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AUSTRALIAN HYDROGRAPHERS ASSOCIATION

Contents

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JACQUIE BELLHOUSE

Editor's Introduction

Three quarters of the year have almost passed and frankly it is a little scary how quickly it has gone; I understand (from my boys as they recently handed me their Christmas lists) there are approximately 90 more sleeps to Christmas. Far more importantly there are only 49 more sleeps (depending on when you get to read this of course) until the AHA 2018 Conference and inaugural Hydrography Week.

Sadly this issue marks the last of the papers from the 2016 Conference papers. I hope you have enjoyed reading the diverse range contributions. To round off the diverse range of subject matter, in this issue, we explore Geordie Durack's work on groundwater monitoring in Coal Seam Gas development areas and examine the background behind on Dr Carla Mooney *et al*'s work to develop standards and strategic plans for Flood Warning Infrastructure. You will also find another great example of the quality of papers coming out of New Zealand with a discussion paper by Brent Hutchby on the Bay of Plenty Regional Councils attempts to better understand groundwater recharge across the region, through the installation of barrel lysimeters.

We have also received a great short article from the Deniliquin Pastoral Times regarding AHA member Richard Brown's retirement. We understand he is going to exchange working on the river with working on his home.

Depending on where you are in Australia you may be reading this issue as you wind down after a mad monitoring season or perhaps you're getting one last read in before work ramps up. I know that in the lower half of WA my counterparts have been kept somewhat busy. For a second year in a row Perth's cumulative rainfall for the year is tracking above the average.

Notably this strong rainfall has given our dams a welcome boost. For example one of Perth's biggest dams, Canning, is now at almost 90% capacity after receiving 10 billion litres of streamflow since the start of winter. It should be noted however that the happy state of the dam is not all down to streamflow. Desalinated water and groundwater have been stored in this dam over many years to be used during periods of high demand over the warmer summer months.

Now for the kicker, for a short period in August 2018, the WA's Water Corporation "misplaced" approximately 20 billion litres of streamflow into its dams. Of course I am being a little dramatic, the Corporation didn't literally lose the water; the loss was a virtual loss. To put it simply the flows, which are estimated via the water balance method using a range of hydrometric data sets (dam water levels, transfers, draw, rainfall and evaporation) were miscalculated. The cause of the miscalculation, a scaling error on a single level sensor recently replaced due to a lightning strike.

The consequence of the error was the graphical misrepresentation of the cumulative dam inflows on the Corporation's website. Fortunately the error was picked up during the monthly data review and the graph was promptly corrected. Unfortunately the correction was not timely enough, the discrepancy noted by some eagle eyed members of the general public including the Water Minister (oops).

This glitch just goes to show how important timely, reliable water information is even when it is as simple as a dam water level. The subject is touched on in our first article by Stuart Hamilton *"Data Drought and Data Flood as Causes of Information Famine"*. Stuart presents a great case for continuously improving water data management so that we can respond to the communities continuously evolving data and information needs in a timely and trustworthy manner.

Regards
Jacquie Bellhouse
Journal Editor

BILL BARRATT

From the President

2018 has been an exciting year with the launch of the Diploma of Water Industry Operations by AHA in partnership with the Riverina Registered Training Organisation of TAFE NSW. Demand for the course has exceeded our expectations with over 20 students enrolled nationally and one from New Zealand. Over the year, in collaboration with TAFE NSW, we have continued to tune our delivery making it more responsive to the needs of students. Although the current Diploma was launched nationally in 2017, the Commonwealth is currently undertaking a major revision. We expect that the revised Diploma will include an additional unit, and have lobbied for change to be more reflective of the needs of Australian hydrographers.

In 2019 we plan to extend our training offerings in consultation with industry.

- First of all we are preparing an induction subject for new hydrographers as they begin the Introduction to Hydrography course. To date, 15 students have enrolled and paid for this course during 2018.
- Secondly we plan to add to the current 5 AHA training subjects (also offered as part of the Diploma) to provide an Intermediate Hydrography course, suitable for all field hydrographers.
- The third level will be an advanced hydrography course, to meet the needs of senior hydrographers, particularly those with a supervisory role.

I am excited by our upcoming conference with its theme of *Extreme Events*. To set the scene we have special keynote speaker Robyn Duell to give an update of the Bureau of Meteorology's outlook for rainfall, temperature and streamflow conditions for the coming months, with a focus on the likelihood of extreme weather events, such as heatwaves, drought, floods, tropical cyclones and bushfires. Ashley Webb from WaterNSW will describe how Australia's highly variable climate and many factors and activities can impact on the quality and quantity of water available in surface and groundwater systems, particularly during the current severe drought in NSW. We hope to see you there.

Regards
Bill Barratt
AHA President

Richard Brown Retires from a Career Working on Water

As published by the Deniliquin Pastoral Times, 18th August 2018.

Figure 1. Richard Brown at his Retirement.

After 43 years in the job, Richard Brown is saying goodbye to work and hello to retirement.

Mr Brown was just 22 years old when he started his first job at the Water Conservation and Irrigation Commission (now WaterNSW).

He started work for the WC&IC in April 1975 at the office in Armidale, where he's originally from, and also started the Hydrography Certificate at TAFE by external studies.

The area covered by the Armidale office was bounded by Walgett, Mungindi, Lismore and Gloucester.

The work encompassed stream gauging, maintaining gauging stations and computation of data collected in the field.

"I found it difficult to do external studies when working away from the Armidale for extended time and was keen to learn more about the theory of open channel flows," he said.

"In December 1976, I accepted a transfer to the Hydrology section of head office in North Sydney. This enabled me to do more study by external studies in addition to attending some classes at Sydney TAFE College, completing the certificate in 1978," he said.

In April 1979, Mr Brown accepted a transfer to Muswellbrook in the Upper Hunter to gain additional practical experience in hydrographic work and was reclassified as a hydrographer grade one in July 1979.

"In December 1981, I was transferred to head office to gain experience with chart digitising to convert analogue data to a digital record for river height." he said.

In September 1982, he was transferred to Deniliquin, calling the town home for the next 36 years of his career and initially collecting hydrometric data from the Edward, Lachlan, Murray, Murrumbidgee, Niemur and Wakool rivers plus Bullatale, Colligen, Gulpa, Tuppal and Yallakool creeks.

Adding to his achievements, Mr Brown graduated from the University of Sydney, Orange campus in 2004 with a Bachelor of Land Management.

"The demand for hydrometric data including water quality, such as electrical conductivity, water temperature and dissolved oxygen has continued to increase in this region over recent years. There has been a constant change in technology in the Hydrometric field throughout my career which has improved safety and efficiency. Equipment to record stream flows and loggers to record and transmit data from the gauging stations to the office have been upgraded to satisfy the demand which improves water management through the region," he said.

"I have always liked the variety and purpose of the Hydrographic work comprising both field and office duties and I would challenge anyone to show me a more interesting river system than exists is in this region which is why I stayed in Deniliquin as it is a great location."

Even with his passion for the job Mr Brown has decided that it's time for retirement, but that comes with many positive memories of his work and his colleagues.

"I will miss the staff and being on the river the most," he said.

"Retirement brings more changes in one's life and my initial plan is to do some renovations to my home before planning any other major ventures."


AHA 2018
CONFERENCE
Extreme Events
The impact of extreme events on surface and ground water hydrography
Southern Cross Club
Woden, Canberra
12 - 15 November 2018
aha.net.au/aha-2018-conference
AUSTRALIAN HYDROGRAPHERS ASSOCIATION
photo by Michael Cuffe (MichaelCuffe.com)

Data Drought and Data Flood as Causes of Information Famine

Stuart Hamilton, Aquatic Informatics, BC Canada.

Abstract

Droughts, Floods, and Famine are a useful metaphor for understanding the importance of water data management. Too little or too much data, like water, have downstream effects. While it is self-evident that lack of water data (i.e. drought) leads to insufficient water information for consumption by water resource managers (i.e. famine), it is somewhat counterintuitive that too much water data (i.e. flood) can also result in information famine. The premise of this part of the metaphor is that an increase in data, without commensurate increase in capacity for data management, reduces the value of the data. Data are mere seeds that must be cultivated into useful information by data management. Without careful cultivation, seeds are blown away by the wind and weeds are likely to thrive and spoil the entire crop.

Water is a shared resource. Historically, civilizations have thrived wherever water quality is excellent and water quantity is abundant. However, migration to discover new sources of freshwater to exploit is no longer an option. The old assumption that 'sharing' means using as much water as you need, with complete disregard for the quality and quantity returned to the environment, is fundamentally unsustainable. In the modern era, 'sharing' means using a 'fair' amount that leaves enough water—of sufficient quality—for the sum of downstream uses. Allocating and enforcing 'fair' amounts of a shared water resource requires shared and trusted water information. Without adequate water information 'fair' is an impossible objective resulting in water overuse, misuse and abuse.

A feedback mechanism is proposed whereby improving water data management can sustain, and even increase, funding for water monitoring. The premise is based on the principle of 'use-it or lose-it' whereby if data is reliably transformed into trusted and useful information the value of the underlying water data collection activities will be recognized and supported with sustainable funding. Unsustainable funding for water monitoring is inevitable if the data are either unavailable or left in a cryptic, unusable state for want of reliable data management.

The rapid adoption of new sensing technologies is resulting in many new sources of water data without a corresponding increase in investments in data management. The result is that the sheer volume of data is overwhelming our ability to make sense of it. Eventually, we may transcend to a 'data about everything, everywhere, all-the-time' status that can be mined by artificial intelligence to answer every relevant water question. In the meantime, while the speed of adoption of new sensing technologies is far greater than the rate of upgrade of data management systems, the information coming from the data can be confusing and even contradictory.

Timely, trusted, reliable water information is needed now more than ever. Water monitoring agencies must adapt and respond to the growing need for modern data management systems that are capable of managing a flood of data and preventing data droughts. Raw data is not good enough. To be useful, water data must be turned into meaningful, actionable, context-rich, information that is instantly accessible to a diverse community of stakeholders. Making the most of our data investment is the best way to ensure that we make the most of our shared water resource.

Introduction

Why are there any surprises in water management and engineering? Surprises are, most often, a result of assumptions that prove to be false. Water management and engineering should not be based on assumptions; decisions should always be based on timely, reliable, meaningful, information. Yet, water often isn't as abundant as expected when-and-where it is needed the most, it can be excessively abundant when-and-where it is needed the least, and the quality of the water is unfit-for-purpose more frequently than expected.

