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AHA

Australian Hydrographers Association
National Office
02 6296 2795
services@aha.net.au
PO Box 1006
Mawson ACT 2607
Australia

Journal Editor and Advertising

Jacquie Bellhouse
journal@aha.net.au

Design

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

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JACQUIE BELLHOUSE

Editor’s Introduction

This quarter I find myself writing to you from sunny Kununurra. Our team flew out just as a cold front was moving in on Perth, consequently I and the team have been enjoying the sun and temperatures ranging from minimums just below 20°C to maximums in the mid-30s, while Perth is finally seeing its first decent winter rains and corresponding drop in temperatures. It seems we picked the right time to travel.

Some fun facts about the Ord region curtesy of the Department of Water and Environmental Regulation’s (DWER) 2014 Pamphlet “Managing water from the Ord River”:

Figure 1: Ord Dam and (a small part of) Lake Argyle.

The Ord River is one of the more significant waterways in Australia, It provides water to the Ord-East Kimberly Irrigation areas, the Ord River (Hydro) Power Station, supports local tourism and sustains a unique set of environmental values. The priority set for the scheme is for secure and reliable water supplies to maximise the irrigation potential, while at the same time support hydro-electric generation and sustaining a healthy downstream river environment. As you can imagine the resulting water release rules are fairly complex. They are also particularly important during times of below-average storage and dry periods, ensuring the most effective water sharing.

Water flows from South to north along the Ord River and is stored in Lake Argyle by the Ord River Dam, the mean annual stream inflow 4,278 GL. The Ord Dam itself is capable of storing 2.5 times the mean annual stream flow or 10,760 GL at full supply level. During floods it can store up to 18,660 GL between full supply and the first auxiliary spillway. In comparison the current combined storage across all of Perth’s Water Supply Dams (as I write this) sits at 282.33 GL.

In the Lower Ord (downstream of both the Ord River and Kununurra Diversion dams) the annual average flow past the Tarrara Bar Gauging station (in semi recent years) has been 3,480 GL a year with a typical dry season flow rate of between 42 to 65 m^3/s.

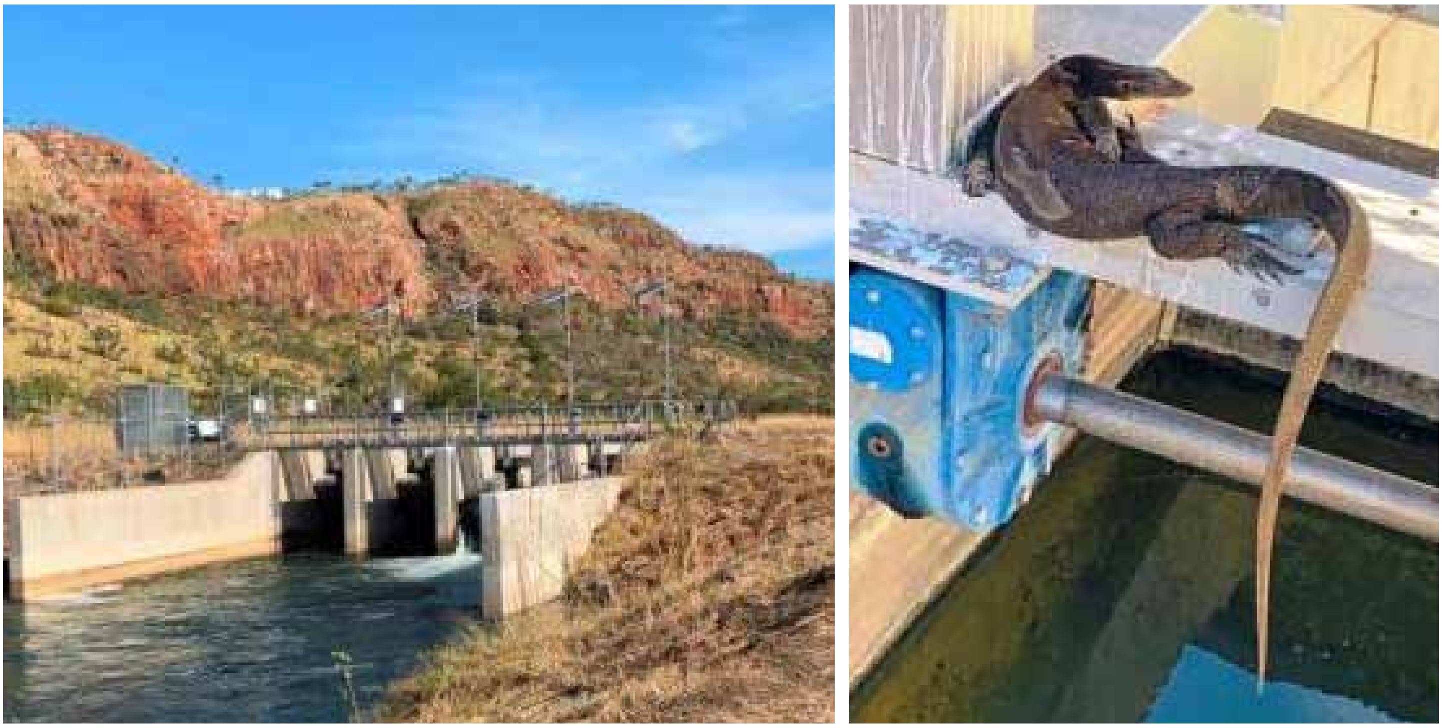

Figure 2: Left, M2 Irrigation Channel, Kununurra. Right, The resident "gatekeeper".

Of particular importance to the agricultural development is the 750 GL/y available from the Main Ord Subarea (using water from Lake Argyle). While losses to the system include net evaporation ranging from 1106 GL/y to 1151 GL/y dependent on the applicable licensing arrangements.

With the volume of water moving around the Ord and Lower Ord systems it is not surprising that the small town of Kununurra has become a bit of a hub for generations of WA Hydrographers. In fact even though I have only just arrived in town I have already bumped into a number of fellow hydrographic professionals from both sides of the fence (the Water Corporation and DWER). These impromptu gatherings as is customary eventually evolved into a few rounds of storytelling.

This is probably why I am so excited to present to you both a profile and article from a past mentor of mine (does he have a story or two to tell!). Russell Mark's latest article "Why Hydrography is Important to Environmental Accounting" is a very interesting and thought provoking article on how hydrography can be critical to Environmental Accounting.

Also inspired by my current location at the top end of Australia I am happy to present a paper presented at the 2018 AHA conference on the Modelling Rating Curves to "Manage Uncertainty in the Fitzroy River Catchment in North West, Western Australia" by Lauren Greening, and a paper from an ex-Northern Territory resident Daniel Wagenaar on the use of the Hypack Application in Topographic Surveys.

I was also excited to receive a submission from NIWA's Jeremy Bulleid on his work to develop a practical tool for the "Automatic Discharge Measurement of Lowland Weedy Streams". Jeremy has indicated that we can look forward to a follow-up article in the coming months.

I hope you enjoy this quarter's content as much as I have and I encourage our members to keep the articles trickling in (no pun intended).

Jacquie Bellhouse
Journal Editor

BILL BARRATT

From the President

Desmond John Sherlock FAHA

25/1/1926 to 15/6/2019.

Des Sherlock with his first powered traveller on a cableway on the Shoalhaven River in the mid 1960s.

Des was born in Maroubra, Sydney, the eldest of 4 children, 2 boys and 2 girls and educated at Randwick and Sydney Boys High, Sydney Technical College and the Maroubra Surf Club.

When finishing high school Des wanted to study Aeronautical Engineering but his father suggested civil engineering with a prediction that there would be lots of roads and dams to be built after the war finished —how true.

So Des started his career as a cadet civil engineer with the Water Conservation and Irrigation Commission of NSW in 1942. On achieving his qualifications, he specialised in the Hydrographic Branch, and from 1946 was mainly involved in constructing and operating the gauging network in the eastern Snowy Mountains, in preparation for the Snowy Mountains Authority, with a group of wild ex-servicemen as his hydrographic staff.

During mid-1948, Des engaged Don Benson, from Khancoban, to build the stone work for a new camping hut at the Swampy Plains River at Geehi, from river stones as specified by Kosciusko State Park administration. The timber work, fitout, and malthoid roof was finished by the hydrographers. In 1949 the roof had to be painted green to satisfy the Parks requirements. Access to this area was by horseback. The hut was originally called *Ibis*, then *Hydrographer's*, then *The Commission* and sometime later *Old Geehi Hut*, which is its current name.

In 1950 Des and Val were married and soon after were sent to Albury to open a new District Office to administer the establishment of the western Snowy Mountains hydrographic network. This was an area with few access roads. They hiked and rode horses in the summer and cross country skied in the winter.

In 1952, this network started to be handed over to the Snowy Mountains Authority and Des was appointed the District Hydrographic Engineer in Armidale where he was responsible for a network covering 75 thousand square miles (194,000 km^2). The following year he was promoted to Hydrographic Engineer Operations, located in Sydney, responsible for all the field work in the state.

In the late 1950s, Des was awarded a Churchill scholarship to study river gauging practices at the United States Geological Survey (USGS). He came home with an added desire to develop and manufacture instruments and equipment in Australia, suitable to our local conditions and costs. He could not see the value in most of the imported overpriced instruments.

The Commission had started buying Stevens servo manometers, designed by the USGS, for gas purge water level sensing. Hence, reducing the need for an expensive float well. These were difficult to operate so Des employed the first instrument technician to help operate these. Thus providing a maintenance back up for the Hydrographers, and training for all new hydrographic assistants.

In early 1961 Des completed the development [in his own time and money with a material cost of £100] of his first powered traveller. It was developed and tested by bringing the milk down to his house at Picnic Point. His bosses reluctantly paid for the cost of materials. The first field unit was installed below Wyangala Dam on the Lachlan River, after remedial works had started. [The dam that walked.]

After having the USGS Stevens Servo Manometers in service for a couple years, Des realised it was about 32 times easier to measure water levels direct rather than the changes in level of mercury in a manometer. So he developed the idea of a force balance system, which became the Sherlock Differential Pressure Sensing Unit model DP30. The detailed design for the prototype was done while travelling around NSW by train to supervise his field staff. The prototype was built in the corner of a friend's aircraft maintenance hangar at Bankstown airport. The bellows design was internationally patented. The metric versions became the financial mainstay of his company, until it became too expensive to manufacture in the 1990s.

His Hydrographic group, in the Commission developed the original Hydrography Certificate course, in conjunction with the Sydney Technical College in the early 1960s.

In 1965, with 3 children at school, frustrated by his superiors refusing to finance equipment development, Des resigned. He went home to Picnic Point and started the *Hydrographic Instrument Company* in his garage. His first order, some 6 months later, was from the Sydney Water Board for the supply, installation and commissioning of a number of Trailer Mounted Powered Travellers, and six permanent travellerways, to be installed in the Shoalhaven Catchment, for the proposed water supply dam for Sydney.

These were followed by two installations on the Clarence River for the Bureau of Meteorology. The first was at Lilydale, where Grafton County Council Hydrographic staff measured the largest discharge by conventional current meters in NSW. The second was installed in the Pilbara for the, then young, late Brian Chester.

In 1969, the company had now outgrown the home workshop, and with the help of a good friend, Ray Green, found the Warwick Farm site on the Georges River, and purchased the 5 acre block complete with the derelict house of Major Moore, circa 1848, built with second hand sand stock bricks. The name was changed to *Hydrological Services Pty Ltd* (HS), to reflect it was both a manufacturing and service provider.

This site was developed over about 10 years, initially with lean-tos attached to the old house, then the back section of the factory, then the office block and finally joining the two [with the removal of the old house] in October, 1978. This coincided with the establishment of the AHA.

Initially, test facilities were built for Powered Travellerways, consisting of a 220 metre cableway, requiring permission from 28 government bodies. Then, manual traveller winches, a 10 metre calibration bore followed by a 50 metre one for gas purge water level instruments. Then, appropriate facilities for each new product developed. The most impressive and expensive was the Current Meter Rating Tank, completed in 1994 by Des during his semi-retirement. This facility was the most accurate in the world at the time!

Des was always interested in the younger generations, whether socially or in the work place. In the early 1960s, he was part of a group that brought in the requirement for NSW hydrographers to have a Leaving certificate [now the HSC]. This carried over as a requirement for Hydrographic Assistants (HA). With the employment of an Instrument Officer, each HA had to spend a 6 month apprenticeship with him to learn to maintain, calibrate and basic repairs of all equipment in use.

At HS, Des employed apprentices in the metal trades, and as the company grew employed university students in their vacations, with some joining the permanent staff on graduation. He believed that our future lay with training the next generation. Training was provided free at the factory for customers, from a few hours to weeks and overseas in association with projects.

He was a tough task master to work for, but a very supportive boss when people were in need. If any of his staff got into personal difficulties, Des would do his best to help them resolve these for the best possible outcome. He believed the community in the work force should look after any one in need of assistance for the benefit of all.

Des was a keen supporter of the AHA from its inception, and was the first financial sponsor, and provided facilities and encouragement for meetings and social events.

When Des finally retired in 2000, he had given nearly 60 years to our hydrographic industry in Australia and many overseas countries. In 2018, Des was awarded a fellowship of the AHA with life membership, in recognition of his service to our industry.

DES IS THE FATHER OF OUR HYDROLOGICAL MANUFACTURING INDUSTRY IN AUSTRALIA.

Bill Barratt. FAHA
President

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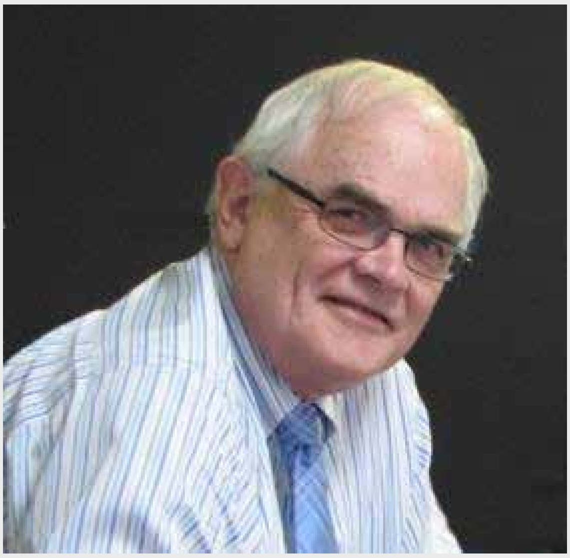
AHA Member Profile – Russell James Marks



I started as a trainee hydrographer in 1970 with the Western Australia Public Works Department (PWD). During my time with the PWD I was awarded the NSW Certificate in Hydrography (1974) and then completed a WA Diploma in Electronic Engineering (1978).

Between 1970 and 1980 I travelled a fair part of Western Australia (WA) gauging, at various times, most of the rivers between Carnarvon and Esperance.

The highlights include the opportunity to gauge the overflow from Mundaring Weir during the flood of 1974. This was the second last time the weir spilled, the last being in 1996. I was also fortunate to be at 9 Mile Bridge on the Gascoyne during the flood of 1978.

I moved to the South Australian (SA) Engineering & Water Supply Department in 1980 which resulted in my travelling over a lot of the settled areas, gauging their rivers. This included the River Murray during the flood of 1983 and some time in Mt Gambier gauging the south east rivers. I was also fortunate enough to spend four weeks at Birdsville gauging the Diamantina during the flood of 1981.

My electronics qualification led me to become involved in the development of computer systems such as the Hydromet Project which was aimed at developing the SA Water Information Database. This led to my being appointed as the Data Manager for the SA Department of Mines and Energy in 1988.

In 1990 I moved with my family back to WA and established Greenbase. During this period Greenbase formed a cooperative with Murray Ryall (Nuytsia) and Kel Baldock CPH (HydroSmart). By the end of the 1990s we had a total of around ten staff working on various consulting projects, not all water related, while I worked as a consultant hydrographer contracted to the Water Authority, Waterways Commission, Alcoa and various other mining companies, as well as a number of local government authorities.

In 1998 we discovered the Commonwealth National Pollutant Inventory (NPI) and, on request from the Sons of Gwalia gold mining company, commenced development of what has become the Greenbase environmental accounting system. This system is based upon all the principles and practises of data management that I learnt as a hydrographer and then further developed over time.

We accumulated a number of mainly mining clients over the period to 2008, providing a web enabled NPI reporting service. In 2008 the National Greenhouse & Energy Reporting System was established by the Commonwealth Govt. We were requested by our clients to extend the system to provide National Greenhouse and Energy Reporting (NGER) reports as most of the base data is common to both NPI and NGER reports.

Since then Greenbase has grown, now employing around 20 staff and involved in providing reporting services to around 80 clients spread across a range of industries in Australia, Canada, Tanzania and for a while Saudi Arabia. We are heavily involved in reporting services related to climate change, emissions trading and sustainability.

These days I am Chairman of Greenbase Pty Ltd and, because the staff won't let me retire (I know too much), I spend my time in semi-retirement. I am still a proud card carrying member of the Noble Order of Antediluvian Hydrographers though.

Hydrography taught me how to manage large volumes of environmental data. This proved to be fundamental to developing an environmental accounting service and has allowed me to be fortunate enough to become involved in the emerging profession of Environmental Accounting.

In 2018 I decided to put down on paper my ideas on the principles of environmental accounting. I am sure that any dedicated hydrographer would recognise and be familiar with these principles.

