Independent review of the impacts of the bottled water industry on groundwater resources in the Northern Rivers region of NSW

Final Report

NSW Chief Scientist & Engineer

31 October 2019

The Hon. Melinda Pavey MP
Minister for Water, Property and Housing
52 Martin Place
SYDNEY NSW 2000

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Dear Minister

Final report: Independent review of the impacts of the bottled water industry on groundwater resources in the Northern Rivers region of NSW

In November 2018, the Hon Niall Blair MLC, the (then) Minister for Regional Water, requested that I undertake an independent review of the impacts of the bottled water industry on groundwater resources in the Northern Rivers region of NSW. I submitted an initial report from the Review on 1 February 2019. I am pleased to submit this Final Report.

The Initial Report outlined the preliminary analysis of available information and reports on the bottled water industry, local groundwater systems, the regulatory framework, as well as the range of stakeholder views gathered through consultations and two site visits to the region in December 2018 and January 2019.

The Final Report draws on further work undertaken to understand better the potential growth of the bottled water industry in the region, the sustainability of water extraction limits in the relevant Water Sharing Plan and the assessment of associated impacts.

I would like to thank all stakeholders who provided contributions to the Review including local residents, farmers, community groups, the bottled water industry, researchers and academics, local government councillors and staff, state government agencies and local water utilities. Their input has greatly informed the analysis of all relevant issues.

Yours sincerely

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EXECUTIVE SUMMARY

In November 2018 the (then) Minister for Regional Water, the Hon Niall Blair MLC, requested that the NSW Chief Scientist & Engineer undertake an independent review of the impacts of the bottled water industry on groundwater resources in the Northern Rivers region of NSW.

The Initial Report submitted in February 2019 followed two site visits to the Tweed and Ballina areas to meet with stakeholders, reported on issues raised in consultations and described relevant groundwater and surface water systems including available data, management frameworks and industry allocations.

This Final Report provides an update to the industry allocations and current and proposed bottled water licences and considers potential growth of the industry, the sustainability of the extraction limits for the groundwater systems in scope and the impacts that extraction of groundwater for bottling may have on groundwater resources, surface water and other local environmental consequences. In doing so, the Review examined available hydrogeological assessments for the industry, how they are developed and assessed, and how localised impacts are accounted for and managed. Technical approaches to address issues relating to truck movements, road integrity and plastics are included.

The Northern Rivers region has alluvial, fractured rock, coastal sands and porous rock aquifers. Four groundwater sources are relevant to the Review, being the New England Fold Belt Coast, the Alstonville Basalt Plateau, the North Coast Volcanics and the Clarence Morton Basin. All are fractured or porous rock aquifer systems and are part of the North Coast Fractured and Porous Rock Water Sharing Plan.

Overall, fractured rock systems in particular are highly variable and complex, making them difficult to characterise on a regional scale. In September, an expert workshop was held on water sharing plans, extraction impacts and current knowledge to inform the technical review findings.

The Review has occurred during a period of widespread concern and public debate about extended drought and long-term water futures.

The issues that prompted this Review also go beyond technical and scientific matters. They encompass fundamental views of community and how resources are valued and allocated. For some respondents, a major concern is potential lack of water resources for agricultural purposes. For others, any extractive activity for water bottling purposes is not supported for a broader range of reasons articulated in the initial Review report. Although beyond the scope of this report, legislative and policy frameworks include requirements for community engagement and consideration of social, economic and environmental factors in planning decisions as well as assessment of risk and scientific knowledge.

Questions of risk and uncertainty and how these are managed are central to many of the issues raised. Importantly, it became apparent over the course of the Review that there were different understandings of these concepts. For this reason, this report includes an explanation about how these concepts were approached by the Review and informed consideration of sustainability factors and impacts under the Terms of Reference.

For the purposes of this report, an impact refers to the physical change that occurs from an action, such as depressurisation of groundwater due to its extraction. Consequences are a result of the impact, for example, temporary or permanent loss of water access or loss of environment for groundwater dependent ecosystems and associated flora and fauna.

High-level findings and recommendations are presented in this Executive Summary. A complete reading of the full report provides further detail for the basis of conclusions reached.

FINDINGS

The bottled water industry

- Available industry data indicates that across Australia, over three-quarters of bottled water is sourced from underground wells, and the remainder from standard reticulated water supplies. Approximately 8% of Australian bottled water production is exported.
- The Review identified seven operators in the Northern Rivers region with allocations of 240.5 ML/y who are actively extracting for water bottling purposes, representing 0.55% of water licences and basic landholder rights (together defined in the WSP as 'total water requirements') and 0.008% of estimated total annual aquifer recharge in the four groundwater sources.
- Four further proposals, if approved, would amount to an additional 168 ML/y, being an additional 0.38% of estimated total water requirements and 0.006% of total annual aquifer recharge.
- Changing consumer preferences, trade imbalances, the availability of tap water and private ('no name') brands and population growth are expected to impact future bottled water production and consumption volumes.
- Scenario analyses conducted by the Review suggest the Australian bottled water industry is most likely to grow at a rate of less than 2% per annum to 2024 and that growth in the Northern Rivers region is likely to be consistent with this trend. Under most scenarios to 2024 considered, the 168 ML/y of additional proposed bottled water operations would be sufficient to meet fully projected growth in demand.
- The Review also considered 'highly unlikely' and 'extremely unlikely' scenarios to 2034, being growth continuing at the current rate of 10% per annum and establishment of a major premium bottled water exporter in the Northern Rivers, respectively.
    - If the 'highly unlikely' scenario occurred, the bottled water industry would represent less than 2.3% of 'total water requirements' and 0.034% of estimated total annual aquifer recharge.
    - If the 'extremely unlikely' scenario occurred, the bottled water industry would represent less than 4.6% of 'total water requirements' and 0.069% of estimated total annual aquifer recharge.
- As the scenario analyses considered an unchanged regulatory and policy environment, these forecasts may be affected by regulatory intervention which directly or indirectly impacts the bottled water industry in this region.
- For the purposes of water extraction licensing, the bottled water industry is treated the same as other prospective commercial users. However, development consent under the *Environmental Planning and Assessment Act 1979* is required for water bottling activities. Approvals identified by the Review for bottled water extraction in the Northern Rivers region date from 1993.

Allocations

- The WSP determines the allowable extraction limit, set from the recharge value of each aquifer, with an amount of the recharge reserved for the environment and the reminder determining the Upper Extraction Limit or the LTAAEL
- Under the North Coast Fractured and Porous Rock Water Sharing Plan (WSP), environmental water and basic landholder rights are given priority over licensed

water extraction. Among licensees, priority is given to water utilities and licensed stock and domestic over commercial licensed purposes.

- At the commencement of the WSP for the four groundwater sources, 100% of storage is reserved for the conservation of the groundwater system.
- Water available for extraction is a portion of the estimated recharge value for each groundwater source. This is determined by the WSP. An amount of the recharge is reserved for the environment. The amount reserved for the environment equates to 97% of the estimated recharge value for New England Fold Belt Coast, 96% for North Coast Volcanics, 82% for Alstonville Basalt Plateau and 48% for Clarence Moreton Basin.
- The remaining amounts can be allocated for licensed purposes. Of these amounts, 38.0% of the New England Fold Belt Coast is allocated, 51.3% of the North Coast Volcanics and 1.7% in the Clarence Moreton Basin. Alstonville is fully allocated.
- These are average values over the groundwater source areas; which means that the environment is not protected to these levels in locally impacted areas.

Water Sharing Plan assumptions and uncertainty

- In groundwater studies and management, there will always be a level of uncertainty associated with predictions (e.g. recharge rates) and a precise value may not be achieved due to the complex and heterogeneous nature of groundwater movement. This is particularly evident in fractured rock systems that are difficult to characterise fully.
- The WSP plan was developed based on the best available data at hand and followed a standard procedure. The assumptions made in the WSP are practical, reasonable and in agreement with standard practice. In general, the WSP incorporates a reasonable level of conservatism for extraction limits based on the risks identified.
- The portion of the estimated recharge value available for extraction is a function of rainfall recharge over low environmental value areas together with an assessment of environmental and socio-economic risk.
- Calculating recharge is complex due in part to the variability and complexity of the hydrogeology and limited knowledge of the systems. Based on the analysis, the Review considers the recharge rates used in the WSP are reasonable and conservative. This statement is made with a relatively low level of confidence due to lack of data for the groundwater sources of interest.
- In practical terms the groundwater sources are treated as geologically homogenous which adds uncertainty and would benefit from further work. The Review recognises that the complexity of the geology makes it difficult to incorporate heterogeneity into the WSP recharge calculations. Particular attention should be given to the effects of geological variability within groundwater sources, and soils and vegetation overlying aquifer outcrops. The Review acknowledges the conservatism incorporated into the current WSP through the allowable allocation figures.
- The application of the sustainability index appears to be a cost and time effective risk tool that is applied as an additional means to protect resources where limited information is available.
- The WSP incorporates a reasonable level of conservatism for the extraction limits when the groundwater sources are not fully allocated and where they are fully allocated at Alstonville, monitoring is applied.

- Additional monitoring in strategic locations in the Tweed would help inform gaps in knowledge on a regional scale and provide a path towards better conceptual understanding of aquifer flows.
- The overall system is managed with some level of adaptive management, including an annual determination of the volume of water per licence share and WSP are subject to an interim review at five years with a full review at ten years.
- Impacts of climate change should be considered in future WSP methodologies. Development of Regional Water Strategies, which are incorporating climate change in calculations, may provide a valuable source of information.

Sustainability of Water Sharing Plan extraction limits

- Due to limited extraction levels (where known allocations in the Tweed region are much lower than the extraction limits contemplated in the WSP), limited data and uncertainties described regarding the WSP parameters, it is not possible to conclude whether the extraction limits are currently sustainable. However, the Review found no evidence at this point in time that current WSP extraction limits are not sustainable.
- Water levels in Department piezometers should be regularly assessed to ensure periods of any sustained water level decline are identified early.
- Analysis of the last thirteen years' data at Alstonville found lagged rainfall an important variable for understanding water levels. This was observed in shallow-sited piezometers and in deeper piezometers sited in systems that are well connected to surface waters and upper aquifers. Observations from deep piezometers showed a greater stability and a steady upward trend over time of groundwater levels and/or pressures. In contrast, readings from shallower piezometers showed greater variability and appear to be recharged regularly with rainfall.

Assessment and management of potential impacts from water extraction

- Based on the review of available information, there is no measured evidence that current bottled water extractions have impacts on other properties' bores, surface water or GDEs in the Northern Rivers region. This is at least partly due to the relatively low current levels of extractions, hydrogeological conditions and lack of monitoring detecting these impacts.
- While all groundwater extractions have impacts, the magnitude of those impacts and potential consequences will vary. Assessment of risks and measurement of local impacts is complex due to the spatial and temporal variability of the hydrogeology of fractured and porous rock systems. There are established approaches to measuring and modelling to better understand local impacts. All have challenges in terms of accuracy, practicability and cost.
- Bore water extraction can potentially impact water within the same aquifer, within a connected aquifer, or within a connected surface water body, leading to possible changes in water quantity and quality. The pump test is a common field technique, used in hydrogeological assessments, to derive local scale aquifer properties and to indicate proposed impacts of the extraction. In fractured rock systems, the fracture network that intersects the point of extraction will determine the response to pumping, which is complex and requires hydrogeological investigations and interpretation of results in order to design the pump test. Impacts may be proximate to or at distance from the point of extraction, and occur vertically as well as horizontally.
- Noting the low level of current groundwater monitoring in three of the four relevant groundwater sources, there would be merit in reviewing the need for additional

monitoring that will provide the baseline data, conceptual hydrogeological models and recharge estimates commensurate with potential future risk levels.

- At a regional scale, the cost of traditional monitoring bore infrastructure is likely to be an ongoing challenge. This is particularly the case in fractured rock systems subject to high hydrogeological variability. Emerging sensing technologies able to gather data over large areas and at depth may provide a step-change to the field, subject to cost and commercial availability. Whether at the local or regional scale the choice of monitoring will be informed by the level of risk and the cost-effectiveness of the monitoring.
- Local scale monitoring during extraction operations can assist with better understanding of local hydrology and extractive impacts and consequences. This may include piezometric monitoring of the pathway between the point of extraction and locations where there is perceived risk. The cost of this monitoring is likely to be a challenge and its requirement should be justified by the risks as identified by an expert following analysis of pump test data.
- Local scale monitoring during extraction operations could potentially support adaptive management, for example, through additional reporting and cease-to-pump rules related to observed groundwater pressures.
- An assessment of hydrological reports submitted to support development applications by bottled water proponents undertaken by the Review indicates both industry and decision makers would substantially benefit from greater clarity, specificity and standardisation of requirements for hydrological reports. Current technology is available to enable standardised templates and reports to be managed electronically.
- Robust local assessment of potential connectivity between aquifer and overlying shallow groundwater and surface water should form part of pump tests and feature in hydrogeological reports. This is important, as observed in Alstonville, where deeper aquifers are not necessarily confined and may have connections to surface systems or shallower aquifers. It is important to increase understanding of how confined the aquifer is, as assessment criteria of allowable drawdown differs between confined and unconfined systems. In addition, field verification is an important part of the process.
- The Review received anecdotal information suggesting bottled water extractors were generally extracting water at an approximately evenly spaced production rate year-round compared with other commercial users who extract on a more periodic basis. The Review was not able to verify these observations. Further, all groundwater users are subject to future changing environmental conditions, which may influence their future patterns of use. The implementation of the NSW Non-Urban Water Metering Policy will provide information about use patterns in the bottled water industry and enable analyses of interactions and impacts.
- The Review received consistent reports from the community and sometimes neighbours of bottled water extractors about observed changes including environmental effects of drying watercourses and loss of water from previously productive bores. The Review has not identified scientific studies or other evidence establishing a causal link between these observed effects and extraction specifically undertaken by the bottled water industry. Going forward, data from extraction bores, together with monitoring bores (piezometers), local studies and other sources of information should help improve knowledge of impacts from a range of sources.

Data

- Lack of extraction data is an impediment to establishing appropriate extraction limits for individual bores, measuring impacts, and at a regional scale, development of WSP and making determinations of available water. A state-wide metering policy for qualifying groundwater works with bore diameters of 200mm and above will take effect in the Northern Rivers region from 2023. Four of the bottled water extractors in the region are currently required by the regulator to have meters installed.
- The accessibility of any data is central and manual collection can be an impediment in this regard. Advances in technology to provide robust and tamper-proof telemetering options that are commercially cost competitive would have a significant impact.
- Making water extraction and monitoring data available in standardised formats through open databases would benefit decision-makers, researchers and the general public to understand better activities and impacts, including cumulative impacts at local and regional scale. Approvals by relevant state and local government authorities could include requirements that all hydrogeological data are published. There are state managed environmental databases (e.g. SEED) that could be utilised.

Decision-making

- As with any environmental, engineering, resource activity, the proponents and decision makers and regulators operate in a realm of imperfect information. This leads to levels of uncertainty around data and information; however, uncertainty need not prevent decisions being made.
- There are a number of approaches and tools employed to reduce uncertainty with regard to the assumptions, hydrological domain, impacts, and consequences of water extraction. These include taking conservative estimates, using multiple lines of analysis, being judicious in decisions around the type and location of monitoring, employing adaptive management approaches.
- There is a lack of clarity around water planning, management and decision-making roles and processes at state and local government level and between relevant authorities.
- State government agencies and local government should work to clarify roles and responsibilities to streamline assessment and approval processes, to avoid duplication of effort, and to address any gaps in the assessment and approvals process.
- If local government is to undertake hydrogeological assessment as part of the development application process, then it needs access to relevant expertise to interpret modelling and technical reports to inform its decision-making, including requirements for development applications.
- Access to government and industry water data through a common open platform housing standardised, well-curated and long-term data sets that can be expanded would assist assessment and decision-making of applications.
- Regional Water Strategies will be developed over the coming months for the 12 catchment regions across the state and will assist to manage the regions' water resources. The Greater Hunter Regional Water Strategy is already in place. These will improve water security within each region and influence decisions about infrastructure, water reuse, water sharing including during droughts, protect the regions' environmental assets as well as addressing community and industry needs.

Truck movements and road impacts

- There are technologies available that can provide accurate, consistent and real-time data on truck movements, which could be included as a condition of the development consent.
- Responsibility for governing truck safety, movements and size spans Federal, State and Local Government authorities. Each of the responsible bodies has measures to regulate and monitor heavy vehicles through existing legalisation, approval of applications and technologies.
- Technologies and strategies are available to measure traffic volumes and impacts. Local government can levy heavy vehicle road users to contribute to the cost of road maintenance and repair.

Plastics

- The presence and management of plastics is international in scope and management of the impacts and solutions will be influenced significantly by factors and developments beyond those extracting water for bottling purposes in the Northern Rivers region.
- The NSW Government is developing a 20-year waste strategy and plastics plan in the context of broader Federal Government and inter-jurisdictional commitments to address waste and transition from linear to circular economies.
- There is a NSW Government container deposit scheme, which has resulted in a one-third reduction across the state of eligible containers, including bottles entering the litter stream.
- Research and development efforts to replace, repurpose and recycle plastics is a fast-moving and evolving space that is predicted to show significant growth within the next five to ten years.

RECOMMENDATIONS

1. Further work is undertaken to incorporate climate change into the development of recharge estimates for the Water Sharing Plan.
2. Consideration should be given to incorporate geological heterogeneity and soil and vegetation types into recharge estimates where practicable. This may be dependent in part on technological advances, including remote sensing, to characterise systems.
3. Improved monitoring of piezometric water levels is needed in locations with a perceived risk and/or lack of knowledge of groundwater responses and flow directions. This could provide baseline data, conceptual hydrogeological models and recharge estimates commensurate with potential future risk levels. Additional investments in monitoring should balance the value of expected improvements in data availability and data quality against the resources required.
4. Robust local hydrogeological assessments of aquifer connectivity with overlying shallow groundwater and surface water should be investigated via well-designed pump tests. This information should feature in hydrogeological reports.
5. Work should continue towards developing practical and comprehensive guidance on the contents of hydrogeology reports to be submitted by proponents, including specificity and standardisation of information provided and reporting requirements. Ideally, these would be able to be lodged electronically and made publically available.

6. State government agencies and local government should work to clarify roles and responsibilities to streamline assessment and approval processes, to avoid duplication of effort, and to address any gaps in the assessment and approvals process. The first step for this would be by February 2020, relevant officers from Water NSW, DPIE Water, NRAR and Tweed Council convene a workshop for Northern Rivers region bottled water to discuss and develop an approach between them.
7. Water extraction and monitoring data should be made available in standardised formats through open and accessible portals. State managed databases and portals (e.g. SEED) should be utilised where relevant.

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1 INTRODUCTION

In November 2018, the (then) Minister for Primary Industries, Minister for Regional Water and Minister for Trade and Industry requested the NSW Chief Scientist and Engineer to conduct an independent review and provide expert advice on the impacts on groundwater quantity arising from extraction by the bottled water industry in the Northern Rivers region of NSW.

In February 2019 an Initial Report was submitted that focused on the local bottled water industry identified in the first phase of work, the geology and hydrogeology of the region and local groundwater systems, the regulatory framework in which activities are undertaken and issues raised in submissions and during consultations and site visits.

This second and final report addresses the sustainability of extraction limits and the impacts and consequences of groundwater extraction. This includes a review of how extraction limits are assessed at the macro level through the Water Sharing Plan (WSP) and locally through water access licences (WAL) and development applications; an assessment of knowledge and data gaps; and sources of uncertainty and how these are managed. An update of the entitlements of the local bottled water industry is provided having regard to total access rights, as is comment on factors influencing demand trends and growth scenarios considered by the Review. Technological approaches to managing issues of truck movements associated with the industry and plastics are provided.

1.1 BACKGROUND

The North Coast Fractured and Porous Rock Groundwater Sources Water Sharing Plan (the WSP) sets out extraction limits and rules for all four groundwater sources in scope within the Northern Rivers region:

- Alstonville Basalt Plateau Groundwater Source – fractured rock aquifer
- Clarence Moreton Basin Groundwater Source – porous rock aquifer
- New England Fold Belt Coast Groundwater Source – fractured rock aquifer
- North Coast Volcanics Groundwater Source – fractured rock aquifer (Figure 1)

The Alstonville source stands in contrast to the three sources further north in the Tweed valley. The Alstonville source is the only fully allocated groundwater system of the four groundwater sources; it has higher use, and it has a network of state operated monitoring bores or piezometers. This Report analyses the monitoring data from these bores from 2006 to present.

Overall use of the other three groundwater systems, in the Tweed, is very low compared with the size of the aquifers, but monitoring data on these systems is also sparse.

For all four aquifers, the parameters used to determine the extraction limits are considered by the Review and focus is also put on local impacts and protection of features.

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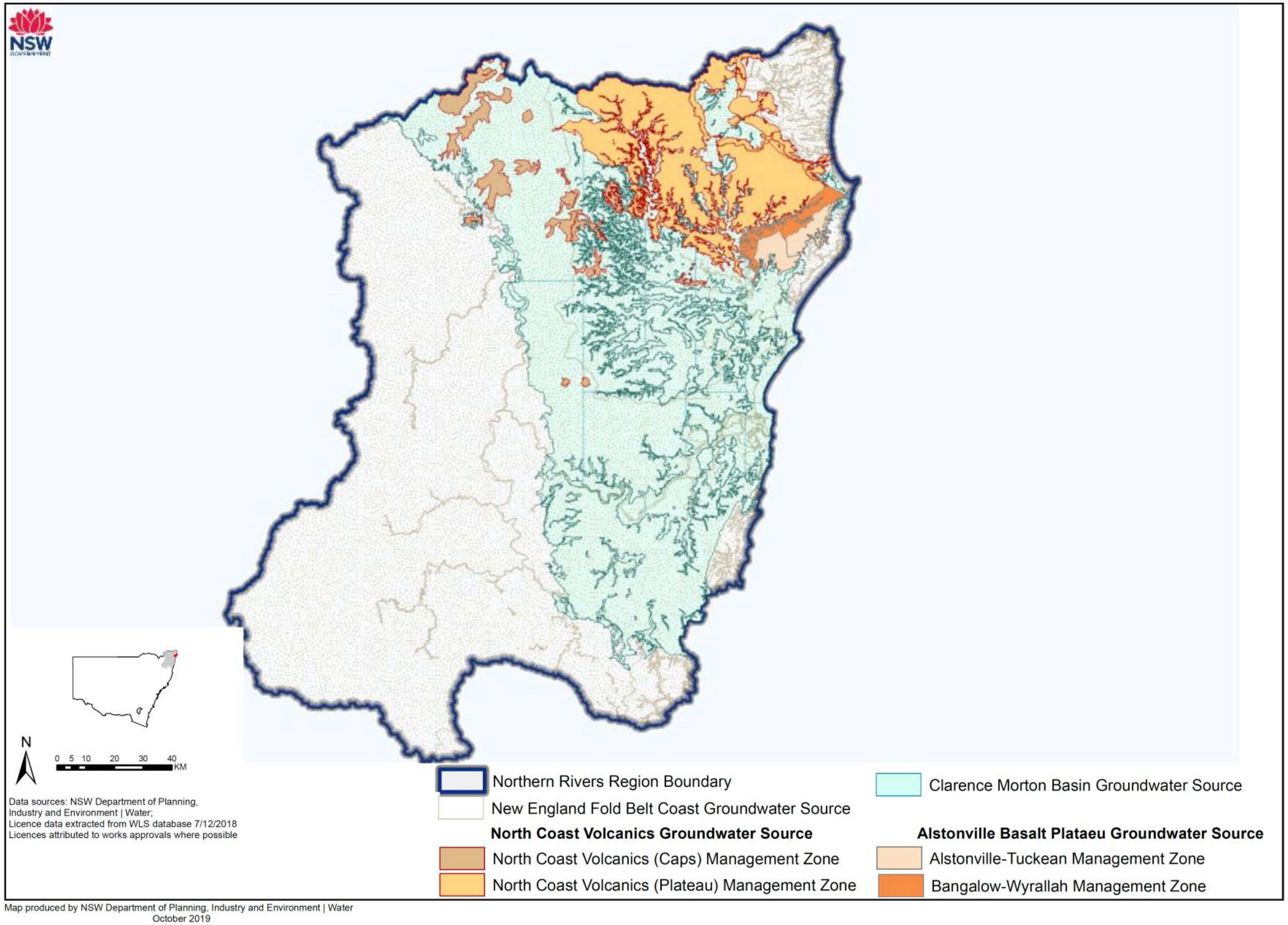

Figure 1: Map of Northern Rivers region showing boundaries of the four groundwater systems

1.1.1 Proposal from Tweed Shire Council to prohibit water bottling facilities

In November 2018, the Tweed Shire Council resolved to prepare a planning proposal to remove clause 7.15 from the 2014 Tweed Local Environment Plan (LEP) with the intended outcome that a water bottling facility will no longer be permitted in RU2 Rural Landscape Zone (TSC, 2019b).[1]

In May 2019, a Gateway Determination allowed the amendment to the LEP to proceed subject to a set of conditions (DPE, 2019).

Tweed Shire Council put a revised proposal on public exhibition in July 2019, accepting submissions until September 2019. At the time of drafting this report, the Tweed Shire Council had not finalised the amendment to the LEP and was in the process of meeting the set of conditions set out in the Determination.

1.2 REVIEW PROCESS

1.2.1 Updated Terms of Reference

On 28 February 2019, the Review Terms of Reference were expanded to include advice on:

- scientific and technical approaches to examining socio-economic factors and impacts and possible solutions using locally relevant examples
- localised environmental consequences related to extraction for bottled water.

The full TOR are at Appendix 1.

1.2.2 Experts

The Office of the NSW Chief Scientist & Engineer (OCSE) engaged technical experts in a range of fields to assist the Review, including hydrology, groundwater, surface water, groundwater and surface water interactions, modelling, monitoring, statistics and uncertainty analysis. Experts engaged included:

- Associate Professor Will Glamore, Water Research Laboratory, School of Civil and Environmental Engineering, UNSW Sydney (Phase 1 and 2)[2]
- Alice Harrison, Project Engineer, Water Research Laboratory, School of Civil and Environmental Engineering, UNSW Sydney (Phase 1 and 2)
- Dr Mahmood Sadat-Noori, Research Associate, Water Research Laboratory, School of Civil and Environmental Engineering, UNSW Sydney (Phase 2)
- Professor Neil McIntyre, Principal Research Fellow, Centre for Water in the Minerals Industry, Sustainable Minerals Institute, University of Queensland (Phase 1 and 2)
- Dr Liliana Pagliero, Postdoctoral Research Fellow, Centre for Water in the Minerals Industry, Sustainable Minerals Institute, University of Queensland (Phase 1 and 2)
- Dist. Professor Louise M. Ryan, Professor of Statistics, School of Mathematical and Physical Sciences, University of Technology Sydney (Phase 1 and 2)

[1] Section 7.15 of *Tweed Local Environmental Plan 2014* states, Water bottling facilities in Zone RU2 Rural Landscape (1) Despite any other provision of this Plan, development may be carried out with development consent for the purposes of a water bottling facility on land in Zone RU2 Rural Landscape if the consent authority is satisfied that development will not have an adverse impact on natural water systems or the potential agricultural use of the land. (2) Despite any other provision of this Plan, development may be carried out with development consent for the construction of a pipe or similar structure on any land for the purposes of conveying groundwater to a water bottling facility. (3) In this clause— water bottling facility means a building or place at which groundwater from land in Zone RU2 Rural Landscape is extracted, handled, treated, processed, stored or packed for commercial purposes.

[2] Phase 1 is work prior to Initial Report; phase 2 is work from Initial Report to Final Report.

Over the course of the Review, information and advice on data, policy, guidelines, monitoring, modelling and regulation, was sought from agencies with roles and responsibilities relevant to the TOR. This included DPIE Water; Water NSW; the Natural Resource Access Regulator; NSW Environmental Protection Agency; Energy, Climate Change & Sustainability (DPIE); Rous County Council, Tweed Shire Council and others.

1.2.3 Site visits and consultations

The Review made two site visits to the Northern Rivers region, in December 2018 and January 2019. These initial site visits concentrated on the areas near and around Dungay, Urliup, Murwillumbah, Uki, Mt Warning, Ballina and Alstonville. Stakeholder meetings were conducted with representatives from local government, the local community and industry. Requests for relevant reports, additional information and data, and details of other interested stakeholders were made to all stakeholders as part of these site visits and meetings. In the second phase of work, the Review Team held various consultations with community members and industry representatives.

Further details are at Appendix 2.

1.2.4 Submissions

Fourteen submissions were received over the course of the Review. Submissions are available on the website of the NSW Chief Scientist & Engineer.

1.2.5 Workshop

To inform the Review, OCSE hosted a one-day multi-disciplinary expert workshop in Sydney on 6 September 2019. The workshop brought together experts in hydrogeology, groundwater hydrology and modelling, groundwater ecology, surface water, climate modelling, geology, planning, uncertainty and statistics. Discussion encompassed:

- Science to inform extraction limits in Water Sharing Plan
- What the data from the Alstonville Basalt Plateau Groundwater Source tells us
- Assessing local impacts – hydrogeological studies
- Assessing impacts – research needs and approaches

Diverse views were presented at the workshop. However, all agreed that characterising fractured rock systems, in particular, are complex due to their heterogeneous structure and there are significant knowledge gaps in the region. High-level observations from the sessions are referred to in relevant parts of the report. A list of participants that attended the workshop is at Appendix 2.

1.3 STRUCTURE OF THIS REPORT

- Chapter 2 analyses growth trends and potential growth scenarios for the industry in the Northern Rivers region, as well as the allocations for the industry compared with overall allocations in the WSP.
- Chapter 3 addresses the TOR seeking advice on the sustainability of the extraction limits in the Water Sharing Plan.
- Chapter 4 addresses impacts and environmental consequences from the bottled water industry extraction, including impact mechanisms, the challenges to understanding impacts and consequences, how impacts are assessed and managed, and further information to assess impacts.
- Chapter 5 considers technical approaches to the socio-economic issues raised in the review, including the use of plastic bottles and truck movements.
- Chapter 6 provides findings and recommendations.

2 THE BOTTLED WATER INDUSTRY

The Review TOR include data on the bottled water industry entitlements and extractions having regard to total water access rights and WSPs; and advice on potential impacts on groundwater resources arising from current industry activities and proposed or potential expansion.

An analysis was undertaken of economic factors influencing supply and demand, which were used to develop growth scenarios to predict future growth of the industry in the region.

Consideration was also given to whether the industry has different extraction patterns to other users that could result in different extraction impacts. This chapter includes findings on industry pumping characteristics as well as monitoring and data collection undertaken by industry.

Issues specifically related to sustainability and impacts and environmental consequences are addressed in subsequent chapters.

2.1 BOTTLED WATER INDUSTRY

2.1.1 The bottled water industry supply chain

The bottled water industry extracts, manufactures and bottles spring water, mineral water, purified water and bulk water for sale (Table 1).[3] Spring and mineral water represent 75% of the bottled water market. The water is extracted from groundwater sources, processed, bottled and primarily sold through grocery and convenience stores, restaurants, bars and vending machines (IBISWorld, 2019).

Table 1: Product segments in the bottled water industry

Product segment	Description	Market share
Spring water	Sourced from underground wells and contains a unique mix of minerals based on the characteristics of the well.	50%
Mineral water	Sourced from underground wells and contains a higher concentration of dissolved salts. No minerals are added.	25%
Purified water	Generally sourced from standard town water supply. Purified to remove impurities and contaminants.	12.5%
Bulk and packaged water	Large bottled water products (>3 litres), generally sold to businesses.	12.5%

Source: (IBISWorld, 2019)
Note 1: Market share measured by reference to segment revenue versus overall market revenue.
Note 2: Bulk and packaged water suppliers source water from both standard water supply and groundwater.

The supply chain in the water bottling industry is generally divided between extractors (operators specialising in water extraction) and water bottlers (operators who process, bottle and distribute to retailers) (Figure 2). This is because most water bottlers (particularly major bottlers) outsource the extraction of water to small local operators who hold the relevant water access licences and approvals. However, some extractors also have small bottling plants.

[3] The bottled water industry typically does not include suppliers of water for soft drinks and other beverages, (for example alcoholic beverages), as this water is generally supplied from standard water supplies (for example town water).

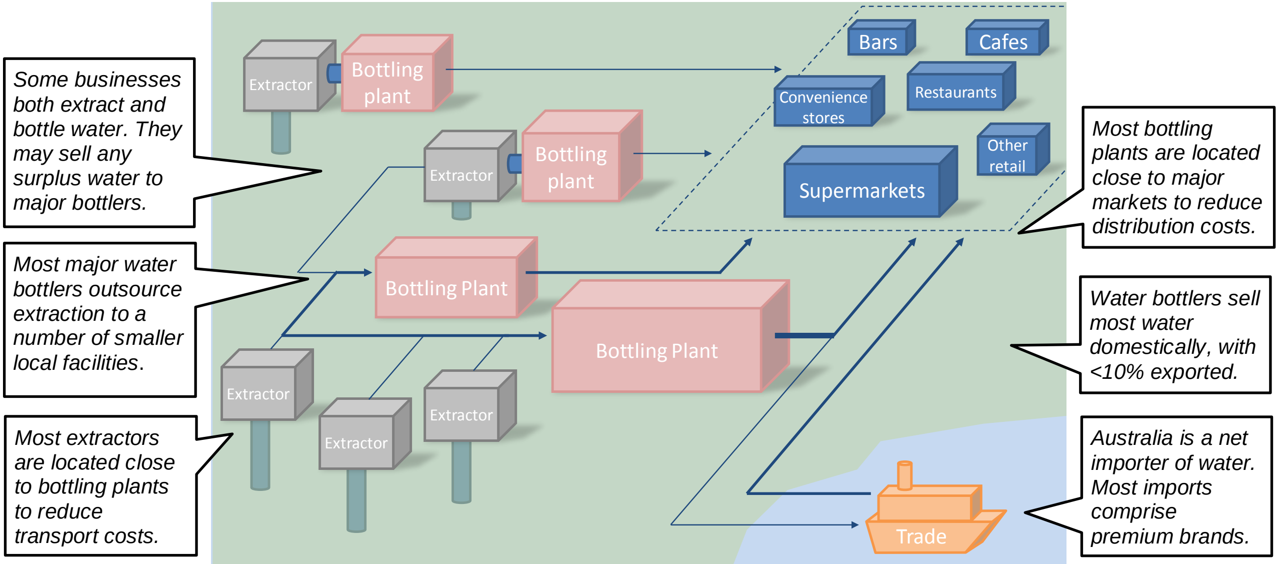

Figure 2: High level supply chain in the bottled water industry

There are approximately 50 water bottlers in Australia, of which approximately 35% are based in NSW (IBISWorld, 2019). As bottled water products are heavy and of low value relative to their weight and size, the distribution of bottled water manufacturing facilities largely reflects population distribution to minimise transportation costs, with most facilities located near major population centres. As a result, larger manufacturers will often collocate water bottling facilities with other bottling facilities (for example soft drinks) to reduce manufacture and distribution costs through economies of scale and scope (IBISWorld, 2019).

Most bottled water manufactured in Australia is sold domestically, with only 8% of revenue generated from exports (IBISWorld, 2019). Australia is a net importer of bottled water.[4] Due to the high costs of transport most of these imports comprise premium bottled water brands which charge higher retail prices. These include brands such as Evian, Voss, Fiji Water, Perrier, San Pellegrino and Vittel (IBISWorld, 2019).

Market share amongst water bottlers is highly concentrated. Coca-Cola Amatil Ltd (CCA), Asahi Holdings (Australia) Pty Ltd and Nu-Pure Pty Ltd represent approximately three-quarters of market share (IBISWorld, 2019). CCA's major spring and mineral bottled water brands manufactured in Australia include Mount Franklin, Pump, Neverfail Springwater, Peats Ridge, and Glaceau Smartwater. Asahi Holdings' major spring and mineral bottled water brands manufactured in Australia include Cool Ridge and Frantelle. However, the industry is also characterised by many small businesses, with 50% of businesses earning less than $200,000 revenue per annum (IBISWorld, 2019).[5]

Market share amongst extractors is more fragmented. Some extractors operate a network of extraction facilities across the country. There are also small extractors who operate only a single site and compete with other extractors to supply water to water bottling plants. Competition between extractors is driven by the quality and price of water that each extractor can supply. Water quality is affected by the characteristics of the groundwater source. Price is influenced by the costs of extraction, processing, transport, economies of scale and margins. Extractors are often geographically proximate to water bottling facilities to reduce transport costs.

[4] In 2018-19, Australia imported approximately $340m of bottled water for domestic consumption and exported approximately $56.1m of bottled water for international markets. Imports have been increasing faster than exports and Australia's net trade deficit of bottled water is expected to exceed $300m by 2022 (up from $283.9m in 2018-19) (IBISWorld, 2019)

[5] Only 7% of businesses earn more than $5m per annum.

The industry reports that the manufacturing of bottled water contributes $186M to the NSW economy per annum, and supports 1,047 full time jobs.[6]

2.1.2 Performance of the bottled water industry in Australia

Between 2014 and 2018, consumption of bottled water in Australia grew at an average rate of 10% per annum by water volume, reaching approximately 1,100 ML in 2018 (Figure 3). This growth in consumption has been driven by several factors, including by consumer preferences trending towards snacks and takeaway meals (IBISWorld, 2019); water being perceived as a healthier beverage alternative to soft drinks (Asahi Group Holdings, 2019); and major grocery stores launching low cost private label bottled water products.[7]

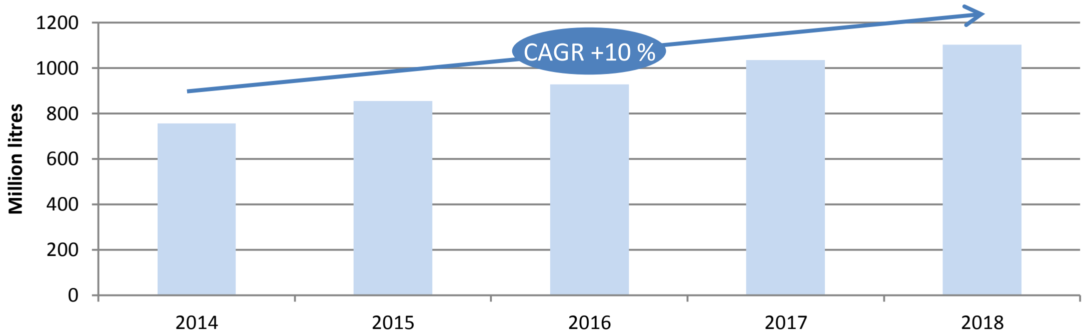

Figure 3: Bottled water consumption in Australia
Source: 2014 to 2018 (Asahi Group Holdings, 2019)

While consumption of bottled water has grown in recent years, overall revenue of the Australian bottled water industry has not been growing. Industry revenue is expected have fallen by 0.4% per annum between 2014 and 2019 to $706.8m (IBISWorld, 2019). This reflects the fact that low cost private label bottled water brands have grown volumes at the expense of the higher priced brands.[8] Overall industry revenue is expected to be flat or grow modestly (at less than 1.5% per annum) over the period 2019-24 (IBISWorld, 2019; Statista, 2019).

2.1.3 Outlook for the bottled water industry in Australia

The Australian bottled water industry is influenced by a number of trends. The extent to which these trends will influence future production is expected to vary. Table 2 sets out the likely trends based on currently available forecasts. Based on these trends, the following section explores a range of future scenarios.

[6] Economic and employment contribution of manufacturing comprises direct manufacturing contribution of $73M and 281 FTEs, and manufacturing supply chain contribution of $113M and 766 FTEs (from activities including extraction, other manufacturing, transport, infrastructure, utilities and professional services) (ABC, 2019).

[7] While bottled water consumption has been growing, this growth has been largely concentrated in sales of private label bottled water products. Major bottled water brands have struggled to grow volumes due to this aggressive price competition from private labels (Asahi Group Holdings, 2019; IBISWorld, 2019)

[8] For example, despite growth in overall Australian bottled water consumption from 2014 to 2018, CCA has reported falling still beverage sales since 2014 and sales volume declines of bottled water of 1.7% from FY17 to FY18. See Coca Cola Amatil Full Year Results 2018 (Coca-Cola Amatil, 2019a), 2017 (Coca-Cola Amatil, 2018a); 2016 (Coca-Cola Amatil, 2017); 2015 (Coca-Cola Amatil, 2016)); and 2014 (Coca-Cola Amatil, 2019b). At the same time, sales of private label bottled water have grown from 21.2% of all bottled water sales in Australia in 2014 to 50% in 2018. However, the growth in market share of private label bottled water has also slowed significantly from 12.2% growth between 2014 and 2015, to 3.2% growth between 2017 and 2018. (Asahi Group Holdings, 2019).