Problems arise when water is managed on the basis of false assumptions. Far better is having relevant and reliable water information to support beneficial choices. Water data need to be produced in sufficient quality and abundance to feed an information hungry world. However every instance where water is overused, misused and abused is evidence that water information either isn't available or is inadequate to inform better choices. In other words, water mismanagement is a too-frequent result of information famine.

There is a greater demand for trusted, timely, and reliable information about the quality and quantity of freshwater than there is supply of such information. Monitoring the quantity and quality of water at any point in a watershed captures the sum of effects of all human-water interactions upstream of that point. Knowledge of the effects is beneficial to downstream water users as well as providing valuable feedback when interventions are required to prevent deleterious effects.

As an example, water eutrophication has emerged as one of the most serious environmental problems often leading to toxic algal blooms. However in a recent study Pace *et al.*, (2016) have demonstrated that continuous water quality monitoring can identify regime shifts predictive of full scale algal blooms giving water resource managers up to two weeks warning to mitigate or prevent harmful events. The key to meeting our expectations for water management is useful, timely and reliable information.

The hydrologic cycle is a continuous process that often is not confined to any single political jurisdiction. Effective water stewardship and the governance of water use — and its reusability—therefore requires horizontal collaboration and cooperation across departments and sectors within a vertical hierarchy of local, state, and national interests. Effective water management is facilitated by agreement among all sectors and stakeholders that depend on it. Water monitoring agencies face issues around jurisdiction, coordination, and sharing of information.

How do we ensure effective water stewardship?

Water overuse is a consequence of inadequate (i.e. not timely, not in the right location, not trusted or reliable) data to inform when or where the available supply (quantity or quality) is inadequate to provide for the sum of beneficial uses. Water misuse is a consequence of inadequate data to prevent unwanted outcomes from occurring (e.g. policy or planning decisions that are based on unverified assumptions about water supply variability rather than substantial evidence). Water abuse is a consequence of inadequate data to identify transgressions of the trust relationship among stakeholders (i.e. purposeful maximization of self-benefit at the expense of benefit to others).

Effective stewardship of water is enhanced if decisions made about water are evidence-based (Hamilton and Price, 2017). It is useful to have baseline-scale monitoring that provides data with a high level of integrity and comparability. It is useful to have mission-scale monitoring needed to address specific water management mandates and priorities. It is also useful to have project-scale monitoring needed to address specific concerns, such as verification or measurement of a water right or permit.

Historically, the information most easily searchable, discoverable, and accessible was managed by centralized agencies. These data providers have typically gathered, maintained, and published data for long time frames, using established methods and documented workflows, resulting in a high degree of user trust. New uses of water data are emerging in parallel with new monitoring technologies resulting in many more sources of data outside of the traditional data silos.

All water data are potentially relevant to effective water stewardship. However, many water resource management decisions are made without access to important, in some cases critical, evidence. Data collected for some specific project may fill a critical data void for some completely different project. Any data that improves water stewardship is of benefit to all stakeholders in the watershed.

Data Drought

A data drought is defined, for this discussion, as when water monitoring activities are denied adequate funding. Droughts can be persistent (e.g. where entire regions are chronically under-served with data) or episodic (e.g. where funding for water monitoring follows disasters but where that funding is unsustainable for more than a few political cycles). Data droughts have space scales (e.g. distinctly unique hydrological regimes are under-sampled), time-scales (e.g. loss of continuous long-term data sets) and intensity-scales (i.e. the trade-off between complete loss versus degraded quality).

Water information is a public good and there is a lot of competition for public funding. Too often the benefits of water monitoring are only known to a few engineers with the patience, perseverance, technical skills and abilities to search for, discover, access and understand arcane, cryptic and complex water data. Data drought is a consequence of a low public awareness of the value of water monitoring data. A low public awareness is an inevitable consequence of old school data management practices that results in data that are relatively unsearchable, undiscoverable and inaccessible for anyone beyond a short list of 'clients'.

Data Flood

Technologies for data sensing are changing rapidly in a way that is flooding the world with the latest data. There are many new sources of data — more parameters, higher frequency, more locations and more sensor redundancy. However investments in data management are not keeping pace. In some cases the additional burden of field installation, servicing and maintenance all of the new field equipment is at the expense of data management activities. The net result of more data is, almost always, a dilution of data management. Poorly managed data usually results in information famine.

For example, Sprague *et al.*, (2017) investigated 25 million nutrient records from 488 different agencies in the United States since 1899. Of these "nearly 14.5 million had missing or ambiguous information for one or more key metadata elements, including (in decreasing order of records affected) sample fraction, chemical form, parameter name, units of measurement, precise numerical value, and remark codes." This ambiguity resulted in a loss of US$12 billion in value relative to the US$8.2 billion value of the properly curated data.

Similarly, De Hayr (2016) investigated data for the Great Barrier Reef Basin and discovered that 80% of the data could not be used because of inadequate record keeping, resulting in a direct loss of AU$2-3 million in value. It should be noted that these valuations are with respect to the data itself, not to the loss of ability to make well-informed decisions that, almost certainly, would have resulted in different and timelier policies, practices, and regulations for protecting the Reef from harm.

Data flooding occurs when increased data volumes overwhelm data management systems designed for a time when the operator was intimately familiar with each and every sensor and had the ability to inspect and manually correct the data before publication. Modern data management systems are expected to deliver data from gauge-to-page in less than 1 second. Gauge-to-page refers to the elapsed from time of transmission to when the data are available on a website and that during this time the data must be correctly identified, parsed, secured, inspected, filtered, graded and published. In combination with more sensors being added to each location every year this creates a need to re-think data management.

Data floods need to be managed with a modern data management system designed from the ground up for high throughput data volumes.

Managing data droughts and floods to prevent information famine

Web portals that expose the results of water monitoring in meaningful, context-rich, displays create great resilience against funding cuts and these same map-based displays can spotlight data voids, which can actually result in public pressure to increase funding for water monitoring. Data sharing enables a wide range of new and innovative uses of water data that are based on high transaction rate machine-to-machine data transfer. The more external applications that are developed with a dependency on water data, the greater the outrage will be when threats arise to sustainable funding for the monitoring activities that support that data.

Agencies that have historically collected data to be used for a single purpose are discovering that sharing their data makes the most of their data investment. Data that may have historically been collected for a specific mandate are now contributing to improved outcomes for watershed stewardship. Conveyance of the quality and confidence becomes critical in a world of openly published and easily accessible data from diverse sources.

As the trend toward more numerous and heterogeneous data providers continues, the provenance, metadata, and more qualitative assessments concerning "fitness for use" or "fitness for purpose" will become a critical attribute to datasets. Value in water data is not an intrinsic property but is created as a function of data management and effective communication. Data that are neglected have low, perhaps even negative, value. Data that are information-rich, timely, trusted, and accessible have unbounded value.

In addition to hydrological measurements and sensor data, many agencies rely on derived water data products such as hydrologic models that ingest data from diverse sensor networks, and the model results. An example would be a report based on a watershed model that utilizes historic streamflow to predict run-off given precipitation, soil moisture, and snowpack characteristics. Other types of derived data products may include aquifer characterization models intended to assess groundwater availability or safe yield limits, as well as estimates of water use and projected demand based on reported withdrawals by community water suppliers or remotely sensed data. They may include regulatory and/or legal and institutional information, such as water rights and permitting, minimum instream flow requirements, environmental assessments, or whether a particular basin is open or closed to further development. These are high-value datasets that can contribute to management on either local, regional, or national scales.

The providers of derived water data can be large or small, and range from large federal agencies with more expansive water-related responsibilities, to state water agencies performing analysis for appropriation or permitting purposes, to smaller local or regional watershed groups or river basin commissions. Therefore, data management solutions must have abilities to integrate these valuable sources of data seamlessly, without manual effort.

Modern times require modern systems

Historically, one-to-many (e.g. a designated state-level water monitoring authority) and one-to-one (e.g. data acquired for a single end-use) use-cases have prevailed. In the one-to-many and one-to-one use-cases, data reporting by tightly controlled publication pathways were supported by a number of metadata strategies ranging from an extreme of “no metadata provided,” to simply providing data sources, to ordinal rankings, to statistical estimations of error and uncertainty, to providing context and provenance.

Modern data management systems enable a many-to-many inter-connectivity opportunity, vastly improving access to many data sources that could provide for greatly improved watershed stewardship outcomes. This new inter-connectivity of many end-users with many data sources imposes a new requirement for enhanced interoperability of keystone metadata that is essential for meaningful data interpretation. High frequency real-time streamflow data for thousands of locations are available to a global audience within seconds of measurement from agencies like the USGS. Timely data feeds like this necessarily deserve some indication of data quality; how likely data are to change before being finalized (e.g., inclusion of a “provisional” qualifier) and qualification of particular conditions that are important for interpretation of the data.

The Internet also has created great potential and demand for sharing data in machine-automated and interoperable ways. To the degree that data quality indicators can be encoded in machine-readable formats, as opposed to free-form narratives, interoperability will be improved. Web services and APIs and their rich interchange formats, such as eXtensible Markup Language (XML) and JavaScript Object Notation (JSON), create an ideal medium in which data quality and fitness of use information can be reported alongside the data themselves in a structured, machine-readable format (Larsen *et al.*, 2016). Less and less will data quality be described by free-form text narratives; more and more will data quality be encoded in machine-readable formats. These machine-readable metadata encoding schemas are highly extensible. There are no longer hard limits on how much metadata can be attached to a data value.

Importantly, these technologies enable everyone (i.e. no longer just sophisticated water data geeks) to easily find water data using map interfaces (e.g. ESRI, Satellite Imagery and OpenStreetMaps) providing a highly visual and interactive environment for information exploration. Once found, data can be placed in historical context (e.g. deviation from normal) or local context for immediate action (e.g. flood warnings). Web portals, viewable on any smartphone, are bringing water data to people in ways that make water monitoring activities a highly valued public asset.

The technology for managing high-throughput data has been changing quickly. As important as it is to have a system built on a robust modern data model that is designed from the ground up to enable fast performance, the new mantra is agile. An agile architecture is one that embraces change, rather than resists it. It is difficult to design, exactly, for what the future will bring (e.g. how long will it be before routine monitoring includes time-series of images and videos from fixed installations or drones?), it is far better to adopt a modern architecture that is designed to adapt as new (and often unanticipated) requirements emerge.

An effective data management system is the best defence against data floods. An effective web portal complete with a high data sharing capacity is the best defence against data droughts. In combination, efficiently and effectively managed data that are easily searchable, discoverable and accessible ensure that desperately needed water information is plentiful (Hamilton 2017).

