Australasian Hydrographer

December 2018

AUSTRALIAN
HYDROGRAPHERS
ASSOCIATION

Contents

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JACQUIE BELLHOUSE

Editor’s Introduction

Wow another year is coming to a close and what a year it has been!

If you look back to April’s edition you will see we announced a change in the way the AHA would communicate with its members. Since then the association has increasingly embraced Social Media (Facebook, Twitter and LinkedIn) and commenced the regular release of eNews blasts. At the same we have been improving the presentation of the Australasian Hydrographer including delivering four editions through the year with the help of our members. Thank you for taking the time to submit an article and please keep them coming as we head into the new year.

You may have also heard that in December the NSW Government recognised Certified Practising Hydrographers (CPH) as sufficiently qualified to undertake many metering tasks in NSW (see *Water Management (General) Amendment (Metering) Regulation 2018*). The is the culmination of tireless behind the scenes efforts by a number of our members including Anthony Skinner and John Skinner. Great work team!

Also in December the **W**ater **M**onitoring **S**tandards **T**echnical **C**ommittee (WaMSTeC) endorsed revisions to the *National Industry Guidelines for Hydrometric Monitoring*. These revisions, the product of extensive work by multiple agencies and AHA members over the past 3 years, keep the guidelines up-to-date and relevant to hydrographic practice. The biggest changes are improved clarity, expanded guidance of Groundwater monitoring and recognition of AHA’s training and certification activities.

On a lighter note, as we approach Christmas, Hydrographers across Australia are celebrating their efforts and sharing stories at events such as the third annual AHA Christmas Drinks in Perth and the Hydro & Related Christmas Gathering in Sydney. Of course I do occasionally wonder what some of the other states get up to around this time of year. Surely WA and NSW aren’t the only party animals *(remember photos, feel free to send to services@aha.net.au, otherwise it didn’t happen guys)*?

Of course we cannot forget this year’s highlight, the inaugural AHA Hydrography Week in Canberra. Here we saw:

- The successful delivery of the AHA 2018 Conference – *Extreme Events*;
- Opportunities for any interested AHA Corporate Partners to deliver User Groups and training during the week;
- The recognition of six AHA fellows; and
- The delivery if the inaugural AHA *Hydrography Fundamentals* course.

The papers and presentations from the AHA conference are a credit to both their authors and the efforts of the conference think tank, so much so that I struggled to limit my selections in this issue.

Of course I couldn’t go past the paper from our keynote speaker and latest AHA Fellow Peter Heweston. Peter’s presentations are always a unique, and appreciated, event and this year’s conference paper was no exception. Mark Randall’s award winning paper, on Space Time Image Velocimetry is also a must read.

Rounding out this issue is a very interesting take on *Extreme Flood Event Measurement Utilising Maximum Velocity* by Rebekah Webb and for the more tech savvy of us Bronson McPherson’s paper on a *New Solution for real-time flood intelligence*.

I hope you enjoy reading my choices over the approaching holiday season.

Jacquie Bellhouse
Journal Editor

BILL BARRATT

From the President

2019 will be a year of strategic readjustment for AHA, increasing our engagement with agencies, the industry and hydrographers.

During November the committee reviewed our directions and determined a new focus for AHA: *To be recognized internationally as the authoritative Australian body for monitoring all aspects of the hydrological cycle.*

This ensures that we address:

- monitoring precipitation, surface and groundwater;
- measuring water level, volume, flow and quality;
- understanding natural water bodies, irrigation, drainage and sewer systems.

The water industry needs certainty in well trained employees. I reported at the recent Annual General Meeting, that 2018 has seen the expansion of training:

- the launch of the *Diploma of Water Industry Operations (Hydrography)* in partnership with TAFE NSW, continuation of the *Introduction to Hydrography Course*; and
- delivery of a new course *Hydrography Fundamentals* in November.

During the year we recognised that achieving a **qualification** such as the current Diploma course, with only nine units of competency, does not cover the full breadth or requirements of the hydrographic industry.

In response, AHA is developing a training framework based on fundamental principles and primary competencies.

The fundamental principles include:

- Resource monitoring, Meteorology;
- Principles of flow measurement;
- Groundwater basics;
- Water Quality;
- Electronics;
- Legal framework.

The primary competencies include:

- Hydrographic Health and Safety;
- Competencies based on all *National Industry Guidelines for Hydrometric Monitoring*;
- WQ sampling and testing;
- Information delivery;
- Surveying.

AHA **certification** will be based on the level of competencies achieved in the **training** framework, rather than **qualifications** such as the diploma.

To make the system relevant, AHA will convene an industry think tank early in the new year that will consist of agencies and major employers. The aim will be to review industry needs in order to shape and deliver the training and certification package. For more information, please contact John Teres in the national office at office@aha.net.au.

Meanwhile have a safe and happy Christmas.

Bill Barratt
AHA President

AHA Recognition: Citations for AHA Fellows and Associate Fellows

Fellows of the Australian Hydrographers Association with Life Membership

Peter Heweston FAHA

From 1968 to 1969 Peter worked as a Trainee Programmer and Programmer with the Prospect County Council in Parramatta.

From 1969 to 1972 Peter held various positions as a Technical Assistant, Technical Officer and Experimental Officer with the CSIRO Division of Land Research. The work involved the maintenance and further development of the EDTRACE system for storage and retrieval of time series data. EDTRACE was developed by CSIRO, and was one of the earliest systems designed specifically to handle time-series environment data.

In 1973 he joined the National Capital Development Commission where he was responsible for all external computing. During this time he further developed the EDTRACE system, using it to store and retrieve traffic flow data recorded on a variety of recorders and loggers.

In October 1984 Peter formed Peter Heweston and Associates, and set up business as a computer consultant, working primarily in the area of PC based systems.

In 1985 Peter was commissioned to review the processing system used by the then Commonwealth Department of Housing and Construction (DH&C) where they were using EDTRACE, and processing their data using CSIRO NET. It was during this period of early HYDSYS development that Peter commenced working with Bill Steen, Trevor Magnusson and Gary Newton.

Bill Steen has memories of Peter and him sitting beside each during the initial development phases of HYDSYS and Peter asking “so how do you process charts?”. After understanding the process, Peter commenced on Hycharts program, with the assistance of Bill to run Hycharts over a digitising machine.

The early programs developed by Peter for Department of Housing and Construction were successful, and performed the desired functions adequately. Over the ensuing years HYDSYS developed, and became quite large with the Department of Housing and Construction proudly showing of their new system. This generated interest within the Australian hydrographic industry.

HYDSYS Pty Ltd was incorporated in 1987, and at the time HYDSYS was installed at the NSW Department of Water Resources. In 1988 the Western Australia Water Authority sign up for HYDSYS, closely followed by Sydney Water Board.

HYDSYS later known as HYDSTRA was something that all hydrographic agencies in Australia and overseas yearned for and the rest is history……

Peter and his work are well recognised as having contributed greatly to the profession of hydrography in Australia. **Congratulations Peter on your appointment as "Fellow of the Australian Hydrographers Association with Life Membership"**.

Des Sherlock FAHA

Brian Sherlock receives the award on behalf of his father Des Sherlock FAHA, with President Bill Barratt FAHA.

Des Sherlock started his career as a cadet engineer with (WC&IC) Water Conservation and Irrigation Commission, NSW.

On achieving his qualifications, he specialised in the Hydrographic Branch, WC&IC.

In 1950 he was sent to Albury, with a wild group of young ex-servicemen, to set up the river gauging and rainfall network for the Snowy Mountains Authority.

There were very few access roads and so they hiked and rode horses in the summer and cross country skied in the winter.

In 1952, this network was handed over to the Snowy Mountains Authority. Soon after Des was appointed as District Hydrographic Engineer in Armidale and then in the late 1950s was promoted to Hydrographic Engineer Operations, overseeing all field work across the whole of NSW.

During this period, Des started developing, locally made field equipment for our Australian conditions, as he could not see the value in some of the overpriced imported instruments.

His Hydrographic Group also developed the original Hydrography Certificate Course, run through Sydney Technical College of External Studies.

In 1965, frustrated by his bosses' refusal to finance the equipment he was developing, Des resigned and went home to Picnic Point to start the Hydrographic Instrument Co, this later changed to Hydrological Services in 1969 to better reflect its work.

At the Warwick Farm site, which was conveniently located on the Georges River, equipment test and training facilities were built for powered traveller-units, manual traveller winches and a 50 metre deep calibration bore for gas purge water level instrument calibration. Additional facilities were built as each new product was developed.

The most impressive of these test facilities, being the rating tank, built in the early 90s, during Des's semi-retirement. This was the most accurate tow tank in the world at that time.

Des is, and has been a keen supporter of the AHA from its inception. He was the first financial sponsor, and provided facilities for AHA meetings and related social events.

Training was provided to customers for free at the Warwick Farm facility and to customers overseas in association with hydrological projects.

When Des finally retired in 2000, he had given nearly 60 years to our hydrographic industry in Australia and to about 40 other overseas countries.

This is why Des is considered the father of our hydrological manufacturing industry in Australia. **Congratulations Des on your appointment as "Fellow of the Australian Hydrographers Association with Life Membership".**

Fellows of the Australian Hydrographers Association

Ray Maynard FAHA

Ray Maynard FAHA with AHA President Bill Barratt FAHA.

In 1975 Ray Maynard joined the Department of Natural Resources, Mines and Energy Queensland (then Irrigation and Water Supply). A short week after starting, Ray camped out for 22 days in order to undertake flood gauging. He was immediately hooked.

Ray continued to work in the remote areas of far north Queensland for a few years before transferring to Bundaberg where he honed his skills in the analysis and application of hydrometric data.

In 1988 he was part of a team that flood gauged the Fitzroy River, possibly at the time the largest, deepest, highest-velocity flows measured by boat and current meter in Australia. Ray then went on to track down evidence of the "big fella" flood in the 1800s, with the help of the traditional land owners, the event apparently dwarfed the highest flood level by 4 metres.

Ray also compiled a 105 page report on Burnett River Floods back to the 1850s. This report is now a key data source for multiple flood modelling projects.

Ray has spent considerable time researching ADCPs and was a member of the inaugural committee that developed the three Australian National Industry Guidelines for ADCPs.

He has presented four papers at three AHA conferences between 1992 and 2016 and delivered two Papers at a Christchurch Rating Curves Workshop.

One of Ray's greatest passions is 'Rainfall', to the extent that he can instantly recall amounts, intensities, durations, times of rainfall related to most flood events in Queensland and often, across Australia. This is why in DNRME Queensland, Ray is affectionately known as Ray "Rainfall" Maynard and he is the 'go to' person with respect to development of rating curves, the hydraulic behaviour of rivers and theoretical computation of discharge.

Congratulations Ray for your significant contribution to the profession and your appointment as "Fellow of the Australian Hydrographers Association".

John Skinner FAHA


John Skinner FAHA with AHA President Bill Barratt FAHA.

John started his career in Latrobe Valley Water & Sewerage Board in 1974. He was later recruited as a trainee Hydrographer by Bill Barratt in 1975, where he worked with Max Hayes and later Alex Springall.

The very next year, John moved to Papua New Guinea overseeing operation and management of the Government's network of hydrometric stations throughout PNG.

In 1984 John joined Ecowise as a Consulting Hydrographer and continued to deliver Water Resources consultancy projects in Australia and overseas.

John was later appointed Group Manager, *Monitoring and Technical Services (MATS), Ecowise Environmental* and during his time, the team grew from a relatively small hydrographic group of specialists based out of Canberra, to a National Company with more than 10 regional offices.

Due to his extensive hydrometric background John was recruited by the Water for Rivers program delivering water efficiency projects for the Murray and the Snowy Rivers. He also continued to work on water efficiency programs with the State Water Corporation and Coleambally Irrigation with ongoing reviews of hydrometric measurement techniques and water delivery procedures and technologies.

In 2016 John took up a role as training consultant for AHA, delivering the *Introduction to Hydrography* course and working with the Riverina Institute of TAFE NSW delivering the *Diploma in Water Industry Operations (Hydrography)*.

John has been an active member of the AHA since its inception and is well recognised for his contribution and his ongoing support including his role in assisting with training and assessment of the next generation of Australian hydrographers. **Congratulations John on your appointment as "Fellow of the Australian Hydrographers Association".**

Associate Fellows of the Australian Hydrographers Association

Simon Cruickshank AFAHA


Simon Cruickshank AFAHA with AHA President Bill Barratt FAHA (image from 2016).

Simon commenced work in hydrography in 1994 after an aborted career within the marine industry.

Signing on with what was then the Department of Land and Water Conservation (now WaterNSW) as a hydrographic cadet, Simon was based in Forbes and for seven years becoming intimately familiar with the hydrology and geomorphology of the mighty Lachlan River including placements at the instrumentation facility and water quality laboratory.

In 2000, with the attraction of returning to the coast, Simon and his family relocated to Darwin in the NT.

Initially employed as the Hydrographic Manager, this role has recently been extended to Director of Water Monitoring. Simon enjoys the challenges of operating in the remote and incredibly diverse NT, where the scale of operations requires staff to wear many different hats.

Simon up until recently had been a great contributor and committee member of the AHA (including his role as AHA Vice-President from 2015-2017). **Congratulations on your appointment as "Associate Fellow of the Australian Hydrographers Association".**

Grant Robinson AFAHA

Grant Robinson AFAHA with AHA President Bill Barratt FAHA.

Grant started his career in Forestry with the Forestry Commission of New South Wales from 1971.

In 1991 he moved across to the *Department of Water Resources*, as a biometrician in the Water Quality Unit. He was part of the team that produce the first *State of the Rivers Water Quality* report for NSW, and later part of a CSIRO led team producing several reports on salinity in the Murray-Darling basin.

During his time in the industry Grant presented various papers at HYDSYS User Group meetings between 1992-1994 including *Implementation for Water Quality and Quality Assurance Models for Water Quality Monitoring*. In 1995 at the AHA Conference at Warwick Farm he also gave a presentation on *Stream Water Quality*.

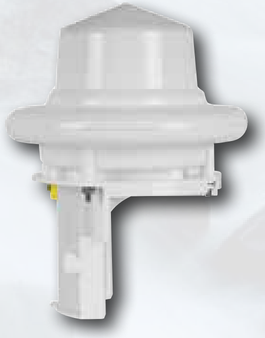
In 1998 he worked on a quality system for electrical conductivity monitoring in rivers and streams and following on from this, in 2000, he introduced the Department to ISO9001 for hydrography.

Grant went on to present papers at the 2008, 2010 and 2012 AHA Conferences with titles including Information Quality: *More than the Hydstra Quality Code; Hydrometric information*; and *A national approach to water information standards*.

From 2009-2010 Grant Project Managed the team development of 7 draft guidelines which were finally published by the Bureau of Meteorology in August 2013 and are now part of the ongoing *National Industry Guidelines for Hydrometric Monitoring.*

Grant became the voluntary AHA Webmaster in 2012 and although he retired in July 2013 he has not stop contributing to the AHA. He joined the AHA Committee as Publicity Officer in 2013, became AHA Secretary in 2015 and has provided volunteer support services to the AHA National Office since 2016.

Grant's ongoing contribution to the professionalism and ongoing success of the AHA is well recognised. **Congratulations Grant on your appointment as "Associate Fellow of the Australian Hydrographers Association".**



The Impact of Extreme Events

Peter Heweston FAHA, KISTERS Pty Ltd, Weston, ACT.

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

Abstract

Extreme events are difficult to quantify, and even more difficult to remember for long. Natural systems are extremely variable, and interact with human society in complex ways. We can learn much from the past as we face the future, certain only that there are probably unpleasant surprises in store.

Introduction

I was both honoured and delighted to present this opening address to the 2018 AHA conference in November 2018. The theme of the 2018 conference was 'The Impact of Extreme Events'. This provided me with very broad canvas on which I'd like to sketch a few observations drawn from a long career in the water business.

I first came into contact professionally with hydrography and water resources when I joined the CSIRO Division of Land Research in 1970 as a very junior technical assistant, working under hydrological giants like Tom Chapman and Jim Goodspeed. I shared lab space with John Savage as he designed and constructed pioneering equipment like the Rimco Event Recorder and the Rimco Chart Digitiser—both of which form part of my personal collection of memorabilia to this day.

Rimco Chart Digitiser.

Rimco Event Recorder.

These pioneers were taking the first tentative steps in bringing hydrography into the computer age, and I was fortunate to be immersed and educated in such an exciting environment. Many years later I took what I learned there and with my colleague Trevor Magnusson went on to develop the HYDSYS (later Hydstra) suite of software which lives on to this day.

Over the intervening years I've been fortunate enough to observe the environment in action in many parts of the world, which has led me to ruminate on some of the philosophical issues involved.

What Is an Extreme Event?

The first philosophical problem we have to confront is what constitutes an extreme event? The Simpson Desert gets a mere 150 mm of rainfall a year, and summer temperatures approach 50 degrees, yet we would not describe the Simpson Desert as having a drought. The mighty Amazon River averages 209,000 cubic meters per second (or in contemporary jargon, 83.6 Olympic Swimming Pools per second), yet that's not necessarily a flood. There's a place and a time for an extreme event.

All natural climate phenomena have highs and lows. Two effects have been noted by many commentators in many disciplines, ranging from financial markets to climate systems, the Noah and Joseph effects. The Noah effect, after the builder of the eponymous ark, suggests that extreme values can be surprisingly larger than you might expect. The Joseph effect refers to the Pharaoh's dream reported in *Genesis 41:29-30. "Seven years of great abundance are coming throughout the land of Egypt, but seven years of famine will follow them"*. The Joseph effect is sometimes paraphrased as "nature abhors the mean", suggesting that long-memory processes are in play which imply that once below average, a system might remain well below average for a long time, then it may quickly move to an above average state and remain there for some time.