Table 2: Trends influencing bottled water production

Trends impacting bottled water production in Australia	Past impact on production	Forecast future impact on production	
(a) Increasing consumer preferences for takeaway meals	▲	▲ ▲	Consumer preferences for takeaway meals are expected to increase as disposable incomes increase (RBA, 2019) and economies of scale reduce takeaway cost.
(b) Increasing consumer preferences for healthier beverages	▲	~	Sugar free, artificially sweetened beverage alternatives are now widely available and accepted.
(c) Increased availability of private label bottled water	▲	~	Private label availability is already high and is unlikely to increase further, evidenced by growth in private label market share having been strong (12.2% between in 2014 and 2015) but having slowed significantly (3.2% between 2017 and 2018) (Asahi Group Holdings, 2019).
(d) Population growth	▲	▲	Population growth is forecast to remain constant at 1.4-1.8% p.a. to 2027. From 2027 to 2042 population growth is expected to reduce to 0.9-1.5% p.a (ABS, 2018).
(e) Increasing international demand for Australian bottled water exports	▲	▲	Exports are forecast to continue to increase modestly, particularly if the Australian dollar remains depreciated (IBISWorld, 2019).
(f) Increasing Australian demand for imported bottled water	▼	▼ ▼	The trade imbalance in bottled water is forecast to grow as imports increase much faster than exports (IBISWorld, 2019).
(g) Increasing consumer awareness of the environmental impacts of plastic	▼	▼ ▼	Consumer awareness is expected to increase rapidly due to media campaigns and incentives (e.g. container deposit schemes) (IBISWorld, 2019).
(h) Wide availability of tap water in Australia	▼	~	Drought may impact the availability of water and reduce disposable incomes in certain communities (RBA, 2019).
(i) High quality of Australian tap water	▼	▼	Quality of Australian tap water is expected to remain high (IBISWorld, 2019).

Note: ▲ = increased production; ▼ = decreased production; ~ = no impact on production

2.1.3.1 Bottled water consumption and production scenarios

The trends set out in Table 2 were used to assess potential future growth in the Australian bottled water industry. Two scenarios were considered – the most likely ('probable') scenario and an 'unlikely' scenario using available data over the next five years to 2024. Two more scenarios are considered later in this Chapter – a 'highly unlikely' scenario and an 'extremely unlikely' scenario using available data over the next 15 years to 2034.

Scenario 1 (probable) – 2% growth per annum

Industry forecasts predict that the most likely scenario is that the Australian bottled water industry experiences modest revenue growth of approximately $11 million per annum (1.5%) over five years from 2019 to 2024 (IBISWorld, 2019). Under this scenario, growth in consumption of bottled water in Australia will slow to 2% per annum (IBISWorld, 2019). Based on the trends in Table 2, under this scenario production growth is likely to slow to less than 2% per annum; in particular because:

- Although consumption of bottled water in Australia grew at an average rate of 10% per annum by water volume between 2014 and 2018, this growth has been trending down, from 13% per annum in 2015 to 6% in 2018, and industry forecasts predict average consumption growth of approximately 2% per annum to 2024 (Asahi Group Holdings, 2019; IBISWorld, 2019).

- Low cost private label bottled water products have grown market share strongly (from 21.2% of all bottled water sales in Australia in 2014 to 50% in 2015), and driven bottled water consumption growth by aggressive price competition. However, the availability of private label products is now high, and the growth in market share of private label bottled water has slowed significantly from 12.2% growth in 2015, to 3.2% growth in 2018 (Asahi Group Holdings, 2019; IBISWorld, 2019). As a result, private labels are unlikely to drive significant consumption growth as they have done in the past.
- The trade deficit in bottled water is expected to grow as imports increase faster than exports. Growth in imported bottled water is forecast to exceed approximately $15 million per annum over five years from 2019 to 2024, while growth in exported water is expected to be more modest at approximately $3 million per annum over five years from 2019 to 2024 (IBISWorld, 2019). Therefore, growth in Australian consumption is likely to be served increasingly by imported bottled water.

At a production growth rate of 2% per annum, the market would reach approximately 1,200 ML per annum by 2024 (a 10% increase).

Scenario 2 (unlikely) – 10% growth per annum

An alternative but unlikely scenario is that growth in consumption and production of bottled water continues at 10% per annum. This scenario is unlikely because of the trends described in Table 2 and discussed above, in particular because of the slowing growth in bottled water consumption; the slowing growth in market share of private label brands; the increasing trade deficit in bottled water; the increased availability of sugar free beverages; and increased consumer concerns over plastic waste (IBISWorld, 2019).

At this growth rate, the market would reach approximately 1,900 ML per annum by 2024 (a 70% increase). Under this scenario, Australia's per capita consumption of bottled water would not reach that of the United States until 2034. The United States has one of the highest levels of bottled water consumption per capita amongst developed economies – four times greater than Australia (Figure 4).

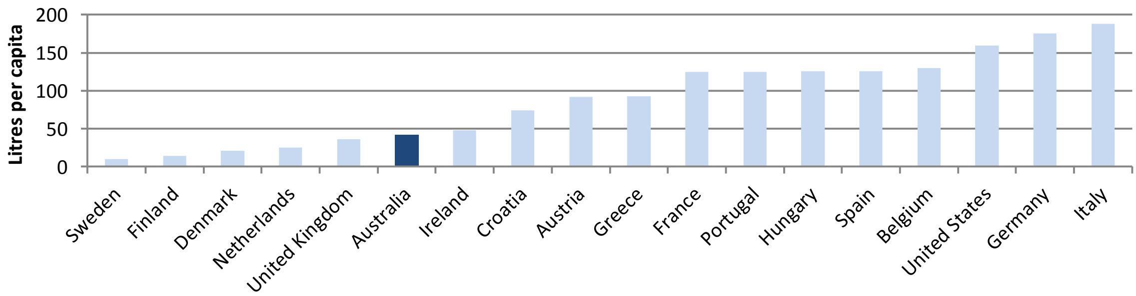

Figure 4: Consumption of bottled water in 2017 in developed economies
Source: (Beverage Marketing Corporation, 2018; Asahi Group Holdings, 2019; EFBW, 2019)

This scenario is also unlikely to occur in Australia because many of the factors that influence high consumption in certain developed economies (e.g. Italy, United States, Germany and France) are not present in Australia. These factors include that:

- High quality tap water is widely available in homes, restaurants, bars and workplaces in Australia. Many other countries do not have high quality tap water or do not offer free tap water in bars and restaurants, and other public spaces (IBISWorld, 2019).
- Many of these other countries have major premium international bottled water brands, such as Evian in France and San Pellegrino in Italy. These brands contribute to increased consumption in those countries through consumer loyalty.

It is also important to note that consumption in many of these markets appears to have reached saturation and growth has peaked. For example, Italy and Germany have experienced bottled water volume growth of only 0.1% and 0.7% respectively from 2012 to 2017 (Beverage Marketing Corporation, 2018). This suggests that there is an effective limit on consumption volumes, even in high consumption markets. This is theoretically sound since consumers can only drink a certain amount of water per day.

Under this scenario, where growth continues at 10% per annum until Australian annual consumption reaches a limit of 160 L per capita (equivalent to the United States), the bottled water market would reach approximately 4,500 to 5,000 ML per annum (depending on population growth). Assuming that the percentage of Australian bottled water demand met by imports remains constant, this would represent an approximately five fold increase in Australia's bottled water production by 2034.

2.1.4 The bottled water industry in the Northern Rivers region of NSW

The Review has identified seven operators, with allocations totalling 240.5 ML/y, that are actively extracting for water bottling purposes from four groundwater sources in the Northern Rivers region (Table 3).[9] In addition to these, the Review also identified:

- two operators that have had their development applications approved but are not yet extracting,
- one application to expand existing operations progressing through the development application process,
- one application that has had the development application refused.

These four proposals, if approved and actioned, would amount to additional extraction volumes of 168 ML/y across the four groundwater sources (Table 3). The Review also identified one application which had been progressing through the development application process but was subsequently withdrawn.

Table 3: Water licences associated with existing and proposed water bottling

Groundwater source	Water licences associated with the bottled water industry (ML/y)	Water licences associated with proposed expansions in bottled water industry (ML/y)
Alstonville Basalt Plateau (fractured)	7.5	-
Clarence Moreton Basin (porous)	50	100
New England Fold Belt Coast (fractured)	163	68
North Coast Volcanics (porous)	20	-

Water licences associated with the current and proposed future expansions in the bottled water industry represent a very small portion of the overall water requirements[10] from groundwater sources in the Northern Rivers region (Figure 5). These licences represent an even smaller portion of total groundwater recharge in the Northern Rivers region, as most groundwater recharge is reserved for the environment or is not licenced (Figure 6).

[9] The Review identified active and proposed water bottling operations in the Northern Rivers region through a search of secondary sources, including local council development applications and related documents, internet searches and information from state agencies, the community and councils. This is because the public water access licence registers (for example, the NSW Water Register and the NSW Water Access Licence Register) do not record the purpose of each licence.

[10] 'Requirements' is a term used in the WSP, which is the sum of the estimated basic landholder rights, town water supply and all other licenced entitlements (ML/yr).

Figure 5: Water requirements in the Northern Rivers region by groundwater source

[a] Potential future water requirements includes proposals for water extraction for water bottling where the proponent (1) has already obtained water allocations or works approval; and (2) is seeking, or has indicated that they will seek a development application, or will commence operation. This analysis assumes that no additional non-bottled water industry water requirements are created – however if this occurred, then the fraction of water requirements associated with the water bottling industry would be even smaller.

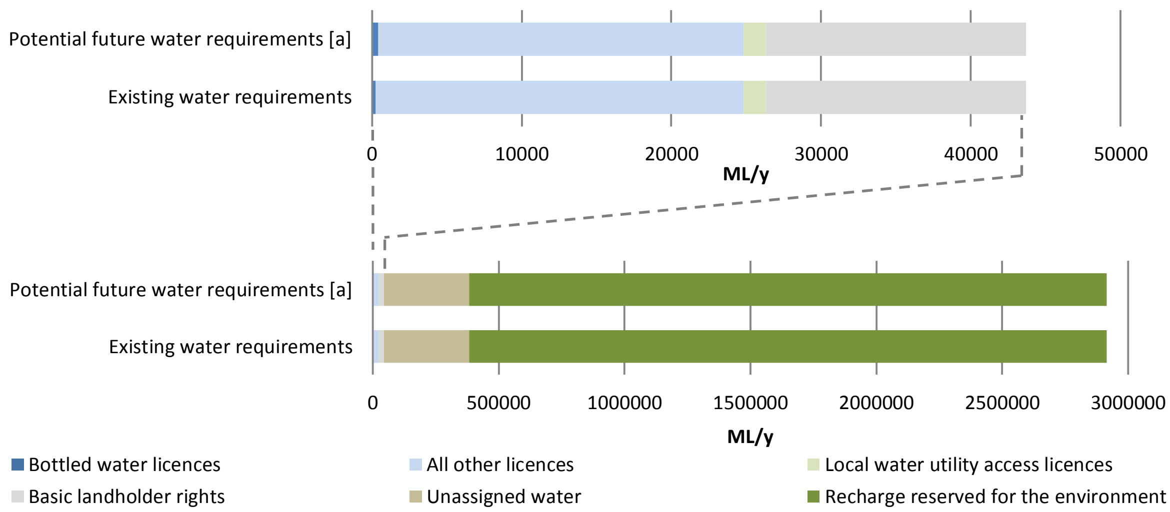

Figure 6: Water requirements, unassigned water, and groundwater recharge reserved for the environment in the Northern Rivers region

[a] See note [a] at Figure 55 above.

Note: Northern Rivers region comprises Alstonville Basalt Plateau, Clarence Moreton Basin, New England Fold Belt Coast, and North Coast Volcanics groundwater sources

2.1.5 Outlook for the bottled water industry in the Northern Rivers region

Based on the scenarios described above for potential future growth in the Australian bottled water industry,[11] forecasts have been made for growth in the bottled water industry in the Northern Rivers region to 2024 and 2034. These forecasts assume that growth rates are likely to be evenly distributed across Australia close to major population centres, and are unlikely to be concentrated in a single region. Bottled water products are bulky and low value relative to their weight and size, and therefore incur relatively high transport costs. Extractors and water bottlers are close to major population centres to reduce these costs through economies of scale in both production and transport (IBISWorld, 2019). For this reason, most large water bottlers have processing facilities across Australia near major capital cities. It is likely any future expansion in the bottled water industry would also be undertaken at multiple sites close to major markets to minimise distribution costs.

As a result, the rate of growth of the bottled water industry (including production and extraction) in the Northern Rivers region is unlikely to significantly exceed the rate of growth bottled water consumption in nearby markets. Furthermore, if the bottled water industry in the Northern Rivers region obtains significant additional water allocations beyond future local demand for bottled water, it is likely that these allocations would not be fully utilised, or would offset existing uncompetitive extraction – under the probable (*Scenario 1*) and unlikely (*Scenario 2*) scenarios discussed below.

2.1.5.1 Forecast groundwater extraction by the bottled water industry to 2024

Scenario 1 (probable) – 2% growth per annum to 2024

As discussed, the most likely scenario for growth in bottled water production in Australia is that it is likely to slow to less than 2% per annum, representing a 10% increase to 2024 (*Scenario 1*). Based on this forecast, and assuming that the 240.5ML/y of water allocated to the current bottled water industry in the Northern Rivers region are fully utilised, then 2% growth in demand for water extraction is likely to be approximately 265 ML/y by 2024 (Figure 7).

[11] Note: scenarios considered were Scenario 1 (probable) – 2% production growth per annum, and Scenario 2 (unlikely) – 10% production growth per annum.

Under this scenario, the 168 ML/y of water licences associated with proposed expansions in the bottled water industry are well in excess of the approximately 25 ML per annum necessary to meet anticipated demand in 2024. Therefore, these water licences would likely be underutilised and/or offset approximately 145 ML/y of water licences associated with the existing bottled water industry in the region (Figure 7).

Scenario 2 (unlikely) – 10% growth per annum to 2024

An unlikely scenario would be that growth in the bottled water industry in the Northern Rivers region will be 10% per annum, representing a 60% increase to 2024 (*Scenario 2*). Under this high growth scenario, the 168 ML/y of water licences associated with proposed expansions in the bottled water industry will still be sufficient to fully meet growth in demand of approximately 150 ML/y in the region by 2024 and no additional expansions would be expected (unless they offset existing extractions) (Figure 7).

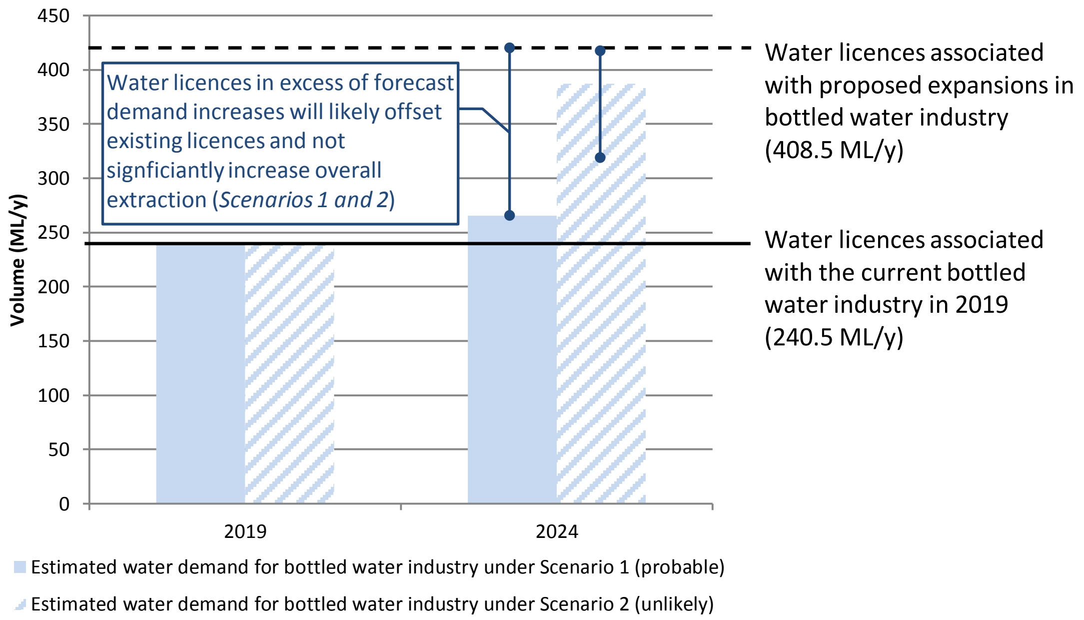

Figure 7: Bottled water industry growth scenarios 1 (probable) and 2 (unlikely)

2.1.5.2 Highly unlikely and extremely unlikely groundwater extraction scenarios to 2034

While the expected growth in the bottled water industry in the Northern Rivers region is expected to be modest to 2024 (see *Scenario 1*), it is useful to consider the impact of highly unlikely scenarios where the industry experiences high growth over a long timescale. These scenarios assist in understanding the theoretical limits on the industry in this region. Two extreme growth scenarios are considered:

- *Scenario 3* is highly unlikely and considers the impact of 10% growth per annum in the bottled water industry in the Northern Rivers region until 2034, under this scenario the growth rate of *Scenario 2* continues an additional 10 years.
- *Scenario 4* is extremely unlikely and considers the impact of a major bottled water exporter being established in the Northern Rivers region.

The impacts of *Scenario 3* and *Scenario 4* are analysed below.

Scenario 3 (highly unlikely) – 10% growth per annum to 2034

Scenario 3 assumes that the bottled water industry in the Northern Rivers region grows at 10% per annum, reaching approximately 1,000 ML/y in 2034, but does not exceed this level (Figure 8). Under this scenario, Australian bottled water consumption peaks at four times current volumes in 2034 – similar to current per capita consumption volumes in the United States (Figure 4).[12] This scenario also adopts the same assumptions as those in *Scenarios 1* and *2*: that growth rates are likely to be evenly distributed across Australia close to major population centres, and are unlikely to be concentrated in a single region.

Scenario 4 (extremely unlikely) – a major bottled water exporter is established in the region

Although the size of the bottled water industry in a region is generally influenced by bottled water consumption in nearby markets, there are a number of international premium bottled water brands that extract water from groundwater sources in a single area, and bottle and distribute it to international markets.[13] This scenario assumes that a major premium bottled water brand is established and that it:

- obtains the necessary licences and approvals to extract water from groundwater sources in the North Rivers Region,
- extracts solely from sources in this region to satisfy its entire customer demand,
- establishes world leading brand recognition and availability in multiple major global markets (e.g. Europe, the Americas, Asia, the Middle East),
- overcomes well-established international competitors to build up significant market share, and
- becomes one of the world's largest producers of bottled water.

If a brand were able to overcome all of these hurdles, this process would take many years. Most premium bottled water brands exporting to international markets have long histories (San Pellegrino, 2019; VOSS, 2019). This is because it takes a significant amount of time to build up an international brand identity that can charge a premium necessary to cover the cost of large scale distribution to international markets.

Evian is one of the largest bottled water brands in the world and sells premium bottled water in more than 140 countries (Danone, 2019). The company has extracted and sold water from groundwater sources near a single bottling plant in Evian-les-Bains in France since 1826 (Evian, 2017). Evian produced 1,441 ML of bottled water in 1999 (Danone, 2000). Assuming this scenario occurred, and a brand of the scale of Evian (i.e. of approximate production of 1400 ML/y) was able to be established, it would still represent a small fraction of groundwater extraction, unassigned water and total estimated groundwater recharge in the region (Figure 8).

[12] Bottled water consumption per capita in the United States is currently four times greater than Australia. This scenario models a four-fold increase in Australian consumption volumes – equivalent to a 3.2-fold increase in Australia's per capita consumption plus forecast population growth in Australia to 2034.
[13] For example, Evian in France, San Pellegrino in Italy, and Voss in Norway.

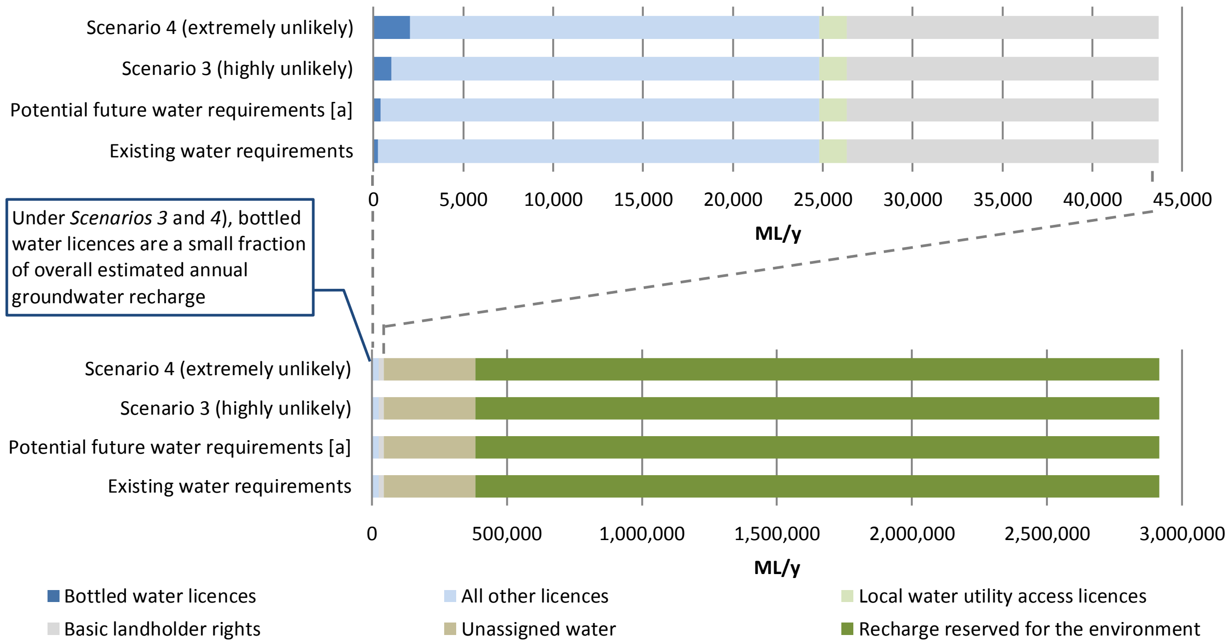

Figure 8: Bottled water industry growth scenarios 3 and 4
Note 1: Northern Rivers region comprises Alstonville Basalt Plateau, Clarence Moreton Basin, New England Fold Belt Coast, and North Coast Volcanics groundwater sources.
Note 2: For *Scenario 4*, this analysis assumes that the impact of a newly established bottled water plant producing 1,400 ML/y would result in an increase in extraction volumes by an additional 1,610 ML/y.[14]
[a] See note [a] at Figure **5**5 above.

2.1.6 Policy and regulatory interventions

The bottled water industry is subject to local council[15] and NSW Government[16] policy, planning and regulatory requirements. These are discussed in detail at Appendix 4 of the Initial Report. It is not possible to forecast possible future changes in laws or regulations which impact groundwater extraction. While regulatory intervention may directly or indirectly restrict groundwater extraction for water bottling in particular areas, these restrictions would be unlikely to impact underlying consumer demand for bottled water or overall bottled water consumption.

[14] As a conservative assumption, this analysis assumes a Water Use Ratio of 1.46L/L (WUR, the litres of water including product water used to make one litre of bottled water) and assumes 30% of the additional water required to produce 1,400 ML/y of bottled water is extracted groundwater, and that the remaining additional water comes from other sources. The WUR for the bottled water industry is 1.32L/L in North America and 1.46L/L internationally (Antea Group, 2015). Note that the Australian bottled water industry anecdotally reports lower WURs. The WUR includes all water used by the facility, including product water, and water used for facility processes (e.g., treatment, cleaning, maintenance).

[15] Local councils can indirectly control the volume of water extraction in their local government areas (LGAs) through restrictions in the development consent, for example, by imposing limits on truck movements. Local councils can also (within limits) control the types of businesses in certain zones through the terms of the relevant LEP, which govern the conditions and types of development that can occur in their LGAs.

[16] The NSW Government, through the *Water Management Act 2000* and WSPs, controls the volume and manner of water extraction from particular groundwater sources. These instruments also regulate the water licencing, allocation and trading process with the objective of ensuring the economically efficient allocation of water to the commercial uses of highest economic value. These instruments also establish priorities between environmental, domestic and stock, and industrial and commercial extraction in particular groundwater sources. However, within the category of industrial and commercial extraction there is no distinction made between the purposes of the groundwater extraction. As a result, the laws and regulations do not incentivise or disincentivise water extraction for water bottling over extraction for other commercial purposes (for example, farming, other manufacturing).

2.2 WATER ENTITLEMENTS FOR BOTTLED WATER FACILITIES IN THE NORTHERN RIVERS

The Initial Report outlined challenges in determining the scope of the bottled water industry, in part due to commercial water access licences specifying allowable extraction rates and not the intended use of the extraction. Other means, including sourcing and reviewing development applications and consents, are required to confirm if groundwater extraction is being used for bottled water.

Table 5 provides an updated overview of the total available water for all purposes by groundwater source. It includes landholder rights and entitlements, as well as an estimate of the water entitlements held by the bottled water industry in the Northern Rivers area. It is emphasised that Table 5 provides a summary of the licence *entitlements*, not a record of *actual* water taken. It also does not reference any additional restrictions imposed on water take imposed through the development consent or any self-imposed limits on water take, so it is likely to overestimate actual water extraction. The Review is aware of several examples where the licence entitlement is higher than the allowable extraction through the development consent; this table reflects the entitlement volume only.

This section examines the volume of existing and proposed total licence allocations for the bottled water industry against the total water requirements, including all licences and basic landholder rights, for each of the four groundwater sources. The percentages of existing and proposed licences used for the bottled water industry for each sources is at Table 4. Under the WSP, environmental water and Basic Landholder Rights are given priority over licensed water extraction. Among licensees, priority is given to water utilities and licensed stock and domestic over commercial licensed purposes.

Table 4: Existing and proposed bottled water licence entitlements as a proportion of total water requirements (including licenced extraction and BLR) by groundwater source

Groundwater source	Existing	Existing and proposed
Alstonville Basalt Plateau	0.1%	0.1%
Clarence Moreton Basin	1.0%	3.0%
New England Fold Belt Coast	0.7%	1.0%
North Coast Volcanics	0.3%	0.3%

Figure 9 illustrates the total estimated annual aquifer recharge for each relevant groundwater source in the WSP, the amounts of the recharge that are reserved for the environment in the WSP and the long-term annual average extraction limit (LTAAEL), including the breakdown by licence, Basic Landholder Rights and unassigned water. This figure does not consider the Upper Extraction Limit (UEL), which in the case of the New England Fold Belt Coast and the North Coast Volcanics, as shown in Table 5, are higher than the LTAAEL.

In the case of the New England Fold Belt Coast and the North Coast Volcanics, the vast majority of the recharge is reserved for the environment (97% and 96% respectively), with only a small proportion that can be allocated to licences. This is because the LTAAEL for these water sources is set as the current entitlement plus estimated future water entitlements for the term of the plan rather than as a percentage of recharge. In these water sources the percentage of recharge protected from extraction (75%) is defined in the UEL. For Clarence Moreton Basin, the amount reserved for the environment is 48% of the recharge, but for this groundwater source, only 1.7% of the amount which can be allocated for licences is allocated. For Alstonville, 82% of the recharge is reserved for the environment, but the remainder that is available for licences is fully allocated. The total volume of storage of the four aquifers is fully reserved for the conservation of the groundwater system.

Of the recharge that is not reserved for the environment (i.e. the LTAAEL in the case of these four aquifers), some is allocated to Basic Landholder Rights and licences, while the remainder remains unassigned water. At present, approximately 38.0% of LTAAEL in the New England Fold Belt Coast is allocated, 51.3% of the North Coast Volcanics and 1.7% in the Clarence Moreton Basin is allocated. Alstonville is fully allocated. A fraction of these allocations are for licences for the bottled water industry (Table 4 and Table 5).

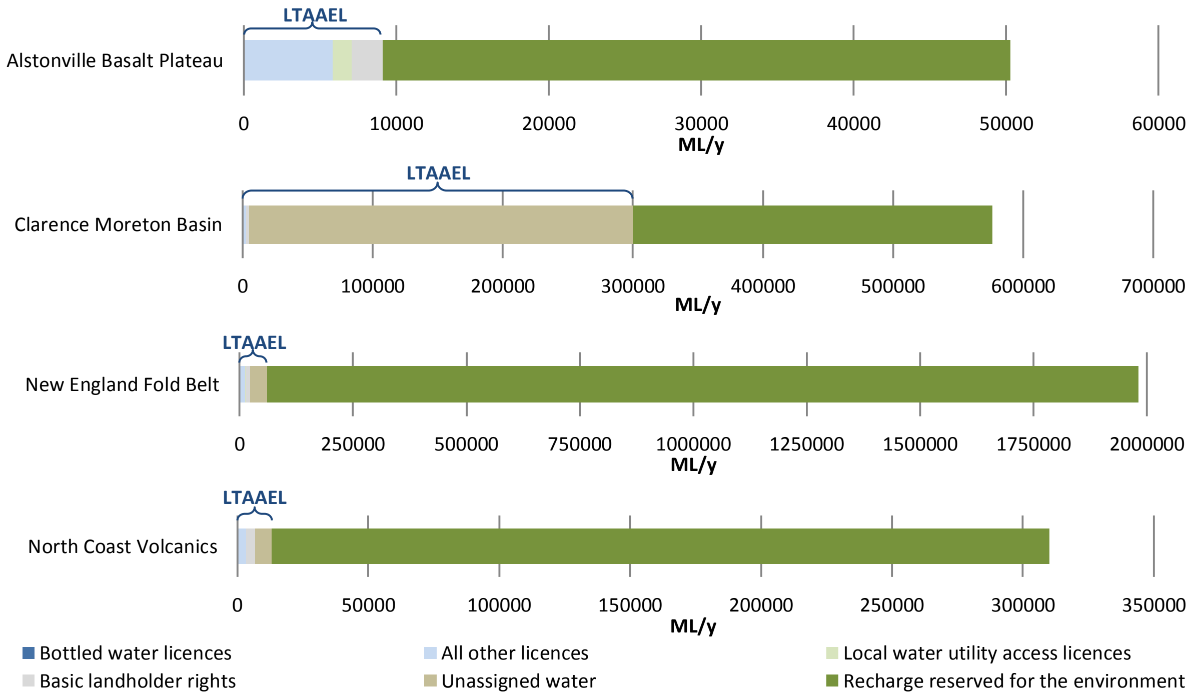

Figure 9: Breakdown of total estimated annual aquifer recharges in the Northern Rivers region by water requirements, unassigned water, groundwater recharges reserved for the environment and LTAAELs

Table 5: Available water, extraction limits and requirements by purpose and groundwater source (updated October 2019)

Groundwater Source	**A** (ML) **Estimated Total Aquifer Storage** [1,a,b]	**B** (ML/yr) **Estimated total annual aquifer recharge** [3]	**C** (ML/yr) **Recharge amount reserved for environment**[3, a]	**D** (ML/yr) **Upper Extraction Limit (UEL)**[2,3]	**E** (ML/yr) **LTAAEL** [2,3,c]	**F** (ML/yr) **Un-assigned Water**[3,4]	**G** (ML/yr) **Total requirements (BLR and licences)**	**H** (ML/yr) **Basic landholder rights (BLR)**[2,3,d]	**I** (ML/yr) **Local water utility access licences** [4]	**J** (ML/yr) **All other aquifer access licences** [l]	**K** (ML/yr) **Bottled Water Licences (Existing Industry)** [e,f]	**L** (ML/yr) **Bottled Water Licences (Proposed Industry)**[f,g]	**M** **Total no. water access licences (WALs)**[4,k]
Alstonville Basalt Plateau	640,000	50,079	41,184	na	8,895	0[h]	9,086[h]	2,014	1,230	5,842[5,i]	7.5	0	192
Clarence Moreton Basin	na	576,000	276,000	na	300,000	294,847	5,153	2,341	31	2,781[4]	50	100	136
New England Fold Belt Coast	24,000,000	1,980,000	1,920,000	375,000	60,000	37,227	22,773	9,605	240	12,928[4]	163	68	558
North Coast Volcanics	4,380,000	310,000	297,000	55,000	13,000	6,327	6,673	3,402	0	3,271[4]	20	-	205
Relationship between columns		*B=C+E*	*(C=B-E)*	*D*	*E*	*F =E-G*[j]	*G=H+I+J*				*Subset of J*	*Subset of J*	

Sources and notes:

1 Estimated based on total area, porosity, average saturated thickness of source (EMM, 2018)
2 WSP NCFPR (July 2016)
3 WSP NCFPR – Background document (Sept 2016)
4 NSW Water Register https://waterregister.waternsw.com.au/water-register-frame - data used is from 19/20 year for each groundwater source
5 Supplied by DPIE Water (DOI Water, 2019)
a. Sources 2 and 3 define Planned Environment Water as equal to the total recharge minus the LTAAEL plus the portion of storage not available for extraction. At the commencement of the WSP NCFPR, 100 percent of groundwater storage is reserved as planned environmental water.
b. Reserved as part of Planned Environment Water – allocations made only on recharge
c. LTAAEL is long-term average annual extraction limit.
d. BLRs comprise domestic and stock but do not include volumes for Native Title Rights due to difficulty predicting volumes used
e. Column K is based on the full volume of a licence entitlement where all or part of that licence may be extracted for bottled water. This number does not reflect any other restrictions on the licences, e.g. through development consent conditions or voluntary etc.
f. Due to difficulty in confirming bottled water industry participants, there may be some small extractions captured in 'all other aquifer licence entitlements' column J that are not yet captured in columns K and L.
g. Under Column L, WALs, water supply approvals or general terms of approval may have been issued; and there is some indication in the public domain of either works approval or development application in process to start/expand extraction.
h. There is no unassigned water in Alstonville Basalt Plateau Groundwater Source. The total requirements do not represent actual take. When considering AWDs, actual water take is assessed against LTAAEL to determine volume or percentage of unit share.
i. DoI Water noted that two licences were handed back to the Water Administration Ministerial for a total of 10 ML/yr. The figure reflects this (DOI Water, 2019)
j. The WSP NCFPR (2016) reflects unassigned water as LTAAEL minus total requirements (p. 35). This method is used with updated figures.
k. Includes Water Utility Licences
l. Total Share Component

2.3 REGULATION AND CHARACTERISTICS OF EXTRACTION

There is a requirement for all food for sale in NSW, including bottled water, to be safe and suitable for human consumption.[17] Bottled water also is subject to the Australian New Zealand Food Standard Code.[18] The Code defines bottled water (the term 'packaged' water is used), its composition and labelling requirements. Bottled water is required to comply with certain limits on with microbiological and chemical contaminants, toxicants and processing aids. For example, the Code specifies a microbiological limit for packaged water, whereby *E. Coli* should not be detected in a sample of 100mL of water.[19]

Although, the Code requires that the bacteriological and physical quality of bottled water comply with these criteria, it does not specify frequency of analysis. However, if samples are found to be contaminated or exceed limits specified in the Code, then appropriate action would be taken by the manufacturer or the relevant regulatory agency. As the Code applies nationally but is enforced locally, the responsible agency will vary in each case but may be the local council, the NSW Food Authority or interstate agencies.

2.3.1 Australasian Bottled Water Institute Model Code

Some members of the bottled water industry within the Northern Rivers region are members of the Australian Beverages Council (ABC), which is an industry body representing the non-alcoholic beverage industry. The Australasian Bottled Water Institute (ABWI), a division of the ABC has developed a Model Code with guidelines relating to quality and safety, including Good Manufacturing Practices (GMP) (ABWI, 2018).

Members of the ABWI are required to comply with certain provisions of the Model Code when producing bottled water. The Code specifies key testing requirements relating to the extraction of water, the transport of water, and the processing of water to minimise the risk from biological, chemical or physical contaminants. In relation to water extraction, the Code also requires that a review be undertaken by a hydrogeologist that demonstrates the integrity of the source and the safety of the catchment operations. This review should also include (ABWI, 2018):

> *"(a) An evaluation of the chemical, physical, microbiological, and radiological characteristics of the source.*
>
> *(b) A report on the regional geology surrounding the site and the specific site geology … to define the recharge area of the aquifer, or in the case of regional aquifers, the zone of influence of the subject source.*
>
> *(c) A report detailing the development of the source …*
>
> *(d) A watershed survey of the recharge area or zone of influence of subject source that identifies and evaluates actual and potential sources of contamination, including any reported discharge that may affect the source.*
>
> *(e) Based on the findings in item (d), a plan for special monitoring of any significant contaminant source and for taking restrictive preventive or corrective measures as appropriate to protect the source water."*

In addition to this hydrogeology review, other tests are required including microbiology tests (for example, for Coliforms, and/or *E. Coli,* yeasts and moulds) and chemistry tests (physical, radiological, inorganics, organics and volatile organics). Testing frequency varies from weekly to every four years (ABWI, 2018).

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[17] *Food Act 2003*, s 3(a).
[18] *Australia New Zealand Food Standards Code*. Standard 2.6.2 Non-Alcoholic Beverages and Brewed Soft Drinks
[19] *Australia New Zealand Food Standards Code* – Schedule 27 – Microbiological limits in food, cl 4.

2.3.2 Characteristics of bottled water extractors

It appears that extractors in the bottled water industry in the Northern Rivers region are using bores which range from a depth of approximately 25 to 90 metres, but more typically range from 30-50 metres.[20] In contrast, stock and domestic bores tend to be shallower as they are generally sunk until water is reached (to minimise costs of drilling and construction). Anecdotally, the Review was advised the purpose is to draw from deeper aquifers to attempt to minimise or avoid interaction with surface water and other shallower bores. Interaction between groundwater sources and surface water can have negative impacts on water quality and quantity.

2.3.2.1 Managing water quality

As discussed, the bottled water industry is subject to the Food Standards Code which regulates the safety and quality of the water. Some operators are also subject to obligations under the ABWI Model Code which control the extraction, transport and processing of bottled water. However, groundwater extractors supplying water bottling plants also have direct commercial incentives in monitoring the quality of their product to ensure that it is of sufficient quality for sale. Unsafe or contaminated water poses issues of legal liability and brand reputation for the extractor and bottled water producer.

Groundwater from depth is generally microbiologically safe and chemically stable, however, contamination of the groundwater bores can still occur. Sources of contamination can include seepages associated with septic tank discharges (potentially introducing pathogens and nitrates), agricultural practices (potentially introducing pathogens, nitrates and pesticides) and industrial wastes (NHMRC & NRMMC, 2011). Contamination can also occur from natural sources including water flowing into the target aquifer from a connected aquifer that has different physical or chemical characteristics. If interference from other sources causes the water quality to change, the water may no longer be suitable for sale for bottling. For example, a connection between a groundwater source and an *E. Coli* contaminated surface stream could contaminate groundwater water for bottling purposes.

2.3.2.2 Managing water quantity

In addition to ensuring water is free from contamination, bottled water extractors have a commercial interest in ensuring a steady supply of water to meet contractual obligations and/or manage commercial risk. Sustainable extraction requires that groundwater levels recover during and after pumping.

The Review received anecdotal information that suggested that bottled water extractors were generally extracting water at an approximately evenly spaced production rate year-round compared with many other commercial users who extract on a more periodic basis. While theoretically sound given supply chain arrangements in the bottled water industry, the Review was not able to independently verify these observations. Further, all groundwater extractors are subject to changing environmental conditions which may influence future patterns of use.

As part of the pump testing requirements, extractors are required to conduct assessments on groundwater levels, pumping rates, drawdown and recovery, and water quality. Conditions of licence also require the collection of information about water extraction volumes and rates of extraction.[21] The implementation of the NSW Non-Urban Water Metering Policy (DOI, 2018b), with specific requirements around groundwater metering for groundwater extraction works over a specified size, will provide improved information about use patterns in the bottled water industry and enable analyses to be undertaken on interactions and impacts.