We can expect to see continuous improvement in water management as more water monitoring agencies upgrade their water data management and information creation capabilities. With better water management there will be fewer incidents of water overuse, misuse or abuse and fewer unwanted surprises of events with too much, too little, or the wrong quality of water.

Conclusions

The ultimate goal of most water monitoring agencies is to ensure fair use of a shared water resource so that all stakeholders can optimize benefits while minimizing their impact on instream flow needs. In the past, there has been a convoluted path from data to decisions. Reporting on the state of the water resource was usually after-the-fact, resulting in methods of water management that are a bit like driving by only looking in the rear-view mirror. Generally speaking only a handful of engineers would have the skills and abilities for searching for, accessing and using data for such retrospective analyses. This community of specialists have a rich understanding of the value of water monitoring but only a very limited ability to advocate on behalf of water monitoring.

Best practice for water data management enables curation and publication of water information almost instantly, making it consumable by a wide and diverse community of users. Data are made relevant, and hence useful, for any given purpose because carefully managed data provenance enables context-sensitive search, discovery and access. Web portals make water information consumable for the right people, at the right time, for the right place. Well managed data transformed into well-used information ensures that shared water resources are managed for current and future needs.

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A new approach to groundwater monitoring in coal seam gas development areas

Geordie Durack, Department of Natural Resources and Mines, Toowoomba, Queensland.
Paper presented to 18th Australian Hydrographers Association Conference Canberra. 24-27 October 2016.

Abstract

The Queensland Department of Natural Resources and Mines[1] have recently implemented a new groundwater monitoring program in areas of coal seam gas (CSG) development. There are two sub-projects: CSG Online and CSG Net.

The CSG Online program involves the installation of continuous monitoring loggers and telemetry on 60 strategically located bores, the data from which is made publically accessibly 'live and online'. Where traditionally the department has installed telemetry equipped water level loggers in department owned, dedicated monitoring bores, the CSG Online program is also utilising suitable private water bores as monitoring locations. The methodology for installing and maintaining telemetry equipped water level loggers alongside water supply pumps in private water bores has required innovation and some trial and error. However, the inclusion of private water bores as potential monitoring locations has greatly increased the spatial reach of the program. The water level data received from bores that are intermittently pumped for water supply can in some instances provide additional information for water resource analysis beyond that obtained by traditional dedicated monitoring bores.

CSG Net is a community based monitoring program where landholders in CSG areas are engaged in groups, provided with information on the CSG industry and groundwater systems and encouraged to measure groundwater levels in their private water bores on a monthly basis. Systems have been developed to enable landholders to submit their monitoring data to the department for storage in the department's groundwater database, the data from which is publicly accessible via the Queensland Globe. Outcomes from the landholder monitoring, and complementary monitoring undertaken by the department and CSG companies, are shared and discussed at annual workshops.

The new monitoring program has been highly successful to date. Similar programs are being actively considered for use in other sectors in Queensland where operational activities associated with industries such as mining or shale gas may impact on landholder's access to groundwater resources.

Background

In the Queensland portion of the Surat and Southern Bowen basins, a significant coal seam gas (CSG) industry exists and is continuing to develop. CSG is produced by extracting water from coal seams to reduce the pressure that keeps the gas in place. This process brings significant quantities of groundwater to the surface. Current water extraction associated with the CSG industry is about 65,000 megalitres per year (OGIA 2016). In and surrounding the areas of CSG development there is significant consumptive use of groundwater for agriculture, industry, town supply, stock and domestic supply. There is community concern that the extraction of water associated with CSG development may have adverse impacts on the State's groundwater resources (Free 2010).

The Office of Groundwater Impact Assessment (OGIA) is establishing a network, implemented and operated by CSG companies, to monitor and assess the impacts of CSG water extraction in the Surat cumulative management area, which encompasses the primary areas of CSG development in Queensland. To support this network and increase community confidence in and understanding of the outputs of this type of groundwater monitoring, the department is implementing a new groundwater monitoring program in areas of CSG development. There are two sub-projects: CSG Online and CSG Net.

CSG Online

Scope and implementation

The CSG Online program involves the installation of continuous monitoring water level or pressure loggers equipped with telemetry on 60 strategically located bores in and surrounding areas of CSG development. The data from which is made publically accessible on the department's water monitoring information portal website. Where traditionally the Department has installed telemetry equipped water level and pressure loggers in department owned, dedicated monitoring bores, the CSG Online program is also utilising suitable private water bores as monitoring locations. Including private water bores as potential monitoring locations greatly increases the feasible spatial reach of the program.

The methodology for installing and maintaining telemetry equipped water level or pressure loggers on private bores alongside existing water supply pumps and other infrastructure has required innovation and some trial and error. Loggers have been installed in both artesian and sub-artesian private water supply bores.

For artesian bores the installation is reasonably straightforward, with a pressure transducer being able to be plumbed directly into an outlet on the bore. Where there is gas entrained in the water supply of artesian bores, it has been observed that it is beneficial to site the pressure transducer on the lowest possible outlet to limit the potential for gas to build up around transducer which is suspected to cause some reading error.

Installation in sub-artesian bores equipped with pumps requires more work with the existing infrastructure. Under the CSG Online program, Ott bubblers and airlines are being used to monitor the water levels in sub-artesian bores. To install an airline in a bore equipped with a pump it is typically necessary to remove the pump and attach the airline to the pump column. For maintenance and calibration of the monitoring equipment manual water levels are taken via a measuring tape lowered directly into the bore, in bores equipped with pumps this process risks getting the measuring tape tangled in the pumping infrastructure and stuck down the bore. To mitigate this risk a dedicated pipe for taking manual water levels is also being attached to the pump column while the pump is out of the hole. Figure 1 presents a cross section diagram illustrating the typical pipe configuration in a sub-artesian bore equipped with a water supply pump, dedicated manual monitoring pipe and airline. Figure 2 presents two photos of monitoring equipment being installed in a sub-artesian private water supply bore.

[1] The department is now known as the Department of Natural Resources, Mines and Energy.
[2] https://water-monitoring.information.qld.gov.au/ accessed 20 September 2018.

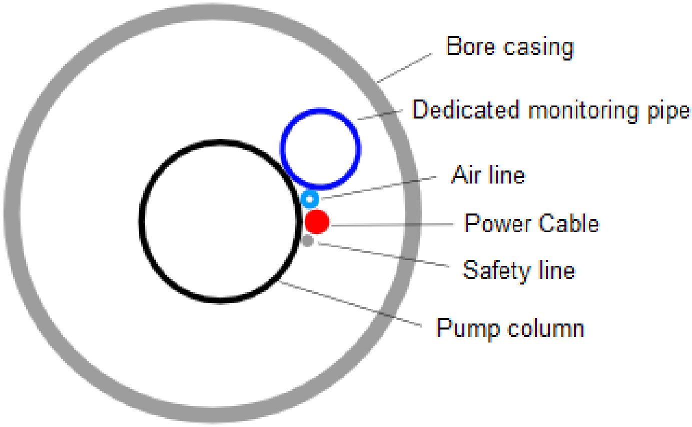

Figure 1. Process for developing and endorsing standards.

Figure 2. Photos of installation process in a sub-artesian private water supply bore.

A multi criteria analysis approach is being utilised to identify private water bores suitable for monitoring under the CSG Online program. Bores must exist in areas useful for assessing the impacts of CSG water extraction, either as background monitoring or in areas of potential impact. The bore should be well constructed in accordance with the minimum construction standards and be sourcing water from only one aquifer. Bores with a history of water level or pressure readings are given higher weightings. Private water supply bores must have a history of use such that the bore is regularly not used for periods of at least 12 hours to allow the water level or pressure to fully recover. Artesian bores must be free from leaks at the headworks and be able to be safely fully shut off. Sub-artesian bores equipped with water supply pumps must have sufficient annular space between the pump column and the bore casing to allow installation of monitoring equipment (available annular space is illustrated in Figure 3). For sub-artesian bores equipped with water supply pumps, due to the need to remove the pump, typically only bore with submersible pumps and poly pipe pump columns are selected as other pump and pump column styles are much more labour intensive to remove.

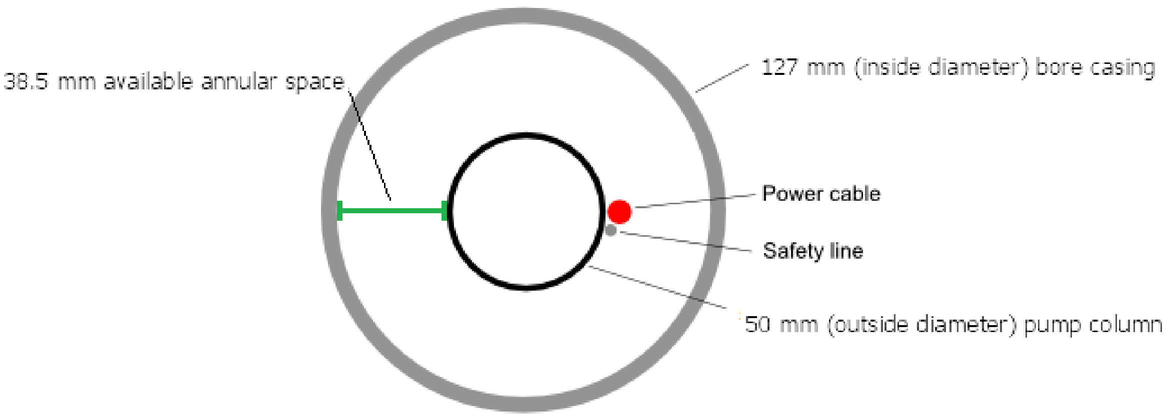

Figure 3. Diagram illustration available annular space (measurements are examples only).

To date, telemetry equipped loggers have been installed on 37 bores under the CSG Online program. Of these, 22 are private water supply bores, six artesian and 16 sub-artesian equipped with water supply pumps. As well as providing a much greater spatial range of potential monitoring sites, using private water bores as monitoring sites has the additional benefit of promoting transparency in the monitoring process. While the programs primary focus is on monitoring the recovered water level, the drawdown and recovery data obtained from water supply bores can also be very useful.

A simple example of the value of the continuous monitoring data obtained under the CSG Online program can be seen by reviewing the behaviour of three bores in and around the town of the Wallumbilla, 40 km East of Roma. There are two CSG Online loggers in the township of Wallumbilla, both in bores targeting the Gubberamunda Sandstone. One logger is monitoring a private water supply bore, RN 58444, which is pumped intermittently, the other logger is monitoring the old town water supply bore, RN 123318, which is no longer pumped. A new town water supply bore, RN 123516, has been drilled, also targeting the Gubberamunda Sandstone. This bore was pump tested in February 2016, the influence of which can be seen in both nearby CSG Online loggers. The locations of the three bores are shown in Figure 4.