According to a study of 170 years of the river Nile flow records, *"it appears that, except for a few short periods of 10-20 years' duration, the river flow was never 'at rest' with respect to average flow in the nearly 300 years surveyed. Prolonged periods, of above or below average discharge prevail with duration on the order of 50 to 100 years."*

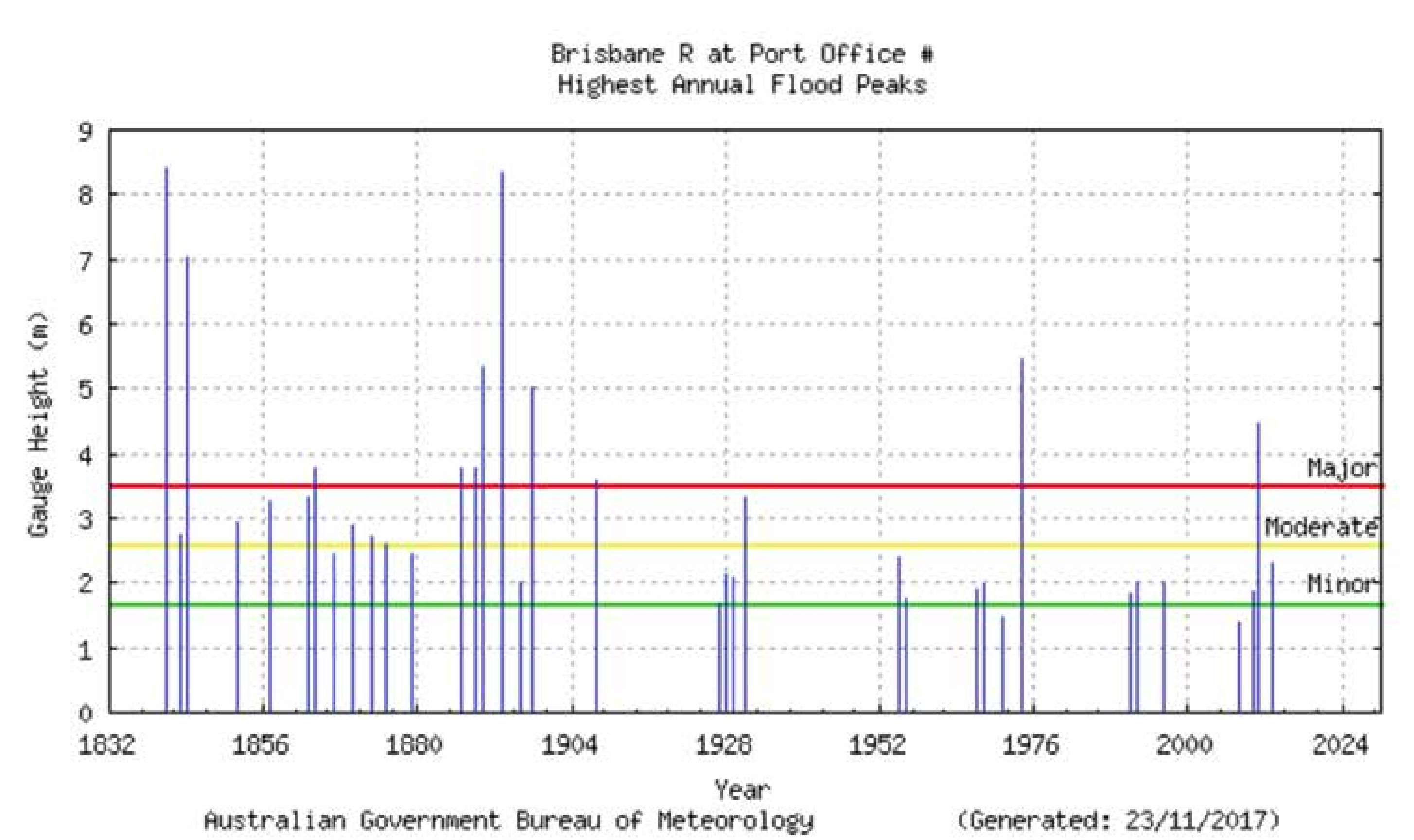
The Famine Stela of Egypt is a rock carved with hieroglyphs and dating to about 300 BCE which tells of a seven year drought. The seven year famine is a motif that occurs in many cultures throughout the Near East, including the Bible and the Epic of Gilgamesh. Perhaps they knew something we have forgotten.

Given the relatively short history of European presence in Australia we had better be cautious about defining what is normal and what is extreme. There has been considerable academic interest recently in researching indigenous stories which seem to accurately record what happened 7500 years ago or more, following the last ice age. One legend from Western Australia recalls a time when hunters could wade or swim to Rottnest Island. Reid et al report several such studies, which seem to verify that oral tradition can indeed accurately preserve information for millennia. Although it was agonizingly slow to happen, you could easily describe a 120m sea level rise as an extreme event.

The Brisbane floods of 2011 were the cause of much grief and blame-shifting in their aftermath. The residents of Brisbane had unfortunately long forgotten the disastrous floods of February 1893, during which two ships were stranded in the Botanic Gardens, the H.M.S. Paluma and the Zuirang, much to the amusement of the locals. The Paluma may have remained there to this day had not another flood occurred two weeks later, allowing it to be re-floated. By comparison with the 1893 flood the 2011 event was merely a flush.

The 'Paluma' and the 'Zuirang', 1893.

Queen Street, Brisbane, 1893.



We intuitively regard an extreme event as being in some way outside normal expectation, whatever 'normal' is. In hydrology we sometimes use the 100 year recurrence or the 1% probability as the boundary between normal and extreme. I recall developing an analysis for an urban council which clearly distinguished between sub 100 year rainfall events and those which exceeded 100 year recurrence. It turns out that urban storm water systems are designed for 100 year events—if a house floods or water comes up your toilet with a 20 year storm then lawsuits will ensue, but if the same thing happens with a 200 year storm then it's an 'act of God' and insurance will quietly pay up. It always amuses me that the influence of God can be so precisely constrained!

In summary then, one man's extreme is another man's normal, and timescale changes perspectives.

What is a Natural Disaster?

We cannot separate consideration of extreme events from their social impacts. We often refer to droughts, floods, earthquakes and fires as natural disasters. There is nothing intrinsically disastrous about a fire or a flood or an earthquake, they have been happening since the beginning of time. What turns a reasonably infrequent natural event into a natural disaster is its impact on humanity, which is related somehow to expectation and preparedness, and to consequential loss of property and life.

The Newcastle earthquake of 1989 was of magnitude 5.6. It caused thirteen deaths, damaged over 35,000 homes, and caused A$4 billion dollars in damage. A 2011 earthquake in Tokyo of equivalent magnitude briefly halted the trains, and there were no immediate reports of damage. The difference was that Tokyo residents expected earthquakes, built for them, trained for them, and survived them. The Newcastle earthquake was rather more surprising, although not entirely unexpected. Records show that at least five earthquakes of magnitude 5 or greater had occurred in the Hunter region since European settlement in 1804. Why were we so surprised?

Hurricanes, cyclones and typhoons are frequent visitors to the shores of many countries. The most notorious storm of this century was arguably Hurricane Harvey which hit Texas and Louisiana in the USA in 2017. It caused an estimated $125 billion in damage and killed 82 people, making it the most expensive hurricane in dollar terms in history. But who remembers the devastating Great Bhola Cyclone of 1970 which struck Bangladesh and killed somewhere between 300,000 and a million people?

The difference in impact between these two events boils down to reasonable warning but high property values in Texas, and poor warning and poverty in Bangladesh. Which was the worse 'natural disaster' is debatable.

The deadliest flood in Australia's history was the Gundagai flood of 1852. The Gundagai settlement had grown up on the river flats, despite warnings about flooding from the local Wiradjuri people. During the 1852 flood local aboriginal men Yarri, Long Jimmy and Jack Jacky rescued 40 people from the floodwaters using their bark canoes, but an estimated 80 people perished, roughly a third of the population of the Gundagai settlement at the time. The town was subsequently relocated up the hill to somewhat safer ground, although floodwaters still reach the main street from time to time.

The most expensive flood in Australia's history was the 2011 Brisbane event, causing 35 deaths and costing half a billion dollars to clean up with 56,000 insurance claims worth $2.55 billion.

Cycles and Recurrence

Nature loves a good cycle, and we understand the easy ones and deal with them quite well. We know not to leave our towel too long on the hard sand at the beach, because the tide will soon come in and wash it away.

Boat owners know that even a boat secured well up the beach may be lost at the next king tide, when the conjunction of moon and sun conspire together to raise larger than usual tides.

Residents of Florida and Texas know how to prepare for a hurricane, they happen every year. Some years ago I was working with a Florida agency when a hurricane started veering towards us. Work stopped, everything was lifted from the floor and put on tables, and covered with tarpaulins, and then everyone went home to look after their own family and property. Hurricanes are frequent enough that everyone knows what to do.

Once we start looking at longer cycles than a few years, we as a society don't remember them so well, and don't deal with them so well. The Bureau of Meteorology suggests that severe droughts occur on average once every 18 years. Any farmer will encounter several during a working life, and indeed many are well prepared when they come. Others unfortunately not so much, and tend to go running to the government for support, whereupon the government (i.e. we taxpayers) bail them out until next time. I recall seeing an interview with a farmer just a couple of months ago reporting that he was about to dig up silage his grandfather had buried in 1996. There's someone with enough family memory to deal with longer cycles.

Other more erratic drivers we know and understand to some extent include the El Niño cycle (ENSO) (though it's not regular) and the Indian Ocean Dipole (IOD). Both of these are major drivers of climate in Australia, and indeed the public understand them sufficiently that their positions are often reported on the news and weather forecasts. When ENSO and IOD are in phase we know are in for a dry hot summer and lots of fires.

There are longer scale cycles we don't understand fully, but need to be aware of. The Little Ice Age (1300-1900) was a period of cooling that led to glaciers expanding and rivers freezing through much of Europe at least. We don't fully understand the drivers of the Little Ice Age, but the impacts were well noted, ranging from the Great Famine of 1315-1317 which cause millions of deaths throughout Europe, and the Great Frost of 1683 when the Thames was frozen solid for two months, and sea ice off the coast of Britain severely impacted shipping.

Even longer cycles are thought to be driven by so-called Milankovitch cycles, which are related to variations in the eccentricity of the earth's orbit, axial tilt and precession causing corresponding variation in the amount of solar energy reaching the earth. This in turn leads to a roughly 100,000 year cycle of ice ages. According to the Milankovitch theory we are in a cooling phase right now, heading for the next ice age … but that doesn't take humanity into account, of which more anon.

Black Swans

In western society prior to the exploration of Australia, all swans were white. The Latin poet Juvenal used the expression *"rara avis in terris nigroque simillima cygno"* which translates to *"a bird as rare on earth as a black swan"*. It more or less meant *"and pigs might fly"*. Imagine everyone's amazement when early European visitors to Australia reported that swans could indeed be black.

In contemporary literature the term ‘Black Swan’ is used to describe an event with three properties:

1. It is an extreme outlier, and completely unexpected;
2. It has an extreme impact;
3. In spite of its rarity we concoct post-hoc explanations for it.

Events considered as Black Swans include 9/11, Brexit, the 2008 Asian economic crisis, the Fukushima disaster, the election of Donald Trump, and many others. The term Black Swan is particularly popular in financial circles.

There are flocks of Black Swans circling our society waiting for the next extreme event. One the more interesting possibilities is an extreme tsunami. We saw the devastating effects of tsunamis during the 2018 Indonesian tsunami and the 2011 tsunami in Japan. Whole towns are swept away by a relentless tide of the incoming sea. In the case of the Japanese tsunami it was made more interesting by the ill-advised decision to build the Fukushima nuclear power station right on the coast, to a design height well below previously observed tsunami heights.

In Australia the maximum tsunami wave in recorded European history was a 6 metre wave recorded in W.A. in 1977 after an earthquake in Indonesia. Earlier paleo records suggest that in the last 10,000 years tsunamis of +100 m have been recorded running inland as far as 10 km along the NSW South Coast. When viewed through knowing eyes the lovely headlands and beaches of Jervis Bay are littered with evidence of massive tsunami events perching boulders on cliffs up to 30 m above sea level. These are even more alarming when we recall that sea levels were much lower in the past. There is even geological evidence of tsunami waves reaching inland as far as the Blue Mountains in times past. Tsunamis are cause by unpredictable events such as earthquakes, undersea landslides, large volcanic eruptions and meteorite impacts. Another big one will come someday, and this time it will be well noticed and remembered.

Extreme Engineering Events

No discussion of extreme events would be complete without discussing a few human-induced engineering disasters. Dams feature in the top ten, being major constructions holding back a lot of potential energy which can very quickly get converted to kinetic energy.

The Teton Dam was an earthen dam on the Idaho River and was being filled for the first time in 1976. Unfortunately not enough attention had been paid to sealing fissures in the bedrock on which the dam stood, and it suffered a catastrophic failure when a leak quickly became a massive breach. 309 gigalitres of water flowed out in 6 hours, causing 11 deaths, $300 million in claims paid, and $2 billion damage estimated. In the aftermath it was disclosed that some of the ‘fissures’ that were to be sealed with grout were in fact caves, one 2.7 m wide and 60 m long, way too large to fill. Many legitimate objections were overruled prior to construction commencing.

The largest loss of life due to a dam failure occurred at Banqiao Dam, Hunan province, China in August 1975. It was an earthen dam that was overtopped after 1060 mm of rain fell in 24 hours. 701 gigalitres of water were released in 6 hours causing havoc as a giant wave proceeded downstream. In total 62 downstream dams were either intentionally bombed by the air force or failed due to the surging floodwaters. In the aftermath some 171,000 people died from either from flooding or from the resulting famine and epidemic. An estimated 5,960,000 buildings collapsed, and 11 million residents were affected by the disaster. In the investigations afterwards it was revealed that a series of technical, financial and communications errors, along with an extreme rainfall event conspired to bring the dam down. As is not uncommon in such situations, the chief hydrologist who had criticized the dam for having insufficient sluice gate capacity was dismissed during construction, brought back after the disaster to help in recovery, and dismissed again. Time and time again the harbinger of doom is shot to avoid hearing the unpleasant news he bears.

Other notable human-induced events include:

- The Hindenburg disaster: The airship was originally designed to use helium, but the United States had a monopoly on helium, and had banned its export under the Helium Control Act (1927) for military reasons, preferring to keep the helium for its own airships.
- The Challenger disaster: The direct cause was leaky silicone O-rings caused by cold weather on launch day, combined with a launch at all costs attitude despite warning from experts. Thiokol engineer Bob Ebeling told anyone who would listen not to launch, and remarked to his wife the night before launch that Challenger was going to blow up, which it duly did.

  The even bigger question of why a rocket had silicone joins in the first place was because the Morton Thiokol factory was in Utah, and the boosters had be transported by rail which set a maximum length on the component size. Which begs the question why manufacture such important components so far away? The answer probably lies in political pressure and pork-barrelling – but that's another story.
- The September 11 2001 disaster: This was the typical Black Swan event, although some of the mostly Saudi hijackers were known to authorities and were on terrorist alert lists. Nobody ever designed buildings to have a fuel laden jet aircraft fly into them. The reason someone chose to do that lies outside the engineering domain, at the intersection of politics and religion. However in the aftermath important lessons were learned about fire in buildings, steel construction methods, escape mechanisms, airline security, and more. And as often happens after any disaster the loony fringe of conspiracy theorists had a field day.

Insurance and Moral Hazard

One of the ways in which society protects itself from extreme events, up to a point at least, is through insurance. The ideal of insurance is that everyone pays a small annual premium to protect against the unexpected rare event that could otherwise destroy your property or even your life (in the case of medical insurance).

The difficulty is that insurance is predicated on two premises—an actuarial calculation of the risk to be spread over the insured population, and an assumption that the insured event was unexpected.

The issue for insurance companies is how to behave as certainty overtakes uncertainty. The precedents have been set in the life insurance arena, where questions about smoking were considered ethical inputs into the insurance process, as were questions about sexual behaviour during the HIV epidemic. In both of these domains there was a statistically strong population-wide correlation between risky behaviours and health outcomes and insurance companies compensated with higher premiums or even by denying insurance completely.

In motor vehicle insurance we accept that under 25 drivers as a population have a much higher accident rate than older drivers, and we discriminate accordingly with higher premiums. Put them in a high performance car and premiums go through the roof—often immediately prior to the roof being cut off to extract the occupant.

So the precedent has been set—insurance can take knowledge into account, and deny policies or make them prohibitively expensive based on that knowledge. It raise some interesting issues for the future as DNA analysis becomes widespread. Will we as a society allow insurance companies to deny health insurance to a baby based on their DNA? In fact, does insurance retreat as knowledge advances? We are led to ponder again the relationship between acts of God, and acts we can explain. When we can explain everything, will there be room left for God or insurance?

So can we reasonably say that another major Brisbane flood is unexpected? It might be unexpected to Mrs. Smith down the street who has just moved into her lovely house, but is it unexpected to the council who allowed the house to be located there? Did Mrs. Smith do any research about floods, for example whether the area was flooded in 1974 or 1893? Should Mrs. Smith be able to get flood insurance and if so, at what cost? Should the insurance company assume that every 30 years or so her house will largely be destroyed and need to be rebuilt? That will make for some pretty stiff premiums.

When insurance fails, for example when you can't get flood insurance for your stylish house with sweeping views of the Brisbane River, then the burden falls back on the state to pick up the mess, literally. And ultimately through flood appeals, drought appeals and other heart wrenching charity appeals to our purse we the people act as insurers of last resort.

The term 'moral hazard' is defined as a situation where one party engages in risky behaviour knowing that another party will bear the cost if things go wrong.

In the US the National *Flood Insurance Act* of 1968 established the National Flood Insurance Program, which provides flood insurance to those who cannot otherwise get insurance. It will come as no surprise that NFIP is in serious financial trouble, and down the drain to the tune of $25 billion. Unfortunately providing insurance to the otherwise uninsurable is the very definition of moral hazard, and does nothing to encourage ethical or sensible behaviour. In fact it more or less incentivises building on floodplains. According to federal flood insurance figures, 26,000 new houses have been built on Houston's floodplains alone since 2001. It has been asserted that some people have claimed on their NFIP insurance as much as a dozen times without their premiums going up. That certainly meets the definition of moral hazard.

By the same token we know that droughts are a fact of Australian farming. Any farm business that doesn't take into account the possibility of drought, and deal with it either by storing fodder in the good times or de-stocking in the bad times is simply being reckless, and the business should be allowed to go broke, just like any other bad business. Appealing to the government for handouts is a moral hazard at its most blatant.

Stasis and Change

Our climate record in Australia is remarkably short. Europeans have only been around a couple of hundred years, and reliable climate records are somewhat shorter even than that. There are ways of extending the record back using techniques like tree rings, sediment analysis, paleohydrology, carbon 14 dating, Optically Stimulated Luminescence and more, and we need to look carefully at them to understand what real climate extremes might be.

Many of the standard analyses we use today for extreme event prediction fit distributions of one sort another to a long term record. You are all familiar with the names—Gumbel, Log Pearson, Generalised Extreme Value and so on. One problem with these statistical methods is that they are predicated on stable but random underlying processes. The term 'stationary' is used to describe processes that have the same distribution across different parts of the time-series.

There are two potential hazards to blindly fitting such distributions to a data set. The first is the rather unlikely assumption that nothing has changed in the past century or so to affect the distribution—no dams, no urban infill, no wide scale clearing or planting. The second hazard, and some might say the elephant in the room, is that of climate change.

If we accept the evidence that the climate really is changing, for whatever reason, then we need to be very cautious about using the past as a predictor of the future. The Black Swans may be bigger and more aggressive than anyone expected.

Causes of Natural Disasters

As I have outlined earlier, there are no natural disasters, only the natural behaviours of the earth and its weather. The disaster starts when we see the interaction of politics, greed, culture and other human forces on the effect of the weather. Why do we build on the floodplain? Why do we deny the climate is changing? Why do we despoil the environment in a few short generations? Why are we extinguishing species at a rapid rate?