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[20] Strictly, the depth at which the bore casing is slotted defines the depth of the extraction, however this tends to be close to the bore depth.

[21] Conditions of licences are discussed further in Section 4.5.1

2.4 CONCLUSIONS

The industry

- Available industry data indicates that across Australia, over three-quarters of bottled water is sourced from underground wells, and the remainder from standard reticulated water supplies. Approximately 8% of Australian bottled water production is exported.
- The Review identified seven operators in the Northern Rivers region with allocations of 240.5 ML/y who are actively extracting for water bottling purposes, representing 0.55% of water licences and basic landholder rights (together defined in the WSP as 'total water requirements') and 0.008% of estimated total annual aquifer recharge in the four groundwater sources.
- Four further proposals, if approved, would amount to an additional 168 ML/y, being an additional 0.38% of estimated total water requirements and 0.006% of total annual aquifer recharge.
- Changing consumer preferences, trade imbalances, the availability of tap water and private ('no name') brands and population growth are expected to impact future bottled water production and consumption volumes.
- Scenario analyses conducted by the Review suggest the Australian bottled water industry is most likely to grow at a rate of less than 2% per annum to 2024 and that growth in the Northern Rivers region is likely to be consistent with this trend. Under most scenarios to 2024 considered, the 168ML/y of additional proposed bottled water operations would be sufficient to meet fully projected growth in demand.
- The Review also considered 'highly unlikely' and 'extremely unlikely' scenarios to 2034, being growth continuing at the current rate of 10% per annum and establishment of a major premium bottled water exporter in the Northern Rivers, respectively.
    - If the 'highly unlikely' scenario occurred, the bottled water industry would represent less than 2.3% of 'total water requirements' and 0.034% of estimated total annual aquifer recharge.
    - If the 'extremely unlikely' scenario occurred, the bottled water industry would represent less than 4.6% of 'total water requirements' and 0.069% of estimated total annual aquifer recharge.
- As the scenario analyses considered an unchanged regulatory and policy environment, these forecasts may be affected by regulatory intervention which directly or indirectly impacts the bottled water industry in this region.
- For the purposes of water extraction licensing, the bottled water industry is treated the same as other prospective commercial users. However, development consent under the *Environmental Planning and Assessment Act 1979* is required for water bottling activities. Approvals for bottled water extraction in the Northern Rivers region identified by the Review date from 1993.

Water entitlements and allocations

- The WSP determines the allowable extraction limit, set from the recharge value of each aquifer, with an amount of the recharge reserved for the environment and the reminder determining the UEL or the LTAAEL.
- Under the North Coast Fractured and Porous Rock Water Sharing Plan (WSP), environmental water and basic landholder rights are given priority over licensed water extraction. Among licensees, priority is given to water utilities and licensed stock and domestic over commercial licensed purposes.

- At the commencement of the WSP for the four groundwater sources, 100% of storage is reserved for the conservation of the groundwater system.
- Water available for extraction is a portion of the estimated recharge value for each groundwater source. This is determined by the WSP. An amount of the recharge is reserved for the environment. The amount reserved for the environment equates to 97% of the estimated recharge value for New England Fold Belt Coast, 96% for North Coast Volcanics, 82% for Alstonville Basalt Plateau and 48% for Clarence Moreton Basin.
- The remaining amounts can be allocated for licensed purposes. Of these amounts, 38.0% of the New England Fold Belt Coast is allocated, 51.3% of the North Coast Volcanics and 1.7% in the Clarence Moreton Basin. Alstonville is fully allocated.
- These are average values over the groundwater source areas, which means that the environment is not protected to these levels in locally impacted areas.

Characteristics of extraction

- The Review received anecdotal information suggesting that bottled water extractors were generally extracting water at an approximately evenly spaced production rate year-round compared with other commercial users who extract on a more periodic basis. The Review was not able to verify these observations.
- All groundwater users are subject to future changing environmental conditions, which may influence their future patterns of use.
- The implementation of the NSW Non-Urban Water Metering Policy will provide information about use patterns in the bottled water industry and enable analyses of interactions and impacts.

3 SUSTAINABILITY OF EXTRACTION LIMITS IN THE WATER SHARING PLAN

This Chapter reports on the analysis of how sustainability is assessed and managed under WSPs, and the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources* (the WSP) in particular.

The *Water Management Act 2000* makes provision for WSPs to be developed which apply to groundwater and surface water systems in NSW and to implement the overall objective of the Act of "sustainable and integrated management of the State's Water" (DLWC 2001).

The WSP sets extraction limits and rules about groundwater extraction for the four groundwater sources in scope of this review based on multiple factors. These factors include groundwater recharge, a risk assessment, planned environmental water and current and future water requirements (including Basic Landholder Rights and licenced entitlements).

Groundwater sustainability relates to limiting the current (environmental and anthropogenic) use of the resource to ensure long-term water security in an aquifer. Short-term changes in an aquifer (e.g. water level declines) do not necessarily indicate unsustainable use due the variability of these natural systems which are inherently dynamic. As such, understanding the impact of groundwater extractions on long-term sustainability of an aquifer can be a complex issue even when substantial data is available.

The extraction limits in the WSP are designed to ensure the sustainable on-going use of the groundwater resource. The aim of this chapter is to understand whether the extraction limits adopted are considered 'sustainable' for the entire groundwater source. However, potential local scale social, environmental or economic effects are also important. These additional considerations are considered separately in Chapters 4 and 5.

This Review considers the impact of uncertainty arising from the variables used to determine extraction limits, particularly the recharge rates which ultimately drive the limits in the WSP, and compares the values to those available for comparable aquifers, as well as alternative methods of calculating recharge. A hypothetical scenario is also presented in this section, in which the impact of reducing the recharge rate by 80% is considered to illustrate the impact of the rate on sustainable groundwater extractions.

For most of the groundwater sources considered in this review, groundwater extraction per year is relatively small compared to the total size of the groundwater source and monitoring data is sparse. The exception to this is in the Alstonville Plateau which has a high (relative to its size) annual extraction, but is also equipped with a network of state operated monitoring piezometers or bores. This section analyses the available monitoring data from 2006 to present to assess the general levels of the aquifer and provide commentary on whether this data can be used to assess the sustainability of current groundwater extractions.

3.1 EXTRACTION LIMITS UNDER THE WSP

The Review's Initial Report included the legislative and policy framework under which water sharing plans are developed, operationalised and reviewed, including that for the Northern Rivers region, and the Initial Report also described the technical approach to assessing and determining extraction limits under the WSP. For convenience, relevant components are reproduced in Appendix 3 of this report. This Section describes the Review's analysis of the use of WSPs as regional water management tools, how sustainability is conceptualised and integrated into the WSP and how the impact of the WSP is monitored, reviewed and can be amended as part of an adaptive management approach.

3.1.1 WSPs as regional water management tools

WSPs support the regional scale implementation of the objectives of the *Water Management Act 2000: "to provide for the sustainable and integrated management of the water sources of the State for the benefit of both present and future generations"*.[22] Generally, each WSP for groundwater will cover a number of different regional groundwater sources. Management zones within certain groundwater sources may be defined where specific access and trading rules are required to control extraction and prevent localised impacts in sensitive areas. An example of this is the Alstonville Basalt Plateau Groundwater Source which is comprised of the Alstonville-Tuckean Management Zone and the Bangalow-Wyrallah Management Zone.

WSPs are influenced by a number of other legislative instruments and policies guiding the management of water in NSW. These include:

- The *Water Management Act 2000:* which governs the management and extraction of water in NSW.[23]
- The *Access Licence Dealing Principles Order 2004:* which provides guidance and rules for water access licence dealings which are reflected in the WSPs.
- The National Water Initiative: an intergovernmental agreement to implement "*a nationally-compatible, market, regulatory and planning based system of managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes*". The NWI relates to water management elements including water access entitlements, environmental and other public benefit outcomes, adaptive management, risk management, managing over allocation, regional variability and allocation decisions.
- The Standard for Quality Natural Resource Management: developed by the Natural Resource Commission to inform natural resource management (including monitoring, evaluation and reporting arrangements) at all scales in NSW including state, regional, catchment and local level.
- Catchment Action Plans: which are non-regulatory plans prepared by Local Land Services jurisdiction that set a strategic direction for the sustainable use and care of natural resources in each region.
- DPIE Water is leading the development of Regional Water Strategies for each of 12 regions across NSW. The strategies will inform plans and management of a region's short and long-term water needs. They look at how much water a region will need to meet future demand and determine ways to manage risk to water availability and security. They will incorporate new data to improve understanding of climate risk, including consideration of climate change and the probability of extreme events.
- Other water planning policies and guidelines developed by NSW Government agencies which support the development and implementation of WSP plans and guide critical aspects of water management including WSP rule changes (DOI, 2018c), consultation (DPI Water, 2015), licensing (DOI, 2018a), assessment (WaterNSW, 2017), and metering (DOI, 2018b).

Most of these legislative instruments and policies apply on a state-wide basis, however some, such as the Catchment Action Plans are regionally focused. These legislative instruments and policies are critical in setting out the framework for water management in NSW and in specific regions, which is then codified in WSPs for each region. This enables a set of water management rules that aim to reflect the particular environmental, social and economic situations of different regions.

The critical elements of the water management approach for each region covered by the WSP are:

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[22] *Water Management Act 2000* s 3.

[23] The overall objective of the *Water Management Act 2000* is to "provide for the sustainable and integrated management of the water sources of the State for the benefit of both present and future generations". See *Water Management Act 2000* s 3.

- **Prioritisation** – the prioritisation of water to the environment and between water users (Table 6) and purposes.
- **Regional sustainability** – the establishment of water extraction limits to protect surface and groundwater sources at a macro level.
- **Local impacts** – the establishment of a set of rules to protect specific groundwater dependent ecosystems, significant sites and other water users and the implementation of take limits on particular bores to manage local impacts.

3.1.2 Prioritisation of water under WSPs

A critical element in the management of water under the WSPs is the prioritisation of water to the environment and between water users and purposes. WSPs establish priorities of allocation with environmental first, Basic Landholder Rights second, town water supply and stock and domestic licences third, and all other licensed extraction for industrial and commercial purposes fourth (Table 6).

Table 6: Prioritisation of water users under WSPs

Priority	Water use	Detail
1	Environmental water	Water reserved for the environment. WSPs reserve 'storage water'. They also reserve a portion of groundwater recharge for the environment before determining available licensed water extraction.
2	Basic Landholder Rights (BLRs) • Stock and domestic rights • Harvestable rights • Native Title rights	BLRs have a higher priority over licensed water extraction and cannot be limited through available water determinations. However, they can still be subject to temporary water restriction order.[24] WSPs must allow for BLRs before determining available licensed water extraction.
3	Local water utility licences Major water utility licences Stock and domestic licences[25]	Priority is given to groundwater extracted for local and major utilities for town water supply and to licensed stock and domestic bores over other licensed water users.[26] Licenced extraction under these licences can be limited through available water determinations and temporary water restriction orders.
4	Water Access Licences	Extraction under these licences can be limited through available water determinations and temporary water restriction orders. No distinction is made between the end use of the water (agriculture, industrial production, etc). The WAL is also separable from the property on which it is being used, so a WAL can be traded within management areas

3.1.3 Regional sustainability and the WSP

WSPs share water and manage the sustainability of extraction from particular groundwater sources through extraction limits. WSPs for most groundwater sources set extraction limits through calculations of the expected groundwater recharge for each groundwater source based on average rainfall, recharge rates, the sustainability index, the type of groundwater source (e.g. fractured versus porous rock aquifer), and the distribution of high conservation areas (e.g. National Parks) where water is excluded from the calculation.[27] The groundwater recharge is then used to calculate the UEL, the LTAAEL and Planned Environmental Water

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[24] *Water Management Act 2000* s 324.

25 Under section 52 of the *Water Management Act 2000*, an owner or occupier of a landholding is entitled to take water from an aquifer that is underlying their land for domestic consumption and stock watering, without the need for a water access licence. However, a domestic and stock access licence may be required for the taking of water for domestic or stock watering purposes where the land does not overly the aquifer from which water would be taken.

[26] *Water Management Act 2000* s 58.

[27] The sustainability index (SI) considers both the environmental risk (based on the prevalence of high priority groundwater dependent ecosystems, water quality, ecology, aquifer integrity and potential for mitigation) and social economic risk (based on the dependence of local communities on the groundwater sources, including alternative water sources and the contribution of groundwater to the local economy).

(PEW).[28] These calculations and the related assumptions as applied in the development of the WSP are described in detail in Appendix 3.

The UEL, LTAAEL, and PEW for each groundwater source are calculated with the intention of reducing the risk of unsustainable extraction from particular groundwater sources in the long term and to inform the distribution of water to achieve environmental, social and economic wellbeing in the region according to the prioritisation of water uses as described above:

- For *fractured rock groundwater sources* under the WSP, the UEL represents the upper limit of extraction that could occur from a groundwater source under the WSP each year taking into account the rainfall recharge over non-high environmental value areas and the sustainability index for that groundwater source.[29]
- For *fractured rock groundwater sources* under the WSP, the LTAAEL represents the long term maximum average volume of water that can be extracted from a groundwater source under the WSP each year taking into account the lower of the UEL, or the current and estimated future requirements for groundwater and a conservative buffer.[30]
- For *porous rock groundwater sources* under the WSP, the LTAAEL represents the long term maximum average volume of water that can be extracted from a groundwater source under the WSP each year taking into account the rainfall recharge over non-high environmental value areas and the sustainability index for that groundwater source.[31]
- The PEW represents the portion of water to be reserved for environmental purposes.[32]

Extraction limits are a critical part of the ongoing adaptive management of groundwater sources under the WSP. For example, during the term of the WSP, as the demand for extractions changes over time and the understanding of the relevant groundwater source improves, the LTAAEL may be increased to be closer to the UEL in those water sources where the LTAAEL is below the UEL.[33] Where growth in water take is assessed to have increased more than 5% above the LTAAEL on average over a three-year period, the water allocation may be reduced to less than 1ML per unit share to bring extraction levels back down to the LTAAEL.[34] This information will also critically inform reviews of WSPs at the end of their 10 year period and the development of replacement WSPs. Adaptive management is described in more detail below.

3.1.4 Local impacts and the WSP

WSPs include rules to address local impacts of water extraction. These rules set limits on the proximity of groundwater extractions to certain assets including groundwater dependent ecosystems (GDEs), other groundwater users, aboriginal heritage sites and major water supply bores (Appendix 7). This approach allows local impacts to be addressed on a case-by-case basis by:

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[28] Note that the UEL is not calculated for all groundwater sources.

[29] Note that the sustainability index for high environmental value areas under the WSP is 0%, and therefore 0% of recharge over high environmental value areas is considered available for extraction. The UEL is not calculated for porous rock groundwater sources as the WSP indicates a high level of confidence in the calculation of the LTAAEL for these groundwater sources. See WSP p.31.

[30] These calculations and the related assumptions as applied in the development of the WSP are described in detail in Section 3.2 of the Initial Report.

[31] Note that as high conservation areas are excluded from the extraction limit calculations, effectively 100% of recharge over high conservation areas is reserved for the environment.

[32] Planned environmental water (PEW), as defined in the WSP, comprises a portion of groundwater held in storage and a portion of groundwater generated from recharge. At the commencement of the WSP, 100% of groundwater storage is reserved as planned environmental water. However, this may be reduced to 99.998% for some porous rock groundwater sources in accordance with the *NSW policy for Managing Access to Buried Water Sources* (NSW Office of Water, 2011).

[33] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 60(1).

[34] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 29(2)-(3)

- a risk assessment which identifies medium and high risk proposed extractions, and
- if appropriate, an assessment that takes into account the particular hydrogeological characteristics of the groundwater source and the local area (including proximate sensitive areas).

The assessment of local impacts under the WSP is described in more detail in Chapter 4.

3.1.5 Adaptive management and the WSP

Adaptive management is a critical process in managing environmental sustainability of groundwater extraction. Adaptive management relies on the collection of information (for example, through monitoring and studies), the assessment of that information against indicators of performance, and if necessary, changes in rules and management actions in response to that information.

3.1.5.1 Monitoring and performance indicators

The WSP identifies monitoring as key to understanding whether the WSP is meeting its environmental, social and economic objectives. To guide the appropriate range of monitoring and to assess the outcomes of those monitoring activities, the WSP specifies a number of performance indicators for all groundwater sources. These are intended to measure the success of strategies in the WSP in reaching its objectives. The WSP performance indicators are the changes in:

- groundwater extraction relative to the LTAAEL
- water quality
- the ecological condition of these groundwater sources and their dependent ecosystems
- the extent to which domestic and stock rights and native title rights requirements have been met
- the economic benefits derived from water extraction and use
- the extent to which water has been made available in recognition of the Aboriginal, cultural and heritage values of these groundwater sources.[35]

However, the Background Document to the WSP notes that it is not practicable to monitor all of these indicators in all groundwater sources covered by the WSP (DPI Water, 2016f). In March 2011, the Department released the *Environmental flow response and socio-economic monitoring. North Coast - progress report 2009* while in 2006 a detailed hydrology report was published on the Alstonville monitoring data (Green, 2006). More information is available in relation to the Alstonville Groundwater source (Section 3.4.1).

3.1.5.2 Amendments and reviews of the WSP

WSPs allow for adaptive management responses at the level of individual licences[36] and through amendment of some provisions of the WSP during its term. The *Water Management Act 2000* permits the Minister to amend the WSP if it is in the public interest to do so, or is in accordance with the terms of the WSP, which allows for certain amendments, including to:

- Modify or add groundwater sources or management zones[37]
- Vary the amount of recharge reserved for the environment as planned environmental water[38]
- Increase the LTAAEL[39]

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[35] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 12.
[36] For example through available water determinations and temporary water restrictions discussed in further detail in Chapter 4 – Local Impacts.
[37] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 58.
[38] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 59.
[39] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 60.

- Allow for the granting of supplementary water (storage) access licences under a controlled allocation order in particular groundwater sources and the granting of Aboriginal Community Development licences[40]
- Establish access rules for managing major utility access licences and for access licences in particular groundwater sources[41]
- Add, remove or modify minimum distance rules[42]
- Impose rate and time restrictions on groundwater extraction [43]
- Amend the map of high priority groundwater dependant ecosystems. [44]

Most of these amendment provisions that allow for certain aspects of the WSP to be revised require evidence (for example hydrogeological studies), that evidence supporting an improved understanding of the system and justifying an adjustment to the WSP.

The WSP is also subject to a range of periodic and end of term reviews. For example, the WSP is subject to an initial review and audit by the NRC within five years of enactment, and a renewal or replacement review at the end of its 10-year life. These reviews focus on the water management principles specified in the *Water Management Act 2000*,[45] as well as the environmental, social and economic outcomes.[46] These review requirements are discussed in further detail in Appendix 4 of the Initial Report.

3.2 SOURCES OF UNCERTAINTIES AND THEIR MANAGEMENT IN THE WSP

The WSP estimates recharge (and ultimately the allowable extraction rates) for each groundwater source covered by the WSP using the equations outlined in Appendix 3. This section investigates the uncertainty associated with each parameter and what approaches are taken in the calculations to manage this uncertainty, with the aim to provide a comment, as far as possible, on the long-term sustainability of the extraction limits in the WSP as per the terms of reference.

There are a number of relevant environmental parameters that introduce levels of uncertainty to the extraction figures in the WSP including:

- Average annual rainfall
- Surface area and impact of confining geological layers
- Recharge rate
- Sustainability index.

This section analyses the uncertainties that have been identified through the review of the WSP. The term uncertainty is used to recognise a range of possible values that could be assigned to a given attribute, such as the recharge rate or the sustainability index. When there is a substantial body of research (or lines of evidence) on a given topic, the uncertainty is typically lower and a higher degree of confidence in the adopted values. Conversely, when there is limited available data and/or research, the uncertainty may be high, thereby including a large range of possible values.

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[40] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 61.
[41] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 62.
[42] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 63(a).
[43] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 63(c).
[44] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 63(d).
[45] *Water Management Act 2000* ss 5 and 43(2).
[46] *Water Management Act 2000* ss 43A(1),(3).

The section below describes how each of the terms used in Equation 1 (Average Recharge) and 2 (UEL) were addressed and if improvements could be made.

> Average Recharge (ML/yr) = Average Rainfall (mm/yr) x Area (km^2) x Recharge Rate (%)/100 (Equation 1)
>
> UEL (ML/yr) = Recharge over non- high environmental areas (ML/yr) x SI(%) (Equation 2)

3.2.1 Average annual rainfall

Annual rainfall is variable over the relatively large area (76,000 km^2) covered by the WSP. Rainfall data used by the WSP was sourced from the Bureau of Meteorology (BOM) gridded rainfall data (approximately 5 km^2 grid) from 1901 – 2011. This rainfall model uses algorithms to estimate a weighted average rainfall in each grid based on the observations at the nearest BOM stations. This accounts for the spatial variability of rainfall throughout large catchments and is based on the best available data. More information on the rainfall data can be found on BOM (2015).

Rainfall data provided by BOM are considered reliable and the spatial distribution of BOM weather observation stations in NSW is considered sufficient to capture the spatial distribution of rainfall and represent the average rainfall over the WSP area. There are 94 BOM rain gauges currently operating in the Northern Rivers region and a further 229 historical gauges.

3.2.1.1 Climate change projection and its effects on rainfall

The earth's climate is expected to change globally in the future (IPCC, 2013). The DPIE's Energy, Environment and Science Branch, formerly Office of Environment and Heritage, has provided a detailed assessment of climate change effects on the North Coast region of NSW (OEH, 2014). The report uses information from the NSW and ACT Regional Climate Modelling project (NARCliM) to make climate change predictions. The NARCliM analysis uses 12 predictive models and report what the majority of models agree on.

The report projects that the North Coast region will see increase in temperatures in the near future (2020–2039) and far future (2060–2079), compared to recent years (1990–2009). The warming is projected to be on average about 0.7°C in the near future, increasing to about 2°C in the far future. An increase in temperatures with climate change could lead to greater or reduced evapotranspiration (evapotranspiration is a function of humidity, irradiance and wind). If evapotranspiration increases, this would contribute to drying over some land areas. With potentially more extreme rainfall (storms), but also longer dry spells in between, storm-affected areas are likely to experience increased risk of flooding, while also seeing increased risk of drought.

The majority of climate models agree that autumn and spring rainfall in the region will increase in both the near and far future, and that winter rainfall will decrease for both timeframes. For summer rainfall, the majority of models predict little change in the near future and an increase in the far future. High intensity rainfall results in fast moving surface water which may not have sufficient time to infiltrate the soil matrix to effectively recharge groundwater aquifers. While rainfall may be predicted to increase over some time horizons, if the increased rainfall is as a result of more frequent high intensity rainfall, recharge may not increase.

Climate modelling results should be interpreted with care as large uncertainties are associated with the direction of change in the region's predicted rainfall. In a CSIRO and Bureau of Meteorology report (Dowdy et al., 2015), projected changes in the region's annual rainfall over the next 20 years range from -15% to +10% relative to 1986–2005. That study also concluded for the region that intensity of heavy rainfall events will increase (with high confidence) and there will be longer periods of meteorological drought by late in the 21st century (with medium confidence). However, natural climate variability will likely remain the major driver of rainfall changes in the next decades. Regardless of the direction in rainfall change, rainfall patterns in the region will change in the future which will have a direct impact on recharge. This should be considered as part of future WSP planning.

3.2.2 Surface area and impact of confining geological layers

The method to determine the UEL in coastal fractured and porous rock groundwater sources assumes a spatially uniform recharge rate as a percentage of rainfall, which is contrary to the high variability in land use and cover, soils, geology and recharge processes that exists. While the uniform rate assumption is justified given lack of data, care must be taken when considering the groundwater source to ensure that the recharge rate is sufficiently conservative to protect the groundwater source, yet reasonably approximated for the region to provide a valid end point.

The WSP provides a surface area for high and non-high environmental value areas for each groundwater source but does not describe how the surface area was delineated. Typically, this information, as derived from a digitised aerial image and/or high-resolution satellite data, is widely used and acceptable.

Modelling reports and hydrogeological reports (e.g. (Bilge, 2003), (Eco Logical, 2016, 2018a, 2018b) and (Kobus Argent, 2018)) suggest that parts of the relevant aquifers are at least locally confined or partially confined in some areas. If the aquifer is confined or partially confined, it is overlain by a layer of low permeability material that inhibits rainfall infiltration over some parts of the aquifer, as illustrated in Figure 10. As a result, a confined aquifer with the same surface area as an unconfined aquifer may receive less recharge for the same direct rainfall. In most cases, unless there has been significant and detailed geological mapping, the area where semi-confined aquifers are recharged is often uncertain. This is addressed in the WSP by not permitting overlaps in the recharge areas of the confined and unconfined aquifers defined in the WSP. However, the variable presence of other confining layers (e.g. local confining clay layers) not being considered in the WSP introduces additional uncertainty in the recharge estimates.

It is unclear whether the percentage recharge rate used in the WSP refers to only the identified outcrops of the aquifers that make up the groundwater source or also the sub-crops beneath a confining layer. The variations in connectivity (permeability) in the different layers in the aquifer can cause local variations in recharge rates. Although, this is a ubiquitous issue for recharge studies, integrating the many layers into one lumped aquifer introduces some level of uncertainty as the fractured basalts are the dominant source for bottled water extractions.

Developing a better conceptual understanding of the geological strata in the WSP, possibly via a 3D geological modelling tool (e.g. Leapfrog Geo) where there is sufficient data would help to reduce the level of uncertainty in the estimated recharge values and assist in understanding whether the assumptions made in the WSP are appropriate. This would require a large scale detailed geological mapping survey or the collation of the existing core log data and geophysical measurements, where available. It is worth noting that this level of detail has not been typically undertaken in other WSPs of a similar nature for easterly flowing systems.

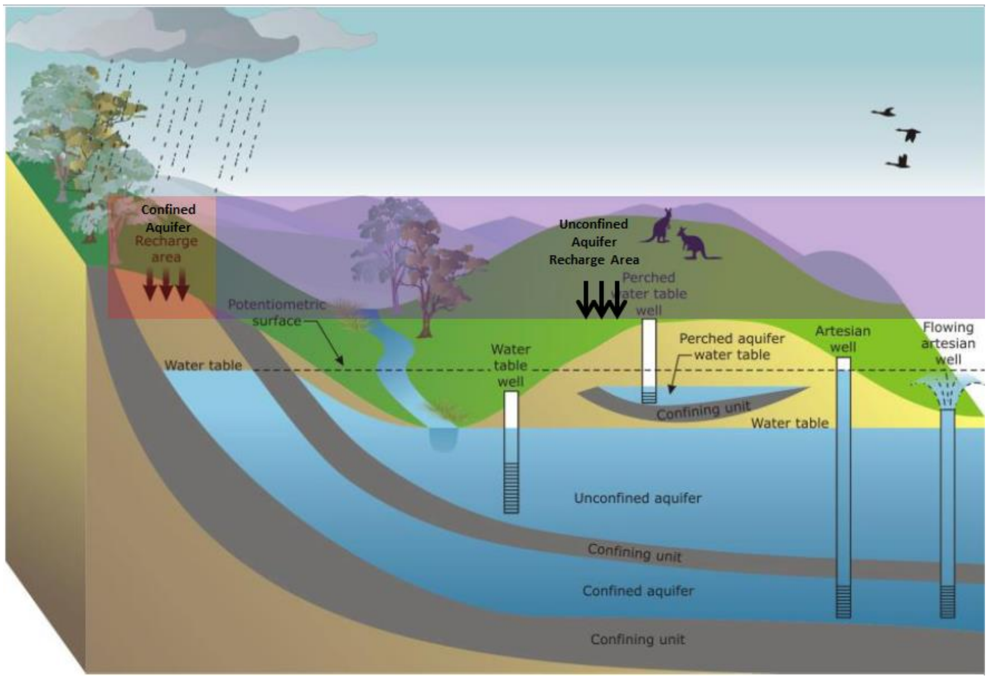

Figure 10: Recharge areas of confined and unconfined aquifers
Note: confined in red highlights; unconfined in purple highlights
Source: UNSW Sydney (2017)

3.2.3 Recharge Rate

The estimates of recharge provide the basis for Planned Environmental Water, LTAAEL or UEL in the WSP and are a source of uncertainty in the WSP (Table 7). While uncertainty in the recharge estimate may be acceptable if the estimates are suitably conservative, or there is limited consequence as a result of possible error bands, it is important to recognise how ambiguity may impact the plans. The systems considered in the WSP are considered to be 'less highly-connected groundwater sources' (DPI Water, 2016f), which means there is limited recharge through creek beds, and thereby, only recharge through rainfall was considered.

Recharge estimates in fractured rock are typically poorly understood due to the spatial variability and complexity of these environments (Crosbie et al., 2010). This may result in over (or under) estimation of recharge rates. Due to the practicality of treating the water sources as being homogenous, it is considered necessary to be conservative in the recharge rates assumed, to account for inherent inaccuracies and uncertainties in this calculation.

The values adopted for each of the groundwater sources considered in the WSP are typically based on estimates dependent on the hydrogeological type. The Coastal Porous Rock Rainfall Recharge Study showed that while the NSW default value of recharge rate in coastal porous rock is 6%, the values reported in calibrated models across the state ranged between 1 – 6%. This indicates that the NSW default value could potentially overestimate recharge in the porous rock groundwater systems in scope of this Review. The Clarence Moreton Basin adopted the value of 6% in lieu of other estimates.

Table 7: Recharge rates used in WSP for groundwater sources with bottled water extraction

Groundwater source	Recharge used in WSP (% of long-term rainfall)
Clarence Moreton Basin (porous rock)	6
New England Fold Belt Coast (fractured rock)	4
North Coast Volcanics (fractured rock)	8
Alstonville Basalt Plateau (fractured rock)	8

More accurate estimates of rainfall recharge could be developed through multiple lines of evidence including field data analyses such as chloride mass balance calculations, water table fluctuation or base flow analyses. As the recharge rate is integral to the allocation of the LTAAEL and planned environmental water, the impact of the adopted values warranted further investigation and are considered further by the Review at Section 3.3.

3.2.4 Sustainability Index

The WSP, which is based on recommendations within DPI Water (2016f) and DPI Water (2015), acknowledges that regional estimates of recharge for large aquifers is not an exact science. As such, the WSP highlights that due to this uncertainty a precautionary approach is warranted. DPIE Water has advised that a precautionary approach was subsequently formulated using 0% recharge estimates for high environmental value areas, with no allowance for recharge other than direct rainfall and a sustainability index, which is further discussed below (DOI Water, 2019).

The sustainability index is a simple method for risk accounting that endeavours to manage the balance between environmental risk, economic and social growth. While the allocation of high, medium or low risk is subjective, the index is a measure that can be applied to all catchments with relatively limited information. Further work could be undertaken to assess whether the risk ratings given to specific catchments are appropriate, but the index appears to be a cost and time effective means to protect resources where limited information is available.

It would be useful to undertake sensitivity testing of the index to assess the implications of changing conditions or additional research that may result in a change in the risk ratings. Where this may result in the aquifer being over-allocated, more research may be required. Estimates of the risks associated with each groundwater source could be better detailed as information comes to hand.

3.3 TESTING THE WSP RECHARGE RATES AGAINST STUDIES AND OTHER APPROACHES

3.3.1 Relevant literature on recharge rates

A review of literature was undertaken to compare the recharge rates adopted in the WSP with existing studies in the same or comparable areas. This section provides an overview of the various approaches to calculating recharge rates in the region presented in the literature.

3.3.1.1 Coastal Porous Rock Rainfall Recharge Study

A primary source of information about recharge across NSW is the Coastal Porous Rock Rainfall Recharge Study prepared for NSW DPI Water (EMM, 2015). The data in that study are estimated from groundwater modelling studies, none of which are in the Tweed or Alstonville areas, or in the groundwater sources of interest, but rather the report considered advice from experts through interviews and a workshop. It also considered the Bioregional Assessment program (Raiber et al., 2016), which was then unpublished but in the process of undertaking recharge estimates for the Clarence Moreton bioregion.

The Coastal Porous Rock Rainfall Recharge Study recommended adopting 6% for the Clarence Moreton Basin groundwater source. It recommended that the ongoing work of the Bioregional Assessments should be considered (as published in 2016). Further, in high-risk locations (i.e. where a groundwater dependent ecosystem could be impacted or a surface water source influenced) and high-demand locations, the report recommended detailed recharge investigations.

3.3.1.2 The Bioregional Assessment

The Clarence Moreton Bioregion sits on top of the geological Clarence Moreton Basin. The Basin includes the Bundamba Group, overlain by the Walloon Coal Measures, overlain by the Lamington and Main Range volcanic rocks and alluvial aquifers. Other minor formations are present.

The Lamington Volcanics geological group encompasses the North Coast Volcanics. Both the Lamington Volcanics and Alstonville Plateau aquifers are fractured basalt aquifers within the Cenozoic basalt group. Based on this geology, recharge estimates for the Lamington Volcanics outcrops may be useful for North Coast Volcanics and Alstonville Plateau groundwater sources (although differences in climate, soils and vegetation are expected to play a dominant role in controlling recharge rates).

The Bioregional Assessment of the Clarence Moreton Bioregion used the chloride mass balance method to produce long-term average recharge estimates. The results from the Bioregional Assessment of the Clarence Moreton Bioregion are provided in Figure 11 (Raiber et al., 2016). The results are based on 3632-point estimates of groundwater chloride at points shown in Figure 12 below. The recharge estimates developed for these points are interpolated and extrapolated spatially over the bioregion, based on the identified relationship between long-term average recharge and long-term average rainfall, as detailed in Figure 13.

Averaging the 172 point estimates of recharge available for the Lamington Volcanics within the Bioregional Assessment data set, results in a 16% recharge rate. Based on Figure 11 and Figure 13, this appears to represent the spatially interpolated average for the Lamington Volcanics (the actual spatially interpolated value is not available from the report or the publicly accessible data set).

It is worth noting that the chloride measurements shown in Figure 13 provide minimal coverage of the groundwater sources of interest. Although 16 % is likely to be the best available estimate for the North Coast Volcanics and Alstonville Plateau groundwater sources, it cannot be used with confidence. Furthermore, while the chloride mass balance method is an established approach for approximating recharge. However, various assumptions inherent within the method mean that it is not generally considered an accurate approach. As such, these results are best complemented with alternative methods and should not be used as a single line of evidence.

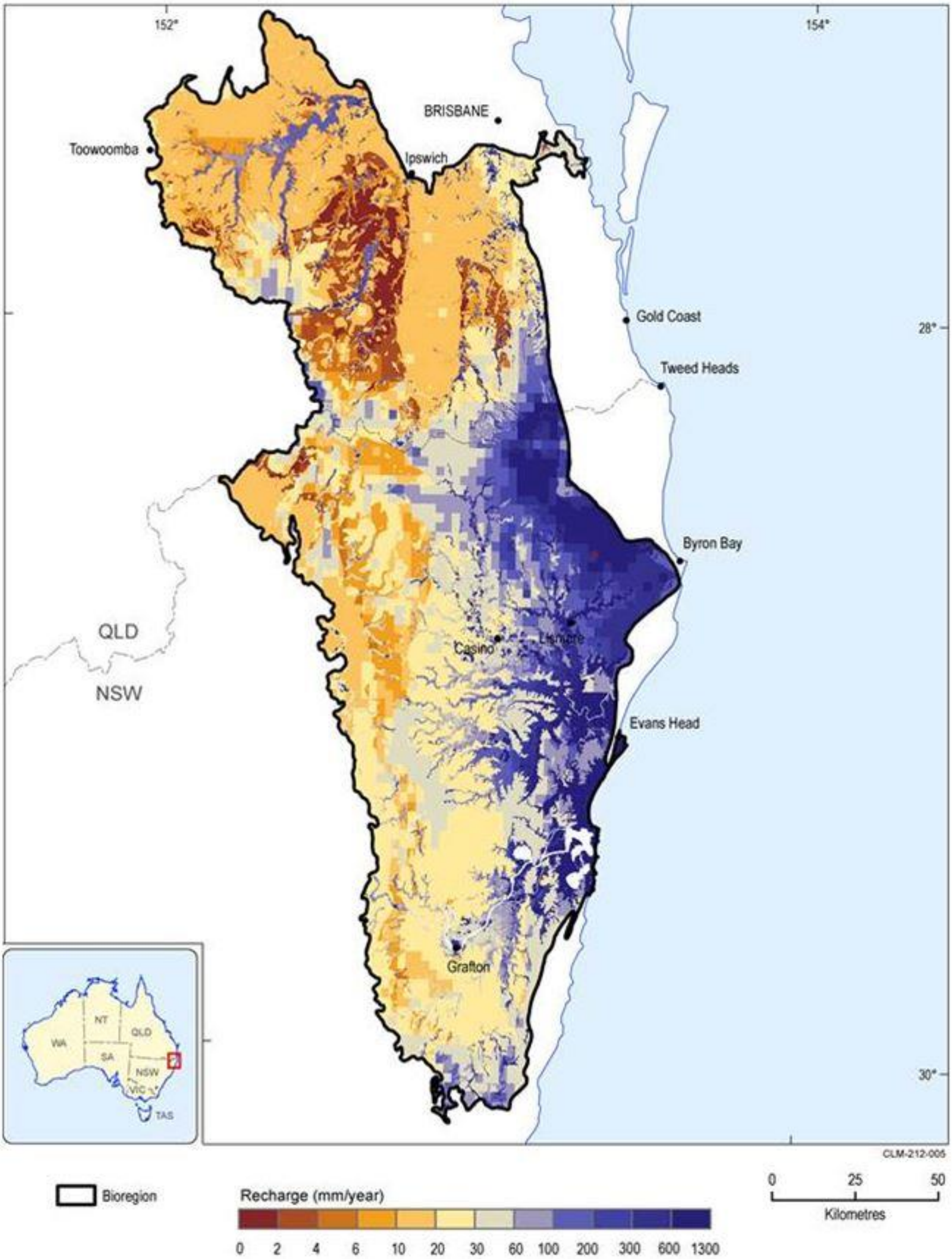

Figure 11: **Mean recharge estimates for the Clarence Moreton bioregion**
Source: Raiber et al. (2016)

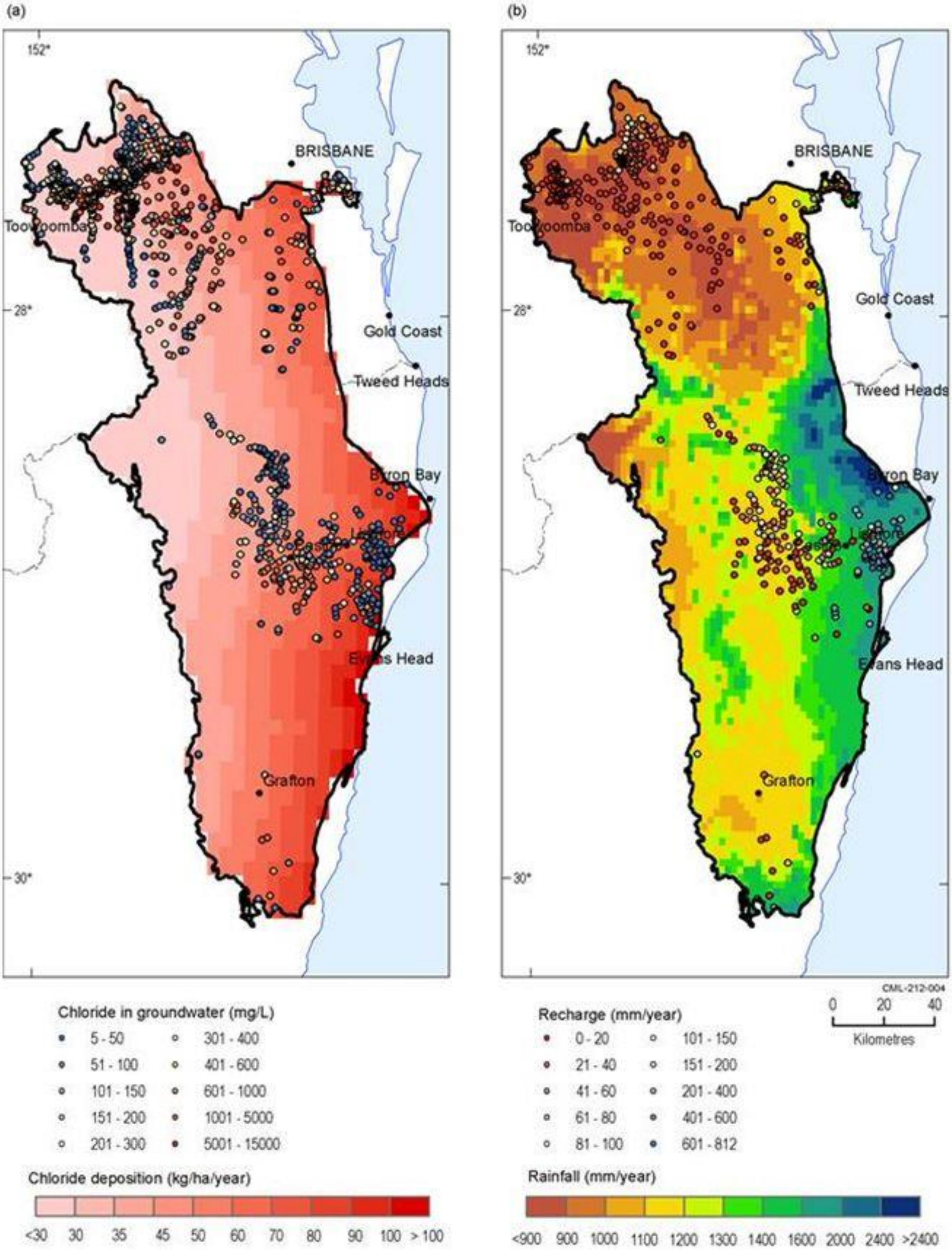

Figure 12: Data used for estimating recharge for the Clarence Moreton Bioregional assessments
Source: Raiber et al. (2016)

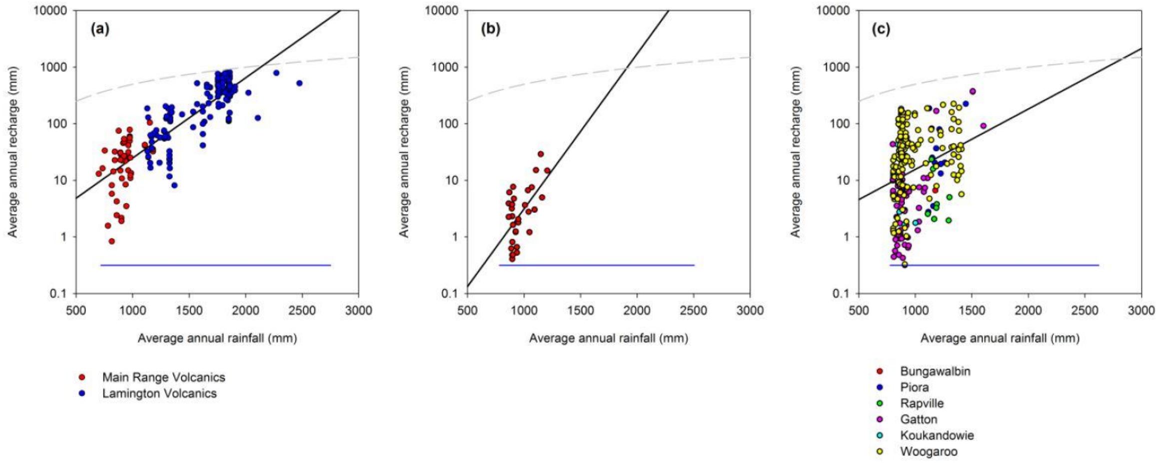

Figure 13: Relations between long-term average rainfall and chloride mass balance estimates of recharge for the hydrogeological units of the Clarence Moreton bioregion - (a) the Cenozoic Volcanics (Lamington Volcanics and Main Range Volcanics), (b) Walloon Coal Measures, (c) other sedimentary rock formations.
Note: The black line is the line of best fit through the data points, the dashed grey line is recharge as half of rainfall and the blue line is the range of annual average rainfall within the bioregion for the surface geology class Source: (Raiber et al., 2016).