Why Hydrography is Important to Environmental Accounting

Russell Marks, Greenbase Pty Ltd, Perth, WA

Abstract

As the world becomes increasingly aware of such issues as climate change and increasing pollution, Environmental Accounting is emerging as an important profession in accurately quantifying environmental performance and impacts.

Hydrographers can be assured that their data are critically important to Environmental Accounting as it is becoming one of the more important end uses. As such, hydrographers have a lot to contribute and should become involved in the developing debate.

This paper discusses the principles underlying environmental accounting in relation to the principles and culture underlying the hydrographic profession.

Introduction

Mother Nature does not settle accounts with money. Instead Mother Nature settles accounts with unintended consequences. Hydrographers learn this early. For example: if we build a flow measurement structure in an unstable creek bed then we had better protect it well otherwise it will disappear in the first high flow. Every hydrographer could relate their-own experiences of this truism.

So it is with the environment in general. If a mining company constructs a huge tailings dam and does not pay proper attention to the geological conditions within which it sits or prevailing climatic conditions then the company risks serious social consequences when the tailings dam fails.

But how do we reliably quantify the environmental account and how do we reliably quantify the consequences? The answer involves the emerging profession of Environmental Accounting.

What is Environmental Accounting?

To answer the question, we must first examine the meaning of 'accounting'. At its most fundamental level accounting seeks to answer the following question:

"Is the information I am reading reliable?"

Since the dawn of civilisation this question has been critical to successful trade, it should be no surprise that it has therefore become critical to financial transactions. Consequently, the word accounting is commonly and almost universally associated with financial accounting. However, the issue of reliability is critical to all forms of information including environmental information and, in particular, water information. Environmental accountants therefore seek to answer the following question:

"Is the environmental information I am reading reliable?"

Similar to financial accountants, it follows that environmental accountants focus upon demonstrating the reliability of the information they are presenting in reports and accounting statements. This invariably involves developing and exposing the audit trail sitting behind the presented information.

Environmental Accounting Principles

Introduction

Demonstrating reliability of information rests upon certain principles. Financial accountants first recognised some of these principles millennia ago but they were only codified in the late 15th Century when Fra Luca Pacioli published his treatise on double entry bookkeeping (Gleeson-White 2012).

Since then modern financial accountants have worked upon a complete definition of the principles underlying their profession. Partly in response to the 1929 stock market crash, this work resulted in the Generally Accepted Accounting Principles (CPA Australia 2012) adopted by professional financial accountants in the United States and increasingly by the western world generally.

Generally Accepted Accounting Principles (GAAP)

The Generally Accepted Accounting Principles (GAAP) are primarily intended to be applied only to financial information and as such do not exactly equate with environmental accounting principles. However, there are sufficient similarities that comparisons with the GAAP principles serve as a worthy starting point for discussing environmental accounting principles.

With respect to GAAP, environmental principles can be grouped into 3 categories:

- Environmental accounting principles directly equivalent with GAAP principles;
- Environmental accounting principles analogous to GAAP principles;
- Environmental accounting principles which have no GAAP equivalent.

Environmental Accounting Principles Directly Equivalent

In brief, the GAAP principles that are equivalent to environmental accounting principles are shown below. If the word “financial” is replaced with “environmental” then the principles read the same.

- **Full Disclosure Principle**
  All information that would “make a difference” in decision making should be disclosed in financial statements.
- **Materiality Principle**
  Financial information is material to the financial statements if it would change the opinion or view of a reasonable person.
- **Conservatism Principle**
  You should always err on the most conservative side of any transaction.
- **Accounting Relevance**
  Accounting relevance relates to the usefulness of financial information to users during the decision making process.
- **Accounting Comparability**
  Information that is prepared using the same measurement techniques is considered comparable.
- **Objectivity Principle**
  Accounting information and financial reporting should be independent and supported with unbiased evidence.
- **Industry Practices Constraint**
  Some industries have practices unlike any other that require specialized accounting or reporting approaches.
- **Accounting Reliability**
  Refers to whether financial information can be verified and used consistently.
- **Accounting Consistency**
  Accounting methods should be used consistently over time.

Environmental Accounting Principles Analogous to GAAP Principles

In brief, the environmental accounting principles analogous to GAAP principles are:

Physical Facility Assumption and Responsible Entity Assumption

All activities and events being accounted for are assumed to be contained within a definable physical (spatial) boundary. This is commonly known as the Physical Facility. Then it is also assumed that all activities comprising the Physical Facility are controlled by a single identifiable person or entity.

Together, these two principles are directly analogous to the GAAP Economic Entity Assumption and are also referred to as the ‘Reporting Boundary’.

The obvious immediate question that springs to mind is: “How do these two principles apply to natural resources?”

With respect to natural resources, the physical facility boundary is the physical extent of the natural resource (e.g. catchment boundary, aquifer, forest, etc.). The responsible entity is the political entity charged with managing and maintaining the natural resource. Inevitably, it will be the case that the natural physical facility boundary and the responsible entity jurisdiction boundary will not coincide. It is from this inevitability that conflicts arise between nation states or other political entities.

Accounting Period Assumption

It is always the case that a measurable quantity in the environment will be in relation to a point in time or a period of time. This is the temporal context.

An item of environmental information devoid of the temporal context has no meaning and therefore no place in the environmental accounts.

The accounting period and reporting period must be stated in all environmental accounting statements.

This is analogous to the GAAP Time Period Assumption.

Viable Entity Assumption

It is assumed that the responsible entity will continue long enough into the future to ‘make good’ future environmental obligations and rehabilitate environmental impacts.

This is analogous to the GAAP Going Concern Assumption.

Unit of Measure Principle

Environmental quantities are measured in many different units of measure depending on the particular parameter. For example: water is usually measured in cubic metres whereas greenhouse gases are usually measured in tonnes.

The Unit of Measure principle is different from the GAAP Monetary Unit Assumption: in that all quantities in an environmental accounting statement are not required to be stated in a single unit — monetary or otherwise.

Instead, all quantities in an environmental accounting statement are stated in a single system of units. For example: Système Internationale (SI) Metric units, Avoirdupois, British Imperial units, etc.

Probability of Use Principle

The GAAP Cost Benefit Principle states that the cost of providing financial information in financial statements must not outweigh the benefit of that information to the users of the financial statements. Like financial information, environmental data is not free.

Companies spend large sums gathering and organizing financial information for the purpose of compiling financial statements and, increasingly, large companies are being required to collect environmental data for the purpose of reporting various environmental performance measures. Environmental data is similarly costly to obtain, manage and maintain.

It seems paradoxical, but on its own, environmental data has no value. Environmental data only has a probability of being used.

The Probability of Use Principle states that the cost of collecting, storing, validating and providing environmental data should be commensurate with the probability that the data will be compiled in environmental accounts and used in decision making.

Data with a low probability of use should be accompanied by the minimum cost of collection and validation. Data with a high probability of use should attract a commensurately higher cost. Zero probability of use data should have zero cost or, in other words, should not be collected at all.

Temporal Integrity Principle

Environmental performance over successive accounting periods should be related primarily to the activities that cause environmental impacts and not related to the methods used in deriving quantities or preparing the environmental accounts.

A clear example is when hydrographers develop a new stage discharge relationship for a particular gauging station. The previous relationships are not deleted or overwritten. Instead each relationship is allocated a period of application.

In that way, there is a clear audit trail tracing a consequential effect in the accounts back to the documented change in stage discharge relationship. A reasonable user of the information is then able to discover the audit trail with relative ease.

As such, the Temporal Integrity Principle is analogous to and an extension of the GAAP Consistency Principle.

Environmental Accounting Principles that have no GAAP Equivalent

The following environmental accounting principles are not matched by GAAP principles. This is because of the unique issues in environmental accounting.

Unit Conversion Principle

It is rare to be able to measure and record environmental quantities directly.

For example: unlike monetary quantities, where a dollar can be identified and counted directly, the mass of a water body must be determined from base measurements of length, breadth and depth. These base measurements are then used to derive, firstly, the volume of the water body and then the mass using a density conversion factor.

The unit conversion principle states that derived quantities must be determined using recognised unit conversion methods. These methods use recognised ratios between quantities of different units of measure and different systems of measurement. For example: 1 foot (British Imperial) = 0.3048 metre (SI).

The unit conversion methods must be stated and/or referenced in the environmental accounts.

Raw Data Principle or Indefeasibility Assumption

The indefeasibility assumption is the most fundamental principle in environmental accounting and is easy to understand but it is difficult to explain. Put simply: it is a principle applied in cricket umpiring, where the umpire's decision cannot be challenged — it is right even when the umpire makes a mistake.

The raw data principle states that a copy must be kept of every original raw dataset. This copy must be catalogued and stored in a secure repository that prevents future alterations. Adopting this practice enables the indefeasibility assumption.

Indefeasibility of data, in its general sense, is defined as that characteristic of a data item or dataset which means it cannot be questioned, made void, or cancelled. In other words; the data stands as is. This is because there is no precursor data in existence which precedes it. It is the first dataset in the chain of data (or audit trail).

Valid Dataset Principle

All environmental quantities can contain errors — particularly observations recorded by automated electronic measuring equipment such as sensors connected to the internet via satellite or some other communication network. This means every raw dataset must be validated against independent information.

For example: assume that an electronic sensor situated at a drainage channel registers an apparently unusual rise in water level. The hydrographer would validate the rise in water level by checking weather records to see if a rainfall event occurred in the vicinity at the same time.

Then assume that weather records show no rainfall event: leading to the conclusion that some other unknown interference caused the rise in water level.

The hydrographer would make a copy of the raw dataset for the purposes of removing the rise in water level from the record and inserting a comment in the dataset to explain the reason for editing the record. At the same time the hydrographer would ensure that the valid dataset contains references to the raw dataset.

This practice leads to a minimum of two datasets in every case: the raw dataset; and the valid dataset.

Thus, the Valid Dataset Principle states that a copy of a raw dataset must be made for the purposes of editing out anomalies and correcting faulty periods of record. Also, an audit trail must be kept to trace the provenance of the validated dataset back to the raw or indefeasible dataset.

Uncertainty Principle

In the world of commerce, it is nonsensical to state something like: "I bought the packet of soap for $5.47 plus or minus 1.37%". All financial accounting quantities are exact.

Conversely, no environmental accounting quantity is exact. All environmental quantities carry a tolerance or level of uncertainty. It is quite reasonable to state something like: "The tank is currently holding 60,648 litres plus or minus 0.5%".

The Uncertainty Principle states that you should understand the level of uncertainty in every quantity, in particular, quantities that have been derived and/or aggregated.

As such, within reason, data derivation and accounting methods should be adopted that serve to minimise uncertainty in the final environmental account quantities.

Then, so as to not convey the impression that the environmental accounting statements are exact, uncertainty should always be stated in every statement.

Facility History Principle

Environmental accounting invariably involves the derivation of quantities that cannot be directly measured (e.g. water flow). Consequently, those quantities must be derived from parameters which can be directly measured (e.g. water level). There will also be instrument calibrations, associated observations, comments and file notes which may have a material effect on the derived data.

Parameter derivation relationships are in many cases site specific and often not simple. They can change over time, particularly site-specific relationships where the relationship is dependent upon physical characteristics at the facility. Instruments are also replaced at times and instrument calibrations are often dependent upon ambient conditions such as temperature.

Thus, the Facility History Principle states that all parameter derivation relationships and associated information which may have a material effect, on the derived data, must be recorded and made available to enable a reasonable stakeholder to verify the environmental accounts.

The usual method by which this principle is implemented is for the environmental accountant to keep a 'Facility History File' onto which all parameter relationships, instrument calibrations, associated observations, comments and file notes are placed.

Environmental Accounting Sub-Divisions

Environmental Accounting relates to physical measurements and comprises three main strands: Water, Land and Air. Of these, water accounting is the most developed. The other two are still in the early stages of development and, as yet, the notion of a land account or an air account does not exist.

The notion of a water account however, is reasonably well understood. It involves a statement of water extractions, water storages and water discharges in terms of water quantity and quality. But this statement must be over a specified period for a particular spatial scope or an industrial facility. As such, a water account becomes critical to accurately quantifying water quality discharges and thus pollutant emissions to water. This particular aspect is important when industrial facilities provide annual reports to the Commonwealth National Pollutant Inventory (NPI) and other reporting frameworks such as the Global Reporting Initiative (GRI) and the Climate Disclosure Project (CDP). Hydrographers should familiarise themselves with these programmes as they show where water data ends up and the things it is used for.

Where do Hydrographers Fit in Relation to Water Accounting?

Clearly, a water account is only as good as the data upon which it is based. It is in this area that hydrographers have a lot to contribute to Environmental Accounting.

The principles and practises that we apply in collating and managing water data are equally fundamental to water accounting and by extension to environmental accounting.

Hydrographers regularly debate uncertainties in their data and intuitively understand how to correctly measure water parameters to minimise those uncertainties at the source. Hydrographers also understand how to then propagate those uncertainties through the various calculations on the way to producing final numbers such as an annual discharge. As such, the hydrographer culture is the reason hydrographer-collected water data is routinely considered to be reliable. Therefore, as water accounting becomes a focus in relation to managing the environment hydrographers should an increasing focus on their profession.

To Sum Up

Of the three strands that comprise the emerging profession of Environmental Accounting, water accounting is the better developed. The reliability of water accounting however, is critically dependent on the reliability of water information. This means that water accounting is critically dependent upon reliable water quantity and water quality data.

As collectors and custodians of water data over long periods (sometimes extending over centuries) hydrographers, in the pursuit of reliable data, have developed a culture that embodies the principles described above. However, those principles have not been formally defined until now (Marks 2018).

During the 20th Century, accounting principles have been defined by the financial accounting profession however, for good reason, the principles do not exactly equate with environmental accounting principles.

Hydrographers should not be surprised to discover that, generally speaking, the principles underlying their profession align with those underlying the profession of financial accounting. This no coincidence, they are both ancient professions dealing with data collection, custodianship and information reporting.

Environmental accounting, as an emerging profession, is beginning to understand the principles that should underlay their vocation. To that end, hydrographers have a lot to offer.

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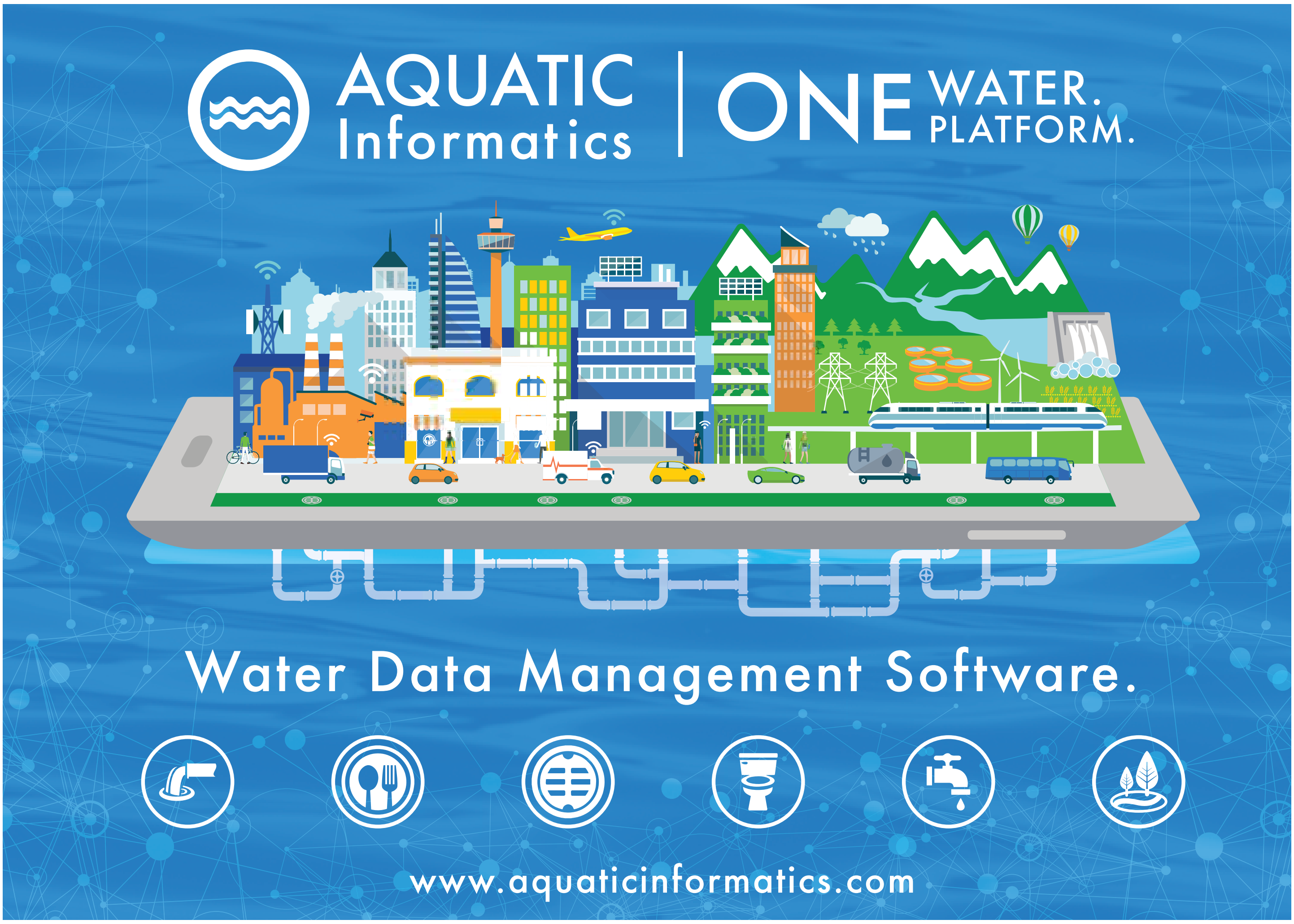


Hypack Application in Topographic Surveys

Daniel Wagenaar, Xylem Water Solutions, Broadmeadow, NSW

Introduction

Hypack Hydrographic Survey software as the name suggests is a specialized software package in the collection, processing and reporting of Hydrographic Survey data from a wide range of instrumentation. One can make the assumption that Hypack application is purely focused towards surveying underwater topography and structures. Although this assumption is correct in most survey applications, the software design enables the user to process and develop required outputs from both hydrographic and topographic surveys.