Figure 4. Map of CSG Online sites and new town bore in Wallumbilla.

The first significant pump test at the new town bore occurred in early March, resulting in a clear water level decline of approximately 5 m in RN 123318. A water level decline of approximately 0.5 m is also evident at this time in RN 58444; the smaller decline is due to being further away from the new town water supply bore. The impact of pumping from RN 58444 are also evident in the water level plot for this bore, highlighting the point source and broader water level impacts at play in this small area. Figures 5 and 6 present the relevant water level plots from the CSG Online loggers on RN 123318 and RN 58444 respectively.

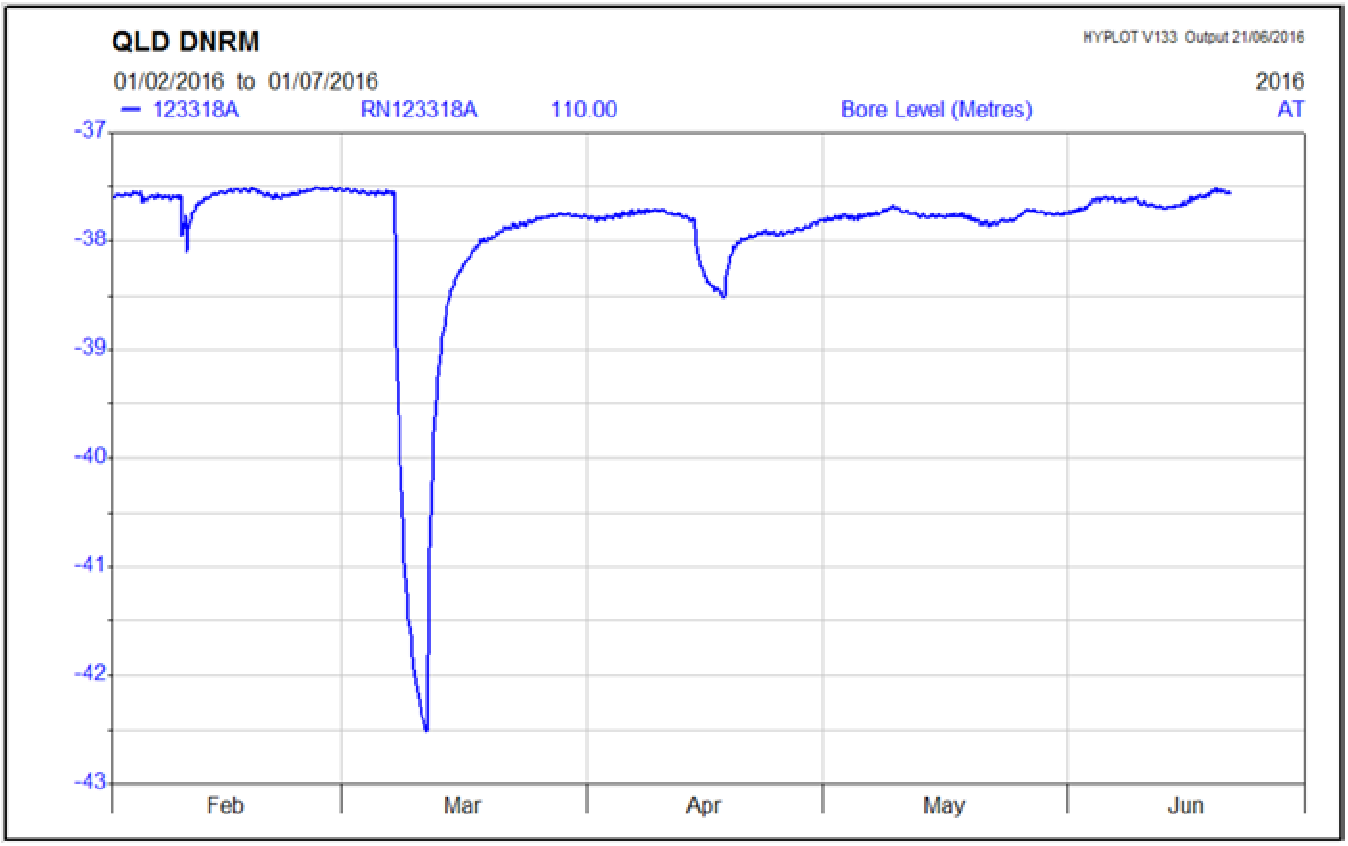

Figure 5. Water level plot from the CSG Online logger on RN 123318.

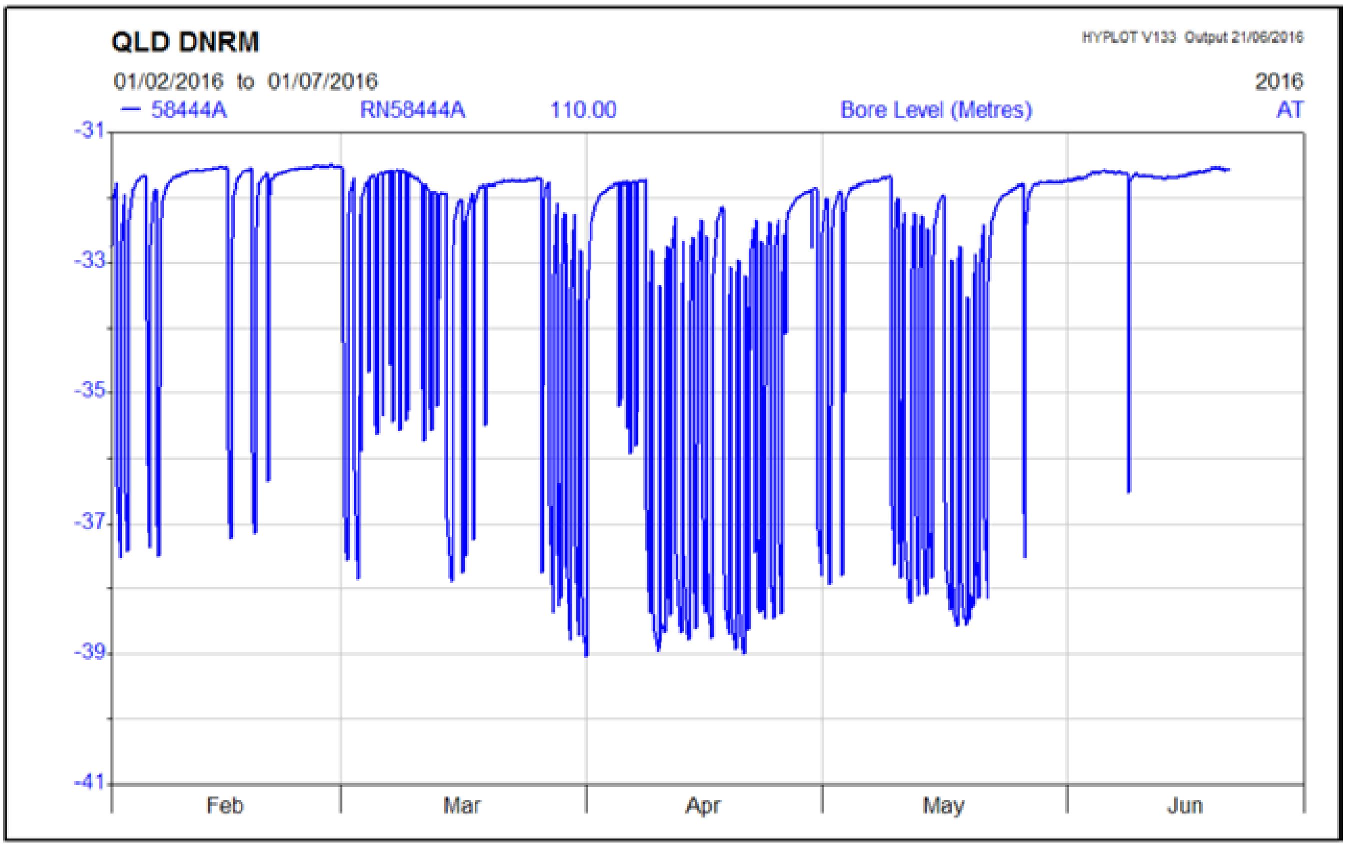

Figure 6. Water level plot from the CSG Online logger on RN 58444.

Without the continuous monitoring provided by these CSG Online loggers any review of these impacts could at best only have been based on theoretical modelling. While it is fair to say that in this case the impacts may have gone unnoticed, this is presented simply as a test case of the potential value of such data.

CSG Net

Scope and implementation

CSG Net is a community based monitoring program where landholders in and surrounding areas of CSG development are engaged in spatially relevant groups and encouraged to monitor water levels or pressure in their own bores. The value of monitoring water levels and pressures is promoted at annual workshops where landholders are provided with information on the CSG industry and the status of local groundwater systems. Landholders are encouraged to take monthly water level or pressure readings from their private bores and are encouraged to submit these readings for storage in the department's Groundwater Database, the information from which is accessible via the Queensland Globe. Monitoring data submitted by landholders under the CSG Net program, as well as complementary monitoring undertaken by the department and CSG companies, is used to develop an annual status report specifically tailored for the geographical area of each CSG Net group. The monitoring results are shared and discussed at annual workshops involving landholders, CSG company hydrogeologists and the the departmental project team.

There have been 15 CSG Net groups established to date, with one more group to be established in the near future. Figure 7 presents the existing and proposed CSG Net groups.