The other groundwater source of primary interest, the New England Fold Belt Coast, is not clearly represented by the Clarence Moreton bioregion, as it underlays the Clarence Moreton Basin.

The Review concluded from the Bioregional Assessment:

- The 6% assumed in the WSP for the Clarence Moreton Basin groundwater sources is a reasonable basin-average estimate. However, there is large spatial variability of recharge within the Basin, and 6% should not be assumed a safe value for particular aquifers or locations.
- The results for the Lamington Volcanics indicate a spatial average recharge value of approximately 16% of rainfall. This is the best available published value to support the WSP values for fractured volcanic basalt aquifers including the Alstonville Plateau and North Coast Volcanics. However, the value of 16% is subject to the various uncertainties in the chloride mass balance method and is based on data points that are well outside the Tweed and Alstonville areas of interest.
- The other groundwater source of interest, the New England Fold Belt Coast, is not represented in the Bioregional Assessment results.

3.3.1.3 The University of Queensland recharge study

The University of Queensland undertook a study “Recharge estimation in the Surat Basin” (West et al., 2018). From discussion with the report authors, the study included recharge estimates in the Main Range Volcanics. These fractured basalt aquifers may be considered comparable in hydrogeological properties to the fractured rock aquifers of interest. However, the Main Range Volcanics are approximately 150 km north-west of the Tweed Valley, in a much drier region (approximately 700 mm annual average rainfall versus 1800 mm in the upper Tweed). Chloride mass balance and baseflow analysis methods were also used in this study and are provided below for comparison.

The recharge using the two methods, spatially averaged over the Main Range Volcanics subcrop, was estimated to be 0.7% and 0.9% of the long-term rainfall. The low values were attributed to relatively impermeable soils. Another recent estimate using the chloride mass balance method (DNRME, 2016) provided an estimate of 1.2%. Further, a broader review of previous recharge studies in this region (West et al., 2018) suggested that recharge results range from 1.9 to 2.3% of rainfall. This range of estimates (from 0.7% to 2.3%) are broadly consistent with the results found for the Main Range Volcanics in the Bioregional

Assessment of the Clarence Moreton Bioregion (the point estimates provided for the Bioregional Assessment ranged from 0.2 to 6.3% with an average of 2.4%). The relatively low percentage values in the Main Range Volcanics compared to the Lamington Volcanics are expected due to the high sensitivity of recharge to the rainfall and potentially attributed to different soil and vegetation covers. While it can be concluded that The University of Queensland recharge study results are not comparable to the aquifers of interest for the Tweed and Alstonville areas, the results illustrate the range of approaches that may be undertaken to estimate recharge in hydro-geologically comparable aquifers.

3.3.1.4 Australian Landscape Water Balance

The Australian Landscape Water Balance website of the Bureau of Meteorology includes a Australian Water Resources Assessment Landscape model (AWRA-L) which is the near-surface component of Bureau of Meteorology's national water balance modelling system. One of the AWRA-L outputs is deep drainage, which is the water moving vertically downward at a depth of 6 m. In most situations, this can be considered to be an estimate of groundwater recharge.

AWRA-L focusses on surface hydrology and is calibrated to river flow gauges. Its accuracy for recharge estimation has been assessed by CSIRO although not specifically for aquifers of interest (Shi, Vaze, & Crosbie, 2015). It was concluded that "*overall, the groundwater recharge assessment in this report indicates that AWRA is able to provide reasonably reliable spatial and temporal (e.g. annual) estimates of recharge across Australia*".

Deep drainage results for the Tweed River catchment and surrounding region are shown in Figure 14. The mapped results are for 2018, which has a modelled deep drainage close to the long-term median value, therefore may be considered typical. The modelled median deep drainage for the catchment is approximately 40 mm/year, or 2.2% of long-term average rainfall. Due to the grid sizes, it is not practical to pick out particular values for the groundwater sources of interest.

It may be concluded from this study that surface water modelling tools, which represent the effects of soil and vegetation and calibrated to surface flows, may give significantly lower recharge rates than assumed in the WSP. The difference between the recharge rates estimated by AWRA-L and the WSP suggest that additional investigations are needed to ensure that the rates used in the WSP are not over-estimated or the AWRA-L are not underestimated.

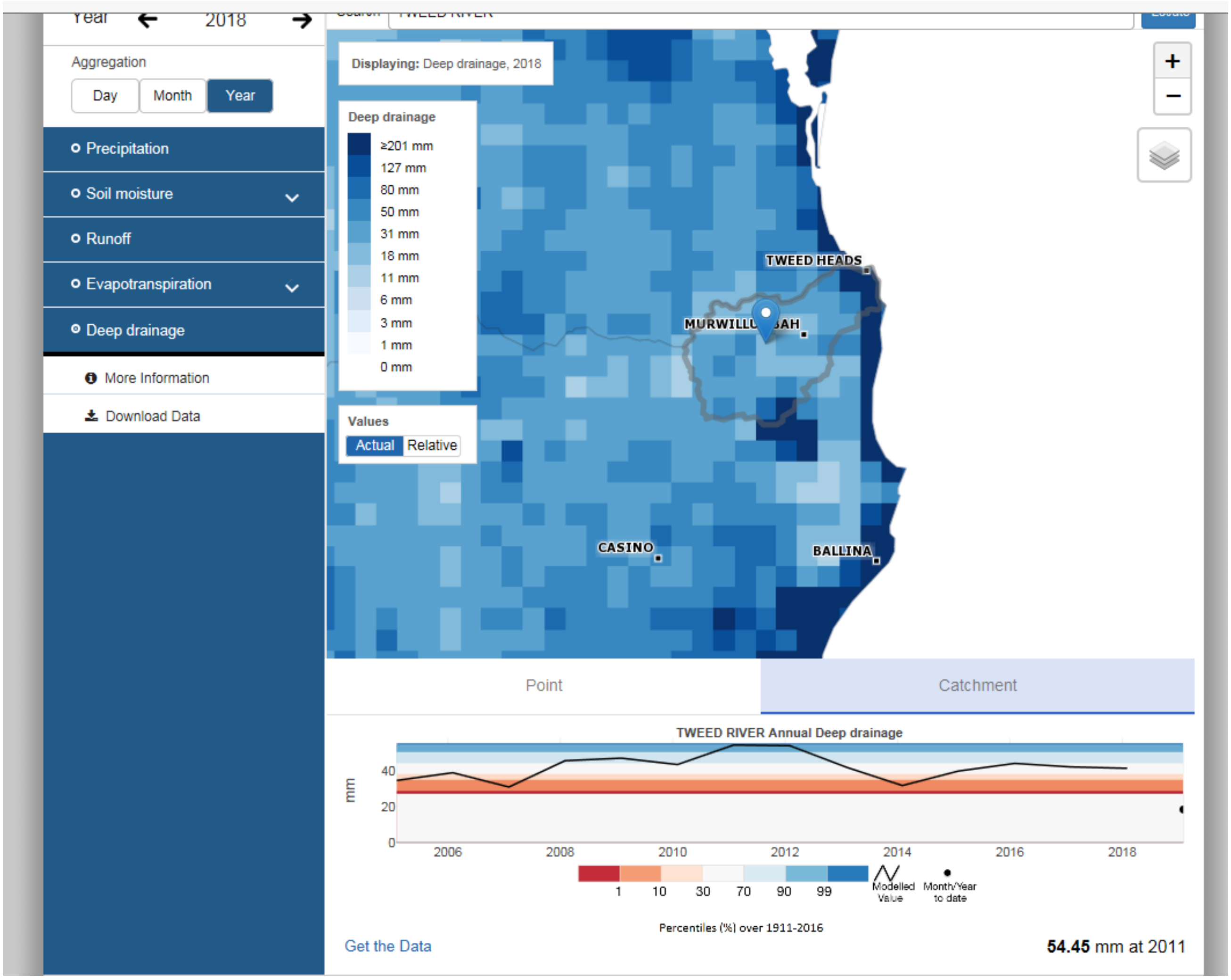

Figure 14: Screenshot of AWRA-L deep drainage results, showing map for typical year 2018
Source: BOM (2019)

3.3.1.5 The National Review of Recharge Studies by CSIRO

In 2010, CSIRO conducted a review of previous recharge studies in Australia (Crosbie et al., 2010). The NSW studies included in the review were for Coastal Alluvium, Inland Alluvium and the Western Slopes of the Great Dividing Range. None of these are relevant to the groundwater sources of interest. Fractured rock aquifers were found to be very poorly represented in the available data.

Vegetation type and soil type were found to be critical determinants of recharge. Relating recharge to surface geology had mixed results. It may be concluded from this review that there is likely to be high uncertainty in generalising recharge rates from surface geology (as used in WSP), especially in fractured rock aquifers.

3.3.2 Application of methods to local area

There is a range of different techniques available to quantify recharge, with the choice of method dependent on the goal of the study, the spatial and temporal scales, and level of information available. Each approach has uncertainties so often multiple techniques are used to increase the reliability of the outputs (Scanlon, Healy, & Cook, 2002)

Two methods were used to estimate groundwater recharge within this Review. These are application of the chloride mass balance method to chloride measurements from the proponents' hydrogeology reports; and filtering baseflow from available surface flow measurements. Both methods have considerable assumptions and uncertainties.

3.3.2.1 Application of chloride mass balance

The chloride mass balance method (Anderson, 1945) is a simple method for estimate groundwater recharge from rainfall based on the following assumptions (Wood, 1999):

- Chloride in groundwater is only sourced from rainfall
- Chloride is conservative in the system (no sources or losses).
- The chloride flux does not change over time (steady state conditions).
- There is no recycling of chloride in the system.

Then,

$$R = \frac{1000\ D}{(Cl^{-})_{gw}}$$

where *R*: recharge [mm/year];

D: Chloride deposition rate [kg/m^2/year];

$(Cl^{-})_{gw}$: Chloride concentration in groundwater [kg/m^3].

The chloride mass balance method was applied to the area under study using values of chloride deposition estimated from the Bioregional Assessment (assuming no Chloride losses) and chloride concentration in groundwater from the proponents' hydrogeology reports (when available).

Long term recharge estimations obtained were averaged per aquifer system and are presented in Table 8. Table 8 also shows WSP values for comparison.

Table 8: Groundwater sources, recharge rates used in WSP and recharge estimated locally

Groundwater source	Recharge used in WSP (% of long-term rainfall)	Recharge estimated locally (% of long-term rainfall)
New England Fold Belt Coast	4	31
Clarence Moreton Basin	6	10
Alstonville Plateau	8	(*)

Note (*): No local data was available for the Alstonville Plateau.

The estimates based on the local chloride measurements are considerably higher than those used in the WSP, however, it should be noted that:

- there is uncertainty in these estimates because they are based on a very small number of chloride measurements
- if losses of chloride due to surface runoff are considered, these values would be lower, but there were no available data to include them
- if the source aquifers are confined, these estimates may be interpreted as estimates at the outcrop of the aquifers
- if the source aquifers are not confined the recharge may come from overlying aquifers and/or surface water sources.

3.3.2.2 Baseflow filtering as an estimate of recharge to the Northern Rivers bottled water industry

Baseflow is the sustained contribution to river flows. Conceptually, baseflow is often considered to be the groundwater contribution to river flows, although may contain other sustained flow contributions. Where baseflow may be assumed to be the groundwater contribution, and considered as the outflow from the groundwater reservoir, it provides an alternative estimate of recharge, although will only provide estimates of recharge to aquifers that discharge upstream of the gauge. Long-term stream flow gauges are needed, like those maintained by the DPIE Water.

At catchment scale, the stream flow components can be broadly grouped in classes based on the different orders of magnitude of the subflow responses to rainfall. Most stream flow series show quick flow and slow flow components (Willems, 2009). The slow flow component corresponds to baseflow.

Baseflow filtering is a data analysis technique that allows users to numerically separate out baseflow contributions from total measured/gauged river flow (Tallaksen, 1995). The method excludes any recharge that does not appear as baseflow at the gauge, and thus may exclude recharge that feeds deep groundwater systems and excludes recharge through the river bed that does not re-emerge before the gauge.

Baseflow filtering was used to estimate groundwater recharge at a number of flow gauging stations within the area of interest. The filtering method used is described in Appendix 4. Figure 15 shows the location of flow monitoring points and groundwater sources.

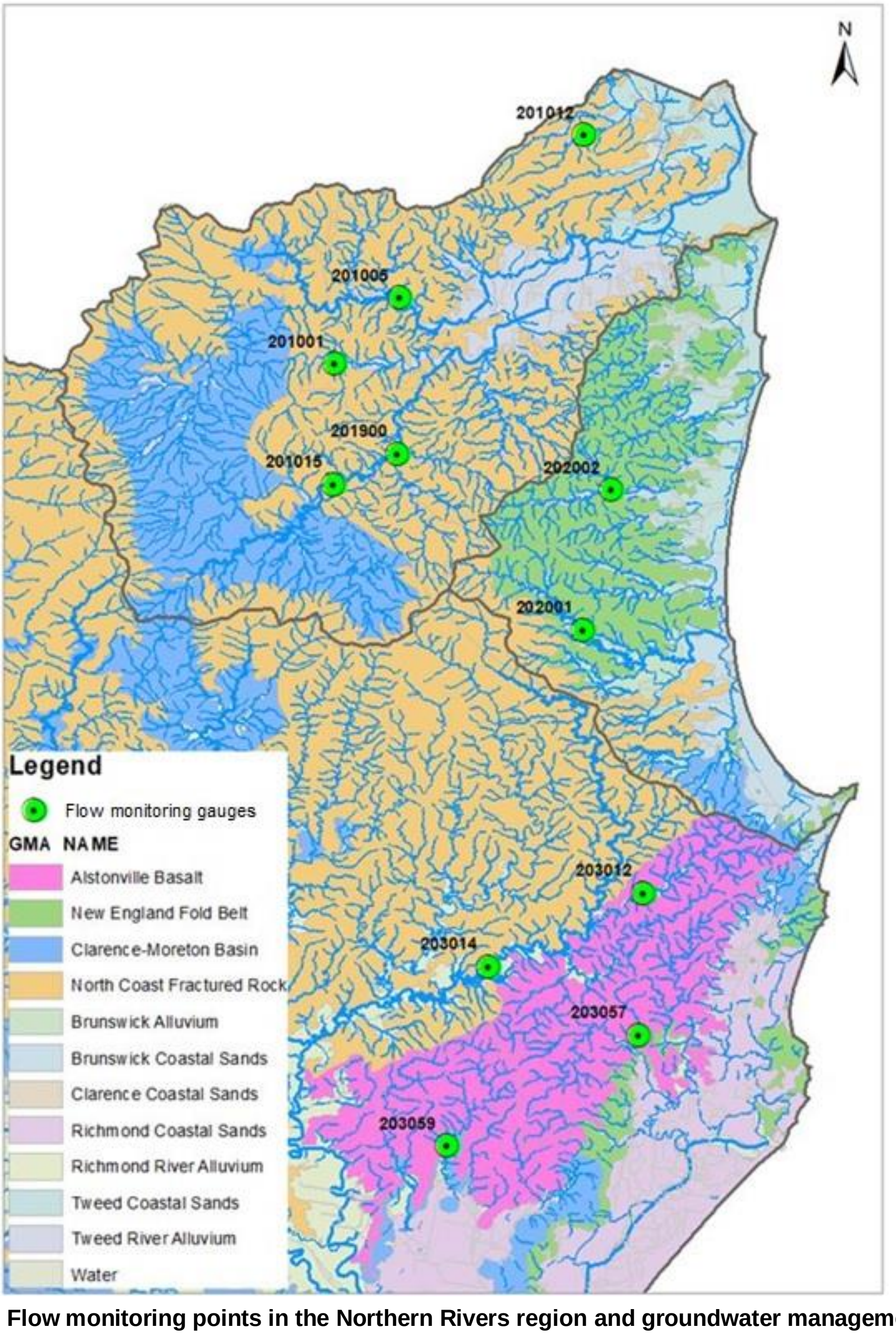

Figure 15: Flow monitoring points in the Northern Rivers region and groundwater management areas

Table 9 shows the flow gauges in the Tweed and Alstonville Plateau Areas. The daily flow time series for monitoring points in Figure 15 and Table 9 were obtained from the BOM. Rainfall is from daily SILO (Scientific Information for Land Owners) data downloaded from (Queensland Government, 2019), SILO uses mathematical interpolation techniques to infill gaps in gauged rainfall time series and constructs spatial grids, and for the current purpose is equivocal to the alternative BOM gridded rainfall data. Rainfall falling over each gauged catchment was averaged from all SILO cells within or overlapping the drainage area.

Table 9: Flow gauges in the Tweed Area and Alstonville Plateau

Code	Area	Name	Latitude	Longitude	Catchment Area km^2
201001	Tweed	Oxley River at Eungella	-28.3537	153.2931	213
201005	Tweed	Rous River at Boat Harbour No. 3	-28.3096	153.336	111
201012	Tweed	Cobaki Creek at Cobaki	-28.200871	153.458926	10
201015	Tweed	Tweed River D/S Palmers Road Crossing	-28.433857	153.291908	156
201900	Tweed	Tweed River at Uki	-28.413522	153.334927	275(**)
202001	Brunswick	Brunswick River at Durrumbul (Sherrys crossing)	-28.531174	153.458183	39 (*)
202002	Brunswick	Burringbar Creek at Burringbar	-28.43774	153.476761	39 (*)
203012	Alstonville	Byron Creek at Binna Burra	-28.706611	153.497897	39
203014	Alstonville	Wilsons River at Eltham	-28.755574	153.394827	223
203057	Alstonville	Houghlahans Creek at upstream Teven	-28.801169	153.494846	10 (*)
203059	Alstonville	Maron Creek at Graham Road	-28.874925	153.36741	39 (*)

(*) Catchment areas with * were estimated (**) Influenced by upstream reservoir so lower value for baseflow analysis

Appendix 4 presents aggregated monthly baseflow for the available period of data for these flow gauges, together with the rainfall over the catchment.

For each monitoring point, aggregated annual values are also presented in millimetres for rainfall, total streamflow (Q) and baseflow (BF). Ratios BF/Rainfall and BF/Q are calculated, and their tendency is analysed by calculating a 5-year moving average. Table 10 shows the average BF/rainfall ratios over the available data periods.

Table 10: Fraction Baseflow/Rainfall for flow gauges for period 1960-2018

Code	Area	No of years with information	Average Baseflow/Rainfall
201001	Tweed	59	0.08
201005	Tweed	37	0.09
201012	Tweed	36	0.10
201015	Tweed	9	0.05
201900	Tweed	37	0.05**
202001	Brunswick	47	0.05
202002	Brunswick	9	0.08
203012	Alstonville	40	0.22
203014	Alstonville	58	0.17
203057	Alstonville	8	0.14
203059	Alstonville	7	0.14

** Influenced by upstream reservoir so lower value for baseflow analysis

From the figures in Appendix 4 and data in Table 10, it is observed that fractions of baseflow:rainfall and baseflow:total streamflow are variable annually. Long-term baseflow:rainfall ratios are in the range of 5-15% in the Tweed, 5-10% in Brunswick and 10-25% in the Alstonville system. These values may be interpreted, with considerable uncertainty, as recharge rates of aquifers that discharge upstream of the gauging locations.

Given that these values are likely to be under-estimates of total recharge because they only capture the groundwater that is discharged above the gauge, and due to the uncertainty in the filtering method, it is concluded that there is no evidence here that the WSP values of recharge are not conservative

3.3.3 Impact of reducing the recharge rates

Despite the available data or research, there is likely to always be some uncertainty in the extraction limits and planned environmental water calculated in any WSP. One approach to assess whether the current level of uncertainty is acceptable is to undertake sensitivity analyses of the results. Sensitivity analyses examine 'what-if' cases for a range of possible values for an attribute in question. In the case of the WSP, a sensitivity analysis could be undertaken to see whether a change in the recharge or sustainability index might result in the aquifers being stressed at the current level of extraction or at the prescribed level of allowable recharge.

For example, in a scenario where recharge was just 20% of that calculated in the WSP, however there was no change to the LTAAEL or current assignment of water, the recharge amount reserved for the environment (RRE) would be as shown below in Table 11.

Table 11: Hypothetical example scenario - reducing recharge to 20% of the estimated recharge in the WSP

Groundwater Source	Hypothetical Recharge - 20% of WSP value (ML/yr)	LTAAEL (ML/yr)	Current Assigned Water (ML/yr)	RRE* (ML/yr)	RRE as a percentage of estimated recharge	Assigned Water as a percentage of recharge
New England Fold Belt Coast	396,000	60,000	35,468	336,000	85%	9%
North Coast Volcanics	62,000	13,000	5,907	49,000	79%	10%
Alstonville Plateau	10,016	8,895	8,895	1,121	11%	89%
Clarence Moreton Basin	115,200	300,000	4,562	-184,800*	-160%*	4%

*RRE is calculated as Average Recharge (ML/yr) - LTAAEL. A negative RRE implies the extraction limit is greater than the expected recharge.

As shown in Table 11, if the recharge rate was reduced to 20% of the WSP value, the RRE in the New England Fold Belt Coast and the North Coast Volcanics remains relatively high (approximately 80%) and the present LTAAEL is likely to remain reasonable. In the Alstonville Plateau, RRE (as a percentage of recharge) would be significantly reduced if the recharge rate had been overestimated. However, there is a network of monitoring bores (piezometers) within the Alstonville aquifer which can be inspected to assess whether there has been any long term changes in water levels throughout the groundwater system. The availability of this data provides a way to scientifically evaluate long term trends in aquifer water level and to identify signs of the aquifer becoming stressed (e.g. systematic decline of water levels over a significant time period).

Table 11 also shows that the reduced recharge would result in the LTAAEL being larger than the annual recharge. However, extraction in this region is presently very low. If there is significant concerns that the recharge rate in this region has been overestimated, the LTAAEL could be reduced without significant impacts to current license holders.

3.4 MONITORING DATA FROM ALSTONVILLE BASALT

The NSW Government operates 29 monitoring piezometers on the Alstonville Plateau (including two in North Coast Volcanics) which continuously measure water levels in various locations at multiple depths throughout the region. Analysis of this data provides a useful way to understand the groundwater system, as well as to identify periods in which water supplies in the aquifer may be stressed.

This section is separated into two distinct parts based on the time of monitoring:

- Pre 2009, a number of reports were released that analysed the existing monitoring data to date;
- Post 2009, the Review hasn't found an updated status report on the groundwater levels. As such, monitoring data was accessed by the review team to provide comment on groundwater levels in the Alstonville Plateau over the last decade.

3.4.1 Alstonville monitoring network and aquifer levels to 2006 and 2009

In 2006, the Department published a status report on the groundwater levels in Alstonville. At the time, the monitoring network consisted of 11 monitoring piezometers measuring both the deep and shallow aquifers, across five sites at Alstonville. This report included the development of conceptual models for the Alstonville GW sources showing the system comprises two major aquifers – a shallow unconfined aquifer (less than 50 metres deep) and a deeper semi-confined/confined aquifer (generally >50 m) (Green, 2006; DECCW Water, 2011).

Green (2006) stated that the shallow unconfined aquifer is rapidly recharged by rain, while the deeper semi-confined/confined aquifer takes longer to recharge after rainfall events. While the deep aquifers do experience periods of drawdown and recovery, the recovery period can be substantially longer than that observed in the shallow aquifers, most likely due to the limited and slow recharge processes associated with these semi-confined systems.

Green (2006) specifically addresses groundwater levels during a drought period in the early 2000s. During this period, surface water runoff was minimal and groundwater extractions were high. As a result, the deep groundwater levels were at some of their lowest observed levels and the aquifer was noted in several reports as stressed over this period of time (Green, 2006; DECCW Water, 2011). While limited monitoring data is available to quantify groundwater extractions during this period, Green (2006) speculated that this was likely associated with the over-extraction of groundwater due to limited surface water availability during the drought. The drawdown covered an area more than 3 km wide with drawdown levels varying from 8 to 19 metres (Green, 2006). An embargo on new licences was also imposed on the Alstonville aquifer in 2000 to prevent further stress on the aquifer (DPIE Water 2019, pers comm., 30 October).

From early 2003 onward when the drought ceased, the levels in the deep aquifer system started to recover. From that time until the data was analysed for the 2006 status report, the deep aquifer levels rose by 8 to 25 metres across the aquifer (Green, 2006; DECCW Water, 2011). By 2009, the Department noted that groundwater levels had recovered to levels seen in the 1980s when monitoring commenced. In addition to rainfall slowly providing recharge to these aquifers, it is likely that extraction of the groundwater reduced significantly when surface water became more plentiful. However, as groundwater use in the Alstonville region is largely un-metered, conclusions about the impact of pumping and climate are difficult to differentiate in the deeper aquifers.

3.4.2 Alstonville monitoring data between 2006 – 2018/2019

In 2005-2006, after completion of the groundwater status report discussed in the section above, the Department expanded the monitoring network to consist of 29 monitoring piezometers across 13 sites measuring both shallow and deep aquifer levels. While no additional reporting had been undertaken analysing the Alstonville Plateau data since the detailed 2006 report (Green, 2006) and a brief update in 2009 (DECCW Water, 2011), groundwater level data has been continually collected on the expanded monitoring network.

A basic analysis of the data from the previous thirteen years (2006-2019) has been undertaken by the Review to provide insight into the state of the Alstonville aquifer today and the impact of environmental variables (e.g. rainfall and seasons) on groundwater levels in the region. Data was accessed for all 29 monitoring piezometers in the Alstonville Plateau. The location of each piezometer (including depth) is summarised in Figure 16 and Table 12.

In summary, the analysis detailed below shows, during the period from 2006 onward, the readings from shallower piezometers, tend to be more variable and show increases following periods of rainfall. The deeper piezometers (depths around 50m+) tend to be more stable, showing a tendency towards a steady upward trend over time. The analysis below has identified lagged rainfall as an important variable for understanding piezometer water levels in the Alstonville Plateau, especially in shallow piezometers and deeper piezometers that are indicating connection to surface waters and upper aquifers. There were no strong seasonal effects shown on water levels or pressures, but almost all the piezometers showed temporal effects.

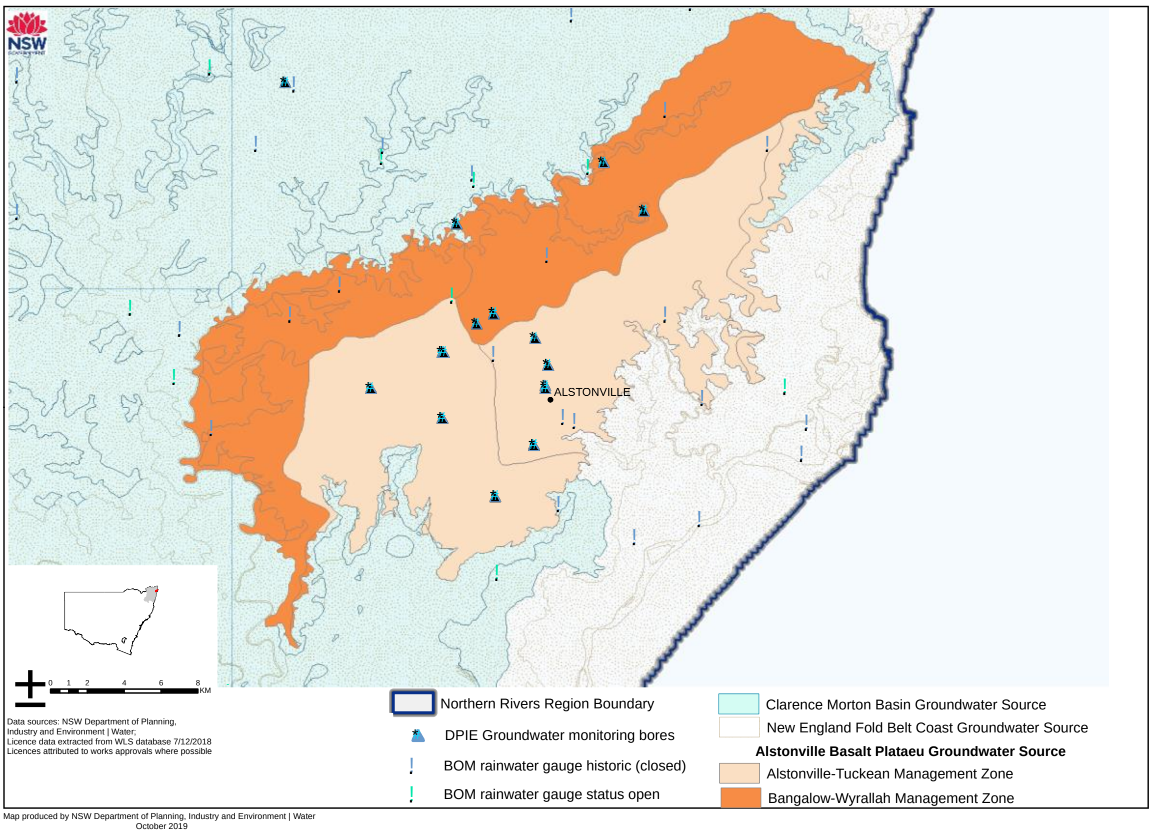

Figure 16: Map of Alstonville showing the 13 sites for the Alstonville monitoring piezometer network
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Table 12: DPIE groundwater monitoring piezometer network at Alstonville
Shows depth classification (shallow, medium or deep)[1], year drilled, the amount of variability of the levels explained by rain, season and time through a GAM analysis.

Piezometer ID	Hole	Pipe	Depth[1]	Year drilled	Lag (days) [&]	Variance Explained (post 2006) [#]		
						Rain	Season	Time
GW040999	1	1	Shallow	2005/6	30	57%*	8%*	10%*
GW040999	2	2	Deep	2005/6	40	1%	7%	98%*
GW041001	1	1	Shallow	2005/6	30	68%*	8%*	8%*
GW041001	2	2	Deep	2005/6	40	3%	2%	99%*
GW041002	1	1	Deep	2005/6	200	61%*	5%	75%*
GW041003	1	1	Shallow	2005/6	30	39%*	11%*	8%
GW041003	2	2	Deep	2005/6	180	63%*	5%	19%*
GW041004	1	1	Shallow	2005/6	150	50%*	11%*	8%
GW041004	2	2	Deep	2005/6	150	51%*	11%*	8%
GW041005	1	1	Shallow	2005/6	30	53%*	3%*	5%*
GW041007	1	1	Medium	2005/6	100	55%*	7%	19%*
GW041007	1	2	Deep	2005/6	120	51%*	7%	22%*
GW041008	1	1	Shallow	2005/6	120	56%*	10%	37%*
GW041008	1	2	Deep	2005/6	150	58%*	16%*	36%*
GW041000	1	1	Deep	2005/6	280	17%	2%	94%*
GW041000	1	2	Deep	2005/6	280	20%*	3%	95%*
GW081005	1	1	Deep	1999	280	2%	1%	99%
GW081006	1	1	Shallow	1999	120	44%*	5%	42%*
GW081002	1	1	Deep	1999	280	45%*	7%	71%*
GW081003	1	1	Medium	1999	150	66%*	14%*	35%*
GW081004^	1	1	Shallow	1999	NA	NA	NA	NA
GW081000	1	1	Shallow	1999	150	47%*	4%	15%
GW081001	1	1	Deep	1999	280	2%	11%	99%
GW036702	3	1	Shallow	1987	150	49%*	4%	8%
GW036702	2	2	Shallow	1987	280	29%*	21%*	18%*
GW036702	1	4	Deep	1987	NA	NA	NA	NA
GW036701	1	1	Shallow	1987	240	33%*	11%	41%*
GW036701^	1	4	??	1987	NA	NA	NA	NA
GW036701	2	2	Deep	1987	280	8%	3%	97%

& Lag associated with the best predictive power
# variance explained corresponds to the percentage of variability in the data that can be explained by a GAM model that includes all three factors (rain, season and time) compared to a model that leaves each respective factor out.
* Significant at p<0.05 based on a likelihood ratio test with block bootstrap
^ This piezometer had only limited data and none past 2006
[1]Classifcation of shallow, medium and deep provided by DPIE Water. Generally DPIE Water are classified shallow with screen interval up to approximately 25 m, medium 25-40 m and deep 40m onwards, with the deepest having a screen interval 150-168 m. The conceptual model indicated the shallow aquifer runs to approx. 50 m with the deep aquifer >50 m

The monitoring data alone will not separate the effects of extraction from climate, but analysis of rainfall patterns over the period can give some indication of the impact of climate variability on groundwater levels. This complements the qualitative analysis of how long-term river baseflows relate to climate in the Initial Report, which found a strong and consistent influence of climate but no evidence of other influences.

The analysis in this section is not intended to be an in-depth hydrogeological analysis, but rather an empirical statistical analysis to assess the long term changes in water levels in each piezometer. The water levels in the piezometers over the last decade are shown in Figure 17 and Figure 18. Piezometer levels here refer to the distance (in metres) from the measuring point to water.

Figure 17 and Figure 18 also shows interpolated rainfall sourced from the SILO database (Queensland Government, 2019) to improve the understanding of the relationship between rainfall and groundwater levels. As evident in these two figures, the groundwater level data is not continuous at every monitoring station, with several extended gaps in a number of the monitoring wells, especially in the earlier periods. There are also several notable dips in the levels from two deep pziemometer. The Review was unable to confirm the cause, but it was speculated that these may have been due to measurement error, periods when the data from the logger was being downloaded or the logger was down.

The shallower piezometers are more variable and appear to be recharged regularly with rainfall. Figure 18 shows that the deeper piezometers (depths around 40-50m+) tend to be quite stable, with a tendency towards a steady upward trend over time.

The Review team undertook some statistical analyses to consider these observations in more detail. In particular, a statistical technique called the Generalized Additive Model or GAM (Hastie & Tibshirani, 1990) was used. GAMs have become very popular as an exploratory data analysis tool that allows one to assess the relationships between variables of interest without having to impose strong modelling assumptions such as linearity. They are popular for modelling environmental data where non-linear effects arise often and where it is desirable to use analysis tools that let the data drive the results rather than imposing strong assumptions.

For the purpose of this investigation, the Review team developed GAM models that predict piezometer level (in metres below measuring point) as a function of time, rainfall and season. The purpose of this analysis is to investigate how much of the variability in groundwater levels in each piezometer is associated with each of these three components. The Review explored a range of options for how to best incorporate rainfall into the model. It found that 'lagged rainfall' averages, where rainfall is reported for each day as the average rainfall over the previous x days (where x was allowed to range from 10 days up to 240 days) provided a better explanation of variability in the piezometers than daily rainfall. While other lagged rainfall distributions may be suitable, for the purpose of this simplified analysis, the unweighted average over the x days is used. For each piezometer, the Review team re-ran the GAM models to identify the most appropriate lagged rainfall average(x). The sixth column in Table 12 shows the best identified rain lag variable value for each piezometer.

Following this analysis, the extent to which each component contributes to the variability of each piezometer was calculated. To ensure that the significance tests were appropriately adjusted for autocorrelation induced by the time-series nature of the data, a technique called the block bootstrap (Kunsch, 1989) was used, which has been implemented using the *boot* package in the statistical programming environment, R (Canty & Ripley, 2019). This analysis is an alternative to using the Seasonal Kendall Trend test, which is popular in hydrogeology.

Table 12 shows the percentage variability in measured piezometer levels that can be explained by lagged rainfall, season and time (shown in columns 7, 8 and 9 respectively). The data is analysed from 2006 onward in order to boost statistical power to detect effects. These figures were computed by running models leaving out each factor and comparing the deviance explained by that model to the deviance explained by the model with all three factors in included. Statistical significance was assessed through use of a likelihood ratio test, using the block bootstrap to adjust for autocorrelation. Numbers that are statistically significantly different from 0 at p<0.05 are indicated by an asterix. A higher percentage indicates that the water levels in that piezometer are more highly correlated to that particular variable.

Table 12 suggests quite a lot of variability between piezometers and locations. In some cases, for example piezometer number GW41008, shown in Figure 19, rainfall averaged over the previous 120 to 150 days could explain quite large amount (>55%) of the observed variability in day to day piezometer levels. The strong association between the lagged rainfall and measured piezometer level is visually quite striking in Figure 19. In general, lagged rainfall was found to explain 30% - 70% of variance in shallow piezometers, which is consistent with the findings of Green (2006) who noted that these shallow aquifers are rapidly recharged through direct rainfall. The Review had anecdotal information that groundwater extraction may be higher during dry periods; this analysis indicates the impact of low rainfall periods on groundwater levels may be from a variety of factors.