Georeferenced Topographic Survey

The topographic survey of a property was required for the development of an access road with the focus on landscape features, farming infrastructure and existing utilities. The survey technique selected for the topographic survey consisted of RTK (real-time kinematic positioning) method, using two GPS (global positioning system) Smart Antennas.

Survey Equipment

The survey equipment selected for the RTK survey consisted of two Hemisphere S321 Smart Antennas and Data Collector. The configuration of the two Hemisphere S321 smart antennas and topographic survey was performed using Carlson SurvCE software installed on the data collector.

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

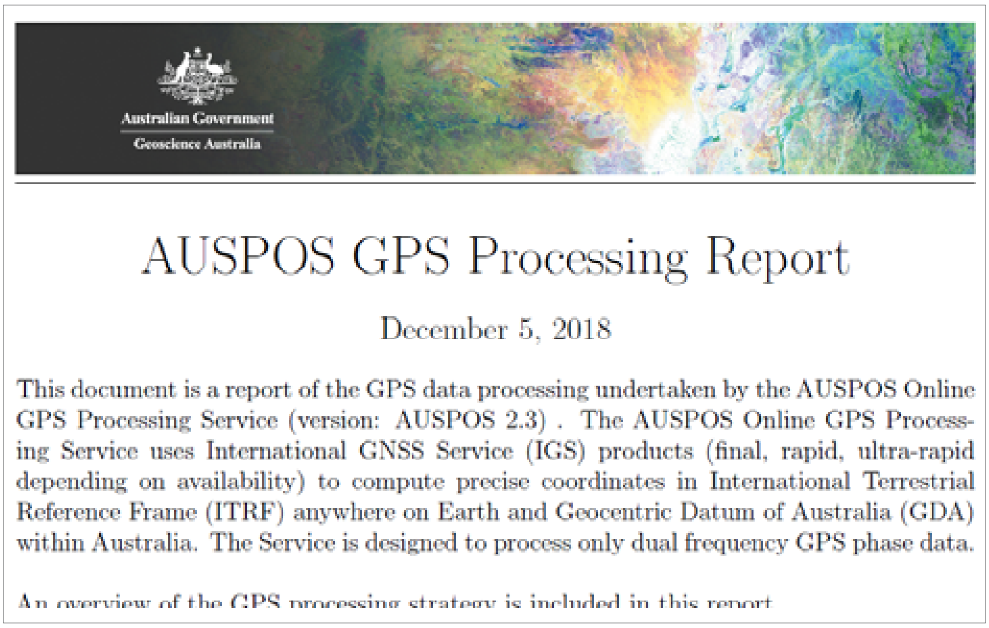
The second Hemisphere S321 or Rover was setup on a survey pole with the exact height of the GPS antenna entered into the SurvCE software.

Figure 1: Hemisphere S321 Smart Antenna.

Survey Control

Two survey markers where established next to the proposed site using GPS static survey technique with a minimum of two hours of raw GPS data collected at each of the survey markers. The recorded files were converted to RINEX format, from where they were submitted to AUSPOS Online GPS Processing Service.

Coordinates reported from AUSPOS GPS Processing Report shown in Figure 2 for both survey markers were in Geocentric Datum of Australia 1994 (GDA94). Elevation of survey markers were supplied in Australian Height Datum (AHD).



Australian Government
Geoscience Australia

AUSPOS GPS Processing Report

December 5, 2018

This document is a report of the GPS data processing undertaken by the AUSPOS Online GPS Processing Service (version: AUSPOS 2.3) . The AUSPOS Online GPS Processing Service uses International GNSS Service (IGS) products (final, rapid, ultra-rapid depending on availability) to compute precise coordinates in International Terrestrial Reference Frame (ITRF) anywhere on Earth and Geocentric Datum of Australia (GDA) within Australia. The Service is designed to process only dual frequency GPS phase data.

An overview of the GPS processing strategy is included in this report

Figure 2: AUSPOS GPS Processing Report.

Stakeout Survey Area

Defining the actual survey area on the ground is complex, especially if dense vegetation or significant landscape features are present at the measurement site.

The Survey area as provided by the client was plotted in Google Earth from where WGS84 (World Geodetic System 1984) coordinates were obtained at each line break.

The coordinates obtained from Google Earth were entered into the SurvCE software. The "Stakeout" feature in SurvCE software was used to mark the perimeter of the survey area shown in Figure 3 based on the coordinates entered.

Figure 3: Staking out the Survey Area.

Survey Data

The survey data collected on the data collector with SurvCE software were exported in CSV (comma separated values) format with Point Name, Easting, Northing and Elevation as the main outputs.

The CSV data set was imported into Hypack using “Geodetic List Conversion” feature from where a XYZ file was created.

The survey points imported are shown in Figure 4 against the background map in Hypack.

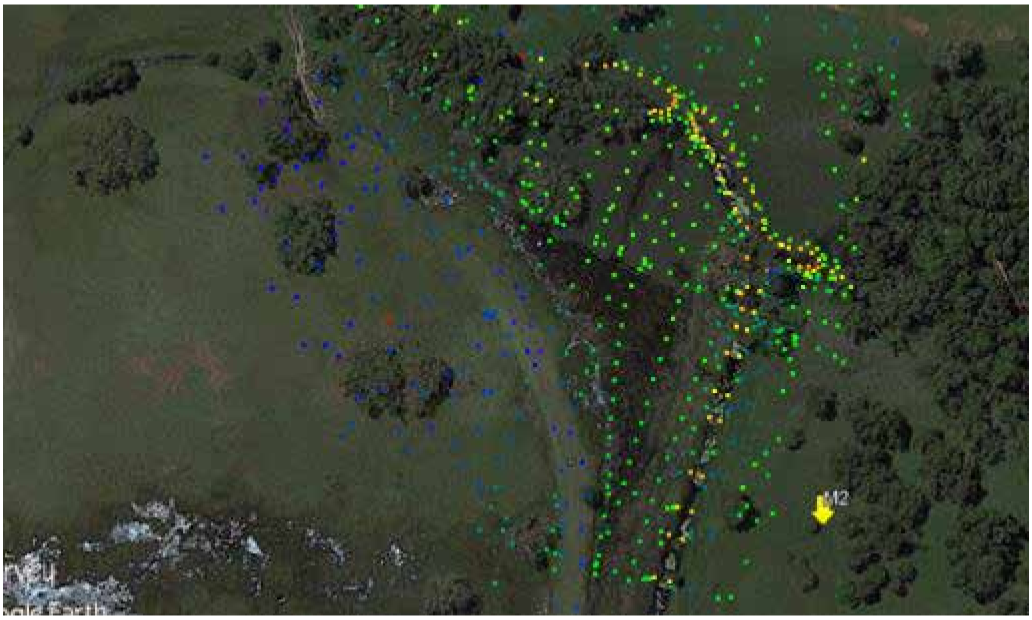


Figure 4:
Survey Data (georeferenced survey).

TIN Model Development

The TIN (triangulated irregular network) Model development in Hypack is based on XYZ components, irrespective if it was derived from hydrographic or topographic survey.

TIN Model that was developed from the survey points collected during the topographic survey is shown in Figure 5.

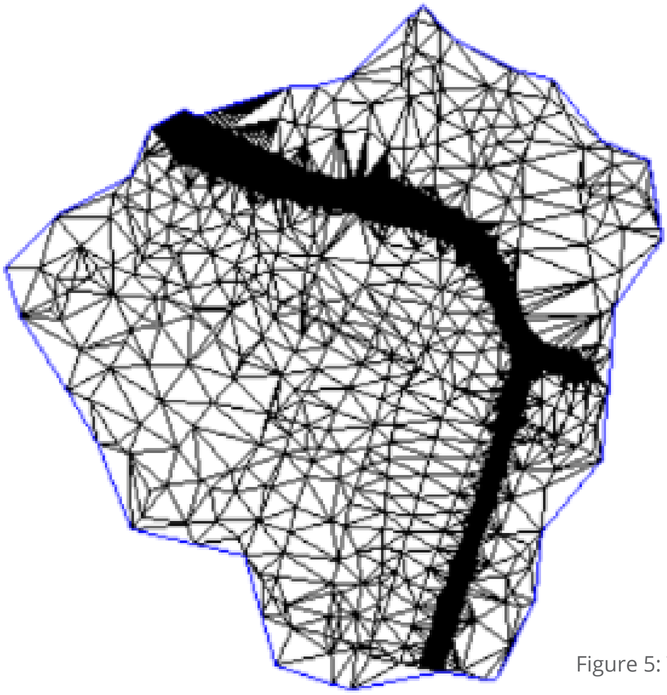


Figure 5: TIN Model (georeferenced survey).

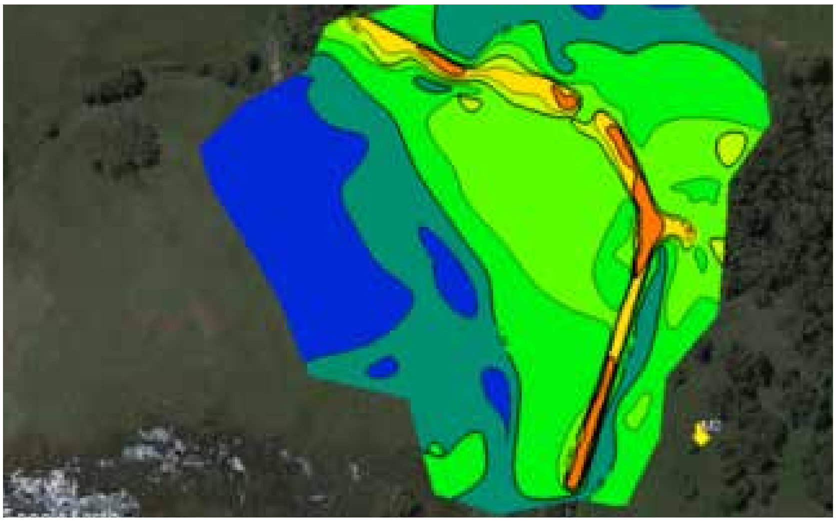


Figure 6: Contour Map.

A contour map was developed in Hypack based on the TIN model developed. The difference in elevation at the survey area are depicted with contours and associated colors shown in Figure 6.

In addition to the topography survey, a detailed survey was also performed of landscape features, farming infrastructure and existing utilities.

The survey points exported from the SurvCE software were imported into AutoCAD to create the drawing shown in Figure 7.

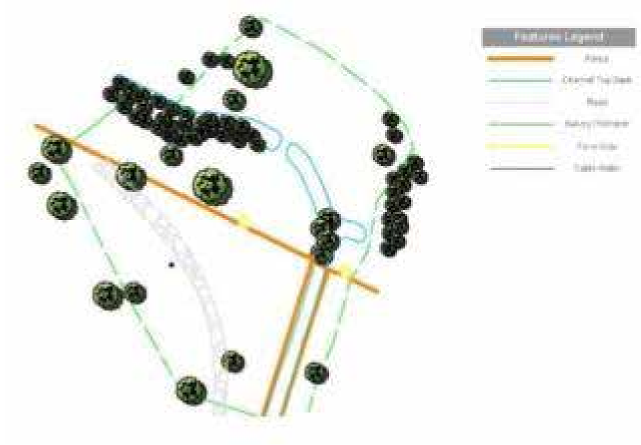


Figure 7: Landscape Features.

Non Georeferenced Topographic Survey

Topographic surveys were required for a number of waterholes around Brisbane. The dense vegetation at the waterholes restricted the use of Differential GNSS for performing topographic surveys. Conventional survey techniques using a Theodolite were selected as it is considered a more suitable technique for areas with dense vegetation.

Survey Equipment

The survey equipment selected for the topographic survey consisted of Leica Total Station and Prism with survey rod.

The Leica Total Station shown in Figure 8 was setup precisely over a known survey marker using tripod and built-in infra-red light.

The coordinates and elevation of the survey marker and height of Total Station were entered into the Total Station to reference the survey against local datum.

Figure 8: Leica Total Station.

Survey Control

The surveys were not required to be referenced to a Geodetic Datum and for this reason a Local Datum was assigned. The coordinates and elevation of the survey marker, over which the Total Station was setup, consisted of the following for each of the waterholes.

The Total Station was orientated to North before the survey commenced.

- X - 100.000 m,
- Y - 100.000 m,
- Z - 010.000 m.

Two additional survey markers were established at each of the waterholes, next to the survey area for future reference, the coordinates of each of the survey markers based on total station measurements.

Survey Data

The survey data collected on the Total Station were exported in CSV format with Point Name, Easting, Northing and Elevation as the main outputs.

The CSV data set was imported in Hypack using “Geodetic List Conversion” feature from where a XYZ file was created.

The survey points as imported into Hypack are shown in Figure 9. It is important to note that it is not possible to display the survey data against background image in Hypack if the survey was not georeferenced.

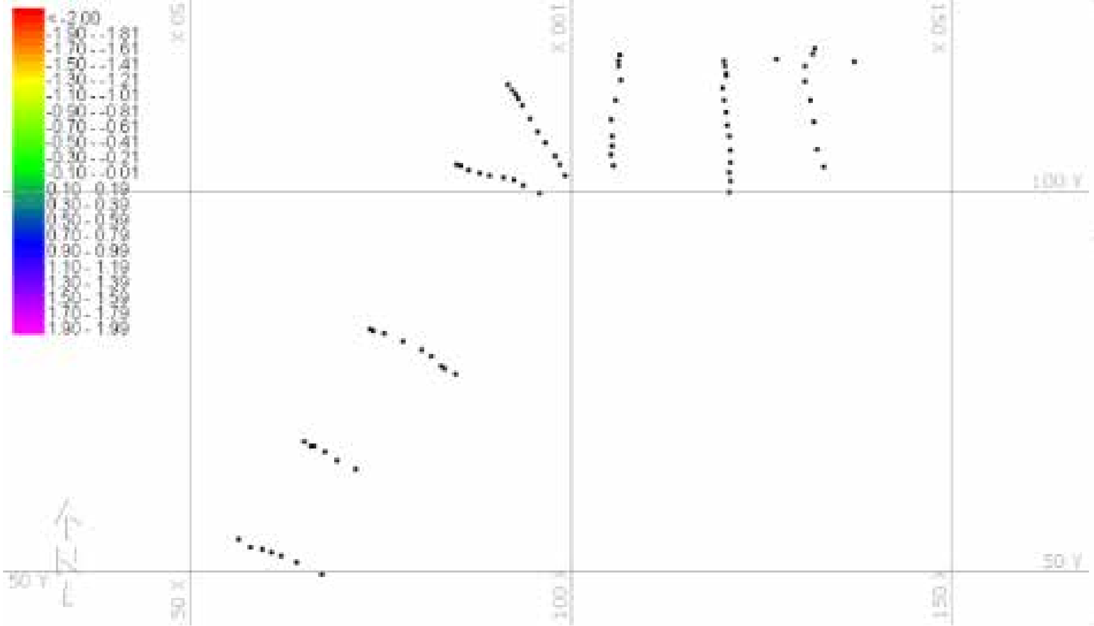


Figure 9: Survey Data (non georeferenced).

TIN Model Development

The TIN Model development in Hypack is based on XYZ components, irrespective if it was derived from georeferenced or non-georeferenced survey.

A Contour map was developed in Hypack based on the TIN model. The differences in elevation within the survey area are depicted with contours and associated colours as shown in Figure 10.

