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JACQUIE BELLHOUSE

Editor's Introduction

This quarter I have been absolutely spoilt for choice by our members. It was hard but I finally settled on four extremely interesting and diverse papers from both new and repeat contributors.

It is with great excitement that I welcome a paper from, a first time contributor, Thomas King. I found Thomas King's paper on *Velocity Indexing side looking Dopplers in man-made canals* extremely interesting. I will however acknowledge that in this instance my enthusiasm is possibly a symptom of what my fourteen year old son would refer to as, my "Noob" status in regards to side looking Dopplers. However I am always interested in growing and expanding my knowledge and articles such as Thomas' provide me with an excellent opportunity.

For the first time (since I became the editor) we also welcome a follow up article, by NIWA's Jeremy Bulleid, on the *Rising Bubble method field trails in Hawkes Bay*. If you haven't yet had the opportunity, grab July's Journal and read Jeremy's first article on *Automatic Discharge Measurement of Lowland Weedy Streams*. Both Articles make for very interesting reading.

The journal also welcomes back some frequent flyers.

While Daniel Wagenaar's paper on *Determining Total Volume of Sludge in Wastewater Ponding Lagoons* might have a little bit of an "ick" factor, it is a great illustration of how we are expanding the use of Remote Survey Boats and associated equipment. An added bonus here is the improvements to our profession's health and safety conditions. Let us just say I am glad I had moved to a job in head office when this work first came in (photos of the old methods to illustrate).

Figure 1: Water Corporation Hydrographers undertaking Sludge Profiling.

Mike Ede and Mic Clayton have also forwarded a very interesting paper on the recent *Space Time Image Velocimetry Training Workshop*, in Wellington, New Zealand. This subject is particularly pertinent as the Water Monitoring Standards Technical Committee (WaMSTeC) begins to discuss where to next for our National Hydrometric guidelines. Is *Image Velocimetry* the way of the future? Should it be the subject of our next Hydrometric Guideline?

Lastly, and perhaps because I recently found the time to read *Till the Stream Runs Dry, A History of Hydrography in Western Australia* (Bill Bunbury, 2010), I would like to put out a call to all of those amateur historians out there with a keen interest (and epic pack rat capabilities) in our Hydrographic History. The Journal is looking to start a "From the Vault" series of articles and we need you! Do you have some interesting points of view on the history of the humble staff gauge or perhaps you are a seasoned professional when it comes to Daily Read Bristols, the Seven Day Recorder or maybe A-35 Strip Charts. If so please get in contact with me via journal@aha.net.au.

Jacquie Bellhouse
Journal Editor

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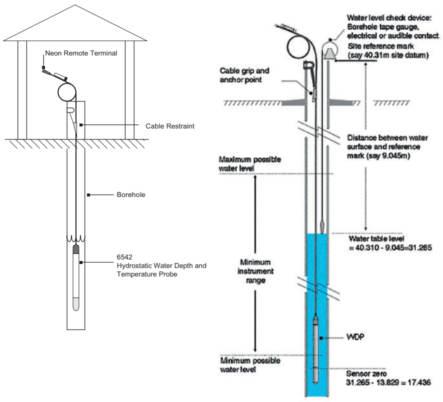
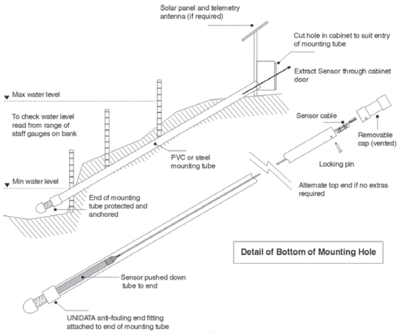


Typical Installation on a stream bank



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BILL BARRATT

From the President

“Water is fundamental to all life on Earth and its sustainable management is critical to the well-being of human societies. Rarely is one sector so important to achieving positive outcomes in numerous other sectors — food security, energy security, biodiversity and ecosystem health, disaster management — as well as many human needs from water supply and sanitation to recreation, spiritual and cultural requirements. It is no wonder that ‘water’ has risen to be consistently one of the top issues on the international development agenda.” [1]

Across the nation, federal, state and local agencies are charged with various aspects of natural resource management, and current drought in the eastern states reminds us of the difficulties of managing our natural resources and the role of water in that management.

The key to sound natural resource management is informed decision making based on objective fact, which needs good data. Good data require well trained field Hydrographers to measure natural processes to consistent standards.

So it is little surprise that the Commonwealth Water Act 2007 charged the Bureau of Meteorology with creating the first national water database, and funded the development of Hydrographer training and published *National Industry Guidelines* for monitoring, activities where AHA and its members have been actively involved.

AHA is one of many organisations involved in monitoring environmental processes and gathering information for environmental managers. Whilst AHA members are “measuring Australia’s water”, there are many organisations filling similar roles in complementary disciplines. The AHA Committee has taken a deliberate decision to become affiliated with such organisations where we believe our activities can be mutually beneficial, both domestically and internationally. The aim is to have AHA recognised, both in Australia and internationally, as the lead association for measuring Australia’s water. To date we have signed Memoranda of Understanding (MoUs) with the NZ Hydrological Society, Irrigation Australia Limited, the International Centre of Excellence in Water Resources Management (ICE WaRM) and the Australian Water Partnership (AWP). Other MoUs are under negotiation and will be announced as they come to fruition. There are clear benefits arising from these affiliations including cross training at member rates, attendance at events at member rates and being at the table with kindred organisations representing water data measurement and collection.

AHA members are encouraged to look at these Affiliates and remember that you can access a lot of the services provided at member rates. AHA Partners are also encouraged to look at the Affiliate organisations as there may be commercial opportunities that have not previously been considered.

You can find more about our Affiliated Organisations on the AHA website under the **Partnership** menu.

Bill Barratt. FAHA
President

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[1] https://waterpartnership.org.au/about/

Rising Bubble Method field trials in Hawkes Bay

Jeremy Bulleid (NIWA), Thomas Wilding (Hawke's Bay Regional Council)

Introduction

In the July 2019 issue of the Australasian Hydrographer, the article *Automatic Discharge Measurement of Lowland Weedy Streams* provided an overview on the Rising Bubble Method (RBM) and the progress in developing a practical RBM tool to improve the reliable measurement of water flowing in lowland weedy streams. This work is part of an MBIE Envirolink Tools project we are carrying out in collaboration with regional councils.

As previously outlined, conventional methods for continuous flow monitoring require a surrogate (water level) translated to discharge using a rating curve. The presence of aquatic vegetation makes this relationship insensitive and unstable, often resulting in 'difficult-to-impossible' measurement. In principle the Rising Bubble Method (RBM) involves releasing 'precision' air bubbles from a streambed to enable direct calculation of Total Discharge Q.

In this follow-up article we share some of the results from recent field trials that we carried out near Napier with Hawke's Bay Regional Council (HBRC) staff.

Measuring Q at Raupare Stream, near Napier

Figure 1: Paul Hodgkinson and Thomas Wilding (HBRC) deploy the bubble line within the Raupare Stream.

The Raupare Stream is located in the lower Karamu catchment, New Zealand. It originates from groundwater springs adjacent to the Ngaruroro River near Twyford, and flows for approximately 7.5 km to the southeast, converging with the Karamu Stream.

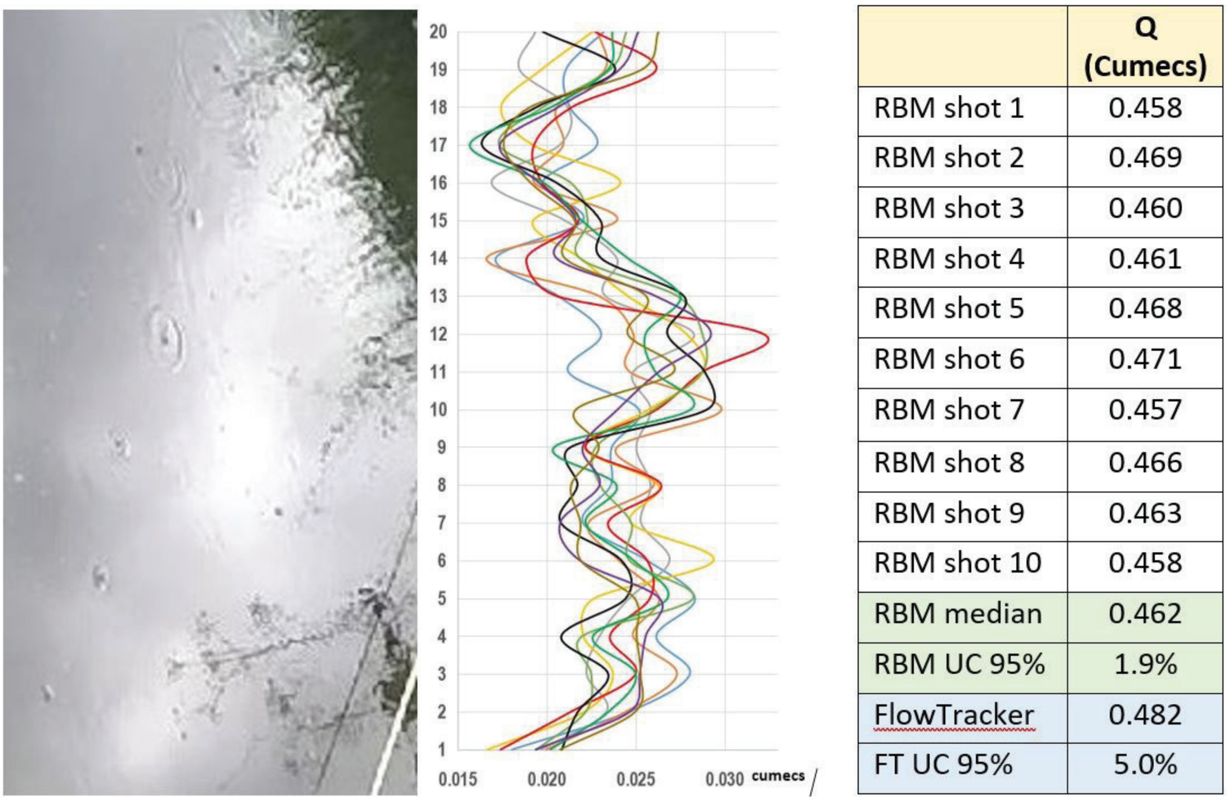
A bubble line, installed to span the 4 m wide stream, was configured with 20 bubble injectors 0.2 m apart.

During the trial we assumed that Q would remain constant over the very short measurement period (a few seconds) and took 10 'snapshots' of Q, calculated from 17 seconds of video (1040 frames at

60 frames per second). A single bubble was injected simultaneously from each of the 20 injectors to release a line of bubbles at the streambed across the width of the stream. This was repeated nine more times (every 1.7 seconds). Each of the 10 snapshots gave an instantaneous value for Q.

Figure 2: Underwater view showing each injector simultaneously releasing a single bubble.

Less than a second elapsed between the earliest and latest bubbles to 'just surface' within each sequence with the difference depending on the depth. The mean depth was 0.6 m. Our reference was a Sontek FlowTracker, sampling at 20, 60 and 80% of depth every 0.2 m.



	Q (Cumecs)
RBM shot 1	0.458
RBM shot 2	0.469
RBM shot 3	0.460
RBM shot 4	0.461
RBM shot 5	0.468
RBM shot 6	0.471
RBM shot 7	0.457
RBM shot 8	0.466
RBM shot 9	0.463
RBM shot 10	0.458
RBM median	0.462
RBM UC 95%	1.9%
FlowTracker	0.482
FT UC 95%	5.0%

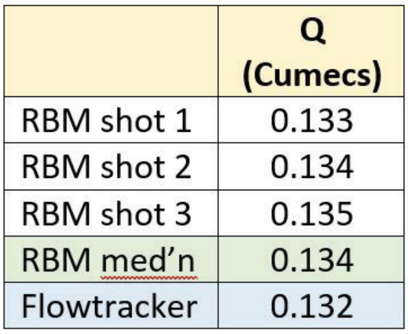
Figure 3: Left – bubbles surfacing. Middle – colour-coded chart depicts the partial discharge that each of the 20 injectors contributed to Q showing how the flow rate (not the velocity) varied across the stream width. Right – results from 10 'flow-shots', producing 10 near-instantaneous snap shots of Q.

We also carried out a wading gauging with a prototype single-point RBM wading rod. Q was 0.448 Cumecs (m^3/s) and 95% of 100 resample replicates fell within 3.3% of the mean.

Measuring Q at Karewarewa Stream

The same bubble line was installed in the Karewarewa Stream. This stream also located within the Karamu catchment, New Zealand. The site receives groundwater via a 4 m thick layer of pumice sand, which is an alluvial deposit from a Taupo eruption. The low gradient and lack of shade allows prolific weed growth.

Since this stream is narrower than the Raupare, only 13 of the 20 bubble injectors were underwater.



	Q (Cumecs)
RBM shot 1	0.133
RBM shot 2	0.134
RBM shot 3	0.135
RBM med'n	0.134
Flowtracker	0.132

Figure 4: Left; Paul Hodgkinson and Thomas Wilding (HBRC) deploy the bubble line at Karewarewa Stream. Thomas did a lot of clearing and weeding on his previous visit to enable FlowTracker measurements. Right; snapshots of total discharge show good repeatability and agreement with the reference.

The Equipment and Results

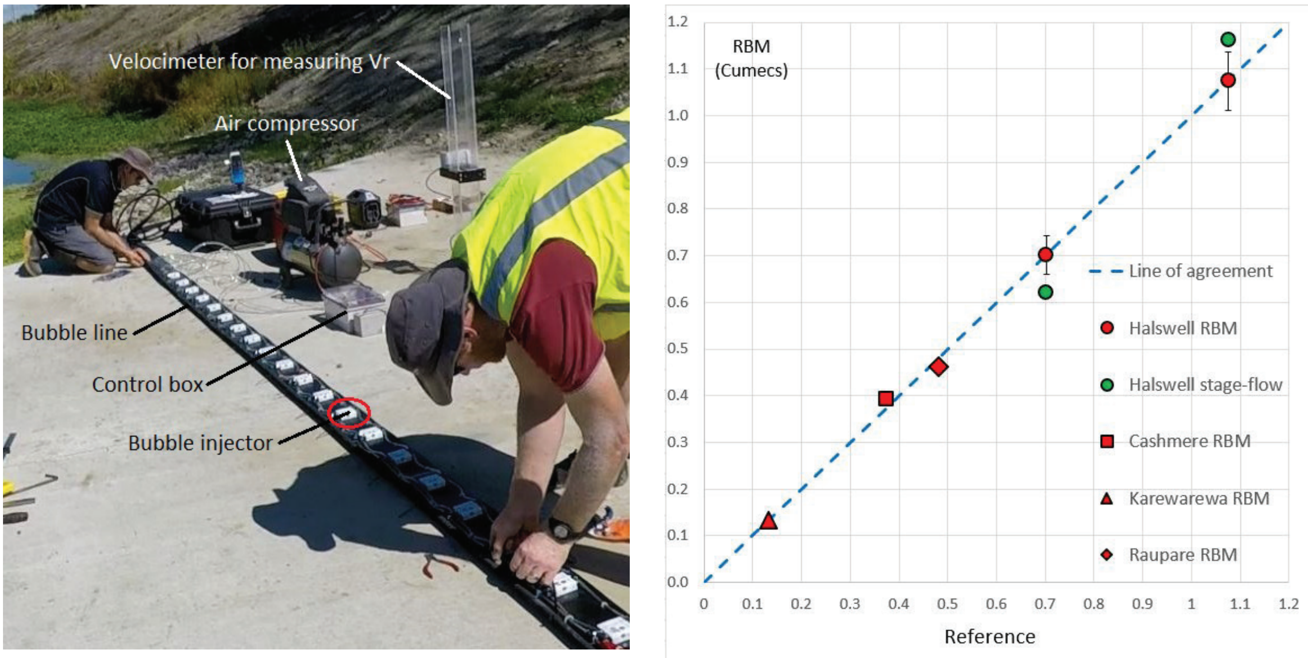


Figure 5: Left – Phil Hall and Thomas Wilding preparing equipment at Karamu Stream. Right – graphical overview of results so far, showing a range of flow rates.

What are the remaining challenges?

Do we always need to measure bubble rise velocity?

As outlined in the previous article the total discharge is equal to the Displacement Area multiplied by the Rise Velocity (Vr).

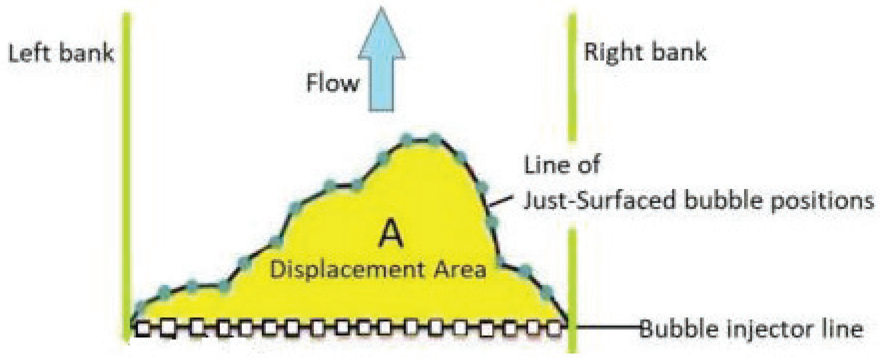


Figure 6: The rationale for RBM gauging.

Therefore because Q is directly proportional to Vr, any uncertainty in Vr is transferred directly to Q.

Initially, to reduce the uncertainty, we considered that it would be good practice to use the Velocimeter on site, to measure rise velocity before and after each reading. However given this method involves extra work, what are the consequences of not always doing this local water calibration (in situ, or taking a sample back to the lab)?

In an attempt to answer this question we analysed Vr data from: Halswell River, over nearly two years, and from five different streams in Hawke's Bay over four days. The table below shows the Vr (m/s) we measured at each stream.

Halswell	Karamu	Tutaekuri-W	Raupare	Paritua	Karewarewa
0.203 (median of 8 measurements)	0.211	0.209	0.219	0.208	0.215

Essentially we need a lot more data before we can answer this question, however if we were to increase the acceptable measurement uncertainty, could we normalise Vr for a given site, range of sites, season or flow rate?

The need for compressed air

During the Hawke's Bay' trials we used a petrol-driven air compressor, since there was no mains power at any of the five sites we visited. Clearly this is not practical for any future monitoring station. It takes a significant amount of energy to compress air, and this will likely have to be supplied on site from solar panels. Alternatively, a dive tank may be used. Either way, it is necessary to minimise the amount of compressed air needed.

In the previous sections we have shown that we can obtain a Q measurement with a single-shot of bubbles. This is encouraging, as it has important practical implications. Taking a measurement every 15 minutes would use very little air. It would therefore minimise compressor/storage size and the energy required to compress air on site. Alternatively, it would also minimise dive tank refills.

Making the bubble line more robust

While the bubble line has survived five deployments, the compressed air fittings are exposed and do not survive being stood on. A good solution is to fit a simple cover with clearance around the bubble outlets. This prevents floating weed from building up around the compressed air supply tubes and facilitates occasional in-situ cleaning with a broom.

Automation

Trials carried out so far indicate that RBM produces excellent repeatability.

While we can now capture a video with a hand-held GoPro camera, and achieve results that compare favourably with the available references (e.g. FlowTracker), manual post-processing of the video is slow, each of the Raupare series taking about 30 minutes. However this is still comparatively quicker than a FlowTracker gauging.

In a permanent (fixed) installation accurate distance references are required, to enable conversion of pixels to true distance. This would lead to the tag lines used during development becoming redundant. The software would 'draw' virtual taglines and these would remain valid for as long as the camera remained fixed.

Our biggest remaining challenge is to automate the RBM process. A datalogger will initiate a 'flow-shot', triggering a line of bubbles and turning on the camera for ~5 seconds. Here we can have two levels of automation; partial and full-automation. In partial automation, short video files would be telemetered for manual post-processing. This would mean not having to travel to the site.

However, the "Holy Grail" is **full-automation**, using Artificial Intelligence (AI) to detect the definitive 'just surfacing' bubbles and calculating their true downstream displacements. An AI network has been developed and is being trained with bubble images. Detection is working well when the images have sufficient resolution. Therein lies the challenge — obtaining this resolution, while getting 'full-stream-width' within the camera's field of view, is the present limiting factor, and therefore our next focus.

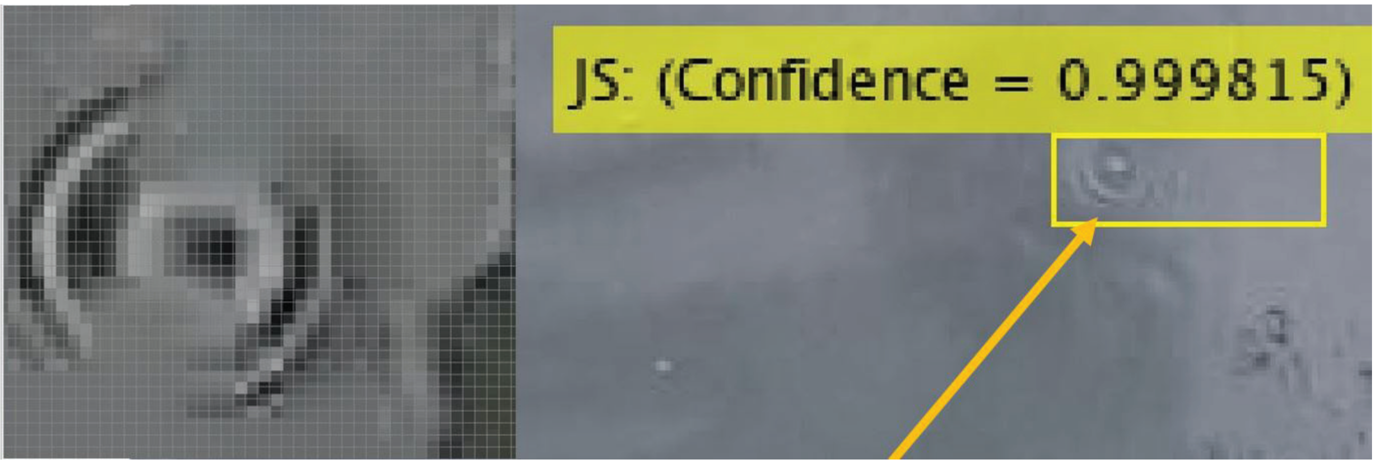


Figure 7: The Artificially Intelligent trained network detects a 'just-surfaced' bubble at the pixel limit of resolution.

Acknowledgements

MBIE Envirolink for funding;

Phil Hall, Paul Hodgkinson and other HBRC field staff for assistance during trials;

HBRC, ECan and NIWA for their support.

Space Time Image Velocimetry Training Workshop, Wellington - New Zealand

Mike Ede (Marlborough District Council, NZHS Committee),

Mic Clayton FAHA (Cooma, NSW)

Introduction

In mid-July, the New Zealand Hydrological Society (NZHS) conducted a 4 day training workshop in the use of Space Time Image Velocimetry (STIV) techniques for stream discharge measurements. The workshop was led by Mark Randall (Senior Project Officer Water Services, North Region, Queensland Department of Natural Resources, Mines and Energy) who has experience in this emerging technology.