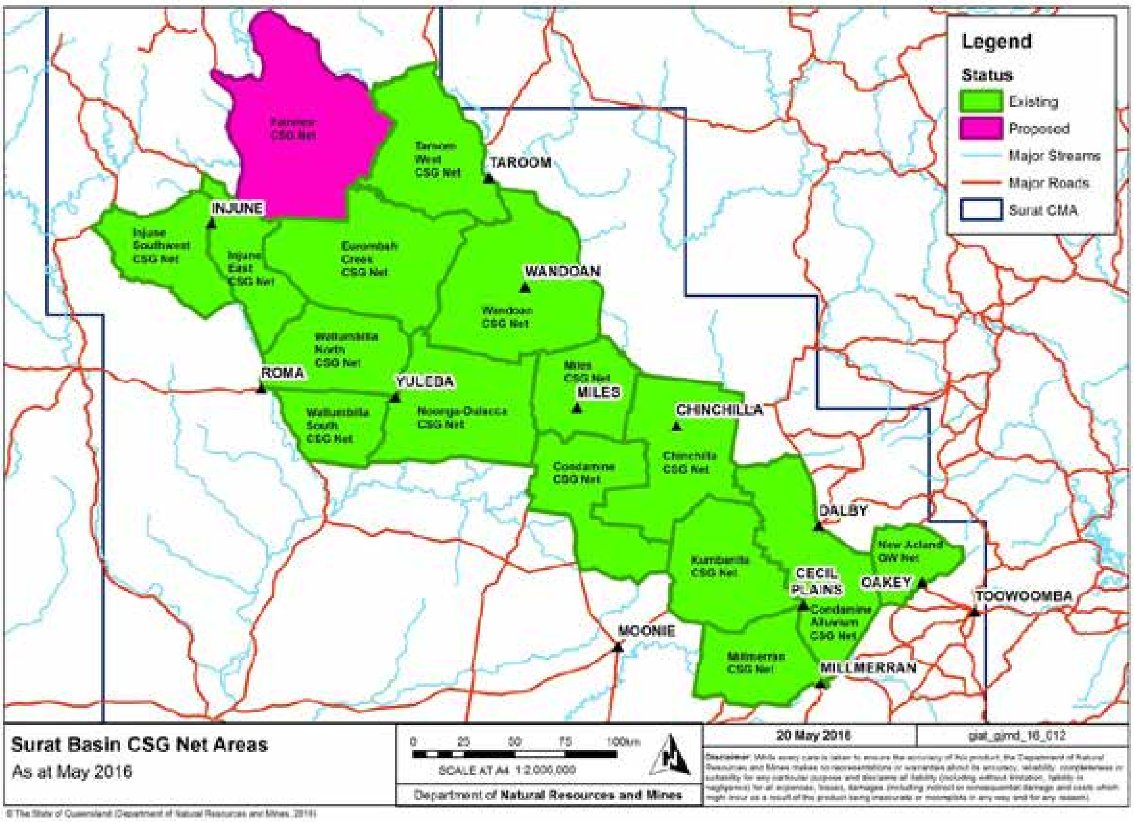

Figure 7. Map of existing and proposed CSG Net group areas.

The CSG Net program has been the catalyst for the development of the department's *My Groundwater Monitoring* web application which allows landholders to submit water level and pressure readings directly to the department via computer or smartphone. Prior to the development of the *My Groundwater Monitoring* web application landholders were limited to submitting paper records via post, fax or email. It is intended that making the process for submitting monitoring records as open and simple as possible will limit barriers to landholder participation. Landcare coordinators have also been contracted to provide local 'on the ground' support for landholder groups and individuals in undertaking the monitoring and submitting their records.

The CSG Net program is receiving very encouraging feedback to date with landholders feeling empowered to monitor their own water bores and accepting that they have a shared responsibility for groundwater monitoring to protect their own interests. The program is also providing the government with a more transparent and effective monitoring network and the regular community engagement is resulting in landholders being more knowledgeable about the status and behaviour of groundwater systems.

Summary

The development of methods to install continuous monitoring loggers and private water supply bores is yielding multiple benefits. The new CSG Online and CSG Net monitoring programs have been highly successful to date, providing a transparent, effective and efficient monitoring network. Effectively involving landholders is helping to build public confidence and is providing a forum for engaging in robust discussions about complex groundwater issues.

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National Collaboration to Develop Standards and Strategic Plans for Flood Warning Infrastructure

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Paper presented to 18th Australian Hydrographers Association Conference Canberra. 24-27 October 2016.

Abstract

Cumulatively flooding is the most damaging of all natural disasters in Australia (van den Honert et al. 2014). Floods also result in more fatalities than any other natural disaster apart from heatwave. However floods have the highest preventable damage of any other natural disaster. Structural measures can help mitigate flood risk, but there remains a need for a comprehensive and integrative approach to address the substantial residual risk.

Flood warnings are the most effective measure available to mitigate the impact of flooding and to increase community resilience. The value of flood warning is to enable people to take action to lessen the impacts of a coming flood and help agencies to carry out their essential tasks during flood events (AIDC 2009).

Recent widespread flooding across many parts of Australia has again highlighted the importance of effective flood warning services that can enable communities to take protective action. Fundamental to the effectiveness of the Total Flood Warning System (TFWS) is the availability of accurate near real-time rainfall and river-level data, essential for preparing useful and specific flood forecasts and warnings.

Background

The Bureau provides riverine flood forecasting and warning services which rely on data collected by other agencies for their own business requirements. It is estimated that there are over 100 organisations involved in flood data collection across Australia (Bureau of Meteorology & Attorney-General's Department 2015). The data from the extensive network of observing sites is fed into hydrological forecasting models which also take in weather forecast information and data from the national radar network. Together this information is used in the models to prepare predictions of future river levels (Bureau of Meteorology 2013).

Flood forecasting and warning is funded on a shared basis with all levels of government and coordinated through State and Territory based consultative committees. The State and Territory roles in flood management are undertaken as part of their activities in emergency management, flood risk management and water resources data collection (Bureau of Meteorology 2013).

While the Bureau has been collecting rainfall data for over hundred years and continues to take the leadership in this area, the responsibility for river monitoring lies primarily with State and Territory authorities, specifically in connection with their water resource, energy and drainage responsibilities.

Strongly cooperative relationships and arrangements exist with the state and local government and regional agencies which enable the provision of data to the Bureau for flood forecasting and warning purposes. However no specific responsibilities exist for agencies to establish special purpose flood warning infrastructure networks. More recently, these arrangements are being documented in non-binding data sharing agreements between agencies and the Bureau.

Figure 1 and Figure 2 illustrate the mixture of ownership of rainfall and river level observation sites used by the Bureau for flood warning and forecasting services.

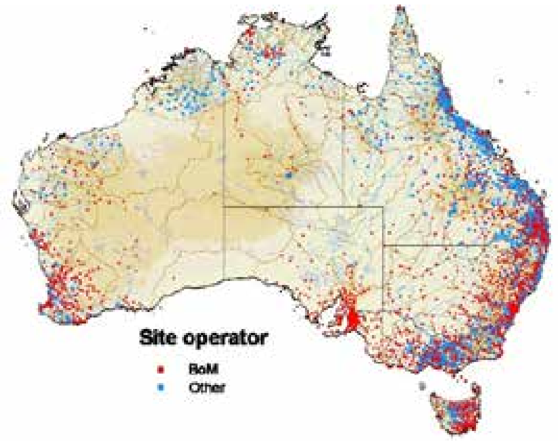


Figure 1. Rainfall stations showing ownership.

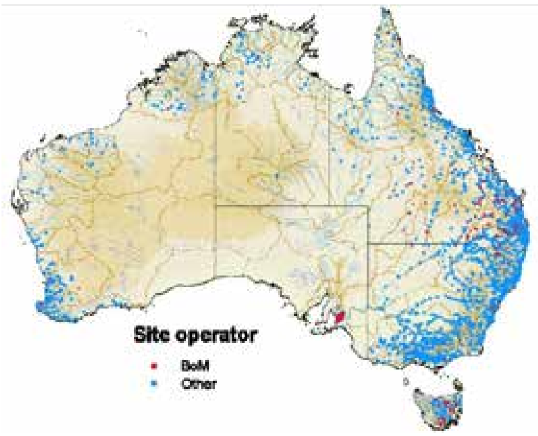


Figure 2. River level stations showing ownership.

Flood services have historically varied significantly across states and territories due to variations in risk and impact due climate, geography, location of populations and other factors such as run-off characteristics (Bureau of Meteorology & Attorney-General's Department 2015). However, lack of clarity about roles and responsibilities in this area contributed to these differences in the past. Another factor which has contributed to the variation in flood warning services across Australia is the availability and quality of data. This issue has been highlighted by several formal reviews.

The Queensland Floods Commission of Inquiry Interim Report (2011) found that the distribution and number of river height and rainfall gauges should be reviewed in areas of identified need (Queensland Floods Commission of Inquiry 2012). In Victoria a major theme or an issue identified in the consultation phase of the Comrie Review (2011) was the lack of appropriate gauges.

The Munro Review commissioned by the Commonwealth looked at the Bureau's capacity to respond to extreme weather events and to produce seasonal outlooks. It identified a number of issues including the variations in delivery of hazard services across the states and the Northern Territory and the lack of clarity about roles and responsibilities for flood management. It further identified gaps in the flood gauge network, lack of automation of gauges (or a dependency on manual gauges) which can be problematic in severe weather as well as issues in the maintenance and management (Munro 2011). The Review noted that an operational risk from a flood warning perspective was reliance on third party information that may not be up to the standard required (Munro 2011:50).

The Commonwealth, being mindful of the nature of the Munro recommendations affecting all jurisdictions, set up a Taskforce with representations from each jurisdiction under the Australia New Zealand Emergency management Committee (ANZEMC), to address the Munro recommendations. The Standardisation of Bureau of Meteorology Hazards Services Taskforce (The Taskforce) was established in October 2013 to respond to the key recommendations of the Munro Review. The Taskforce identified a number of critical issues including the lack of consistency in flood data collection networks, the absence of standards for instrumentation and data communication technologies, unreliable, not fit-for-purpose infrastructure. In addition, reactive network funding, the lack of effective flood monitoring systems in places and variable levels of network maintenance were also noted as issues.

The Taskforce agreed that the mitigation of flood-related damage through investment in critical flood warning infrastructure designed to established standards and prioritised based on flood risk is the most cost-effective way to deliver greater public benefit than simply responding to flood damage (BoM & AG 2015). One of the key outcomes of the Taskforce was a recommendation to establish a time-limited National Flood Warning Infrastructure Working Group directly reporting to ANZEMC to focus specifically on the issues of flood warning infrastructure.

The National Flood Warning Infrastructure Working Group

The National Flood Warning Infrastructure Working Group (Infrastructure Working Group) has been set up under the auspices of the ANZEMC with a very specific mandate. Chaired by the Bureau of Meteorology and co-chaired by the Attorney-General's Department, the Infrastructure Working Group will bring considerable focus onto the issues of flood warning infrastructure over the next 3 years. The Infrastructure Working Group is made up of senior officers from the Emergency Service Agencies and relevant water authorities from each state and territory. This membership, which includes both the key client of flood warning services and the agencies responsible for providing the river level and rainfall data used to develop the forecasts, will help to build understanding of the key issues and dependencies.