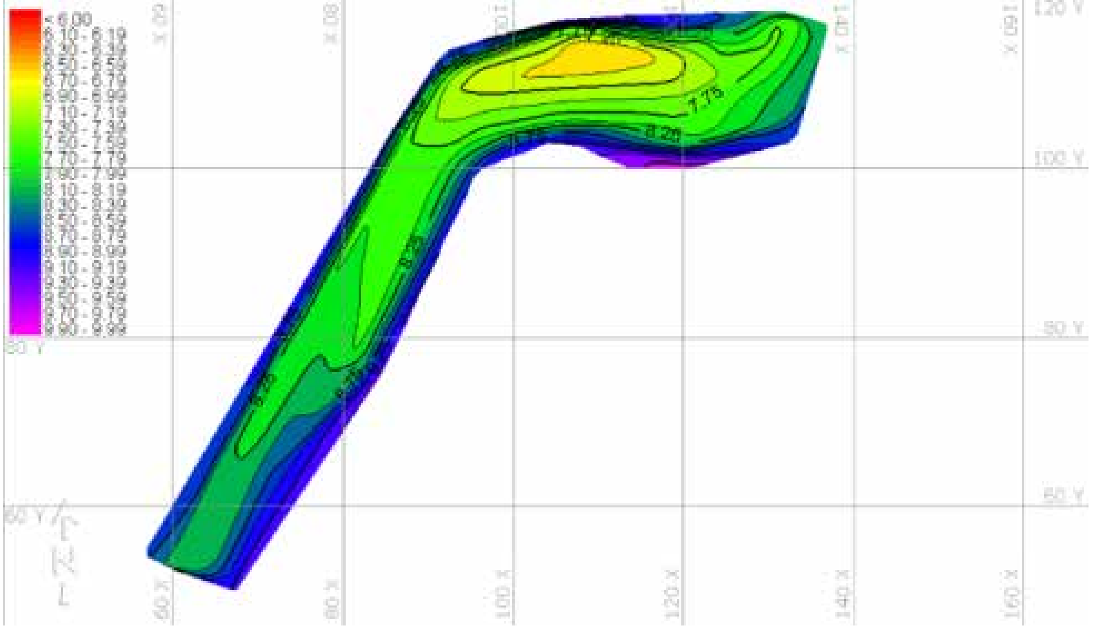


Figure 10: Contour Map (non georeferenced).

Conclusion

It was observed that the Hypack Hydrographic Survey Package can accommodate a wide range of data sets from hydrographic or topographic surveys referenced to either a Geodetic or Local datum.

The data collection platform and datum used during the hydrographic or topographic survey will dictate the process involved in the collection, processing and reporting of survey data in Hypack software.

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Automatic Discharge Measurement of Lowland Weedy Streams

Jeremy Bulleid, National Institute of Water and Atmospheric Research (NIWA), New Zealand

Thomas Wilding, Hawke's Bay Regional Council, New Zealand

Introduction

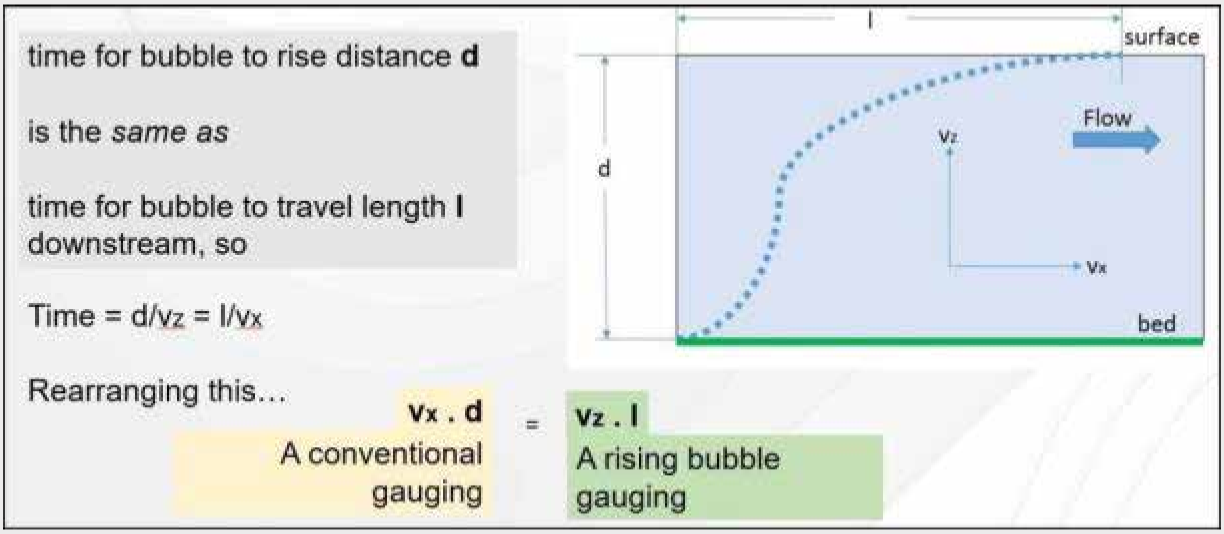
In this article we describe the progress in developing a practical tool to improve the reliable measurement of water flowing in lowland weedy streams. This is part of a Ministry of Business Innovation and Environment (MBIE) Envirolink Tools project being carried out in collaboration with regional councils. We are using air bubbles and Artificial Intelligence (AI) to realise a technology that shifts the paradigm of conventional flow measurement.

Limitations of conventional measurements

Conventional methods for continuous flow monitoring require a surrogate (water level), translated to discharge using a rating curve. The presence of aquatic vegetation makes this relationship insensitive and unstable, often resulting in 'difficult-to-impossible' measurement conditions.

The Rising Bubble Method

Because there is no current technology that can easily, accurately, directly and continuously measure discharge in weedy streams, we are developing an idea to transform the Rising Bubble Method (RBM) into standard measuring equipment. The principle, as summarised in Figure 1, is to release a bubble from the stream bed. This is displaced downstream by the flow as it floats to the surface. The downstream displacement integrates velocity throughout the water column.



time for bubble to rise distance **d**

is the *same as*

time for bubble to travel length **l** downstream, so

Time = $d/v_z = l/v_x$

Rearranging this…

$\mathbf{v_x \cdot d}$ = $\mathbf{v_z \cdot l}$

A conventional gauging = A rising bubble gauging

Figure 1: The rationale for, and difference between conventional gauging and RBM gauging, showing the path of a single bubble. Vz is the same as rise velocity but emphasises the direction (z axis).

This principle can enable us to measure flows 'where we need to' not just 'where we can'. This will produce more impactful knowledge.

Our bubble injector module injects bubbles with the precise diameter needed to achieve constant rise velocity (Vr). A bubble is injected simultaneously from each of the injectors spanning the streambed. Previous research has proven that the bubbles intrinsically integrate the downstream displacement as they rise to the surface. The horizontal distances, from the line of bubble injectors (the origin) to where the bubbles break the water surface, are directly proportional to discharge. We need to accurately determine this bubble *Just-Surfaced* location, from video taken of the water surface. We have therefore transformed the conventional measurement domain (the stream cross-section) to the water surface.

Tool Overview

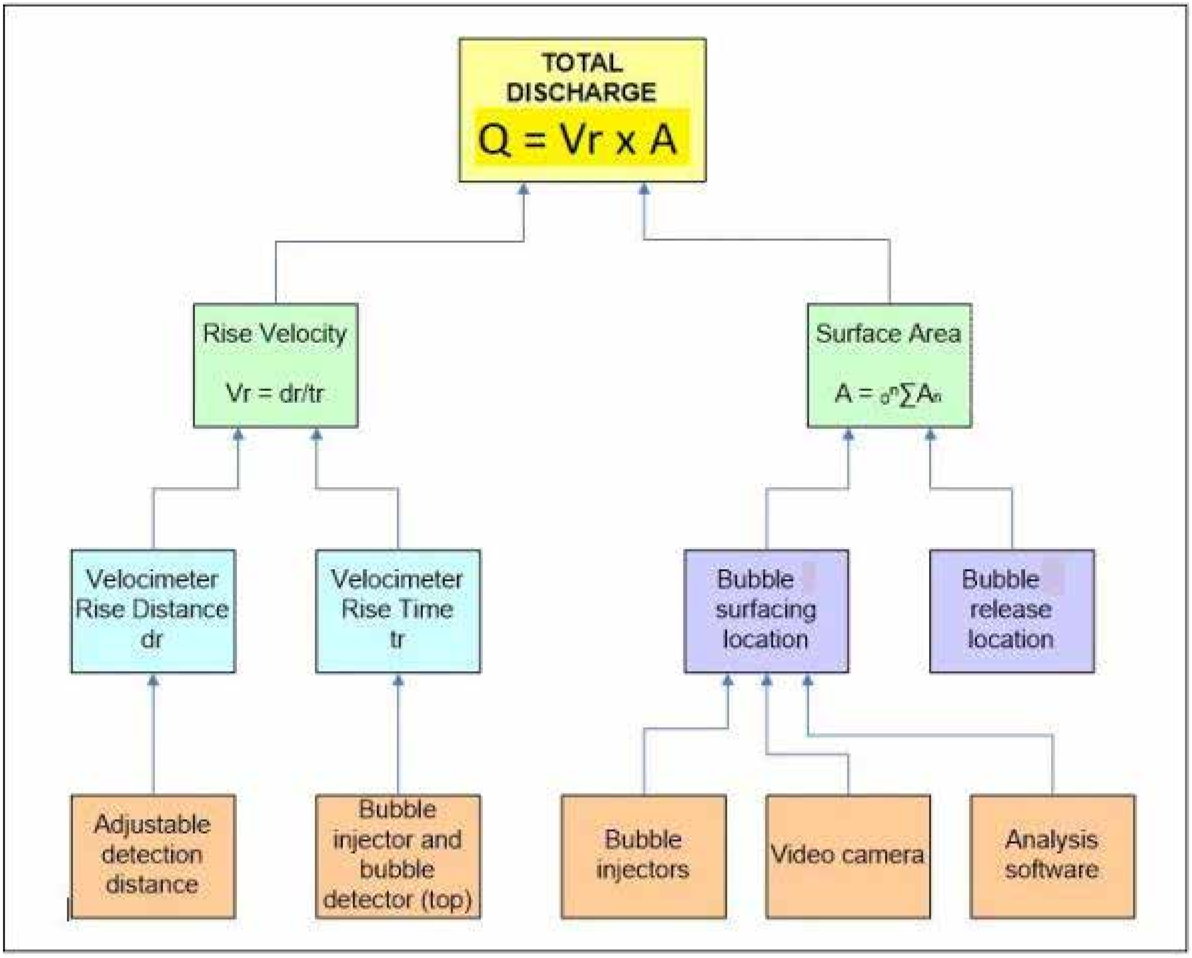


Figure 2: Overview of the process employed, where there are n bubble injectors. The surface area A is the displacement area.

Artificial Intelligence — stage 1

Because it is not humanly possible to differentiate a Just-Surfaced bubble from other classes (Background, Just-Surfaced, On-Surface and Burst), instantaneously, across a line of bubbles, we need a faster, flexible and more insightful method... video, and Artificial Intelligence (AI).

An AI Neural Network (NN) was created and taught to recognise a Just-Surfacing bubble, by training it with 600+ images of each of the other classes. When tested with images it has never seen before, the NN now routinely exceeds 99% accuracy from 200 diverse validation images.

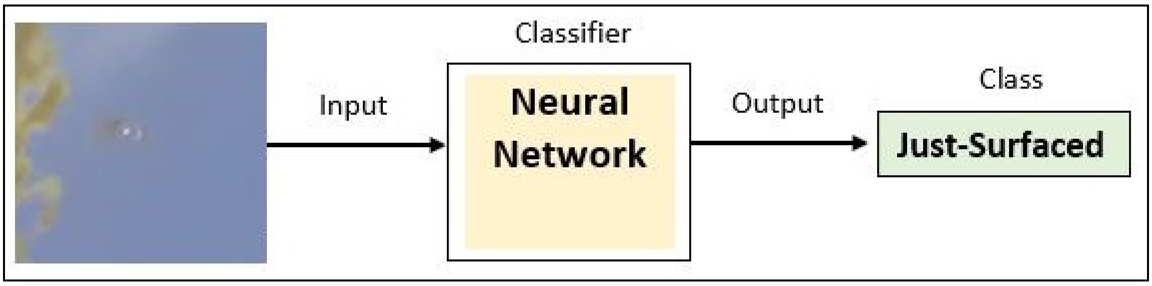


Figure 3: The AI classifier correctly identifies input images from four different classes.

Calculating Q

Q = Vr x A. So how do we measure these?

Measuring Rise Velocity (Vr)

The Velocimeter measures Rise Time. The characteristics of the bubbles released in the Velocimeter are the same as those released at the streambed so have the same rise velocity. The uncertainty in Vr translates directly to uncertainty in Q. We have met the uncertainty target we needed for Vr (<1%) to meet our 5% uncertainty target in Q.

Figure 4: Rise times (Halswell River) measured in the version2 Velocimeter. The Vr calculated from these data is 0.207 m/s (Calculated uncertainty is 0.36%).

Figure 5: Velocimeter.

Measuring Displacement Area (A)

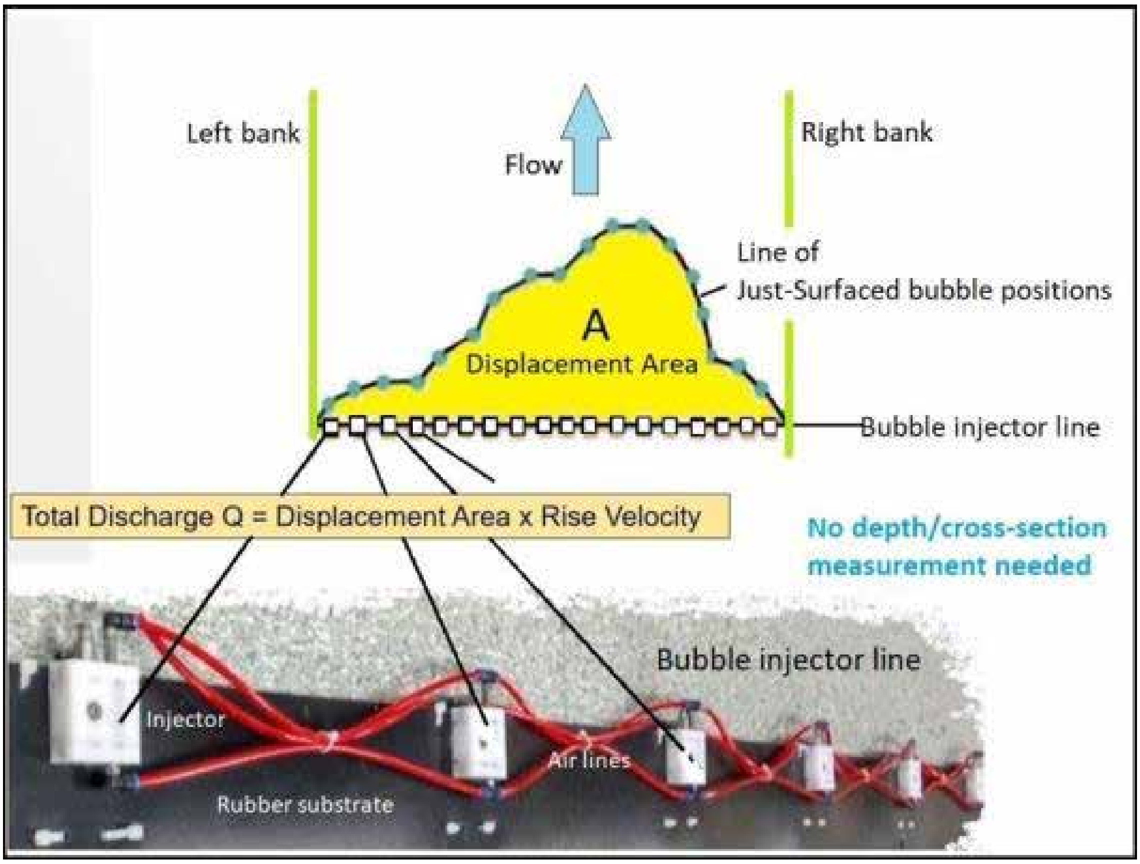


Figure 6: This 13-point prototype bubble line is easily rolled up. The injectors are mounted 0.4 m apart on a rubber substrate with a flat lead diver's weight under each injector to provide stability.

An early field trial at the reference Environment Canterbury site

Figure 7: This is how we laid out the site for the trial on 3 October 2018. The water was flowing at over 1000 litres per second (L/s) and was quite turbid, so the bubble line is not visible.

Post-processing of the video, frame-by-frame, yielded a credible result. The Just-Surfaced location of each bubble was identified: the downstream displacement of each bubble determined by manually measuring the on-screen image, from the origin to each Just-Surfaced position, then scaling. When tracking a bubble sequence manually frame-by-frame, it is easy to verify that the Just-Surfaced position has been correctly identified… although rather tedious. Here is the result (U is uncertainty, D depth).

	Q (L/s)	U_Q (%)	U_Q (95% CL)	Horiz. points	Vert. points
Rated	1162		8	-	-
Flowtracker	1076	1.3 (stats)	5.9 (ISO2007)	23	0.6 D avg.
Rising Bubble	1074	2.9	5.8	13	Integral 0 to D

AI — stage 2; from manual to automatic

We are now developing a second NN to work at stream-width scale. This will incorporate the stage 1 NN and will be trained to locate Just-Surfaced bubbles across the full stream width. When complete, we will compile the AI model, add operational functions (e.g. start video) and run it as a standalone software application, on-site. To enable automatic calculation of Q it will scan a few seconds of video, frame-by-frame, ‘look’ for and locate the position of Just-Surfaced bubbles, ‘join the dots’, calculate the area (A) displaced from the origin and multiply A by Vr.

Acknowledgements

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National Institute of Water and Atmospheric Research (NIWA).