Fully subscribed, the course was attended by over 30 technical field hydrologists from a majority of regional councils around New Zealand as well as some vendor and surveyors. (There was even a participant from the often forgotten Australian Regional Council!)

STIV is part of a cluster of non-contact measurement techniques. This includes Particle Tracking Velocimetry (PTV) and Large Scale Particle Image Velocimetry (LSPIV), which utilise video imagery of stream surface velocities and the application of appropriate algorithms and stream hydraulic assumptions to generate stream mean velocities and hence indirect calculation of stream discharge.

Other non-contact techniques include radars (fixed and handheld) to measure surface velocities but still need the application of correct algorithms to produce discharge measurements of suitable accuracy.

Background

The use of video imagery collection and processing for flood discharge measurements has seen growing traction in recent years, with various visual analysis techniques being developed in a variety of research and field application environments.

In New Zealand, increasingly bank side fixed cameras and drones are being used to video floods. There is therefore a growing interest on the types of equipment to purchase, how to install sites, best methods to use, drone or fixed, and how to use the various video processing STIV software.

The workshop evolved as a result of a presentation by Mark Randall to the 2019 New Zealand Hydrological Society Technical Workshop in Blenheim. Mark had previously presented on STIV technologies at the 2018 AHA Conference in Canberra, where he was voted the best presentation and awarded the Alex Miller Award.

Jérôme Le Coz (IRSTEA France) gave similar presentations at the 2016 NZHS Technical Workshop and other organisations presented around the techniques and technologies at the WMO/IAHR/IAHS International Hydrometry Workshop held in conjunction with the New Zealand Hydrological Symposium in 2016.

Imagery being collected, by today's now relatively cheap technologies (fixed cameras and drones), contain a lot more information than just the soft relaxing images of water for meditative activities! Image data collected also contains information such as time and movement, pixels, rasters and the ability to apply Gaussian processes to calculate velocities from random patterns and particles in the stream!

Over time the quality of video has increased (providing more information for processing) while site establishment costs have decreased (meaning a cost effective additional tool in the hydrometric toolbox).

Workshop Program

The program over the first three days was as follows:

Day 1 (Training Room)

- Introduction to image velocity methods — PTV, LSPIV and STIV;
- Image velocimetry best practice — getting good videos and data for STIV and LSPIV;
- IP camera setups, resolution, ground control point setup, drones, data collection standards;
- Surface velocity coefficients (Stream Alpha) – derivation from ADCP data, drones, and current meters;
- STIV – Australia. Field experience (IP cameras and drones), methods and discharge results, future directions;
- Introduction to KU-STIV software;
- KU-STIV data walk through;
- Field day preparation – groups/setups/tasks.

Day 2 (Field)

Field data collection day at Hutt River at Taita Gorge steam gauging station north of Wellington, organised and run by Greater Wellington Regional Council, where three groups were tasked to establish a fixed image velocimetry site including:

- Camera placement;
- Ground control placement;
- Real Time Kinematic (RTK) survey of ground control points and cross section (assisted by the survey team from Palmerston North);
- Fixed camera data collection.

In addition to the teams setting up and collecting imagery, an assortment of drones with differing features were sent aloft to capture aerial imagery for processing as well as providing opportunity for those with little or no drone experience to have some hands on with the technology.

Greater Wellington council staff also undertook simultaneous ADCP gaugings for comparison of results as well as providing cross section data and additional stream velocity data for the determination of alpha (stream velocity co-efficient).

Day 3 (Training Room)

This was the number crunching day using the image and site survey and cross section data collected the previous day.

- KU-STIV software use;
- Practical processing of fixed camera data;
- Pre-processing data and imagery from drones for use in KU-STIV.

Day 4 was an optional extension day for participants wishing to work on image data collected from their own networks and for further practical learning with the KU-STIV software.

KU-STIV

KU-STIV *(Kobe University Space-Time Image Velocimetry)* software was used in this training workshop. Ichiro Fujita, a Professor at the Graduate School of Engineering in Kobe University, has led the development of this software through research programs since 2007 and a number of organisations are looking at way to utilise this image processing process in hydrometric data processing systems.

In a simple description of the software, the basic workflow the software undertakes is:

- Orthorectification of the video imagery (removing the effect of perspective and creating a 2D image area for analysis);
- Superimpose "searching lines" (each between 10 and 20 metres long) on footage of the river as measurement standards;
- Calculates the water's surface speed from the time it takes water surface features and floating matter on the surface of the river to move through these lines;
- Analyse velocity distribution, with suitable 'alpha' co-efficients, to indirectly calculate the river flow rate.

00:00:00 / 00:00:14

38100.000 | 0.10 m/pixel

138226.671 | 138360.000

37927.832 | ☐ Fixation

Scale 1.0

☑ Check line

☑ Flow rate value

☐ Mesh

Moving image: 20140425魚野川橋上流 10時.avi

Water level: 79.40

	velocity	S x-coordinate	S y-coordinate	E x-coordinate	E y-coordinate
1	1.67	138241.769	37950.866	138252.447	37939.451
2	2.04	138246.769	37955.866	138257.447	37944.451
3	2.06	138251.769	37960.866	138262.447	37949.451
4	1.62	138256.769	37965.866	138267.447	37954.451
5	2.22	138261.769	37970.866	138272.447	37959.451
6	1.53	138266.769	37975.866	138277.447	37964.451

Please run the STIV analysis

Figure 1: A screen shot from KU-STIV software.

Depending on the strength of the luminescence of features and patterns on the water surface the technique will have varying degrees of success in the initial computation of the surface velocities. Lots of features and particles result in good confidence, while conversely, where there are limited or no particle or pattern movement along the lines the confidence is lowered. Note: the word is Rice Bubbles® or Doritos® tortilla chips cast across the stream make for good particle tracers!

Manual calibration of the velocity lines is available to the user, as the human eye and mind can often see flow patterns the software may not consider useable or be fooled by. This was particularly evident when reviewing velocity lines that where in sections that the image was partially blocked by bank vegetation. In this instance the vegetation movement or lack thereof was the dominate feature the software focused on to determine velocity. At the end of the day strong particle or surface flow features provide strong 'data' for the software to interpret and analyse.

The software was initially designed to do the orthorectification in order to correct the perspective from the angles of bank mounted cameras, but when it comes to a drone looking straight down on a river (eliminating almost completely any need to correct for perspective), the software in its current version needs to have the data and information worked on before entering the final analysis in the KU-STIV software. This is achieved by calibrating the pixels in the captured footage to known distances between features close to the water surface datum, then inputting these values back into the software.

The next version of the software, due for release in October this year, is expected to have improved features catering for vertically positioned drone footage.

Observing the group working through the software and how data needs to be prepared, we were very impressed how all the participants 'got it'. Even though the processing into and around the software is a bit clunky (Japanese research mind meets easy going Kiwi and Oz Minds!) and the little help that hovers over some of the buttons are great if you can read Japanese! Overall the session gave the participants a better understanding of the process and the need for good metadata around the gauging locations including:

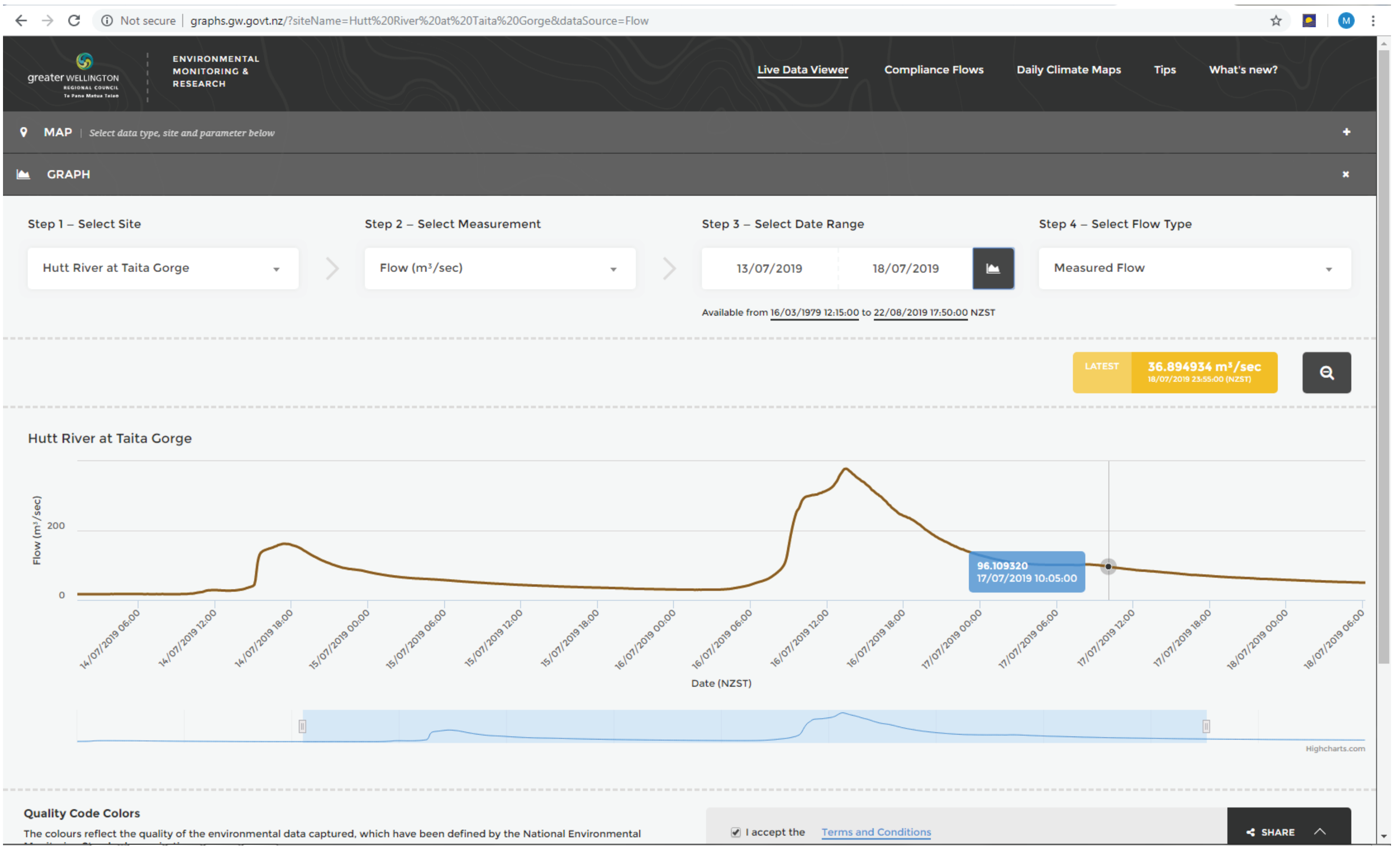
- Clear and fixed control points — well surveyed and documented;
- Cross sections developed for the measuring sections;
- Everything related to a common datum!

Collection and evaluation of Data – The Field Day on The Hutt River at Taita Gorge

In the days leading up to the field day, the Hutt River had been running at approximately 15 cumecs for a long spell. However, reflecting the recent form of NZHS workshops, some fortuitous rainfall events, on the day, resulted in flow measurements between 90-100 cumecs on a slowly falling limb (marked on graph, Figure 2).

Three teams set up fixed camera installations (basically SLR and or video cameras on tripods) on the bank of the river, while the surveyors surveyed in Ground Control Points (GCP) on both sides of the river and water surface levels to tie the points into gauge datum. (Note the orange cones and markers in Figure 3).

All the fixed camera installation sites suffered, to some degree, from vegetation and other obstructions in the field of view. As a consequence it was initially perceived that the teams may have missing data and hence lower quality data to work with. It was surprising though, during the following days post processing and analysing the data for these obstructed areas, how much good information was available to analyse velocities. In some cases it improved the ability to identify velocity lines compared to the main unobstructed vision!



Step 1 – Select Site: Hutt River at Taita Gorge

Step 2 – Select Measurement: Flow (m³/sec)

Step 3 – Select Date Range: 13/07/2019 18/07/2019

Available from 16/03/1979 12:15:00 to 22/08/2019 17:50:00 NZST

Step 4 – Select Flow Type: Measured Flow

LATEST 36.894934 m³/sec 18/07/2019 23:55:00 (NZST)

Hutt River at Taita Gorge

Quality Code Colors

The colours reflect the quality of the environmental data captured, which have been defined by the National Environmental

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Figure 2: Hutt River at Taita Gorge stream flow information. (Blue marker STIV training day) – Source, Greater Wellington Council website.

A couple of workshop participants even bunked off on the first class room day to ensure that some drone footage was captured on the peak of the event at around 380 cumecs. Unfortunately the data review was not available at time of preparation of this article.

Figure 3: Left, “Fixed” camera installation setup. Right, Total Station survey of ground control points.

Drone vision collected for post processing into the software was collected with a DJI *Phantom Pro* and DJI *Spark*.

Figure 4: Drone shot of STIV workshop section.

A *River Ray* ADCP, deployed via a HS *Cable Fox*, collected a measurement as well as providing cross section data for use in the proceeding image data processing exercises.

Following the primary data collection exercises at Hutt River, and prior to the workshop dinner, the group relocated to an area where opportunity for participants was provided for familiarization and flight time with a variety of drones. This provided a great opportunity for those with little or no experience with the technology to gain an appreciation of how cost effective drones are and how they can be used to capture great hydrological information and data can be worked with in conjunction with other gauging techniques.

Figure 5: Participants get an opportunity to familiarise themselves with the variety of drones used at the workshop.

Post Analysis Data Processing

Day three of the workshop was devoted to processing the data files from the fixed installations and the drone imagery.

As mentioned the flow at the site was approximately 90 cumecs (slow falling limb through the morning), however a majority of the post processing analysis seemed to be bracketed in the 80 to 100 cumec range.

This equates too approximately ±10% of the rated and ADCP measured flows. A problem, some might say? Not necessarily so! Consider the potential error that can be generated in a flood gauging, whether by current meter or ADCP techniques. In this context the results, being generated during the workshop, could be considered robust in comparison, in light of the uncertainties accepted within these other methods.

Earlier in the year at the NZHS workshop, the ADCP regatta results included a 'drone' gauging of a low flow. The 'drone' gauging was 0.452 cumecs, the rated flow was 0.420 cumecs, the mean of gaugings on the day was 0.422 cumecs. The following is a plot of all the gaugings undertaken using a variety of techniques. The drone gauging at this other end of flow magnitude (less than a cumec) sits well within the spread of discharge results obtained during that workshop.

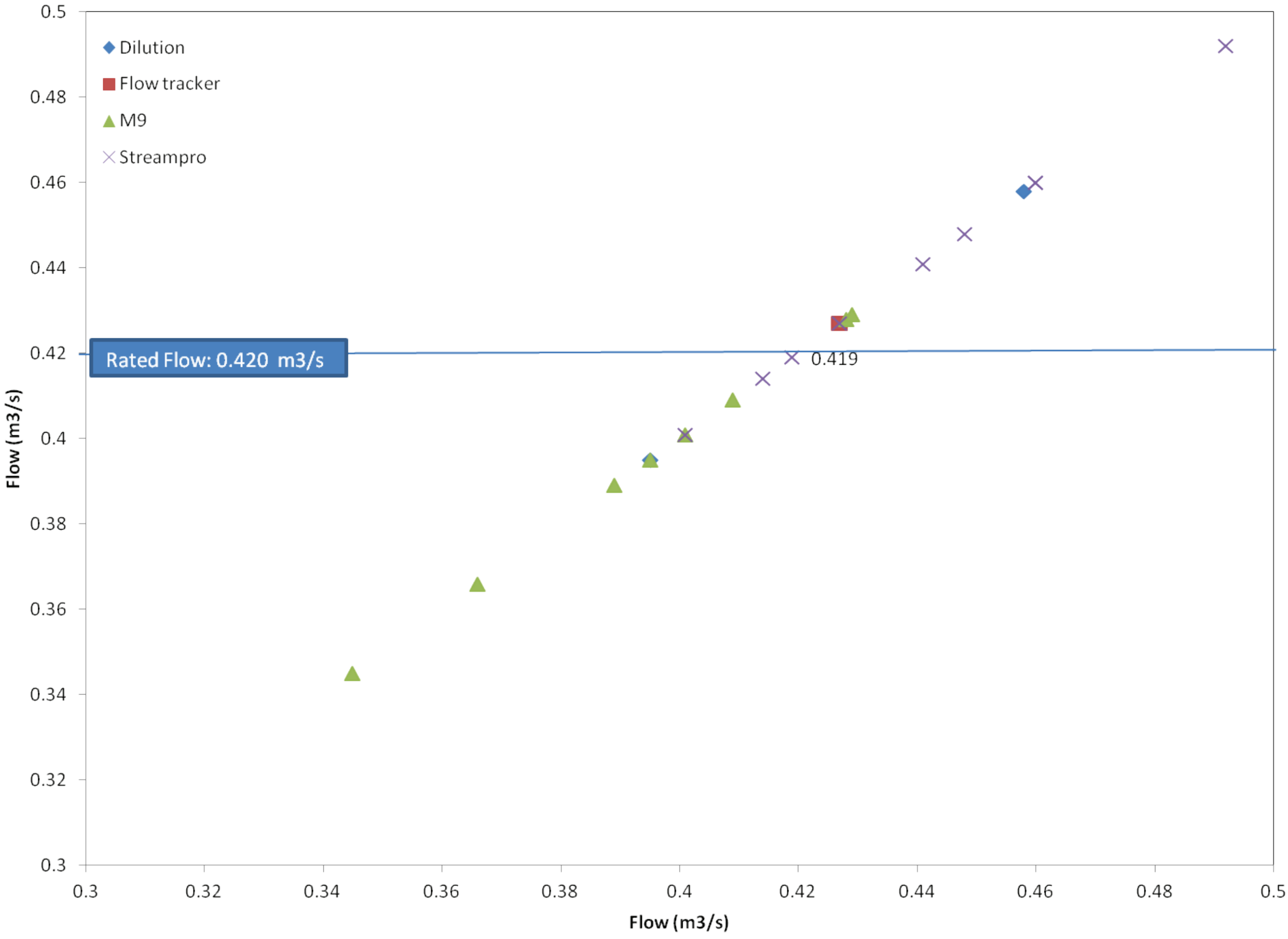


Figure 6: Spread of gauging results from NZHS regatta, 2019. (The 'drone' gauging was at 0.452 cumecs).

Out of Session Workshop Activities

Collaboration outside the formal workshop timetable occurred well into most evenings. A fine workshop dinner was hosted at the Boneface Brewing Company in Upper Hutt following the field day component of the workshop.

Figure 7: Technical selection at Boneface Brewing Company.

Boneface Brewery, located in a now repurposed industrial complex that was once the Dunlop Tyre Factory! The complex also accommodates a number of other craft breweries and has become a fantastic social hub in the Upper Hutt area.

The workshop dinner also included a brewery tour with our guide explaining the brewing process from raw material through to the final pouring.

Figure 8: Workshop dinner brewery tour, Boneface Brewing.

Final Summary

The Space Time Image Velocimetry Training Workshop provided by the NZHS was a fantastic opportunity for participants to investigate and become familiar with an alternative measuring technique, in order to inform how it may potentially fit in with their monitoring programs. It is predicted that this technique will become an additional accepted method of discharge measurement complimenting current measurement and monitoring techniques. In Australia this non-contact technique, along with other non-contact techniques such as radar, was tabled at the May 2019 meeting of the Water Monitoring Standards Technical Committee (WaMSTeC) as a National Hydrometric Guideline subject.

Potential improvements to the safety of Hydrographic practitioners, being able to gain measurement data from locations inaccessible during a flood using fixed camera technology, and utilising drone technology during flood events when resources become to stretched to support mainstream flood gauging techniques, were amongst a number of improvement opportunities identified during the workshop.

The hands on activities including the data collection and post processing, highlighted the need for having good metadata for the site (survey data, bathymetry etc.) as well as going back to basics and understanding of basic stream flow monitoring knowledge, including impacts of stream roughness and geometry on how mean velocities in a stream can be shaped. This re-appreciation of basic stream hydraulics and metadata also extends to better evaluation techniques for other gauging techniques including ADCP and current meter gaugings.

Conducting nationally co-ordinated workshops, like this, is extremely important. They enable the hydrological profession to develop a common understanding enabling a consistent application of knowledge and the development of guidelines for alternative monitoring techniques as they develop.

Determining Total Volume of Sludge in Wastewater Ponding Lagoons

Daniel Wagenaar, Xylem Water Solutions, Newcastle, NSW

Introduction

This paper details the surveys that were performed on three Wastewater Ponding Lagoons at the Kalgoorlie-Boulder Wastewater Treatment Plant (KBWWTP) and Total Waste Management's (TWM) storage lagoon in order to determine the total volume of sludge. The volume of sludge at each lagoon was calculated based on a surface elevation model developed from land survey and as-constructed drawings.

It provides a broad overview of the equipment and surveying techniques used during the survey process, as well as the methodology applied to develop the surface elevation models and calculate the total volume of sludge in the respective wastewater ponding lagoons.

Background

The Kalgoorlie-Boulder Wastewater Treatment Plant (KBWWTP) is located to the south of the City of Kalgoorlie-Boulder, approximately 560 kilometres to the north-east of Perth. Located immediately north of the treatment plant is Total Waste Management (TWM) a commercial provider of liquid waste collection and treatment.

The KBWWTP receives sewerage from the township of Kalgoorlie-Boulder via a reticulated sewerage system, Septage Wastes via by road transport and received at a designated drop-off pit, and condensate from the adjacent premises of Total Waste Management (TWM) which is currently regulated by the Department of Water and Environmental Regulation (DWER) under a separate licence.

The treatment plant, operated by the City of Kalgoorlie-Boulder is regulated by DWER in accordance with Schedule 1 of the *Environmental Protection Regulations 1987* (WA). The licence specifying a range of conditions from acceptable emissions (including Biochemical Oxygen Demand (BOD), pH, Total Suspended Solids (TSS), Faecal Coliforms, pH and discharge volume) required monitoring and any improvements required.

As with all wastewater ponds, the KBWWTP is designed to accumulate sludge within the treatment ponds. However this sludge requires management to enable the treatment plant to function properly and meet the requirements of its licence. The rate of sludge accumulation is a function of location (climate), loading, and the pond design.

It is therefore important for operators to be able to understand the level of sludge build-up. Excessive amounts can cause inadequate wastewater treatment by:

- Reducing pond volume and retention time, resulting in high effluent Biochemical Oxygen Demand (BOD);
- Encouraging uneven sludge distribution, leading to dead spots and/or short circuiting;
- Allowing anaerobic conditions to dominate causing foul odours.

Sludge profiling is important as it allows for a more effective operational decisions and allocation of funds when the need to de-sludge arises. Sludge profiling and density information commonly used to:

- Inform if desludging is required;
- Calculate polymer dose rates to aid sludge dewatering;
- Size any dewatering technology required; hence
- Inform de-sludge contracts.