The Infrastructure Working Group has to undertake two separate but complementary tasks. Firstly, it will develop a set of national performance based standards for flood warning infrastructure, outlining a tiered approach to ensure standards are fit-for-purpose and commensurate with the level of flood risk being addressed. The second major task is to develop a risk based National Strategic Flood Warning Infrastructure Plan based on individual jurisdictional plans.

It was seen as essential to bring in subject matter experts from each jurisdiction to support the Working Group and a Flood Warning Infrastructure Standards Technical Advisory Group (Standards TAG) and a Strategic Planning Technical Advisory Group (Strategic Planning TAG) have been set up. Members of the TAGs were nominated by the Working Group members and are subject matter experts with several years of experience. The TAGs were formed in July 2016 and have met several times since then. The Secretariat to the Working Group is being provided by the Bureau of Meteorology.

The scope of the Infrastructure Working Group activity includes riverine and flash flood warning infrastructure. The Bureau of Meteorology's flood forecasting and warning service is for riverine floods, caused by rainfall where typical rain-to-flood times are six hours or more. Due to the short lead times (less than 6 hours) associated with flash flood, quick and effective response is required at local level. For this reason, the responsibility for local flash flood warning sits with state and territory agencies in partnership with local councils (where appropriate).

Flood warning infrastructure standards

The Standards TAG was formed under the Infrastructure Working Group to support the development of performance based standards for flood warning infrastructure. The Standards TAG includes several flood warning infrastructure experts from the States and Territories. The knowledge and expertise they bring will ensure that the Standards are robust, relevant and practical.

One of the deliverables of the Working Group is to develop and deliver a set of national technical standards for the flood warning infrastructure,

a. outlining a tiered approach to ensure the standards are fit-for-purpose and compatible with the level of flood risk being addressed;
b. on site, equipment, data format and communication method selection;
c. requirements for maintenance, calibration and upgrade of equipment;
d. data assurance processes; and;
e. performance indicators that will include functionality, data latency, asset life cycle management, adequate maintenance, resilience and reliability.

In moving forward with this task three critical questions have been explored. They are:

- What is the 'legal' status of the proposed Flood Warning Infrastructure Standard?
- What is the scope of the Standard?
- What is a performance based standard and how do you go about developing one?

The 'legal' status of the proposed Flood Warning Infrastructure Standard

The ANZEMC Taskforce agreed that standards rather than guidelines were required. One of the earliest questions considered by the Infrastructure Working Group and the Standards Technical Advisory Group was the 'legal' status of the proposed Standard. A consensus has emerged that the Standards will be non-mandatory. That is, if a certain standard is not met, then it is recognised that a lower standard is being met and that infrastructure requirements for a lower flood risk are only available.

The Water Monitoring Standardisation Technical Committee (WaMSTeC) is the successor to the Water Information Standards Business Forum. The Business Forum was established to coordinate and foster the development of water information standards and guidelines across Australia. As with WaMSTeC it was made up of jurisdictional agency representatives and industry experts. They have endorsed several non-mandatory guidelines in the area of data collection.

WaMSTeC has defined voluntary standards or guidelines as 'published documents that provide requirements, specification, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose'. Standards Australia, International Standards Organisation, the World Meteorology Organisation and others produce voluntary standards and guidelines.

The role of voluntary standards is to provide a reference framework against which organisations can declare a level of conformance (Johnston and Robinson 2012:3). In the case of the Flood Warning Infrastructure Standards, to provide an agreed basis on which to consider the adequacy of the existing flood warning infrastructure to collect the data required to provide the flood forecasting and warning services that are commensurate with the level of flood risk. The Standards, while being non-mandatory, will be a valuable input into the Flood Warning Infrastructure Planning and provide a consistent basis on which each of the states and territories can form an opinion about the degree to which current infrastructure needs to be upgraded or improved.

The scope of the Standard

The Infrastructure Working Group Terms of Reference provide that the scope includes flood warning infrastructure from field instruments and communication equipment, through to the data ingest software for receiving, storing and displaying real time flood data. Typically, monitoring sites in the data collection network use a range of instrumentation types and telemetry combinations to measure and transfer rainfall depths and river levels (Bureau of Meteorology 2015). This continuum has been grouped into three components for the purposes of the standard development (Figure 3). Metadata management is a requirement that spans across for all components and will be developed as separate standard.

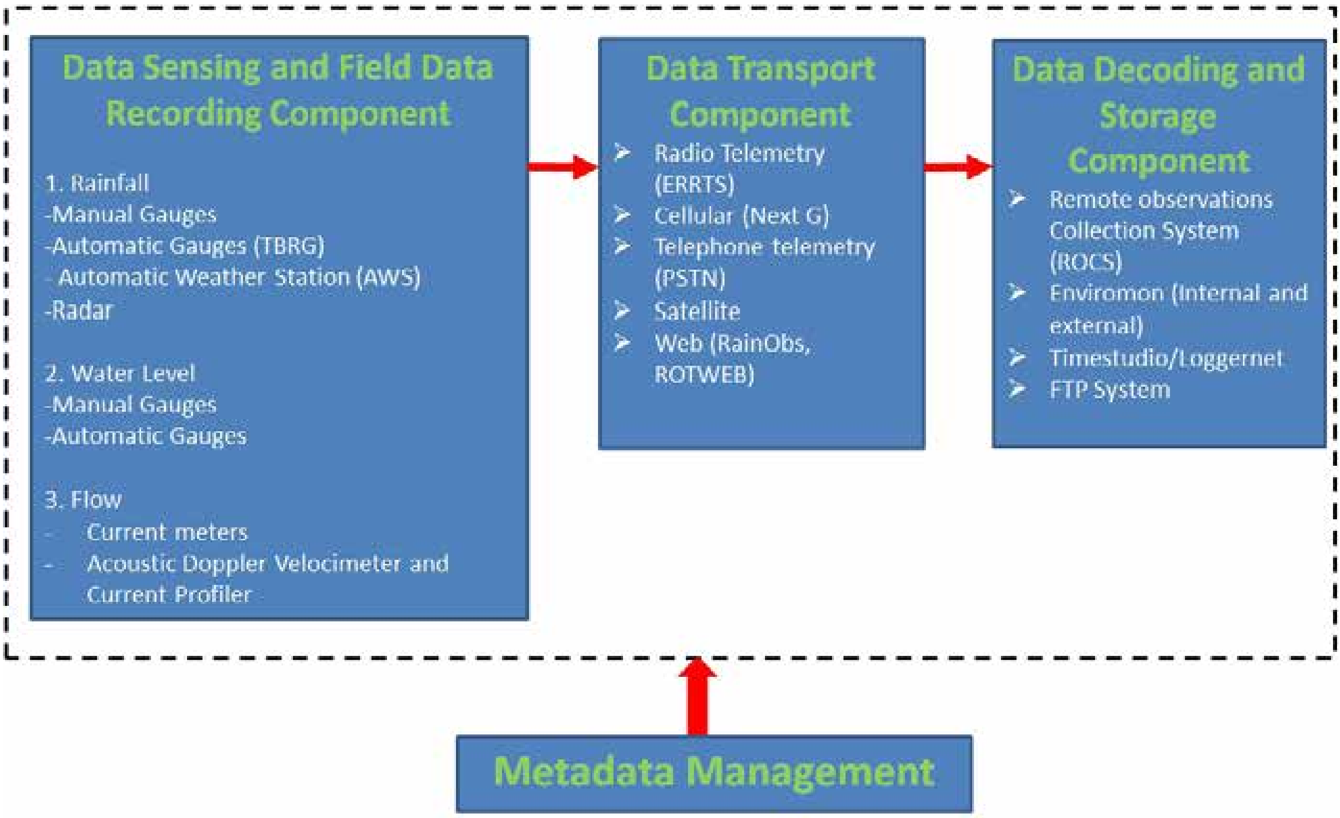


Figure 3. Components of the Flood Warning Infrastructure Standard.

Performance based standards definition and development

Standards which apply to water monitoring infrastructure are typically prescriptive standards. This means that they express requirements in precise, often quantitative terms (Standards Australia 2016:6). A desktop analysis of Standards which are currently applied to flood warning infrastructure in Australia found at least 40 in use (Bureau of Meteorology 2016). They were almost all prescriptive standards.

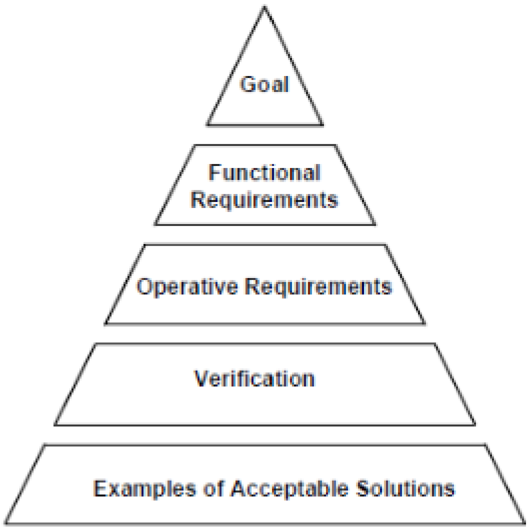
In contrast, performance based standards have their requirements expressed in terms of performance, i.e. outcomes to be achieved (Standards Australia 2016:6). This approach allows for any future innovative technical methods to be used to meet the requirements of the Standard. Performance Based Standards include the criteria, testing or other approved form of verification required to assess performance and to ensure consistency across the solutions developed to meet requirements.

Performance based standards are relatively common in the building and environmental sectors. The performance based approach aims to promote flexibility with accountability for results whereas the prescriptive approach emphasises consistency and accountability for complying with rules (May 2003). Performance based standards are particularly relevant in an environment in which technology is changing rapidly and there is importance placed on ensuring competitive neutrality in procurement activity. A performance based standard is [a] document that expresses requirements for [flood warning infrastructure], in terms of societal goals, functional objectives and performance requirements (Meacham 2010:27). Acceptable solutions and verification methods for demonstrating compliance are also referenced in the standard. The functional requirements are expressed in qualitative terms, stating what is to be achieved.

Most performance-based regulatory frameworks are based on the Nordic Five Level System (Foliente 2000). The Nordic Five Level System has been helpful both in understanding the components of a performance based standard and as a way to of thinking about how to develop one (Figure 4).

The early development of an interim set of standards is necessary because the infrastructure planning activity is progressing in parallel, and will be informed by, the content of the standards. The interim standards will be comprised of a goal and functional requirements for each component of the scope. It is anticipated that the interim standards will be drafted by the end of 2016 and made available to the Working Group for review. The interim standards will then be taken through an extensive industry consultation and development phase in 2017. The draft Flood Warning Infrastructure Standards including the interim standard and operative requirements (quantitative requirements in terms of performance criteria or expanded functional descriptions) will be completed by September 2017. This draft standard will then be taken through a second round of industry consultation.