The correlation between rainfall and water level variance in deeper piezometers was less consistent. Rainfall was observed to account for more the 50% of variability in some deeper piezometers (such as GW410002_1_1, GW410003_2_2, GW410004_2_2). This indicates that some of the deeper piezometers have some connection with surface waters (possibly through upper aquifers) and are unlikely to be within confined aquifers. However, rainfall effects were less significant in other deep piezometers (see GW040999_2_2, GW041001_2_2, GW041000_1_1, GW041000_1_2, GW081005_1_1, GW081001_1_1, GW036702_1_4, GW036702_2_2). This suggests that these aquifers are confined (or semi confined) as per the observations of Green (2006). Further work could be undertaken, based on this analysis and existing geological mapping, to potentially identify confined aquifers, but this analysis has not been undertaken as part of this review.

The majority of the piezometers showed no significant seasonal effect after adjusting for rainfall. However, almost all the piezometers showed significant temporal effects. By this we mean that including time in the model provided a statistically significant improvement compared to models that did not include time. We undertook further analysis to determine whether these time effects could be described as linear or non-linear. For the most part, we found significant non-linear effects, though visually these effects were not strong. For the majority of deep piezometers, the overall time-effect explained the majority of variation in observed levels. The significance of the time variable may reflect other factors not incorporated into our modelling, for example changes in patterns of extraction or other aspects of rainfall not adequately captured with the lagged rainfall variable tested in the GAM analysis.

The three panels in Figure 19 provide more detail on the GAM analysis for a single piezometer (GW041008) to further illustrate the outcomes of this analysis. Panel a) reveals a strong and fairly linear relationship between lagged rainfall and piezometer water levels. This suggests that as rainfall occurs, piezometer water levels respond. As such, there is a possible recharge mechanism of the rainfall to the aquifer and the aquifer is unlikely to be fully confined.

Panel b) shows the relationship between piezometer water levels and time. While there does appear to be some correlation between time and water level, the pattern is not particularly linear or systematic (in terms of either a general increase or decrease). As stated above, this is likely to reflect other environmental factors (e.g. extraction or surface water connections) that have not been considered in the analysis. Further analysis would be required to identify other factors that may be significantly impacting groundwater levels throughout the Alstonville Plateau.

Panel c) shows the relationship between piezometer water levels and seasonal effect. While technically this particular piezometer shows a statistically significant seasonal effect (in terms of having a p-value less than 0.05), it is not a strong effect and no clear pattern can be visually discerned. The contribution of seasonal effects to piezometer water level variability was generally found to be small for most of the piezometers considered in this analysis. Even in cases where the analysis revealed a statistically significant seasonal effect, the magnitude of change in piezometer levels over a season tended to be very modest (after accounting for rain and overall time effects). This suggests that the season has a relatively minor impact on piezometer water levels in the Alstonville Plateau. Similar detailed analysis for all piezometers is provided in Appendix 5.

The availability of reliable monitoring data on these piezometers from the Alstonville region provides an invaluable tool for stakeholders who wish to understand how patterns might be changing over time or in response to rainfall and other factors. While the simple empirical analyses presented above are by no mean a replacement for more sophisticated hydro-geologically based models and might be improved by further or modified inputs, they are a useful tool for planning and monitoring. This analysis has identified lagged rainfall as an important variable for understanding piezometer water levels in the Alstonville Plateau, especially in shallow piezometers and deeper piezometers that are well connected to surface waters and upper aquifers.

Water levels in these piezometers should continue to be regularly assessed to ensure periods of sustained water level decline are identified early. If further analysis can identify how changes in extractions relate to trends in groundwater decline and recovery, it may be appropriate to set trigger values for water levels in key deep aquifers that allow for adaptive management of groundwater extractions (e.g. once water levels fall below a certain level, restrictions may be placed on extractions in that area).

Figure 17 and Figure 18 were created using an on-line tool created by the Review team that can be used to interactively view hydrographs similar to those reported by Green (2006) and showing the piezometer levels over time, along with a graphical display of rainfall levels over the same time period. The online hydrograph tool allows the user flexibility in terms of which piezometers to plot as well as whether to display daily rainfall or lagged averages (discussed above). The hydrograph tool also allows flexibility in terms of zooming in to a particular time period of interest. While this tool does not offer the same breadth of information as available in Groundwater Explorer, it has the advantage of being simpler to use and is also much quicker to run. The Review will explore the possibility with DPIE Water of the interactive hydrograph tool being made more widely available.

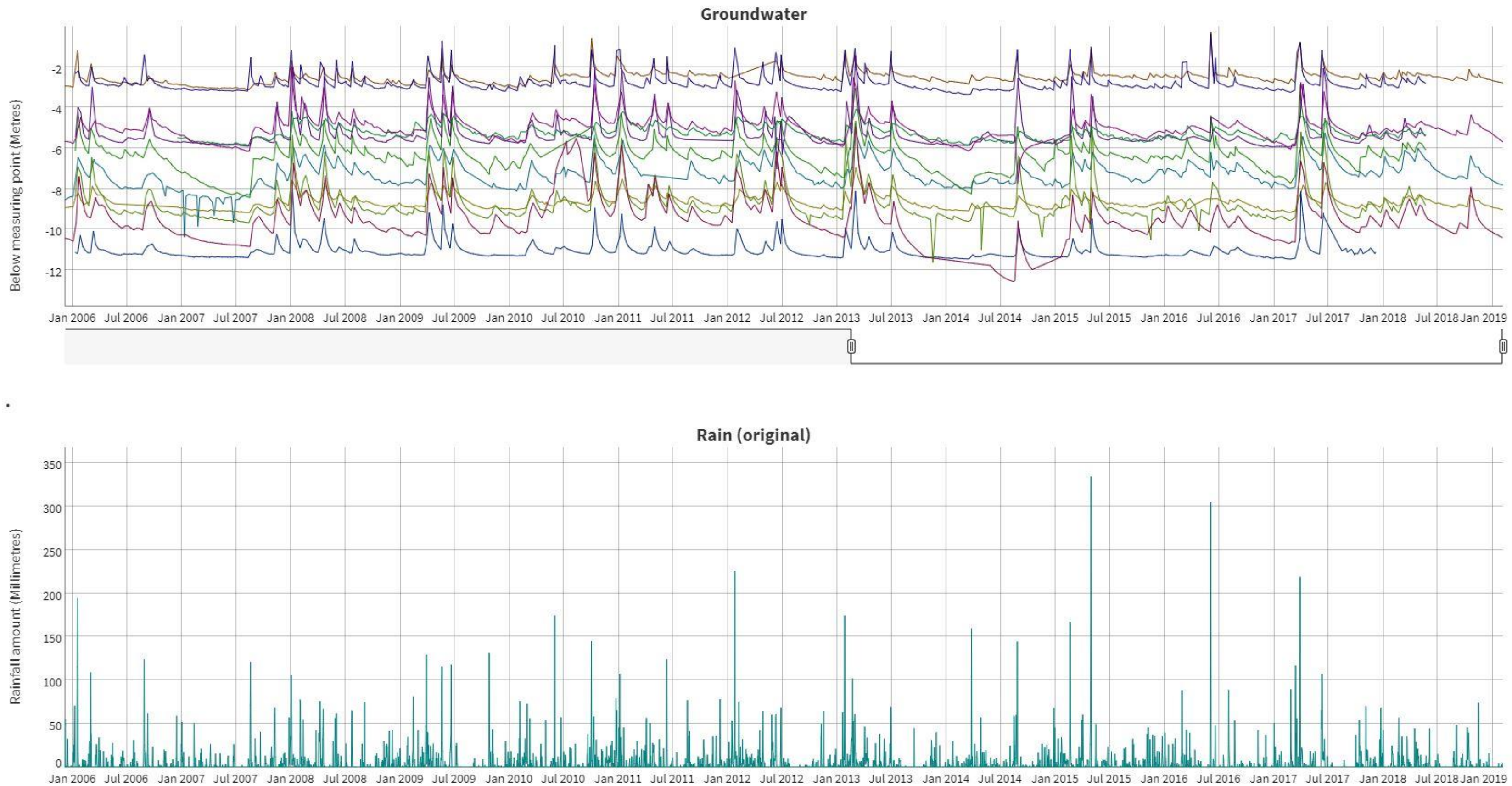

Figure 17: Hydrographs showing the levels of 12 'shallower' piezometers in the Alstonville Plateau from 2006 to present.
These include GW040999.1.1, GW041001.1.1, GW041003.1.1, GW041004.1.1, GW041005.1.1, GW041008.1.1, GW081006.1.1, GW081004.1.1, GW081000.1.1, GW036702.3.1, GW036702.2.2, GW036701.1.1. The vertical axis in the top panel shows the distance from measuring point to water for each piezometer while the x-axis shows date. The bottom panel shows daily rainfall associated with the Alstonville Tropical Research Station.

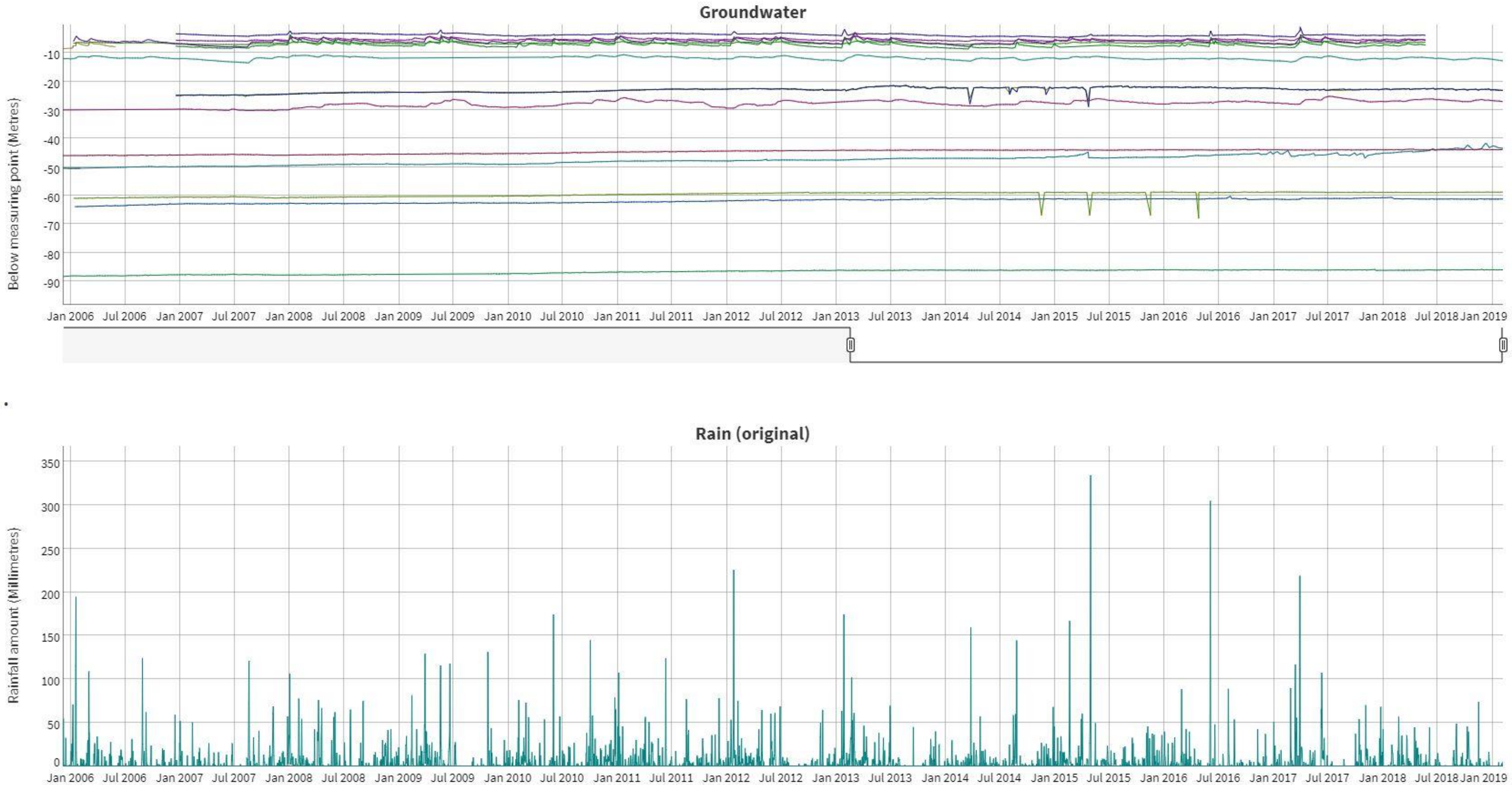

Figure 18: Hydrographs showing the levels of 16 'deeper' piezometers in the Alstonville Plateau from January 2006 to present.
These include, GW040999.2.2, GW041001.2.2, GW041002.1.1, GW041003.2.2, GW041004.2.2, GW041007.1.1, GW041008.1.2, GW041000.1.1, GW041000.1.2, GW081005.1.1, GW081002.1.1, GW081003.1.1, GW081001.1.1, GW036702.1.4, GW036701.1.4, GW036701.2.2
The vertical axis in the top panel shows the distance from measuring point to water for each piezometer while the x-axis shows date. The bottom panel shows daily rainfall associated with the Alstonville Tropical Research Station.

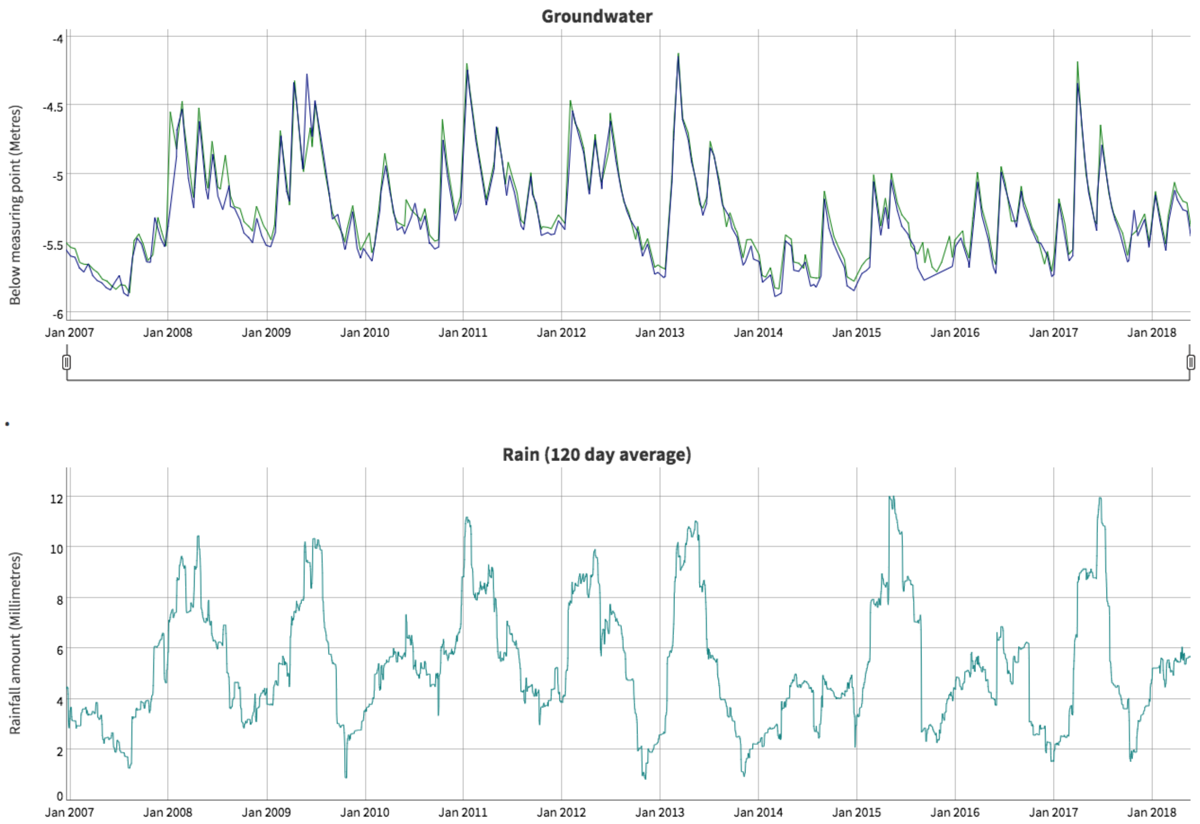

Figure 19: Hydrograph for Piezometer GW041008, Hole 1, Pipes 1 and 2 with 120 day rainfall average plotted in the lower panel.

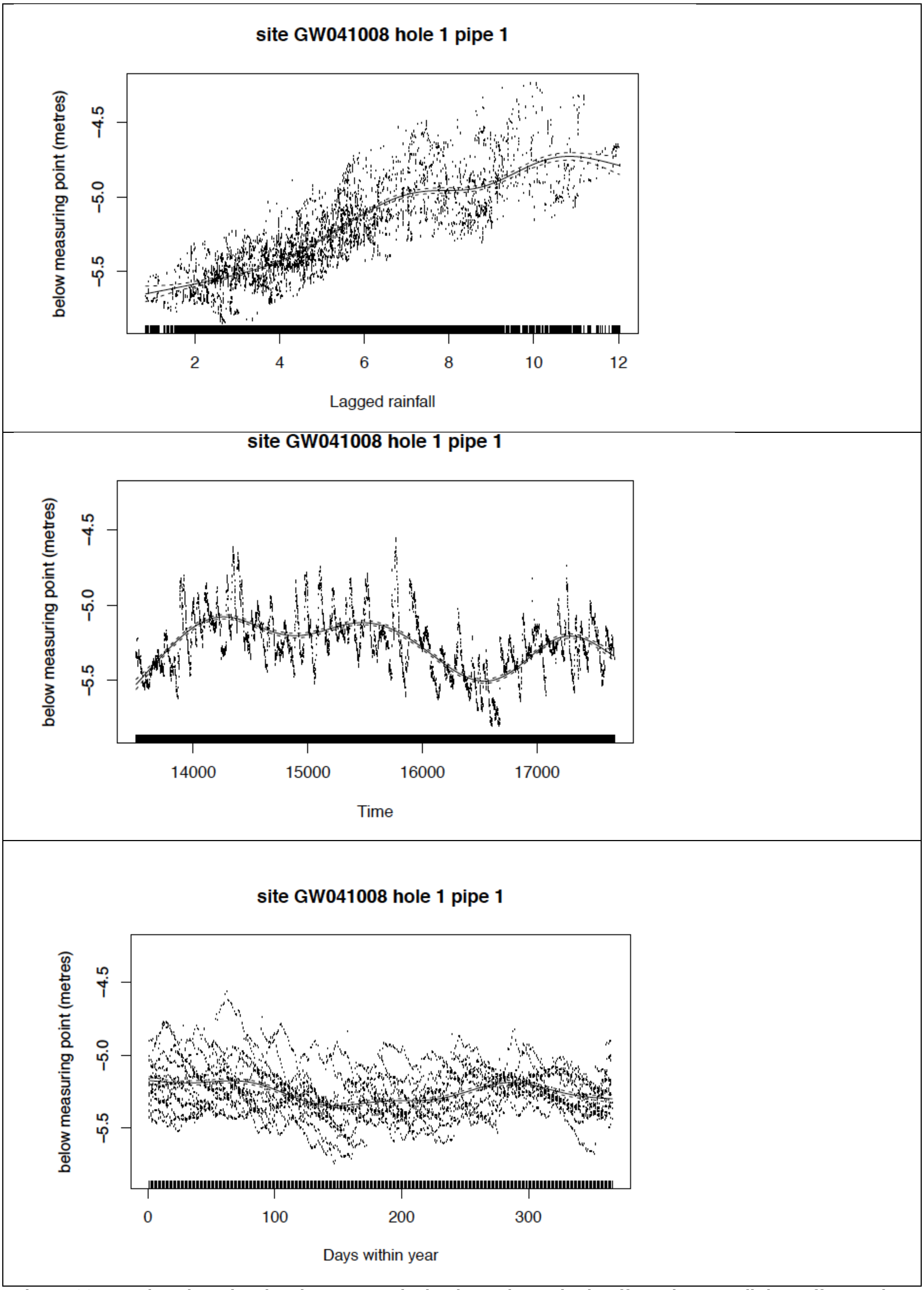

Figure 20: Panels a, b and c showing, respectively, the estimated rain effect, the overall time effect and the seasonal effect estimated from fitting a GAM model

3.5 CONCLUSIONS

The WSP aims to set sustainable extraction limits for the groundwater sources through consideration of a number of parameters, including rainfall over the area, recharge rates, areas of high and non-high environmental value and a sustainability index. These variables are subject to a level of uncertainty associated with the predictions and a precise value may not be achieved due to the complex and heterogeneous nature of groundwater movement. This is particularly evident in fractured rock systems that are difficult to fully characterise. Given this, a range of practices have been used in developing and managing the WSP to account for, or reduce, uncertainty – conservative calculations, adaptive management, sensitivity testing, examining multiple lines of evidence.

The recharge rate, in particular, was considered in detail in this Review as a key technical variable in the determination of the extraction rates. This was done through a review of literature of recharge rates on comparable aquifers and application of alternative techniques as a basis for recharge rates (chloride-mass balance and baseflow filtering).

WSP assumptions

- In groundwater studies and management, there will always be a level of uncertainty associated with predictions (e.g. recharge rates) and a precise value may not be achieved due to the complex and heterogeneous nature of groundwater movement. This is particularly evident in fractured rock systems that are difficult to characterise fully.
- The WSP plan was developed based on the best available data at hand and followed a standard procedure. The assumptions made in the WSP are practical, reasonable and in agreement with standard practice. In general, the WSP incorporates a reasonable level of conservatism for extraction limits based on the risks identified.
- The rainfall data used and the methodologies are sound and apply limited uncertainty to the extraction rates.
- The portion of the estimated recharge value available for extraction is a function of rainfall recharge over low environmental value areas together with an assessment of environmental and socio-economic risk.
- Calculating recharge is complex due in part to the variability and complexity of the hydrogeology and limited knowledge of the systems. Based on the analysis, the Review considers the recharge rates used in the WSP are reasonable and conservative. This statement is made with a relatively low level of confidence due to lack of data for the groundwater sources of interest.
- In practical terms the groundwater sources are treated as geologically homogenous which adds uncertainty and would benefit from further work. The Review recognises that the complexity of the geology makes it difficult to incorporate heterogeneity into the WSP recharge calculations. Particular attention should be given to the effects of geological variability within groundwater sources, and soils and vegetation overlying aquifer outcrops. The Review acknowledges the conservatism incorporated into the current WSP through the allowable allocation figures.
- There is evidence to suggest that for the WSP recharge variable, there is a wide range of values that can be applied as well as a number of different approaches to calculate it. Limited field data is available to support a single estimate and best practice is to use more than one estimation method to reduce uncertainty if possible.
- Recharge rates applied to the four groundwater sources in scope in the WSP ranged from 4% - 8% with studies and alternative methods indicating, with considerable uncertainty, levels between 1% and 31%. The calculations by the Review using CBM and baseflow filtering for recharge rates had results mostly above the values used in

the WSP. The Review noted the important contribution that surface conditions and soil could make to the recharge of the underlying geology.

- The Review tested a scenario in which the recharge rates were reduced by 80%. It found the recharge reserved for the environment for the New England Fold Belt Coast and North Coast Volcanics would remain at around 80% of recharge. For Alstonville, it would be reduced, but the network of monitoring bores provides the ability to monitor long-term changes in levels. For the Clarence-Moreton Basin, with a relatively low volume water allocated, the LTAAEL could be reduced with no impact on licences.
- Based on the analysis, the Review considers the recharge rates used in the WSP are reasonable and conservative. This statement is made with relatively low level of confidence due to lack of data for the groundwater sources of interest.
- The application of the sustainability index appears to be a cost and time effective risk tool that is applied as an additional means to protect resources where limited information is available.
- The WSP incorporates a reasonable level of conservatism for the extraction limits when the groundwater sources are not fully allocated and where they are fully allocated at Alstonville, monitoring is applied.
- Additional monitoring in strategic locations in the Tweed would help inform gaps in knowledge on a regional scale and provide a path towards better conceptual understanding of aquifer flows.
- The overall system is managed with some level of adaptive management, including an annual determination of the volume of water per licence share and WSP are subject to an interim review at five years with a full review at ten years.
- Impacts of climate change should be considered in future WSP methodologies. A warming climate can lead to increases or decreases in rainfall at a location, variations in the timing and frequency and strength of rainfall events, and increases or decreases in evapotranspiration. The development by the NSW Government of Regional Water Strategies will provide further insights into the impact that climate change could have on the region and catchments over the coming decades, which can further inform management approaches for the region's water resources.

Sustainability of WSP extraction limits

- Due to limited extraction levels (where known allocations in the Tweed region are much lower than the extraction limits contemplated in the WSP), limited data and uncertainties described regarding the WSP parameters, it is not possible to conclude whether the extraction limits are currently sustainable. However, the Review found no evidence at this point in time that current WSP extraction limits are not sustainable.
- For the Alstonville Basalt Plateau Groundwater Source, which is fully allocated, and there is a network of monitoring piezometers, data from 2006 onwards was analysed by the Review, which concluded:
    - The deeper piezometers (depths greater than around 25 m) showed a greater stability and a steady upward trend over time of groundwater levels and/or pressures. In contrast, the shallower piezometers showed greater variability and appear to be recharged more regularly with rainfall.
    - Lagged rainfall is an important variable for understanding piezometer water levels in the Alstonville Plateau. This was observed in shallow-sited piezometers and in deeper piezometers sited in systems that are well connected to surface waters and upper aquifers.

  - There is limited amount of information available on current actual extraction volumes. The Review notes that enhanced metering requirements will come into force in the region in 2023 for eligible groundwater extractors. Given this lack of data on extraction volumes, it is difficult to separate the effects of environmental variables (such as rainfall) from the impacts of human extraction (which tends to increase during dry periods).

Methodological improvements

- The Review considers there is room for improvement in the future assessment of the variables underlying the extraction limits.
- Impacts of rainfall patterns in the region on recharge should be considered in future WSP methodologies, including changing patterns associated with climate change.
- Particular attention should be given to assessment of groundwater recharge rates across broad spatial areas and the associated need to distinguish between confined versus unconfined aquifers.
- Developing a better conceptual understanding of the geological strata in the WSP to reduce the level of uncertainty in the estimated recharge values. This could possibly be undertaken via a 3D geological modelling tool (e.g. Leapfrog Geo) where there is sufficient data and should include some soil mapping. This would require a large scale detailed geological mapping survey or the collation of the existing core log data and geophysical measurements, where available. The Review notes this level of detail has not been typically applied in similar WSP for easterly flowing rivers and would require allocation of time and resources.
- Sensitivity testing could be undertaken to see whether a change in the recharge or sustainability index might result in the aquifers being over allocated or stressed.
- Further work could be undertaken to assess whether the risk ratings given to specific groundwater sources are appropriate.
- Water levels in the Department's piezometers should be regularly assessed to ensure periods of sustained water level decline are identified early. With further analysis, it may be appropriate to set trigger values for water levels in key deep aquifers that allow for adaptive management of groundwater extractions (e.g. once water levels fall below a certain level, restrictions may be placed on extractions in that area).
- Where the system is fully (or near fully) allocated, additional monitoring/sampling and routine data analyses could be applied, as was undertaken at Alstonville, within an adaptive management framework.

4 EXTRACTION IMPACTS: UNDERSTANDING, ASSESSMENT AND MANAGEMENT

The focus of this Chapter is on the mechanisms that cause impacts and consequences; the complexities in measuring local scale impacts from bore extraction; the hydrogeological assessments that form part of the development application and licencing processes; associated assessment challenges and potential management solutions; and additional information that would help to understand the systems better.

4.1 EXTRACTION IMPACTS AND CONSEQUENCES

For this Review, an impact refers to the physical change that occurs from an action (such as groundwater extraction), while a consequence (following the analogy) may be the temporary or permanent loss of water access or loss of environment for GDEs and associated flora and fauna. An example would be if groundwater extraction results in reduced pressure heads and groundwater discharge to a local creek (impact), which then affects flora or fauna dependent upon that water source (consequence). Risk refers to the level of potential consequence combined with its likelihood of occurring.

4.1.1 Impact mechanisms

There is an extensive volume of literature detailing the impact mechanisms from a bore (or bore field) on the surrounding aquifer or connected waters. Readers are directed to Acworth (2019) for a recent and detailed description of processes in Australia. In brief, groundwater extraction from an aquifer (via a groundwater bore) reduces hydrostatic pressure heads at the bore, creating a differential pressure gradient that induces water flow towards the lower pressure area (i.e. towards the bore). The area influenced is called the ‘zone of influence’ or ‘cone of depressurisation’ or ‘cone of depression’ surrounding the bore (Figure 21). The size of this zone, and the nature and degree of the pressure head change and resultant flow paths, depends on the hydrogeological properties of the rock or soil matrix, as well as on the rate and duration of the extraction(s).

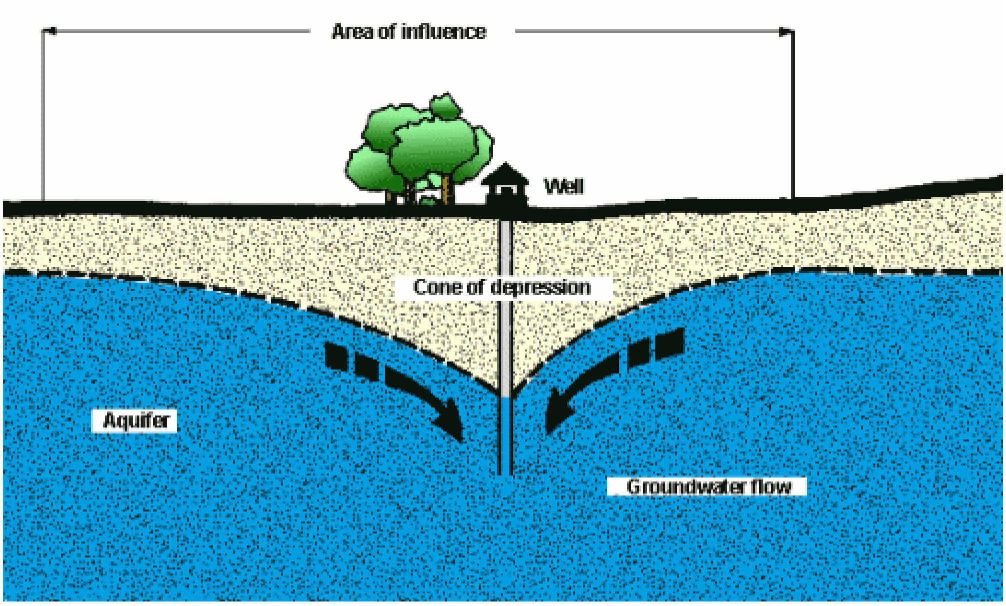

Figure 21: Area of influence and cone of depression in the aquifer due to groundwater pumping
Source: Oregon State University (2019).

The primary means to calculate flow in porous media is Darcy's Law. This equation states that flow is a function of the differential pressure heads across an area and the saturated hydraulic conductivity. The saturated hydraulic conductivity is a measure of how water flows through an aquifer and its value varies widely – over at least 10 orders of magnitude - depending on the rock or soil type, integrity and structure. Large variations in hydraulic conductivity may apply even in the vicinity of a single zone of influence. Whereas pressure heads can be directly measured via piezometers, assumptions are often made (based on our geological understanding) to determine broad acre values of hydraulic conductivity.

In many locations the subsurface geology is complex and difficult to characterise. Natural geological structures may be heterogeneous, with variations in geology, identity, structure, and physical properties both laterally and with depth. This can result in important regional and local-scale variations in saturated hydraulic conductivity and other properties. To overcome these uncertainties, a variety of field techniques have been developed, including geophysical methods, to derive local-scale values of hydrogeological properties. The most commonly used field method is the well pump test, where water is extracted from a bore for an extended period and adjacent piezometer pressure heads are measured before, during and post the pumping period (which may be 12 hr, 24 hr, 48 hr or longer periods depending on the extraction rate and geologic properties). Other commonly used methods to calculate hydraulic conductivity include slug tests, direct pressure testing or core analysis.

In locations where the aquifer is connected (either directly or indirectly) to other systems, drawdown may reduce water yields in adjacent bores or induce diversions from other aquifers. Further, if any adjoining aquifers are unconfined, a decline in the water table elevations may decrease groundwater discharge to connected surface waters and potentially influence groundwater dependent ecosystems (GDEs). The induced flow between aquifers or from surface water may also result in water quality impairments. Importantly, if the zones of influence of two or more bores overlap, then the drawdown impacts are cumulative.

Mechanisms of impacts in practical terms are different between porous rock (e.g. Clarence Moreton Basin Groundwater Source) and fractured rock aquifers (e.g. Alstonville Basalt Plateau, North Coast Volcanics and New England Fold Belt Coast Groundwater Sources). Flow through fractured rock is dominated by discrete fractures and complex folds that formed through volcanic activity often tens or hundreds of millions years ago. In these fractured rock environments the extraction point (the bore location and pumped depth) depend on the fracture network that intersects that point. This network is difficult to accurately map without extensive hydrogeological investigations and, in many cases, cannot be explicitly determined. This means that extractions in fractured rock aquifers may be unpredictable and do not comply to Darcian theory (i.e. flow is a function of fracture size and fracture connectivity, versus pressure gradients and hydraulic conductivity). In contrast, flow through porous rock better conforms to drawdown prediction models and hence, local impacts may be more accurately predicted.

In either circumstance, expert interpretation of bore logs and pump test results is typically required to determine aquifer hydrogeologic behaviour. In a practical sense, this variance suggests that fractured rock aquifers require more investigations as they have higher uncertainty, although this should not be used as rationale to limit data gathering in porous systems. Further considerations are addressed below.

Extraction impacts are assessed in the hydrogeological assessment process for some new water extraction approvals (for example, in water access licence dealings or water supply works approvals). The range of impacts assessed and the standards for acceptable impacts are discussed below.

4.1.2 Extraction consequences

Bore water extraction can potentially impact connected water within the same aquifer, within a connected aquifer, or within a connected surface water body, leading to possible changes in water quantity or water quality.

The range of impacts described in the DOI (2018a) document includes those on the groundwater source itself (both in terms of quality and quantity), on groundwater dependent ecosystems (GDEs), surface water, culturally significant sites, and other water supply bores, as well as the compaction of sediments, and cumulative drawdown from existing approved water supply works and entitlements (DOI, 2018a). For the purposes of the Review's report, for ease of explanation, physical impacts (such as on groundwater quantity and quality) are distinguished from consequences (such as on culturally significant sites). Depending on the magnitude and extent of the impact, these changes can result in environmental consequences both within and outside the aquifer.

GDEs are a type of ecosystem which can be impacted by groundwater extraction. GDEs are generally recognised as "*ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services"* (Kuginis et al., 2016). Not all GDEs draw on groundwater directly and not all are solely reliant on groundwater, and the groundwater dependence of GDEs will vary due to climate, geology and land use.

The extraction of groundwater can harm GDE ecology if it impacts the amount of water entering wetlands and water courses, may lead to alteration of the ecosystem and loss of ecosystem services (Eamus et al., 2006). For example, where extraction increases the depth to groundwater, the availability of water within the root zone of terrestrial groundwater dependent vegetation will be reduced, which could lead to stress and the potential loss of vegetation (Eamus et al., 2015). Further monitoring and studies are required to improve understanding of tolerance thresholds; and the relationships between drawdown, changes to the groundwater environment and impacts on biota. Impacts to GDEs are considered in the hydrogeological assessment process for groundwater extraction approvals. This process seeks to minimise impacts on groundwater levels associated with GDEs and prevent unacceptable consequences on GDEs.[47]

4.2 COMPLEXITIES IN MEASURING LOCAL SCALE IMPACTS FROM BORE WATER EXTRACTION

4.2.1 Variability of fractured and porous rock systems

There are well established methods for measuring and/or predicting local scale groundwater and surface water impacts. However, in the complex systems of interest here, considerable technical challenges and costs are expected. Addressing these challenges can lead to conservative generalisations or assumptions that idealise the system features, which may or may not be conservative. A brief discussion of these challenges is provided in this section.

The region of interest is characterised by complex geology, with three fractured rock systems (New England Fold Belt Coast, North Coast Volcanics and Alstonville Basalt Plateau) and the Clarence Moreton Basin porous rock. As noted above, fractured rock systems may be highly variable and it is often difficult to assess the size, shape or connectivity of the fracture network. Typically, this uncertainty cannot be resolved via field data collection and assumptions are required to predict sustainable yields.

In contrast, the Clarence Moreton Basin generally consists of porous rock aquifers that are easier to conceptualise. Nevertheless, aquifer property variability within the Clarence

[47] Other potential activities that can impact GDEs include contamination, salinisation, vegetation clearing and filling or draining of wetlands.

Moreton Basin can lead to fractured rock-like behaviour. Overall, the complexities, challenges and costs involved when working in these hydrogeologic systems must be recognised when considering new monitoring guidelines or requirements.

There are considerable challenges in measuring impacts from groundwater extractions. Spatial and temporal variability means that existing groundwater pressure monitoring is unlikely to be sufficient, and monitoring should consider the need for an adequate number of appropriately located measurements. Analytical or numerical modelling may be required to extrapolate the measured pressure drawdowns to the asset locations but these models are only as sufficient as the data used to conceptualise the system. Therefore, it is not a trivial decision to request or require comprehensive assessments/modelling especially where there is already available field (including local) information to indicate that the risks are low.

4.2.1.1 Spatial variability of hydrogeology

Spatial variability in aquifer hydrogeology exists over both regional and local scales. Over regional scales, there will be significant variability in the source aquifer properties and their overlying (potentially confining) layers. This suggests that broad-scale generalisations about aquifer properties, and their degree of confinement (including those made in the WSP), cannot be directly applied to a local scale impacts assessment. Similarly, using hydrogeological properties measured in other water catchments and aquifers, even those of the same classification, is of limited value. Over local scales, fractures and other variations in hydrogeological properties in the area around an extraction bore mean that single or even multiple observations of hydrogeological properties or drawdowns (e.g. during pump tests) may not adequately characterise the Representative Elementary Area (REA). The concept of the REA suggests that the area under observation should be of sufficient size to adequately represent the broader characteristics. In porous media the REA can be relatively small, whereas in fractured rock areas the REA must be much larger to be equally representative.

Another key factor is the connectivity between deep and shallow aquifers. Bore logs showing clay layers (aquitards) between shallow and deep aquifers are sometimes used to support the view that shallow aquifers and surface water are unlikely to impact one another (e.g. aquitards or aquicludes). Moreover, while it may be correct that this supports the argument that there is no connectivity along the profile of the bore log, the spatial continuity of the aquitard is typically uncertain and the area in question may not be characteristic of its REA.

The local-scale spatial variability means that consequences for GDEs and water supply works will not necessarily be at the locations closest to the proposed extraction point. Further, flow pathways between the extraction point and the assets may deviate substantially from straight lines. It is therefore challenging to determine appropriate monitoring locations for measuring depressurisation as the extraction point propagates in various means towards the assets at risk.

The complexities of evaluating and ascertaining potential connections between the deeper groundwater system, the shallower aquifers and impacts on local assets, as a result of spatial variability, is detailed in a case study of town water supply bores at Lumley Park and Convery's Lane which draw from the deeper aquifer in the Alstonville Basalt Plateau Groundwater system. This case study is included at Appendix 6.

4.2.1.2 Temporal variability

Temporal variability of groundwater pressures and surface flows is related to climate, extractions and potentially other human influences. These influences on pressures and flows can have time-lags varying between minutes to years and have complex interactions that make measurements difficult to interpret. This complexity is illustrated in the analysis of the Alstonville groundwater data in Chapter 3. In many cases (but not confined aquifer systems), there is a cone of depressurisation that encompasses assets, but there may also be assets where the impact or consequence is present but more difficult to detect and unambiguously attribute to the extraction. Continuous monitoring technology such as weather stations, pressure transducers and extraction meters facilitate detailed analysis of responses and potential drivers/influences. However, months, years or even decades of data may be required to desegregate the various influences at sites of interest.