Survey Control

A. Survey Equipment

The equipment chosen for the surveys consisted of two Global Navigation Satellite System (GNSS) receivers, CEE HydroSystems CEESCOPE with dual frequency echo sounder and rQPOD with autonomous navigation. The survey software utilized during the surveys consisted of HYPACK® Hydrographic Survey and Carlson SurvCE software respectively.

GNSS

Base Station: Hemisphere S321 Smart Antenna was setup precisely over a known survey marker using tripod and tribrach shown in Figure 1. The coordinates and elevation of the survey marker and height of GPS Antenna were entered into the SurvCE software to reference the survey against known datum.

Rover: Hemisphere S321 Smart Antenna was setup on either rQPOD or survey pole with the exact height of the GPS antenna entered into the survey software.

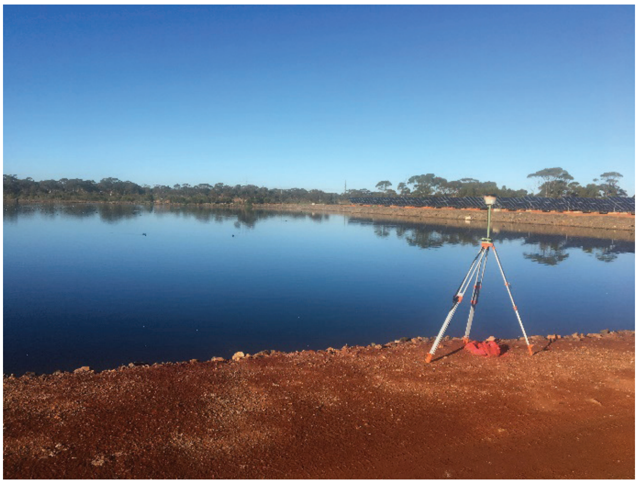


Figure 1: Hemisphere S321 Smart Antenna.

Echo Sounder

CEESCOPE and M195 Dual Frequency echo sounder from CEE HydroSystems shown in Figure 2 was mounted on an unmanned surface vehicle (USV) for the bathymetric component of the survey. The data was transmitted from the CEESCOPE to land based HYPACK® Hydrographic Survey software using CEE-LINK™ shore radio module.

Figure 2: CEESCOPE & M195 Dual Frequency.

An autonomous rQPOD Modular Remote Survey Boat (Figure 3) was used for the USV. A special mounting was designed for the M195 echo sounder to fit into the existing instrument wet-well.

The line plan developed in HYPACK® Hydrographic Survey software was uploaded onto rQPOD. This enabled rQPOD track the lines autonomously during the bathymetric survey ensuring much higher efficiency in performing the surveys.

Figure 3: Autonomous rQPOD.

B. Survey Control Design

The horizontal and vertical survey control for the bathymetry surveys at Kalgoorlie-Boulder WWTP was based on two survey markers, 101 and 103 shown in Figure 4. The position of the survey markers was selected based on requirements for Real Time Kinematic (RTK) survey technique that was used for both topographic and bathymetric surveys.

Figure 4: Location of Survey Markers.

C. Horizontal and Vertical Control

The two survey markers were established using Static GNSS survey technique, collecting more than 2 hours of raw satellite data at each survey marker. The raw satellite data was collected using Hemisphere S321 (multi-GNSS, multi frequency) Smart Antenna. The data collected during the static surveys were converted to Receiver Independent Exchange (RINEX) format from where it was uploaded to the AUSPOS post processing facility on the Geoscience Australia website.

D. Survey Localization

The results obtained from Geoscience Australia of the static surveys performed at the survey markers showed a higher accuracy in position and elevation at survey marker 103. Based on the higher accuracy survey marker 103 position and elevation was used to localize the entire survey.

Bathymetry Survey

A. Survey Procedure

The survey procedure at each of the lagoons comprised of a topographic and bathymetric component. The topographic component consisted of surveying the top of bank and water elevation and the bathymetric component consisted of surveying the sludge elevation.

The topographic survey was performed by surveying elevation at top of bank and water level every 10 steps.

The bathymetric survey area was defined by a boundary based on actual measurements from where a line plan was developed at 10 m grid intervals shown in Figure 5.

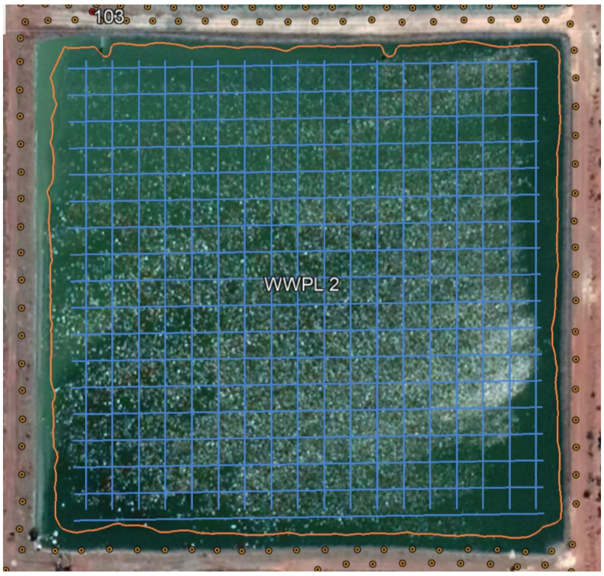


Figure 5: Border and Line Plan.

Figure 6: rQPOD Platform.

The topographic and bathymetric surveys were based on RTK survey technique, using Hemisphere S321 Smart Antennas.

The bathymetric survey was performed using a CEE HydroSystem with dual echo sounder and HYPACK® Hydrographic Survey software. The survey vessel consisted of rQPOD remote control platform with autonomous feature shown in Figure 6.

B. Water Elevation

The water elevation was relatively constant during the surveys within each of the respective lagoons. The inlet and outlet gates were completely open, ensuring that any inflows that may have occurred were discharged. Water elevation was surveyed at each lagoon and the average elevation in meters AHD is supplied in Table 1.

Table 1. Water Elevation

Lagoon	Surveyed Points	Elevation (mAHD)
WWPL1	80	334.825
WWPL2	94	332.591
WWPL3	97	332.578
TWM	41	333.421

Model Development

A. TIN Model

Triangulated Irregular Network (TIN) Models were developed for each of the respective lagoons in HYPACK® Hydrographic Survey software.

The models were based on the XYZ soundings from both the bathymetric (dual frequency echo sounder), topographic surveys and as constructed drawings.

The TIN Models developed were the main source for all generated outputs in HYPACK® Hydrographic Survey software. The Wastewater Ponding Lagoon 1 sludge surface elevation TIN Model is illustrated in Figure 7.

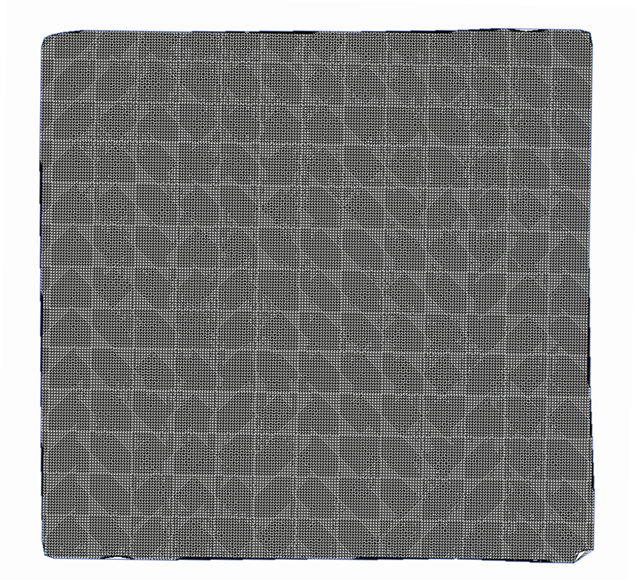


Figure 7: TIN Model.

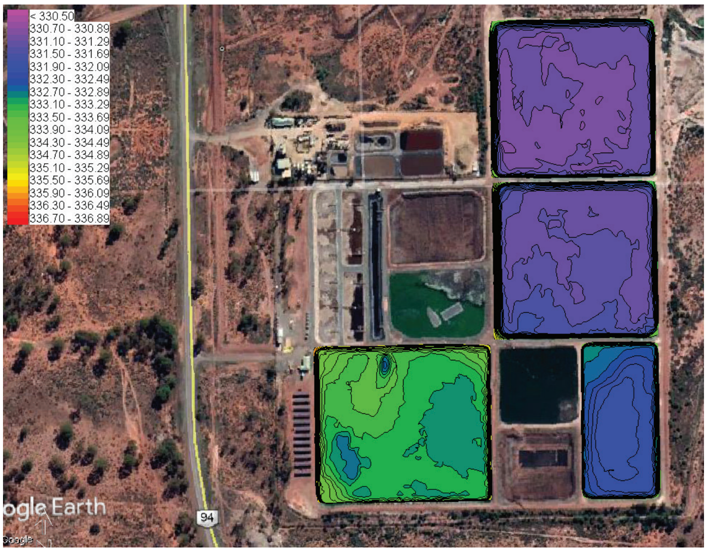


Figure 8: Sludge Surface Elevation.

B. Sludge Surface Elevation

Sludge surface elevations were developed from the respective TIN Models for each of the lagoons shown in Figure 8.

An elevation colour scheme range of 330.50 – 337.00 m AHD was adopted for all four lagoons. This clearly shows the difference in elevation of the sludge surfaces between the four lagoons.

A 3D view of the sludge surface elevation within the Wastewater Ponding Lagoon 1 is shown in Figure 9.

The discharge locations, into Wastewater Ponding Lagoon 1, are clearly evident as demonstrated by the scoured locations within the lagoon.

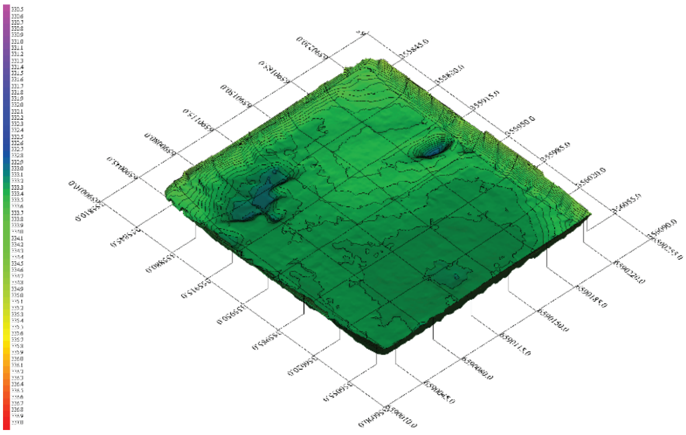


Figure 9: 3D Sludge Surface Elevation.

C. As-constructed Surface Elevation

As-constructed surface elevations were developed from the respective TIN Models for each of the lagoons as shown in Figure 10.

The floor levels of the respective ponds are summarized in Table 2.

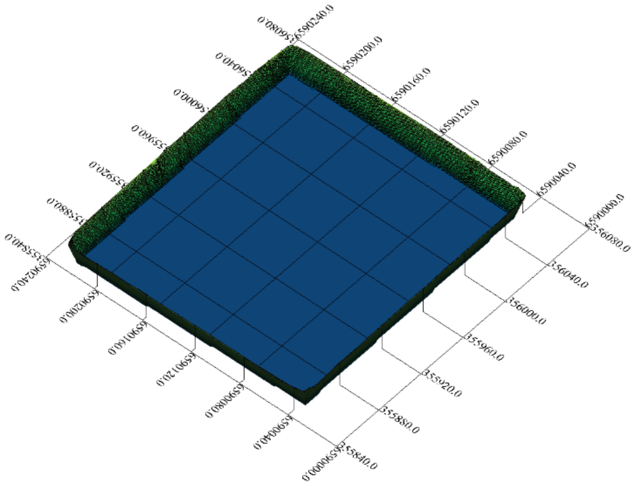


Figure 10: As-constructed Surface Elevation.

Table 2. Floor Level

Lagoon	Floor Level (mAHD)
WWPL1	332.74
WWPL2	331.34
WWPL3	331.34
TWM	331.89

D. Sludge – As-Constructed Elevation

The section across the width of Wastewater Ponding Lagoon 1 in line with the discharge point is shown in Figure 11. The difference in elevation between the sludge surface (red trace) and as-constructed (blue line) demonstrates the scouring taking place at discharge location.

Figure 11: WWPL1 Width Cross Section.

The section diagonally across Wastewater Ponding Lagoon 1 is shown in Figure 12. The build-up of sludge (red trace) is evident when compared to the as-constructed elevation (blue line) in the lagoon.

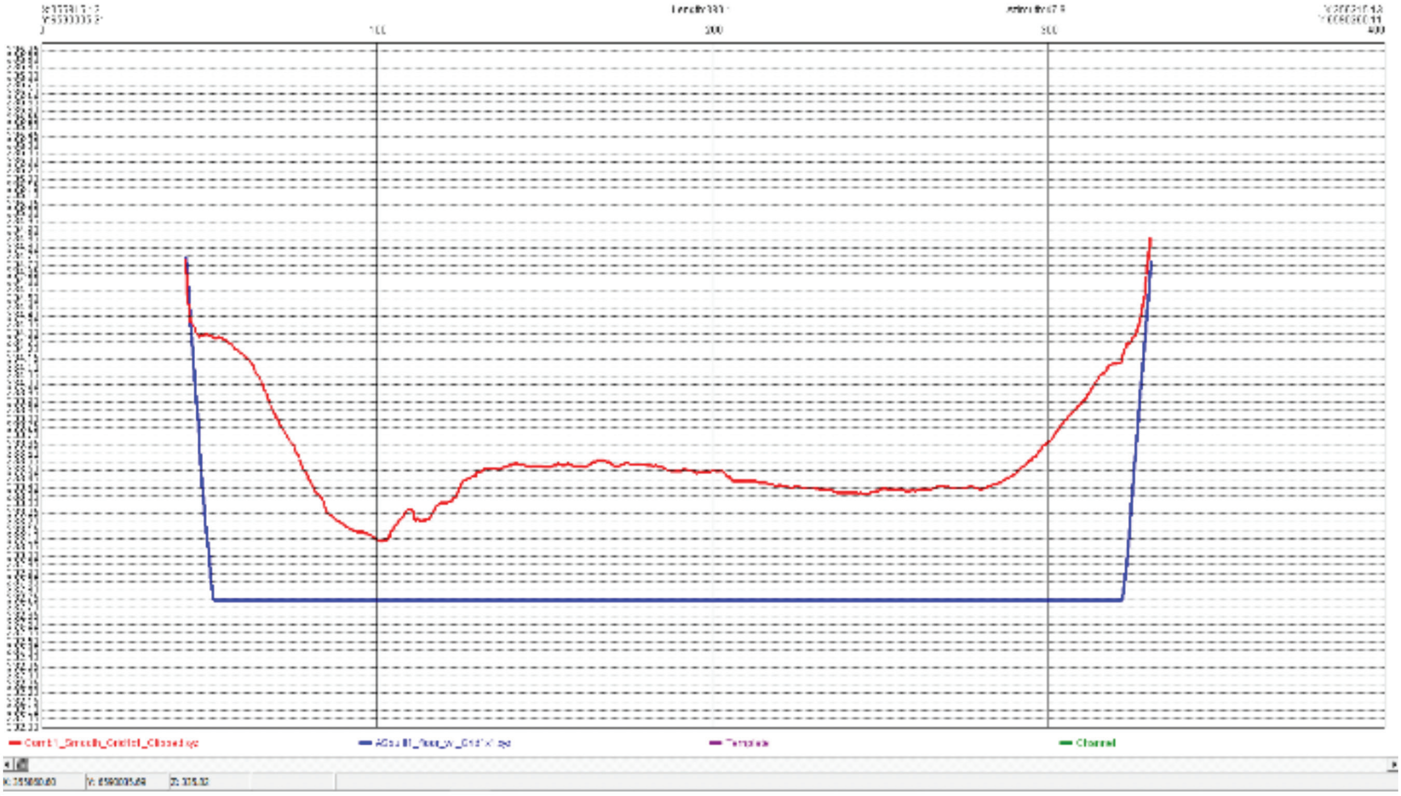


Figure 12: WWPL1 – Diagonal Cross Section.

E. Sludge Thickness

The sludge thickness was determined by developing an elevation model for Sludge Surface and the As-Build drawings of the lagoons. The difference in elevation between sludge surface and as-build elevation models resulted in the total thickness of the sludge at each of the lagoons. The total sludge thickness at Wastewater Ponding Lagoon 1 is depicted in Figure 13.

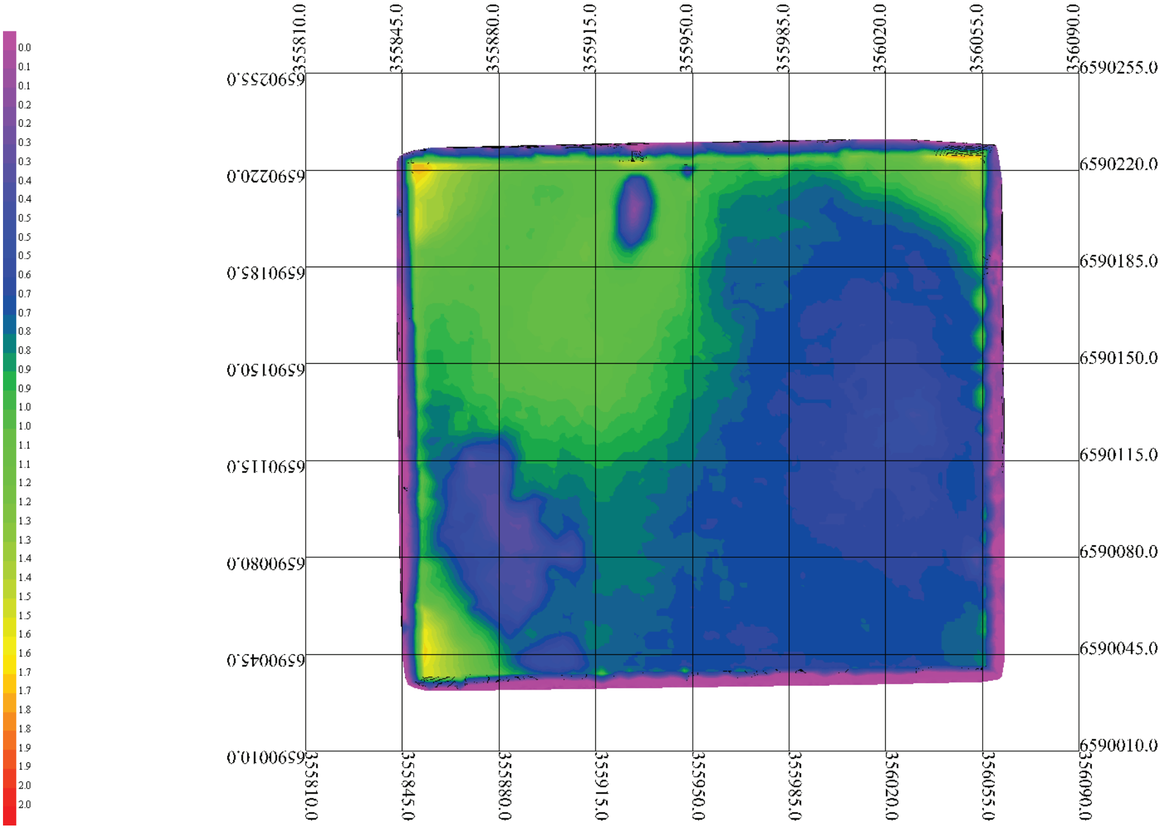


Figure 13: Sludge Thickness at Wastewater Ponding Lagoon 1.

F. Sludge Volume

Volume and Area calculation was performed between the difference of the Sludge Surface Elevation and As-constructed models for the three Wastewater Ponding Lagoons and TWM storage lagoon. The volume and area of total sludge is summarized in Table 3.

Table 3: Sludge Volume and Area Calculation

Lagoon	Volume Above (m^3)	Area Above (m^2)	Volume Below (m^3)	Area Below (m^2)
WWPL1	31761.9	41781.4	282.3	1047.2
WWPL2	10851.4	35830.6	240.3	1462.9
WWPL3	3144.6	28132.5	750.2	10404.3
TWM	7594.5	17120.1	173.0	635.5

The volume and area above is the total amount of sludge above the floor level supplied in Table 2. The volume and area below is the total volume below the floor level.

The volume below for WWPL1, WWPL2 and TWM could be a combination of the actual floor level and the accuracy of as-constructed model developed. WWPL3 was the only lagoon that showed clear difference in the actual floor level and the as-constructed elevation and the reason why the volume below is more than the other lagoons.

Conclusion

It is important for operators of Wastewater Treatment Plants to be able to understand the level of sludge build-up within the treatment ponds, excessive amounts of sludge and uneven distributions leading to inadequate wastewater treatment. Effective sludge profiling is therefore important in the effective operation and remediation activities such as desludging.

The simple hardware setup and software configuration between HYPACK® Hydrographic Survey software, CEE HydroSystems and rQPOD shows that the combined integration between the products provides a package that proves itself ideal for both general and specialized bathymetric surveys such as that required for effective sludge profiling.

Stunning sunset, event at wastewater treatment plant.

Velocity Indexing side looking Dopplers in Man-made Canals

Thomas King, Xylem Water Solutions, Hemmant, QLD

Daniel Wagenaar and Xylem Water Solutions, Newcastle, NSW

Introduction

Xylem Analytics Australia was contracted by Downer Engineering to supply and commission two SL1500-3G (SL) acoustic Doppler flow meters and CR850 data loggers at Wildes Meadow and Burrawang Canals in association with the Burrawang Pump Station upgrade project. The equipment supplied for both the flow monitoring sites, was installed by Downer Engineering for Water NSW at predefined monitoring sites.

A number of site visits were conducted over the calibration period in parallel with pump tests being carried out. The site visits enabled the collection of a suite of acoustic Doppler data from the SL instruments and reference discharge measurements, obtained using a RiverSurveyor M9. The data collected from the SL and M9 at each of the monitoring sites were used to develop unique Index Velocity Rating.

The commissioning of the acoustic Doppler flow meters comprised of configuring the instruments at each monitoring site based on the channel geometry, hydraulic conditions present and Index Velocity Rating. To add to the challenging site conditions – pump runs were only carried out through the middle of the night to minimise power costs to the client.

Monitoring Site Locations

The Wildes Meadow and Burrawang flow monitoring sites are strategically positioned on either side of the Burrawang pump station shown in Figure 1. The strategic positions were selected to accurately measure the abstraction from Fitzroy Falls Reservoir and inflow into the Wingecarribee reservoir during pumping at Burrawang pump station.