Modelling Rating Curves to Manage Uncertainty in the Fitzroy River Catchment in North West Western Australia

Lauren Greening, Department of Water and Environmental Regulation, Perth, WA

Leith Bowyer, Department of Water and Environmental Regulation, Perth, WA

Dean Pegoraro, Department of Water and Environmental Regulation, Perth, WA

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

Abstract

Seventeen streamflow gauging stations have been commissioned in the Fitzroy River catchment from 1955 to 1997, thirteen of which are currently operating. Stage-flow relationships at streamflow gauging stations are dependent on discharge measurements (gaugings) to relate the water level to a flow rate. Effort to record high flow discharge measurements has occurred when possible and continues to be a priority, however the majority of stations don't have the number of measurements required to generate a reliable stage-flow relationship (rating curve). Hydraulic modelling to understand stage-flow relationships for high to mid flows has been adopted in the absence of field measured discharge at the majority of gauging stations in the Fitzroy River catchment to enable a time series of streamflow to be generated for use in hydrologic analysis.

Hydraulic models of the Looma (802007) and Fitzroy Barrage (802003) gauging stations in the Lower Fitzroy catchment have been used to develop the stage flow relationship. Both gauges were modelled in one dimension using HEC RAS in the late 2000s and a rating was developed and adopted although it was acknowledged that a two dimensional model would be preferential to capture flow through multiple braided channels across the 10 km wide floodplain. The same high flow discharge measurements were used to calibrate both models that were taken at a gauged cross section in between the two sites. A reliable relationship exists to transpose the discharge measurements to the Looma gauging station, however no relationship is available to transpose the measurements to the Fitzroy Barrage gauge and numerous hydrologic interactions occur between the two gauges which are difficult to define. Both gauges have been re-modelled in two dimensions using HEC RAS as the available input data, software and computing power are now accessible. The same discharge measurements are used for calibration with the same uncertainty in relation to the Fitzroy Barrage gauge. Near the completion of this project, an additional high flow discharge measurement was captured in 2017, used to validate the modelled rating and also to verify the earlier discharge measurements. The two dimensional modelled rating at the Looma station is similar to the previous rating up to the highest discharge measurement, however flow is greater for the same water depth above this height, up to 18% greater at the high end of the rating. The two dimensional modelled rating is more accurate at this location, because of the more detailed representation of the geometry, and has been adopted. The two dimensional modelled rating at the Fitzroy Barrage gauge is the same as the current rating which confirms the one dimensional model, however uncertainty remains in the calibration data. Sensitivity analysis of the calibration variable Manning's n shows that up to 25% uncertainty exists in the applied rating.

Modelled stage-flow rating analysis means the number of discharge measurements required at a gauging station can be minimised, but over time the number of gaugings across a network of gauges can be maximised. Field measurements can be targeted and fewer in number, whilst enabling streamflow data to be generated within a quantified level of uncertainty. Quantifiable uncertainty allows the data to be used in management decisions.

Streamflow Gauging in the Fitzroy River Catchment

The Fitzroy River catchment is located in North West Western Australia and covers 97 000 km^2 from Halls Creek to Derby. The tropical climate is driven by cyclones causing extreme rain and streamflow events in the wet season from November to April. Average annual rainfall is 544 mm per year and has varied from 191 mm to 1078 mm at the Halls Creek rainfall gauge in the period from 1908 to 2017. The variation in annual and inter-annual rainfall is reflected in the streamflow resulting in a variable hydrologic regime which incorporates large and vast floodplains, channels, gorges, periods of no flow, periods of flood, permanent pools supported by groundwater and surface-groundwater interaction.

Aboriginal people were the first people to inhabit the land surrounding the Fitzroy River and continue to be the predominant inhabitants today. Land and water are integral to cultural values and daily life of the aboriginal people in the Fitzroy River (Toussaint *et al.*, 2001). It is one of the only remaining unregulated river systems in Australia and supports many high conservation value aquatic ecosystems and fauna and flora species including the Freshwater and Dwarf Sawfish, Prince Regent Hardyhead (fish), Gouldian Finch and Purple-Crowned Fairy Wren (Loomes, 2018 and Storey *et al.*, 2006). In addition, the Camballin floodplains meet the criteria as a RAMSAR listed wetland (Storey *et al.*, 2001). The ecologic, social and cultural values are dependent on the variable hydrologic regime.

Large scale irrigated agriculture was attempted from the 1950s to mid-1980s (GHD, 2009). The township of Camballin and irrigation infrastructure to provide water for the Camballin Irrigation Area were developed in the 1960s. Irrigation infrastructure included Fitzroy Barrage, irrigation channels (Uralla and Snake Creek, M1 and M2 channels), offtake structures, 17 Mile Dam, pump stations, flood levees and irrigated plots. Rice, fodder crops, grain, sorghum, oats, wheat and barley were grown with limited success. The Fitzroy Barrage was designed with gates that could be raised to store and divert irrigation water, and lowered to allow floodwaters to pass. The operation was manual and required operators to raise and lower the gates. The hydrology of the Fitzroy River; wet season flooding and the low reliability of irrigation water in drier years, is a primary reason the irrigation scheme failed, compounded by grossly underestimating streamflow when little data was available in the planning phase of the project (GHD, 2009). From the early 1990s onwards the Barrage gates were laid flat. The remaining irrigation infrastructure is used for small scale pivot irrigation, to develop fodder for beef grazing at Liveringa station, which occurs to this day.

The Fitzroy River is over 1000 km long and has over 50 tributaries including the Hann River, Margaret River, Christmas Creek, Cunningham River, Horse Creek, Leopold River and the O'Donnell River. Seventeen streamflow gauging stations have been commissioned in the catchment from 1955 to 1997, thirteen of which are currently operating (Figure 1, Table 1). Streamflow gauging has historically been for flood warning and to understand streamflow for irrigation and the environment, however more recently there is increasing interest in understanding the groundwater-surface water interactions. Stage-flow relationships at streamflow gauging stations are dependent on discharge measurements to relate the water level to a flow rate. The vast area, remoteness, extreme volumes of water, flow variability and large braided river channels prove difficult to take discharge measurements required at high to medium flows in parts of the catchment. Nine of the streamflow gauges have discharge measurements covering less than 50% of the recorded stage height (Table 1). Fourteen of the streamflow gauges have discharge measurements covering less than 50% of the flow from the current applied rating (Table 1).

Effort to record high flow discharge measurements and flood marks has occurred when possible and continues to be a priority. High flow discharge measurements were recorded in 1991, 1993, 2011 and 2017 during some of the largest events in the catchment. In 1991 and 1993 high flow discharge measurements were taken for Main Roads Western Australia (MRWA) as part of a project to build a road crossing for the Great Northern Highway, the main transport route to the Kimberley from the south. A gauging section was cleared across the floodplain at Old Liveringa Homestead and vertical markers were erected to direct hydrographers in high flows. Four measurements were taken, the largest recorded a flow of 17 700 m^3/s over 11.25 km and 9.5 hours. Four gaugings were also taken at Willare to understand flow to the ocean at King Sound. The gaugings were taken across four bridges and three floodplains, the largest recorded a flow of 14 545 m^3/s over 6.6 km (Clews 1993). This level of interference to record discharge measurements; clearing and erecting vertical markers, would no longer be considered appropriate. In March 2011 high flow discharge measurements were taken at Fitzroy Crossing and Willare close to the flood peak. Two flow gaugings over 10 km wide were taken at Fitzroy Crossing (802055) at 10 000 m^3/s and 15 300 m^3/s which covers 99% of the recorded stage height and 60% of the recorded flow range at the station. Two flow gaugings over 10 km wide were taken at Willare (802008) at 11 500 m^3/s and 11 300 m^3/s while navigating four bridges and three different floodways. The gaugings were taken by boat using ADCP (Acoustic Doppler Current Profiler). Staff worked long days for three weeks straight. Roads, phone and internet were down, equipment was lost and the gauge boat was carried over mud and road to reach the flood extent (Harris 2011, internal publication).

In 2017 a team of hydrographers were mobilised from Kununurra's Department of Water and Environmental Regulation (DWER) office in an attempt to capture a significant flow event at Looma, utilising the Myroodah Road approximately 7 km upstream of the Looma gauging station. The measurement was the first attempt at using the RiverRay ADCP coupled with DGPS during Fitzroy River high flows. The RiverRay's ability to auto range depth allowed hydrographers to measure flows across the varied depths of the 10km flood plain. The measurement was cut short by a small parcel of land dividing a braided channel on the Liveringa Station side of the Fitzroy River. Due to the size of the boat utilised for the measurement, hydrographers were unable to move the boat and finish the gauging. Fortunately the gauging was conducted at a similar stage to a measurement captured during the early 90s when a gauging section had been cleared across the floodplain. By utilising this measurement hydrographers were able to formulate a result for the event and provide a further level of confidence for this section of the rating. The discharge measurements taken during high flows across all years have been invaluable to the development of rating curves at these stations.

Hydraulic modelling to understand stage-flow relationships for high to mid flows was first adopted in the Fitzroy River catchment in the 2000s (Harris & Bowyer, 2010). It was acknowledged that the analysis of river hydraulics was required to understand how to reliably estimate and measure river flow at gauging stations in the absence of field measured discharge. A number of river reaches were surveyed as models fundamentally depended on defining river channel geometry, slope and roughness. The hydraulic models were used to substantiate existing, and develop new, river flow rating curves. The availability of digital elevation models, such as LiDAR, and 2D modelling software, such as HEC RAS 5 has made it possible to further understand stage-flow relationships at gauging stations in the Fitzroy River catchment.

To date hydraulic models have been developed to determine or confirm rating curves at thirteen of the seventeen gauging stations in the Fitzroy River catchment. The modelling has enabled the development of stage-flow relationships within a level of confidence acceptable to produce streamflow data at these stations (Figure 1). The modelling also facilitates the understanding of targeted field measurement requirements to further improve the stage-flow relationships at the stations across the Fitzroy River catchment. The remaining four gauging stations will have hydraulic models developed when the required information becomes available. This paper discusses the development of stage-flow relationships at the Looma (802007) and Fitzroy Barrage (802003) streamflow gauging stations.

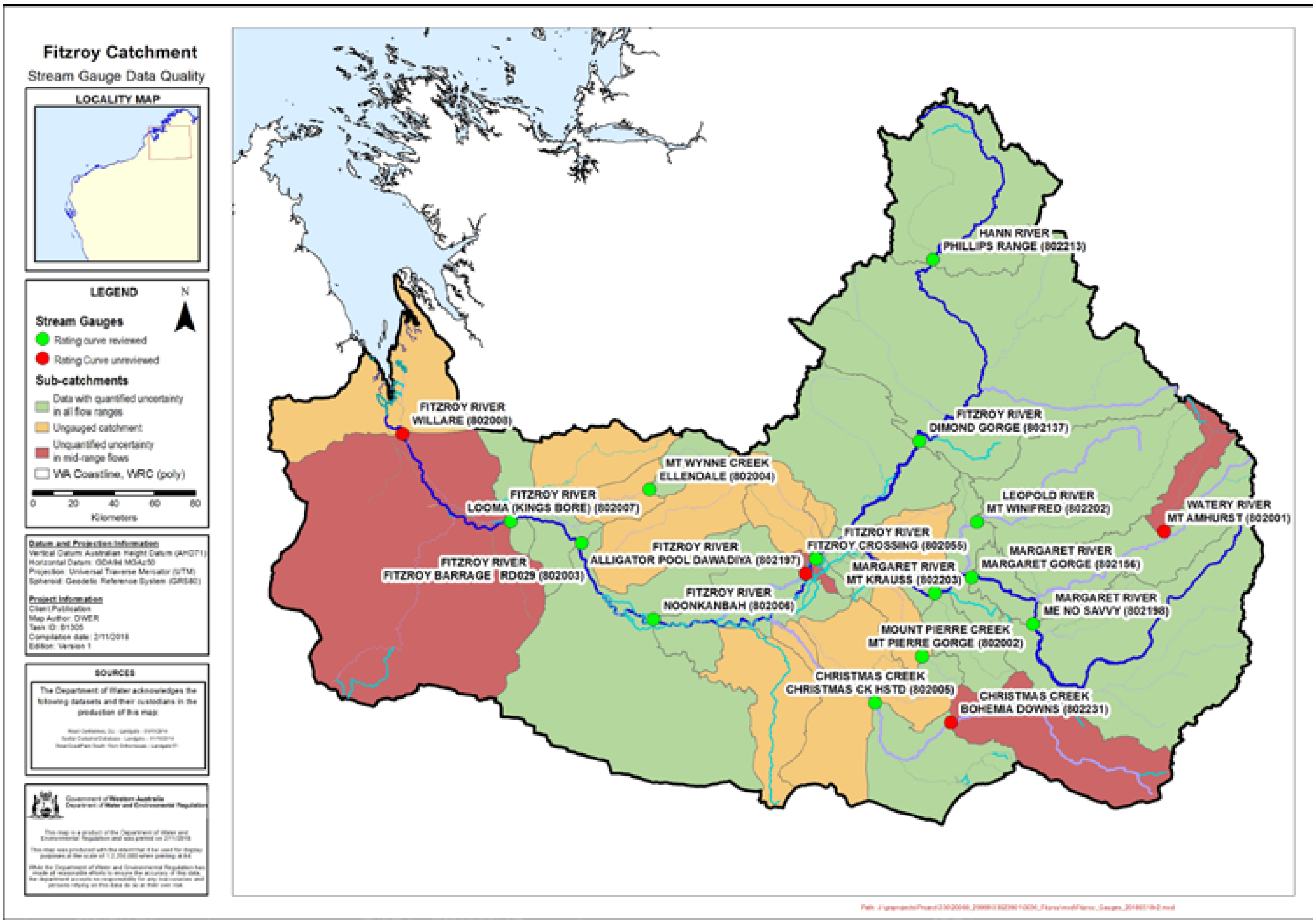

Figure 1: Streamflow gauging stations and flow rating development in the Fitzroy River catchment.

Table 1. Streamflow gauging stations in the Fitzroy River catchment

Item	Gauge Number	Gauge Name	Hydrology	Period of Gauging		Highest Discharge Measurement		% of recorded stage height	% of recorded flow	Rating
				Start	End	Flow m³/s	Stage mSL			
1	802055	FITZROY CROSSING	FITZROY RIVER	01 Oct 1955	current	15300	22.64	99.57	59.89	Rating curve review completed
2	802137	DIMOND GORGE	FITZROY RIVER	23 Sep 1962	current	1451	14.96	37.14	11.87	Rating curve review completed
3	802197	ALLIGATOR POOL	FITZROY RIVER	21 Nov 1964	27 Jun 2002	1176	17.40			Hydraulic model scheduled for 2017118
4	802202	MT WINIFRED	LEOPOLD RIVER	22 Nov 1964	current	2684	18.31	71.00	26.79	Rating curve review completed
5	802203	MT KRAUSS	MARGARET RIVER	23 Sep 1965	current	4966	18.29	63.85	28.49	Rating curve review completed
6	802198	ME NO SAVVY	MARGARET RIVER	01 Oct 1965	current	34	10.95	6.47	0.38	Rating curve review completed
7	802213	PHILLIPS RANGE	HANN RIVER	02 Nov 1966	current	245	13.70	25.32	5.06	Rating curve review completed
8	802231	BOHEMIA DOWNS	CHRISTMAS CREEK	17 Nov 1966	15 Oct 1979	311	14.19	60.27	24.21	Hydraulic model scheduled for 2017/18
9	802001	MT AMHURST	WATERY RIVER	17 Sep 1967	03 Oct 1979	3	10.76	11.04	0.44	Hydraulic model scheduled for 2017/18
10	802002	MT PIERRE GORGE	MOUNT PIERRE CREEK	03 Sep 1970	17 Jan 2018	12	11.42	12.20	1.82	Rating curve review completed
11	802008	WILLARE	FITZROY RIVER	01 Jan 1980	current	14545	19.88	105.56	121.36	Hydraulic model scheduled for 2017/18
12	802156	MARGARET GORGE	MARGARET RIVER	01 Jan 1980	current	852	14.10	42.82	17.80	Rating curve review completed
13	802007	LOOMA	FITZROY RIVER	01 Jan 1980	current	6735	17.47	81.55	33.89	Rating curve review completed
14	802005	CHRISTMAS CK HSTD	CHRISTMAS CREEK	01 Jan 1980	current	18	10.77	11.13	0.46	Rating curve review completed

Item	Gauge Number	Gauge Name	Hydrology	Period of Gauging		Highest Discharge Measurement		% of recorded stage height	% of recorded flow	Rating
				Start	End	Flow m³/s	Stage mSL			
15	802003	FITZROY BARRAGE	FITZROY RIVER	12 Sep 1986	current	39	10.65	6.33	0.14	Rating curve review completed
16	802004	ELLENDALE	MT WYNNE CREEK	19 Nov 1986	current	122	13.23	93.74	6.60	Rating curve review completed
17	802006	NOONKAN-BAH	FITZROY RIVER	25 Oct 1997	current	1620	18.22	67.01	13.43	Rating curve review completed

Looma and Fitzroy Barrage Gauging Stations

The Looma (802007) and Fitzroy Barrage (802003) gauging stations are located on the Fitzroy River near the small township of Camballin, 120 km from the mouth of the river where the floodplain extends into the tidal zone, King Sound (Figure 2). The river consists of a main channel which is an open sand bed 100-300 m wide and 5-10 m deep and a vast 10 km wide floodplain including multiple braided channels with medium density river gum stands, brushes, grasses and clumps of spinifex.