4.3 EXISTING TECHNICAL APPROACHES TO MEASURING LOCAL SCALE IMPACTS

4.3.1 Groundwater pressure monitoring

Groundwater pressure or level monitoring is fundamental to impact monitoring. This requires the drilling and construction of monitoring bores called piezometers. This technology is well established. Generally, costs increase with the depth and numbers of bores. As much of the cost is associated with hiring a drill rig and operator, installing additional monitoring bores may not induce significant additional costs when other bores are being drilled simultaneously. Nonetheless, the location and depth of the piezometer should be based on the potential impacts being assessed and the hydrogeological conditions.

Monitoring of groundwater pressures continuously in time is undertaken in two main ways:

1) Conventional water level monitoring. Slotted pipes are installed at the required monitoring depth, whereby the groundwater stabilises to a level equivalent to the water pressure head in the aquifer. A pressure transducer installed below this level or ultrasonic transducer installed at the top of the casing can accurately measure the groundwater level at a desired time interval. This is an accurate method and has a secondary benefits as it can also be used as a sampling piezometric well to collect water quality data;

2) Vibrating wire piezometers allow pressure heads to be monitored at multiple depths, but with lower accuracy, higher cost and limited flexibility regarding the function of the bore. In any case a traditional monitoring bore would also be required to take validation measurements. Hence, conventional technology is typically more applicable in small-medium enterprises, although in principle, the later would be useful if costs reduce and accuracy rises.

4.3.2 Chemical and temperature tracers of water flow

Chemical and temperature tracers to identify groundwater flow patterns are sometimes used to supplement groundwater pressure data. The presence of multiple drivers of water pressures and flows (climate, extractions and potentially others) means that there is often ambiguity in the cause-effect relationship. In hydrogeology, this is often addressed by investigating water chemistry. For example, if the river water chemistry changes from the typical background surface water chemistry to include components of a local aquifer's groundwater chemistry, this may signal a groundwater discharge point. Vice-versa, the chemistry can be used to identify where surface water is being drawn into (recharging) groundwater.

Temperature may also be used in the same way, since groundwater temperatures are usually distinct from surface water temperatures. In this context, the chemistry or temperature are called 'tracers' of water flow. The combination of pressure data and tracers provides further lines of evidence to suggest connectivity between aquifers, or between aquifers and the surface water. Many tracers are straightforward and low cost to implement (although isotope tracers that provide more precise results and give additional information about groundwater age require specialist methods). Indeed, Radon (222Rn) is a commonly used natural environmental tracer as it provides an indicator of the volume of groundwater within a surface waterbody or it can be used to identify groundwater sources.

4.3.3 Numerical modelling

Numerical modelling is often employed where limited field data is available to make adequate predictions. In these cases, hydrogeological, surface hydrology and ecological numerical models may be used based on monitored sites/periods. Numerical models may also be used to simulate scenarios that test the effects of a single existing or proposed extraction bore field if sufficient data is available to adequately characterise the aquifer properties. The use of numerical models introduces many new technical challenges including:

- the value of the numerical model is dependent on the accuracy of the underlying conceptual model and the numerical calibration and validation process,
- the quality of the model depends on the quantity, quality and relevance of available measurements; and,
- the time, data and expertise required for numerical modelling can increase assessment costs.

The limited existing conceptual models and data sets to support modelling is a particular challenge in the Northern Rivers and even more so in the Tweed Shire due to limited previous projects that have warranted the investment. The cost of developing complex numerical models means that they are generally used for larger projects where the potential risks are considerable and the data is limited.

4.3.4 Surface water monitoring

Surface water levels can be measured continuously in time in a similar manner to groundwater. For rivers, the water levels can be converted to flow rates using a rating curve. Unless a hydraulically suitable natural site can be found, achieving accurate rating curve will require an intrusive structure (weir or flume) to be built in the river as well as calibration and regular maintenance.

Alternative non-intrusive river flow measurement technologies are also available. Another limitation of using flow measurements to detect impacts of groundwater extractions is that river flows tend to be dominated by climate influences. Along with the accuracy limitations of the flow gauge, this can make it more difficult to discern the impacts of extractions unless they are large compared to river flows. Extractions near to headwater streams may be relatively large; however further downstream the catchment (where most existing flow gauges are situated) the impacts of extractions of the magnitude relevant to this Review are unlikely to be discernible.

4.3.5 Groundwater dependent ecosystems (GDE) monitoring

Assessing the potential impact of an extraction bore relies on monitoring data measuring the local groundwater level or pressure heads. Applying information about the groundwater level to a terrestrial GDE requires an understanding of the GDE's groundwater use from surficial and deeper aquifers. In many cases there is limited information available to know the exact water requirements of the species of concern.

Methods for monitoring terrestrial GDEs include soil moisture, evapotranspiration and various ecological indices (Richardson et al., 2011). Various technologies and theoretical approaches combined with other data sources can be used to measure soil moisture and evapotranspiration. Both soil moisture and evapotranspiration can be highly variable in space and accurate estimates at one measurement do not always mean sufficient representation of potentially impacted areas. Terrestrial GDE studies conducted in other areas of NSW have generally used a multiple lines of evidence approach combining various monitoring approaches.[48] However, it is rare for this full range of monitoring approaches to

[48] Including measuring the stress of groundwater dependent vegetation through tree growth point dendrometers (stem gauges that monitor tree growth increment at small timescales), sapflow gauges and isotopic analysis of leaf samples (Eamus et al., 2015)

be considered in impact assessments except when high priority GDEs are considered to be at risk.

4.4 ASSESSMENT OF POTENTIAL IMPACTS

The WSP requires hydrogeological reports for certain extraction and development applications. This section provides further detail on the assessment processes associated with these hydrogeological reports. The next section considers the substantive content of these hydrogeological reports.

4.4.1 Applications that require hydrogeological assessment

Hydrogeological assessments may be required under the *Water Management Act 2000* for applications that will change the authorised groundwater extraction volumes from new or existing bores, for example, applications for water supply works approval or applications for water licence dealings. The types of applications that may require a hydrogeological assessment are summarised in Table 13 below.

Table 13: Types of applications under the *Water Management Act 2000* that may require hydrogeological assessment

Application type	Description
s 92: Water supply works approval	Approval to construct a new or additional groundwater work
s 71P: Subdivision and consolidation of access licences	Division of a licence into two or more licences (usually so a portion can be sold); or combining of licences
s 71Q: Assignment of rights under access licence dealing	Reduction of the share component on a licence and the increase by the same amount on another (previously referred to as a permanent trade)
s 71R: Amendment of share component of access licence	Cancel an access licence and grant a new licence in another water source or management area
s 71S: Amendment of extraction component of access licence	Change the times or rates at which water can be extracted (not generally applicable to groundwater)
s 71T: Assignment of water allocations	Reduction of allocation in a licence account and increase by the same amount in another (previously known as a temporary transfer)
s 71U: Interstate transfer of access licences	Same as 71Q dealing except it is between two interstate access licences
s 71V: Interstate assignment of water allocations	Same as 71T dealing except it is between two interstate access licences
s 71W: Nomination of water supply works to access licence	Nomination of a works removed from or added to an access licence, irrespective of ownership and location.

Source: (DOI, 2018a)
Note: Applications for interstate transfer of access licences (s 71U) or water allocations (s 71V) will not require a hydrogeological assessment if they do not impact bores in NSW.

4.4.2 Process for applications requiring hydrogeological assessment

Applications for water access licence dealings or water supply works approvals are lodged with WaterNSW.[49] WaterNSW may refer these applications to DPIE Water for hydrogeological assessment if required. DPIE Water has the necessary expertise to conduct hydrogeological assessments of applications as required. Figure 22 outlines the DPIE Water process for assessing applications for water access licence dealings or water supply works approvals.

[49] WaterNSW is responsible for responsible for granting and managing water licences and approvals for rural landholders, rural industries, developments which are not SSDs or SSIs. However, NRAR is responsible for granting and managing water licences and approvals for government agencies, state owned corporations, water utilities, licensed network operators, mining companies, irrigation corporations, Aboriginal communities, floodplain harvesting, state significant developments (SSD), state significant infrastructure (SSI), schools and hospitals

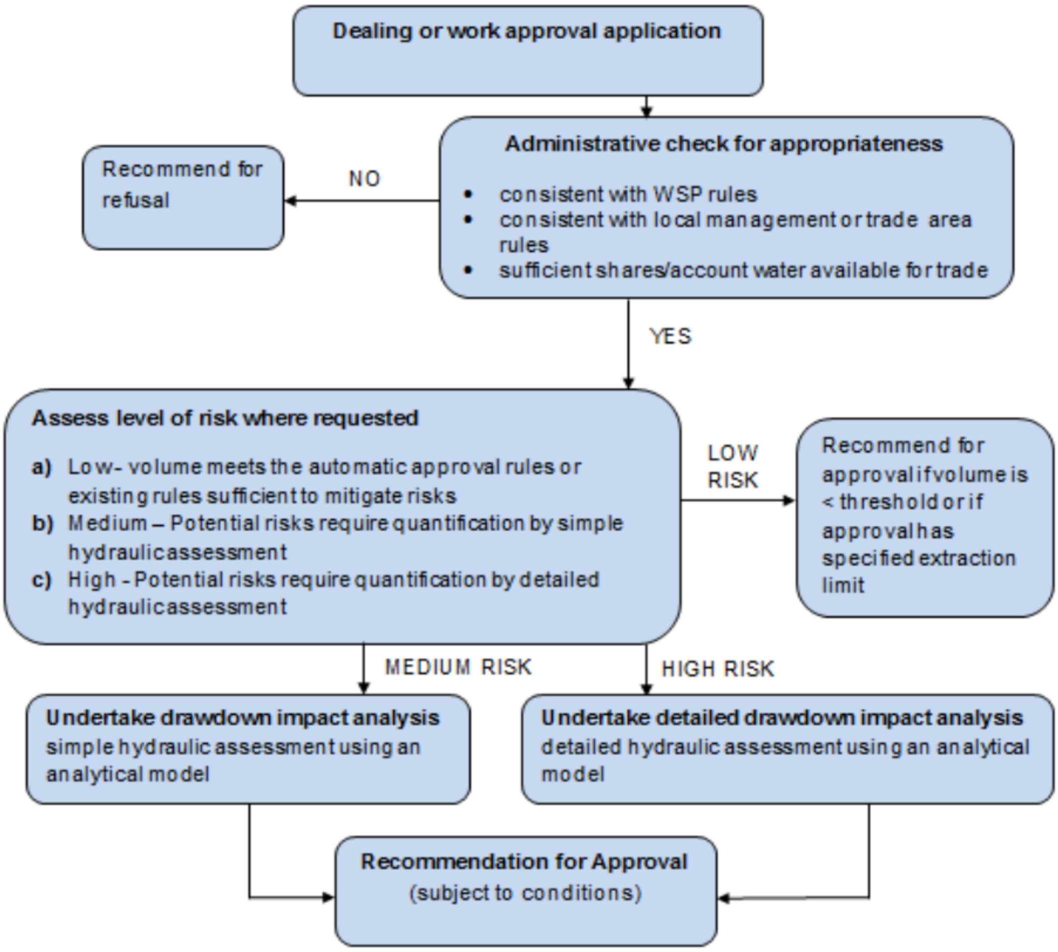

Figure 22: Process for assessing applications for new water supply works approvals and water licence dealings

4.4.3 Applications must satisfy minimum set of conditions

Prior to determining if a hydrogeological assessment is required, all applications must firstly satisfy a minimum set of conditions including:

- **Consistency with the WSP rules** – for example, the WSP may specify conditions on minimum distances to certain environmentally sensitive features (refer to Appendix 7 for further detail);[50]
- **Local management or trade area rules** – for example, certain water dealings may be subject to additional restrictions;[51] and
- **Sufficient water for trading** – for example, the seller must have sufficient shares/account water to trade.

[50] For example, the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 40-3 specifies rules for minimum distances between water supply works to minimise interference.

[51] For example, the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 48(1)-(2) specifies prohibitions on trading between groundwater sources in the WSP and on certain assignments of rights from an access licence in the Alstonville Basalt Plateau (Bangalow-Wyrallah) Management Zone to an access licence with an extraction component that specifies the Alstonville Basalt Plateau (Alstonville-Tuckean) Management Zone. Note that this prohibition only applies if it would cause the sum of the share components of all access licences in the Alstonville Basalt Plateau (Alstonville-Tuckean) Management Zone to exceed the sum of the share components of all access licences in the Alstonville Basalt Plateau (Alstonville-Tuckean) Management Zone at the commencement of this Plan.

The *Access Licence Dealing Principles Order 2004* also specifies general principles and rules for managing dealings in rights and allocations under water access licences. The core principles expounded in the Order focus on minimising negative interference with other water users and the environment, and maximising the value to society gained by extracting the water. These principles include:

- Dealings should not adversely affect environmental water, water dependent ecosystems, or geographical and other features of indigenous, cultural, heritage or spiritual significance.[52]
- Dealings should not adversely affect the exercise of basic landholder rights.[53]
- Dealings should have no more than a minimal effect on the ability of a person to take water using an existing approved water supply work and any associated access licences.[54]
- Dealings should maximise social and economic benefits of access licences to the community. Access licence dealings rules should allow maximum flexibility in dealings to promote this objective.[55]

4.4.4 Applications are subject to a risk assessment

Applications that satisfy minimum conditions are then assessed by DPIE Water for risk to determine what level of hydraulic analysis is required to support the application. Applications can either be considered to be:

- **Low risk** – no further hydrogeological impact assessment is required;
- **Medium risk** – assessment of drawdown impacts using a simple analytical hydraulic model undertaken; or
- **High risk** – assessment of drawdowns using a detailed analytical hydraulic model a is undertaken (DOI, 2018a).

As a general rule, applications which request approval to take larger volumes of water,[56] or which are proximate to other bores, groundwater dependent ecosystems, or other sensitive areas will generally require hydrogeological evidence to support them and validate that the impacts will be acceptably minor. For example, the WSP rules require a hydrogeological report to establish evidence of acceptably minor impacts to approve proposed bores within certain minimum distances from GDEs, groundwater dependent culturally significant sites, other water supply works, and contamination sources (see Appendix 7).[57]

4.4.5 Applications may be subject to a hydrogeological assessment

Based on the risk assessment process, medium and high risk applications are subject to hydrogeological assessment.[58] To inform this hydrogeological assessment, the applicant seeking approval for a dealing or water supply work should supply a hydrogeological report. These reports are prepared by a groundwater consultancy, and will generally comprise a pump test (see further detail below) and a hydrogeological study that includes a technical

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[52] Access Licence Dealing Principles Order 2004 cl 7, 8.
[53] Access Licence Dealing Principles Order 2004 cl 9(1).
[54] Access Licence Dealing Principles Order 2004 cl 9(2).
[55] Access Licence Dealing Principles Order 2004 cl 10.
[56] The Review notes that the licences entitlements for bottled water operators in the region cover a broad range from 5 ML up to greater than 100 ML/year, with some operators drawing on their licences from multiple bores.
[57] *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016* cl 40-3. Note that the standard of acceptability varies depending on the protected feature the works would be proximate to, for example another bore versus a GDE or an environmentally sensitive area versus a source of contamination. WSP applies minimum distances determined by Water Management Committees based on aquifer type and technical advice from the Department (DPIE, 2019a). The Department is developing a fact-sheet detailing the assessment process including assessment of potential impacts on GDEs (DPIE, 2019a). Minimum distance rules may also be influenced by the application of more accurate GDE mapping, developed from the PCT vegetation mapping (DPIE Water, 2019a).
[58] Note that applicants submitting applications for low risk dealings or works would generally not required to provide a hydrogeological report or conduct a pump test.

analysis of the pump test data; and assesses the potential drawdown of the proposed extraction on neighbouring water uses and environmental assets.

4.4.5.1 Applications over 20ML/year will require a pump test

A pump test is required to support an application for approval to construct and use a bore to extract over 20ML/y of water from a groundwater source within the coastal management area of NSW, including areas within the WSP*,* for irrigation, industrial, recreation or other commercial purposes. This pump test should be conducted by a groundwater consultant and form part of the hydrogeological report consistent with WaterNSW guidelines (see Table 15), including providing a "*technical analysis of the pumping test information; and identification of the potential drawdown impacts of the proposed operation on neighbouring users and surrounding sensitive environmental assets*" (WaterNSW, 2017).

Pump tests will generally require a test bore licence from WaterNSW prior to drilling, and must be conducted in accordance with Australian Standards. The proposed volume of water extraction will determine the minimum duration of pump testing,[59] and drawdown and recovery measurements from observation bores may be required (WaterNSW, 2017).

4.4.5.2 Applicability of the Aquifer Interference Policy (AIP)

The NSW Government's AIP focuses on proposed high risk aquifer interference activities where the purpose of water extraction is for disposal, not for use, for example, mine and construction project dewatering involving hundreds of megalitres. WaterNSW and DPIE Water have advised the Review that they consider all applicable policies when considering applications for licences and approvals or providing hydrogeological advice, respectively. However, they do not refer to the AIP for activities that are not defined as high risk under the AIP or do not involve large volumes of water.[60]

4.4.6 Relevant impacts considered in the hydrogeological assessment

As discussed above, the hydrogeological assessment consider the potential drawdown impacts of the proposed water dealing or works on neighbouring water users and environmental and cultural assets. This includes impacts:

- on the groundwater source in question,
- on groundwater dependent ecosystems (GDEs),
- on connected surface water sources,
- on culturally significant sites,
- on neighbouring water supply bores,
- on groundwater quality,
- of compaction of sediments,
- of cumulative drawdown from existing approved water supply works and entitlements (DOI, 2018a).

A key consideration is the impact of any drawdown on GDEs and culturally significant sites. This reflects the objectives of the *Water Management Act 2000*, including to "*protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality*" as well as to recognise and foster social and economic benefits from the sustainable and efficient use of water.

[59] For applications seeking a 21 to 50ML/year entitlement, a minimum one day pumping duration and recovery will be required. For applications seeking a 51 to 100 ML/year, a minimum seven day pumping duration and recovery will be required. For applications seeking more than 100 ML/year entitlement, a minimum 70 day pumping and recovery will be required (WaterNSW, 2017)

[60] See Appendix 4, Initial Report.

4.4.6.1 Groundwater dependent ecosystems (GDEs)

To be able to protect and monitor the health of GDEs, knowledge of their broad-scale distribution, location and vulnerability to changes in groundwater level is required. The NSW Government has undertaken work to identify groundwater dependent ecosystems to meet its legislative requirements under the WMA and WSPs, which require spatial mapping of GDEs to apply the minimum distance rules as discussed above.[61]

The report used remote sensing analysis, including vegetation and groundwater mapping data to identify a model for high, medium and low probability terrestrial vegetation GDEs. However due to the conservative nature of the decision rules, the report acknowledges that some GDEs may have been inadvertently filtered out.[62] The GDE model generated was refined and tested against other existing literature, knowledge of underlying geology and environment, and ground-truthing in other areas of NSW.[63] This mapping will be further updated for the coastal region of NSW following an update of the underlying vegetation classification scheme, resulting in more accurate GDE maps (DPIE 2019, pers. comm., 02 August).

While the probability GDE mapping layers are used by DPIE, the GDE mapping used in the WSP is a point layer map that is not electronically available and only recognises GDEs considered 'high priority'[64]. DPIE has indicated that new WSPs under development or being re-made in NSW will refer to a full dataset of all GDEs identified by NSW DPIE and link to the National GDE Atlas (DPIE 2019, pers comm., 23 October).[65] The WSP allows for the list of high priority GDEs to be amended after year five of the plan as further GDEs are identified, or during the life of the plan following approval by the Minister (DPI Water, 2016f).

4.4.6.2 Culturally significant sites

Six different Aboriginal nations occupied the NSW north coast prior to European settlement due to the high diversity and abundance of natural resources in the area, particularly around the Northern Rivers region. The Tweed and Northern Rivers region is the traditional home of the Bundjalung Nation. The area has a number of culturally significant coastal sites, special meeting places, middens, campsites, hunting and gathering sites, crafting sites, and ceremonial places. The water and vegetation in the area provided the people with critical resources including flora and fauna.

The WMA and hydrological assessment process recognise and protect culturally significant sites and aim to foster social and economic benefits to culture and heritage. The WMA specifically aims to recognise and foster "*benefits to the Aboriginal people in relation to their spiritual, social, customary and economic use of land and water*."

These objectives are reflected in the WSP, which recognises the multidimensional relationship Aboriginal people have with land and water – including spiritual, customary and economic. This means that not only should certain sites be protected because of their spiritual and environmental significance, but also because the ecosystems and flora and fauna they support should be preserved to enable ongoing traditional practices including hunting, fishing and gathering. The WSP recognises this multidimensional relationship by establishment and prioritisation of Native Title rights within Basic Landholder Rights as well

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[61] This work is summarised in the report, *Methods for the identification of high probability groundwater dependent vegetation ecosystems* (Kuginis et al., 2016).

[62] This technique recognised some but not all wetlands; other potential GDEs such as stygofauna (groundwater invertebrates important to maintaining water health) and groundwater baseflow contributions to surface water were not included.

[63] Note that this mapping will be updated to provide a more comprehensive and accurate GDE map for the coastal region of NSW following an update of the underlying vegetation classification scheme (DPIE Water, 2019b)

[64] Identified in 'The GDE Map' attached in Appendix 10 of WSP Background Document (DPI Water, 2016f) and Appendix 3 of the WSP

[65] The Atlas includes data obtained through a national assessment process as well as NSW. GDEs will be prioritised according to the High Ecological Value Aquatic Ecosystem (HEVAE) Framework developed as part of the Aquatic Ecosystems Toolkit (2012).

as permitting Aboriginal communities to apply for a WAL for cultural purposes or community development purposes. The WSP identifies a number of groundwater sources that represent areas of spiritual and cultural significant to Aboriginal people.

The hydrogeological assessment process also recognises and protects culturally significant sites, including sites of significance to Aboriginal people, by considering the potential drawdown impacts of proposed water dealing or works on these sites (including with respect to the traditional uses of these sites). As discussed above, the WSP specifies minimum distance rules to groundwater-dependent culturally significant sites to avoid unacceptable impacts on these sites. These rules apply not only to sites of significance to Aboriginal people, but also to other sites of cultural and heritage significance.

Information on groundwater-dependant culturally significant sites is constantly updated by DPIE through engagement with Aboriginal peoples (DPIE 2019, pers comm., 25 September). This is an ongoing activity as even once a site has been identified, further information may be required to understand the cultural significance of the site, its interrelationship with the groundwater source and the associated water requirements of the site.

4.4.7 Defining the level of acceptable impacts

For different groundwater sources, the magnitude of acceptable impacts currently applied by DPIE Water for groundwater dealings and water supply work approvals on water drawdown varies. Table 14 details the acceptable impacts on the water table and groundwater pressure for most porous and fractured rock groundwater sources in NSW.[66] These criteria apply to all four groundwater sources within the scope of this Review.

Table 14: Acceptable level of impacts for porous and fractured rock groundwater sources

Type of impact	Level of acceptable impacts
Impact on water table (unconfined aquifers)	1. Less than 0.1 metre cumulative drawdown in the water table 40 metres from any: a. High-priority, groundwater dependent ecosystem, or b. High-priority, culturally significant site. 2. An additional drawdown of not more than 10% of the pre-development Total Available Drawdown (TAD) to a maximum of 2 metres at any: a. 3rd or higher order surface water source measured at 40 metres from the high bank. b. Water supply works (excluding those on the same property), subject to negotiation with impacted parties. 3. A cumulative drawdown of no more than 10% of the pre-development TAD of the unconfined aquifer at a distance of 200 metres from any water supply works including the pumping bores.
Impact on groundwater pressure (confined/semi-confined aquifers)	1. A cumulative drawdown of not more than 40% of the pre-development TAD at a distance of 200 metres from any water supply works including the pumping bores. 2. An additional drawdown of not more than 3 metres at any water supply works (excluding those on the same property) subject to negotiation with impacted parties.

Source: (DOI, 2018a)

When assessing expected impacts against the acceptable level of impacts, the impact period considered varies from one year for temporary trades,[67] to 10 years for permanent trades.[68]

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[66] Except for porous and fractured rock groundwater sources within the Great Artesian Basin for which different criteria apply.

[67] For example, assignment of water allocation to another licence under s 71T of the *Water Management Act 2000 (DOI, 2018a)*

[68] For example, assignment of share component of a water access licence under s 71R or 71Q of the *Water Management Act 2000 (DOI, 2018a)*

4.5 MANAGEMENT OF IMPACTS AFTER APPROVAL

The primary mechanisms for managing the impacts of groundwater extraction under existing groundwater entitlements are conditions on works approvals or access licences, conditions on development consents through the councils, water allocations (or 'available water determinations') and temporary water restrictions.

4.5.1 Conditions imposed on approvals (WALs and works approvals)

Approvals may be subject to conditions, including:

- 'Mandatory conditions' – conditions imposed by the *Water Management Act 2000*, *Water Management Regulations 2018*, or the relevant WSP,[69]
- 'Discretionary conditions' – conditions specific to the particular approval and location, for example to give effect to agreements between an applicant and an objector, or to protect the environment.[70] These conditions would be informed by the hydrogeological assessment that may identify particular areas of risk that can be managed through conditions of approval.

Mandatory conditions prevail over discretionary conditions to the extent of any inconsistency between them.[71] The applicable conditions are specified in the relevant licences or approvals. Common conditions on water access licences and works approvals for groundwater extraction include:

- Installation, maintenance and operation of appropriately configured water meters.
- Installation, maintenance and operation of a data logger.
- Recording of pumping activities in a logbook.
- Provision of data, records and reports to the Minister and/or the Department covering water quantity, water quality, application of water, etc.
- Permitting the Department access to the site to inspect and test the works.
- Duty to notify the Minister or Department of breaches.[72]

4.5.2 Conditions of development consents

Bottled water operators in the Northern Rivers region generally require a development consent under the *Environmental Planning and Assessment Act 1979* (EP&A Act) to construct or expand the necessary facilities to extract water for bottling purposes. To obtain the necessary consent, the operator submits a development application to the local council. Historical development consents for water bottling firms operating in the region date back to 1993.

It is within council's remit to apply conditions and performance measures to the consent, which can be in relation to impacts and consequences of the development. These may require the operator to develop a plan for monitoring and reporting their performance against these conditions. For example, a recent consent (issued late 2018), imposed conditions related to water take (specifically, the volume in ML/y of water permitted to be extracted), a requirement to use a daily log book, and the transport of that water (specifically, maximum truck movements and daily hours of operation permitted). Conditions provide a mechanism for councils to set standards and outcomes for protecting certain environmental values and to monitor and assure compliance. Conditions may be varied subject to an application by a proponent to modify the consent, but only in relation to the subject area of that modification application.

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[69] *Water Management Act 2000*, s 100(1)(a) and s 100(1AA)
[70] *Water Management Act 2000*, s 100(1)
[71] *Water Management Act 2000*, s 100(1)(a) and s 100(1AA)
[72] A search was conducted of conditions of water access licences and water supply works approvals for bottled water extraction operations in the Northern Rivers region.

The Review considered a number of development consents for bottled water operators in the Northern Rivers region. While the scope of conditions contained in these consents was broad, the Review did not identify conditions that related to local impacts on aquifers or groundwater, or potential environmental consequences associated with those impacts.

Tweed LEP 2014 required the Council to be "*satisfied that development will not have an adverse impact on natural water systems or the potential agricultural use of the land*"[73] and under the EP&A Act, to consider the likely environmental impacts of the development.[74] As a result, Tweed Shire Council has informed the Review that it expects more detailed hydrogeological information to be submitted during the assessment process for development approvals for the bottled water industry, including seeking information on conceptual models, testing and ongoing monitoring plans.

The Review also notes that these expectations around hydrogeological assessment also need to be seen in the context of a regulatory framework that places significant responsibility for hydrogeological assessment and licence or works approvals with the state government.

Tweed Shire Council has informed the Review that where the extraction of water has been subject to the hydrogeological assessment and approval by the state government, the Council historically focused on assessing and imposing conditions on other environmentally relevant matters not covered by conditions of the water licence or works approval – for example, noise, truck movements and hours of operation.

However given the LEP, there was a question as to the extent to which the Council needed to or should undertake its own hydrogeological assessment.

Given the implications of the overlap between development consent conditions and water licences or works approvals, further work should be undertaken to ensure consistency, to avoid duplication of effort, and to address any gaps in the assessment and approvals process.

4.5.3 'Water allocations' or 'available groundwater determinations'

WSPs provide a mechanism, a 'water allocation' or an 'available water determination' (AWD), to control water take for each licensed water user each water year. The AWD is intended to ensure that water take is managed to the extraction limit, to prevent impacts on the water source and other users or consequences to GDEs, and to provide certainty to water users regarding the amount of water that can be taken and under what conditions.

The AWD process for groundwater sources determines the available water in the coming water year by considering the LTAAEL,[75] water entitlements under access licences and basic landholder rights, and actual water take. The AWD assigns a portion of the available water to each licensed water user based on their water entitlement. While the AWD is conducted each water year, the focus of the AWD is to manage sustained growth in actual water take to the LTAAEL, which is a long-term measure.[76]

On 26 June 2019, DPIE Water issued an *Available Water Determination Order for the North Coast Costal Sands and the North Coast Fracture and Porous Rock Groundwater Sources 2019* for the 2019-20 water year commencing 1 July 2019. The statement allocated local water utility and aquifer licence holders covered by the WSP groundwater sources an allocation of 100 percent of their entitlement, or 1 ML per share unit.

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[75] The LTAAEL represents the extraction limit of a particular groundwater source over the long term, expressed as an average.
[76] For example, the standard water allocation for licensed water users is 1ML/unit share, but Clause 29(2)-(3) the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 specifies that where growth in water take is assessed to have increased more than 5 percent above the LTAAEL extraction limit over a three-year period, the water allocation may be reduced to less than 1ML/unit share.

4.5.4 Temporary water restrictions

Under section 324 of the *Water Management Act 2000*, temporary water restrictions can be imposed in the public interest.[77] These restrictions can prevent or impose restrictions on the taking of water from a specified water source and area for a specified period:

- to maintain or protect water levels,
- to maintain, protect or improve water quality,
- to prevent land subsidence or compaction,
- to protect groundwater dependent ecosystems, or
- to maintain pressure or to ensure pressure recovery.[78]

The majority of Temporary Water Restriction Orders that have been enacted are for regulated river systems. Fewer Orders have been enacted for groundwater sources.[79]

4.5.5 Collaborative data and approach

The Natural Resources Commission's 2005 Standard for Quality Natural Resource Management established 'Opportunities for collaborations' as one of seven components of the Standard, and the subsequent 2013 NRC review of the 2004 WSP was undertaken in view of this Standard (NRC, 2005). The 2013 review identified a number of examples of collaboration and further opportunities, including sharing spatial information between agencies, with licence holders on operational matters; to ensure shared data is used; and ensure NSW Government's various regulatory frameworks, investments and interventions complement each other (NRC, 2013).

This Review (by the NSW Chief Scientist & Engineer) has also identified opportunities for enhancements in the way that agencies and council collaborate on data sharing and their various roles in the water management process including with respect to the bottled water industry. These include the need for relevant authorities to:

- Develop a shared understanding of the data, modelling and information needed by each agency in decision making
- An agreed and documented set of standards for data capture, sharing, storage (frequency, metadata requirements, computational and program requirements, data sharing protocols including in relation to commercial data)
- When potentially new measurement and monitoring technologies or regimes are introduced, an approach to discuss (and reach agreement on) the most effective measures to roll out new monitoring to maximise the utility and outcomes for the group of agencies
- Where new performance indicators are identified through the WSP or performance measures conditioned on proponents, a shared understanding by agencies of which legal instrument these measures should be attached to, and how data on these measures is communicated with relevant agencies for the purpose of compliance, or measuring cumulative impacts, or providing for research activities. Where new performance measures are required of proponents, a forum to discuss between

[77] *Water Management Act 2000*, s 324(1).
[78] *Water Management Act 2000*, s 324(2)
[79] On 21 February 2018, temporary water restrictions were imposed for the Botany Sands Groundwater Source in response to a threat to public health and safety, see NSW Government Gazette No 23 of 23 February 2018, 816. On 1 September 2009, temporary water restrictions were imposed for the Mid Murrumbidgee Groundwater Management Area 013 in response to a threat to public health and safety, see NSW Government Gazette No 136 of 25 September 2009, 5229. On 17 August 2009, temporary water restrictions were imposed for the Upper Namoi Zone 11 – Maules Creek Groundwater Source to protect water levels in an aquifer and to protect groundwater dependent ecosystems, see NSW Government Gazette No 113 of 18 August 2009, 4815. On 25 June 2009, temporary water restrictions were imposed for the Lower Murrumbidgee Groundwater Sources and Lower Murray Groundwater Source in response to a water shortage, See NSW Government Gazette No 95 of 26 June 2009, 3797-8. On 14 March 2009, temporary water restrictions were imposed for all aquifers or parts of aquifers underlying the Blue Mountains City Council Local Government Area to protect groundwater dependent ecosystems, see NSW Government Gazette No 52 of 20 March 2009, 1431.

agencies where there are potential contradictory measures, and the most appropriate instrument to reflect conditions in a way that prevents duplication.

4.6 OBSERVATIONS ON PAST HYDROGEOLOGICAL REPORTS

Hydrogeological reports dating from 2007 to 2019 were made available to the Review by seven operators (or proponents) of bottled water extractions in Tweed Shire and Ballina Shire. These represent a large proportion of the industry hydrogeological reports that are being used to support recent licence or development applications related to the bottled water industry. Two reports that did not support license or development applications are discussed in this section in general terms only. The Review notes that a small number of operators have historical licences and documentation was limited.

This section summarises the reports' purposes and contents, public and government responses to the reports, and general observations regarding the comprehensiveness of the assessment and alignment with currently available guidelines. The purpose of this analysis is to identify general challenges that emerge in developing reports (versus a full technical assessment) that are sufficient to inform license assessments or development applications.

The hydrogeological reports, in most cases, assess hydrogeological impacts of proposed developments on surface flows, GDEs and surrounding groundwater bores. Some of the hydrogeological reports have additional purposes including assessing the commercial viability of the bores. One report focusses solely on the water quality risks to the bore. One report is an update of a historical report, including supplying updated water quality results, without supporting a current development or entitlement application.

The focus and style of the reports varies depending on the purpose and the identified or perceived risks. Six of the seven reports are presented in conventional consultancy report format; one is presented as a letter to the proponent.

4.6.1 Review of the available hydrogeological reports for the industry

The collective content of the hydrogeological reports is reviewed here against the *Groundwater Consultancy Requirements - Hydrogeological investigation report standardised table of contents* in the "Coastal groundwater: Test pumping groundwater assessment guidelines for bore licence applications". This guideline is specific to pump tests for supporting license applications and does not provide a definitive guideline for the hydrogeological reports in question; however, it provides a useful, established template for this review (Table 15). Other relevant comments regarding the content of the hydrogeology reports, for the purpose of supporting development applications, are listed below.

4.6.1.1 Level of detail in the hydrogeological reports commensurate with the risks and requirements of applicable guidelines and policies

All reports refer to the WSP. Identification of specific relevant requirements of the WSP is variable between the reports.

The main public policy document referred to in the hydrogeology reports is the WSP. This policy stipulates minimum distances of extractions from high priority GDEs, high banks of a river or stream, culturally significant sites and water supply works. There is provision for changing these distances on a site specific basis if risks can be shown to be low, implying additional investigation would be required. In most of the existing/proposed bottled water sites, these minimum distances are reportedly met, and so there is no explicit requirement in the WSP to conduct further hydrogeological investigation.

In cases, there are rivers/creeks within the stipulated minimum distance (40 m) of the extraction sites, and in all cases there are rivers/creeks within a few hundred metres; therefore there is an onus on the proponent to demonstrate there is no (or very low) hydraulic connectivity between the target aquifer and the surface water. This is done with reference to the regional-scale classifications of connectivity in the WSP, to bore logs that show confining layers, to results of pump tests, and, in cases, to differences in water chemistry between the aquifer and surface water and anecdotal evidence of stable surface water responses.

During consultations in the Review, concern was expressed over the lack of objective, local-scale evidence to demonstrate low connectivity between the target aquifer and surface water. This is reflected in hydrogeology report conclusions by use of subjective terms such as “unlikely to cause impacts”, which are considered by some stakeholders as lacking an evidence base.

Beyond the WSP requirements, the purpose of the reports includes satisfying the council requirements that the hydrogeological risks are acceptable. Meeting the minimum distance requirements of the WSP and the largely qualitative analysis of connectivity undertaken in the reports is not necessarily sufficient to meet this purpose. The absence of detailed modelling or significant monitoring of assets at potential risk means impacts and risks are unquantified. The cost-benefit of additional modelling and monitoring where this is not explicitly required by the WSP or other published guidance is predominately based on judgement and is disputable even among hydrogeology experts .

The hydrogeology reports all recognise that lack of data hinders understanding. In most cases the reports include recommendations for further investigation, although they do not explicitly recommend this is required prior to approval. Two reports recommend further pump tests to confirm sustainable extraction rates, two recommend additional monitoring during bore operations, and one recommends monitoring shallow groundwater with an associated cease-to-pump trigger. The review of the hydrogeology reports also noted that in some cases uncertainties and data limitations were identified in the report; however these were not always well reflected in the report’s conclusions or executive summary.

Table 15: Contents of five bottled water industry hydrogeological reports from the Tweed and Ballina Shire compared against standardised table of contents in the coastal guidelines

Hydrogeological investigation report standardised table of contents		Included in report	Extent of detail
Certification	Groundwater consultant (qualified)	Yes, in all reports	
Introduction	Property location, identification of the proposed development	Yes, in all reports	All reports provide maps showing property location. All reports include a map or maps showing key features of the property (~1 km); all but one show the location of the property with respect to locality features (~5-10 km); and most also show location on the regional scale (~50-100 km scale). Quality of maps is variable.
	Purpose for which the licence is being sought	Yes, in all reports	Sufficient
Geology	Geological description of the property and surrounding region	Yes, in all reports	All reports describe the site's geological context. The level of detail in all reports is constrained by lack of available regional and local scale geological data. All full reports contained one or more bore logs that describe geology over the depth of the bores. Only one report provides a regional geological map, although the value of this is debatable, and other reports refer to relevant published maps.
	Stratigraphic boundaries or structural features that may influence groundwater availability	No	Available data does not permit this, although it is likely to be relevant to at least some of the sites
Hydrogeology	Setting: Description of the type of aquifer and a summary of typical water bearing zones encountered in test bores in the vicinity of the property	Yes, in all reports	In some reports the information could be improved using existing sources of data
	Licensed: Details of licensed water supply bores within 1km of the property including works purpose and likelihood of being impacted should the proposed development proceed	All reports identify nearby water supply bores, but not all use a 1 km radius; all assess likelihood of impacts	The likelihood of impacts is addressed with support from pump test results, water quality data, bore logs, regional hydrogeology data, the thresholds specified in the WSP and in some cases the AIP, and in two cases other (unsubstantiated) local hydrological observations. Due to absence of monitoring and modelling at the potential receptor bores/GDEs and pathways from the extraction to these receptors, the analysis of likelihood is subjective.
	Environment Identification of ecosystems likely to be groundwater dependent, surface water systems that could be affected by reductions in discharge with prolonged pumping	Yes, in all reports	The identification of GDEs in most cases relies on the High Priority Groundwater Dependent Ecosystem (GDE) Map in the WSP and the National GDE Atlas webtool supplemented by site visits. One report is vague about criteria used for determining presence of GDEs.
	Particular identification of sensitive ecosystems of special conservation value	Yes, in all reports	
Field work	Test bore establishment: Details of the drilling and construction of the subject bore, identifying the test bore licence under which it was authorised. A statement of compliance with the Minimum Construction Requirements for Water Bores in Australia – Second Edition 2003 or	Information about the bores is provided in all cases although the level of detail is	The pump test bores in all cases are existing pumping and monitoring bores (piezometers). I.e. they were not drilled for the purpose of the reported pump tests. The available details on bore establishment are variable. In most cases bore logs are provided. A statement of compliance is made in only one case.