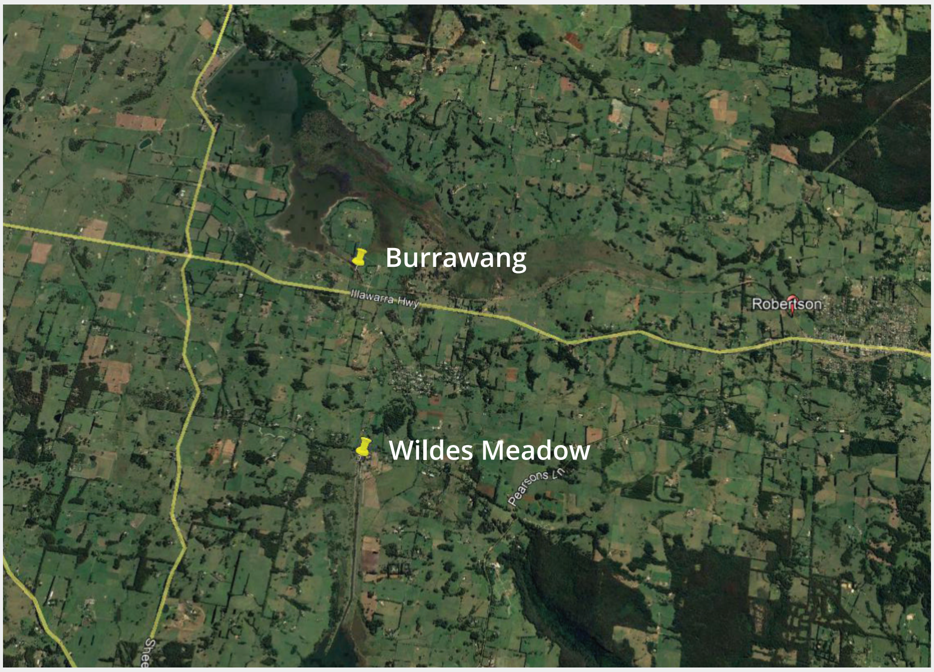


Figure 1: Location of Wildes Meadow and Burrawang Flow Monitoring Sites.

Wildes Meadow Canal – at Wildes Meadow

The flow monitoring site is located within the Wildes Meadow canal upstream of the extraction end of the Burrawang pumping station. The Wildes Meadow canal is classified as an earth canal, excavated in solid granite rock.

Figure 2: Location of Wildes Meadow Flow Monitoring Site in relation to Burrawang Pumping Station.

Burrawang Canal – at Wingecarribee Dam

The flow monitoring site is located within the Burrawang Canal directly upstream of the radial gate but within the flank walls on the delivery end of the Burrawang pumping station.

Figure 3: Location of Burrawang Flow Monitoring Site in relation to Radial Gate Hydraulic Structure.

Scope of Works

The scope of the contract consisted of, the supply and commissioning of instrumentation, to facilitate real-time flow measurement, at the Wildes Meadow and Burrawang canal flow monitoring sites. All equipment was to be installed and connected by the client at respective monitoring sites.

Monitoring System

Hardware Components

The Wildes Meadow and Burrawang canal monitoring sites have similar hardware layout, and were equipped with the following infrastructure and instrumentation:-

- SonTek SL1500-3G
- Retractable instrument slide
- SL1500 communications cable
- Campbell Scientific CR850
- Local power enclosure and platform

Figure 4: Station backing panel consisting of SCADA RTU, data logger, and solar system.

Both SL units were configured to measure the sample volume for 13 minutes every 15 minute period. This ensures enough time for the instrument to complete the measurement and process the results before the data is passed to logger. From here the CR850 pushes the data through to the RTU via Modbus where flow rate, total flow, velocity, and stage height are displayed for operators.

Station Details

Burrawang Canal

The nominated measurement section for the SL was not ideal, due to the nature of the measurement site and the hydraulic conditions present, impacting both the velocity measurements and overall operation. The proximity of the radial gates, in relation to the SL is the biggest concern, placing the SL measurement volume within the spillway's drawdown zone, as well as being influenced by the resulting higher approach velocities through the section.

Site Cross Section

The SL cross section is located between the Wingecarribee radial gate spillway and rounded approaches of the radial gates flank walls.

Figure 5: Upstream, looking downstream towards radial gate.

Figure 6: The SL cross section just upstream of the gate.

Site Configuration

The SL was mounted 0.8 m above the channel bed, and when the canal is within normal operating depth, situated approximately 0.6 m below the water surface. The SL is configured to measure 9.3 m of the 11 m channel, broken down into 12 cells of 0.7 m wide. This is in keeping with industry best practice, and avoiding the last 10% of the channel width to prevent any side lobe interference.

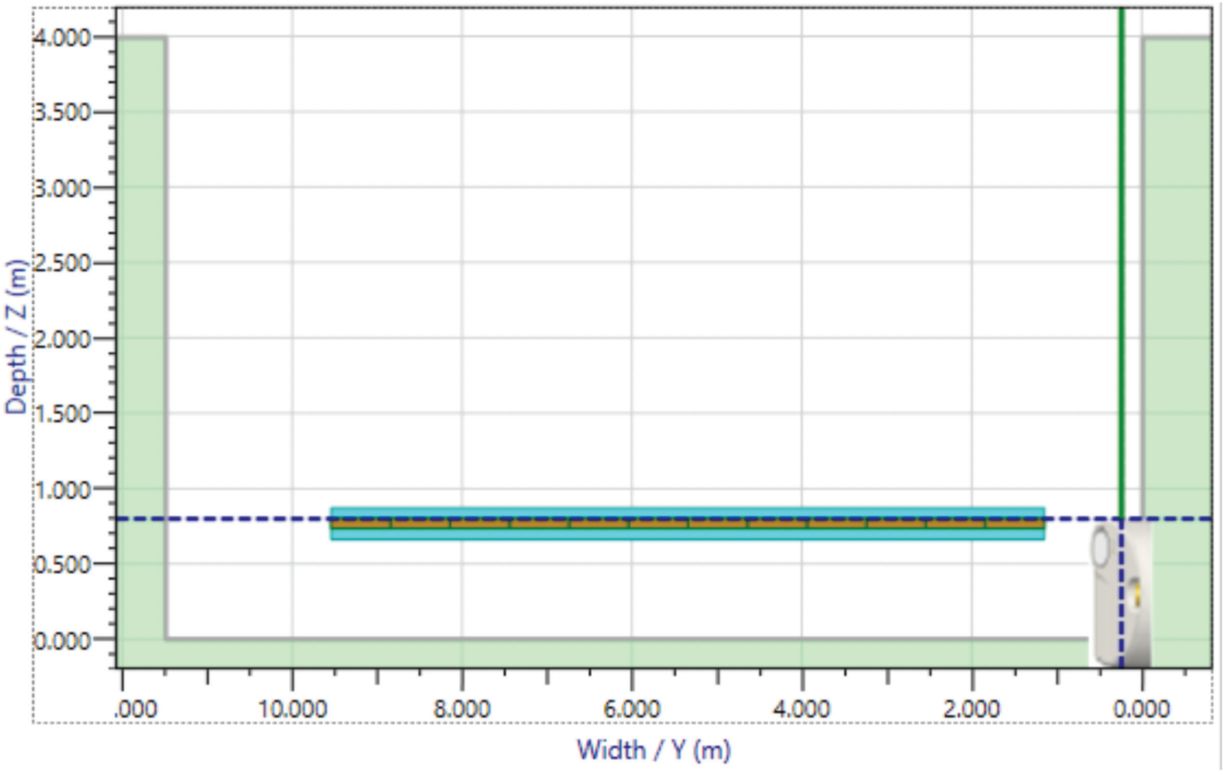
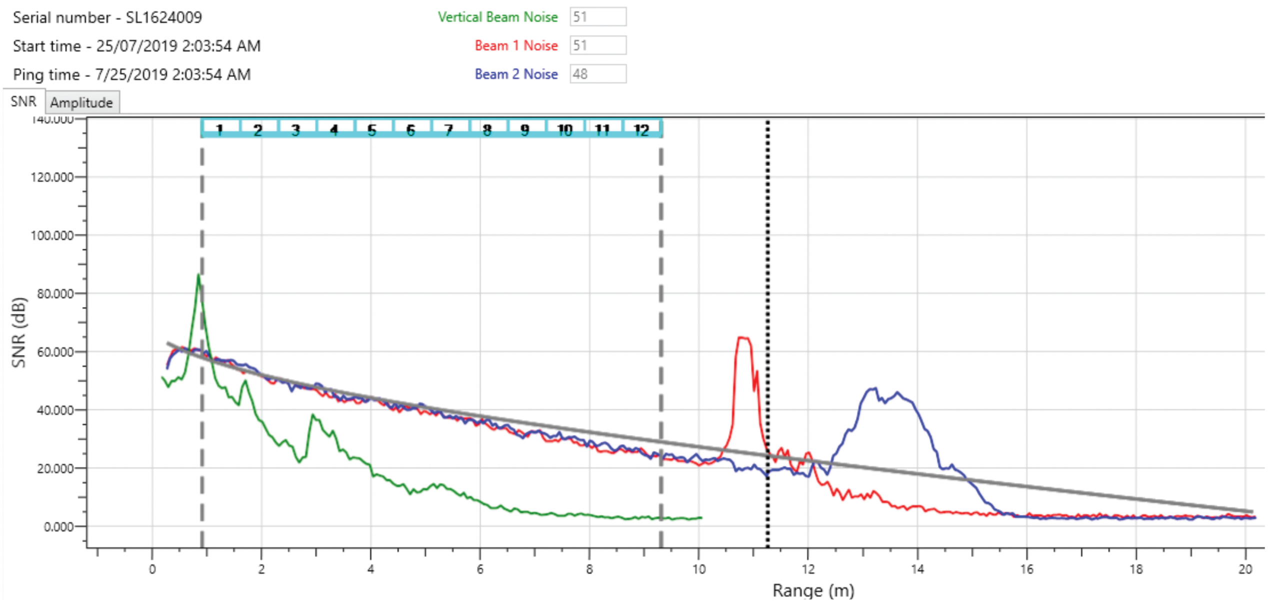


Figure 7: Burrawang SL configuration and Cross Section.

Beam Check

The beam check data illustrates the drop off in signal strength of the beams, and shows a strong return when the beams interact with an obstacle. The red beam (downstream) interacts with the spillway past 10 m, whilst the blue beam (upstream) interact with the radial gate flank walls around 12 m. Readings are consistent with observed channel geometry and no abnormalities were detected.


Serial number - SL1624009
Start time - 25/07/2019 2:03:54 AM
Ping time - 7/25/2019 2:03:54 AM

Vertical Beam Noise 51
Beam 1 Noise 51
Beam 2 Noise 48

Figure 8: Burrawang SL beam check data.

Wildes Meadow

Site Cross Section

The Wildes Meadow canal excavated in solid granite rock is classified as trapezoidal channel with steep slopes. The channel depth of 6.3 m versus width of 8.2 m recorded during measurements results in small aspect ratio.

Figure 9: Downstream of the SL, looking upstream towards measurement section.

Figure 10: SL Measurement Section.

Canal Bathymetry

A bathymetric survey was conducted upstream and downstream of the measurement section to determine if any obstacles are present that may impact acoustic Doppler measurements within the measurement volume. The bathymetry survey results showed that the channel along the measurement section is uniform with no abnormalities within the measurement area.

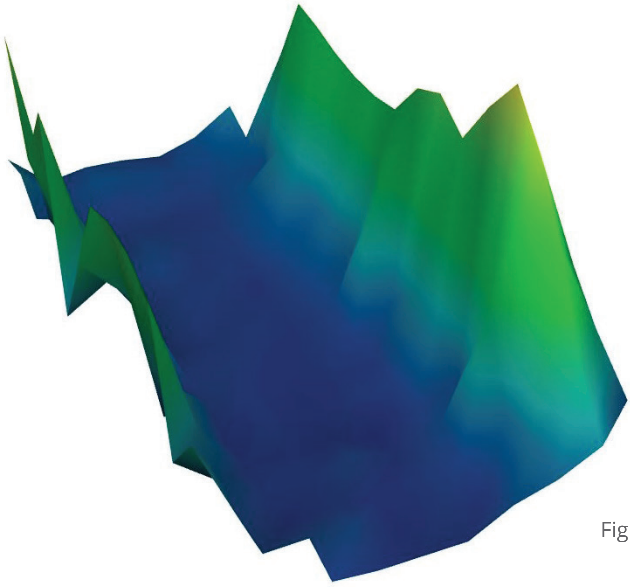


Figure 11: Interpolated Canal Bathymetry.

Site Configuration

The SL was mounted 4.5 m above the channel bed, and when the canal is within normal operating depth, the SL is situated approximately 0.8 m below the water surface. The SL is configured to measure 5.7 m of the 7 m channel, broken down into 10 cells of 0.5 m wide. This is in keeping with industry best practice, and avoiding the last 10% of the channel width and to prevent any side lobe interference.

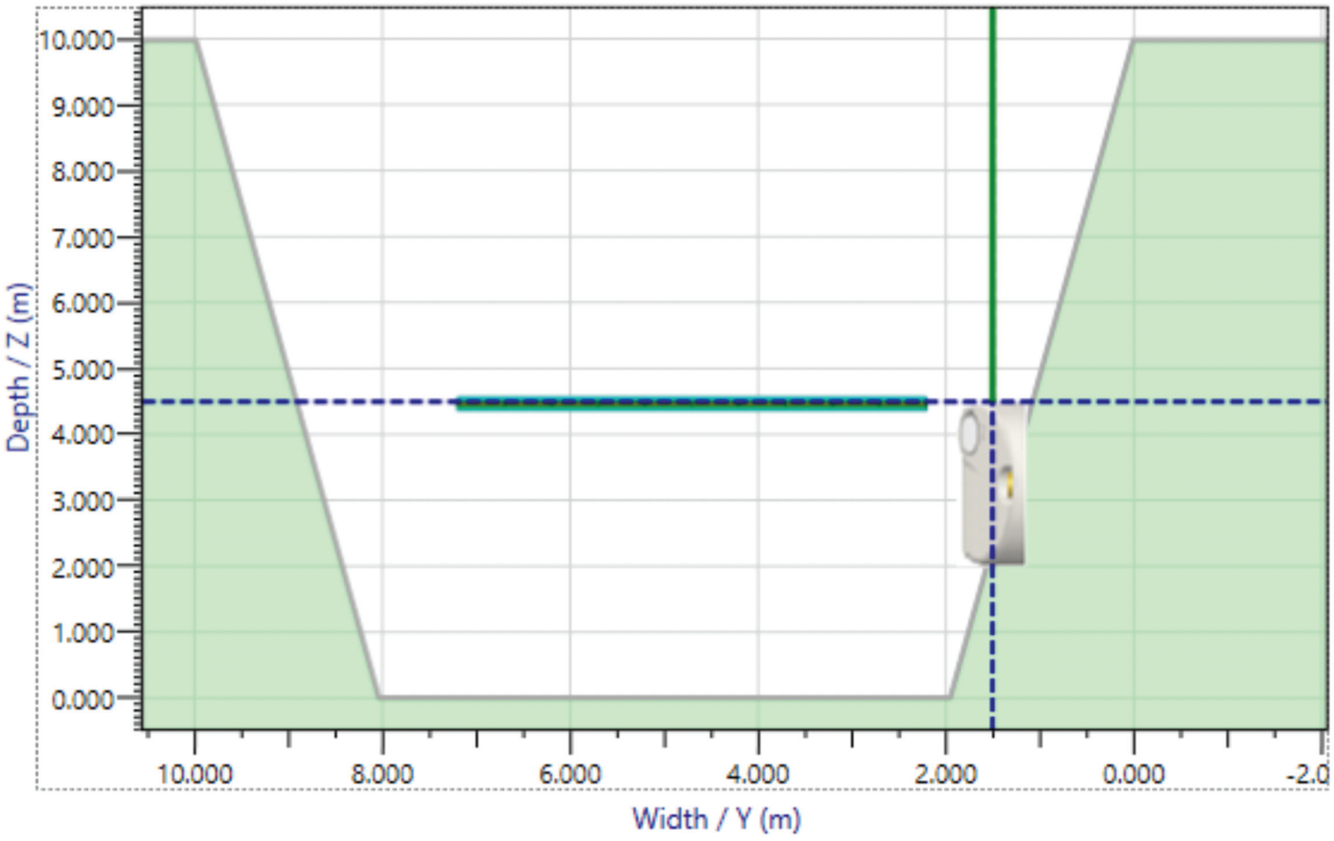
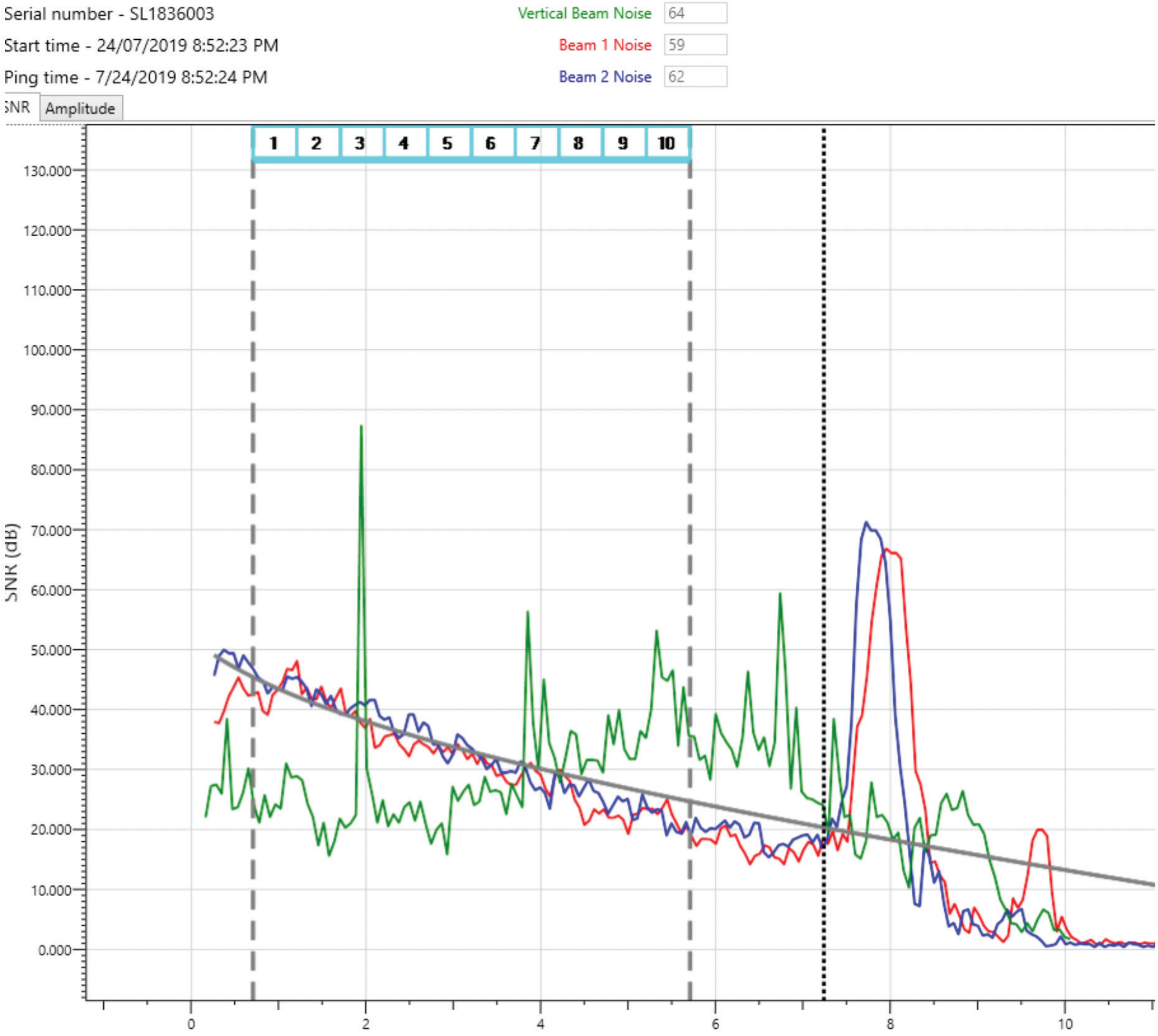


Figure 12: Wildes Meadow SL Cross Section.

Beam Check

The beam check data illustrates the drop off in signal strength of beams, and shows a strong return when the beams interact with an obstacle. Both beams show strong signal return at approximately 7.2 m, which is consistent with observed channel geometry. No abnormalities were detected.



Serial number - SL1836003
Start time - 24/07/2019 8:52:23 PM
Ping time - 7/24/2019 8:52:24 PM

Vertical Beam Noise: 64
Beam 1 Noise: 59
Beam 2 Noise: 62

Figure 13: Wildes Meadow SL Beam Check data.

Calibration Gauging

Gauging Scope

The measurement site and hydraulic conditions present at both flow monitoring sites; with the deep trapezoidal channel at Wildes Meadow, and the proximity to the radial gate at Burrawang, are not ideal for SL measurements and required an index velocity rating to be developed.

In order to compile a representative index velocity equation for both sites, data needed to be captured from the SL at high frequency (~60 second) intervals, as well as recording from an M9 simultaneously. The full velocity profile captured by the M9 is then used to adjust the measurements from the SL, resulting in representative flow rates.

Prior to any calibration gaugings being undertaken, several pump tests were carried out. It was found during these that both SL units measured approximately 5-10% differently from expected pump flow rates at both locations. Two operational states exist where either one pump is active, or both pumps are active making for a relatively straight forward indexing.

Gauging Method

In order to get representative data, from the gaugings, both sites measured during a single pump run and a dual pump run. Both sites were measured, whilst the SL units were logging at 1 minute intervals, with an M9 using moving boat method. GPS was not used during the measurements due to the steep canal walls and high sided hills either side of the canal, instead bottom track was used as a location reference. Both sites were checked for moving bed using the loop method measurement and confirmed to be suitable.

At Wildes Meadow the M9 was positioned just downstream of the SL, whilst at Burrawang the measurement section was upstream of the SL in order to mitigate uneven velocities across the section close to the radial gates. The M9 was manoeuvred into place and moved with a continuous rope.

Figure 14: Equipment setup in preparation for pump run measurement.

Gauging Results

Wildes Meadow

The geometry of Wildes Meadow channel especially with respect to the steep gradient of both channel banks and the aspect ratio between the total depth (6.320 m) versus width (8.241 m) was challenging when attempting to perform accurate and consistent discharge measurements with acoustic Doppler current profiler instruments.

RiverSurveyor Data

The steep gradient of both channel banks directly impacts the percentage measured of the total measurement section. Standard procedure for performing ADCP moving boat measurements, at measurement sites with vertical or steep banks, is to start half the depth from the water edge. This would have resulted in 75% of the channel not being measured due to the 6.320 m water depth.

Consequently another approach was followed by positioning the instrument at a distance of 0.9 m from the water's edge, outside the minimum range required for an acoustic pulse to perform a single cell measurement.

The velocity profile (shown in Figure 15) shows a trapezoidal shape towards the edges directly related to the steep banks. ADCP instruments such as RiverSurveyor M9 uses the shallowest beam to determine the velocity profiling range. As the instrument moved closer to the bank, one of the beam's depths measurements were reduced due to the steep bank. The flow measurements are summarized in Table 1.