The Camballin township and the Looma and Liveringa Aboriginal Communities are located just north of the floodplain. The Fitzroy Barrage gauge is located between the barrage and the Uralla Creek offtake used to divert irrigation water to the Camballin Irrigation Area. The barrage ceased operation in 1991/92 and the gates laid flat, however some water is still diverted down Uralla Creek to maintain environmental flows and provide irrigation water to Liveringa Station. The Looma gauging station is located 45 km downstream of the Fitzroy Barrage gauge near the Looma community. Multiple tributaries and creek lines join the main channel in between the two gauges and a large flood storage area exists where the Camballin Irrigation Area was once located (Figure 2).

The geology of the river bed is made up of the Fitzroy River Alluvium which extends approximately the distance of an average flood (Lindsay and Commander, 2005). The Fitzroy River Alluvium is 30-40 m thick and comprises of sand and gravel overlain with approximately 10 m of black silt and clay across about 50% of the floodplain (Harrington and Harrington, 2015, Lindsay and Commander, 2005). The Fitzroy River Alluvium in between the Fitzroy Barrage and Looma gauging stations lies on top of the Noonkanbah formation which forms a confining aquitard made of siltstone and shale (Harrington and Harrington, 2015). The geology and surface water groundwater interaction between the two gauges means it is difficult to develop relationships or make assumptions about the flow between the two gauges without verified field data.

Both gauges were commissioned as flood warning sites, however more recently have become of interest to provide an understanding of surface water runoff in the Fitzroy River catchment and increasing interest in the connected groundwater resource for potential future agricultural water supplies. The initial ratings at both sites were based on 1D hydraulic modelling although it was acknowledged that further analysis was required due to the complexity of flow paths and size of the floodplain. The accessibility of 2D modelling packages meant these gauges could be re-modelled and the ratings re-assessed.

At the time of this study six high flow discharge measurements had been recorded at Myroodah Crossing (Figure 2) by the Water Authority of Western Australia on behalf of MRWA in 1987, 1991 and 1993 when the Willare bridge and floodway investigations were undertaken. Two discharge measurements in 1987 only recorded flow and two discharge measurements in both 1991 and 1993 recorded stage and flow. An additional high flow discharge measurement was taken in 2017 after the completion of this study. Discharge measurements have been taken at Myroodah Crossing because the road across the floodplain provides the opportunity to take a discharge measurement in otherwise difficult terrain. These measurements provide important flow and water level information for these sites.

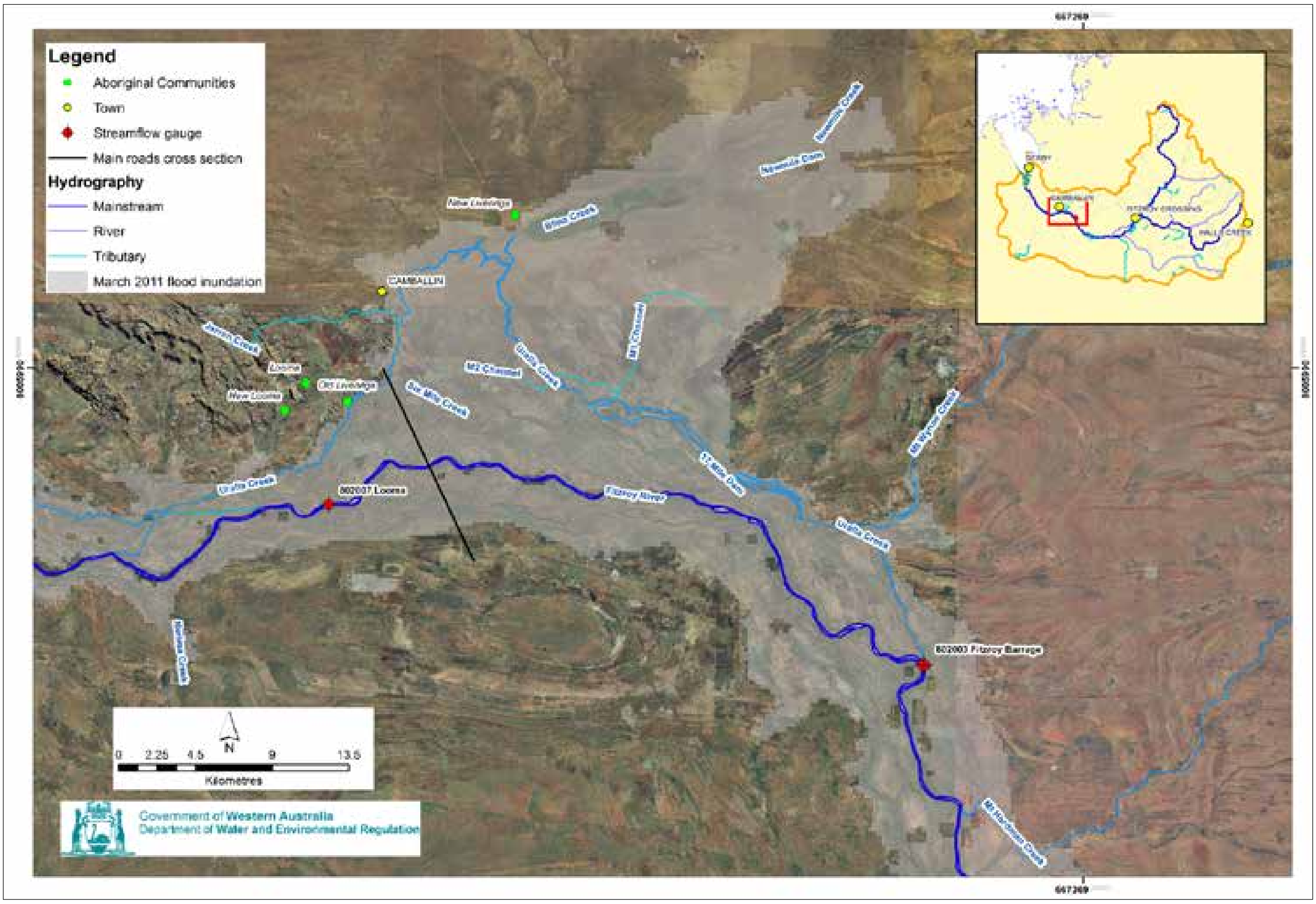

Figure 2: Looma and Fitzroy Barrage stations and inundation from the March 2011 event.

Looma (802007) Streamflow Gauging Station

The Looma streamflow gauging station has been in operation from October 1997 onwards. Prior to the establishment of the gauge, flow and peak flood levels were recorded manually at the Old Liveringa staff gauges and at Myroodah Crossing where the Myroodah-Luluigui Rd crosses the Fitzroy River. Over the period of flow record eleven ratings have been applied at the Looma gauging station. Initially the flow rating had not been well established because of limited discharge measurement information. At the time this project was completed twenty low flow discharge measurements had been taken at the site from 2004 to 2016 (Table 1). The highest discharge measurement, 61.2 m^3/s was in April 2009 (11.767 mSL[1]) which covers less than 1% of the recorded stage height. Discharge measurements in the mid flow range are not possible as flow is distributed through multiple channels across the floodplain. Discharge measurements in the high flow range, when flow across the floodplain is connected, are possible; however cost, priorities and safety are a consideration.

An additional high flow discharge measurement was taken in 2017 after the completion of this study. The discharge measurement was taken near Myroodah Crossing and related to the gauging station at a stage height of 17.470 mSL and a flow of 6.735 m^3/s. The flow was measured by a RiverRay ADCP coupled with DGPS on a boat under difficult circumstances. A portion of flow could not be gauged due a small parcel of land and vegetation blocking access to the southern floodplain and was estimated based on one of the earlier 1991 discharge measurements. The new gauging has been used as validation; however it is recognised that the 2017 discharge measurement is dependent on an earlier 1991 discharge measurement used in calibration and is not an independent validation measurement. Table 1 shows recorded peak water levels at the gauging station and the total number and maximum discharge measurements taken each year.

The model was calibrated to the four high flow discharge measurements taken across the floodplain at Myroodah Crossing, seven kilometres upstream of the gauging station, in 1991 and 1993. A gauging section was cleared across the floodplain and vertical markers were erected to direct hydrographers in high flows. These discharge measurements were collected before the gauging station was established and are related to the station using a relationship with the levels at the Old Liveringa Homestead. The discharge measurements range from 7.536 m³/s to 17.749 m³/s (17.669 mSL – 18.952 mSL) which covers 99% of the recorded stage height over the life of the gauging station.

The largest event recorded at the Looma gauging station occurred in March 2011. Streamflow increased from the 10th March 2011 peaking on the 20th March 2011 at 19.225 mSL and 18 656 m³/s. Total daily flow was over 1 600 GL on the 20th March 2011, more than five times the annual water use for Perth. Three flood marks from the March 2011 event were taken near the Looma gauging station by DWER and the inundation extent for the event was produced by Landgate using satellite imagery (Figure 2). The flood inundation and floodmarks from the March 2011 event have been used as model validation.

In 2008 a 1D HEC RAS model was developed and calibrated to the high flow discharge measurements. A flow rating was developed based on the modelled rating and the low flow discharge measurements collected. Flow rating changes and periods of application were based on the discharge measurements and variations in cease to flow. The cross sections for the 1D model were extracted from a 1 m digital elevation model created from LiDAR captured in September 2008 by Fugro on behalf of the DWER. The 1D modelled rating at the orifice produced a good fit to the calibration data (Figure 4). Two dimensional modelling packages weren't suitable for use at the time; however it was acknowledged that it would be preferential to capture the geometry and flow in the multiple channels across the vast floodplain.

Table 2. Summary of discharge measurements and annual peak level details for the gauging station

Year	Discharge Measurements		Annual Max Water Levels Recorded
	Total Discharge Measurements Collected	Max Discharge Measured m³/s	mSL
1991	2	14923.600	-
1993	2	17749.000	-
1997	-	-	13.048
1998	-	-	16.154
1999	-	-	16.689
2000	-	-	18.437
2001	-	-	17.666
2002	-	-	18.75
2003	-	-	16.789
2004	2	4.011	16.591
2005	1	0.307	14.985
2006	1	0.578	16.538
2007	3	7.916	16.532
2008	2	5.908	16.144

[1.] mSL refers to the metres height relative to a standard level.

Year	Discharge Measurements		Annual Max Water Levels Recorded
	Total Discharge Measurements Collected	Max Discharge Measured m^3/s	mSL
2009	3	61.200	17.349
2010	3	3.699	14.943
2011	1	2.900	19.225
2012	2	37.800	16.419
2013	-	-	15.795
2014	-	-	16.781
2015	1	6.006	16.339
2016	1	0.219	17.366

* discharge measurements taken before the gauge was established and transposed to the gauge location.

A 1 m Digital Surface Model (DSM) was produced from 10 cm imagery captured by Landgate in 2016 on behalf of the DWER (Figure 3). The earlier digital elevation model (DEM) did not extend far enough upstream to create a 2D model which is why the additional DEM was acquired. The elevation model was compared to surveyed cross sections and benchmarks to ensure its accuracy. Errors were identified where standing water was present in the channel at the time the elevation data was acquired, which can be expected. The errors in channel elevation were rectified by using interpolation techniques in ArcGIS upstream and downstream of the standing water.

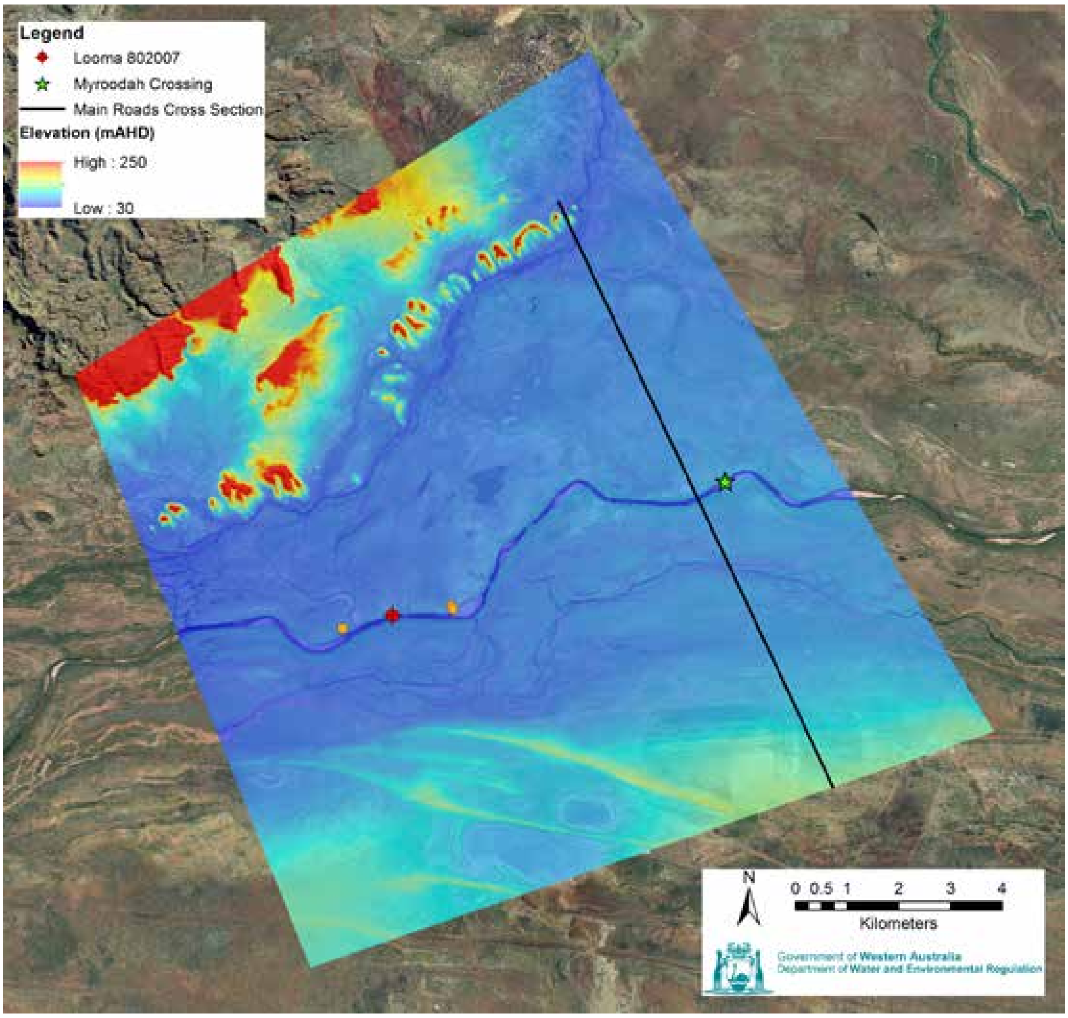

Figure 3: 1 m High Resolution Digital Surface Model at the Looma Streamflow Gauging Station.

A simple two dimensional model was developed in HEC RAS 5.0.1 to reassess the flow rating at the Looma Gauging station. The 1 m HRDSM was used to create a 20 x 20 m grid with 5 m grid spacing orientated along the main channel and 1 m grid spacing orientated along a cross section perpendicular to the flow at the gauging station orifice. One model inflow and one model outflow was included at the upstream and downstream end of the geometry file. Resistance categories in the model domain were represented by Manning's n and defined as main channel and floodplain. An hourly time step flow hydrograph was created for the inflow boundary based on the March 2011 event and multiplied by two to create a rating for larger events. The model was calibrated by iteratively altering the roughness coefficients until the stage flow relationship produced a good fit to the calibration points (Figure 4). The model was validated against the 2017 gauging and the flood marks and inundation extent from the March 2011 event which produced a good validation result (Figure 3, Figure 4 and Table 3).

The calibrated 1D and 2D model ratings both produce a good fit to the calibration points and are similar below a stage height of 18.77 mSL and a flow of 15 000 m^3/s. This provides additional confidence in the stage-flow relationship in the medium flow ranges where no discharge measurements are possible. Above 18.77 mSL the 2D modelled rating is lower, meaning flows are greater for the same depth of water. The difference becomes greater as flows increase. Flow is 2% greater at a stage height of 19 mSL and 18% greater at a stage height of 20 mSL (Table 4). It is expected that the 2D model will provide more accurate results in the mid to high flow range in this instance because the channel characteristics are represented more accurately in the two dimensional geometry file.

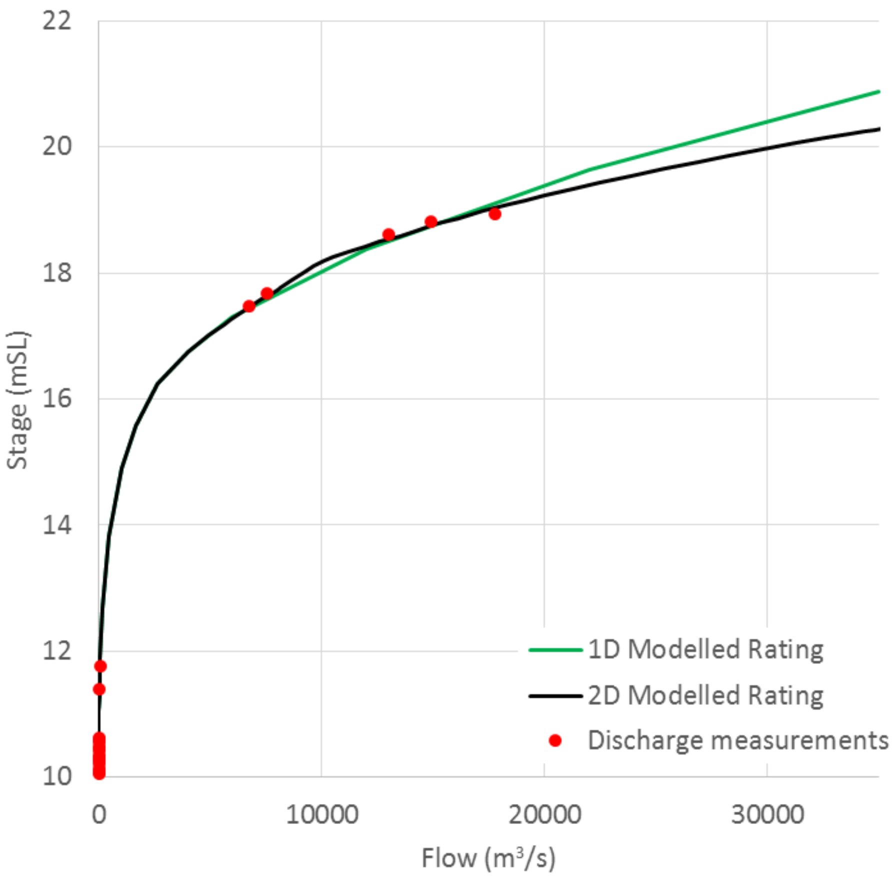

Figure 4: 2D modelled rating, 1D modelled rating and calibration points.