Interim standard development **Sept – Dec 2016**	Definition of goal for flood warning infrastructure. Definition of goal for flood warning infrastructure component. Development of functional requirements expressed using qualitative terms, stating an objective to be achieved. Review by Infrastructure Working Group.
Draft standard development and consultation **Feb – Sept 2017**	The draft standard would build on the interim standard and include operative requirements (actual quantitative requirements in term of performance criteria or expanded functional descriptions). Verification involves a description of the methods that could be used to assess performance. At the operative requirements level, the standard could also include reference to the range of technical standards that relate to the aspect of flood warning infrastructure. Industry consultation and development.



NKB Model (NKB, 1976)

Draft Standard review and consultation
Sept 17 – Nov 18

Final Standards endorsement
December 18[3]

Figure 4. Standards development process[4].

[3] Consultation remained open until the end of August 2018, proposed to be submitted for endorsement Mach 2019. http://www.bom.gov.au/water standards/floodwarning.shtml accessed 20 September 2018.

[4] Meacham (2010) citing NKB (1976) Nordic Committee on Building Regulations (NKB), Program of Work for the NKB, Report No. 28, Stockholm.

Flood Warning Infrastructure Plans

The Infrastructure Working Group is required to develop a risk based National Strategic Flood Warning Infrastructure Plan. The National Plan will be based on individual jurisdictional Strategic Flood Warning Infrastructure Plans.

The planning task is being undertaken by a Technical Advisory Group (TAG) which is made up of representatives from each State and Territory and the Bureau's Regional Hydrology Managers. The TAG members have the necessary expertise and knowledge to develop plans which outline:

- functionality and condition assessment of existing flood warning infrastructure;
- gaps in flood warning infrastructure and knowledge;
- issues and opportunities;
- priorities, strategies and actions;
- compliance with national technical standards including transition over time of sub-standard infrastructure to meet appropriate standards.

The flood warning infrastructure planning process (Figure 5) involves a number of steps. It will involve analysis of flood prone communities, document the risk assessment method, review of the performance of the existing network and the sufficiency of the infrastructure to provide appropriate flood warning services. The planning will follow a consistent framework but this will not replicate work already undertaken by the states and territories. Considerable progress has been made in Queensland and Victoria implementing the recommendations of their Flood Inquiries. The intention is to build on, leverage and learn from these current developments.

At this stage, the Planning TAG members are collating baseline information about the existing network and documenting the approach to flood risk assessment. This information will be compiled over the next few months. Draft flood warning infrastructure plans will be completed for each jurisdiction during 2017.

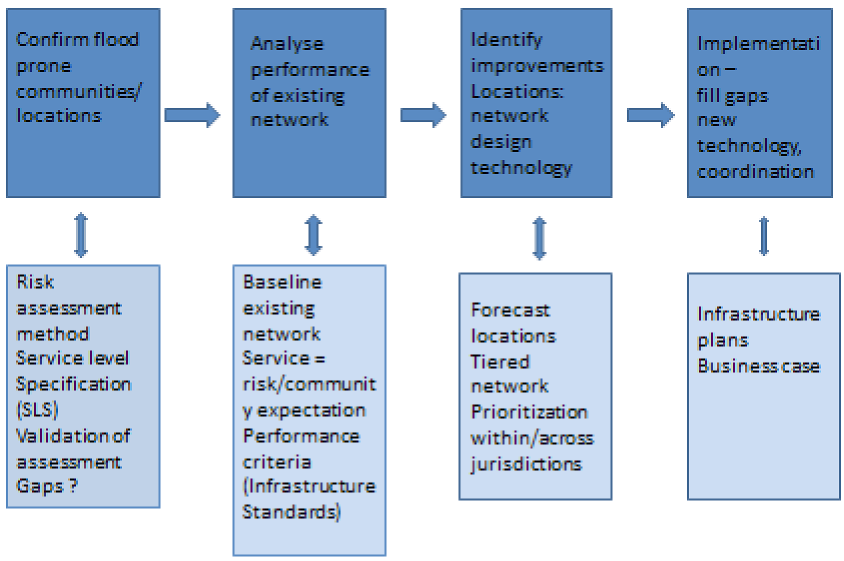


Figure 5. Flood warning infrastructure planning process.

Way forward

The National Flood Warning Infrastructure Working Group project is in its early stages however considerable progress has already been made. Recognition of the importance of flood warning infrastructure to the capacity of organisations to collect fit-for-purpose data to provide appropriate forecasting and warning services has been encouraging. The states and territories have demonstrated a strong commitment to work together to understand, document and build the case for improvements to the infrastructure. Recent significant flooding in several states has confirmed the importance of the underpinning flood warning infrastructure to an effective warning service to the community. Over the next two years the Commonwealth, states and territories will develop Flood Warning Infrastructure Standards and Plans which will provide a sound foundation for the Total Flood Warning System into the future.

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A Discussion Paper on the Installation and Data Collection of Bay of Plenty Regional Council Lysimeter Sites, for the Consideration of Specific National Environmental Monitoring Standards for Groundwater Recharge Barrel Lysimeter Sites in New Zealand

Brent Hutchby, Bay of Plenty Regional Council, Whakatane, Bay of Plenty, New Zealand.

Paper presented to 18th Australian Hydrographers Association Conference Canberra. 24-27 October 2016.

Abstract

The Bay of Plenty region was named on account of its abundant food resources and this continues to hold true today. The region is a key producer of kiwifruit and avocados, has significant forestry resources and a pulp paper mill, and as well as general cropping and farming it supports an intensive dairy industry. Thus there is significant demand for water and increasingly groundwater.

With the aim of better understanding groundwater recharge across the region, the Bay of Plenty Regional Council has installed a network of barrel lysimeters. After a decade in deployment and recent expansion of this network, I will discuss some of the issues involved in the installation and collection of lysimeter data in the Bay of Plenty with the objective of creating a discussion to establish National Environmental Monitoring Standards (NEMS) for groundwater recharge lysimeter monitoring in New Zealand.

Introduction

Groundwater is a valuable and important resource in the Bay of Plenty (BOP) region. The BOP covers 12,231 km^2 and comprises of approximately 49% indigenous forest and vegetation (largely hill and mountainous country), 23% exotic forest, 22% agricultural pasture, and 2% horticulture. The horticulture in the BOP is most notably kiwifruit, apples and avocados, and the main agriculture; dairy, grazing and sheep farming (BOPRC Geospatial data as at 2012). Groundwater resources provide irrigation to the horticulture and agriculture industries as well as domestic supply, industry and commercial bottling. To guide the development of groundwater management policy and sustainable allocation of groundwater resources, the Bay of Plenty Regional Council (BOPRC) has installed seven lysimeter sites for the purpose of quantifying rainfall recharge of groundwater. The BOPRC commissioned GNS Science (Institute of Geological and Nuclear Sciences Ltd) to install barrel lysimeters then continued installation of lysimeter sites in-house. The following paper is presented with the objective of creating a discussion around the field practices of installing and collecting data from barrel lysimeter sites for the purpose of groundwater recharge monitoring with the aim of establishing associated National Environmental Monitoring Standards (NEMS) in New Zealand.

BOPRC Lysimeter Design

The basic design of a BOPRC lysimeter site includes two or three barrel lysimeters, a tipping bucket rain gauge, a rainfall check gauge and a soil moisture and temperature sensor. The barrel lysimeters are 500 mm in diameter (inside catch 490 mm diameters) with a 45° bevelled steel ring welded on the inside at the base, and 700 mm deep. The bevelled ring provides an internal cutting edge to allow installation in the soil column while limiting soil compaction. The barrel has a baseplate with a drainage hose that feeds a tipping bucket gauge (TB gauge) by gravity. The lysimeter TB gauges record tips instantaneously, are validated every three months and data is adjusted from validation results if necessary. Barrel lysimeters are installed with the rim at ground level and are designed to collect water that percolates through the top soil, root zone and soil column and drains via the drainage hose to the TB gauges. This design assumes vertical movement of water through a soil column and creates the isolation of the soil column from the surrounding ground which can unnaturally affect the hydraulic gradient resulting in flow from the lysimeter only occurring when the entire profile is fully saturated, thus free draining lysimeters tend to record less groundwater recharge than natural environments, however this effect can be reduced with the use of a capillary wick (Freeman 2010).

Installation

The installation of BOPRC barrel lysimeters are detailed in reports by Lovett and Harvey 2013, Harvey 2015, and Freeman 2010.

It is essential to install lysimeters with the least possible disruption to the soil column. The lysimeter barrels are placed in location with the cutting rim facing down; pressure is asserted with the use of an excavator ensuring vertical movement only. Levels are used to monitor the vertical movement of the barrel; if the barrel is installed on an angle it will create cavities between the soil column and barrel affecting the rate of drainage. Grass sod and soil is excavated from outside of the barrel as it is inserted to release pressure from the surrounding soil, usually 100 mm depths at a time but this is dependent on the soil structure. The barrel is driven down until the top rim is at ground level.

Once all the barrels are inserted and the soil columns isolated, a level pit is dug around the barrels no deeper than the base of the lysimeter barrels to allow a cutting plate to sever the enclosed soil lysimeter column from the underlying soil. The cutting plate is secured to the barrel and the barrel containing the secured soil column is removed from the pit and placed upside down for the baseplate fitting. The cutting plate is removed, the soil is levelled to the rim of the barrel and a sediment cloth is applied to prevent sediment flow into the drainage hose. A fiberglass capillary wick is applied by splaying an end out onto the sediment cloth leaving the other end to protrude into the drainage hose. The baseplate and drainage hose plumbing is clamped to the base of the barrel with tightening rods on the outside of the barrel and the contact area between the baseplate and barrel is sealed with sealant. The barrels are then righted and heated petroleum jelly is injected in the cavity between the soil column and barrel created by the cutting rim. Petroleum jelly is used as a waterproof impermeable layer preventing unnaturally rapid drainage down the sides of the barrel.

The pit created by the removal of the soil columns is extended to allow for the installation of a prefabricated enclosure 2.1m deep which will house the TB gauges at a suitable depth allowing water to exit the lysimeter soil column and flow via gravity through the drainage hose to the TB gauges. The barrel lysimeters are returned to the same location they came from, the drainage hoses are plumbed and the pit is backfilled and the grass sod is relayed. Once installed you should not see the top rims of the lysimeters as any protruding lip may cause water to pool within the barrel or alternatively exclude natural runoff outside the barrel. The lysimeter barrels are located approximately 1.75m apart and the equal distance from the enclosure pit.