Table 1: RiverSurveyor M9 Flow Measurement Summary

Pumps	Mean Velocity	Mean Average	Mean Flow Rate
1	0.301 m/s	44.639 m^2	13.411 m^3/s
2	0.585 m/s	45.169 m^2	26.437 m^3/s

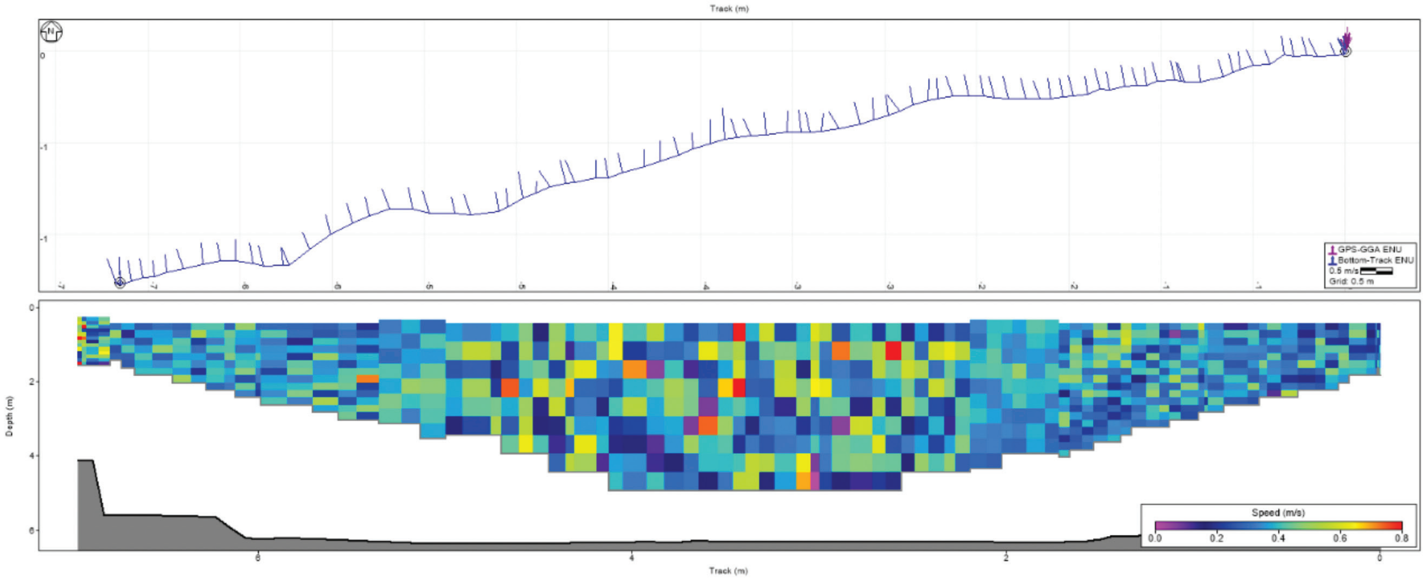


Figure 15: Wildes Meadow Single Pump data cross section.

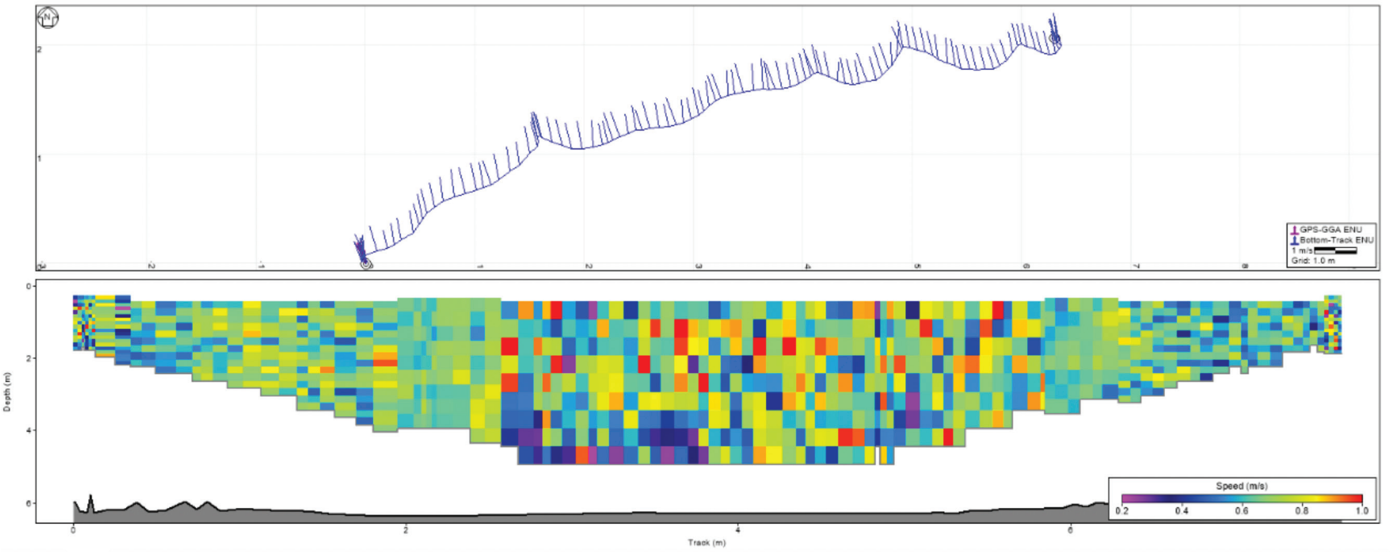
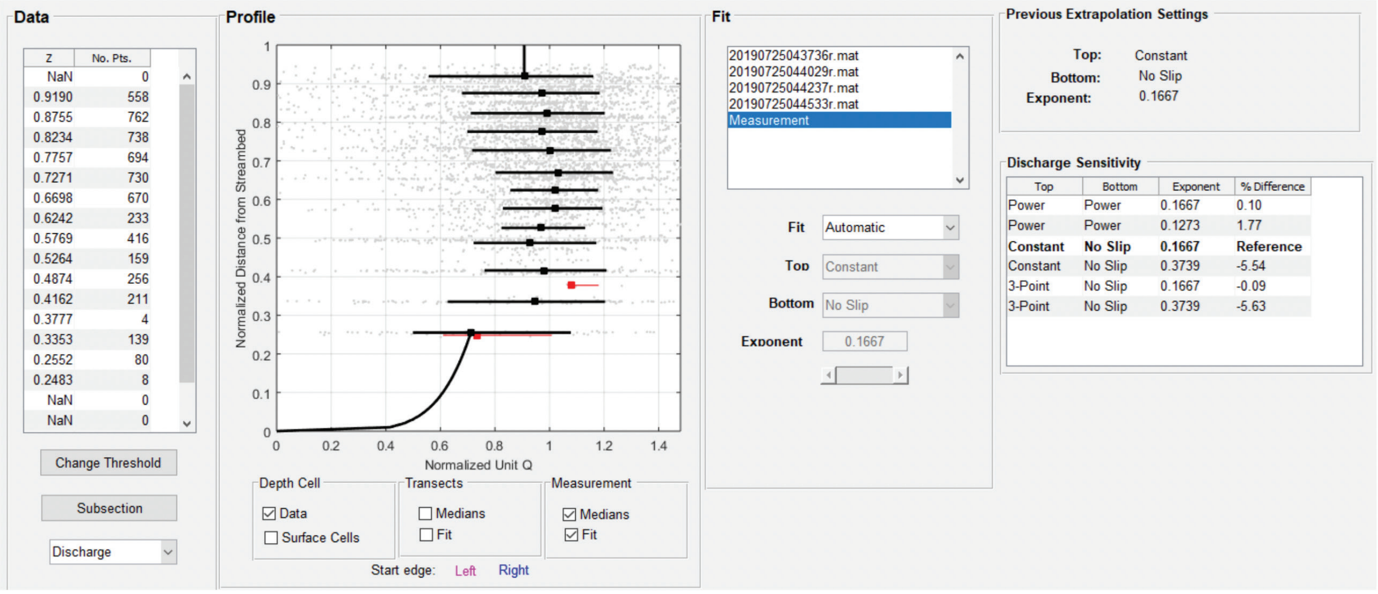


Figure 16: Wildes Meadow Dual Pump data cross section.

QRev Data

QRev is a software package developed by the United State Geological Survey (USGS) for post processing of ADCP data, which was used to determine the velocity profile at the measurement section.

Channels with an aspect ratio (total depth versus width) smaller than 10 will result in the maximum velocity occurring below the water surface based on work published by Chow (2009). The velocity distribution at the measurement section during both single and dual pump releases clearly shows that the maximum velocity is occurring below the water surface.



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0.8755	762
0.8234	738
0.7757	694
0.7271	730
0.6698	670
0.6242	233
0.5769	416
0.5264	159
0.4874	256
0.4162	211
0.3777	4
0.3353	139
0.2552	80
0.2483	8
NaN	0
NaN	0

Depth Cell: ☑ Data ☐ Surface Cells
Transects: ☐ Medians ☐ Fit
Measurement: ☑ Medians ☑ Fit
Start edge: Left Right

20190725043736r.mat
20190725044029r.mat
20190725044237r.mat
20190725044533r.mat
Measurement

Fit: Automatic
Top: Constant
Bottom: No Slip
Exponent: 0.1667

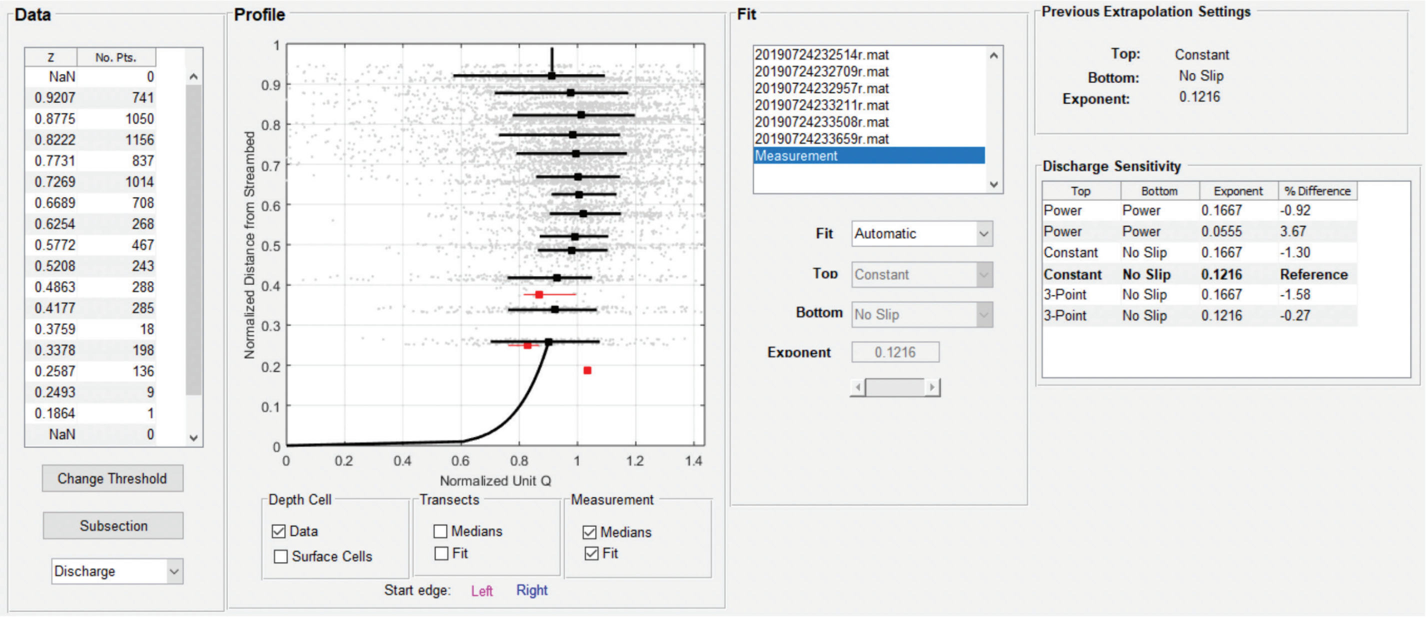
Previous Extrapolation Settings

Top: Constant
Bottom: No Slip
Exponent: 0.1667

Discharge Sensitivity

Top	Bottom	Exponent	% Difference
Power	Power	0.1667	0.10
Power	Power	0.1273	1.77
Constant	**No Slip**	**0.1667**	**Reference**
Constant	No Slip	0.3739	-5.54
3-Point	No Slip	0.1667	-0.09
3-Point	No Slip	0.3739	-5.63

Figure 17: Wildes Meadow Single Pump run.



Z	No. Pts.
NaN	0
0.9207	741
0.8775	1050
0.8222	1156
0.7731	837
0.7269	1014
0.6689	708
0.6254	268
0.5772	467
0.5208	243
0.4863	288
0.4177	285
0.3759	18
0.3378	198
0.2587	136
0.2493	9
0.1864	1
NaN	0

20190724232514r.mat
20190724232709r.mat
20190724232957r.mat
20190724233211r.mat
20190724233508r.mat
20190724233659r.mat
Measurement

Fit: Automatic
Top: Constant
Bottom: No Slip
Exponent: 0.1216

Previous Extrapolation Settings

Top: Constant
Bottom: No Slip
Exponent: 0.1216

Discharge Sensitivity

Top	Bottom	Exponent	% Difference
Power	Power	0.1667	-0.92
Power	Power	0.0555	3.67
Constant	No Slip	0.1667	-1.30
Constant	**No Slip**	**0.1216**	**Reference**
3-Point	No Slip	0.1667	-1.58
3-Point	No Slip	0.1216	-0.27

Figure 18: Wildes Meadow Double Pump run.

Burrawang

Flow measurements at the Burrawang measurement site has traditionally shown higher flow rates than the Wildes Meadow measurement site, which can be attributed to the channel geometry. The channel geometry at the measurement section is much more favourable in regards to both the hydraulic and measurement site conditions required for a flow monitoring site.

RiverSurveyor Data

Flow measurements were performed upstream of the radial gate flank walls, where the SL measurement section is situated, to avoid the impact of vertical walls on the flow measurement. The velocity profile measured in Figure 18 clearly shows close resemblance between the channel geometry and the velocity profile range. M9 flow measurements are summarized in Table 2.

Table 2: RiverSurveyor M9 Flow Measurement Summary

Pumps	Mean Velocity	Mean Average	Mean Flow Rate
1	0.630 m/s	22.158 m^2	13.961 m^3/s
2	0.961 m/s	28.575 m^2	27.447 m^3/s

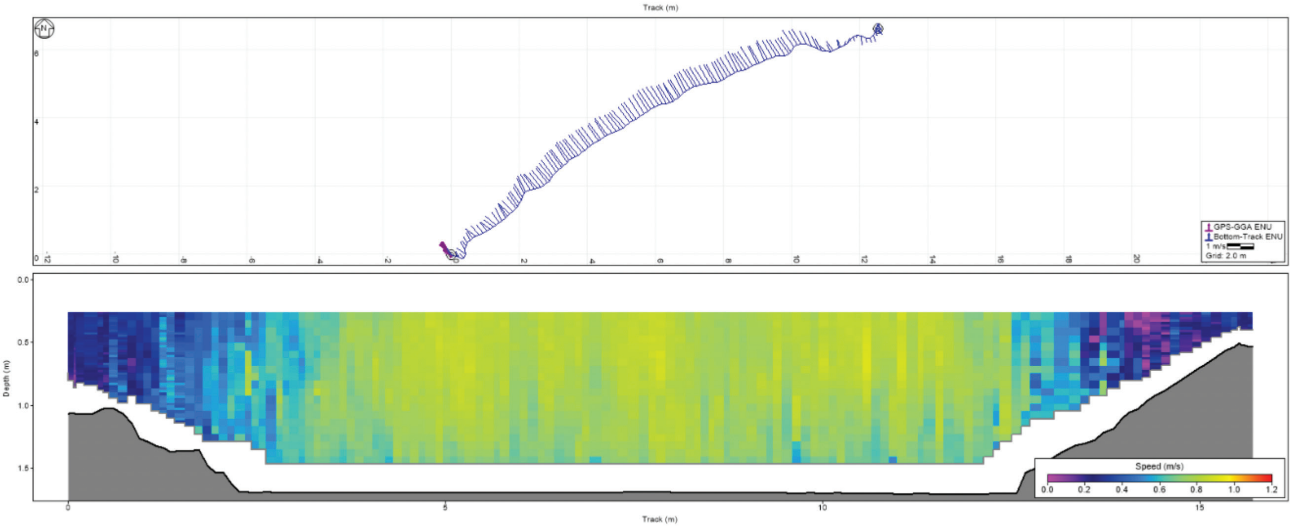


Figure 19: Burrawang Single Pump data cross section.

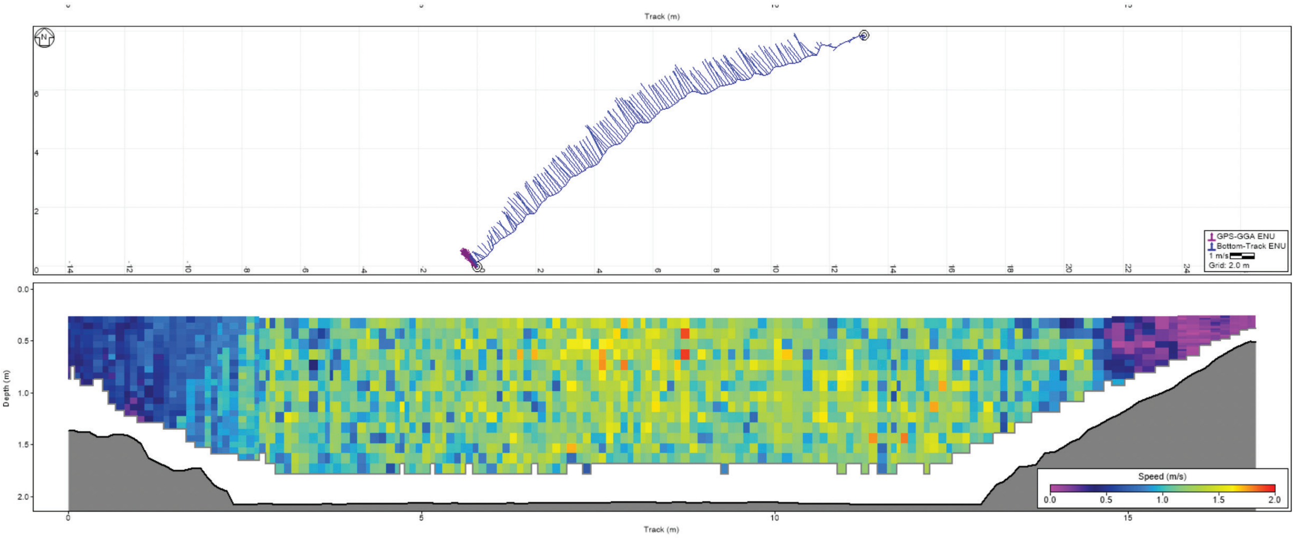
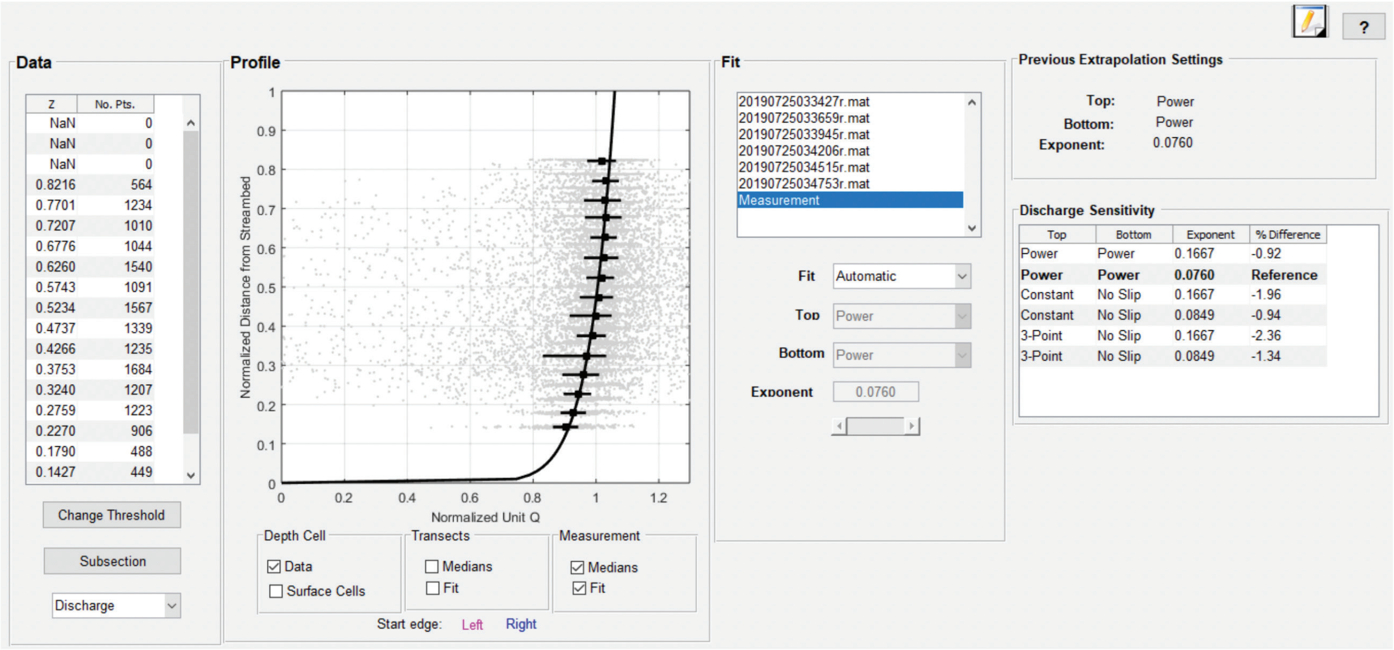


Figure 20: Burrawang Dual Pump data cross section.

QRev Data

The velocity distribution at the measurement section during both single and dual pump releases clearly shows that the velocity profile resembles the theoretical 1/6th power law as expected in well-defined channels with uniform flow conditions.