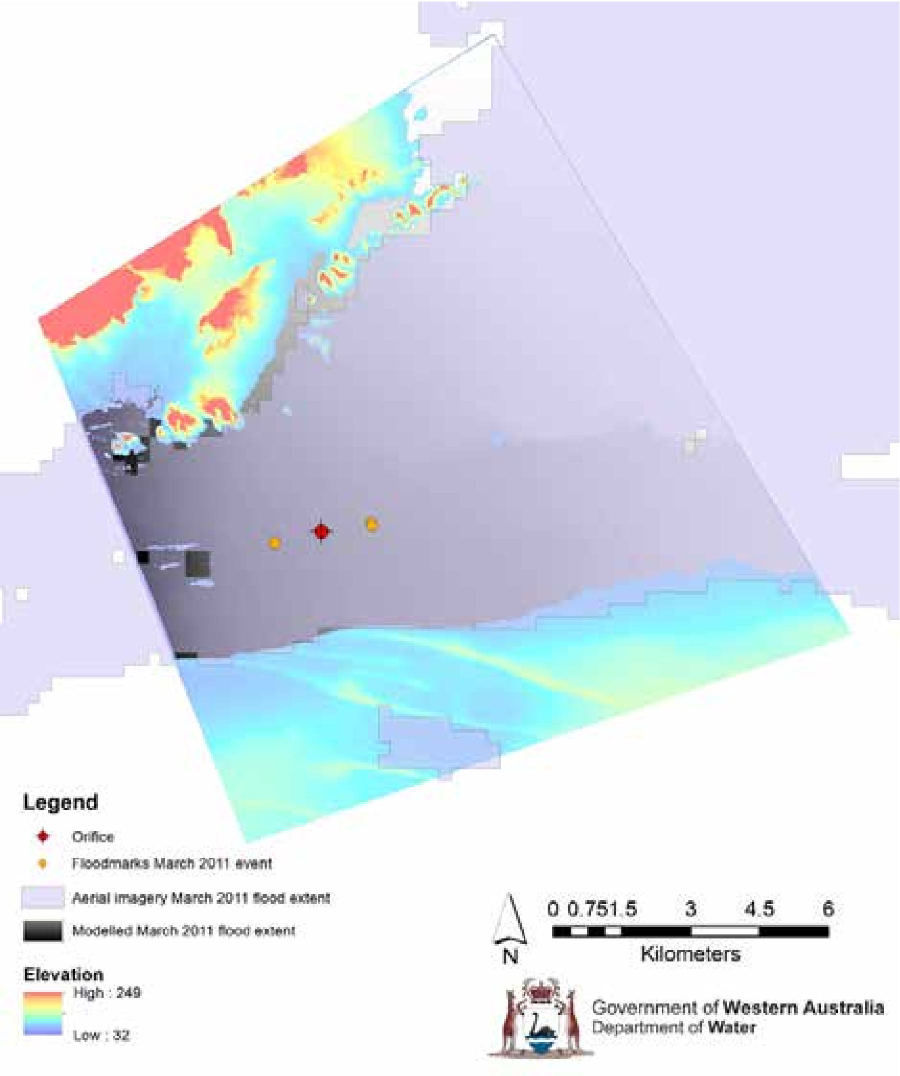

Figure 5: Model validation from the March 2011 event.

Table 3. Model validation from the March 2011 floodmarks

Floodmark	Level mSL	Level mAHD	Modelled Level mAHD	% Difference	Source
2	19.25	42.19	42.43	-0.58%	other side of fence on juvenile white gums
3	19.23	42.16	42.43	-0.64%	dead tree
1	18.92	41.86	41.88	-0.05%	>2 m high in tree

Table 4. Comparison of the 1D & 2D Model Rating

Water Level mSL	1D Model Rating Flow m^3/s	2D Model Rating Flow m^3/s	Percent Difference %
17	4936	4893	-1%
18	9944	9155	-8%
19	16961	17366	2%
20	25774	30414	18%

The modelled flow rating is not capable of calibrating to low flow discharge. The final applied rating is based on the 2D modelled rating in the mid to high flow range and fit to the available discharges in the low flow range. Uncertainty in the rating is greatest in the mid flow range where no discharge measurements are possible and in the extreme flow range above the highest available calibration point.

Additional and independent high flow discharge measurements at the gauge location will provide further information to calibrate and validate the model. This is dependent on the cost and benefit involved in obtaining these discharge measurements. Additional floodmarks from multiple events would improve the accuracy of validation and may provide further calibration data.

Fitzroy Barrage (802003) Streamflow Gauging Station

The Fitzroy Barrage streamflow gauging station was established in September 1986. Officially named Fitzroy Barrage the site has colloquially been called Camballin Barrage interchangeably as it is located 40 kms south east of the Camballin town site where an offtake weir was used to divert irrigation water to the Camballin Irrigation District (Figure 2). The gauge has measured water levels from September 1987 onwards, however a rating wasn't possible due to the ungauged diversion of irrigation water. Based on local information and analysis of the stage record the barrage ceased operation in 1991/92 and the gates were laid flat which made the site less complicated to rate. Some water is still diverted down Uralla Creek to sustain environmental flows and irrigation requirements at Liveringa station which leaves uncertainty in the rating at low flows, however this becomes negligible above a stage height of 10.45 mSL (Figure 7 and Figure 8).

Over the period of flow record three ratings have been applied at the Fitzroy Barrage gauging station. Initially the flow rating had not been well established because of limited discharge measurement information. At the time this project was completed twenty three low flow discharge measurements had been taken from 2004 to 2016 (Table 5). The highest discharge measurement, 39.2 m^3/s was in May 2012 (10.665 mSL) which covers less than 7% of the recorded stage height. Discharge measurements in the mid flow range are not possible as flow is distributed through multiple channels across the floodplain. Discharge measurements in the high flow range, when flow across the floodplain is connected, are possible; however cost, priorities, safety, remoteness and limited flood frequency are a consideration. In particular, traversing the connected floodways by boat is extremely difficult due to vegetation blocking access and hindering the bottom tracking accuracy of the ADCP gauging equipment utilised.

Figure 6: Fitzroy Barrage.

Figure 7: Offtake Gates to Uralla Creek.

The largest event recorded at the Fitzroy Barrage gauging station occurred in February 1993, which is larger than the highest recorded event at Looma. Streamflow increased from the 18th February and peaked on the 27th February at 19.497 mSL and 25.267 m^3/s. Total daily flow was over 2 100 GL on the 27th February 1993, more than seven times the annual water use for Perth. A larger event is known to have occurred in 1914 which is estimated to be 8 cm higher than the 1993 event (The West Australian, 1986).

The only available high flow discharge measurement available for calibration of the stage-flow relationship are the seven high flow discharge measurements recorded 35 km downstream at Myroodah Crossing in 1987, 1991, 1993 and 2017. Five of the measurements were also used to define the rating curve at the Looma gauging station. The discharge measurements collected in 1987 weren't used in the calibration of the hydraulic model for the Looma gauging station because there wasn't associated stage data recorded, only measured streamflow, however the Fitzroy Barrage gauging station was in operation which provides stage data for the associated flow measurements and all seven of the points are used for calibration. It is difficult to transpose the high flow discharge measurements to the Fitzroy Barrage station as the downstream Looma gauging station also relies on these measurements for calibration meaning an independent correlation isn't possible. As well as this, numerous hydrologic interactions occur between the two gauges which are difficult to define. There is a large flood storage area, incoming rivers and surface water groundwater interactions within the Fitzroy River alluvium, above the Noonkanbah formation (Figure 2). In the absence of independent high flow calibration data, levels from the Fitzroy Barrage gauging station stage record, and flow from 35 kms downstream where the discharge measurements were completed, are used as calibration points. Total flow was assumed to be equivalent. The discharge measurements range from 256 m^3/s to 17,749 m^3/s (11.930 mSL – 19.032 mSL) which covers 95% of the recorded stage height over the life of the gauging station. It is accepted that a level of error exists using this assumption, however in the absence of more information the simplest method available was adopted.

Table 5. Summary of discharge measurements and annual peak level details for the gauging station

Year	Discharge Measurements		Annual Max Water Levels Recorded
	Total Discharge Measurements Collected	Max Discharge Measured m^3/s	Stage Height mSL
1986	-	-	11.857
1987	-	-	16.697
1988	-	-	15.148
1989	-	-	16.403
1990	-	-	13.965
1991	-	-	19.041
1992	-	-	12.274
1993	-	-	19.497
1994	-	-	16.448
1995	-	-	18.068
1996	-	-	17.327
1997	-	-	17.004
1998	-	-	16.278
1999	-	-	16.700
2000	-	-	18.131
2001	-	-	17.949
2002	-	-	18.886
2003	-	-	16.843

Year	Discharge Measurements		Annual Max Water Levels Recorded
	Total Discharge Measurements Collected	Max Discharge Measured m^3/s	Stage Height mSL
2004	2	1.473	16.871
2005	2	21.205	13.841
2006	2	1.093	16.907
2007	3	7.874	16.903
2008	3	5.751	16.204
2009	4	7.730	17.175
2010	1	0.531	13.645
2011	1	2.970	18.838
2012	3	39.200	16.485
2013	-	-	15.226
2014	-	-	16.823
2015	-	-	16.178
2016	2	0.419	13.609

Table 6. Summary of high flow calibration data

High Flow Discharge Measurements		
Year	Discharge Measured* m^3/s	Stage Height mSL
21st January 1987	256	11.930
4th February l987	714	13.568
4th February 1991	7536	17.312
27th February 1991	14924	17.770
6th February 1993	12717	18.462
28th February 1993	17749	19.032
23rd February 2017**	6735	17.224

*Discharge is from 35 km downstream. Stage is taken from the Fitzroy Barrage gauge 802001.

In 2009 a 1D HEC RAS model was developed of the Fitzroy Barrage using a combination of surveyed cross sections and cross sections extracted from a 5 m digital elevation model upstream and downstream of the gauge. The model was calibrated to four of the earlier six high flow discharge measurements available 35 km downstream of the gauge using the same assumption to transpose the discharge measurements. A rating curve was generated at the site using a combination of the low flow discharge measurements, standard flow relationships for a weir, and the calibrated 1D HEC RAS model. When the channel is well connected during higher flows it is expected that the calibrated 1D model will produce a reasonably accurate rating, with consideration of the assumptions used to transpose the high flow discharge measurements to the gauge. When flow is dispersed in multiple braided channels across the floodplain (<4000 m^3/s and 16.5 mSL) the rating is expected to be less accurate, as the complex flow paths are difficult to represent in 1D from a 5 m elevation model and the ungauged flow down Uralla Creek becomes more significant. The 1D modelled rating at the orifice produced a good fit to three of the four high flow discharge measurements used in calibration (Figure 8). Two dimensional modelling packages weren't accessible at the time although it was acknowledged that 2D modelling using detailed floodplain geometry could improve the confidence in the modelled rating. Due to the lack of further calibration data or software the rating was considered the best possible with the information available and applied back to 1991 when the gates of the Barrage were laid flat.

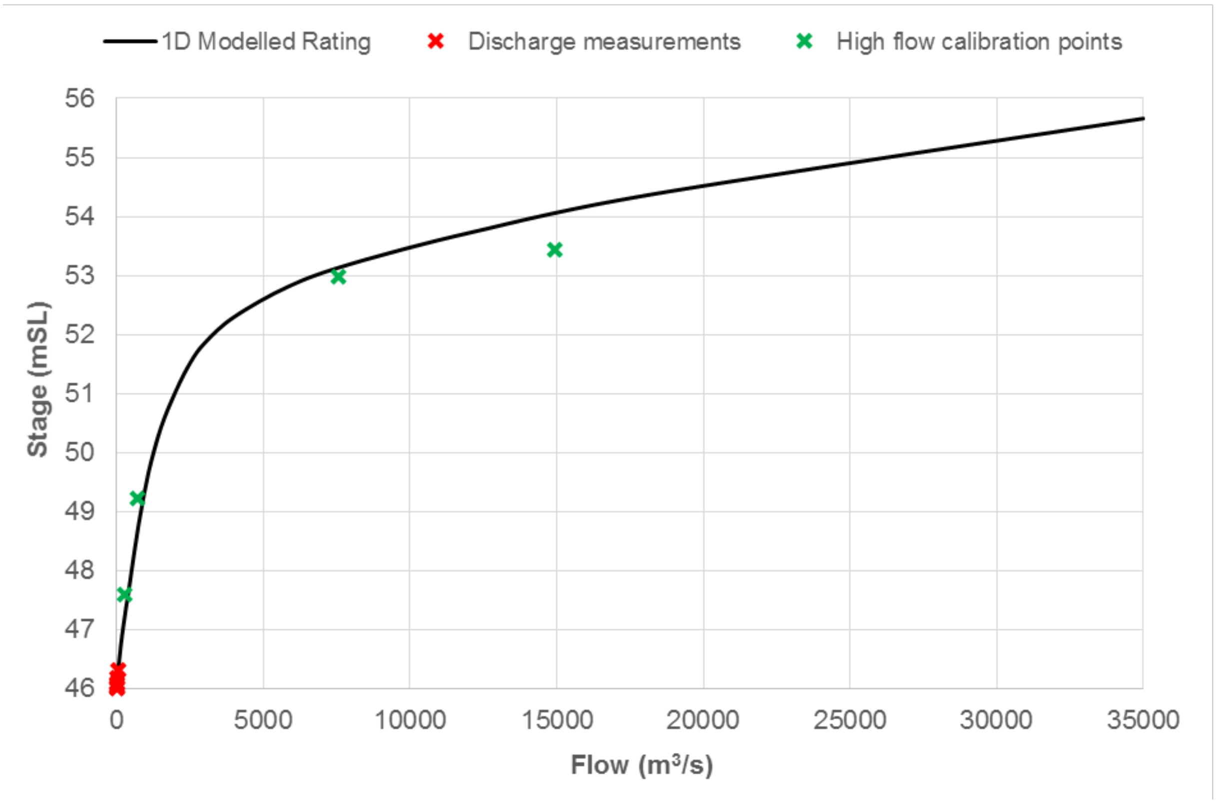

Figure 8: Calibrated 1D modelled stage-flow rating.

A 1 m DEM was produced from 10 cm imagery captured by Landgate in 2016 on behalf of the DWER (Figure 9). Surveyed cross sections are available of the channel upstream and downstream of the gauge and of the adjacent floodplain which were used to ground truth the elevation model. This showed that the DEM had a reasonable level of accuracy including an even amount of levels both higher and lower than surveyed data. Due to the barrage structure a permanent water body exists upstream of the gauging station and the bed level isn't captured as a part of the DEM. A bathymetry survey of the pool was completed in July 2016. Hydrographers surveyed the river pool using the SonTek M9 ADCP with integrated RTK and HydroSurveyor software. A total of 43.7 km of bathymetry track was travelled to capture the river bed elevation and was included in the DEM to give an accurate representation of the bed level upstream of the gauging station (Figure 10, Ramsey & Donovan, 2016).