I have a theory about so-called natural disasters. There are only a handful of causes, all human related:

1. Poverty—people live in Bangladesh and endure the floods because they are too poor to move. They live on the volcano's slopes because they have no other choice. Perhaps they live in the Brisbane floodplain because houses were cheaper there.
2. Ignorance—people are unaware of the peril they are in for cultural or educational reasons. Perhaps people really didn't know they were living in the Brisbane floodplain.
3. Stupidity—people understand the clearly available evidence and still don't prepare. They build a house amongst the trees, or on the floodplain, despite all the warnings to the contrary.
4. Greed—developers build on the floodplain, governments in the pocket of the coal industry deny climate change, farmers pump aquifers dry and overstock their paddocks. Perhaps the council that approved development in the floodplain was stacked with real estate interests.

That's my theory. There are no natural disasters, only weather combined with poverty, ignorance, stupidity and greed. And no thank you, I won't be contributing to the drought appeal, or the bush fire appeal, or the flood appeal.

Conclusion

As Hydrographers we are in the business of measuring the world—it's what we do. And measurements form the basis of all scientific knowledge. Yet there is a disturbing anti-science movement afoot in the world. You only need to look at the anti-vaccination movement, the rise in flat-earthers, the teaching of creationism in schools, and the dominance of climate change deniers in certain quarters of politics to see that science and the scientific method is under attack.

I believe it was Alex Miller, known to many of you here, who first enunciated to me the maxims by which our industry lives:

- Don't measure unless you record;
- Don't record unless you analyse;
- Don't analyse unless you act.

Let us all do our best in face of adversity to measure the environment we live in, record the measurements, analyse the data, and act on the data. And with good data perhaps we can hope to hold back slightly the rising tide of ignorance, stupidity and greed.

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Space Time Image Velocimetry: Measuring High Flow Events in Queensland

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

Abstract

In a bid to improve the Queensland Government's ability to collect high flow discharge data, the Department of Natural Resources, Mines, and Energy (DNRME) established the Alternative Technologies Project (ATP). The ATP trialled the use of image velocimetry techniques using in-situ cameras installed at eight gauging stations and developed a mobile methodology for unmanned aerial vehicles (UAV). During 2016–18 the Space Time Image Velocimetry (STIV) methodology was used to collect high flow discharge measurements which were compared to more traditional measuring techniques such as acoustic Doppler current profilers (ADCP), and OTT C31 current meters. The ATP demonstrated that using STIV is a viable discharge measurement option for quantifying high flow events with many additional benefits over currently used methods. These benefits include improved safety for hydrographic staff as well as a cost effective measurement solution. STIV allows for an increased frequency of high flow discharge measurements over multiple events highlighting the limitations of using a single rating curve to define a stage discharge relationship. DNRME are continuing and expanding the use of STIV as a standard method for measuring discharge.

1. Introduction

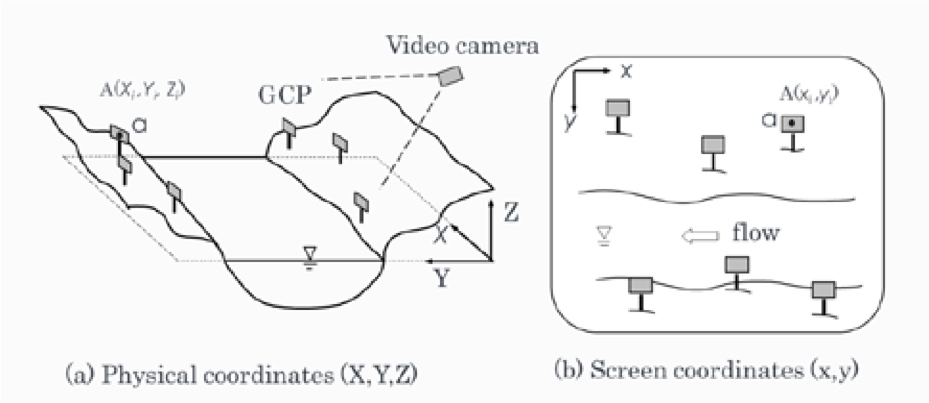
Image velocimetry is a method of calculating stream discharge from a recorded video. The video is analysed to generate surface velocity data which is then applied to a cross sectional area to calculate discharge via the mid-section method. The methodology was first published in 1998 (Fujita *et al*., 1998). This initial method was known as **Large Scale Particle Image Velocimetry** (LSPIV) and is currently the most widely used application of image velocimetry in countries such as France, Argentina, and more recently the USA and Canada (Muste *et al*., 2008; Jodeau *et al*., 2008). There are currently two free LSPIV software packages available known as FUDAA (Le Coz *et al*., 2010 and 2014) and RIVeR (Patalano *et al*., 2017). LSPIV utilises a cross correlation analysis within a search and interrogation area between user specified frames extracted from a video. LSPIV produces a 2D velocity analysis across the entire region of interest. **Space Time Image Velocimetry** (STIV) developed in 2007 (Fujita *et al*., 2007) as an improved methodology over LSPIV. The first STIV software package was developed in 2014 (KU-STIV). Unlike LSPIV, STIV calculates 1D surface velocities along user specified search lines placed in the stream wise direction. STIV does not use a cross correlation analysis and is therefore computationally less demanding than LSPIV. This allows all of the recorded frames to be used to generate a surface velocity. STIV is therefore is a more robust analysis technique for field applications and simpler to integrate into a quality management framework. The latest advancement in image velocimetry is **Space Time Volume Velocimetry** (STVV) (Tsugi et al., 2018) which amalgamates the robustness of STIV with the 2D surface velocity analysis of LSPIV. The use of image velocimetry has been gaining interest from water monitoring agencies worldwide due to the potential operational benefits that it can provide. These benefits not only include greater data collection capabilities but also improved workplace health and safety conditions for monitoring staff. In the following sections the use of STIV to calculate discharge from high flow events in Queensland will be presented including how this methodology can be used to change the way we collect flow data in the future.

2. Space Time Image Velocimetry

STIV is a non-intrusive method of measuring surface velocities to calculate discharge. Image velocimetry is not limited in its measurement capabilities by the types, depths, and magnitude of velocities that could be encountered by a hydrographer. It does however require surface movement to be visible for analysis to take place. STIV and image velocimetry as a whole is a method well suited for the measurement of high flow events.

2.1. Image Orthorectification

The first requirement of using image velocimetry (LSPIV and STIV) is the orthorectification of the video imagery. This is especially important for bank mounted cameras that will be filming from an oblique angle. A minimum of six ground control points (GCPs) are required to be distributed across the camera's field of view. Each GCP has its real X, Y, and Z coordinates mapped against its x, y pixel coordinates (Figure 1). This allows the mapping relationship between the two coordinate systems to be ascertained and an orthorectified image produced from the original video screen image [Fujita *et al.* 1998].



(a) Physical coordinates (X,Y,Z)

(b) Screen coordinates (x,y)

Figure 1. Ground control points required for camera calibration.

In the case of an in-situ IP (internet protocol) camera the calibration is only valid for that mounting position and field of view (FOV). Should the camera position or angle change then a new calibration must be undertaken to correct the video image.

Figure 2. GCPs at GS111101D Russel River at Bucklands.

When using a UAV with the camera in a nadir position no GCPs are required as the image does not require orthorectification. However, the imagery still requires the pixels to be scaled to a known distance located at water level. Not requiring surveyed GCP allows UAV STIV measurements to be undertaken quickly and at multiple sites as and when flooding occurs.

2.2. Space Time Image Generation

A space time image is generated along each search line placed in the orthocorrected image. The space time image is constructed by stacking the image intensity distribution for each frame along the length of the velocity search line. Changes in luminosity over the distance of the search line and the time span of the video allows an angled pattern to be created. The mean gradient of the pattern in the space time image can then be used to calculate a surface velocity for that measurement point (Fujita *et al*., 2007).

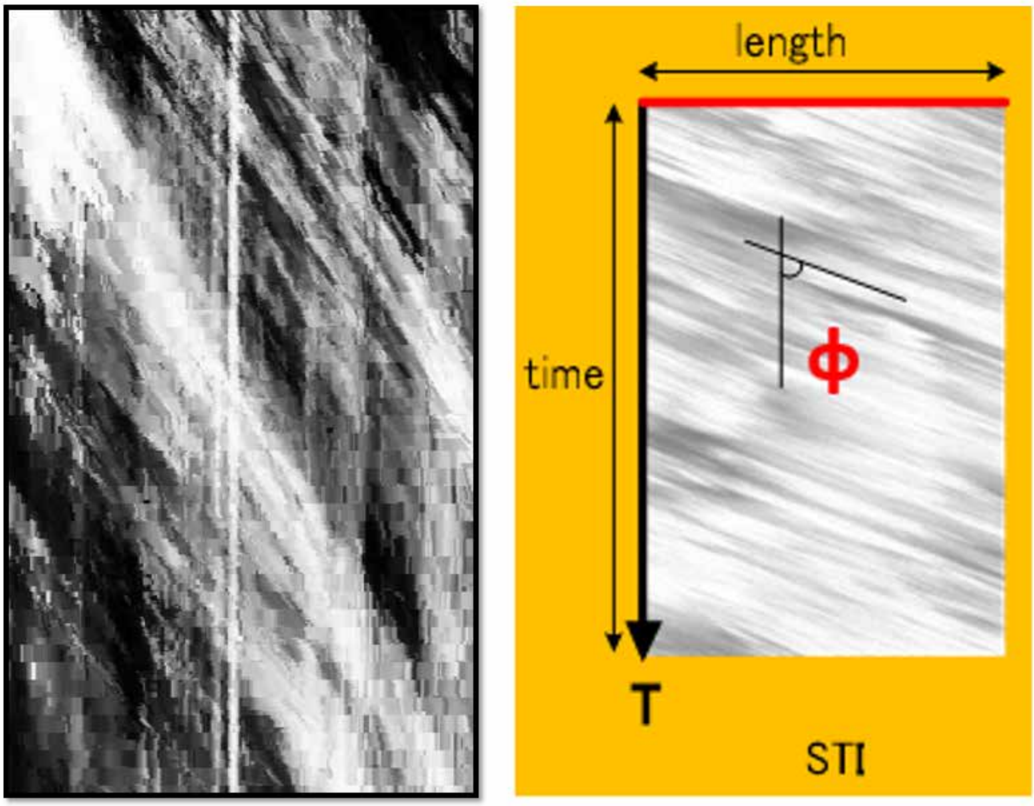


Figure 3. An example of a space time image used to calculate a point velocity.

Each velocity calculated for each velocity search line is applied at the point of intersection between the velocity search line and the channel cross section. Discharge can then be calculated using the mid-section method.

2.3. Surface Velocity Alpha

Image velocimetry provides a surface velocity only. To convert each STIV generated surface velocity into a mean velocity for that vertical requires the use of a surface velocity coefficient commonly referred to as the surface alpha. The surface alpha can easily be identified through ADCP data analysis. ADCPs calculate a vertical velocity profile based on the collected measurement data to help select the best extrapolation methods for the top and bottom parts of the ADCP measurement profile. Surface alpha calculation can also be ascertained from the power law and Manning's exponent:

$$\text{Surface alpha} = m / (m+1)$$

Where m = the Manning's power law exponent.

A 1/6th power law is therefore equivalent to a surface alpha of 0.86 (6/7=0.857). Typically, high flow events have a surface alpha between 0.91 and 0.95 however ADCP data from a measurement site should be analysed to develop a site-specific surface alpha.

3. Site and Instrumentation Selection

During stages 1 and 2 of the ATP eight gauging station sites were selected across the state of Queensland. Sites were selected based on proximity and ease of access to hydrographic offices, and the onsite cameras ability to view across the entire channel during a range of flow events. Each gauging station IP camera was assigned a web address allowing remote access to the camera, its settings and recorded videos. A video recording schedule was configured to allow the camera to record a 20 second video every 15 minutes during daylight hours. Videos were stored on a 128 gigabyte internal memory card. Videos selected for STIV discharge analysis could be downloaded remotely or while on site.

The choice of UAV used to collect aerial videos for STIV discharge analysis was the DJI Phantom 4 and 4 Advanced. This model of consumer UAV was selected due to its 28 minute battery life, flight stability, and image quality. UAVs would record a 20 second video at 4K resolution[1].

Trial sites in the tropical north region of Queensland received several flood events allowing image velocity data to be collected and for STIV discharge calculations to be compared to onsite ADCP measurements and gauging station rating curves.

Figure 4. An example of an *in-situ* camera installation and its view of the river. Located at GS111101D Russel River at Bucklands.

4. STIV discharge analysis

STIV discharge analysis was undertaken on suitable videos collected during high flow events. The KU-STIV software allows the GCP orthorectification parameters and STIV line positions to be saved in a project file. Therefore, each new IP camera video required only the water level value to be corrected within the software when deriving a new discharge value.

The site-specific surface alpha value determined for the discharge calculations remained relatively constant during the rise and fall of flood events at each of the gauging station sites. IP camera and UAV videos used the same site specific surface alpha during discharge calculations.

To ensure confidence in the STIV discharge data analysis a comparative ADCP measurement would be conducted whenever possible. UAV data and IP camera data would be collected at the same time as the ADCP allowing discharge data comparisons (Figure 5) These comparative measurements provided confidence not only in the data collection methods but also in the STIV discharge data calculated from IP camera videos collected during flood events when hydrographic staff could not be present.

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[1]. 4K resolution: https://en.wikipedia.org/wiki/4K_resolution

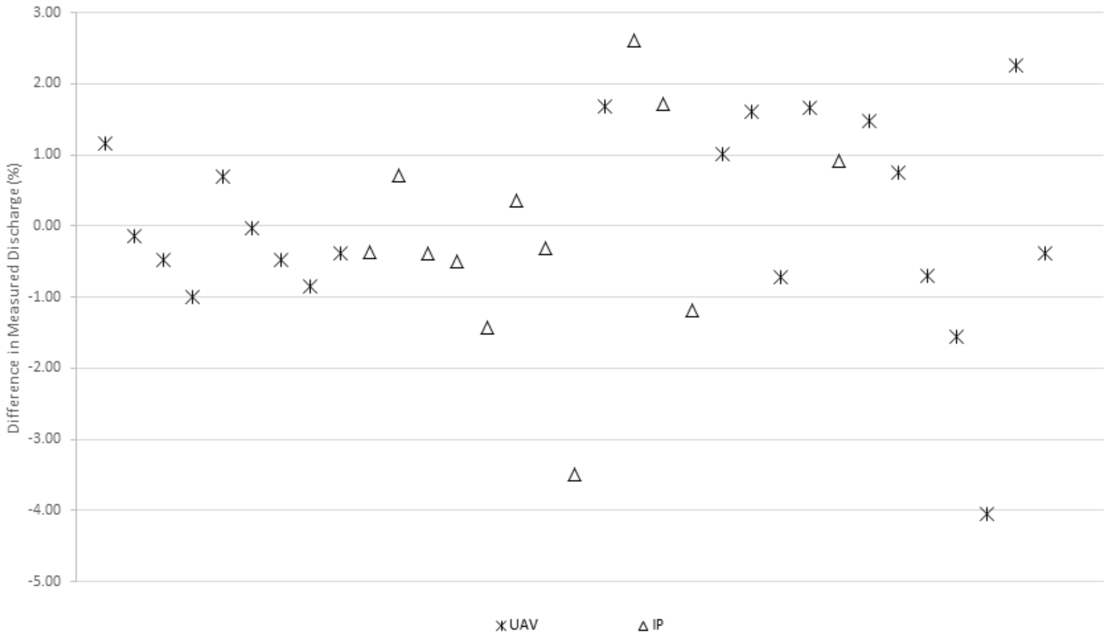
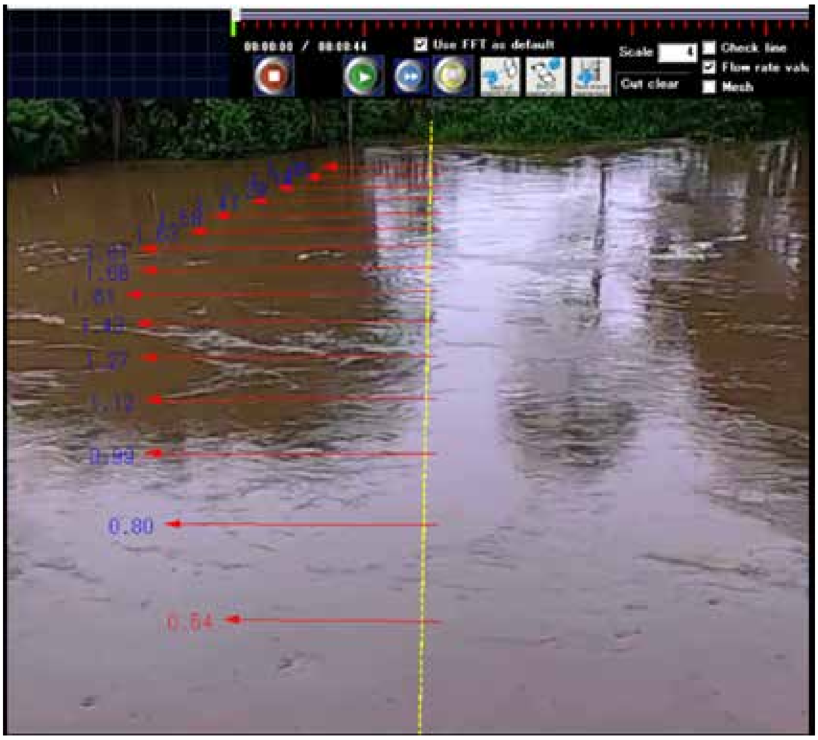


Figure 5. The percentage difference between ADCP discharge data and simultaneous STIV discharge measurements using onsite IP cameras and/or UAVs. Comparison measurements were collected at DNRME gauging stations and ranged from 61 to 2040 cumecs.

STIV discharge data could not be solely validated directly against a gauging station rating tables due to the occurrence at some sites of flow hysteresis and other complicating factors associated with high flow events that increased the uncertainty of the rating table data.

4.1. STIV and IP cameras

The onsite IP camera provided a means of data collection when it was not possible for hydrographic staff to access a gauging station site. Site access was not always possible for several reasons including but not limited to adequate site access, staff availability, site visit priorities, and staff safety concerns. The onsite camera allowed high flow STIV discharge measurements to be undertaken collecting valuable flow data that would otherwise have gone unmeasured.



The onsite IP camera allowed the collection of more STIV discharge measurements than would normally have been measured using an ADCP. Possessing more high flow discharge measurements revealed errors and limitations in the traditional gauging station rating curves.

Figure 6.
An IP camera STIV discharge measurement showing surface velocities and distribution. The video was captured at 06:55 as the flood peak was approaching.