Data

Z	No. Pts.
NaN	0
NaN	0
NaN	0
0.8216	564
0.7701	1234
0.7207	1010
0.6776	1044
0.6260	1540
0.5743	1091
0.5234	1567
0.4737	1339
0.4266	1235
0.3753	1684
0.3240	1207
0.2759	1223
0.2270	906
0.1790	488
0.1427	449

Discharge

Profile

Depth Cell: ☑ Data ☐ Surface Cells
Transects: ☐ Medians ☐ Fit
Measurement: ☑ Medians ☑ Fit
Start edge: Left Right

Fit

20190725033427r.mat
20190725033659r.mat
20190725033945r.mat
20190725034206r.mat
20190725034515r.mat
20190725034753r.mat
Measurement

Fit: Automatic
Top: Power
Bottom: Power
Exponent: 0.0760

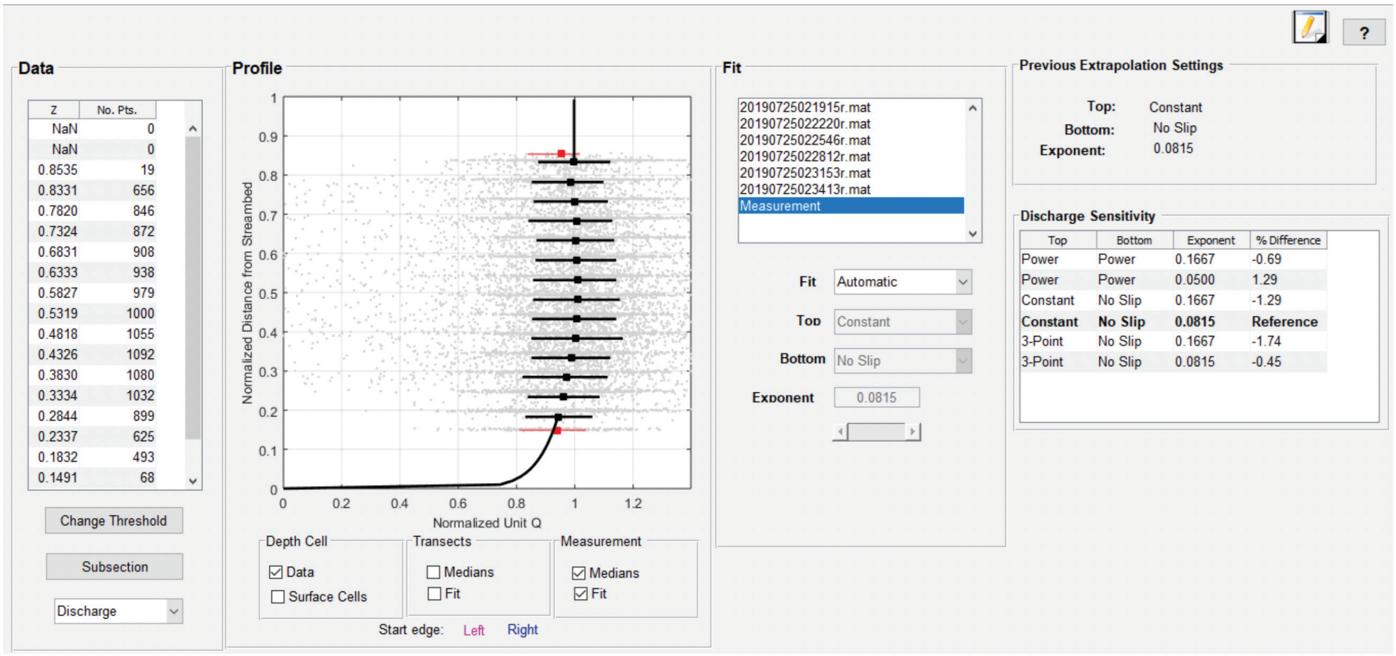
Previous Extrapolation Settings

Top: Power
Bottom: Power
Exponent: 0.0760

Discharge Sensitivity

Top	Bottom	Exponent	% Difference
Power	Power	0.1667	-0.92
Power	**Power**	**0.0760**	**Reference**
Constant	No Slip	0.1667	-1.96
Constant	No Slip	0.0849	-0.94
3-Point	No Slip	0.1667	-2.36
3-Point	No Slip	0.0849	-1.34

Figure 21: Burrawang Single Pump run.



Data

Z	No. Pts.
NaN	0
NaN	0
0.8535	19
0.8331	656
0.7820	846
0.7324	872
0.6831	908
0.6333	938
0.5827	979
0.5319	1000
0.4818	1055
0.4326	1092
0.3830	1080
0.3334	1032
0.2844	899
0.2337	625
0.1832	493
0.1491	68

Discharge

Profile

Depth Cell: ☑ Data ☐ Surface Cells
Transects: ☐ Medians ☐ Fit
Measurement: ☑ Medians ☑ Fit
Start edge: Left Right

Fit

20190725021915r.mat
20190725022220r.mat
20190725022546r.mat
20190725022812r.mat
20190725023153r.mat
20190725023413r.mat
Measurement

Fit: Automatic
Top: Constant
Bottom: No Slip
Exponent: 0.0815

Previous Extrapolation Settings

Top: Constant
Bottom: No Slip
Exponent: 0.0815

Discharge Sensitivity

Top	Bottom	Exponent	% Difference
Power	Power	0.1667	-0.69
Power	Power	0.0500	1.29
Constant	No Slip	0.1667	-1.29
Constant	**No Slip**	**0.0815**	**Reference**
3-Point	No Slip	0.1667	-1.74
3-Point	No Slip	0.0815	-0.45

Figure 22: Burrawang Double Pump run.

Index Velocity Rating

Data was validated on the fly for both measurement sections, in order to verify the quality of the captured data before winding the second pump up or down. This was quite a feat in the cold small hours of morning and running on minimal caffeine.

The data captured simultaneously on the SL units was retrieved and compared against the M9 transects to produce the following comparisons.

Wildes Meadow Data

Table 3: Wildes Meadow Index Velocity Rating

Pumps	Mean Channel Velocity	SL Measured Velocity	Index Velocity Equation
1	0.301 m/s	0.361 m/s	y = 0.8321x + 0.0007
2	0.585 m/s	0.702 m/s	

Burrawang Data

Table 4: Burrawang Index Velocity Rating

Pumps	Mean Channel Velocity	SL Measured Velocity	Index Velocity Equation
1	0.869 m/s	0.630 m/s	y = 0.7158x + 0.0082
2	1.331 m/s	0.961 m/s	

Conclusions

Despite both sites being impacted by steep, almost vertical walls on both side of the channel, a reasonable set of data was collected for both instruments.

The main impact on the data set at Wildes Meadow was one of the M9 beams interacting with the sloped side of the channel. QRev does offer a 3 Beam solution however this does not let the operator select individual beams, and SonTek is trialling beta software which allows the profile to be reprocessed with manually selected beams (RSQ).

At Burrawang canal, there were no major influences in the M9 data, and the measurements were representative of conditions. During post-processing of the SL beam check data, it was identified that there are no obstructions in the sample volume; however the diagnostic data did show obstructions.

As with all acoustics and other instruments, site selection is the primary driver of received data quality. All users need to keep in mind when installing side lookers an aspect ratio 1/20 is ideal, and the further away from respective boundaries, there is a higher likelihood this will impact measurements. When carrying out any ADCP measurements in channels with sloped or vertical walls it is important to understand the effects this will have on captured data, and how to make the most of it.

References

Chow, VT 2009, *Open-Channel Hydraulics* 30057th Edition 2009. The Blackburn Press. ISBN-10: 1932846182, 700 pages.

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From the Ashes – How the 2016 Waroona Bushfire is Influencing the Management of Drinking Water Catchments in Western Australia

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Professor Pierre Horwitz, Edith Cowan University, Perth, Western Australia.

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

Abstract

In early January 2016 a major bushfire swept down from the parched Darling Escarpment and across the farms of Western Australia's Swan Coastal Plain. At its worst the Waroona fire, could be seen from space and with the naked eye from Perth, 118 km north. The fire was so large that it formed its own weather system, a massive pyro-cumulonimbus cloud form, which generated unpredictable winds, lightning, and ember showers.

Over seventeen days the fire burned a total area of 69,165 ha comprising 31,180 ha of private property and 37,985 ha of public land. One hundred and eighty one properties were destroyed. The small town of Yarloop, home to around 500 people, was virtually wiped out. Tragically, two residents also lost their lives.

It has been estimated that the cost of the fire, including the costs of suppression, losses, damage and recovery totalled approximately $155 million. The comparative impact of the fire on the regions hydrometric monitoring network was, relatively, negligible, (costed at a $40,000 for the Corporation, $30,000 for Harvey Water and $10,000 for the Department of Water and Environmental Regulation (DWER)) however the impact on the surrounding environs was significant.

Within the Samson Dam catchment, the fire was extremely intense and wide spread. This resulted in extensive loss of vegetation and natural buffers within the catchment and surrounding properties. This included 100% of the riparian zones. This not only presented a high risk for erosion, and adverse water quality in supply reservoirs and the sensitive Peel Harvey Estuary, but also threatened the stability of local ecological communities.

However out of the ashes rose a range of exciting opportunities for water resource management in WA. In fire prone areas of the southwestern Australia knowledge on the impacts of wildfire on water quality is relatively minor. In the case of wildfire where water and aquatic assets are involved community, industry and resource managers have few means to prioritise their mitigation efforts.

In the wake of the 2016 Waroona fire a university study utilised available discharge and water quality data to examine the role of wildfire in causing erosion and producing water quality impacts.

This paper will attempt to illustrate the short and longer term impact of this extreme incident on surface water monitoring and management within the region by:

- *Presenting an overview of the immediate to medium term consequences of the fire on the local hydrometric networks;*
- *Examining the unique learning opportunities events such as these provide resource managers, including:*
  - *Insights into the responses of riverine ecology following extreme fire events;*
  - *Insight into how researchers could apply existing models capable of determining the spatial variability of soil erosion following fire in water source catchments;*
  - *Insight into the future work to further improve existing hydrologic models such that they may be able to predict the possible hotspots for erosion and water quality prior too controlled burns.*

1. Background

In the evening of Tuesday the 5th of January 2016 in the State forest south of Dwellingup, lightning ignited two fires. Despite a concerted response by local air and ground firefighters the fire quickly became unmanageable, sweeping down the parched, unburnt forest and heavily revegetated areas of the Darling Escarpment.

At its worst the Waroona fire, could be seen from space and with the naked eye from Perth (118 km north). The fire was so large that it formed its own weather system, a massive pyro-cumulonimbus cloud form, which generated unpredictable winds, lightning, and ember showers. It is now thought that new fires, which started on the eastern side of Waroona, where the product of lightning induced by the cloud form.

Figure 1: Pyro-cumulonimbus cloud visible at 19:34 hr on 6 January from Dwellingup, about 19 km north of the fire position. (Photo: Allan Clarke, Parks & Wildlife Dwellingup).

In the evening of Wednesday the 6th of January the fire rapidly spread west of Waroona, on the coastal plain, aided by the Waroona Main Drain. The drain effectively acted as a “fire fuse” to the coast, the intense fire fuelled by the heavy fuels loads within the drain and roadside vegetation, hindering suppression efforts.

By Thursday evening the fire entered the town of Yarloop from the east. Due to a massive ember attack many houses ignited simultaneously, overwhelming firefighters and a small number of remaining residents. Tragically two residents of Yarloop lost their lives.

Towards the coast, the fire crossed the Forrest Highway and subsequently cut off the small town of Preston Beach. Led by local residents and a number of Bush Fire Brigades, people sheltered at a carpark adjacent to the beach until they were ferried by, volunteer Marine Rescue activated boats to Bunbury.

Figure 2: Harvey Water vehicle parked at the front of the Yarloop Fire Brigade headquarters (Photo: Kate Duzevich, Harvey Water).

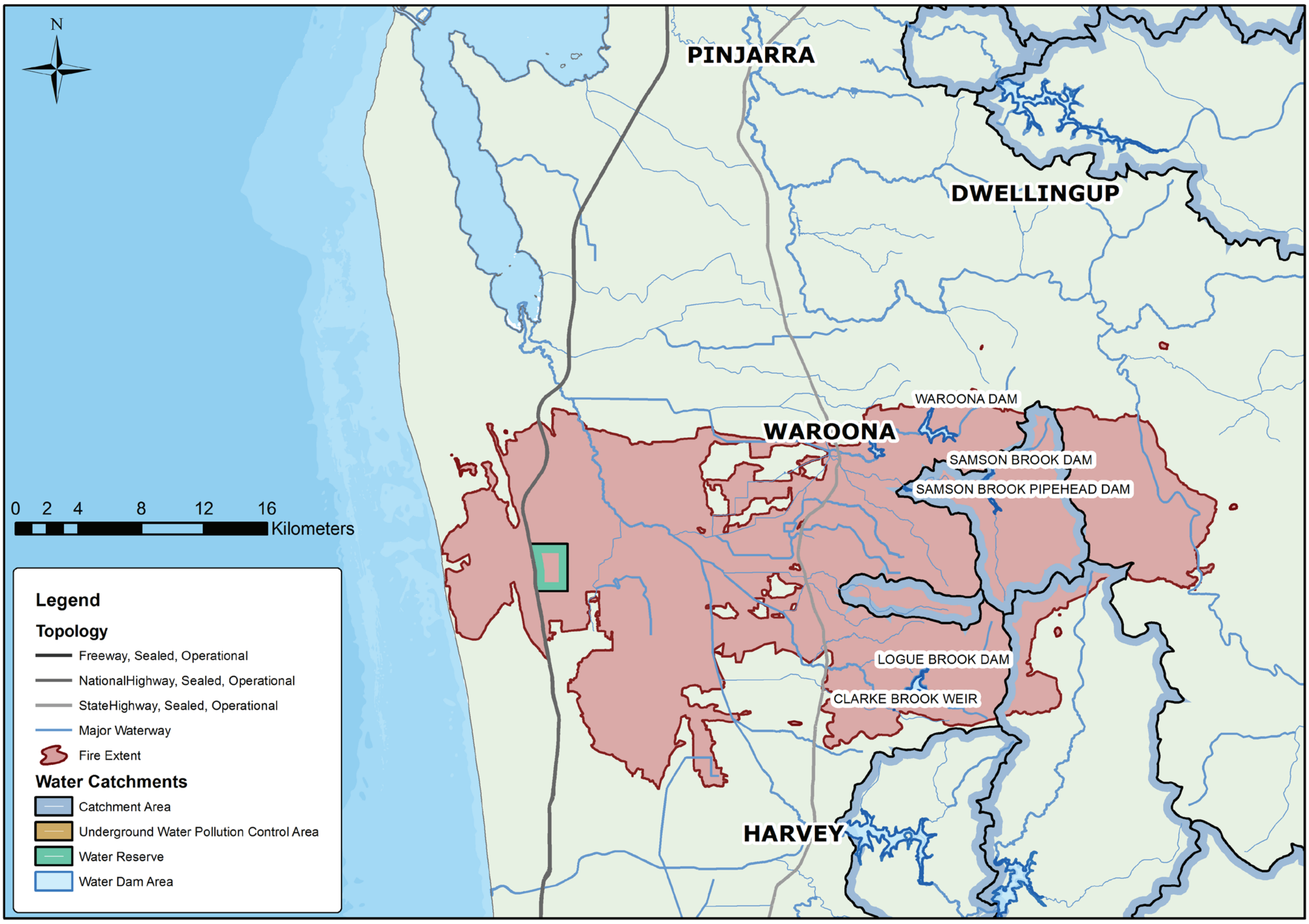


Figure 3: Map of Burn Extent.

2. Prior to the fire

2.1. Climate

The South West of WA typically experiences a Mediterranean-type climate with cool moist winters and dry warm to hot summers. Due to an orographic uplift created by the Darling Escarpment, increased rainfall is experienced on the western margins of the plateau. The mean annual rainfall declines steadily with distance east from the escarpment while mean monthly temperatures are 1-2° cooler on the plateau than on the coastal plain

Overall since the mid-1970s rainfall has been declining across much of south-west Western Australia, since 2000 the area has had a number of years with rainfall very much below normal. Prior to the fire the Bureau of Meteorology (BoM) reported rainfall in the South West, significantly below average. In addition prior to the fire Dwellingup experienced its warmest year in 75 years of record.

2.2. Vegetation and Land Use

On the Darling plateau and escarpment the dominant vegetation type is open eucalypt forest of jarrah *(Eucalyptus marginata)*, blackbutt *(Eucalyptus patens)*, bullich *(Eucalyptus megacarpa)*, wandoo *(Eucalyptus wandoo)* and marri *(Corymbia calophylla)*. Open forests typically have an understorey of woody shrubs that can vary from scattered low shrubs (fringing rocky outcrops) to dense stands of taller shrubs. Fuel loads within these areas are strongly influenced by the time since the last fire. Most of the forest burnt during the Waroona fire had been unburnt for at least ten years, some of it for over 30 years.

A majority of the forest on the plateau is public land either as conservation reserve or State forest where timber harvesting may periodically occur. Large parts of the forest have been mined for bauxite since the mid-1980s.

These areas have become highly fragmented by mine infrastructure. Because the rehabilitation of the pits commonly includes the dispersal of a seed mix that includes native tree and understorey shrub species, the pits are often densely stocked with even-aged saplings. Depending on the age of the stand fuel loads within the rehabilitated areas can range from minimal to abundant.

The escarpment is predominantly freehold land, much of it partially cleared and grazed.

Figure 4: Stand of bullich and blackbutt, typical of revegetated bauxite mine site. This stand has not been burnt for 30 years. Note the abundant fuel.

The coastal plain is mainly freehold land used for a range of agricultural enterprises including irrigated dairying, horticulture and dryland beef production. An extensive network of irrigation channels and deep drains has been established to service agricultural lands, but over the past decade open channels have progressively been replaced with pipes to reduce water loss from seepage and evaporation.

State-owned plantations of *Pinus pinaster* and *Pinus radiata* have been established on the Bassendean dunes along the Forrest Highway. West of the highway the Yalgorup National Park includes woodland of tuart (*Eucalyptus gomphocephala*), peppermint (*Agonis flexuosa*) and a variety of coastal scrubland communities. Prescribed burning of native vegetation adjacent to pine plantations has taken place on a limited scale for hazard reduction.

3. Loss and Damage

Over seventeen days the fire burned a total area of 69,165 ha comprising 31,180 ha of private property and 37,985 ha of public land. One hundred and eighty one properties were destroyed, including areas of the prime dairy and beef grazing within the region of Harvey. Sections of the Bibbulmun Track and Munda Biddi trail, national parks and dam catchments were also severely burnt. The bushfire had a severe impact on the settlements of Waroona, Yarloop, Preston Beach and surrounding areas. The small town of Yarloop, home to around 500 people, was virtually wiped out.

During the Special Inquiry into the January 2016 Waroona Fire, it was estimated that the cost of the fire to date, including the costs of suppression, losses, damage and recovery totalled approximately $155 million (Ferguson, 2016).

3.1. Impact on the Waroona-Harvey Region Hydrometric Network

The comparative impact of the fire on the region's hydrometric networks was, relatively, negligible, with the combined cost of the three primary agencies in the order of $80,000. However the, the impact on the surrounding environs was significant.

Hydrometric monitoring within the Harvey-Waroona region is undertaken by three proponents.

The Department of Water and Environmental Regulation

The Department of Water and Environmental Regulation (DWER) supports Western Australia's community, economy and environment by managing and regulating the State's environment and water resources. The department is responsible for environment and water regulation, serving as a 'one stop shop' for industry and developers, with the aim of streamlining and simplifying regulation (DWER, 2018).

Within the Waroona-Harvey Region DWER have an extensive network of long term Surface Water, Rainfall and Groundwater sites. The data form these sites is utilised within water allocation planning.

Fortunately the impact of the Waroona fire on DWER's monitoring network was minor. The overall estimated cost to repair and resurvey within $10,000.

"We (DWER) had a total of 7 groundwater monitoring bores damaged to the point of requiring headwork replacements. None required redrilling. Several other bores sustained superficial damage, which only required repainting of the headworks. The bores are monitored on a maximum/minimum frequency (Mar, Apr, May and Sep, Oct, Nov) and repairs were made before monitoring commenced so fortunately no data was lost.

Our surface water hydrometric infrastructure was largely unaffected by the fires, with only a bit of ash found in the cabinets/floatwells" (Andrew Weatherburn, DWER, pers. comment June 2018).

Figure 5: Bore HS24A, Damage to surrounds and inner casing post Waroona Fire.

Figure 6: Samson Brook below Main Dam — DWER Rainfall Site post fire.

Harvey Water

Located to the west of the Darling Scarp, on the Swan Coastal Plain, the Harvey Water Irrigation Area (HWIA) covers an area of 112,000 ha. The scheme which is divided into three Irrigation Zones: Harvey, Waroona and Collie, delivers non-potable water to cooperative members, small private irrigators and industrial users via a network of irrigation assets between Waroona and Dardanup. The network permanently supplies around 10,000 ha of land for dairy farming, beef grazing and horticulture, with a total irrigable area of approximately 30,000 ha (Harvey Water, 2018).

"The impact of the Waroona fire on Harvey Water's monitoring network was primarily in the form of damage to electronic and mechanical meters, pressure gauges and data loggers installed within the Waroona and Harvey Irrigation Districts. The estimated cost to repair these assets in the order of $30,000" (Kate Duzevich pers. comment, June 2018).

Figure 7: Example of Harvey Water Hydrometric Assets damaged by the Waroona Fire. Left: Mechanical Meter, Right: Pressure Gauge.

Water Corporation

The Water Corporation is a state-owned water utility accountable to Western Australia's Minister for Water. The utility is the the principal supplier of water, wastewater and drainage services in WA.

Within the Waroona-Harvey region the Water Corporation operates the Samson Brook and Stirling reservoirs which, in addition to Perth's Integrated Water Supply Scheme (IWSS), supply water to the towns of Waroona, Harvey and their surrounding districts.

At the dams the Corporation plays a role in managing both the dam and conveyance infrastructure and the upstream catchments. Management of the catchments is undertaken in accordance Water Source Protection Plans issue by DWER.

Overall the damage to the corporation's hydrometric network from the fire and post fire events was limited to $40,000. The primary damage was to six gauging stations installed in series along the Samson Brook reach. The sites were commissioned in 2014 for the *Samson Brook Environmental Water Provisions* Research Project.

Figure 8: Damaged Logger from 6215W001 — Samson Brook at 1st Below Pipehead.

4. Samson Brook Environmental Water Provisions Research Project

4.1. Background

Between 2010 and 2013, during construction work to improve the safety of Samson Dam, the Water Corporation sought a temporary reduction in the base-flow component of the Environmental Water Provisions (EWP). The reduction was granted conditional on dissolved oxygen (DO) levels remaining above 5 mg/L throughout the Samson Brook reach from the main dam to the South West Highway Bridge.

In order to ensure the conditions were being met during construction, DO was monitored by Water Corporation staff using hand-held meters. Surprisingly the results, which were presented to DWER at the end of the improvement works, demonstrated that DO levels within the reach were not necessarily reliant on flow, but were strongly influenced by the water temperature and turbidity.

The corporation subsequently theorised that DO levels could be sustained above the minimum 5 mg/L required, to maintain the ecological processes within the reach, at base-flow levels much lower than the existing EWP requirements (3.1 ML/day between Samson Dam and Samson Pipehead Dam, and 3.6 ML/day below Samson Pipehead Dam).

As the South West of Western Australia has experienced a prolonged decline in rainfall since the early 1970s accompanied by serious reductions to inflows into the major storage systems, new approaches balancing the provision of water to the environment with the sustainable management of the water source are becoming increasingly important.

The “Samson Brook Environmental Water Provisions Review” was commissioned in July 2014 to demonstrate if the Corporation could reduce the current base-flow levels through the Samson System without adversely impacting on the ecological processes within the reach.

4.2. Project Aim

The aim of the trial was to provide sufficient evidence to 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 trail is required to quantify the minimum flow rate required in order to:-

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

To enable the quantification of an appropriate minimum base-flow rate, in 2014, the project commissioned:

- Additional monitoring for continuous DO and water temperature at two existing compliance flow monitoring points;
- An additional four temporary monitoring points to monitor continuous flow, dissolved oxygen and water temperature along the Samson Brook reach;
- Routine ecological condition assessments (fish and crayfish surveys) in spring and autumn in order to assess the ongoing state of the Samson Brook ecosystem prior to and during the trail.