Site Selection

Lysimeter site location is largely confined by suitable geography, geology, ecology and topography. BOPRC lysimeter sites were selected to represent an area for recharge monitoring taking into consideration access, topography and representative free draining soil profiles without any dense lenses or pans (Harvey 2015).

BOPRC Lysimeters have been installed in exposed areas avoiding rainfall interference from large vegetation and other objects. This essentially limits sites to pastoral areas which make up 22% of Bay of Plenty land area. This area was further reduced by the need for several requirements; agreed access, lysimeters needing to be installed in flat land away from the influence of surface water runoff therefore excluding hill slopes, valleys and zones that will be affected by either, the water table needs to be greater than the depth of the 2.1 m housing pit to avoid submerging the TB gauges, the soil profile should be representative of the area and not be subject to cropping, ploughing or irrigation, and stock grazing over the lysimeters should also be representative of the area. Once all site considerations are taken into account, it must be confirmed how regional or local your representative area is and how applicable the data is to the wider area or region.

BOPRC Lysimeter Data and Issues Related to Installation Operation

AECOM Consulting Services Ltd was commissioned by the BOPRC to undertake an assessment of data from the BOPRC lysimeter sites in 2015. Of the seven BOPRC lysimeter sites data from five was assessed and the remaining two were not considered due to recently being installed and lack of sufficient record. The sites, number of lysimeters, sensors and installation dates are outlined in Table 1 below.

Site	# Rain gauges	# Check gauges	# Soil Moisture and Temperature Sensors	# Lysimeters	Date of installation	Years of Assessment
Mangorewa at Kaharoa	1	1	1	2	26/10/2005	9
Mangorewa at Waite B	1	1	1	3	11/07/2013	2
Pongakawa at Pongakawa Bush Road	1	1	1	2	27/07/2010	4
Rangitāiki at Hogg Road	1	1	1	3	20/08/2015	0
Rangitāiki at Kokomoka	1	1	1	3	23/10/2013	1
Raparapahoe at Collins Lane	1	1	1	3	16/01/2015	0
Wairoa at Lower Kaimai	1	1	1	3	18/03/2013	1

Table 1. Lysimeter Sites.

There are several factors associated with the site selection, installation and data collection from lysimeters that should be considered when reviewing the collected data.

While care is taken to disrupt the soil column as little as possible, some compaction and disruption of the soil must be assumed to occur and subsequently there may be a settling in or bedding period after initial installation. Different BOPRC lysimeters have shown variances between lysimeters at the same site and significant recharge increases at sites over time (AECOM 2015) suggesting soil stabilisation may be a factor. This period of stabilisation would differ within each lysimeter depending on installation, soil structure, season, and location.

Soils are variable regionally, locally, and potentially within the same vicinity especially if previous land use has significantly altered soil profiles by ploughing, cropping and other forms of agriculture and horticulture. All 5 of the 7 BOPRC lysimeter sites reviewed by AECOM Consultancy Services Ltd (2015) had consistent variance between the other, or where there are three barrels, at least one lysimeter within a site. This variance is significant in its consistency at all sites and at some sites significant due to the difference; Rangitāiki at Kokomoka lysimeter 2 and 3 vary by 7.8 % while lysimeter 1 records 20% more recharge than the mean of 2 and 3, Wairoa at Lower Kaimai lysimeter 1 and 3 vary by 10% while lysimeter 2 records 54% more recharge than the mean of 1 and 3. This difference may eventually be attributed to a long settling/bedding in period (there was only 1 year of record assessed at Kokomoka and Wairoa due to the recent installations) or it could be attributed to large impermeable objects in the soil column such as rocks affecting recharge rates in different barrels, and if so it raises the question of what to do at such sites; ignore/remove outliers and/or remove any randomness of lysimeter placement and only install in identical soil columns or consider all data valid despite outliers? Either option may not best represent the area if recharge data is to be extrapolated spatially. The presence of large rocks within soil also makes installation problematic and creates an issue to address when selecting a site; if a rock is encountered protruding into the selected lysimeter soil column, do you remove it disrupting the natural profile, cut through it with a grinder and leave it in situ so the barrel can include it, or move the installation to avoid large rocks crossing the path of the barrel cutting rim potentially biasing the level of local representation?

Initial site installations (Mangorewa at Kaharoa and Pongakawa at Pongakawa Bush Road) had two lysimeter barrels installed but it was decided, based on variability between the two lysimeters at a site and to minimise the suspicion of Lysimeter failure due to leakage, to expand to three lysimeter barrels installed at each future site (Mangorewa at Waite B, Rangitāiki at Kokomoka, Wairoa at Lower Kaimai, Rangitāiki at Hogg Road, Raprapahoe at Collins Lane). Leakage in a lysimeter barrel was identified as an issue at Mangorewa at Kaharoa after suspicions were verified by the removal of a suspect lysimeter barrel and testing in 2008 (Cameron, White 2008). The design of a barrel lysimeter setup makes identification of barrel leakages difficult to detect unless the barrel is removed and tested. Suspicions resulting simply from recorded variance may be misleading as evidenced by outlier lysimeters that significantly record greater recharge than two others that are similar; for example Wairoa at Lower Kaimai and Rangitāiki at Kokomoka . This may suggest that two out of three lysimeters and if so the two leaking barrels are recording a similar recharge rate. Mangorewa at Waite B lysimeter outlier consistently records less recharge potentially indicating a leak in lysimeter 1; lysimeter 2 and 3 vary by 5% while lysimeter 1 records 20% less recharge than the mean of 2 and 3. To avoid unnecessary disruption of the site record by removing and testing a lysimeter barrel, a reasonable level of variance needs to be determined to decide if an outlier exceeds it and this variance level would potentially have to be specific to a site.

Site variance of rainfall within a small area is an unlikely explanation for an outlier as all sites have a separate intensity rain gauge and rainfall check gauge that do not show significant variances. To consider differences at site due to multiple TB intensity gauges as opposed to a single rainfall TB intensity gauge with a primary check gauge (as in the case of Lysimeter sites that have a TB gauge for each barrel and no check gauge), data from the BOPRC rainfall site Haparapara at Haparapara, which consists of two rainfall TB intensity gauges next to each other and require the same BOPRC field maintenance practices as lysimeter TB gauges, was reviewed to question any occurrence of significant differences between multiple TB gauges at a site. Haparapara showed no significant short or long term variance with the difference between the gauges over a 14 year period to be less than 1.5%. While this is a single site and this is not a comprehensive study of TB gauge site variations, it suggests that under BOPRC field maintenance practices there is no evidence of significant site rainfall record variation when multiple TB gauges are used at the same location. With field validated TB gauges and no significant variation of recorded rainfall between the rain gauge and rainfall check gauge, it would suggest variation between lysimeters at a site to be largely influenced by what's at and/or below the ground; the vegetation, soil profile and/or the lysimeter set up and possible failure.

A potential explanation as to variation between lysimeters at some sites that show a high recording outlier is the presence of livestock. BOPRC lysimeter barrels are exposed to grazing stock so as to maintain the vegetation cover to the surrounding immediate area and to avoid excessive vegetation growth up taking more potential recharge than the surrounding area, essentially to be representative of the farmed pastoral area the site is located. To keep livestock off the enclosure pit that houses the lysimeter TB gauges, the rainfall gauge, check gauge and logger, fences have been constructed around the pit grate and in some cases electric fences installed. While there is no obvious evidence livestock have favoured a particular lysimeter at any of the sites to congregate over or near the fence, if this is the case it could potentially add significantly to the recharge. Dairy cows urinate approximately 2 litres at a time 5 to 12 times a day and this occurs in concentrated patches of about 0.23 m^2 (Moir et al. 2010). The average size of a dairy herd in New Zealand is 413 cows and the average cows per ha is 2.87 (Dairy NZ 2014), if cows urinate 2 L a time 10 times a day, this would equate to approximately 20,951 litres of urine annually per ha or 2.1 mm of rainfall. However, due to grazing rotation on dairy farms and urine deposited in patches, this additional recharge could occur in far greater concentrations (2 litres per cow 5 to 12 times per day deposited in concentrated patches 0.23 m^2 within a paddock containing 400 cows) and over a short period of time potentially adding to recharge values, or potentially decreasing recharge values due to excess grass growth caused by nutrient loading. When considering groundwater recharge and monitoring standards it must be determined what recharge actually includes; effects from livestock and irrigation may or may not be included depending on what the monitoring needs to achieve.

While there does not appear to be significant variance of rainfall within a site, there can be significant variance within a local catchment that a rainfall recharge site is representing and this should be considered when a site is selected. Rangitāiki at Hogg Road is located on the Whakatāne plains which are approximately 230 km^2 of reasonably flat land, most of which is drained swamp land, bordered by the sea to the northeast and low hills elsewhere. The BOPRC had eight rainfall monitoring stations within a 10 km radius on the Whakatane plains in 2014 that recorded a variance of 38% between the highest and lowest record with the remaining sites reasonable evenly dispersed between. This variance can be explained by the geography and prevailing weather patterns but it suggests a limiting factor to the extent recharge data can be used to represent a wider area without a detailed examination of local rainfall distribution.

Conclusion

If groundwater recharge monitoring is to progress National Environmental Monitoring Standards (NEMS) need to be established for lysimeter installation and data collection to allow for consistent and comparable data collection across New Zealand. There are issues to address and practical solutions applied with the design and installation of barrel lysimeter sites and these solutions should be uniform across the regions to best present comparable data.

When considering the methodology of installation and data collection several key factors need to be addressed; selecting a suitable lysimeter site is problematic in that it is limited by geography, geology, topography, ecology, and access. This raises questions on the accuracy and application of recharge data spatially and whether it can be used to represent a wider area with very different variables.

Settling/bedding in periods are dependent on local and installation conditions so the time period before the data is reliably representative is site specific but needs to be determined at some point. Vegetation and soils are variable regionally and locally and this can cause outliers in collected data, increasing the number of lysimeters at a site from two to three raises issues as what to do with outliers and how to treat the final data that should be addressed to be consistent between sites. Lysimeter failures and leaks are difficult to identify without disrupting the site record and may require site specific tolerances. There are factors other than rainfall percolating through a soil column that could potentially influence groundwater recharge records and they need to be considered for the scope of the desired data.

National Environmental Monitoring Standards could provide consistency of site installations and data collection methodologies but the practical application of recharge data from lysimeter sites needs consideration as to whether it is representative to a specific site, local or regional area.

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