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These curves were based on single point measurements or theoretical extrapolations. During two flood events that differed in their hydraulic nature, STIV analysis at GS116001F produced two distinct rating curves. One for each flood event, diverging at approximately 5 m gauge height. (Figures 7, 8, and 9).

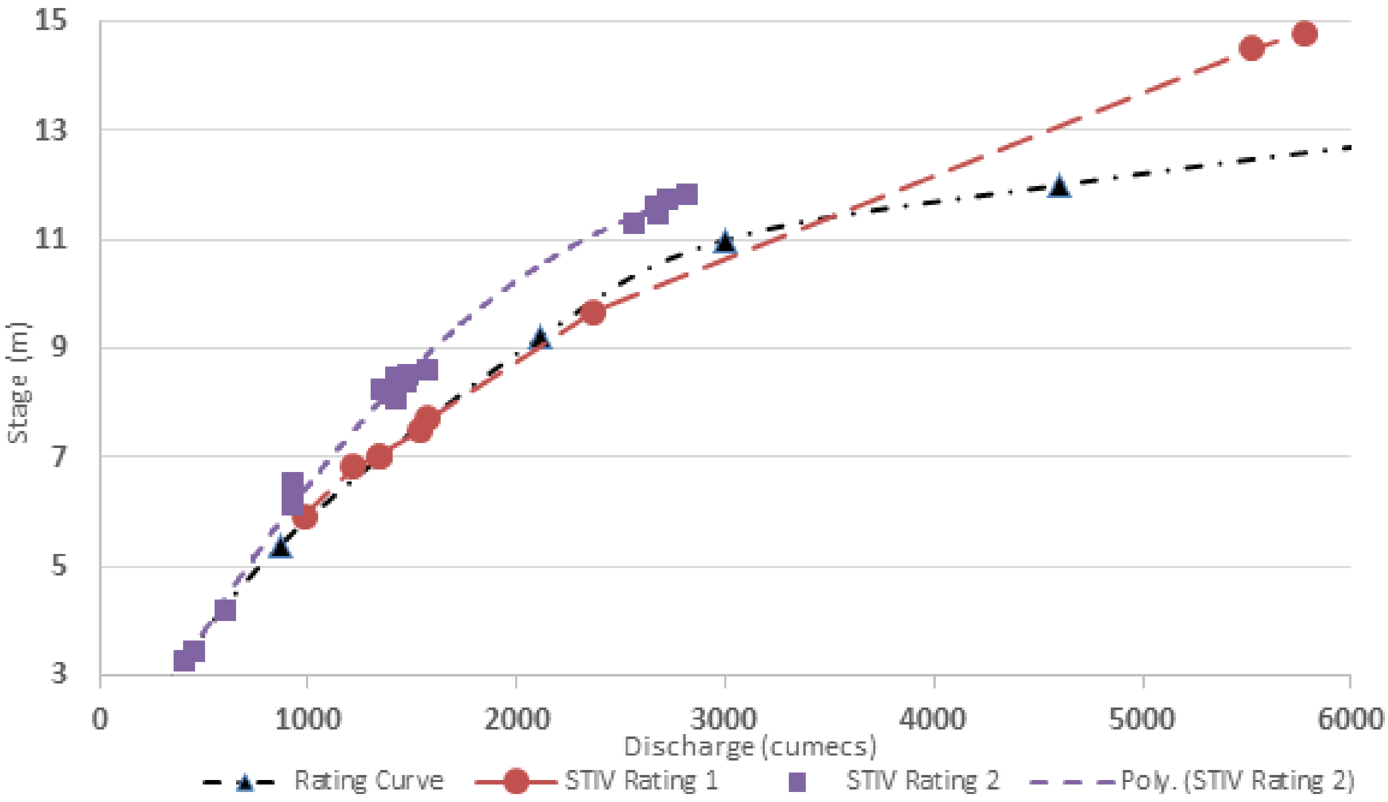

Figure 7. Two STIV ratings developed from IP camera videos of two flood events at GS116001F. STIV rating 1 was developed from a large 14.8 m flood event. STIV 2 shows a later more prolonged flood event of 11.82 m. The theoretical station rating curve overestimated peak flow by approximately 5000 cumecs at 14.8 m.

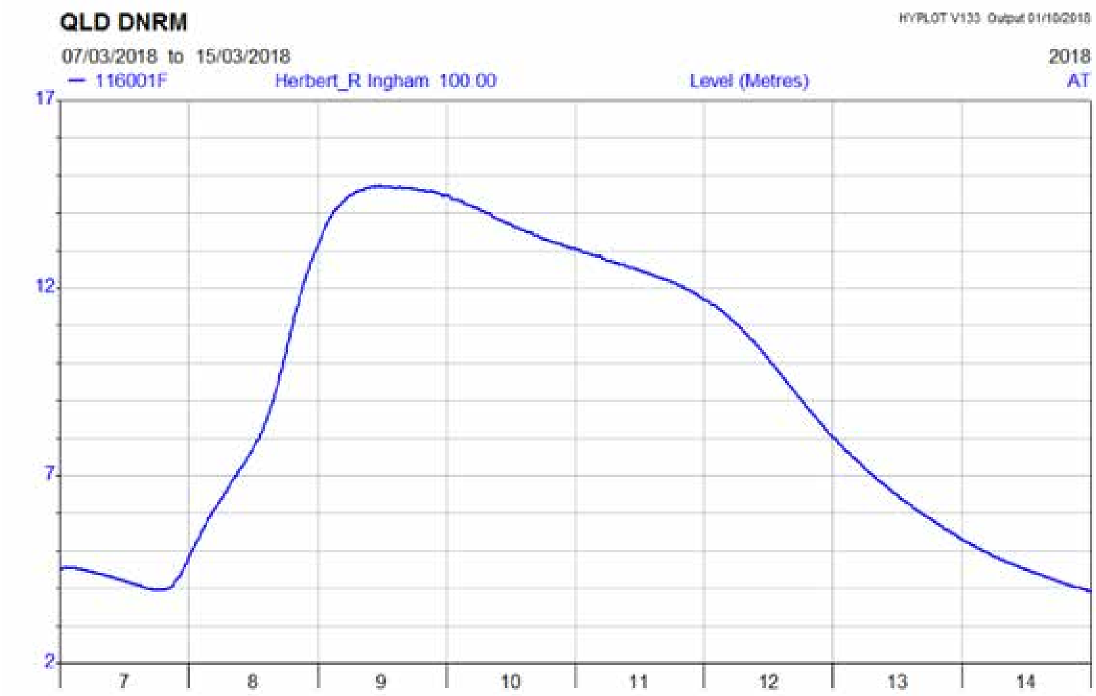

Figure 8. Stage height data for first flood event at GS116001F between 7 and 14 March 2018. STIV discharge analysis from IP camera videos provided the basis of STIV 1 rating development.

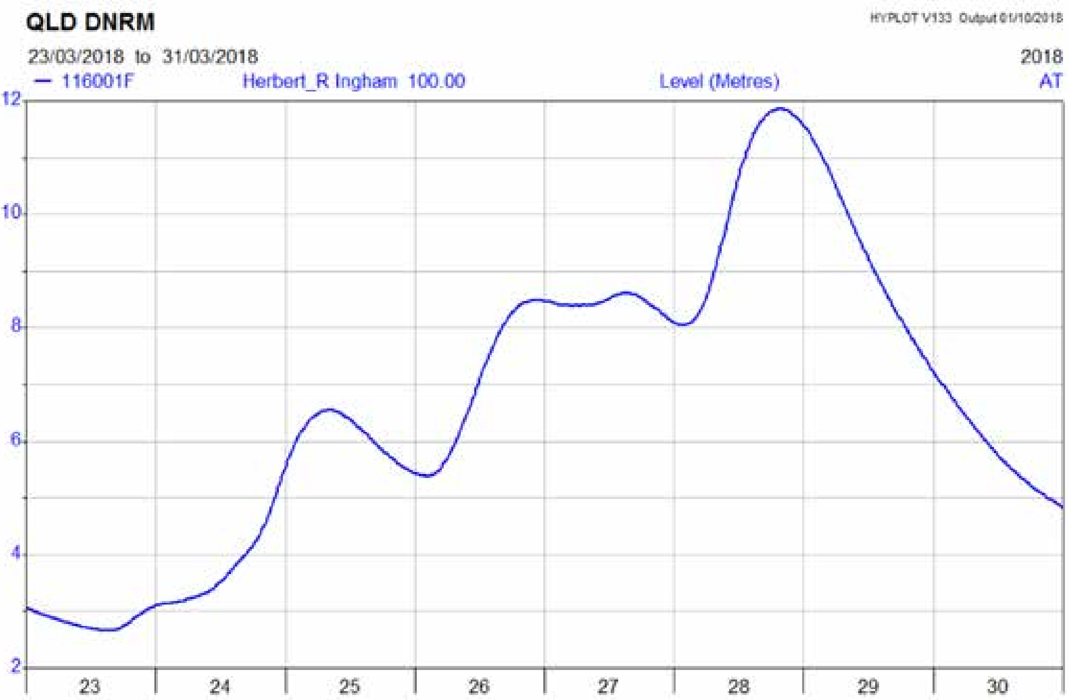

Figure 9. Stage data for the 2nd flood event at GS116001F from 23 to 30 March 2018. STIV discharge analysis from IP camera videos provided the basis of the STIV 2 rating development.

Limitations of traditional gauging station rating curves was also witnessed at other STIV trial sites and confirmed via ADCP comparison measurements.

4.2. STIV and UAVs

UAVs provided a mobile form of undertaking STIV discharge measurements. The operational advantages of using a UAV is that only a single person is required to collect a discharge measurement which can be undertaken far more quickly and safely than undertaking an ADCP boat measurement. Due to DNRME being one of the first monitoring agencies to begin implementing the collection and processing of UAV videos, a methodology had to be first developed and refined. UAVs have allowed data to be collected at sites where it was not possible to collect discharge data by any other method either due to site access or staff safety issues.

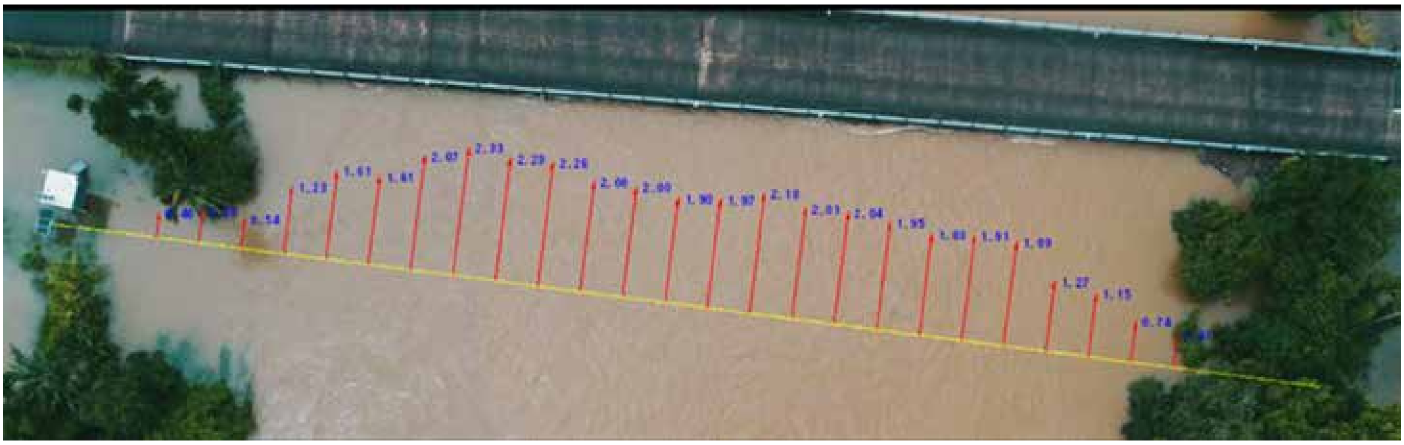

Figure 10. UAV measurement at GS113006A Tully River at Euramo. The site was not accessible due to the bridge approaches being flooded. The road bridge being just above water level was a safety concern preventing ADCP data collection via boat.

The use of UAVs has also allowed some of the largest ever discharge measurements to be undertaken at gauging stations as well as providing support to the collection of ADCP high flow measurements. This support included the confirmation or refinement of the extrapolation coefficient used in the unmeasured area above the ADCP, and providing an aerial view for operating ADCP remote control boats safely.

The UAV could be used to collect STIV discharge data during periods of high flow events where hydrographic staff felt that the flow conditions were unsafe for themselves personally or at a risk to the ADCP equipment. Without the ability to collect STIV discharge data with the UAV it would not have been possible to measure discharge by any other means, Figure 10.

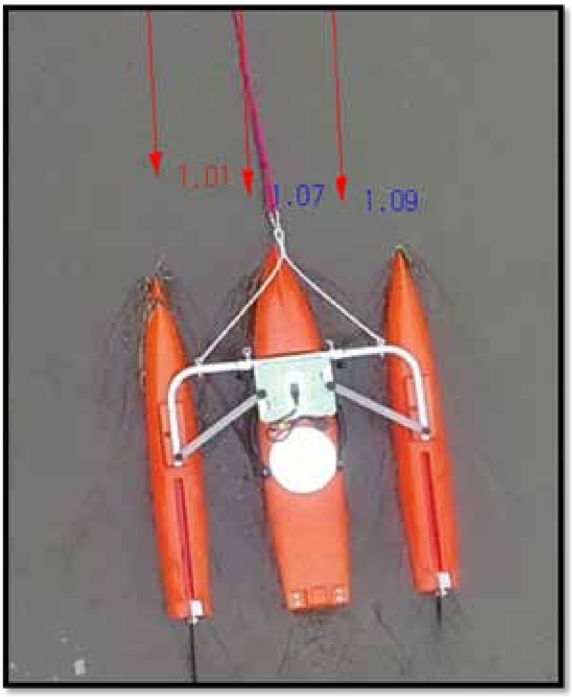

Figure 11. UAV generated surface velocities used for confirming the correct extrapolation method to be applied to the ADCP discharge measurement during post processing.

As well as high flow events UAV videos were also used to measure low flows. STIV is not restricted by water depth and so can therefore be used to measure overland flow and surface runoff as shallow as a few centimetres in depth.

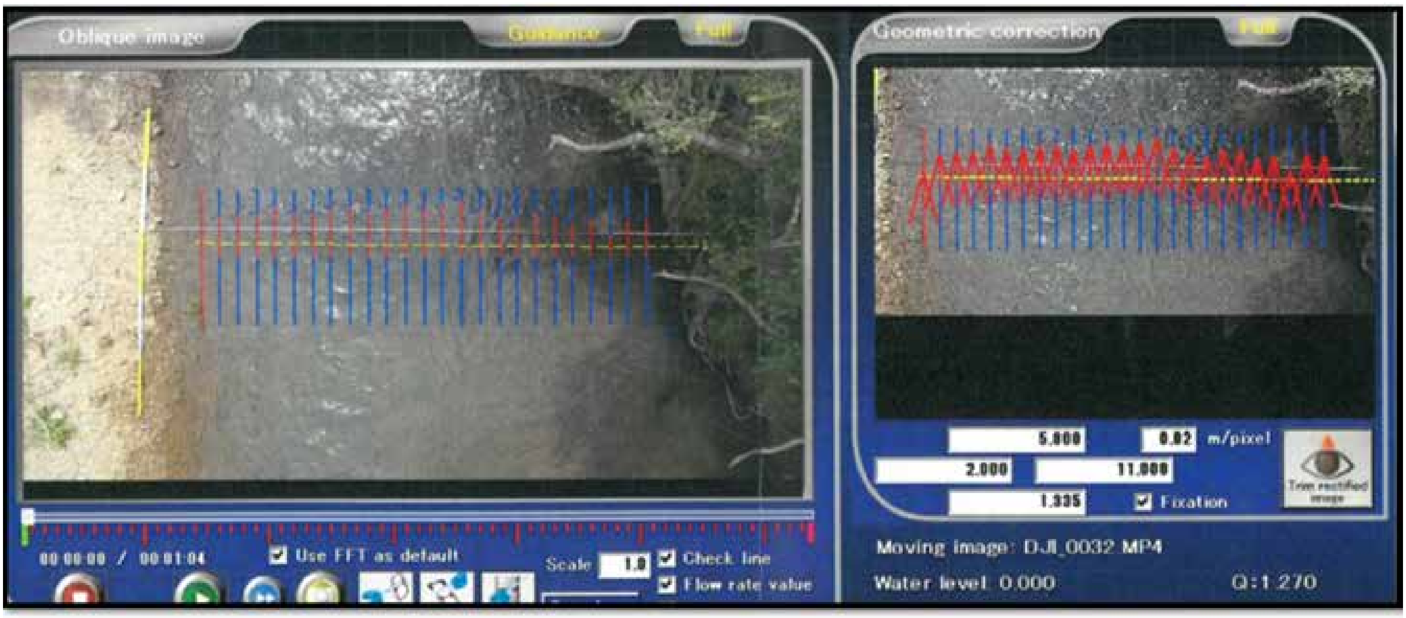

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Figure 12. Low flow UAV measurements at Kolan River, Springfield. Ott C31 measured discharge 1.265 cumecs. Three separate UAV videos measured discharge as 1.213, 1.270, and 1.257 cumecs (data provided by Ray Maynard, DNRME, Bundaberg).

5. Conclusions and Future Direction

The trials undertaken have demonstrated that STIV can be used to calculate discharges that are comparable with currently accepted methods of discharge measurement. Confirming the accuracy of STIV discharge data has provided DNRME staff trained in STIV with the confidence to apply this new methodology practically in the field and with the discharge results obtained from it. The use of image velocimetry and STIV provides a remote, non-contact method of acquiring discharge measurement data that would otherwise be unobtainable via currently accepted methods. Unlike other non-contact methods such as surface velocity radar, image velocimetry can accurately resolve velocities across an entire channel width (280m at GS116001F). Discharge calculations do not rely on the development of an index velocity rating but instead calculates discharge via the mid-section method and a surface alpha coefficient that is simple to determine.

STIV discharge data has highlighted the complexity of high flow ratings by confirming that different flood events can differ in their hydraulic characteristics and therefore differ in the discharges measured. Current procedures target discharge measurements at specific gauge heights, once measured, the target gauge height or even the measurement site is reassigned. Gauging records used to develop high flow rating curves are therefore commonly based on a few single measurements collected over a number of years. Collecting discharge measurements at a much higher resolution over multiple events has demonstrated that high flows cannot always be represented by a single rating curve banded by ±5%. In fact the level of uncertainty (not error) of high flows can be much larger than 5 or even 10%. Only by collecting multiple discharge measurements over multiple high flow events is it possible to accurately quantify this associated uncertainty.