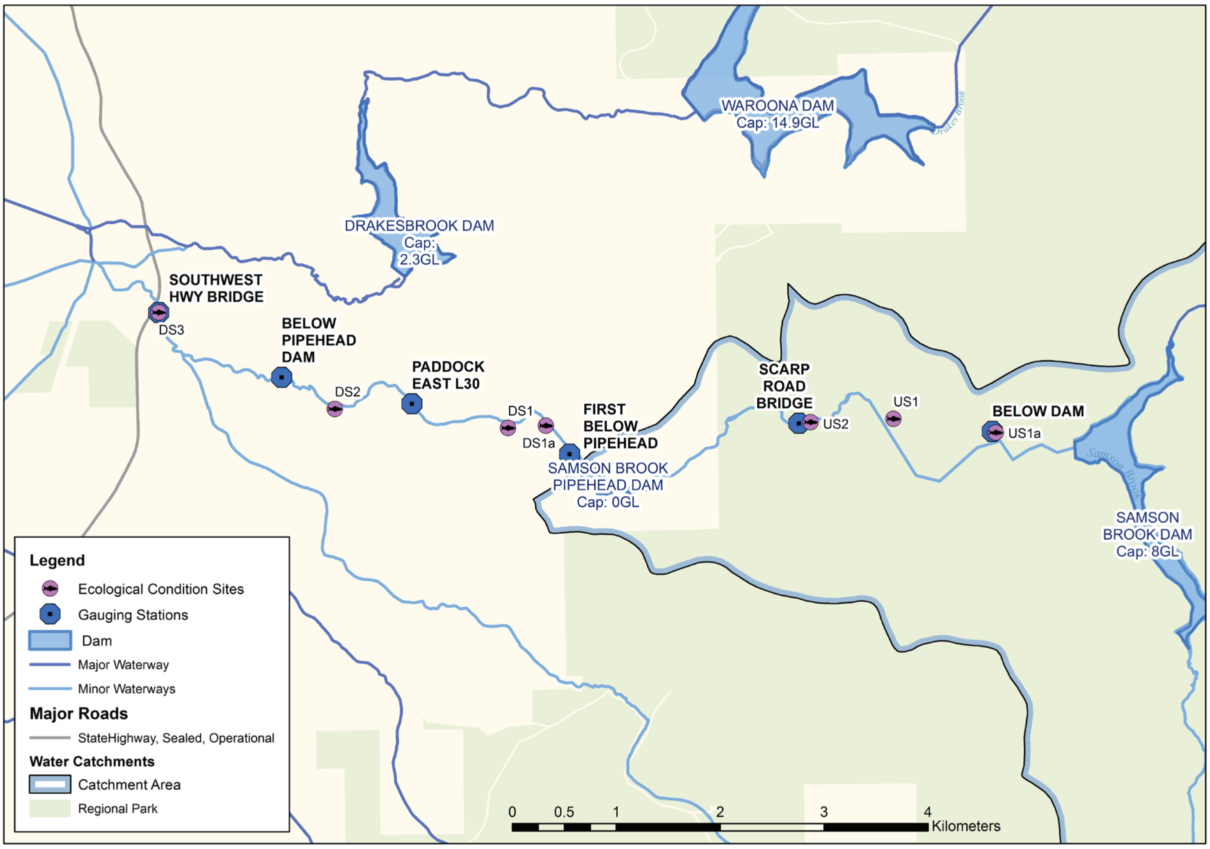


Figure 9: Samson Brook Environmental Water Provisions Research Project Site Locations.

The Samson Brook Project was scheduled to run for four years. The intent to collect two years of baseline data on the current flows and ecological processes proceeded by two years monitoring the reduced base-flows over the summer/autumn periods (from 1st November until 30th April).

Table 1: Samson Brook Research Sites

Reach	Station name and number	Location		Monitoring		
		Easting	Northing	Pre-existing Site	Flow	Temp & DO
REACH 1: SAMSON DAM TO SAMSON PIPEHEAD DAM	W8000969 Below Main Dam	407805	6361953	Yes	Yes	Yes
	6215W000 Scarp Road Bridge	405916	6362064	No	Yes	Yes
REACH 2: SAMSON PIPEHEAD DAM TO SOUTH WEST HIGHWAY BRIDGE	6215W001 First Below Pipehead	403709	6361767	No	Yes	Yes
	6215W002 Paddock East L30	402191	5362252	No	Yes	Yes
	W8002559 Below Pipehead Dam	400937	6362505	Yes	Yes	No
	6215W003 Southwest HWY Bridge	399753	5363128	No	Yes	Yes

4.3. Post Waroona Fire

At the time of the Waroona fire the Samson Brook Research and Development Project had been in operation for 1.5 years with preparations in place to progress from baseline monitoring to phase 2 (reduced base-flows).

However with Samson Brook directly in the burn path, a majority of the damage to the Corporation's network was centred on the six gauging stations within Samson Brook Reach (a summary of the overall damage has been provided in Table 2).

Consequently the planned transition to Phase 2 of the project was postponed to enable the catchment to recover. During this pause monitoring continued in order to provide invaluable data on the catchment and ecological responses post fire.

Table 2: Damage to Samson Brook Research Sites post Waroona Fire

Reach	Station name and number	Damaged				Data Loss
		Housing	Level	Temp & DO	Telemetry	
REACH 1: SAMSON DAM TO SAMSON PIPEHEAD DAM	W8000969 Below Main Dam	Yes	No	Yes	Yes	No loss of level data DO data loss post 7th January 2016
	6215W000 Scarp Road Bridge	Yes	Yes	Yes	Yes	All data lost post 7th January 2016*
REACH 2: SAMSON PIPEHEAD DAM TO SOUTH WEST HIGHWAY BRIDGE	6215W001 First Below Pipehead	Yes	No	Yes	No Telemetry	Level data lost from November 2015 – No loss of DO data*
	6215W002 Paddock East L30	No*	No*	No*	No	No data loss**
	W8002559 Below Pipehead Dam	No	No	No	No	No data loss
	6215W003 Southwest HWY Bridge	No	No	No	No	No data loss

*Equipment and/or data later compromised by post fire catchment responses.

Due to the severity of the fire in the upper catchment the damage and subsequent loss of data was the most significant within this zone. Thanks to the use of near real time telemetry the resultant loss of data was minimised to post fire events at W8000969 and 6215W000 however the loss of data at 6215W001 was significant due to it being an un-telemetered site.

Fortunately an estimated $27,000 to replace the infrastructure and equipment was covered by insurance; however the additional unplanned labour costs were incurred by the research project.

Of even greater concern was the level of damage to the Samson Brook catchments, and how the ongoing impacts on erosion and subsequent water quality and would eventually influence the operation of the monitoring sites and research outcomes given the level of damage to the catchment environs.

5. Impact of the Waroona Fire on the Samson Brook Catchment

5.1. Immediate Impact

As demonstrated in Figure 10 most of the Samson Brook drinking water catchment was burnt by the fire. This included all surrounding properties and most critically 100% of the riparian zones.

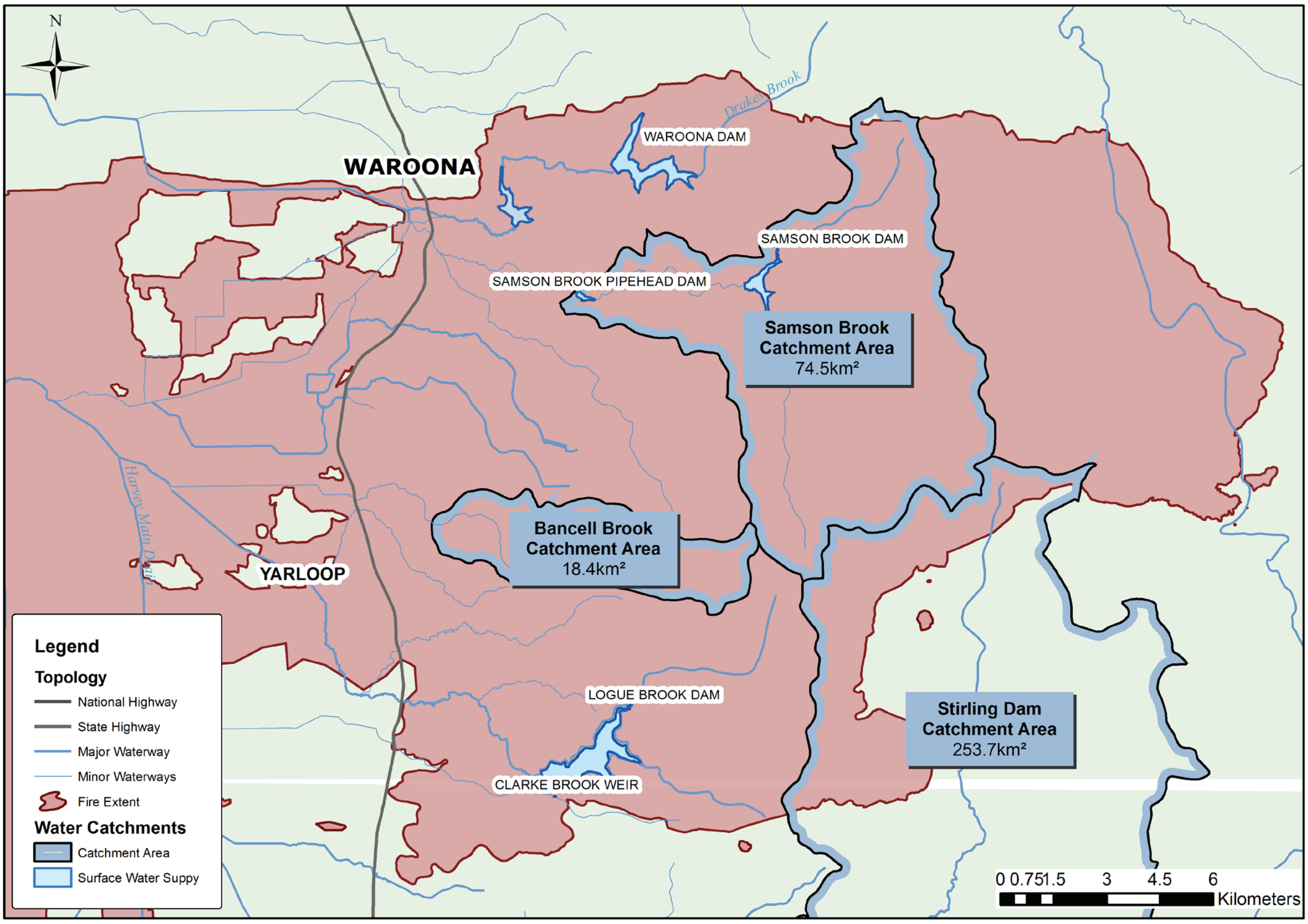


Figure 10: Impact of the Waroona fire on the Samson Brook Drinking Water Catchment.

Across the Upper Samson Brook Catchment the fire was extremely intense, completely removing all littoral and vegetation cover. However between the main dam and the Samson Pipehead the intensity of the fire resembled that of a prescription burn leaving leaves on the tops of trees and some leaf litter on the ground (Figure 11).

Figure 11: View of typical damage to catchment. Left: Upper Samson Brook Catchment,
Right: View to Samson Pipehead Dam Wall (Images by M. Sturges, Aroona 2016),
Bottom: Samson Brook at Paddock East

Below the Samson Pipehead dam the effect of the fire on the remaining forests also resembled a prescription burn whilst within the lower pastoral land; the impact was limited to the riparian zones (see to Figure 11).

Prior to the fire, the foreshore condition of the Upper Samson Brook Catchment riparian zones was rated as pristine. Flowing through forested conservation and water resource protection areas the brook contained abundant native vegetation, very few exotics, a variety of in stream habitats and bank vegetation. As a consequence the reaches supported a strong community comprised of native crayfish (marron and gilgies) native fish and limited introduced fish (rainbow trout and gambusia). Several Ecological surveys had also found evidence of a colony of Raki (Water Rats).

Figure 12: Below Main Dam W8000969. Left: Prior to the Waroona Fire March 2015, Right: Post Fire February 2016.

In February 2016, following the fire, the foreshore condition was re-assessed. The riparian zone was found to be disturbed with most of the tree canopy and understory vegetation burnt. The underlying ground, a combination of bedrock and stone, interspaced with sections of loose sand and clayey loam, showed preliminary signs of erosion as a result of recent rains. Waters flowing through the reach were also observed to be turbid with an abundance of suspended sediments.

5.2. Intermediate Impact

Following the fire, catchment managers determined the Samson Dam Catchment to be at a high risk of erosion. With undulating terrain throughout the catchment, and soils that include lateritic soils and red loamy earths over areas of exposed granite, it was determined that the:-

- Exposed granite surfaces could increase runoff speed; while
- The extensive loss of the vegetation holding the soil together could enable erosion to occur, especially in areas where the slopes were ≥ 7 deg.

In the six months following the Waroona fire drastic changes were observed in the run-off regime and water quality within the catchment. Increased surface run-off as a consequence of the loss of vegetation cover and changes to soil properties resulted in increased:

- Runoff from the catchment;
- Erosion throughout the catchment;
- Sediment deposits within the Samson Brook.

These impacts caused further issues for the Samson Brook Environmental Water Provisions Research Project.

In late May 2016 following 106 mm of rainfall over 4 days a large amount of sediment, and debris mobilised down the Samson Brook between the Samson Dam to the Samson Pipehead dam and the reaches below.

Follow-up visits in early June 2016 discovered a number of sites had been impacted by debris and sediments mobilised during the May event.

Figure 13: Samson Dam to Pipehead Creek Line. Left: Bank erosion, Right: Suspended sediments in the brook, post rainfall event May 2016 (Images by M. Sturges, Arrona 2016).

6215W000 – Scarp Road, was impacted by large amounts of sediment washing down the hillslopes and brook. The deposited sediment built up around bends in the bank and the instrument housing compromising both the DO and Microsonic water level sensor readings.

During the site visit a section of the sediment was excavated to allow for effective water level measurement and the DO sensor was raised in order to allow for continued recording.

As the channel characteristics had been altered by the sediment and subsequent remediation current rating was no longer applicable beyond the 21st May.

Figure 14: June 2016 (4 months after the fire) 6215W000 Samson Brook at Scarp Rd.
Top Left: Hillslope Erosion, Centre: Sediment Build up in the channel, Right: Excavated pool around DO Sensor.

At **6215W001 – Samson First Below Pipehead**, erosion of the banks and hillslope upstream and the mobilisation of the sediments in the Brook, filled the pools with fine to coarse grain sediments.

While the instrument housings remained intact, the DO sensor became buried and the readings from the Microsonic water level sensor were distorted by the sediment level.

Immediate actions included the removal of the sediment in a portion of the pool to allow for continued DO and water level recording however it was noted that continued remediation would be required as more sediment was mobilised.

The rating at this site was impacted however it was determined that it was likely to return to a more stable state as the sediment migrated further downstream over time.

Figure 15: Erosion, Sediment, Debris and Turbid Water at 6215W001 Samson First Below Pipehead June 2016 (4 months after the fire).

At **6215W002 - Paddock Lot** the event had the most significant impact. As a result of the erosion of the banks and underlying earth supporting the stay and instrument housings the housing collapsed. In addition the sensors were buried by a large amount of debris (mainly medium sized tree branches) and fine to coarse grain sediment.

As a consequence the natural channel control, specifically its low flow channel characteristics, were severely impacted the rating for the site void beyond 21 May 2016. Data was retrieved from the loggers but was severely impacted by water damage.

Immediate actions on arrival at the site included digging out the sensors and removing the debris, equipment housing and stay.

Figure 16: Damage to 6215W002 Samson Brook at Paddock East June 2016 (4 months after the fire).

Over the coming months the impact of sediments, which continued to erode from the hillslopes into the riparian zones, persisted. Routine maintenance at the sites now included the de-silting of the pools to allow for effective DO and water level recordings.

At all six sites the water flowing through the Brook continued to have high levels of turbidity.

Because turbidity has historically been shown to have a strong influence on Dissolved Oxygen levels, the project team commissioned the installation of continuous turbidity meters at select sites for the remainder of the project.

Figure 17: Turbid Water at Left: W8000969 Samson Brook at Below Main Dam,
Right: 6251W001 Samson Brook First Below Pipehead August 2016 (8 months after the fire).

Whilst the impact of the fire and subsequent erosion on the water quality and station performance have proven to be profound, extensive post fire monitoring of the recovery of the riparian vegetation and in-stream ecological condition has revealed that the riverine systems have a degree of post fire resilience:-

Overall the riparian vegetation appeared be recovering well even in the upper areas where the impact of the fire was the most significant (refer to Figure 19). Two years after the fire ongoing monitoring is demonstrating that the native vegetation has remained intact and its recovery is consistent with the expected post fire responses;

While initially (within the first 6 months) a decline was observed on diversity and numbers of freshwater crayfish and fish, after eighteen months populations had returned to a similar or better state to that observed prior to the fire. Some species of fish were observed in the reach for the first time in 10 years; however,

Since the fire the summer rainfall has been unseasonably high, and not representative of recent typical seasonal climate conditions. Similarly, base-flow during summer 2017–18 was well above the longer-term average (refer to Figure 19), impart due to the rainfall but also as a consequence of altered rainfall runoff regimes and the ongoing release of water from the dams (due to unacceptable aesthetic water quality for drinking water supply). This may have had some positive bearing on the level of recovery observed within the system.

Figure 18: Samson Brook Riparian Vegetation Transect. Top: Autumn 2016 (~ 2 months after the fire), Bottom: Summer 2018 (2 years after the fire) (Mattiske, 2018).

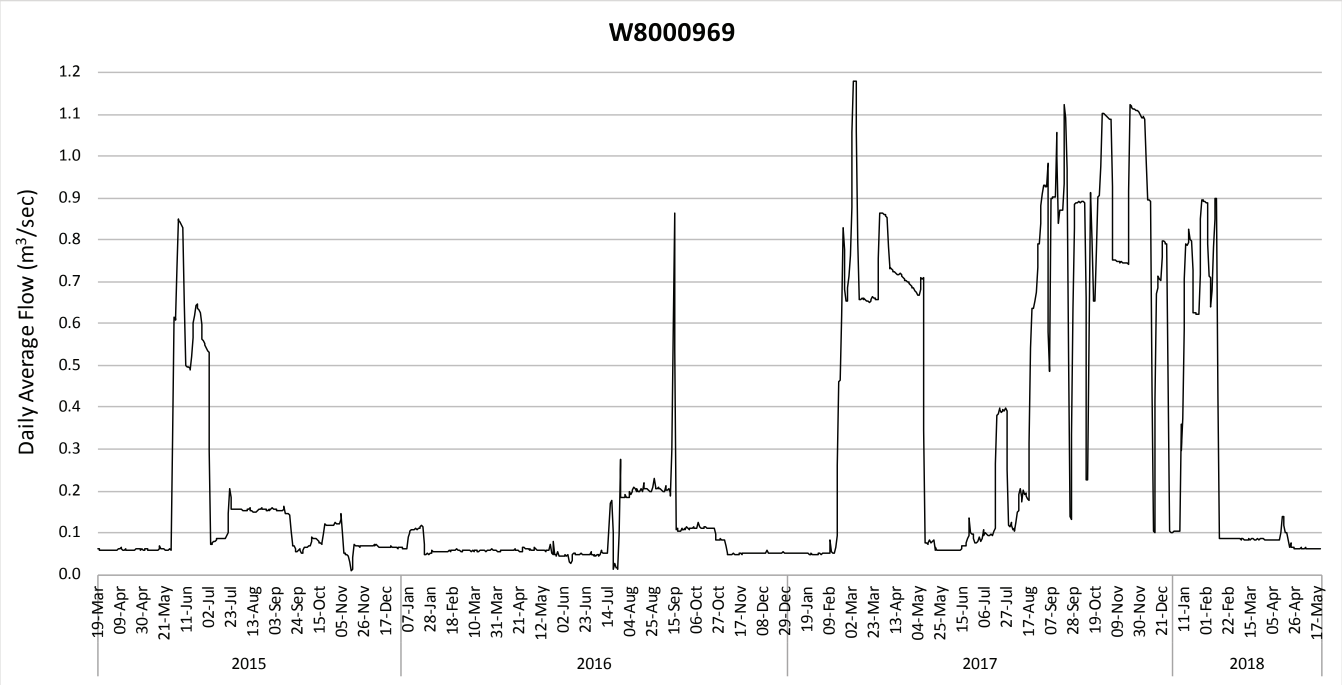


Figure 19: Samson Brook Below Main Dam Average Daily Discharge March 2015 to May 2018 (WRM, 2018).

Impact of Fire on Water Resources

Given the critical importance of water resources to human populations and the environment, and the potential for severe impacts by fire on the surrounding landscape and water quality; a thorough understanding of the effects of fire on water resources is becoming increasingly important.

Recent wildfires in eastern Australia, Waroona and other fire-prone regions around the world have demonstrated the potential for fire to elicit strong adverse water quality responses. These responses have significant implications for water supply (see for example Smith *et al.* 2011; Oliver *et al.* 2012; Bladon *et al.* 2014; Dahm *et al.* 2015) and aquatic ecosystems.

The duration and degree of impact by a fire on the landscape, the associated water quality and the subsequent impact on the ecological processes depends on a range of factors including:

- Pre-fire vegetation state;
- Fire intensity and timing;
- Impacted terrain, including the soil type; and
- Post fire rainfall patterns.