Hydrogeological investigation report standardised table of contents		Included in report	Extent of detail
	subsequent equivalent guideline.	variable.	In all cases but one, other relevant observations of the local hydrological and land use context made during field visits are described.
	Test pumping and recovery: Measurements and graphical analysis documentation of drawdown and recovery data for pumping and observation bores. Calculated aquifer transmissivity and storativity values, together with bore efficiency estimates. Details of the water quality tests (compliant with requirements; National Uniform Drillers Licensing Committee, 2012) undertaken to demonstrate the groundwater is suitable for the intended purpose.	Pump test data are provided in all cases. In all cases water quality information is provided to show fitness for purpose although compliance is not stated.	As stated above, the observations make use of available bores rather than being drilled specifically for the tests. In one case an observation bore was not used (it was recommended if the approval was given). In all cases but that one, aquifer transmissivity and storativity values are estimated, together with bore yields. Water quality assessment is extensive due to its commercial importance. Sufficiency of pump tests (including location of monitoring bores (piezometers) and length of test) is questionable in cases, and further pump tests are recommended in some cases.
Impact assessment	Sustainability: Predictions of the impacts of pumping of the subject bore on neighbouring licensed users and potential groundwater dependent ecosystems based on the required controlled test pumping, together with the predicted effects on groundwater levels for the region surrounding the subject property and the potential to affect discharge to surface water systems	All reports undertake this to some extent	The level of quantitative analysis presented is variable, depending on the availability and quality of pump test data for identifying a zone of influence. In most cases expert judgement is relied upon, including caveats about lack of data. The potential to affect discharge to surface systems is not assessed because aquifer discharge locations are unknown but are not thought to be local based on the regional-level connectivity descriptions in the WSP. Connectivity of the target aquifers with shallow groundwater and surface water is assessed using regional scale knowledge supplemented by bore logs and water quality.
	Trigger levels: Identification of the threshold drawdown levels adopted to prevent impacts on neighbouring bores or ecosystems, and estimations of the maximum drawdown impact on neighbouring bores, monitoring bores (piezometers) and ecosystems with and without trigger levels being active	One report recommended a shallow groundwater trigger level	Only one report recommends a trigger. In all cases, risks to neighbouring bores and GDEs are concluded to be low, and it may be assumed that triggers were not considered appropriate (cease-to-pump triggers are generally only used as part of groundwater licensing in high-risk projects such as mining).
	Management Responses: Actions to be taken if threshold levels are reached or exceeded, including reporting to regulatory authority, cease-to-pump conditions, and provision of water to affected users		
Operation	Schedule Identification of the proposed operating regime including discharge rate and hours of pumping	All reports refer to pumping volumes.	All reports refer to licensed volumes; some also refer to proposed annual volumes; and some to hours of pumping that can be sustained at a given pumping rate. None refer to the specific operating regime, which is likely to be unknown at the time of the analysis.

Hydrogeological investigation report standardised table of contents		Included in report	Extent of detail
	Monitoring Descriptions of the location of monitoring bores (piezometers), the frequency at which monitoring is to be undertaken and the type of data to be collected	Monitoring piezometers and the monitoring used during pump tests are described	Most reports recommend continual monitoring of drawdowns at existing or new monitoring bore (piezometers).
	Reporting Details of the timing of reports, the type of information to be reported to the regulatory authority, the number and nature of exceedances and response times between an occurrence and management actions being implemented, and methodologies to be adopted to mitigate impacts should they be ongoing	This is not included in the hydrogeology reports	The reports are not written in the context of an adaptive regulatory regime, since this does not typically apply to low risk extractions. Most reports recommend continued monitoring to inform sustainable extractions.
Constraints	Identification of any consent conditions imposed by council or other regulatory authority that would prevent the requested entitlement being realised in full for the purpose for which the licence is being sought. In particular, conditions limiting the supply of water to other parties are to be identified	All reports describe current relevant licenses	The reports identify the status of license and development applications and relevant constraints. In most cases licenses exist and the application is about a change of bore use and/or a council development application.
References	Citations of all documentation referred to within the report.	Yes, in all reports.	There are cases where the referenced documentation must be inferred, rather than being properly cited.
Figures	All diagrams referred to within the report, including a locality map, a plan of the property identifying separation distances between the subject bore and site boundaries or other features (especially suspected groundwater dependent ecosystems, licensed works and surface water bodies), geological map and sections, together with a plan illustrating the extent of predicted drawdown during the proposed pumping operation	All reports include maps	The maps vary from excellent quality showing all relevant available information, to poor quality and of questionable completeness.
Appendices	Raw data and additional diagrams or text required to provide background or support to the findings of the investigation	All reports (except that in the format of a letter) provide appendices with further data	All relevant raw data are not included in all reports, and in cases where it was provided, there was no accompanying interpretation or description of methods used to obtain the data.

Source: (WaterNSW, 2017)

4.6.1.2 Accessibility of the hydrogeological reports to a non-technical audience

The hydrogeology reports are necessarily highly technical are not comprehensible to non-experts. In most cases the Executive Summary and/or Conclusions sections of the reports are more accessible; however these alone cannot be relied upon to make approval decisions since they do not always reflect the full detail of the report including any particular uncertainty in the local hydrogeological conditions and limitations of the tests and data employed.

During consultation, some councils commented on their limited internal hydrogeological capacity and reliance on guidance by WaterNSW/DPIE Water and/or external consultants and hydrogeologists when necessary. Documents show that significant assessments are made to support the Council by WaterNSW (using technical advice from DPIE Water). It is important that the reports retain the highly technical content given the complexity of groundwater assessments in general, but particularly in complex systems like those in this region and the risk of losing vital information. Clarity around this could be improved through the application of standardised table of contents like the one in the Coastal Groundwater guidelines.

4.6.2 Public responses to the hydrogeology reports

In three cases, the Review team has seen responses by public interest groups and/or their expert advisors, where concerns about the methods and conclusions of the hydrogeology reports are raised. The concerns mainly relate to:

- *The lack of measured data to support assessment of local impacts.* In particular, the responses from experts and interest groups argue the lack of characterisation of the connectivity between the proposed extraction point and nearby creeks. Recommendations are made by academics, commissioned to peer review the reports, to: measure shallow and confined groundwater pressures to understand the connectivity; conduct shallow groundwater monitoring over different depths between the creek and target confined aquifer to measure responses to pumping; and to measure creek flow responses to pumping including in low flow periods that are most vulnerable to impacts. In one case, the expert presents calculations that demonstrate the potential for large impacts on creek flows if a high degree of connectivity is present. In another case, water quality data are re-interpreted by an expert as signifying the potential for a connection between the targeted aquifer and the creek.
- *The over-reliance on aquifer-scale generalisations to support local scale assessment.* This relates to assumptions about connectivity taken from regional generalisations in the WSP. While the low levels of the proposed extractions compared to the extraction limits in the WSP are recognised by the expert, this is considered to be an insufficient indicator of local impact risk. Cumulative impacts due to future potential extractions are also raised as a concern.
- *Uncertainty.* Following from the above points, the experts and interest groups argue that some conclusions of the reports are unreasonable given the level of uncertainty in the assessment.
- *Perceptions of factual errors.* In one case the interest group notes that there are bores near the proposed site that are omitted from the report. In a later response, the hydrogeology consultant noted that these bores could not be identified from publicly available databases and welcomed further information about them.

4.7 FURTHER INFORMATION TO UNDERSTAND SYSTEM IMPACTS FROM BORE WATER EXTRACTIONS

As discussed, there are considerable challenges in measuring and managing local impacts from groundwater extractions due to numerous factors, in particular the spatial and temporal variability of hydrogeological systems, and imperfect monitoring technologies and modelling methodologies. However, further improvements could be made to assist in measuring, assessing and managing the impacts of groundwater extraction within acceptable limits. While some of these improvements could pose resourcing challenges for proponents and government, a set of potential improvements is discussed below.

4.7.1 Investment in monitoring and technological advances

One of the challenges associated with assessing potential impacts from extractions is the limited amount of field data available, particularly in the Tweed systems. At present there are very few monitoring piezometers in the Tweed, although this is not the case with the state monitoring network in the Alstonville region. Improving piezometric monitoring is needed, at multiple complementary locations where there is perceived risk and/or lack of knowledge of groundwater responses and flow. However, investment in additional monitoring should balance the resources required to install and maintain equipment, and record and interpret the data against the value of expected improvements in data availability and quality. This should be informed by the characterisation of the risk level that the system is in – systems at greater risk would be prioritised over locations and systems at lower risk.

Another important development is the increasing ease at which sensing technologies can be deployed to the field at low cost. These technologies are variously commercially available or under development, and include improved traditional sensing technologies (for example, lower cost and more adaptive remote sensors), as well as advanced technologies offering novel capabilities (for example, quantum gravity sensors able to penetrate depth with significant accuracy).

4.7.2 Metering data

Water extraction metering supports the validation of actual groundwater extraction against licenced allocations and is an important improvement for water policy and management at a regional level (including the development of water sharing plans and available water determinations), as well as enforcement actions against individual licence holders. Access to extraction volumes would also help better determine impacts caused by extractions versus climate variability.

The Review notes that four of the bottled water operators in the region were required in December 2018 to install meters on their systems. The metering policy for qualifying groundwater systems will take effect in this region in 2023 (DOI, 2018b).

4.7.3 Improving clarity on NSW government's expectations of hydrogeological assessment reports

The evolving regulatory context has resulted in a number of policy and guidance documents that are potentially applicable.[80] These documents have led to a complicated array of guidance to proponents and consultants about what is required for a hydrogeological assessment.

As discussed above, hydrogeological assessment reports are variable in content and the level of contextual information, monitoring and data analysis included reflects the characterisation of the risk (Figure 22). Some of the hydrogeology reports this Review considered contain assessments of commercial viability of the bores as well as environmental assessments. In cases, the monitoring or methods used were not considered adequate by experts representing interest groups or by the agencies responsible for evaluating the reports. To a large extent this can be addressed by comprehensive and

[80] These include the WSP and its supporting documents, the AIP and its supporting documents, the 2018 Water resource Plans – Fact sheet – Assessing groundwater applications, and the Coastal groundwater test pumping assessment guidelines, among others.

consistent guidance on approaching the hydrogeological assessment as discussed above.[81] To help facilitate consistent contents of the reports, the environmental component could be a separate report or be clearly signposted.

These challenges have been addressed to some extent by the recent fact sheet (September 2018) that provides definitive criteria for acceptable levels of impacts (DOI, 2018a). The Review is also aware that DPIE Water is currently updating some pump test requirements. It is recommended that the relevant NSW government agencies should seek feedback from consultants on this document and its interaction with other policies, potentially leading to revised and integrated guidance. Similarly, feedback on applicable pump test guidelines could be sought and considered. The NSW government should continue to strive towards publicly available guidelines that reflect consistent internal assessment methods of agencies, and continue to provide access to its technical experts to provide any clarification needed to consultants.

4.7.4 Additional requirements concerning shallow groundwater drawdowns

The assessment of impact risks in the approvals process is presently based on minimum distances between extraction and assets, maximum permissible drawdowns in groundwater pressure heads at stipulated distances from assets, as well as guidelines on minimum requirements for pump tests and their reporting.

Currently there are no explicit requirements for the proponent to demonstrate that there are no detectable impacts at assets surrounding the site or detectable hydraulic connection between extractions from (assumed) confined aquifers and overlying shallow groundwater and surface water. However, monitoring of shallow aquifers is seen by many experts as a practicable method of measuring whether pressure drawdown at the extraction point has propagated towards assets at potential risk. In principle, this may be implemented as part of the pump tests, and/or as a requirement of the approval with an associated cease-to-pump criterion. This would require careful selection of appropriate monitoring points, which represent the potential hydraulic connection between the extraction and assets at potential risk, as well as a criterion for assessing acceptability of any observed effect. The requirement for an adequate period of baseline data would be an additional consideration.

In projects involving large groundwater extractions, it is common for shallow groundwater, surface water flow and/or GDE health indicators to be used to define triggers, whereby a defined level of impact would trigger a cessation of pumping. In practice, such monitoring is expensive to install and operate, requires a process for identifying acceptable impacts and triggers, a process for reporting and auditing, may require access to private land and increases investment risk for the proponent, due to increased uncertainty over continuity of operations. Therefore it is most appropriate in potential high risk cases. In the case of managing local impacts of high volume extractions on high-risk assets, a viable option may be to monitor easily measured parameters such as shallow groundwater levels on the property in question. However, in many cases the link between shallow groundwater levels and surrounding off-property assets such as GDEs will be arguable.

As well as providing an increased (although not comprehensive) safeguard against impacts, provide insight into factors like how the shallow system responds to rainfalls and the layering of the system at the local scale.

It is also important to consider the appropriate authority for any additional monitoring requirements. For example, if this monitoring is to be required as part of a development consent condition, local government should consider how risk tolerances should be balanced

[81] For example, the AIP comes with an application guide for consultants that includes a checklist, which allows the consultant to specify where in the hydrogeology report the AIP requirement is addressed. This might be considered for other applicable guidance.

against imposing further obstacles to development. Further, if the monitoring requirements for development consents are different from requirements of license dealings and works approvals, this would require a separate guidance documents for proponents and their consultants. Since the requirements regarding number, location and depth of shallow groundwater monitoring will be project-specific, the guidance is likely to be about the process, principles and general criteria rather than monitoring design.

4.7.5 Field verification

To address hydrogeological complexity, site investigations may be undertaken or required prior to designing an impacts assessment. This may include exploratory drilling, and/or the examination of drill logs from existing or new site bores before designing a pump test. This preliminary work may result, for example, in a recommendation for multiple monitoring bores (piezometers) in non-linear locations to understand better how depressurisation propagates in three dimensions. Intermittent review and iterative improvements to monitoring may be appropriate during this process.

Furthermore, temporal variability of groundwater pressures and surface flows means that adequate baseline data are essential to isolate effects of new extractions. Baseline data require foresight from project proponents, and also from asset owners/managers or the government if they wish to ensure that baseline data exists for valued assets. These baseline data requirements must balance the risks of the proposed extraction against the value of the extended baseline data required as collecting this data can require significant time and cost.

Methods to identify and classify vegetation can be designed to recognise GDEs and estimate the extent of impact. Vegetation assessment methodologies, such as the Bioregional Assessment or Biodiversity Assessment Methodology are useful approaches. However, engagement of an ecohydrologist consultant to undertake field verification on environmental assets would complement the assessment of potential impacts.

4.7.6 Improving data collection, accessibility and management

Data from the monitoring network at Alstonville is publicly available on the WaterNSW website (https://www.waternsw.com.au/waterinsights/real-time-data). This website provides real-time data on NSW river heights, streamflow, groundwater bores, meteorology and rainfall, as well as dam and reservoir levels and volumes.

It was noted above that extraction data is not readily available, but would greatly assist to better understand whether observed impacts on water levels and pressures are due to water extraction or climate variability.

For data that can be made publicly available, there are state managed environmental databases (e.g. SEED) that could be utilised.

The accessibility of any data is central and the preponderance of manual collection is an impediment in this regard. Advances in technology to provide robust and tamper-proof telemetering options that are commercially cost competitive would have a significant impact.

Current technology is also available to enable standardised templates and reports to be managed electronically. This would improve the flow of information to relevant agencies and other parties.

4.7.7 The potential role of local research studies

Knowledge of the groundwater requirements of GDEs is limited and research tends to be conducted on unconfined aquifers or systems that are simpler than fractured rock systems. Identification and requirements of subterranean GDEs and the contribution of groundwater to surface water baseflow is even more limited. Local impact studies that monitor groundwater drawdown on nearby GDEs may be considered where there is concern about the impacts (e.g. near Tweed World Heritage site or areas of high extraction) of drawdown on the local environment, surface water or other users.

Monitoring as part of a development consent or as a requirement of an approval can go some way to detecting local impacts or increasing confidence that they are acceptable or not, and to detecting local connectivity between deep and shallow groundwater at monitored locations. However, it is likely to leave gaps in knowledge about local (~0.01-0.1km^2) scale processes and conceptual models, and practical and cost constraints mean it is unlikely to provide new knowledge about catchment/regional-scale impacts (0.1-100km^2). For these, multi-year, multi-scale research projects would be needed.

Research should be encouraged, which monitors continuously at both the local scale and in the surrounding catchment to understand sources of groundwater water, the transmission of depressurisation due to pumping, and impacts on groundwater discharges. This would ideally require voluntary participation of a bottled water operator and surrounding landowners, including installation of continuous pressure transducers in pumped bores, monitoring piezometers and shallow water bores, and availability of metered pumping rates. It should also include tracer studies and surface flow monitoring, and potentially could include ecological indicators.

4.8 CONCLUSIONS

Impacts

- Based on the assessment of available information and analysis undertaken by the Review, there is no measured evidence that current bottled water extractions have impacts on other properties' bores, surface water or GDEs in the Northern Rivers region. This is at least partly due to the relatively low current levels of extractions, hydrogeological conditions and absence of monitoring capable of detecting these impacts.
- Alstonville is the location that has the greatest level of extraction and has monitoring that has been assessed, which provides confidence on the health of the groundwater source. In the case of the Tweed area, while this has minimal monitoring, it also has very low extraction levels for the water source overall – far below the allowable extraction limits.
- While all groundwater extractions have impacts, the magnitude of those impacts and potential consequences will vary. Whether these impacts are measureable, or are of a magnitude to have detrimental consequences on an ecosystem or environmental asset is the focus of monitoring and measurement that occurs both during the assessment phase, and also during the operational phase for approved operations.
- There are significant complexities in measuring local impacts from water extraction due to the spatial and temporal variability of the hydrogeology of fractured and porous rock systems
- While there are existing approaches to measuring and modelling local impacts, these have challenges in terms of accuracy, practicability and cost. Decisions about these investments are also typically done in light of the risk that is being addressed – risk likelihood and consequence.
- Bore water extraction can potentially impact water within the same aquifer, within a connected aquifer, or within a connected surface water body, leading to possible changes in water quantity and quality. The pump test is a common field technique, used in hydrogeological assessments, to derive local scale aquifer properties and to indicate proposed impacts of the extraction. In fractured rock systems, the fracture network that intersects the point of extraction will determine the response to pumping, which is complex and requires hydrogeological investigations and

interpretation of results in order to design the pump test. Impacts may be proximate to or at distance from the point of extraction, and occur vertically as well as horizontally.

- Noting the low level of current groundwater monitoring in three of the four relevant groundwater sources, there would be merit in reviewing the need for additional monitoring that will provide the baseline data, conceptual hydrogeological models and recharge estimates commensurate with potential future risk levels.
- At a regional scale, the cost of traditional monitoring bore infrastructure is likely to be an ongoing challenge. This is particularly the case in fractured rock systems subject to high hydrogeological variability. Emerging sensing technologies able to gather data over large areas and at depth may provide a step-change to the field, subject to cost and commercial availability. Whether at the local or regional scale the choice of monitoring will be informed by the level of risk and the cost-effectiveness of the monitoring. Local research studies may prove a useful adjunct.
- The assessment process for proposed extractions takes into account the risks of local impacts through a risk assessment process, requirements for some applicants for proposed medium and high risk extractions to submit a hydrogeological report to support their application, and criteria for acceptable levels of local impacts.
- Local scale monitoring during extraction operations can assist with better understanding of local hydrology and extractive impacts and consequences. This may include piezometric monitoring of the pathway between the point of extraction and locations where there is perceived risk. The cost of this monitoring is likely to be a challenge and its requirement should be justified by the risks as identified by an expert following analysis of pumping test data.
- Local scale monitoring during extraction operations could potentially support adaptive management, for example, through additional reporting and cease-to-pump rules related to observed groundwater pressures.
- The Review considered a number of past hydrogeological reports submitted to support proposed extractions by the bottled water industry in the Northern Rivers area as components of development applications. The hydrogeological reports, in most cases, assess hydrogeological impacts of proposed developments on surface flows, GDEs and surrounding groundwater bores. The focus and style of the reports varies depending on the purpose and the identified or perceived risks.
- Both industry and decision makers would substantially benefit from greater clarity, specificity and standardisation of requirements for hydrological reports. Current technology is available to enable standardised templates and reports to be managed electronically.
- Robust local assessment of potential connectivity between aquifer and overlying shallow groundwater and surface water should form part of pump tests and feature in hydrogeological reports. This is important, as observed in Alstonville, where deeper aquifers are not necessarily confined and may have connections to surface systems or shallower aquifers. It is important to increase understanding of how confined the aquifer is, as assessment criteria of allowable drawdown differs between confined and unconfined systems. In addition, field verification is an important part of the process.
- The Review received consistent reports from the community and sometimes neighbours of bottled water extractors about observed changes including environmental effects of drying watercourses and loss of water from previously productive bores. The Review has not identified scientific studies or other evidence establishing a causal link between these observed effects and extraction specifically

undertaken by the bottled water industry. Going forward, data from extraction bores, together with monitoring bores (piezometers), local studies and other sources of information should help improve knowledge of impacts from a range of sources.

Data

- Lack of extraction data is an impediment to establishing appropriate extraction limits for individual bores, measuring impacts, and at a regional scale, development of WSP and making determinations of available water. A state-wide metering policy for qualifying groundwater works with bore diameters of 200mm and above will take effect in the Northern Rivers region from 2023. Four of the bottled water extractors in the region are currently required by the regulator to have meters installed.
- The accessibility of any data is central and manual collection can be an impediment in this regard. Advances in technology to provide robust and tamper-proof telemetering options that are commercially cost competitive would have a significant impact.
- Making water extraction and monitoring data available in standardised formats through open databases would benefit decision-makers, researchers and the general public to better understand activities and impacts, including cumulative impacts at local and regional scale. Approvals by relevant state and local government authorities could include requirements that all hydrogeological data are published. There are state managed environmental databases (e.g. SEED) that could be utilised.

Decision-making

- As with any environmental, engineering, resource activity the proponents and decision makers and regulators operate in a realm of imperfect information. This leads to levels of uncertainty around data and information, however uncertainty need not prevent decisions being made.
- There are a number of approaches and tools employed to reduce uncertainty with regard to the assumptions, hydrological domain, impacts, consequences of water extraction. These include taking conservative estimates, using multiple lines of analysis, being judicious in decisions around the type and location of monitoring, employing adaptive management approaches.
- There is a lack of clarity around water planning, management and decision-making roles and processes at state and local government level and between relevant authorities.
- Given the implications of the overlap between development consent and water licences or works approvals, work should be undertaken to clarify roles to ensure consistency, avoid duplication and address any gaps in the assessment and approvals process.
- If Local government is to undertake hydrogeological assessment as part of the development application process, then it needs access to relevant expertise to interpret modelling and technical reports to inform its decision-making, including requirements for development applications.
- Access to government and industry water data through a common open platform housing standardised, well-curated and long-term data sets that can be expanded would assist assessment and decision-making of applications.

5 TECHNICAL APPROACHES TO SOCIO-ECONOMIC FACTORS

Term of Reference 3a requests advice on the scientific and technical approaches to examining socio-economic factors and impacts and possible solutions using locally relevant examples. These related primarily to concerns about the potential growth of the industry, issues associated with truck movements and the use of plastics. The first is dealt with in Chapter 2, the latter two here.

5.1 TRANSPORT (TRUCKS AND ROADS)

Heavy vehicles are used to transport water from the extraction site. These vehicles comprise either bulk water tank trucks or general-purpose freight trucks. The Initial Report also found a total of 128 return truck journeys per week for the bottled water industry in the Northern Rivers region.

Issues raised include: truck movements occurring outside of approved hours or number of trips; dangers from the presence of large trucks on small roads, including in school zones; potential for more significant harm from larger vehicles in the event of an accident; loss of visual amenity and stress from truck-associated noise; and the scale of road damage and maintenance requirements associated with large truck movements shouldered by the broader community.

5.1.1 Frequency and hours of operation

The Heavy Vehicle National Law (HVNL) prescribes a national regulatory framework for a nationally-consistent approach to heavy vehicle legislation (over 4.5 tonnes gross mass) (NTC, 2019). The HVNL is the result of a collaborative process between industry and government and is led by the National Transport Commission (NTC). In most states of Australia, including NSW, the HVNL establishes the Heavy Vehicle National Regulator (HVNR) as the regulator responsible for truck standards and on-road enforcement.

The HVNL regulates driver fatigue management by specifying heavy vehicle operations that require the maintenance of a work diary with driving and rest times. This requirement is linked to a heavy vehicle licence that is regulated in NSW through Roads and Maritime Services (RMS) and NSW Police. Outside of driver fatigue management, the HVNL and Regulations do not prescribe specific conditions that prohibit trucks moving within certain times of the day or how many times they can traverse a region.

Development consent is required for the extraction of water from groundwater systems for commercial bottling. In approving a development application, it is within the remit of local government to apply conditions related to trucks and truck movements, including permissible numbers of movements to and from properties and hours of operations, as well as to enforce compliance. For all new or modified development applications for water bottling, a traffic assessment may be required by council. Councils can only revoke or modify development consents on a limited number of grounds. Where applicants seek to modify conditions of approval, the conditions can be modified only on the issue the application seeks to amend.

A summary of conditions of approval for truck movements is provided in Table 16. Generally, approved truck movements occur between 7:00 – 18:00 on weekdays, with shorter hours on weekends. The number of truck movements per day is highly variable, ranging from two to twelve trips per day. Local Government authorities are responsible for compliance with conditions of development consents.

Table 16: Summary of conditions of approval for truck movements

Issue	Current measures	Responsibility of current measures
Timing	Range: 7:00-18:00 (Monday to Friday) and 8:00-12:00 (weekends)	Council (through the development consent)
Frequency	Range: 2-12 trips (Monday to Friday) and 4-8 trips (weekends)	Council (through the development consent)

If operational approval under the relevant development consent includes school zone times, trucks are legally entitled to operate during those hours. Trucks are held to the same speed conditions in school safety zones as other road vehicles, and these conditions are enforced by NSW Police.

Reviewing development applications currently pending, the Review identified conditions requiring traffic report assessments for the primary road that the water trucks enter and exit from the property, at major intersections and in swept paths within the immediate route of the extraction property. However, the Review has not identified traffic reports being required for historical water extraction licences at the time of assessment.

5.1.1.1 Potential solutions and technologies

Potential strategies available to councils to assist with ongoing monitoring of compliance with conditions of approval include use of written or digital logbooks and electronic tracking. Logbooks would enable collection of data such as odometer reading, location of operation and timing. Electronic products linking data to a database or a phone application could also facilitate accurate record keeping and ease of analysing results. Currently, the majority of development consents for bottled water extractors currently active do not require the use of logbooks to track specific truck movements in and out of the properties. However:

- An approval dating from 2016 stipulates "*an annual statement of truck movements to and from the subject site is to be supplied to council at the end of each financial year to the satisfaction of the General Manager or his delegate*".[82]
- A development application currently under consideration includes a draft condition that states "*The movement of trucks off the site in accordance with this development consent is to be maintained in a daily log which records the date and time of all inbound and outbound trucks from the subject site. At any time, Tweed Shire Council officers may request a copy of the log to be provided for audit of compliance with conditions of this development consent in regard to the times and frequency of truck movements in and out of the subject site…and is to be accompanied by a Statutory Declaration…declaring that the information contained in the log is true and correct*."[83]
- Tweed Shire Council advised that any new or modified applications for water extraction could have conditions requiring logbooks and the installation of security cameras (CCTV) to assist in the monitoring of truck movements (TSC 2019, pers comm., 20 September).

Alternative technologies for monitoring truck movements include active or passive vehicle tracking systems utilising GPS navigation devices and software to collect data for a comprehensive picture of vehicle movements.[84] These systems would be useful in collecting haulage logistics and transport data as they can provide precise and constant data on average speed, distance, fuel consumption, driver time and location.

[82] Development application DA06/1023 (condition 4.2; 10-20 Edwards Lane, Kynnumboon)
[83] Development application DA16/0936 (Rowlands Creek Road)
[84] Passive systems store data and are required to return to a predetermined point where the information from the device can be downloaded and analysed, whereas active systems transmit the date in near-real time via cellular or satellite networks to a computer or data centre for evaluation. Many modern devices will combine both active and passive tracking abilities so that if the cellular network becomes unavailable, the device will store the data to the devices internal memory.

Most devices are installed in the vehicle; however, new technologies also enable mobile phones to be used for tracking multiple variables. These tracking devices are readily available and relatively inexpensive, ranging from approximately $100-$400 (depending on functionality) plus monthly ongoing costs of $20-$30 per month for real-time tracking, history, odometer readings etc.[85]

Traditional approaches, such as traffic surveys, could be used to gather a broader picture about traffic, particularly on roads of concern. Traffic surveys have the capacity to collect data on traffic volumes, vehicle passing probability, road widths and swept paths and can be conducted as observational data during peak traffic times or conducted using Automatic Tube Counts (ATC).[86] Using ATC, data can be collected on the number of vehicles, speed, vehicle types and platoon data by time intervals.[87]

5.1.2 Truck noise

Noise standards for heavy vehicles are prescribed at a national level under the Australian Design Rules (ADRs). All Australian road vehicles must comply with the relevant ADR in place at the time of manufacture and supply to the Australian market. New noise standards for heavy vehicles took effect in 2005 and provide for a national standard for vehicle safety, anti-theft, lighting, noise, engine exhaust emissions and braking.

The National Transport Commission (Model Law on Engine Brake Noise Limits) Regulations 2009 also impose limits on the level of noise emitted by engine brake devices. RMS enforce these regulations through periodic inspections of heavy vehicles at testing stations to ensure that silencers are fitted and maintained and ensure they meet all other noise requirements as specified in the ADR and the HVNL. Current measures and responsible bodies surrounding truck noise is summarised in Table 17.

Despite the regulations, the NSW Environmental Protection Authority (EPA) reports a high instance of complaints from the broader NSW community regarding noise from engine or compression brakes from all types of heavy vehicles (EPA, 2013), and RMS have advocated for tighter vehicle noise stands. RMS and EPA report that noise from trucks braking can be intrusive and it is advisable that heavy vehicle drivers should avoid using exhaust brakes, engine compression or ‘Jake’ brakes near residential and noise-sensitive areas to help reduce the stress associated with excessive truck noise (EPA, 2013).

Currently, a national scheme is being implemented to impose noise limits from engine compression brakes using roadside noise ‘cameras’ as an aid to enforcement. There is currently no legislative basis to issue fines for noise from engine compression brake use in any jurisdiction in Australia. However these noise ‘cameras’ can be used to issue warning notices to truck owners whose vehicles exceed the national engine brake noise in-service noise standard (Parliament of NSW, 2012).

5.1.2.1 Potential solutions and technologies

Council can assist in controlling noise levels generated by trucks through the assessment process and conditions of approval. For all pending or future applications to modify development consents associated with the water extraction industry, a statement of environment effects is required, possibly including an Environmental Noise Impact Assessment. As vehicle noise regulations are set at a federal level, state and local authorities have limited powers to regulate low noise technologies on the vehicles themselves. However, other infrastructure technologies, for example sounds walls designed

[85] These devices are commonly used across haulage companies. In Australia, Linfox, one of the country’s largest logistics and supply chain company deploys a GPS system to record a range of real-time data including road speed, engine RPM, fuel efficiency, vehicle location, kilometres travelled, driver identification and engine fault codes and warnings. The data is captured on a small digital recorder mounted in the front of vehicles, with data uploaded to a control room for analysis (Linfox, 2019)
[86] Automatic Tube Counts (ATCs) detect the axles of vehicles using a rubber pneumatic tube to measure vehicle movements.
[87] Platoon data measures the speed of groups of vehicles.

to reduce vehicle traffic noise in specific locations, are a technical option that could be considered.

Table 17: Summary of regulation relating to truck noise

Current measures	Responsibility of current measures
Restrictions on truck movement frequency, route and hours of operation	Council (through the development consent)
Engine noise standards during manufacture	Australian Design Rules
Heavy vehicle noise level limits	Heavy Vehicle National Law (National Transport Commission)
Heavy vehicle inspections	NSW Police, NSW Roads and Maritime Services

5.1.3 Truck size and road damage

A summary of development consent conditions related to truck size is provided in Table 18. The allowable truck size for water extraction under development consents varies across extractors, but generally ranges from 6 to 9 metre long B-double trucks and infringements can be issued if conditions are breached.

The NHVR classifies vehicles of this size as 'General Access Heavy Vehicles'.

Table 18: Summary of conditions of approval for truck size

Issue	Current measures	Responsibility of current measures
Safety	Range: 6m to 19m B-double truck	Council (through the development consent)
	Heavy vehicle standards on horns, mirrors, lights and reflectors	Heavy Vehicle National Law (National Transport Commission)
Damage	Registration cost for operating a heavy vehicle	Proponent/ NSW Roads and Maritime Services
	Road contribution plan Range: $1200 - $ 17536	Council (through the development consent)
	Road maintenance (state and council roads)	NSW Roads and Maritime Services and Council
	Heavy Vehicle Safety Stations	NSW Roads and Maritime Services

The NHVR provides specifications and standards for all heavy vehicles registered on NSW roads to ensure the safety of the trucks and other road users within the community. In terms of safety, these include specific standards on horns, vision mirrors and lights and reflectors. Water trucks are subject to the same regulation.[88] Under national mass and loading arrangements, General Access Heavy Vehicles have unrestricted access to the road system, except where a road or bridge is sign-posted otherwise. Provided these vehicles have current registration appropriate to the vehicle configuration, no specific access restrictions or additional safety precautions apply and no additional permits are required (RMS, 2019).

RMS also has a compliance program to inspect heavy vehicles that may be operating in an unsafe manner on NSW roads. Heavy Vehicle Safety Stations (HVSS) inspect the mass, dimension and loading of a heavy vehicle and ensure it is compliant with the vehicles registration.

The cost associated with road damage caused by heavy vehicles falls to State and Local Governments and the proponent of a development consent in accordance with the

[88] Note that although additional safety precautions are required for vehicles that are considered 'Oversize Over Mass (OSOM) Vehicles', the size of all approved water trucks across the LGAs within the Northern Rivers region meet the OSOM vehicle criteria (TSC, 2019a)

conditions. State registration charges for heavy vehicles aim to recover expenditure on roads from trucks and ensure safe roads for all road users. This registration fee, which includes a regulatory component, is collected through the RMS. The quantum of the fee depends on several factors including the number of axles, gross vehicle mass and what category of vehicle it falls into. These charges are contained in the Heavy Vehicle Charges Model Law.[89]

Although passenger cars account for a high proportion of vehicle-kilometres travelled in Australia, trucks make a greater contribution to pavement damage (Bureau of Transport and Communications Economics, 1997). Pavement damage attributable to a specific vehicle depends on a number of factors including roadway design as well as weight and axle configuration. A commonly agreed method to approximate the relative impact of different categories of vehicles on roads is through the 'Generalized Fourth Power Law', which predicts that the change in pavement damage is proportional to the difference in the vehicles axle weight to the fourth power (Freight on Rail, 2019). However, determining the number and types of wheel/axle loads that a particular pavement is subject to in any given time is more complex.

Road ownership generally determines the authority responsible for road maintenance charges. In the Northern Rivers region most roads are owned by local government, with only a few large inter-passes that are state owned. Some council roads that are strategic to traversing the region and have high use may receive a state contribution for their maintenance.

Councils can adopt Road Contribution Plans (RCP), as a mechanism to collect contributions from developers to support public road infrastructure. [90] The RCPs include an additional component relating to vehicle weight.[91] The Review found that development applications for bottled water extraction approved over the last decade include a contribution under the RCP. Tweed Road Contribution Plan modelling found that the Tweed Shire road network will experience considerable traffic growth, especially on the Tweed coast and in urban areas, as a result of the anticipated urban development and that most major urban road corridors will be required to carry considerably more traffic (TSC, 2016).

5.1.3.1 Potential solutions and technologies

Where feasible, increased council or police presence or random spot checks at extractors during operational hours may assist to regulate truck size compliance and alleviate community concern that larger than authorised trucks are being used. Technologies described in previous sections would also be relevant.

Councils can continue to exercise their powers in relation to truck size when approving development applications.

5.1.4 Conclusions

- There are technologies available that can provide accurate, consistent and real-time data on truck movements, which could be included as a condition of the development consent.
- Responsibility for governing truck safety, movements and size spans Federal, State and Local Government authorities. Each of the responsible bodies has measures to

[89] As implemented by each jurisdiction .The heavy vehicle registration fee is based on the pricing principles set by the Transport and Infrastructure Council and the Council of Australian Government (COAG) and undergoes annual adjustments (Transport and Infrastructure Council, 2017).
[90] Section 7.11 of the *Environmental Planning and Assessment Act 1979* is the principal legislation enabling Councils to levy development contributions for public amenities and services. A monetary contribution can be imposed by a way of a condition of development consent and can be in the form of a Road Contribution Plan.
[91] For example, the Tweed Road Contribution Plan (s 6.5) includes a heavy haulage fee based on a formula comprising the value and life of pavement.

regulate and monitor heavy vehicles through existing legalisation, approval of applications and technologies.

- Technologies and strategies are available to measure traffic volumes and impacts. Local government can levy heavy vehicle road users to contribute to the cost of road maintenance and repair.

5.2 PLASTIC BOTTLES

The Initial Report included concerns expressed during consultations about the environmental impacts of plastics used in the bottled water industry. These views were reiterated in submissions received by the Review.

The issue is international in scope and management of the impacts and solutions will be influenced significantly by factors and developments beyond the Northern Rivers region.

5.2.1 Extent and management of plastic

The main polymers that plastic bottles for drinking water are produced from are Polyethylene terephthalate (PET) and High density polyethylene (HDPE) (PricewaterhouseCoopers, 2008; Locock et al., 2017). PET and HDPE are predominately made of non-renewable sources such as oil or gas (CIEL, 2017) although recycling can collect waste PET and HDPE for reprocessing (recyclate). New plastic water bottles can contain PET recyclate (Locock et al., 2017).

Across Australia, 3.4 million tonnes of plastics were consumed (Envisage Works, 2019) in 2017-18 and approximately 58% of total plastic packaging generation was disposed to landfill from collection (Madden & Florin, 2019).[92] The recycling rate of PET in Australia has increased from 16% in 2016-17 to 21% in 2017-18 (Envisage Works, 2018, 2019).[93] In the same period, consumption increased from 345,600 tonnes to 355,300 tonnes, 32% of which was from NSW (Envisage Works, 2018, 2019).

NSW, together with the Commonwealth and other jurisdictions has committed to establishing a timetable and strategy to ban the export of key waste materials, including plastic; reduce plastics waste and diversion to landfill; and build capacity to recover value from waste and generate high-value recycled products (COAG, 2019). This follows a 2018 commitment for 100% of Australian packaging to be recyclable, compostable or reusable by 2025 and 70% of plastics to be recycled or composted (Waste Management Review, 2019). The Australian Packaging Covenant Organisation (APCO) manages the national product stewardship scheme for the delivery of the sustainable packaging pathways in Australia, and is leading the delivery of the 2025 National Packaging Targets.[94]

A nationally harmonised approach will facilitate implementation of NSW policies and initiatives. The NSW Circular Economy Policy Statement ‘Too Good To Waste’ was released in February 2019 (EPA, 2018), building on the NSW Waste Avoidance and Resource Recovery Strategy 2014–21 (EPA, 2014) and associated programs. These strategies are driven by the most efficient approaches for resource use, guided by the waste hierarchy to avoid and reduce waste in the first instance, followed by options to reuse and recycle waste, to recover energy and treat waste and finally to dispose of waste (EPA, 2014).

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[92] Consumption is defined as the Total use of product by Australian industry and consumers. It includes locally made and used product, imported product and locally utilised recyclate. Does not include locally made product that is exported for sale.
[93] The Recycling rate is determined from the extent of recyclate sent to plants domestically and internationally for re-processing
[94] APCO is a co-regulatory not-for-profit organisation administering the Australian Packaging Covenant, an agreement between Federal, state and territory governments and the packaging industry to reduce the harmful impact of packaging on the environment. Plastics in packaging accounts for 60% of the plastics waste stream. National Packaging Targets to be achieved by 2025 are: 100% reusable, recyclable or compostable packaging; 70% of plastic packaging being recycled or composted; 30% of average recycled content included in packaging and the phase out of problematic and unnecessary single-use plastics packaging (APCO, 2019d).

The NSW Government is currently developing a NSW Plastics Plan as well as a 20 Year Waste Strategy. In 2017, the NSW Government Return and Earn Container Deposit Scheme was introduced, resulting in the return of 750 million drink containers and a 33% reduction of eligible containers in the litter stream in one year (Blue Environment, 2018). Over January to June 2019, sorted PET plastic containers made up 28.1% of the volume collected across NSW, while HDPE made up 1.4%. A number of collection points are located in the Northern Rivers and there has been an increase in the return of containers since 2017 (Figure 23).