Using onsite IP cameras not only allows more discharge measurements to be collected it also provides a way of collecting discharge measurements remotely and more cost effectively. An image velocimetry gauging station can be established at a fraction of the cost of a traditional monitoring station. Potentially a network of IP camera sites can provide a whole of system approach to streamflow monitoring.

Having the ability to measure high flow discharges using a UAV provides hydrographic staff with a ‘safe’ option for measuring high flows. The UAV option can minimise the loss of valuable discharge data when flow conditions are rightly determined as unsafe for staff to measure or present a damage risk to costly ADCP equipment. The use of UAVs has proved a popular and valuable tool allowing hydrographic staff to not only measure discharge using STIV but also for conducting photogrammetry surveys, aerial surveillance of suspended sediment inflows, and site inspections.

UAVs provide an additional cost effective solution to collecting high flow data that is comparable to currently used measurement techniques.

DNRME is committed to the continued expansion of its image velocimetry network with 45 sites to be installed over the next three years. Having validated the methodology further trials are expected into the use of far infrared cameras for night measurements, real time discharge processing from IP camera and UAV videos. DNRME is providing practical advice and training in the use of STIV to monitoring agencies both nationally and internationally.

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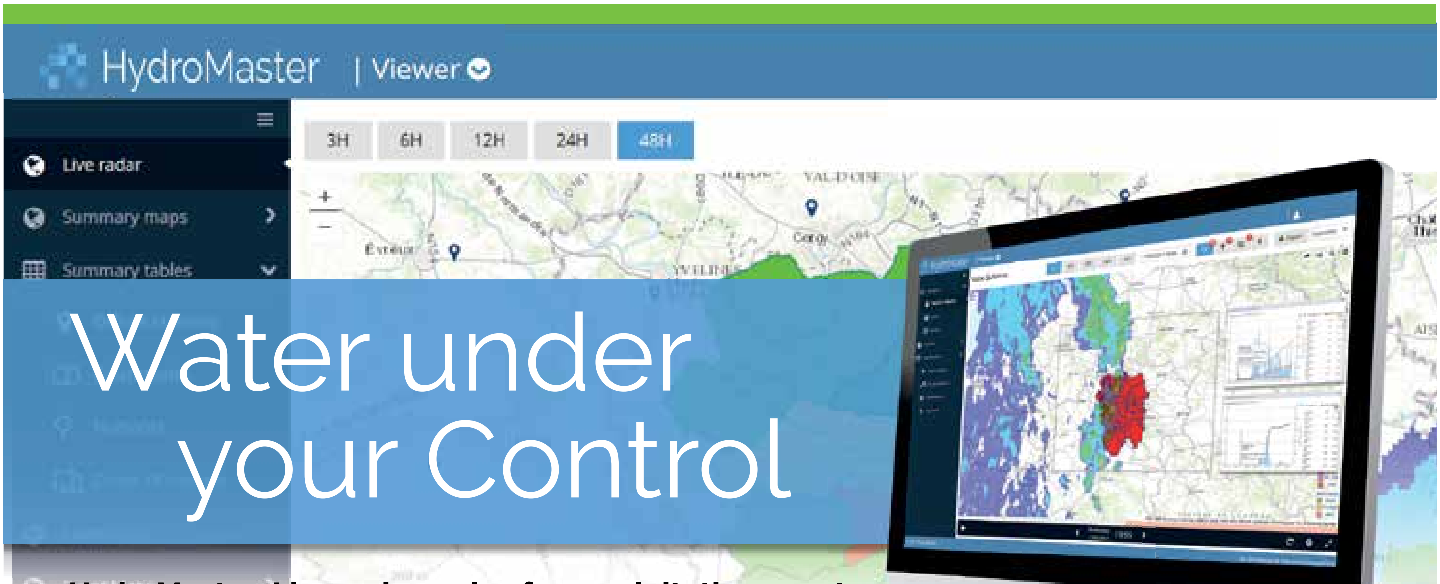

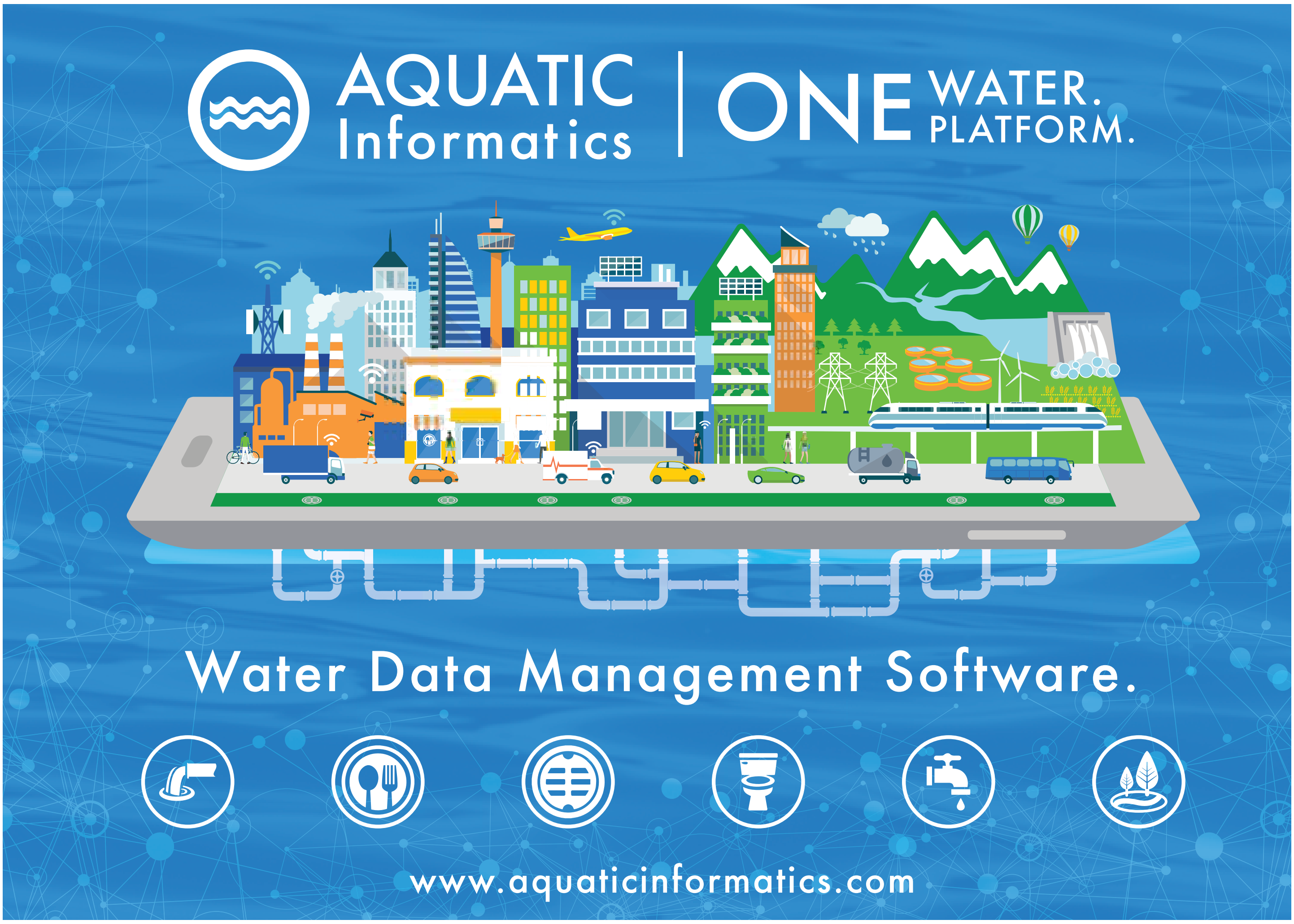

Extreme Flood Event Measurement Technique Utilising Measurement of Maximum Velocity

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

Abstract

Flood events represent a valuable opportunity to collect stream discharge measurements which may then be used to calibrate hydraulic models. As hydraulic models are relied upon to predict flood levels, it is imperative that the data collected during floods is accurate. Unfortunately, undertaking discharge measurements during a flood event may be a difficult and dangerous task with significant risks posed to the hydrographer and the instruments used in this activity.

During the Victorian floods in 2010, 2011 and 2012, analysis of gaugings conducted at some sites conducted with both traditional mechanical current meters and acoustic Doppler current profilers (ADCP) indicated that both instruments failed to produce reasonable results. In some cases, the ADCP failed to detect the bottom of the river to measure the depth, or the velocity was not accurately determined due to heavy sediment load or excessive cavitation. Additionally, during these events there were times when the measuring instrument was swept away.

As velocity and water height in a river vary drastically with time during a flood event, obtaining an accurate discharge measurement using traditional techniques may not be possible, even at sites where it is safe to deploy instruments. Therefore, a new measurement technique which allows a quick sampling of the velocity may be more appropriate in such flow events. Such a method would also provide greater personal safety for both the hydrographer and the instruments by reducing their exposure time.

Ventia has developed a method based on the site-specific relationship between mean velocity, maximum measured velocity and hydraulic depth. The method was derived from the historical discharge measurements taken at each site. It is envisaged that this measurement technique will be utilised at sites during extreme flood events, when it is unsafe to either the hydrographer or the instruments to allow a long exposure time. This is most likely at heights that have yet to be measured at the stations and the technique is designed to allow the collection of data even under these trying conditions.

General Theory

Velocities in a cross section change vertically and horizontally. They vary from zero at the channel bed to a maximum value either at the water surface or some distance below the surface depending on many factors including channel geometric characteristics, longitudinal bed slope, and presence of bends, contractions or expansions within the immediate reach of a section. The non-uniformity in the velocity distribution from the river bed to the water surface is caused by shear stresses and complex interaction with boundaries and irregularity in a natural river system. This induces randomness which makes it difficult to have theoretical stochastic or mathematic models describing the velocity distribution accurately.

The most well-known velocity distribution formulas are the universal logarithmic and power laws. The logarithmic velocity distribution law is only inherently valid within the wall region, which is for the region below 0.2 of depth[2] and is inaccurate in the outer region. The power law cannot describe the dip

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[2] The position in the vertical profile is described as a decimal of depth, from 0 depth (surface) to 1 (depth at bottom of profile).

phenomenon caused by secondary currents (Nikuradse, 1933, English translation, 1950), or deformations of the mean velocity contours, due to side wall effects which result in the maximum velocity occurring below the water surface.

Chiu (1988) derived a velocity distribution equation using the probability concept and entropy-maximisation principle which may describe the variation of velocity in both vertical and transverse directions even when the maximum velocity occurs on or below water surface. According to Chiu's approach, the entropy parameter of a section can be determined through the relationship between mean and maximum velocities which is constant even though the ratio of mean to maximum velocities may vary from section to section along the channel.

As Chiu cited in his paper "there are regularities in open-channel flows that, if detected, analysed, and properly understood, can be used as the basis to simplify data collection and improve the flow forecasting, design, and control of engineering systems... that is the mean value of the ratio of the mean and maximum velocities of flow in a channel section is constant," (Chiu and Tung, 2002). The technique was developed in 1995 (Chiu and Said, 1995) to determine discharge from the entropy parameter "M" of a channel section and velocity profile on a single vertical where the maximum velocity occurs in a cross section.

Various other researchers have applied this method and have proven that there is a strong relationship between mean and maximum velocities. This research is based on data collected from rivers as well as from experiments conducted in laboratories, (Leopold, *et al*. 1995, Xia, 1997, Moramarco, *et al*. 2004, Mohammadi, 2009). "In natural channels in the United States, V_{max} is between $1.25V_{mean}$ and $1.50V_{mean}$ (Leopold *et al*., 1995) that can be translated into V_{mean}/V_{max} or ø between 0.66 and 0.8 or M between about 2 and 5" (Xia, 1997).

A similar approach to that proposed by Chiu who utilised probability concepts to relate mean velocity to maximum velocity was adopted to create the discharge measurement technique. Cross sectional mean velocity (V_{mean}) was related to hydraulic depth, (cross sectional area, A, divided by W, surface width) and the maximum velocity ($V_{max\_at\_0.2}$) which is measured at 0.2 of the depth below the water surface during a measurement. The relationship differs from site to site due to each site's unique characteristics.

It is known that the velocities in a channel are not uniformly distributed within the section. Observation of historic measurements indicates that the maximum velocity in a channel normally occurs below the free surface at a distance to 0.5 to 0.25 of the depth. The shape of the section, the roughness of the channel, the presence of bends, contractions or expansions in the vicinity of the section are the factors that affect the vertical velocity distributions and therefore the relationship between maximum measured velocity and cross sectional mean velocity.

When conducting a discharge measurement, the methods recommended by the Australian Standard are used. This means that the cross section is divided into more than 22 sections to approximate the cross-sectional area and velocities are sampled at two or three points at each vertical, at 0.8, 0.6 and 0.2 of a depth below water surface respectively to estimate the mean velocity of a section.

Utilising Chiu's approach, the relationship between the maximum velocities measured, generally at 0.2 of a depth below water surface, and the cross sectional mean velocities of the measurements was sought by examining the discharge measurements undertaken at 154 stream gauging sites with different hydraulic characteristics and geometrical shapes over the past 40 to 50 years.

Experience has shown that maximum velocities are generally observed at 0.2 of a depth below the water surface; a depth which is the least affected by boundaries and is therefore more resilient to change over time. To have a representative sample, sites located on mountain rivers with steep slopes, sites on slow moving rivers with very mild slopes, rivers with sand, gravel, and pebble or rock bed materials with dense vegetation on the banks were selected across catchments exhibiting different characteristics to those stream gauging sites which have man-made low-level controls which become submerged at mid and high flows. One quarter of the selected sites have natural controls which are subject to constant scouring and depositing, therefore the stage discharge relationships governed by the controls, downstream disturbances and approach channels often change.

The reason why the relationship between three parameters, V_{mean}, $V_{max\_at\_0.2}$ and hydraulic depth, d, was sought is that;

- Researchers around the world have proven that there is a strong relationship between the mean and maximum velocities. On the other hand, while the magnitudes and the locations of maximum velocities at the stream gauging sites of Victoria are not available, the relationship between V_{mean} and $V_{max\_at\_0.2}$ at these sites can be easily established utilising the historical discharge measurements;
- There is a sound relationship between the physical characteristics of a cross section such as the area, depth, channel width and the location of maximum velocity and hence the vertical velocity distribution (Schlichting 1987, Montes 1998, Nezu 2005). As a result, the relationship between V_{mean} and $V_{max\_at\_0.2}$ can be improved with a parameter characterising the shape as well as the impact of the boundaries;
- Hydraulic depth, d, is a sensitive parameter reflecting the irregularity and non-uniformity of a cross-section as well as changes in flow roughness. It is easy to calculate in field by a hydrographer;
- Hydraulic depth takes any changes at a section into account which may occur over a long period. The analysis of data has shown that while the relations between mean and maximum velocities at many sites have changed over a time, the relationships between V_{mean}, $V_{max\_at\_0.2}$ and d for 154 stream gauging sites are robust and stable;
- These parameters are readily available or can be surveyed from flood peak levels; hence the method negates requirement for any estimation.

Relationship for Flood Gauge Calculation

The relationship between V_{mean} and $V_{max\_at\_0.2}$ can be plotted linearly however it can vary slightly due to changes in the cross-section characteristics and the roughness over time. It can be seen from the linear relationship displayed below between V_{mean} and $V_{max\_at\_0.2}$ that the two parameters overestimate the mean velocity below 2.8 m/sec and underestimates above this range, though the relationship does yield results within ±10%.

The addition of hydraulic depth as a parameter into the relationship allows for the irregularity and non-uniformity within a cross-section, as well as changes in roughness which may occur over a long period to be considered.

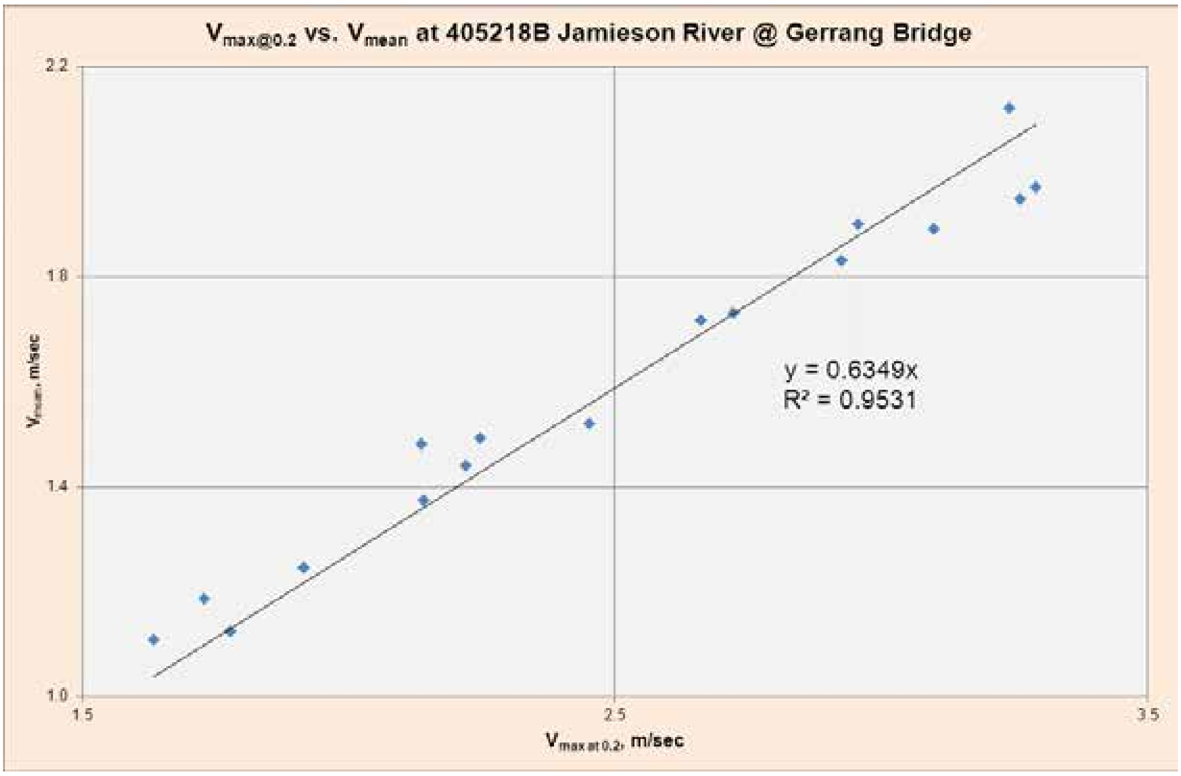


Figure 1. Simple Linear Relationships between V_{mean} and $V_{max\_at\_0.2}$ for 405218B Jamieson River @ Gerrang Bridge.