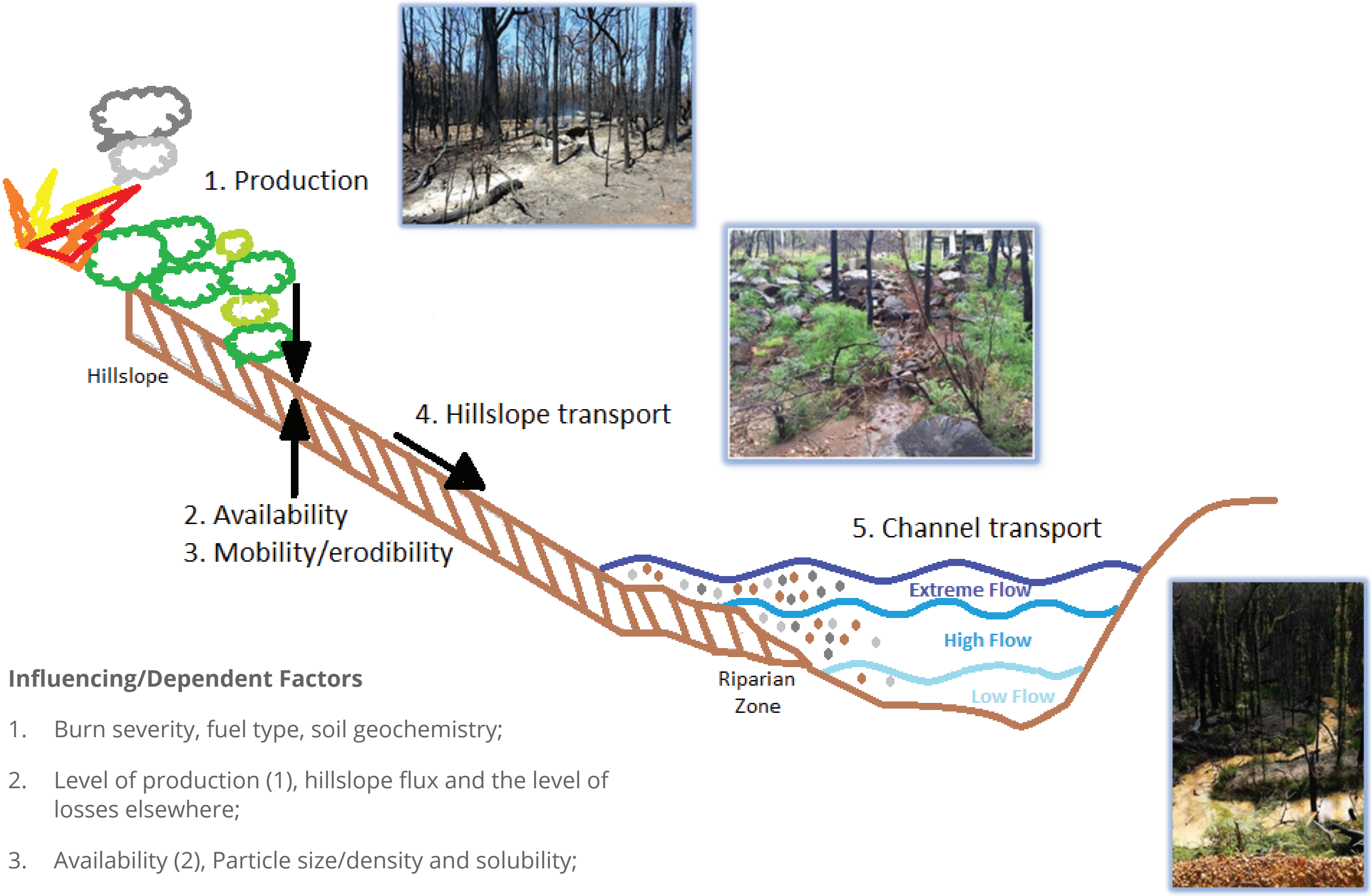
In the short term the effect of fire can mimic the effects of land use changes (e.g. agricultural and urban development and logging) including:

- Changes to soil thermal properties due to reductions in the litter layers and organic matter content;
- Changes to soil chemical and physical properties leading to soil hydrophobicity (this decreases with time);
- Loss of vegetation resulting in reduced interception, evapotranspiration and natural buffering.

In the medium term these changes lead to a change in the run-off regime predominantly observed as increased surface run-off. The consequence of these faster, stronger, flows from a greater catchment area is an increase in erosion and transport of sediments into the water ways.

Figure 20 reflects the five key factors that control the contaminant transport by streams following a fire: 1) production of erodible constituents by fire (wildfire/planned fire), 2) their availability to erosion, 3) their mobility once eroded, 4) rate of hillside transport during rainstorms and 5) inundation of the riparian zone and subsequent channel transport during periods of high flow.

The longer term impacts on the quality of the water and continued viability of the water resource is strongly influenced by the mass balance of the sediment and constituents within the hillslopes, riparian areas and channels.



Influencing/Dependent Factors

1. Burn severity, fuel type, soil geochemistry;
2. Level of production (1), hillslope flux and the level of losses elsewhere;
3. Availability (2), Particle size/density and solubility;
4. Pollutant availability (2) and mobility (3), topography, rainfall intensity/erosivity;
5. Degree of Hillslope transport (4), discharge and channel morphometry.

Figure 20: Conceptual model of post fire Contaminant Transport Mechanisms.

The water quality consequences of the contaminant transport can include increased suspended sediment, nutrient concentrations and other constituents such as heavy metals and PAHs associated with burned soil and ash (Smith *et al*., 2011; Bodí *et al*., 2014; Burton *et al*., 2016; Nunes *et al*., 2018). The transport of these constituents in to water supply stores may result in:

- Eutrophication of the storage;
- Algae outbreaks;
- Fish Kills;
- Increased pathogen levels.

As a consequence there is a substantial risk of major disruptions to water supply. For a water utility this can include:

- Increased operating costs due to the need for remediation and increased sanitation;
- A need for higher Environmental Water Provisions to support healthy ecological processes during post fire recovery;
- In the case of significant contamination, taking supplies off line; resulting in
- The potential loss of desalinated or other water stored in reservoirs.

The overall impact of fire decreases with time however, from previous observations, a catchment subjected to an intense burn within the South West of Australia can be expected to take up to 5-7 years to return to pre-fire conditions.

Rising from the Ashes – Researching the Impact of Fire on Water Resources in the South West of Australia

The escarpment in the SW corner of Australia is heavily forested, receives relatively high rainfall and contains important catchments for water supply, irrigation and wetlands on the coastal plains. It is also is amongst some of the most flammable ecosystems on earth and is subject to highly erosive rain storms. In addition significant declines in rainfall, warming trends and an increased incidence of weather extremes suggest worsening bushfire conditions for the region (see Dowdy 2018).

Within the escarpment eleven reservoirs supply approximately one third of Perth's water supply. The reservoirs receive surface runoff, provide holding capacity for treated groundwater and desalinated water during off peak demand periods and provide rapid supply at peak times.

These forested catchments also help support aquatic ecosystems that are unique to this region (Pennifold *et al*. 2017) whilst the water that reaches the coastal plains is often used directly for irrigation and/or ultimately ends up in wetlands, rivers and estuaries that are of high ecological, social and economic value.

Bushfire statistics show an increase in the area burnt by large summer bushfires since the early 2000s. The 2005 Perth Hills bushfire, which affected over 27,700 ha of drinking water catchment (Batini and Barrett 2007) and the 2016 Waroona fire, which burnt in excess of 12,500 ha, provide striking demonstrations of the potential impact of high intensity summer bushfire on erosion and resulting water quality within Perth's Water Supply catchments.

Existing research from different fire-prone regions on earth (Wondzell and King, 2003; Smith *et al*., 2011; Sheridan *et al*., 2015) has demonstrated that the post-fire impacts on erosion and water quality are both locally and regionally distinctive.

For the South Western Australian landscapes, a combination of factors makes them unique:

- Ancient relatively infertile soils founded on geological formations that have an extensive history of prolonged leaching, erosion, and deposition (Wardell-Johnson and Horwitz 1996);
- Subdued landscapes;
- Climatically buffered/stable with a remarkably consistent "fire Season";
- Distinctive vegetation which is, by international standards, considered to be highly flammable.

These attributes distinguish the SW Australian landscapes from the southeast where much of the post-fire erosion and water quality consequences have been investigated to date.

Overall there are fundamental research gaps related to the availability and mobility of water quality constituents after fire in the south west of Australia (Nunes *et al*., 2018). As a consequence the relations between fire severity and the availability and mobility of contaminants such as heavy metals, nutrients and polyaromatic hydrocarbons (PAHs) on the hillslopes of Perth's water supply catchments are currently poorly quantified.

Following the 2016 Waroona and 2005 Perth Hills fires, the Corporation invested considerable effort into managing the impacts on water quality in the drinking catchments including:

- Remediation of burnt areas with focus on reducing erosion and turbidity loads to the reservoirs from high risk areas either by filtering or by reducing the speed of overland flow (see Figure 21 for examples).
- Increased water quality sampling and monitoring regimes including the installation of turbidity probes at select locations.

Figure 21: Left: limestone and geofabric sedimentation structures installed in Mundaring Catchment post 2005 Hills fire, Right: Coir Logs installed near 6215W000 Samson Brook at Scarp Rd.

Despite these efforts the impacts were not wholly mitigated resulting in the need to:

- Dose with poly aluminium chloride,
- Restrict the transfer of water; and
- Take sources off line.

It is estimated that following the 2005 fire, inspite of the remediation the eventual loss in supply was in the order of 10-16GL.

Lessons learnt analysis, following the events, indicated the Corporation has in place a robust range of mitigation activities to prevent fire and/or respond post events, however there is no defined process, mechanism or tool capable of influencing their effective prioritisation and placement.

In response in 2019 the Corporation, Department of Biodiversity, Conservation and Attractions (DBCA) and Edith Cowan University have joined forces in order to kick off the Research project “Predicting and managing the impacts of wildfire and prescription burns on water quality and water-related assets”.

The $1.5 million project will seek to improve the predictive capabilities of existing fire response models, enabling the Corporation to predict possible impacts, identify risks and hotspots for water quality and erosion concerns, and make risk based decisions in regards to the catchments and assets in fire risk areas. The project also aims to further strengthen the Corporation’s ability to appropriately react to fire events with correct mitigation/recovery activities, and with the assistance of ECU develop in-house models, along with a training program for Corporation personnel.

The types of risks that are to be addressed through this project include:

1. The possible impacts of fire, taking into account possible burn severity (as influenced by the level and extent of fuel loads). Predicting these impacts will enable the:-
   - Identification of risks associated with controlled burns or unplanned fires in association with our catchments and other assets; with an aim to being able to
   - Risk-based decision-making as to where/where not to proceed with controlled burns; and/or
   - Improved risk-based decision-making regarding the prioritization of bushfire mitigation activities.

The response capacities to fires in our catchments, by:

- Identifying key hotspots for possible erosion and or WQ post fire;
- Determining areas for increased WQ sampling/monitoring in response to a fire event; and
- Identifying how to best operate our assets post burn (e.g. if modified release regimes are required, priority areas for remediation, etc.).

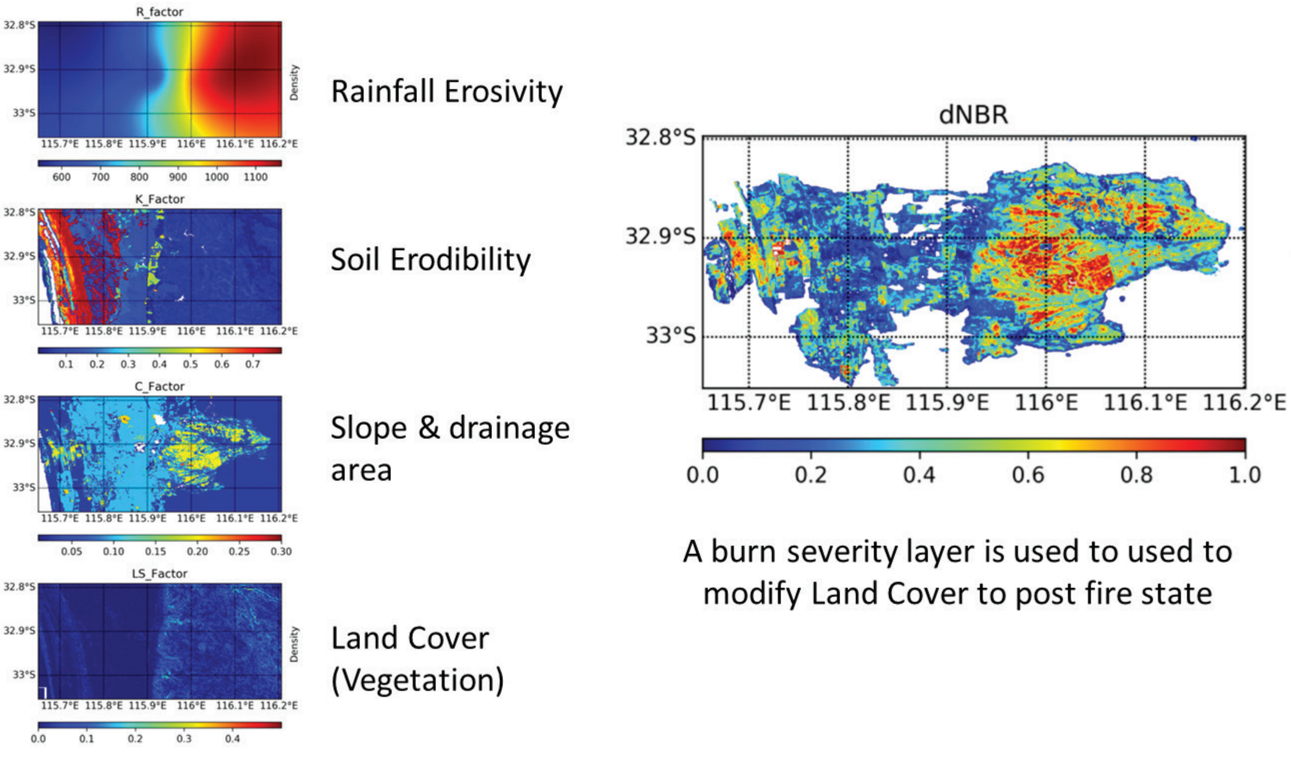


Figure 22: Inputs into a fire response model.

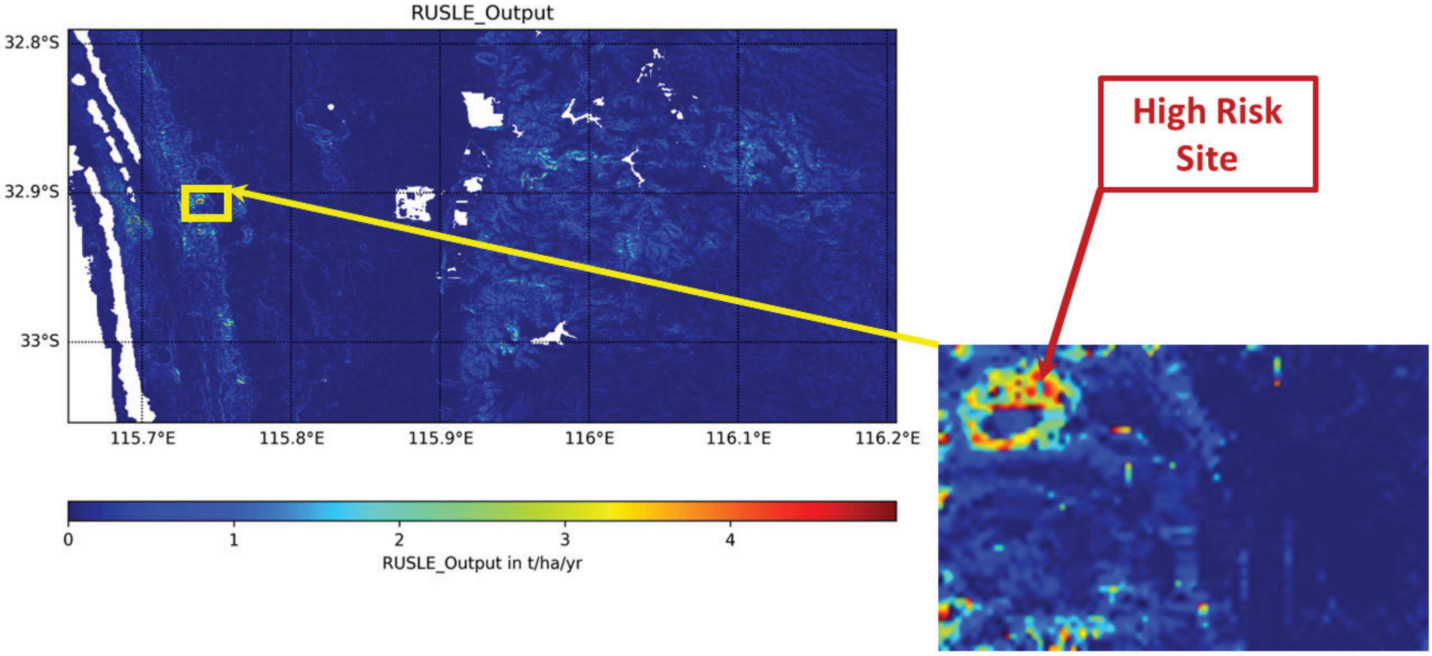


Figure 23: Example of a fire response model output.

The project objectives are:

- To develop a locally-relevant model that is able to predict not just sediment export but other water quality components;
- Improve the “reactive” capabilities of existing and developed models within Western Australian environs in response to fires in water source catchments;
- Improve the “predictive” capabilities of existing and developed models within WA catchments;
- To improve predictions regarding burn severity, and hence develop the capability for the key stakeholders to develop in-house models to facilitate day to day asset management activities.

The Project has entered its first year and is currently in the process of refining its scope, securing researchers and establishing its Reference and Steering committees.

In year two (2020/2021 Financial year) the project will commence the Conceptual Model development and establishment of monitoring sites in the nominated experimental catchments.

Conclusion

After 17 days the Waroona fire, which claimed two lives and almost wiped out the town of Yarloop, was extinguished. The fire burnt more than 69,000 hectares including 181 properties, national parks, dam catchments and vast tracts of farming land, including areas of the prime dairy and beef.

It has been estimated the cost of the fire to date, including the costs of suppression, losses, damage and recovery is in the order of approximately $155 million. In comparison the immediate impact of the fire on the regions hydrometric networks was negligible, the combined cost of the three primary agencies in the order of $80,000. However the longer term impact on the surrounding environs and particularly the water supplies was significant.

In January 2018, it was two years since the fire. While the vegetation and fauna populations of the region are demonstrating remarkable resilience, impacts on the quality of the water and stream morphology are still being observed along the Samson Brook catchment. Originally installed to trial new approaches to maintaining Environmental values on the reach, the sites are now providing detailed insights into the responses of catchments in the South West of Australia following significant fire events.

This information is proving to be invaluable. Whilst there are a robust range of mitigation activities, available to those who manage WA's water supplies, to prevent fire and/or respond post events, it is acknowledged that there is currently ineffiecencies in how the controls are deployed.

Overall in the post-fire hydrological research domain, there are fundamental research gaps related to the availability and mobility of water quality constituents after fire in the south west of Australia (Nunes et al., 2018). As a consequence the relations between fire severity and the availability and mobility of contaminants such as heavy metals, nutrients and polyaromatic hydrocarbons (PAHs) on the hillslopes of Perth's water supply catchments are currently poorly quantified.

However out of the ashes of the Waroona fire the WA Water Corporation, DBCA, Edith Cowan University and Melbourne University are proactively planning to use the knowledge gained to deliver a $2.9 million research project "Predicting post-fire water quality contaminant production and mobility".

The aim of the project is to:

1. Quantify the relationship between fire severity and the transport of contaminants within catchments in the South West of Australia.
2. Build a prototype empirical model capable of predicting catchment responses to fire, enabling catchment managers to make more informed decisions ahead of prescribed burns and post wildfire events.
3. Develop the capability for the Water Corporation's Asset/Catchment Managers to build and maintain fire response models for WA drinking water catchments, facilitating effective asset management.

The escarpment in the SW corner of Australia is heavily forested, receives relatively high rainfall and contains over eleven reservoirs which supply approximately one third of Perth's water supply.

The catchments are also an important factor in maintaining the ecological processes within the coastal plains. Being amongst some of the most flammable ecosystems on earth and is subject to highly erosive rain storms it is important the Catchment Managers have effective mechanisms for their sustainable management.

With significant declines in rainfall, warming trends and an increased incidence of weather extremes suggesting worsening bushfire conditions for the region it is hoped that the research project "Predicting and managing the impacts of wildfire and prescription burns on water quality and water-related assets" will provide one such tool.

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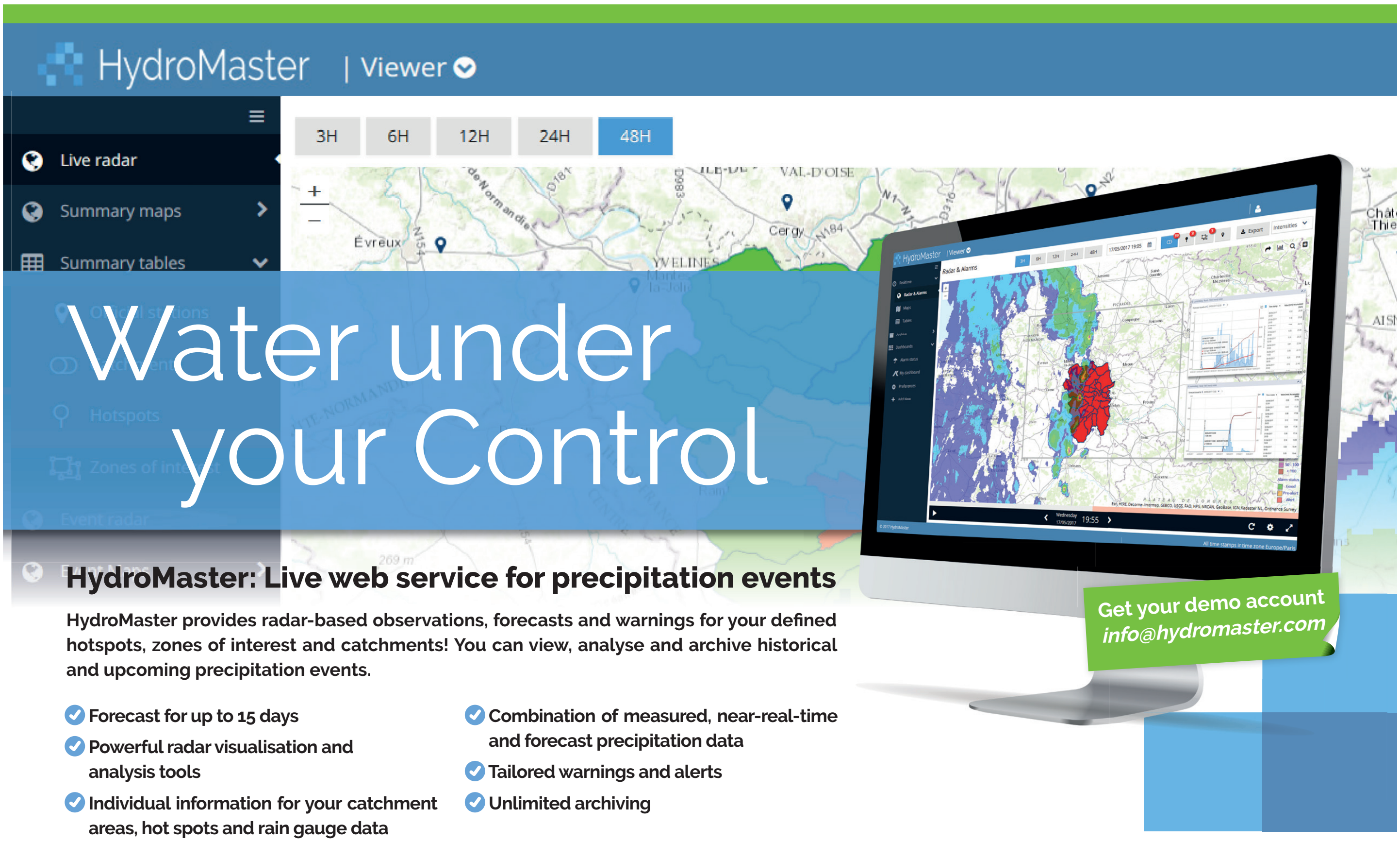
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Summary tables
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