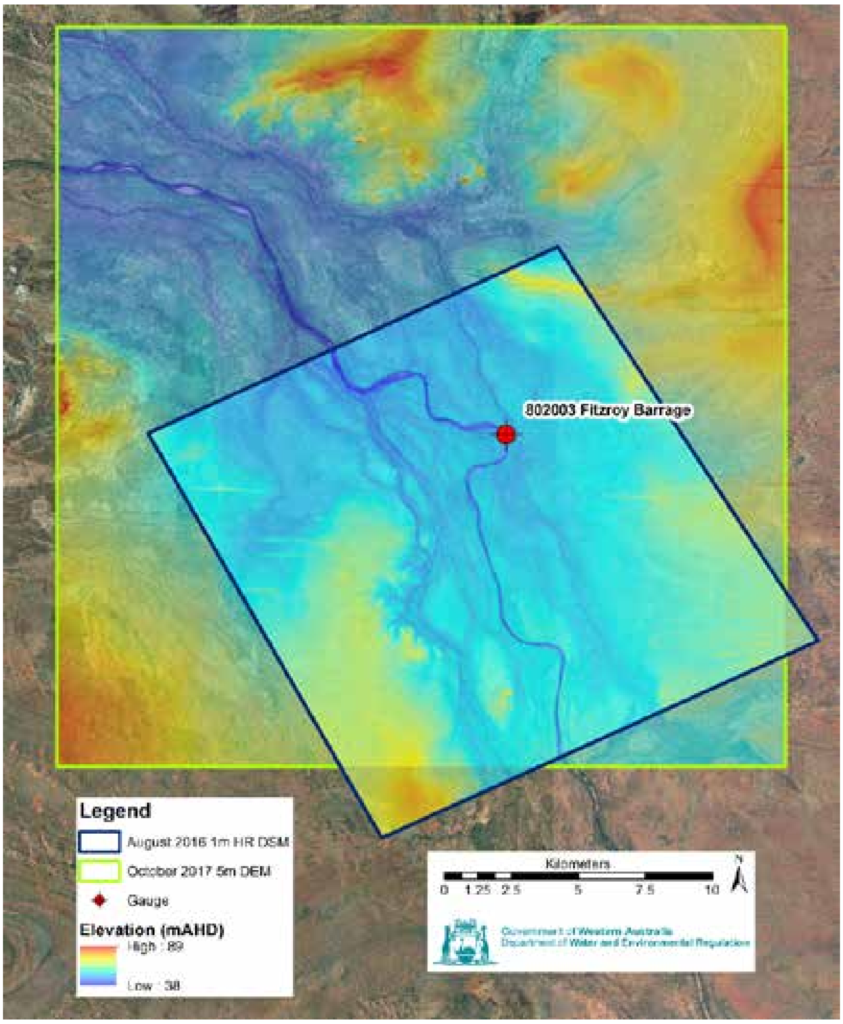

Figure 9: 1 m High Resolution Digital Surface Model and 5 m DEM at the Fitzroy Barrage Gauging Station.

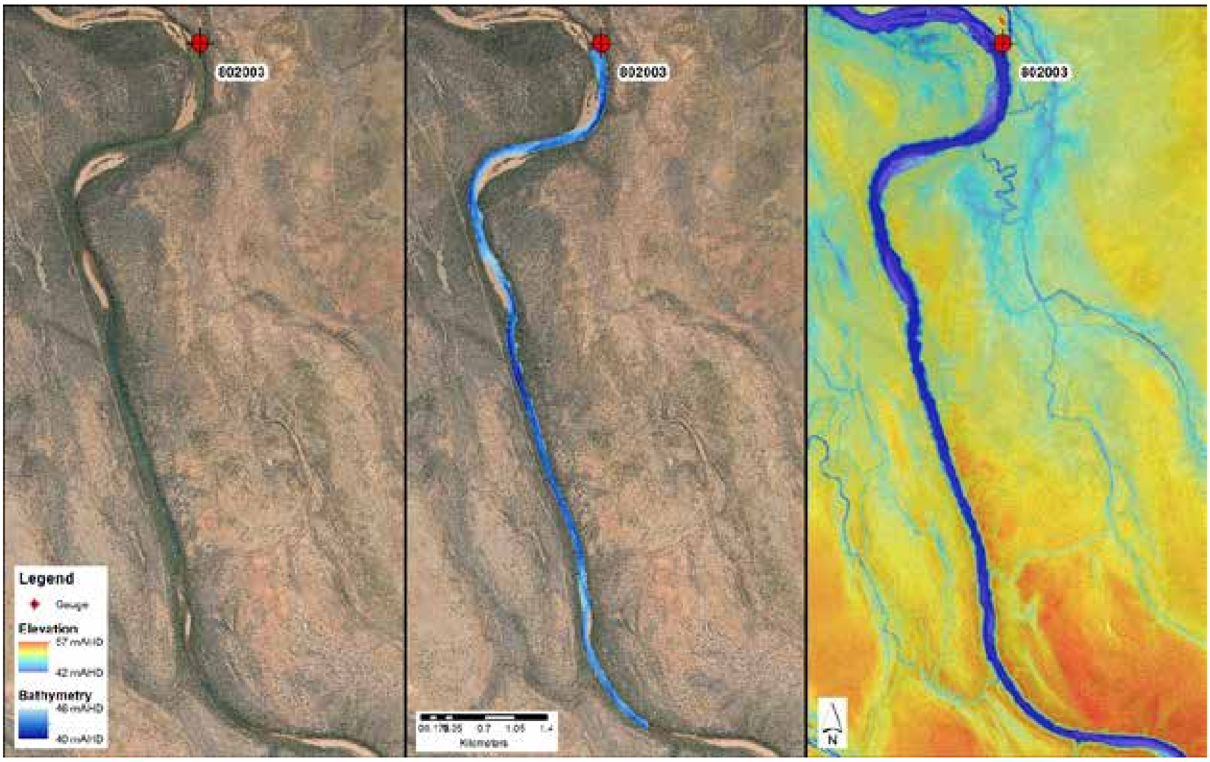

Figure 10: Bathymetry survey of the pool upstream of Fitzroy Barrage included in the DEM.

A simple two dimensional model was developed in HEC RAS 5.0.3 to reassess the flow rating at the Fitzroy Barrage gauging station. The 1 m HRDSM was used to create a 50 x 50 m grid with 20 m grid spacing orientated along the main channel and 1 m grid spacing orientated along a cross section perpendicular to the flow at the gauging station orifice. One model inflow and one model outflow was included at the upstream and downstream end of the geometry file. During calibration it was found the 1 m DEM didn't extend far enough downstream of the gauge to produce an un-impacted modelled rating so the larger 5 m DEM was also used to create the geometry file (Figure 9). Resistance categories in the model domain were represented by Manning's n and defined as main channel and floodplain. A one minute flow hydrograph was created for the inflow boundary based on the February 1993 event, the highest recorded event.

The model was calibrated by iteratively altering the roughness coefficients until the stage flow relationship produced a good fit to the calibration points (Figure 11). The calibrated 1D and 2D model ratings both produce a good fit to the calibration points and are similar throughout the whole range of flows. This provides additional confidence in the stage-flow relationship developed from the 1D model. The 2D model confirms the rating shape in the medium and high flow ranges when the floodplain characteristics have been represented more accurately in the two dimensional geometry file.

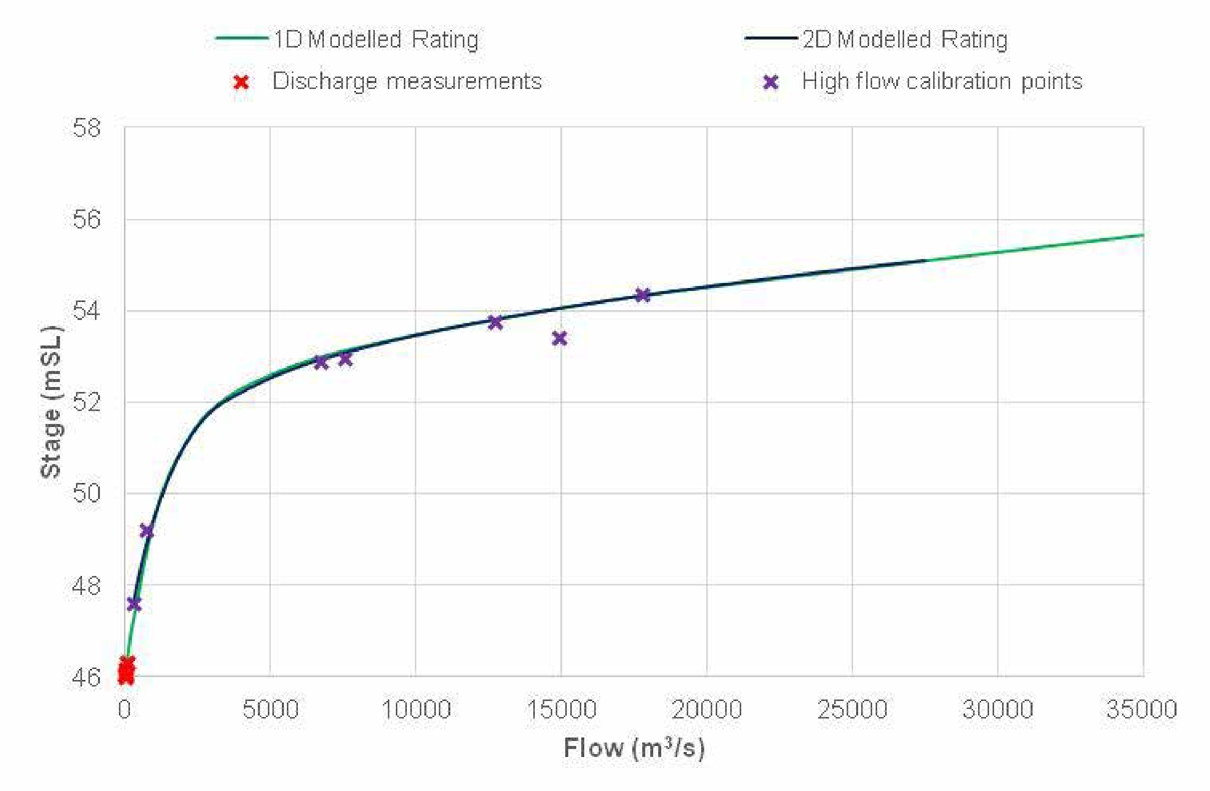

Figure 11: Calibrated 1D & 2D modelled stage-flow rating.

The modelled ratings are not capable of calibrating to low flow discharge at this location. The final stage-flow rating curve is a combination of the low flow discharge measurements, standard flow relationships for a weir and the calibrated 1D HEC RAS model. With consideration of the assumptions used to transpose the high flow discharge measurements to the gauge, the rating in the mid to high flows is expected to be an accurate shape, however may be at an incorrect datum. The rating remains less accurate at low flows as ungauged flows down Uralla Creek become more significant. A sensitivity analysis was completed to quantify the error generated by the assumptions used to transpose the high flow discharge measurements to the gauge. The resistance coefficient, Manning's n, was altered to be higher and lower than the calibrated value and the results compared. The sensitivity analysis shows that the modelled rating may have up to 25% uncertainty due to the lack of independent calibration data.

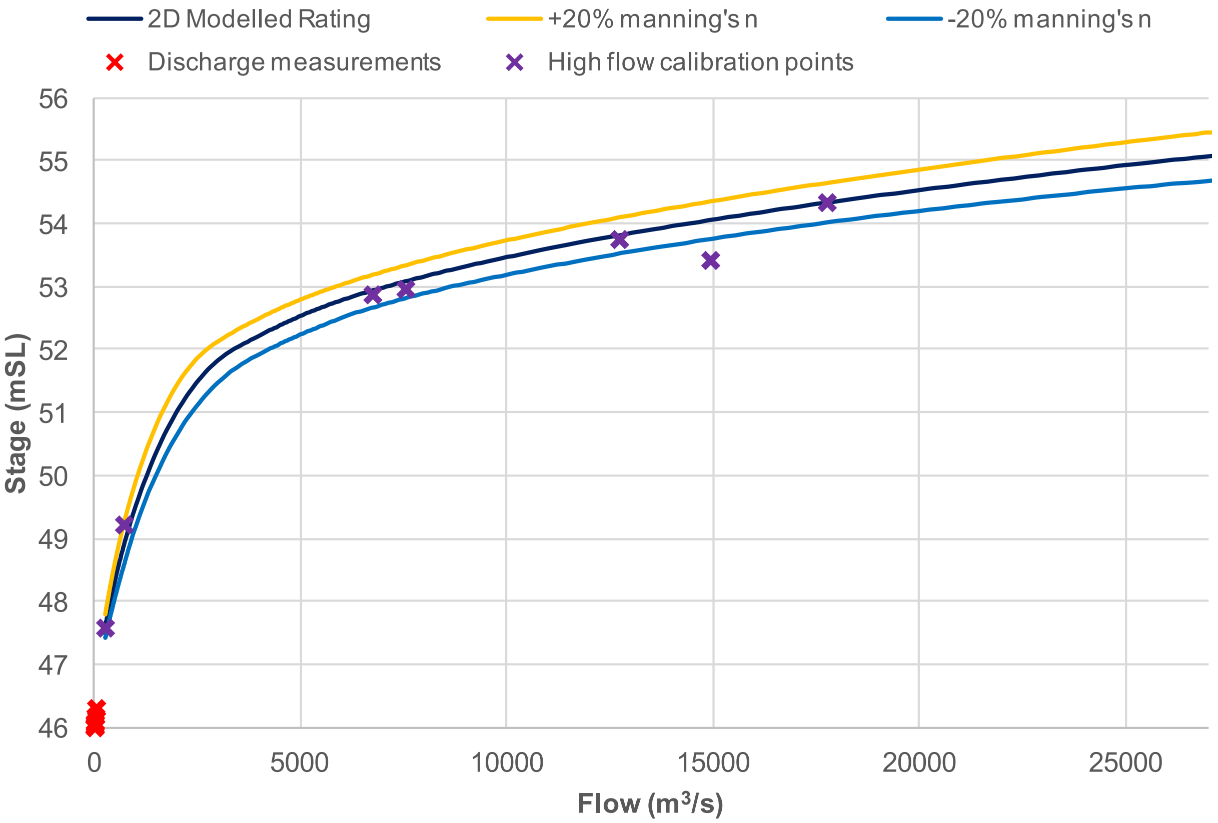

Figure 12: Sensitivity analysis of Manning's n on the 2D modelled stage-flow rating.

Table 7. Sensitivity analysis of Manning's n on the 2D modelled stage-flow rating

Calibrated Rating		20% Manning's n Increase		20% Manning's n Decrease	
Water Level m AHD	Flow m^3/s	Flow m^3/s	Percent Difference %	Flow m^3/s	Percent Difference %
48	409	316	25%	474	-15%
49	752	624	19%	948	-23%
50	1257	1050	18%	1567	-22%
51	1893	1716	10%	2423	-25%
52	3377	2768	20%	4267	-23%
53	7074	5938	17%	8823	-22%
54	14432	12151	17%	17997	-22%

It is accepted that this is the best possible rating without further information. Independent high flow calibration data from the gauge location, either discharge measurements or flood marks, would improve the model calibration or validation. This is dependent on the cost, benefit and opportunity involved in obtaining these discharge measurements. A relationship between the two gauging stations which is independent of the existing high flow discharge measurements at the gauging cross section could improve the model calibration or validation. If a digital elevation model covering both gauges was available a model could be used to understand the correlation, however the hydrology in between the two gauges is hard to define so independent calibration data is preferred. The modelled rating will be re-assessed when more calibration data is available. Sensitivity analysis of the calibration variable Manning's n is used to define the uncertainty of the applied rating up until more calibration data becomes available.

Conclusions

Hydraulic models have been used at the Looma (802007) and Fitzroy Barrage (802003) streamflow gauging stations to develop the stage-flow relationship required to produce streamflow from measured stage data in the absence of the necessary quantity of field measured discharge. A one dimensional hydraulic model for both stations was originally used and a two dimensional hydraulic model has since been used to refine and confirm the rating based on the current data available.

The Looma streamflow gauging station has the required field measurements available to calibrate a modelled stage-flow rating which can be used to develop streamflow data within ±10% accuracy. The two dimensional modelled rating varies from the one dimensional modelled rating above the highest field measured discharge. Flow is greater for the same water depth above this height, up to 18% greater at the high end of the rating. The two dimensional modelled rating is considered more accurate at this location and has been adopted because the complex geometry is represented more accurately.

The Fitzroy Barrage gauging station doesn't have the required field measurements available to calibrate a modelled stage-flow rating. The two dimensional modelled rating produced the same result as the one dimensional modelled rating which confirms the current applied stage-flow relationship with consideration of the uncertainty in the calibration data. Sensitivity analysis of the calibration variable Manning's n shows that up to 25% uncertainty exists in the applied rating. This enables the streamflow data to be used in management decisions with a quantified level of uncertainty. It is accepted that these are the best possible ratings at both of these gauging stations with the calibration data available and additional modelling would not improve the result.

Hydraulic models have been used to develop, refine or confirm stage-flow relationships at thirteen of the seventeen streamflow gauging stations in the Fitzroy River catchment. Models of the remaining four stations will be completed when the required input data becomes available. Model flow ratings can be applied where the river reach channel and floodplain geometry changes very little without variable tailwater conditions. The benefit of using this method is to minimise the number of discharge measurements at a gauging station and maximise the number of gaugings across a network of gauges. This approach is adopted to improve the quality of flow record by the gauges and runoff information available for hydrological studies where field measured discharge is only possible sporadically. Field measurements can be more targeted and fewer in number whilst enabling flow data within a quantified level of uncertainty.

Model sensitivity to changes in channel conditions and field data uncertainty can be tested to understand the accuracy and repeatability of the flow rating at a gauging station. The repeatability of a flow rating is dependent on a large number of discharge measurements over time. And the accuracy of streamflow data, from a flow rating and recorded water level, are dependent on the flow sensitivity to the uncertainty in stage record. Sensitivity analysis using the modelled flow rating provides a way of predicting the flow uncertainty caused by an error in stage measured by the stage transducer. This is particularly important for gauges located on floodplains where the flow insensitivity can cause a significant under and over estimation of peak flows from recorded peak levels, such as the Lower Fitzroy. This information is particularly important to the hydrologist in flood mapping or infrastructure design.

A similar concluding remark is left as the 2010 paper on this same topic (Harris and Bowyer, 2010) – it is a work in progress; however we are further along in this process.

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