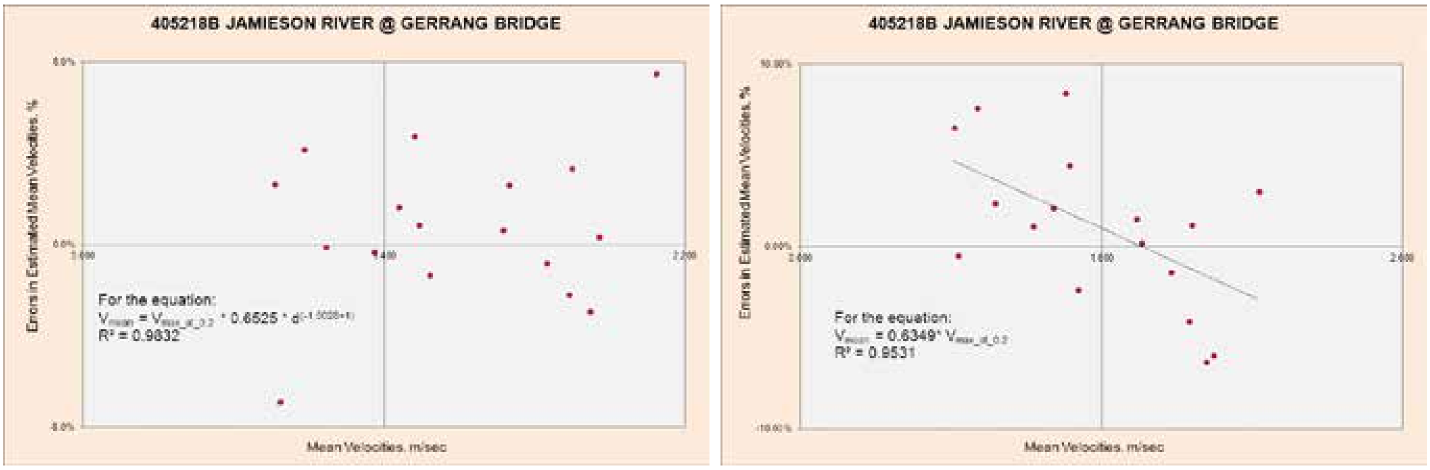


Figure 2. The error residual plots yielded by the equation developed in this project and the simple linear relationship respectively.

To estimate the mean velocity at a site during an extreme event, the algorithm below was determined to characterise the site-specific relationships between mean velocity, hydraulic depth and maximum measured velocity at 0.2% of a depth as;

$$V_{mean} = V_{max\_at\_0.2} \times \alpha \times d^{(\beta+1)}$$

… Equation 1

Where:

V_{mean} is cross sectional mean velocity.

$V_{max\_at\_0.2}$ is maximum velocity measured at 0.2 (20%) of the depth below surface.

d is hydraulic depth and calculated by dividing cross sectional area, A, to water surface width, W.

α and β are the site-specific coefficients derived from historical discharge measurements.

For each historical measurement, parameters, $\frac{\frac{V_{mean}}{V_{max\_at\_0.2}}}{d}$ and d were calculated and were plotted against each other. The data from all sites has shown the general equation given above plots as a straight line on logarithmic graph paper, see the example given in Figure 3 below.

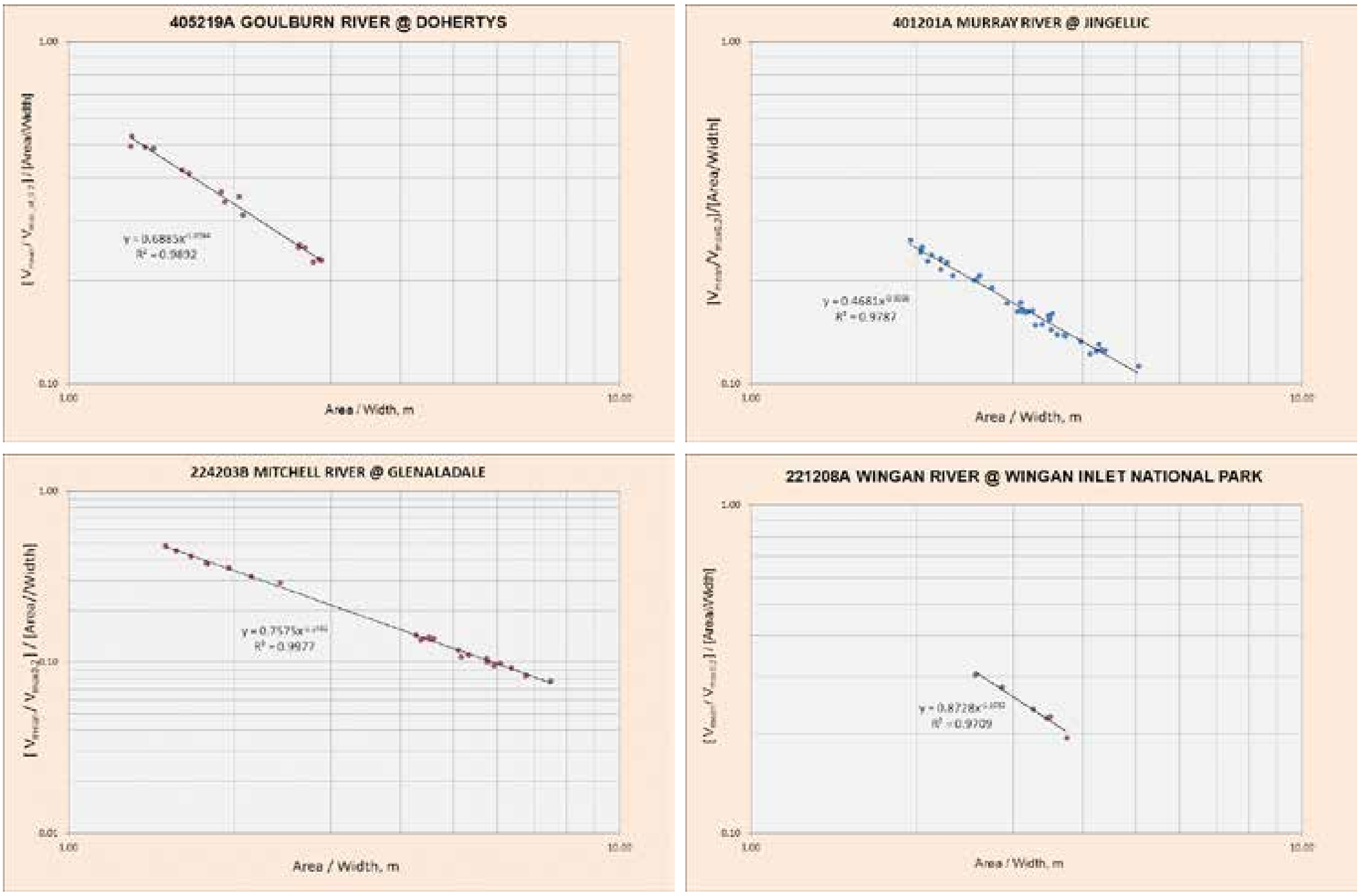


Figure 3. Relationships between $\frac{\frac{V_{mean}}{V_{max\_at\_0.2}}}{d}$ and *d* for Dohertys, Jingellic, Glenaladale and Wingan.

The measurements used in the extreme flood analysis of 401201A Murray River @ Jingellic and 405219A Goulburn River @ Dohertys have been undertaken between 1971 and 2010 and between 1974 and 2010 respectively. Similarly, although the limited numbers of measurements for the flood analysis are available for the site at Wingan River, the measurements undertaken between 1971 and 2012 have proven that the relationship at this site is robust, invariable over a long period and plots as a straight line on logarithmic scale. The results from 147 sites have confirmed that the applicability the equation in describing relationships between V_{mean} and $V_{max\_at\_0.2}$ at stream gauging sites of Victoria is sound and as resilient as the relationship between maximum and mean velocities despite the fact that the observations of the maximum velocities over the years during each measurement were not done at exactly the same locations.

All measurements have errors even after all known corrections and calibrations have been applied. The errors may be positive or negative and may be of a variable magnitude. Many errors vary with time. Some have very short periods while others vary daily, weekly, seasonally or yearly. Those which remain constant or apparently constant during the test are called systematic errors. The actual errors are rarely known, however upper bounds on the errors can be estimated.

Flood discharge measurements are no exception to this universal truth. During a flood event, pulsing flow and force on a mechanical current meter emanating from excessive water speed will, unavoidably, introduce additional uncertainty into discharge measurement. Combined and expanded uncertainty in a discharge measurement with a mechanical current meter during a flood may vary between 10% and 15% depending on the speed of the water, flow conditions, measurement sections, instrumentation and infrastructure such as cross wire or bridges at sites. For this reason, the errors in mean velocities were also calculated to provide a guide for likely upper bounds on the errors in estimated discharges, see figure below.

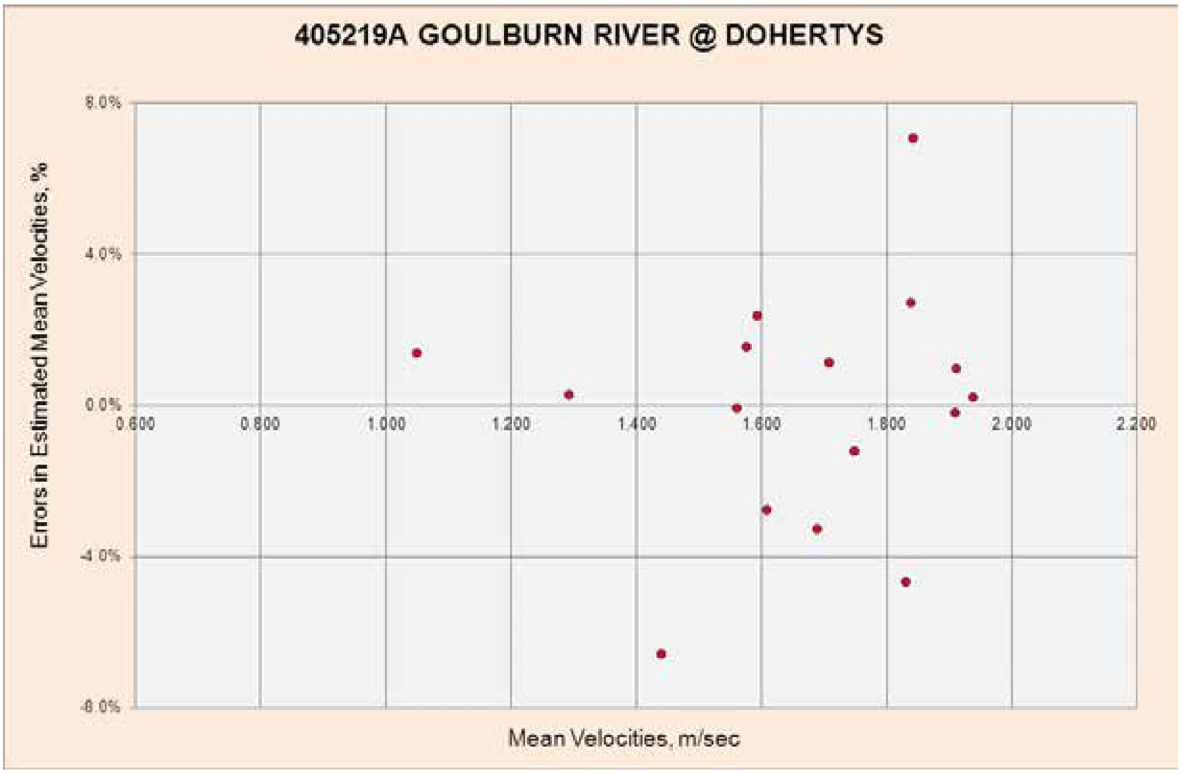


Figure 4. The error residual plot for 405219A Goulburn River @ Dohertys.

While most of the errors are within ±4% in this example, the errors in three out of 17 measurements are greater than ±4%. Outliers can be observed by chance in any data set, which indicates either measurement error or that the population has a heavy-tailed distribution. In the former case they can be discarded, or statistical tools can be used to identify outlier appropriately. If the samples have a heavy-tailed distribution, then they indicate that the distribution has high kurtosis and using tools to treat them as outliers that assume a normal distribution may not be appropriate. As the typical uncertainty in a flood measurement varies between 10 and 15%, the measurements plotting within the 15% upper bounds have not been discarded in this study unless compelling evidence exists to do so. Such error plots also are important in showing the upper error band occurring under the most unfavourable measurement conditions including human error.

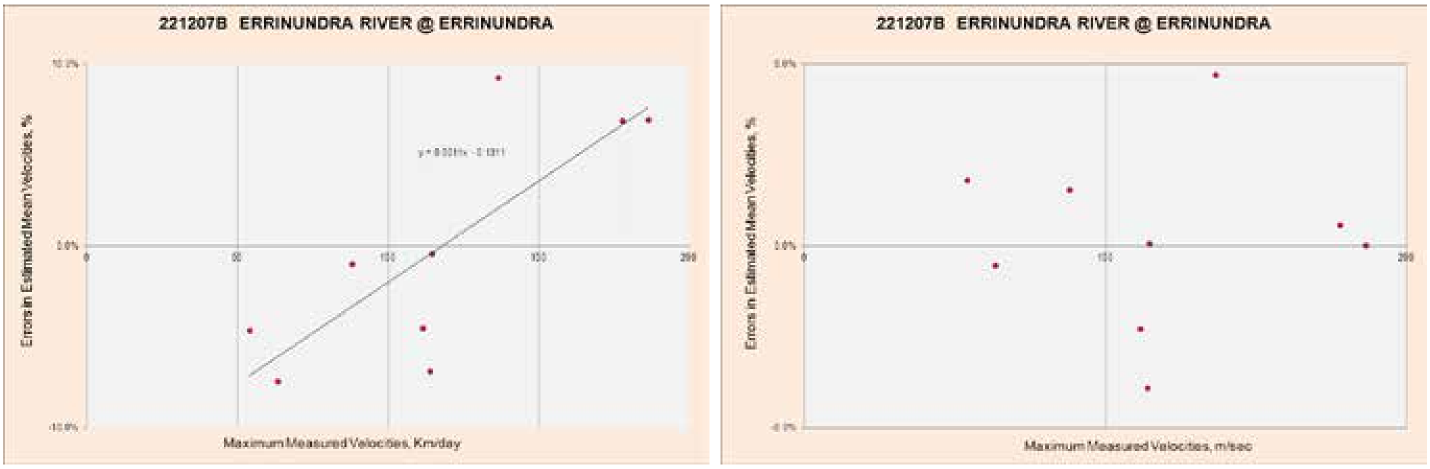


Figure 5. Data indicating systematic error in regression and it is removed by deploying a linear regression.

The assumptions of the linear regression model are that the variance of the error term and of the dependent variable is constant across all the observations. If analysis indicates that the data points are scattered further from the estimated regression line and the residuals, the vertical distances between the regression line and the individual observations are getting larger when one of independent variables, $V_{max\_at\_0.2}$, increases, it may suggest that variance is not constant, but is greater for larger $V_{max\_at\_0.2}$ values indicating a systematic error in the empirical equation as displayed above.

In this circumstance, a linear algorithm is added to the general equation to remove the systematic error in the data. This example is for 221207B Errinundra River @ Errinundra:

$$V_{mean} = [1 + (V_{max\_at\_0.2} * 0.0011 - 0.1311)] * V_{max\_at\_0.2} * d * [0.7094 * d^{(-1.0867)}]$$

The approach aims to reduce the variance between the regression line and the individual observations that were getting larger as $V_{max\_at\_0.2}$ increases. This was important to achieve higher accuracy in estimating discharges because ideally the measurement technique will be deployed beyond the maximum observed velocities. This method was applied because;

- The analysis of data of at stream gauging sites has indicated the variance is greater for larger $V_{max\_at\_0.2}$ but not hydraulic depth, d.
- It is easy to implement in the field.

Utilising the site-specific equation allows for V_{mean} to be determined during an extreme event. The site cross section may then be used to determine the appropriate area for the height. If the event is higher than the existing cross section, it may be levelled in at a later date to complete the measurement.

Data Availability

In developing an amended measuring technique, historical data was examined. Those sites with gaugings from the 1970s onwards were used, though for some sites information back to the 1960s was also available. In Victoria, the last 40 to 50 years has seen long dry spells interrupted by severe floods which generate major changes in the waterways. Physical heterogeneity at a site is expected to modify any relationship over time, though using a long period of data has enabled an examination of the persistent of the relationship between the mean velocity, maximum velocity and hydraulic depth.

The analysis at sites has only been conducted on high flow measurements. As a result, any waded discharge measurements have been excluded. This means that many of the stream discharge measurements considered were conducted at cross wires, which allows for some similarity with the area and widths observed.

While 154 sites were examined, the analysis could not be conducted at several sites due to a lack of high flow measurements. Since the determination of the calculation equation relies on the examination of historic data, these sites have become a priority measurement during future events, or for other methods to be used.

Outcome

For each of the 154 sites considered, the relationship between V_{mean}, $V_{max\_at\_0.2}$ and hydraulic depth d was determined (Equation 1). If necessary, the additional linear algorithms were added to Equation 1 to allow a more accurate determination of V_{mean} during flood events. Some example equations are displayed in Table 1. As can be seen, most fit the general relationship of Equation 1, but two sites have had an additional linear equation added to provide extra accuracy.

