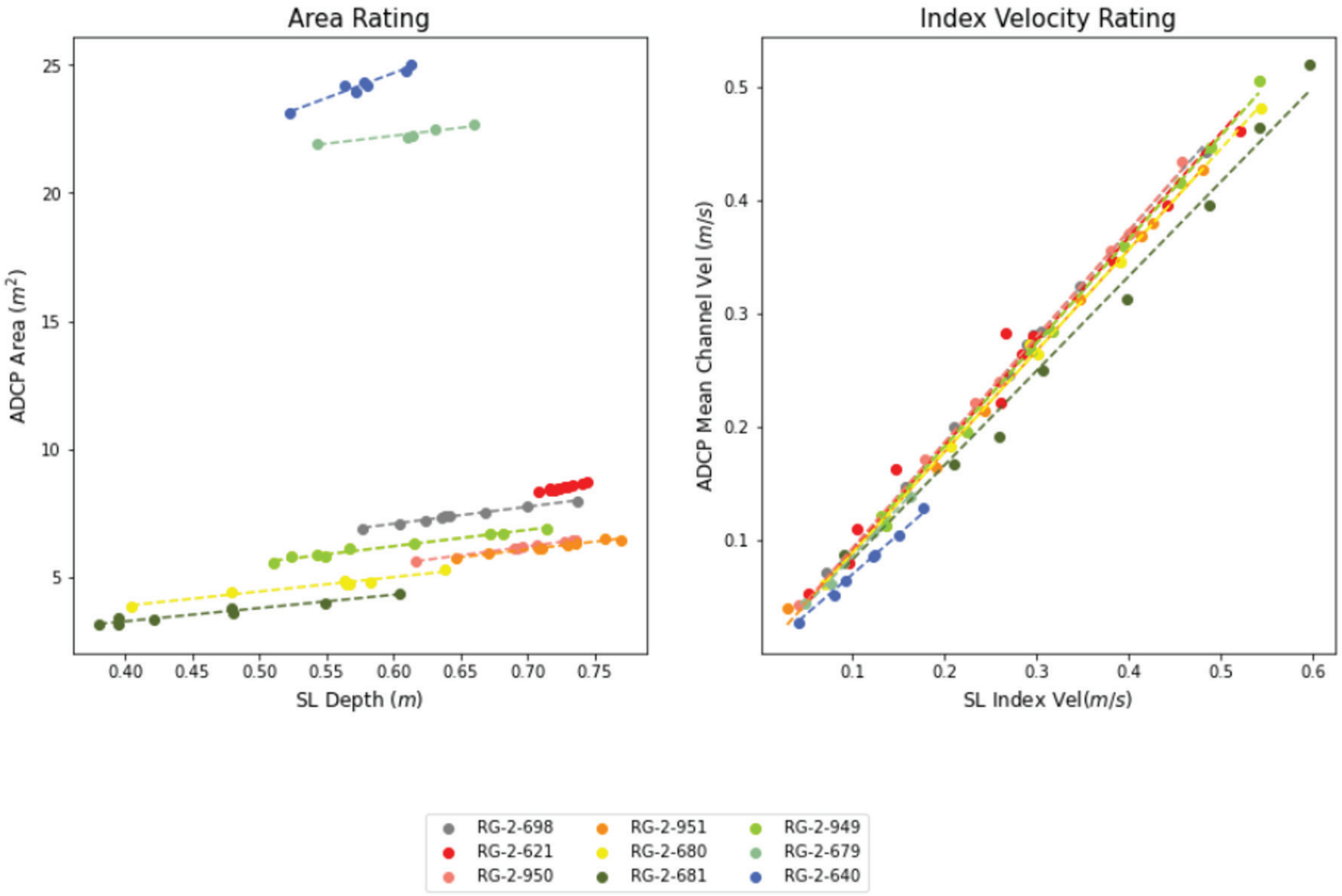


Figure 19. Linear Relationship of Index Velocity Ratings for all 9 Measurement Sites.

The results from the rating development procedure are summarized in Table 8. The coefficient of determination (R^2) was used as an applicability of fit measure that gives the percentage variance in a dependent variable that can be explained by an independent variable. The area rating, R^2 was ≥ 0.95 for all measurement sites except for RG-2-679, which showed a strong relationship between depth and area. RG-2-679 is a wide (22 m) earth channel where the discharge measurements had a higher variance compared to other measurement sites; this explains the slightly weaker area rating for this site.

The R^2 values for the Index-Velocity ratings were ≥ 0.98 for all sites which shows a very strong relationship between the measured index velocity and the mean channel velocity.

Table 8. The rating parameters and good of fit measure R² a, Area rating and R² for the Index-Velocity rating for all 9 measurement sites.

Site ID	w_a	c_a	$R^2 a$	w_v	$R_2 v$
RG-2-698	6.68	3.06	0.99	0.93	0.99
RG-2-621	8.64	2.24	0.99	0.92	0.98
RG-2-949	6.35	2.38	0.98	0.91	0.99
RG-2-950	6.97	1.31	1	0.93	1
RG-2-951	6.11	1.79	0.99	0.89	0.99
RG-2-679	6.23	18.5	0.90	0.86	0.99
RG-2-640	19.5	13	0.95	0.7	0.99
RG-2-680	5.61	1.62	0.96	0.89	0.99
RG-2-681	5.47	1.03	0.98	0.83	0.98

The ratings were used along with the data collected by the ADVMs over the three-month period to calculate the continuous flow rate and cumulative volume at each site. The percentage difference between the volume measured by the ADVM and the regulator at each of the measurement sites is provided in Table 9. Except for two sites, RG-2-950 and RG-2-951, the measured volume at the regulator was within 5% of the ADVM measurement.

Table 9. Cumulative Error in Volume between the ADVM Measurements and the Regulator at nine measurement sites.

Site ID	Cumulative volume Error (%)
RG-2-621':'Andreattas	2.70
'RG-2-950':'Apolonis	19.51
'RG-2-951':'Overs'	11.12
'RG-2-949':'Nericon'	3.99
'RG-2-680':'Temora'	4.03
'RG-2-681':'Rosetto'	3.18
'RG-2-698':'Scotts Rd'	2.49
'RG-2-640':'NBC-1'	2.92
'RG-2-679':'NBC Offtake'	-1.83

Conclusion

The flow verification process implemented by Murrumbidgee Irrigation resulted in accurate flow measurements at key sites in the network. Comparison of the flow measured by the ADVM instruments against the reported regulator flow at the measurement sites showed that 7/9 sites were within 5%. The result gives Murrumbidgee Irrigation confidence in the regulator flows that are used primarily for operating the network.

The two sites with higher variance in flow, experience different flow conditions to the rest with the regulator gates being exposed to higher levels of submergence. This presents an opportunity to improve the flow calculation at these sites.

Furthermore, Murrumbidgee Irrigation now possess highly accurate instruments and have developed standard procedures that allows them to set up temporary flow monitoring sites, develop stable ratings and accurately measure flow anywhere within the irrigation network.

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