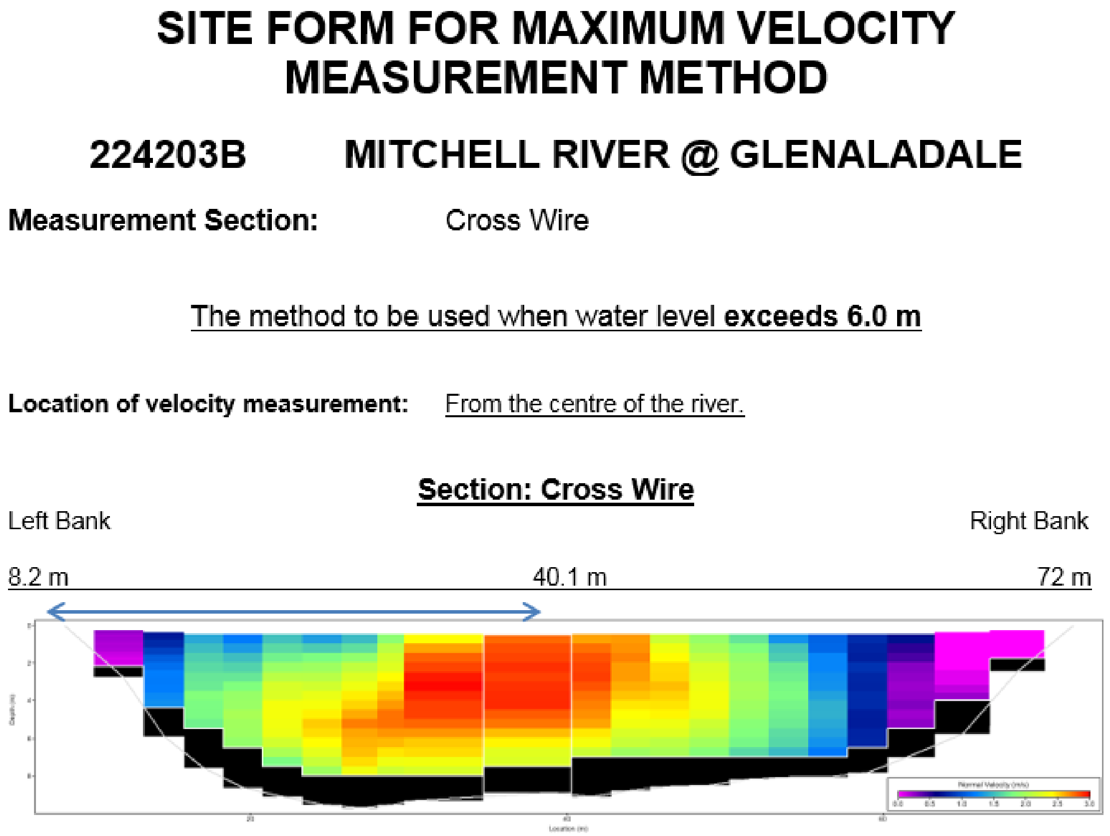
Table 1. Examples of the relationship between V_{mean}, $V_{max\_at\_0.2}$ and d for sites in Victoria

Site	Mean Velocity Equation
221207B Errinundra River @ Errinundra	$V_{mean} = [1+(V_{max-0.2}*0.0011 - 0.1311)] * V_{max-0.2} * d * [0.7094 * d^{-1.0867}]$
221208A Wingan River @ Wingan Inlet	$V_{mean} = V_{max-0.2} * d * [0.8728 * d^{-1.1032}]$
224203B Mitchell River @ Glenaladale	$V_{mean} = V_{max-0.2} * d * [0.7575 * d^{-1.1431}]$
401201A Murray River @ Jingellic	$V_{mean} = V_{max-0.2} * d * [0.4681 * d^{-0.9098}]$
405218B Jamieson River @ Gerrang Bridge	$V_{mean} = [1 + (-V_{max-0.2} * 0.0005 + 0.0993)] * V_{max-0.2} * d * [0.6525 * d^{-1.0528}]$
405219A Goulburn River @ Dohertys	$V_{mean} = V_{max-0.2} * d * [0.6885 * d^{-1.0394}]$

Of the 154 sites considered, at 7 sites the relationship between V_{mean}, $V_{max\_at\_0.2}$ and hydraulic depth d was unable to be determined due to a lack of historic high-level measurements. At other sites, it was discovered that high flow discharge measurements had not been captured for many years which may lead to increased uncertainty when using the site equation.

However, by itself an equation is not useful without appropriate field information. To fully develop the measurement technique, an instructional form was created for each of the sites where the relationship was determined. The form was placed on site, and into the State records. This is because Victoria has a history of flood events separated by extended dry periods. Having the instruction form on site ensures that when the next flood event occurs, the hydrographer will have access to the technique, if required.

The form includes information on where to measure at the site to determine the maximum velocity in the stream and an example is shown below. This information was determined from the analysis of the historic measurements at each of the sites. The relationship between V_{mean}, $V_{max\_at\_0.2}$ and hydraulic depth, d, and the residual errors is also provided to ensure that an estimate of error can be determined on site. A step by step calculation form has also been included to ensure that no piece of information is missed and to provide instructions on what to do if one parameter may not be determined.



SITE FORM FOR MAXIMUM VELOCITY MEASUREMENT METHOD

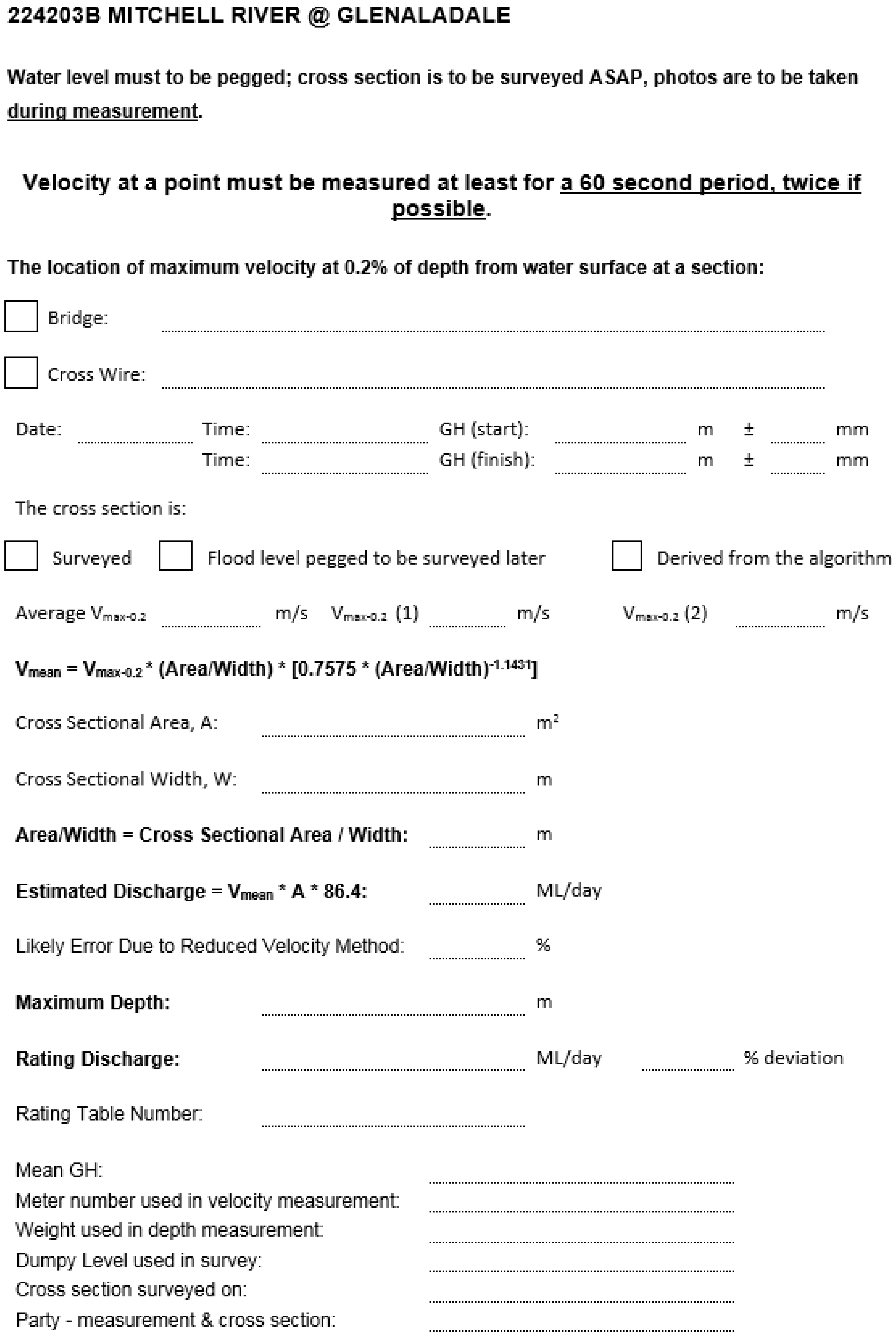
224203B MITCHELL RIVER @ GLENALADALE

Measurement Section: Cross Wire

The method to be used when water level **exceeds 6.0 m**

Location of velocity measurement: From the centre of the river.

Section: Cross Wire



224203B MITCHELL RIVER @ GLENALADALE

Water level must to be pegged; cross section is to be surveyed ASAP, photos are to be taken during measurement.

Velocity at a point must be measured at least for a 60 second period, twice if possible.

The location of maximum velocity at 0.2% of depth from water surface at a section:

☐ Bridge: ……………………………………………………

☐ Cross Wire: ……………………………………………………

Date: ………… Time: ………… GH (start): ………… m ± ………… mm
Time: ………… GH (finish): ………… m ± ………… mm

The cross section is:

☐ Surveyed ☐ Flood level pegged to be surveyed later ☐ Derived from the algorithm

Average $V_{max-0.2}$ ………… m/s $V_{max-0.2}$ (1) ………… m/s $V_{max-0.2}$ (2) ………… m/s

$V_{mean} = V_{max-0.2} * (Area/Width) * [0.7575 * (Area/Width)^{-1.1431}]$

Cross Sectional Area, A: ………… m^2

Cross Sectional Width, W: ………… m

Area/Width = Cross Sectional Area / Width: ………… m

Estimated Discharge = V_{mean} * A * 86.4: ………… ML/day

Likely Error Due to Reduced Velocity Method: ………… %

Maximum Depth: ………… m

Rating Discharge: ………… ML/day ………… % deviation

Rating Table Number: …………

Mean GH: …………
Meter number used in velocity measurement: …………
Weight used in depth measurement: …………
Dumpy Level used in survey: …………
Cross section surveyed on: …………
Party - measurement & cross section: …………

Figure 6. Excerpts from the Site Form for the Maximum Velocity Measurement Method for 224203B Mitchell River at Glenaladale.

If all parameters are available, then the $V_{max\_at\_0.2}$ may be measured and V_{mean} calculated using the site-specific equation. The level of the event may be read from the onsite gauge boards, though it is acknowledged in high level events that reading gauge boards may introduce a degree of error due to the surging nature of the water. Area, at the level the $V_{max\_at\_0.2}$ was measured may be determined from the site cross section and the flow calculated from the basic hydrographic equation:

$$Q = V_{mean} \times A \qquad \textit{... Equation 2}$$

Where:

Q is discharge.

V_{mean} is mean velocity in a section.

A is area of the cross section.

Conclusions

Using flood analysis performed at 154 stream gauging sites around Victoria has allowed for the development of a new measurement technique which may be applied when all other measurement methods have failed due to difficult conditions on site. This allows for the collection of flood discharge information in extreme events. It has the added advantage that the likely error in measurement has been quantified based on the historical information collected at the site.

The methodology is relatively simple for the hydrographer to use in the field and allows for the potential safe guarding, and at the very least, the reduction of exposure time of an acoustic Doppler current profiler, an instrument worth approximately $60,000, during extreme high flow measurements. The reduction in risk to the field technician cannot be underestimated.

Since often the long profound dry spells have been interrupted by severe floods in Victoria, the availability of such knowledge about the site characteristics and flood behaviours at the stream gauging sites is crucial to collect the required information during high flow events. The methodology allows correct and valuable high flow information to be collected during events.

Collecting this information allows for the identification of gaps in the rating tables at stream gauging sites. At some sites there has been only limited opportunity to capture flood measurements due to the flood sequence in Victoria. In other cases, limited resources such as man power, appropriate instrumentation and access to the site have made it impossible to capture flood measurements. This project has allowed for these gaps to be identified and for these sites to be highlighted so that during the next high flow events, they may be considered a priority for information collection.

There is further benefit from the collection of these extreme flow measurements. It allows for certainty in the upper ratings by providing measurements which may not otherwise have been able to be collected. This has significant, positive implications for the calibration of flood studies and hydrological models of river systems. Instead of having estimations of peak events, these measurements will provide a value of flow with upper band on error that is measurable and repeatable.

Acknowledgement

The author would like to acknowledge the contribution of Nurullah Ozbey, who was the developer of the technical details and the Department of Environment, Land, Water and Planning for funding the project to develop the technique.

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A New Solution for real-time flood intelligence in NSW Integrating Coastal Flooding Information

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

Abstract

MHLFIT is a tool designed to help flood managers and emergency responders make decisions about flood events as they develop. It incorporates real-time and predicted data from a range of sources and provides interactive inundation and timing data in a web-based format in near real-time. Users are able to account for uncertainty by using built in what-if scenario tools and see results immediately. The tool is developed in conjunction with councils and the State Emergency Services (SES) to provide the most important and useful information required for decision making.

Flood prediction in Intermittently Closed and Open Lakes and Lagoons (ICOLLs) is complicated by the highly variable downstream conditions which are constituted by tidal behaviour, berm height, entrance dynamics and morphology, ocean waves, and differing management policies for lagoon entrances. The timing of opening entrances can also have a significant impact on the peak flood level and must take into consideration not only tidal cycle but also the degree of scour an entrance may be subject to. These factors all impact on the actual peak height during a flood event.

A case study will be presented of the Manly and Narrabeen Flood Intelligence Tool which integrates these considerations and provide a means to perform on-the-fly sensitivity and scenario testing to ensure informed decisions are made in an emergency. Additionally, it also incorporates forecast tidal and Bureau of Meteorology (BoM) rainfall predictions into its automated predictions.

Introduction

Of the ~135 estuaries on the NSW coast, approximately 90 are lakes or lagoons greater in area than one hectare (DPI, 2018). Many of these rely on naturally varying entrances to regulate the tidal and catchment flows into and out of the estuary and are classified as Intermittently Closed and Open Lakes and Lagoons (ICOLLs). The majority of these ICOLL entrances have been greatly altered from their natural configuration due to human intervention and, now, surrounding communities often place great pressure on the regulatory bodies (i.e. Council) to actively manage and maintain entrances for human amenity. ICOLLs, however, are prone to flooding from traditional rainfall-runoff behaviour as well as ocean inundation from passing low-pressure systems and, where local communities are at risk, must be managed to mitigate flood risk. Finally, Council must also consider NSW legislation based on environmental protection which suggests that, in general, ICOLL entrances should be managed with minimal interference and only artificially opened when the benefit is demonstrably greater than the associated cost (DPI, 2018). ICOLLs, then, often represent a significant managerial challenge to Council and require time and resources dedicated to flood studies, community consultation, entrance management studies, estuary process management studies, and environmental reviews to understand these systems and properly manage all of the key stakeholders and conflicting interests.

Looking solely at the flood-related side of this management challenge, many ICOLLs have historically been assigned trigger levels that, when reached, mean that the entrance must be artificially opened or risk inundation of nearby property and infrastructure. These levels have been set based on reasons ranging from detailed hydrodynamic study and local knowledge, to political/community pressure and historical continuity, and do not always represent best practice operationally. Further, the timing of any artificial breakout must be carefully considered to account for tidal cycles, wave climate, entrance condition and anticipated rain to ensure that works are performed only when required and that the overall flooding risk will be reduced. It is an extremely complicated management decision to determine when to initiate the opening of an ICOLL entrance and there is a need for professional guidance and decision support systems to assist managers and operational staff.

MHLFIT

NSW Government's Manly Hydraulics Laboratory has put together a flood modelling and visualisation suite it has branded the Flood and Coastal Intelligence Tools (MHLFIT). Leveraging off 40+ years of being the maintenance and data custodians for coastal NSW's environmental monitoring sites on behalf of NSW Office of Environment and Heritage (OEH), these tools were developed to provide Council with easy to access, highly available, and rationally based decision support mechanisms. MHLFIT is a bespoke, cloud-based technology which provides Council and the NSW State Emergency Service (SES) with online web portals which can be accessed anywhere with an internet connection and allow for interactive data access and visualisation. These tools are supported by MHL's high availability database named ORRCA, which provides near real-time environmental data for over 1000 sites across the state sourced from the Bureau of Meteorology (BoM), Water NSW, as well as internally managed sites. This database also supports the NSW Floods Near Me app.

MHLFIT was designed to provide value adds to communities which have little-to-no flood information, few resources or have particular flood-related issues which require fast and reliable specialist input. It is currently supporting data for many coastal councils in NSW and is looking to expand to inland areas where flash floods are prevalent and little information is currently available.

ICOLL Modelling

Due to the hydraulically complex nature of dynamically opening and closing tidal lagoons and the sensitivity of their flood peaks to tailwater conditions, ICOLL modelling was one of the first tools which was developed for MHLFIT. The system was developed to provide near real-time modelling using physically-based hydrologic, hydraulic and entrance models. MHLFIT uses the Watershed Bounded Network Model (WBNM) hydrologic model to route real-time and predicted rainfall into the lagoon and is supported by a 10-day antecedent moisture calculation to estimate initial losses for the Initial / Continuing Loss based model. From there, water is routed through the entrance using simplified 1-D flow calculations using projected tides as the downstream boundary condition and entrance condition (bed/berm heights, openness) to determine flow and scour characteristics. Entrance conditions for dynamically changing ICOLLs are estimated daily using a flow regression of the assumed vs. modelled flows for the prior 10-day period. These parameters are then used in the prediction calculations. Tides are forecast using astronomical forecasts with current tidal anomaly trends projected forward as well as pumping due to run-up of the localised wave climate. The nearshore wave climate forecast is collected from the NSW Nearshore Wave Toolbox which was developed in conjunction with Baird (http://www.nswwaves.com.au). The result of all of this is a lagoon level hydrograph projected an arbitrary length of time into the future.

Due to the uncertainty inherent in predictions of this nature it was determined to provide on-the-fly sensitivity testing using what-if scenarios. This feature required that the entire model be able to be run on demand and within a small enough time window that users could immediately view the results of their what-if scenario. This guided many of the model design decisions and ultimately resulted in ICOLL models which could project 36 hours into the future with runtimes in the order of 10-15 seconds. This scenario modelling will be further discussed later in this paper.

Manly and Narrabeen Lagoons

Manly and Narrabeen Lagoons are part of a chain of four ICOLLs located in the Northern Beaches LGA on the northern coast of Sydney (Figure 1). Active management of these lagoons has been ongoing since the 1970s and residents have ranked lagoon management as the second most important environmental service Council should provide (Ruszczyk *et al*., 2014).

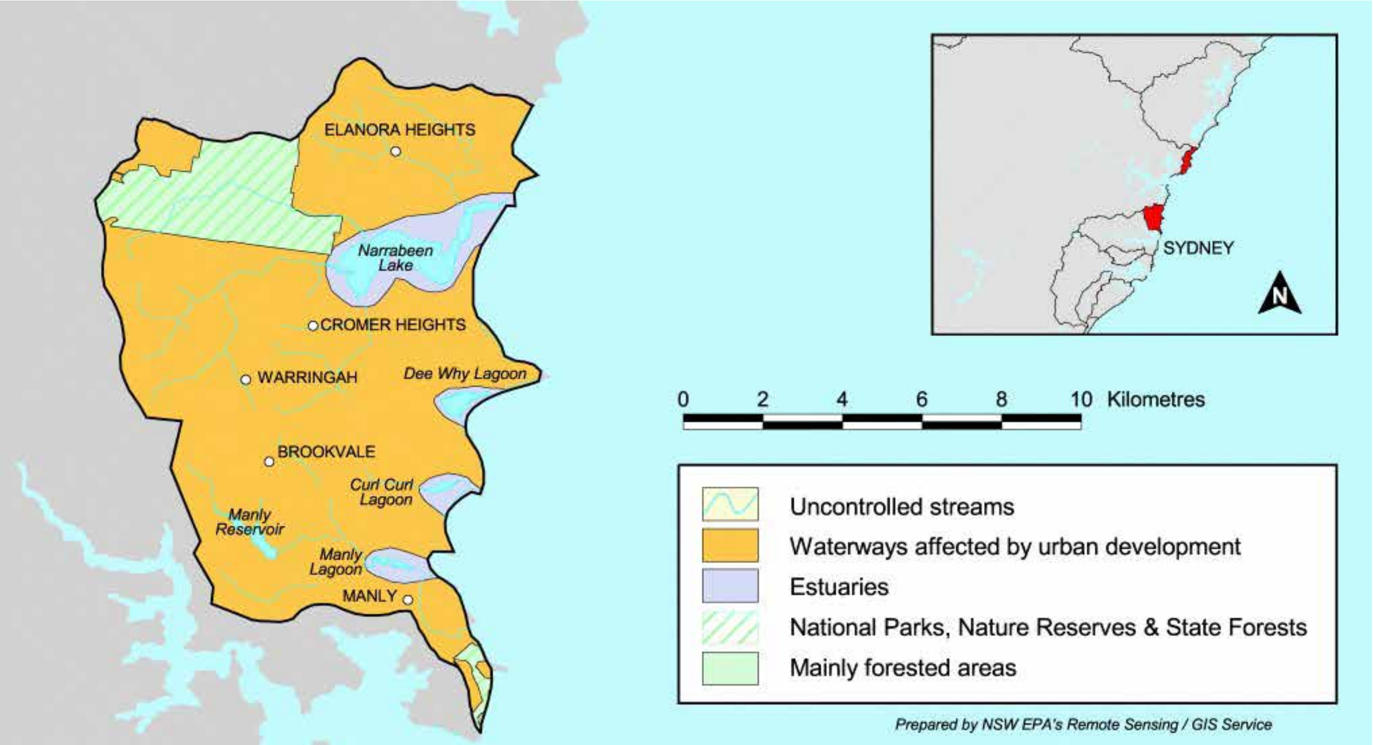

Figure 1 – Northern Beaches ICOLLs (from NSW Office of Environment and Heritage).

Recent flood events have been some of the worst on record, culminating with the June 2016 east-coast low which saw the highest level recorded in the last 30 years at Narrabeen Lagoon (2.2 m AHD). These events have placed increased pressure on Council to provide transparency in their management practices and improve their predictive capacity to better coordinate emergency operations.

Manly Lagoon

Manly Lagoon is a relatively small body of water lying within a ~1700 ha catchment which also contains Manly Dam. The lagoon entrance is closed under normal operating procedure but remains connected to the ocean via two low-flow pipes which allow flow of water both into and out of the lagoon. Due to the size of the catchment and high level of urbanisation, Manly Lagoon floods tend to be very 'flashy' with flood levels typically rising rapidly and declining over a longer duration. As a result, response times for emergency procedures are short (in the order of hours) and to reflect this, Council has earthmoving equipment permanently staged at the entrance to allow expedited entrance opening. Adding further to the management challenges, any outflow from the dam is routed directly into the lagoon via Manly Creek. The lagoon itself is quite low-lying with a minimum bed level of around 0.2 m AHD and floodplain expanding to the two adjacent golf courses.

Narrabeen Lagoon

Narrabeen Lagoon is a much larger body of water than Manly and lies within a catchment of ~5200 ha. It is a more traditional ICOLL with a dynamically varying entrance which closes due to longshore sedimentation from Collaroy-Narrabeen Beach and then opens when flood levels in the Lagoon exceed the natural berm height of the deposited sand. Council performs mechanical entrance breakout of Narrabeen, similar to the process of Manly by digging a channel connecting the lagoon to the ocean through North Narrabeen Beach. Council also maintains the entrance through occasional dredging of the lagoon around the Ocean St bridge. There is a rock shelf at the entrance to Narrabeen Lagoon which maintains a minimum entrance height of about 0.1 m AHD when the entrance is open. There is a lot of pressure placed on Council by the community to keep the entrance open and, when works are performed, the quality of the works are judged by factors such as how long the entrance remains open.

Northern Beaches Model Setup

The Manly and Narrabeen Lagoon hydrologic models were adapted from those developed for their respective flood studies. A number of different entrance equations were developed that could be utilised by the various models under different conditions. In the case of Manly Lagoon, more than one flow is necessary during a mechanical entrance opening as there are two distinct channels through which flood waters may pass. The models were set up to accommodate this behaviour when appropriate.

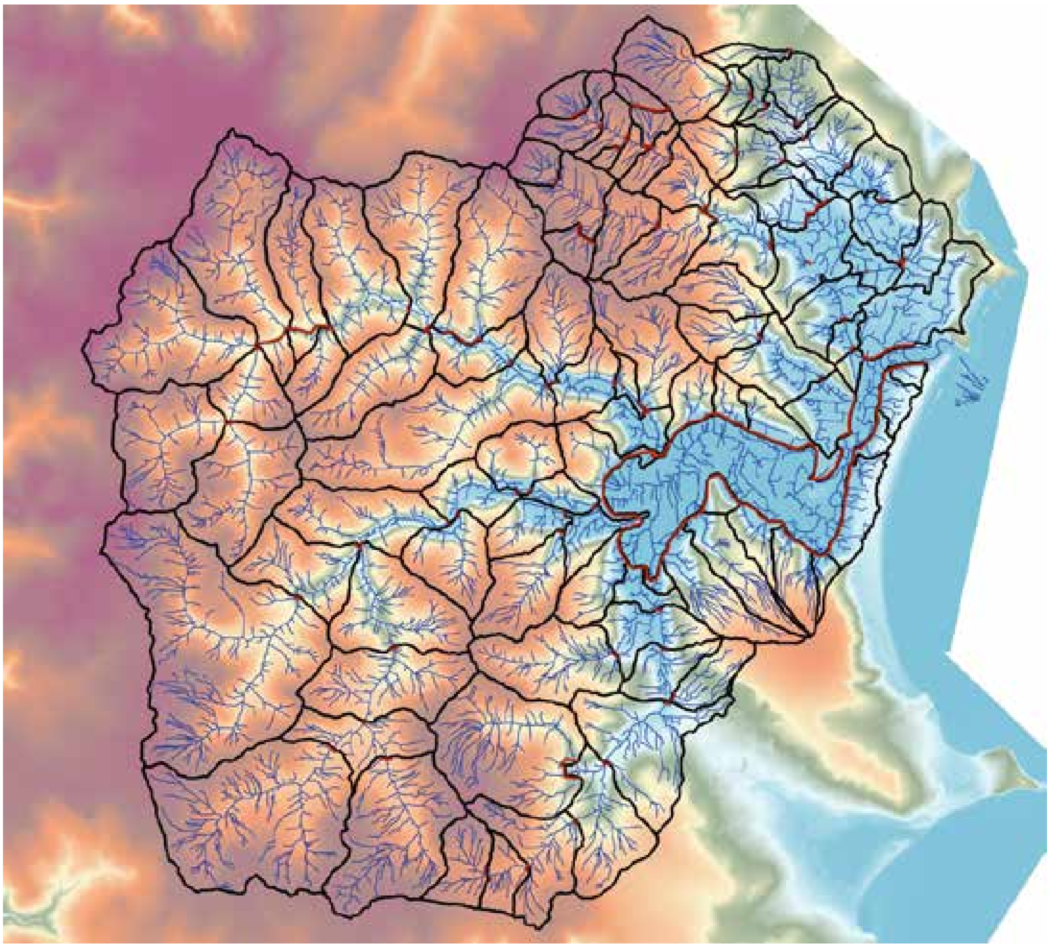

Figure 2 – Narrabeen Lagoon hydrologic model setup.

Scenario Modelling

The models were set up to run under two forecast scenarios initially: a persisting condition in which the average of the prior 4-hours of rainfall is projected for the entire projection period, and an abating condition in which all rainfall ceases immediately. These scenarios aim to present a lower and upper bound for hydrograph peaks once a rainfall event has already begun. Gridded rainfall predictions from BoM have now been included into the system as a third prediction timeseries in the web portal.

The gridded forecast provides some useful indication of potential rainfall threats up to 3 days out, however as peak lagoon levels are most sensitive to incoming rainfall spatial and temporal patterns, it was important to be able to test user defined scenarios within the MHLFIT framework. To achieve this, Council has been provided with a what-if scenario page within the MHLFIT web portal. This page allows users to input up to two different rainfall events which the model will run, providing output hydrographs for the scenario. These events can be of a specified intensity over a given period, or a discrete quantity of rain over a chosen period. Additionally, users can set a tidal anomaly to simulate an East-Coast Low type event and assign a time when the entrance channel will be mechanically opened to determine how the flood peak will change with opening timing. An example of the output of one of these scenario runs is presented in Figure 3. As mentioned previously, these runs take less than half a minute to run and can be changed as many times as desired by the user. Once set, these scenarios will run every 15 minutes, when the model updates, along with the three base scenarios, providing a dynamic view of the flood as it develops.

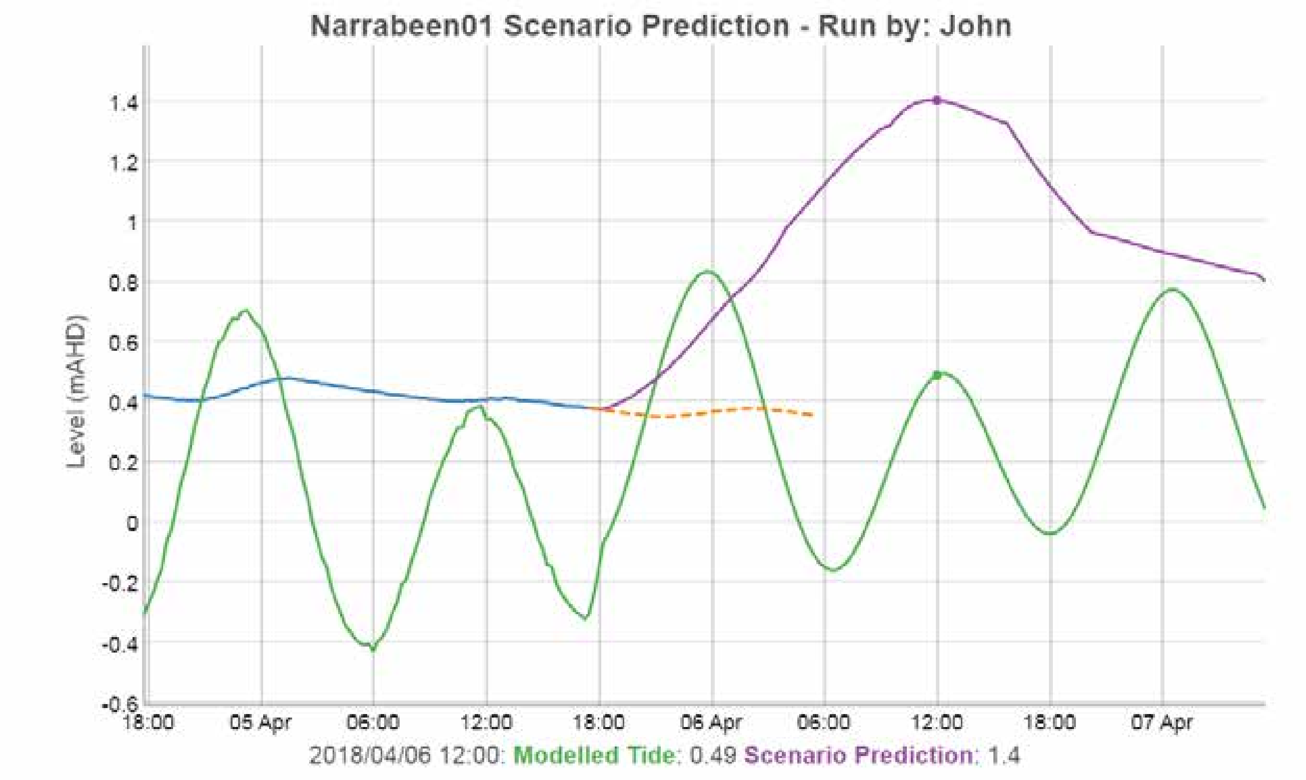

Figure 3 – Example of user defined scenario model output.

Visualisation and Decision Support

In order to better assist Council and emergency operations personnel, outputs from both models have been integrated with modern data visualisation techniques. 1D predictive model results are extrapolated using behaviour derived from observation of 2D modelling. An interactive flood extent is presented on a map element with each model update, displaying the timing and magnitude of the predicted flood (Figure 4). The tool provides at-a-glance inundation potential and is anticipated to aid emergency operations personnel in the field. Also presented are key road and infrastructure levels which are displayed as points using a traffic light system to indicate when roads might become cut-off or pieces of key infrastructure might become damaged or unserviceable.

Figure 4 – Example peak inundation extent map element for Manly Lagoon.

These maps also prepare managers and the SES to plan for evacuation routes and resource priorities given advanced warning of an event. Both of these elements together are presented in a lagoon level (or stage) explorer. This page lets users select a predicted lagoon level and view the potential flooding at that level based on ocean inundation (contour) and mainstream flooding (hydraulic gradient), as well as whether any of the chosen points of interest would be affected at that lagoon height. Finally, users may view the following 12 hours of flooding as an animated inundation raster to get a more intuitive feel for how the flood might develop as well as view flooding depths more carefully (Figure 5). These visualisation elements were developed in conjunction with Council to fulfil their requirements for decision making using the MHLFIT portal as well as anticipated requirements from the local SES.

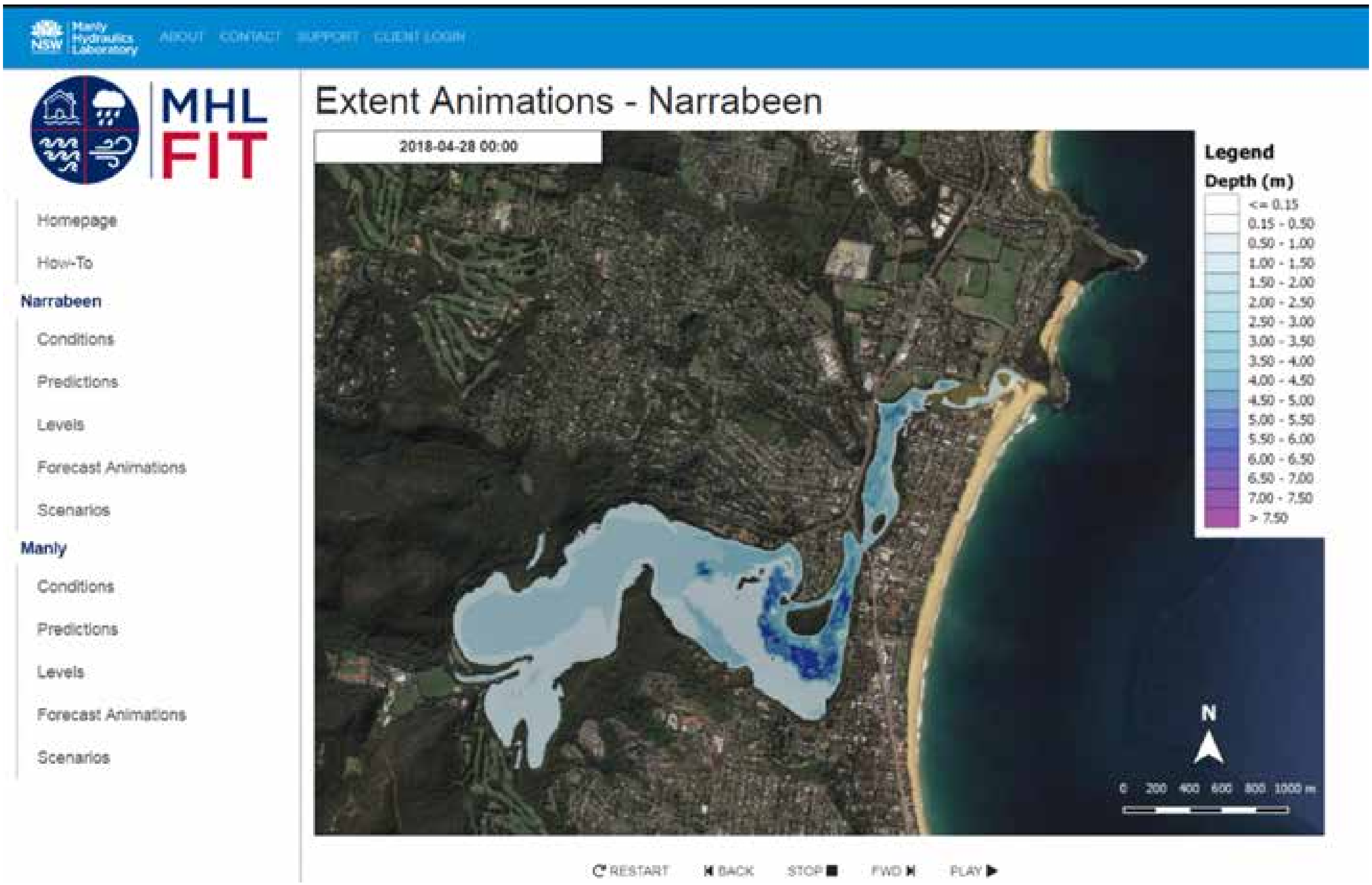

Figure 5 – Example frame from Narrabeen predicted inundation animation.

All data visualisation elements are tailored to Council's needs and are undergoing iterative improvements to provide ongoing support and cutting-edge tools to aid in decision making.

MHLFIT in Operation

The Northern Beaches MHLFIT portal has been operational since August 2017. Provisions have been incorporated for a backup gauge to be used in each model should the primary gauge become unresponsive or faulty during an event. Further, all relevant MHLFIT models now have access to the BoM's Australian Digital Forecast Database (ADFD) gridded rainfall forecasts which feed in as another automated prediction scenario. Investigation is currently underway to integrate forecast products to further improve the accuracy of predicted rainfall. These short-term forecasts are created by BoM using rain radar data and update in the order of minutes (compared to the 12-hour cycle of the ADFD) which is better suited to flash flood prediction. Once the forecast is publicly available, it will be integrated into a prediction timeseries for all applicable MHLFIT tools. Further work is currently underway to investigate berm heights at Narrabeen Lagoon. One of the big sources of uncertainty when the lagoon is closed is what level the lagoon waters need to reach to start escaping into the ocean. Understanding when and at what level this will occur for any given event will help Council plan beyond a simple trigger level approach to entrance management.

The Narrabeen model was successfully used to help inform the decision of when to open the entrance during a storm in March this year. The system is being continually improved by actively seeking feedback from MHLFIT users to help improve the system and has an ongoing communication channel open with Northern Beaches Council to help tailor their portal to fit the requirements and improve presentation of their flood intelligence.

Acknowledgments

Thank you to Northern Beaches Council for sharing their experience and knowledge during the development of the system.

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