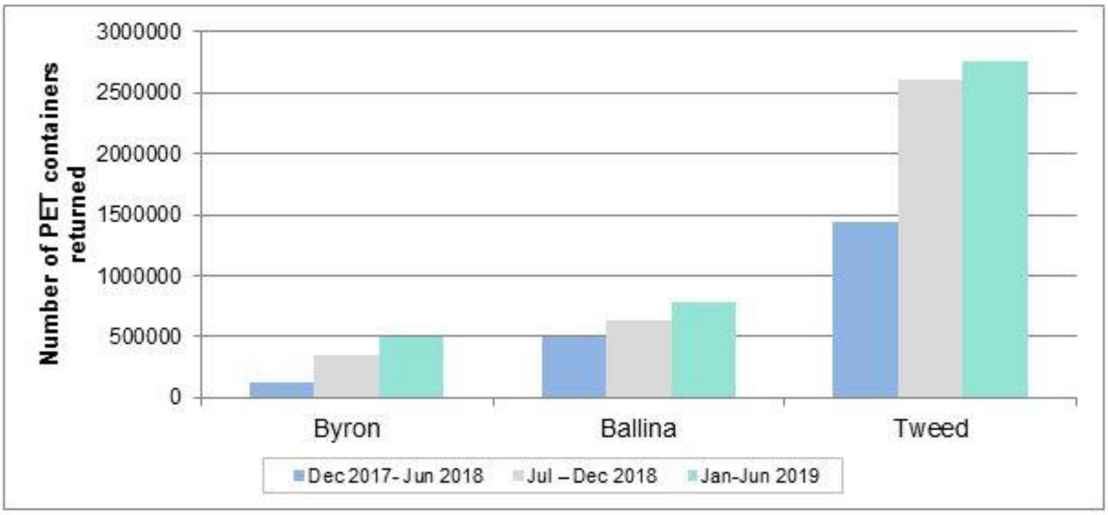

Figure 23: Return and Earn collection volumes of sorted PET plastics in select areas
Note: data includes Reverse Vending Machine, Automated Depot return volumes and disaggregated Over The Counter weekly return volumes collected through the Network Operator Exchange for Change

5.2.2 Bottled water industry – current practices and commitments

In the Northern Rivers region, proponents extracting water for the bottled water industry either sell the water on to a bottler and/or bottle the water themselves. Large companies, CCA, Asahi Holdings (Australia) Pty Ltd and Nu-Pure Pty Ltd account for over 70% of the market share of Australian bottled water products (IBISWorld, 2019). Both CCA and Asahi are signatories to the Australian Packaging Covenant, and were graded as level four (leading) out of five against the 13 criteria of the Sustainable Packaging Framework (APCO, 2019a, 2019b).

Coca-Cola Amatil has committed to reducing the amount of waste sent to landfill by making 100% of all packaging recyclable by 2030 (APCO, 2019b); has targets for increasing the recyclability of on-pack labelling, light-weighting bottles (i.e. reducing the amount of plastic used in containers) (APCO, 2019b); and increasing the amount of recycled plastic in PET bottles (Coca-Cola Amatil, 2018b). In 2019, the company announced seven out of 10 of its bottles manufactured for the Australian market would be 100% recycled plastic by the end of the year.[95] Asahi's Action Plan to meet the 2025 Targets include more than 50% of primary packaging to be recoverable, and improving material efficiency in up to 20% of products (APCO, 2019a). Asahi have commenced blowfill manufacturing to produce lightweight PET CSD bottles (Asahi Beverages, 2016). The Nu-pure spring water range uses 50% recycled PET (Nu-Pure, 2019).

There are smaller operators in the Northern Rivers who both extract and bottle, who use a range of plastic bottle products. While some use small plastic PET bottles (350-650ml); other operators are using options that may encourage minimisation of plastic production and waste. This includes use of large plastic containers designed for water coolers (up to 19L),

[95] This includes the Mount Franklin and Pump water brands. See https://www.marketingmag.com.au/news-c/news-coca-cola-recycled-bottles-2019/

that are returnable or with a refundable deposit fee per bottle; use of plastic bottles with the addition of a compound (reverte) to encourage oxo-biodegradation and substitution of glass for plastic.

5.2.3 Opportunities and challenges

To achieve the 2025 National Packaging Targets, a whole of supply chain approach is required to focus on design, collection and recycling systems, reuse, materials circularity and consumer engagement (APCO, 2019f). It is anticipated that this period of transition for industry and consumers will see waste management initiatives implemented in a series of stages that are in line with a global shift to reduce waste entering landfill and improve recycling.

Globally, identified opportunities and challenges include improving design to avoid pollutant materials and minimise reprocessing challenges; improving recycling capability; increasing the quality and value of processed material; substitution and decoupling plastics from non-renewable resources (Ellen MacArthur Foundation, 2014; DEE, 2018).

APCO is leading a number of pieces of work on Australian used packaging volumes and resource recovery capabilities. Due for release later this year, these include reports on recycling infrastructure and emerging and at-market technologies to manage a range of waste streams, including plastics. These reports will provide a more granular picture than currently available at both national and state levels and will be a key input to strategies going forward.

Better characterisation of waste streams, understanding of material stream flows and establishing mechanisms to support market development will also underpin uptake of technologies.[96] The Institute of Sustainable Futures at the University of Technology Sydney was commissioned by APCO to provide a packaging material flow analysis (Madden & Florin, 2019) and developed a packaging sustainability framework that has been implemented as an online self-assessment tool for companies (Kelly et al., 2017).

Design choices at the manufacturing stage would help reduce contamination as recyclable containers that use different polymers for caps, adhesives and labels can present sorting challenges. Eliminating polymers and certain colours that are problematic for recycling would also improve recycling efficiencies as well as improving collection and sorting into clean single-polymer streams.

In Australia the majority of used plastic packaging that is disposed to landfill is not collected for recovery (Madden & Florin, 2019) and contamination also results in large volumes of recyclable plastics going to landfill (DEE, 2018). A large source of contamination is due to the handling and compaction of glass in co-mingled collections, causing the glass to break and producing glass fragments that are difficult to separate (Madden & Florin, 2019). Plastic bottles placed in co-mingled recycling bins for municipal kerbside collection are generally sent to Materials Recycling Facilities (MRFs) and are sorted into either a mixed-plastics grade, or more commonly three grades: PET, HDPE and other residual mixed plastics (DEE, 2018).

MRFs vary in technological sophistication, most using a mix of human, mechanical and electronic processes to sort co-mingled recycling, and lack capacity to sort highly contaminated waste (DEE, 2018). Of 12 reprocessing plants Australia-wide, three in NSW are reprocessing PET (DEE, 2018). There are opportunities to improve collection and processing infrastructure to reduce contamination and improve the quality and value of recycled materials, including through the use of automated optical sorting equipment (DEE, 2018).

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[96] In May 2019, the Federal Government committed $1.6 million to develop an online platform and marketplace and a further $9.2 million in August 2019 to advance innovation in plastics recycling under Round 8 of the Cooperative Research Centres Projects program (CRC-P).

PET recycling is mature technology and driven by markets for recycled PET overseas and locally. There is significant local capacity capable to recycle PET to food grade and there are projects in train that will increase this capacity. The capacity for recycling HDPE back into food grade remains limited compared to the volumes consumed.[97]

The market for recyclate is also influential, fluctuations depending on manufacturing capacity as well as oil and gas prices for the production of new plastic (Locock et al., 2017).

Many of the NSW Government 2018 *Waste Less Recycle More* grants will address the issues of increased restrictions on export of recyclate, cross contamination of recyclables; and will initiate opportunities to process recyclate for new purposes and update MRFs.[98]

5.2.3.1 Alternatives and additives

Alternatives to plastic bottles being explored by the global bottled water industry include glass and paperboard (Carton & Co Water, 2019). Substitution with glass may be influenced by market forces e.g. due to the lower cost of importing bottles (Meldrum-Hanna, Davies, & Richards, 2017; DEE, 2018), the quality of glass collected by municipal kerbside recycling (DEE, 2018) and higher transport costs (freight and energy) associated with glass (Meldrum-Hanna et al., 2017).

Bioplastics are produced from renewable sources, usually from vegetable fats or corn starch.[99] Currently, over 75% of bioplastics on the market are non-biodegradable (Australasian Bioplastics Association, 2019). Bioplastics can be designed to be either recyclable or compostable, but not both. Developing a consistent labelling system and avoiding compostable packaging contaminating the recyclables stream (and vice versa) has been identified as a priority (APCO, 2019c; Australasian Bioplastics Association, 2019). Most compostable bioplastics require specific conditions; as a result, the speed of biodegradation is different in industrial composting plants compared to home composts.

Plastic bottles may also be made with conventional polymers that have an oxidising additive to assist with degradation. These are referred to as oxo-degradable, hydro-biodegradable or oxo-biodegradable plastics (PACIA, 2007). Issues include establishing the timeframe in which complete degradation occurs in order for a biodegradable product to have an environmental benefit (European Commission, 2018) and concerns about oxo-degradable products (European Commission, 2015; Selke et al., 2015; European Commission, 2018). In Australia, APCO has identified working towards a ban on oxo-degradable plastics as a priority project as these plastics are included in problematic and unnecessary packaging to be phased out by 2025 (APCO, 2019e).

5.2.3.2 Emerging technologies

There are increasing examples of, and opportunities for, end of use applications for plastic where strong, light-weight material is required. Science and engineering advances in materials, chemistry and synthetic biology also have a role in improving design, substitution and reuse. While some developments are at early stages, many are in scale up to commercialisation stage. Research and development efforts to replace, repurpose and recycle plastics is a fast-moving and evolving space that is predicted to show significant growth within the next 5-10 years.

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[97] Australian manufacturers are required to comply with the Food Standards Code that outlines standards for plastic materials in contact with food. The Code refers to a voluntary Standard (AS 2070:1999) which states that post-consumer recycled material is not to be used in direct contact with food. However, it is understood the Code is currently under revision, and the reference is likely to be removed.

[98] Through this program, Lismore City Council will undertake technological updates to reduce cross contamination of recyclables at an MRF that services four council areas in the Northern Rivers region (DPIE, 2019b).

[99] Bioplastics can also be made from agricultural by-products, used plastic bottles and other containers using microorganisms.

This capacity for growth was highlighted in the 'Innovation in the NSW environmental goods and services' report. The report found that the environmental goods and services sector valued at $43.9 billion in 2017-2018, is growing at a rate of 7.1% per annum, faster than the wider economy, with exports worth $3 billion (NSW Innovation and Productivity Council, 2019).

Emerging research in materials engineering using Green Steel technology was invented at the Centre for Sustainable Materials Research and Technology (SMaRT) at UNSW. The Polymer Injection Technology substitutes coke with waste, using old tyres and plastics to provide a source of carbon to replace a significant proportion of the non-renewable coke used to make steel in electric arc furnaces. The SMaRT facility is also home to Green Microfactories™ designed to reuse and repurpose materials including transformation of plastic waste into high-quality 3D printing filaments. The recently announced ARC Research Industrial Transformation Research Hub for Microrecycling of Battery and Consumer Wastes opens up numerous new pathways to leverage high temperature process to access the wealth of resources embedded within complex wastes such as metals, plastics and glass. Instead of becoming landfill, they will be transformed into valuable materials and products, including metallic alloys, oxides and carbon.

In the field of Chemical engineering, the CSIRO Chemistry and Polymer Research Group is scoping projects to substitute materials for plastics, product development and the development of new materials (additives) to aid polymer reprocessing.

Licella and the University of Sydney have co-developed a technology called the Catalytic Hydrothermal Reactor, or "Cat-HTR", to chemically recycle End-of-Life Plastics. Cat-HTR breaks plastics down into smaller hydrocarbon components, using water at high temperature and pressure and a mix of catalysts to stabilize the break-down products, preventing the intermediate radicals from reacting with each other. The resulting liquid and gas products can be readily upgraded using existing hydrocarbon refining and blending infrastructure into useable products such as high-value waxes, lubrication oils, fuels, chemicals and gases. Since the hydrocarbon products closely resemble the crude oil from which the plastics were made, the Cat-HTR products can also be further cracked and refined to monomers from which new plastics can be made, providing a circular economy advantage to the technology. A large pilot plant with commercial scale reactor modules is established on the NSW Central Coast. The first commercial Cat-HTR plant is currently under development in Wilton (North East UK) and will convert 20,000 tonnes of End-of-Life Plastic annually. Similar commercial plants are under development in Australia.

Synthetic Biology is an emerging field where complex artificial biological systems are engineered. This research can be applied to the generation of plastics using genetically engineered microbes to replace polymers from petrochemical sources. A recently approved Australian Research Council Centre of Excellence in Synthetic Biology headquartered at Macquarie University is focusing on converting biomass from agriculture or waste streams to a range of products including bioplastics, building on work previously undertaken through the international Yeast 2.0 consortium.[100] While developments in this space may not be commercially viable in the short term, the university has industrial partners undertaking pilot projects to develop cost-effective manufacturing solutions at market scales.

5.2.4 Conclusions

- The presence and management of plastics is international in scope and management of the impacts and solutions will be influenced significantly by factors and

[100] *The Yeast 2.0 project is a global partnership focused on utilising synthetic biology tools to build the world's first synthetic eukaryotic genome".* See www.mq.edu.au/research/research-centres-groups-and-facilities/centres/synthetic-biology-consortium/our-projects.

developments beyond those extracting water for bottling purposes in the Northern Rivers region.

- The NSW Government is developing a 20 year waste strategy and plastics plan in the context of broader Federal Government and inter-jurisdictional commitments to address waste and transition from linear to circular economies.
- There is a NSW Government container deposit scheme that has resulted in a one-third reduction across the state of eligible containers, including bottles entering the litter stream.
- Research and development efforts to replace, repurpose and recycle plastics is a fast-moving and evolving space that is predicted to show significant growth within the next five to ten years.

6 FINDINGS AND RECOMMENDATIONS

This Review has occurred during a period of widespread concern and public debate about extended drought and long-term water futures. The Review recognises the community concern about water allocations and use, and the desire for greater certainty and more definitive information to inform decision making.

Yet all decisions are made in the context of imperfect knowledge. In groundwater studies and management, there will always be a level of uncertainty associated with predictions and a precise value may not be achieved due to the complex and heterogeneous nature of groundwater movement. This is particularly evident in fractured rock systems that are difficult to characterise fully.

The question of how to manage risk and uncertainty optimally in relation to water resources is long-standing. Managing risk relies on efforts of the proponent, the regulator, state agencies and local government and other stakeholders. Policy and regulatory instruments provide a framework and strategies to help manage risk and reduce impacts. These include adaptive management, risk assessment of proposed developments and approval conditions for licences and development applications.

However, within these frameworks, judgements still need to be made. Relevant are risk appetite, context, available information, potential consequences and the degree of confidence in the assumptions made. Also important is access to tools that can be drawn on to reduce uncertainty and manage risk in a way that is cost effective and proportional to the level of risk.

6.1 FINDINGS

6.1.1 The bottled water industry

- Available industry data indicates that across Australia, over three-quarters of bottled water is sourced from underground wells, and the remainder from standard reticulated water supplies. Approximately 8% of Australian bottled water production is exported.
- The Review identified seven operators in the Northern Rivers region with allocations of 240.5 ML/y who are actively extracting for water bottling purposes, representing 0.55% of water licences and basic landholder rights (together defined in the WSP as 'total water requirements') and 0.008% of estimated total annual aquifer recharge in the four groundwater sources.
- Four further proposals, if approved, would amount to an additional 168 ML/y, being an additional 0.38% of estimated total water requirements and 0.006% of total annual aquifer recharge.
- Changing consumer preferences, trade imbalances, the availability of tap water and private ('no name') brands and population growth are expected to impact future bottled water production and consumption volumes.
- Scenario analyses conducted by the Review suggest the Australian bottled water industry is most likely to grow at a rate of less than 2% per annum to 2024 and that growth in the Northern Rivers region is likely to be consistent with this trend. Under most scenarios to 2024 considered, the 168 ML/y of additional proposed bottled water operations would be sufficient to meet fully projected growth in demand.

- The Review also considered ‘highly unlikely’ and ‘extremely unlikely’ scenarios to 2034, being growth continuing at the current rate of 10% per annum and establishment of a major premium bottled water exporter in the Northern Rivers, respectively.
    - If the ‘highly unlikely’ scenario occurred, the bottled water industry would represent less than 2.3% of ‘total water requirements’ and 0.034% of estimated total annual aquifer recharge.
    - If the ‘extremely unlikely’ scenario occurred, the bottled water industry would represent less than 4.6% of ‘total water requirements’ and 0.069% of estimated total annual aquifer recharge.
- As the scenario analyses considered an unchanged regulatory and policy environment, these forecasts may be affected by regulatory intervention which directly or indirectly impacts the bottled water industry in this region.
- For the purposes of water extraction licensing, the bottled water industry is treated the same as other prospective commercial users. However, development consent under the *Environmental Planning and Assessment Act 1979* is required for water bottling activities. Approvals identified by the Review for bottled water extraction in the Northern Rivers region date from 1993.

6.1.2 Allocations

- The WSP determines the allowable extraction limit, set from the recharge value of each aquifer, with an amount of the recharge reserved for the environment and the reminder determining the Upper Extraction Limit or the LTAAEL
- Under the WSP, environmental water and basic landholder rights are given priority over licensed water extraction. Among licensees, priority is given to water utilities and licensed stock and domestic over commercial licensed purposes.
- At the commencement of the WSP for the four groundwater sources, 100% of storage is reserved for the conservation of the groundwater system.
- Water available for extraction is a portion of the estimated recharge value for each groundwater source. This is determined by the WSP. An amount of the recharge is reserved for the environment. The amount reserved for the environment equates to 97% of the estimated recharge value for New England Fold Belt Coast, 96% for North Coast Volcanics, 82% for Alstonville Basalt Plateau and 48% for Clarence Moreton Basin.
- The remaining amounts can be allocated for licensed purposes. Of these amounts, 38.0% of the New England Fold Belt Coast is allocated, 51.3% of the North Coast Volcanics and 1.7% in the Clarence Moreton Basin. Alstonville is fully allocated.
- These are average values over the groundwater source areas; which means that the environment is not protected to these levels in locally impacted areas.

6.1.3 Water Sharing Plan assumptions and uncertainty

- In groundwater studies and management, there will always be a level of uncertainty associated with predictions (e.g. recharge rates) and a precise value may not be achieved due to the complex and heterogeneous nature of groundwater movement. This is particularly evident in fractured rock systems that are difficult to characterise fully.

- The WSP plan was developed based on the best available data at hand and followed a standard procedure. The assumptions made in the WSP are practical, reasonable and in agreement with standard practice. In general, the WSP incorporates a reasonable level of conservatism for extraction limits based on the risks identified. .
- The rainfall data used and the methodologies are sound and apply limited uncertainty to the extraction rates.
- The portion of the estimated recharge value available for extraction is a function of rainfall recharge over low environmental value areas together with an assessment of environmental and socio-economic risk.
- Calculating recharge is complex due in part to the variability and complexity of the hydrogeology and limited knowledge of the systems. Based on the analysis, the Review considers the recharge rates used in the WSP are reasonable and conservative. This statement is made with a relatively low level of confidence due to lack of data for the groundwater sources of interest.
- In practical terms the groundwater sources are treated as geologically homogenous which adds uncertainty and would benefit from further work. The Review recognises that the complexity of the geology makes it difficult to incorporate heterogeneity into the WSP recharge calculations. Particular attention should be given to the effects of geological variability within groundwater sources, and soils and vegetation overlying aquifer outcrops. The Review acknowledges the conservatism incorporated into the current WSP through the allowable allocation figures.
- There is evidence to suggest that for the WSP recharge variable, there is a wide range of values that can be applied as well as a number of different approaches to calculate it. Limited field data is available to support a single estimate.
- Recharge rates applied to the four groundwater sources in scope in the WSP ranged from 4% - 8% with studies and alternative methods indicating, with considerable uncertainty, levels between 1% and 31%. The calculations by the Review using CBM and baseflow filtering for recharge rates had results mostly above the values used in the WSP. The Review noted the important contribution that surface conditions and soil could make to the recharge of the underlying geology.
- The Review tested a scenario in which the recharge rates were reduced by 80%. It found the recharge reserved for the environment for the New England Fold Belt Coast and North Coast Volcanics would remain at around 80% of recharge. For Alstonville, it would be reduced, but the network of monitoring piezometers provides the ability to monitor long-term changes in levels. For the Clarence-Moreton Basin, with only around 1.5% of available water allocated, the LTAAEL could be reduced with no impact on licences.
- Based on the analysis, the Review considers the recharge rates used in the WSP are reasonable and conservative. This statement is made with relatively low level of confidence due to lack of data for the groundwater sources of interest.
- The application of the sustainability index appears to be a cost and time effective risk tool that is applied as an additional means to protect resources where limited information is available.
- The WSP incorporates a reasonable level of conservatism for the extraction limits when the groundwater sources are not fully allocated and where they are fully allocated at Alstonville, monitoring is applied.
- Additional monitoring in strategic locations in the Tweed would help inform gaps in knowledge on a regional scale and provide a path towards better conceptual understanding of aquifer flows.

- The overall system is managed with some level of adaptive management, including an annual determination of the volume of water per licence share and WSP are subject to an interim review at five years with a full review at ten years.
- Impacts of climate change should be considered in future WSP methodologies. A warming climate can lead to increases or decreases in rainfall, variations in the timing and frequency and strength of rainfall events, and increases or decreases in evapotranspiration. The development by the NSW Government of Regional Water Strategies will provide further insights into the impact that climate change could have on the region and catchments over the coming decades, which can further inform management approaches for the region’s water resources.

6.1.4 Sustainability of Water Sharing Plan extraction limits

- Due to limited extraction levels (where known allocations in the Tweed region are much lower than the extraction limits contemplated in the WSP), limited data and uncertainties described regarding the WSP parameters, it is not possible to conclude whether the extraction limits are currently sustainable. However, the Review found no evidence at this point in time that current WSP extraction limits are not sustainable.
- For the Alstonville Basalt Plateau Groundwater Source, which is fully allocated, and there is a network of monitoring piezometers, data from 2006 onwards was analysed by the Review, which concluded:
    - The deeper piezometers (depths greater than around 25 m) showed a greater stability and a steady upward trend over time of groundwater levels and/or pressures. In contrast, the shallower piezometers showed greater variability and appear to be recharged regularly with rainfall.
    - Lagged rainfall is an important variable for understanding piezometer water levels in the Alstonville Plateau. This was observed in shallow-sited piezometers and in deeper piezometers sited in systems that are well connected to surface waters and upper aquifers.
    - There is limited amount of information available on current actual extraction volumes. The Review notes that enhanced metering requirements will come into force in the region in 2023 for eligible groundwater extractors. Given this lack of data on extraction volumes, it is difficult to separate the effects of environmental variables (such as rainfall) from the impacts of human extraction (which tends to increase during dry periods).

6.1.5 Methodological improvements

- The Review considers there is room for improvement in the future assessment of the variables underlying the extraction limits.
- Impacts of rainfall patterns in the region on recharge should be considered in future WSP methodologies, including changing patterns associated with climate change.
- Particular attention should be given to assessment of groundwater recharge rates across broad spatial areas and the associated need to distinguish between confined versus unconfined aquifers.
- Developing a better conceptual understanding of the geological strata in the WSP to reduce the level of uncertainty in the estimated recharge values. This could possibly be undertaken via a 3D geological modelling tool (e.g. Leapfrog Geo) where there is sufficient data and should include some soil mapping. This would require a large scale detailed geological mapping survey or the collation of the existing core log data and geophysical measurements, where available. The Review notes this level of

detail has not been typically applied in similar WSP for easterly flowing rivers and would require allocation of time and resources.

- Sensitivity testing could be undertaken to see whether a change in the recharge or sustainability index might result in the aquifers being over allocated or stressed.
- Further work could be undertaken to assess whether the risk ratings given to specific groundwater sources are appropriate.
- Water levels in the Department's piezometers should be regularly assessed to ensure periods of sustained water level decline are identified early. With further analysis, it may be appropriate to set trigger values for water levels in key deep aquifers that allow for adaptive management of groundwater extractions (e.g. once water levels fall below a certain level, restrictions may be placed on extractions in that area).
- Where the system is fully (or near fully) allocated, additional monitoring/sampling and routine data analyses could be applied, as was undertaken at Alstonville, within an adaptive management framework

6.1.6 Assessment and management of potential impacts from water extraction

- Based on the review of available information, there is no measured evidence that current bottled water extractions have impacts on other properties' bores, surface water or GDEs in the Northern Rivers region. This is at least partly due to the relatively low current levels of extractions, hydrogeological conditions and lack of monitoring detecting these impacts.
- While all groundwater extractions have impacts, the magnitude of those impacts and potential consequences will vary. Whether these impacts are measureable, or are of a magnitude to have detrimental consequences on an ecosystem or environmental asset is the focus of monitoring and measurement that occurs both during the assessment phase, and also during the operational phase for approved operations.
- There are significant complexities in measuring local impacts from water extraction due to the spatial and temporal variability of the hydrogeology of fractured and porous rock systems
- While there are existing approaches to measuring and modelling local impacts, these have challenges in terms of accuracy, practicability and cost. Decisions about these investments are also typically done in light of the risk that is being addressed – risk likelihood and consequence.
- Bore water extraction can potentially impact water within the same aquifer, within a connected aquifer, or within a connected surface water body, leading to possible changes in water quantity and quality. The pump test is a common field technique, used in hydrogeological assessments, to derive local scale aquifer properties and to indicate proposed impacts of the extraction. In fractured rock systems, the fracture network that intersects the point of extraction will determine the response to pumping, which is complex and requires hydrogeological investigations and interpretation of results in order to design the pump test. Impacts may be proximate to or at distance from the point of extraction, and occur vertically as well as horizontally.
- Noting the low level of current groundwater monitoring in three of the four relevant groundwater sources, there would be merit in reviewing the need for additional monitoring that will provide the baseline data, conceptual hydrogeological models and recharge estimates commensurate with potential future risk levels.

- At a regional scale, the cost of traditional monitoring bore infrastructure is likely to be an ongoing challenge. This is particularly the case in fractured rock systems subject to high hydrogeological variability. Emerging sensing technologies able to gather data over large areas and at depth may provide a step-change to the field, subject to cost and commercial availability. Whether at the local or regional scale the choice of monitoring will be informed by the level of risk and the cost-effectiveness of the monitoring. Local research studies may prove a useful adjunct.
- The assessment process for proposed extractions takes into account the risks of local impacts through a risk assessment process, requirements for some applicants for proposed medium and high risk extractions to submit a hydrogeological report to support their application, and criteria for acceptable levels of local impacts.
- Local scale monitoring during extraction operations can assist with better understanding of local hydrology and extractive impacts and consequences. This may include piezometric monitoring of the pathway between the point of extraction and locations where there is perceived risk. The cost of this monitoring is likely to be a challenge and its requirement should be justified by the risks as identified by an expert following analysis of pump test data.
- Local scale monitoring during extraction operations could potentially support adaptive management, for example, through additional reporting and cease-to-pump rules related to observed groundwater pressures.
- The Review considered a number of past hydrogeological reports submitted to support proposed extractions by the bottled water industry in the Northern Rivers area as components of development applications. The hydrogeological reports, in most cases, assess hydrogeological impacts of proposed developments on surface flows, GDEs and surrounding groundwater bores. The focus and style of the reports varies depending on the purpose and the identified or perceived risks.
- Both industry and decision makers would substantially benefit from greater clarity, specificity and standardisation of requirements for hydrological reports. Current technology is available to enable standardised templates and reports to be managed electronically.
- Robust local assessment of potential connectivity between aquifer and overlying shallow groundwater and surface water should form part of pump tests and feature in hydrogeological reports. This is important, as observed in Alstonville, where deeper aquifers are not necessarily confined and may have connections to surface systems or shallower aquifers. It is important to increase understanding of how confined the aquifer is, as assessment criteria of allowable drawdown differs between confined and unconfined systems. In addition, field verification is an important part of the process.
- The Review received anecdotal information suggesting bottled water extractors were generally extracting water at an approximately evenly spaced production rate year-round compared with other commercial users who extract on a more periodic basis. The Review was not able to verify these observations. Further, all groundwater users are subject to future changing environmental conditions, which may influence their future patterns of use. The implementation of the NSW Non-Urban Water Metering Policy will provide information about use patterns in the bottled water industry and enable analyses of interactions and impacts.
- The Review received consistent reports from the community and sometimes neighbours of bottled water extractors about observed changes including environmental effects of drying watercourses and loss of water from previously productive bores. The Review has not identified scientific studies or other evidence

establishing a causal link between these observed effects and extraction specifically undertaken by the bottled water industry. Going forward, data from extraction bores, together with monitoring bores (piezometers), local studies and other sources of information should help improve knowledge of impacts from a range of sources.

6.1.7 Data

- Lack of extraction data is an impediment to establishing appropriate extraction limits for individual bores, measuring impacts, and at a regional scale, development of WSP and making determinations of available water. A state-wide metering policy for qualifying groundwater works with bore diameters of 200mm and above will take effect in the Northern Rivers region from 2023. Four of the bottled water extractors in the region are currently required by the regulator to have meters installed.
- The accessibility of any data is central and manual collection can be an impediment in this regard. Advances in technology to provide robust and tamper-proof telemetering options that are commercially cost competitive would have a significant impact.
- Making water extraction and monitoring data available in standardised formats through open databases would benefit decision-makers, researchers and the general public to understand better the activities and impacts, including cumulative impacts at local and regional scale. Approvals by relevant state and local government authorities could include requirements that all hydrogeological data are published. There are state managed environmental databases (e.g. SEED) that could be utilised.

6.1.8 Decision-making

- As with any environmental, engineering, resource activity the proponents and decision makers and regulators operate in a realm of imperfect information. This leads to levels of uncertainty around data and information; however, uncertainty need not prevent decisions being made.
- There are a number of approaches and tools employed to reduce uncertainty with regard to the assumptions, hydrological domain, impacts, and consequences of water extraction. These include taking conservative estimates, using multiple lines of analysis, being judicious in decisions around the type and location of monitoring, employing adaptive management approaches.
- There is a lack of clarity around water planning, management and decision-making roles and processes at state and local government level and between relevant authorities.
- State government agencies and local government should work to clarify roles and responsibilities to streamline assessment and approval processes, to avoid duplication of effort, and to address any gaps in the assessment and approvals process. The first step for this would be by February 2020 relevant officers from Water NSW, DPIE Water, NRAR and Tweed Council convene a workshop for Northern Rivers region bottled water to discuss and develop an approach between them. to:
    - Develop a shared understanding of the data, modelling and information needed by each agency in decision making
    - Documenting a set of standards for data capture, sharing, storage between agencies

- Maximise the utility and outcomes for the group of agencies when new monitoring is being rolled out
- Discuss gaps and overlaps in conditions between regulatory and compliance instruments of different agencies. Access to government and industry water data through a common open platform housing standardised, well-curated and long-term data sets that can be expanded would assist assessment and decision-making of applications.

- If Local government is to undertake hydrogeological assessment as part of the development application process, then it needs access to relevant expertise to interpret modelling and technical reports to inform its decision-making, including requirements for development applications.
- Regional Water Strategies will be developed over the coming months for the 12 catchment regions across the state and will assist to manage the regions' water resources. The Greater Hunter Regional Water Strategy is already in place. These will improve water security within each region and influence decisions about infrastructure, water reuse, water sharing including during droughts, protect the regions' environmental assets as well as addressing community and industry needs.

6.1.9 Truck movements and road impacts

- There are technologies available that can provide accurate, consistent and real-time data on truck movements, which could be included as a condition of the development consent.
- Responsibility for governing truck safety, movements and size spans Federal, State and Local Government authorities. Each of the responsible bodies has measures to regulate and monitor heavy vehicles through existing legalisation, approval of applications and technologies.
- Technologies and strategies are available to measure traffic volumes and impacts. Local government can levy heavy vehicle road users to contribute to the cost of road maintenance and repair.

6.1.10 Plastics

- The presence and management of plastics is international in scope and management of the impacts and solutions will be influenced significantly by factors and developments beyond those extracting water for bottling purposes in the Northern Rivers region.
- The NSW Government is developing a 20-year waste strategy and plastics plan in the context of broader Federal Government and inter-jurisdictional commitments to address waste and transition from linear to circular economies.
- There is a NSW Government container deposit scheme, which has resulted in a one-third reduction across the state of eligible containers, including bottles entering the litter stream.
- Research and development efforts to replace, repurpose and recycle plastics is a fast-moving and evolving space that is predicted to show significant growth within the next five to ten years.

6.2 RECOMMENDATIONS

1. Further work is undertaken to incorporate climate change into the development of recharge estimates for the Water Sharing Plan.
2. Consideration should be given to incorporate geological heterogeneity and soil and vegetation types into recharge estimates where practicable. This may be dependent in part on technological advances, including remote sensing, to characterise systems.
3. Improved monitoring of piezometric water levels is needed in locations with a perceived risk and/or lack of knowledge of groundwater responses and flow directions. This could provide baseline data, conceptual hydrogeological models and recharge estimates commensurate with potential future risk levels. Additional investments in monitoring should balance the value of expected improvements in data availability and data quality against the resources required.
4. Robust local hydrogeological assessments of aquifer connectivity with overlying shallow groundwater and surface water should be investigated via well-designed pump tests. This information should feature in hydrogeological reports.
5. Work should continue towards developing practical and comprehensive guidance on the contents of hydrogeology reports to be submitted by proponents, including specificity and standardisation of information provided and reporting requirements. Ideally, these would be able to be lodged electronically and made publically available.
6. State government agencies and local government should work to clarify roles and responsibilities to streamline assessment and approval processes, to avoid duplication of effort, and to address any gaps in the assessment and approvals process. The first step for this would be by February 2020, relevant officers from Water NSW, DPIE Water, NRAR and Tweed Council convene a workshop for Northern Rivers region bottled water to discuss and develop an approach between them.
7. Water extraction and monitoring data should be made available in standardised formats through open and accessible portals. State managed databases and portals (e.g. SEED) should be utilised where relevant.

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APPENDIX 1: TERMS OF REFERENCE (UPDATED FEB 2019)

The Chief Scientist & Engineer is requested to conduct an independent review and provide expert advice on the impacts on groundwater quantity arising from extraction by the bottled water industry in the Northern Rivers region of NSW.

1. **In undertaking the review, the Chief Scientist & Engineer will:**
    a. review existing data and information on the bottled water industry's entitlements and extractions in the context of:
        i. total water access rights (basic landholder rights and access licences), and
        ii. extraction limits established in statutory water sharing plans
    b. provide advice on the sustainability of the extraction limits in the relevant water sharing plans for groundwater sources in the Northern Rivers of NSW
    c. provide advice on whether the current or proposed groundwater monitoring bores on the Northern Rivers are sufficient.
2. **Provide advice on potential impacts:**
    a. on groundwater resources, having regard to the sustainable take of the resource and the scale of the current bottled water industry and proposed or potential expansion of the industry
    b. of the groundwater take of the bottled water industry on surface water.
3. **Provide advice on:**
    a. scientific and technical approaches to examining socio-economic factors and impacts and possible solutions using locally relevant examples
    b. localised environmental consequences related to extraction for bottled water.
4. **As needed, the Chief Scientist & Engineer may:**
    a. seek advice from relevant Government agencies and other organisations
    b. draw on additional sources of advice and expertise
    c. commission or recommend studies.
5. **The Chief Scientist & Engineer will:**
    a. consult with key local stakeholders
    b. provide an initial report by 1 February 2019
    c. provide a final report by Oct 2019.

APPENDIX 2: SITE VISITS, CONSULTATIONS, WORKSHOP AND SUBMISSIONS

Table 19: Site visit consultations

Date	Location	Facility
9 December 2018	Urliup	Karlos Family Trust • Larry Karlos
10 December 2018	Uki	Mount Warning Spring Water • Shaun Martin • Tessa Martin
20 January 2019	Kynnumboon	Pristine Water Supply Pty Ltd • Steve Bell
20 January 2019	Nobbys Creek	Rosehill Estate 1890 Pty Ltd • Gary Appleby • Trevor Johnson
21 January 2019	Lynwood	Prime Flowers Pty Ltd • Geoffrey Bottomley • Ian Cooke
21 January 2019	Alstonville	Rous County Council Groundwater Bore • Michael McKenzie

Table 20: Consultations

Date	Location	Present
9 December 2018	Murwillumbah	Northern River Guardians • Daniele Voinot • Marian van Gestel • Gwyn Hooper • Scott Sledge • Julie Beesley Water Dragons • Greg O'Donnell • Michele Bevis
9 December 2018	Murwillumbah	Dungay Action Group • Betty Wood • Lucy Campeanu • Joy Baker • Jack Griffis • Dale Holt
9 December 2018	Murwillumbah	Tweed Water Alliance • Pat Miller • Pamela Veness • Denise White • Trevor White • Pamela Smith
9 December 2018	Murwillumbah	Bilambil Urliup Action Group • Anna Champ • Jasmin Derrington • Peter McIlveen • Barbara Downes • Louis Lambert
9 December 2018	Murwillumbah	Bunjalung community members • John Hunt • Thomas Paulson • Murray
10 December 2018	Murwillumbah	Tweed Shire Council • Michael Banks • Robyn Eisermann

		• Iain Lonsdale • Denise Galle • Danny Rose • Ray Clark • Tracey Stinson Lismore City Council • Leonie Walsh Richmond Valley Council • Mike Perkins
10 December 2018	Murwillumbah	Tweed Shire Council • Warren Polglase • James Owen • Katie Milne • Reece Byrnes • Pryce Allsop • Troy Green Hon Justine Elliot MP's Office • Jurgen Schanzenbacher
10 December 2018	Murwillumbah	Rous County Council • Phillip Rudd • Michael McKenzie
10 December 2018	Uki	• Graham Dietrich
13 December 2018	Sydney	Australian Beverages Council • Alby Taylor • Shae Courtney
20 January 2019	Murwillumbah	Combined Tweed Rural Industries Association • Colin Brooks
20 January 2019	Murwillumbah	Richmond Wilson Combined Water Users Association • Chris Magner • Catherine Richardson-Magner
20 January 2019	Ballina	• Ceridwen Quick • Clive Quick
21 January 2019	Rous Mill	• Bryan Douglas
21 January 2019	Alstonville	Nu-Pure Beverages • Brendan Moroney • Bruce Taylor Black Mount Spring Water • Tim Carey
21 January 2019	Alstonville	Save Alstonville Aquifer • Michael Hogan • Troy Outerbridge • David Huett
21 January 2019	Alstonville	Ballina Shire Council • Sharon Parry • Eoin Johnson • Ben Smith • Phillip Meehan • Sharon Cadwallader • Matthew Wood • David Wright • Andrew Smith • Simon Scott • Georgia Lee • Keith Williams (Chair of Rous County Council) Byron Shire Council • Jason Stanley • Andrew Cameron • Michael Bingham • Bryan Green

1 August 2019	Level 48, MLC Centre 19 Martin Place, Sydney	Australian Beverages Council • Shae Courtney Blackmount Spring Water • Tim Carey • Scott Wallace
15 October 2019	Phone consultation	Kevin Graham
17 October 2019	Phone consultation	Lance Rawson

Table 21: Expert Workshop Participants – 6 September 2019

Participant Name	Affiliation
Peter Cook	Flinders University
Grant Hose	Macquarie University
Lucy Reading	Queensland University of Technology
Liliana Pagliero	University of Queensland
Neil McIntyre	University of Queensland
Louise Ryan	University of Technology Sydney
Ian Acworth	UNSW Sydney
Jason Evans	UNSW Sydney
Lucy Marshall	UNSW Sydney
Mahmood Sadat-Noori	UNSW Sydney
Martin Andersen	UNSW Sydney
Scott Sisson	UNSW Sydney
William Glamore	UNSW Sydney
Daniel Deere (independent facilitator)	Water Futures
Luk Peeters	CSIRO
Tomonori Hu	NSW Smart Sensing Network
Jenny Johnson	DPIE
Jon Stone	DPIE
Danielle Doughty	DPIE Water
Fabienne d'Hautefeuille	DPIE Water
Lynn Tamsitt	DPIE Water
Mark Simons	DPIE Water
Richard Green	DPIE Water

Table 22: Submissions

No.	Organisation
SUB 001	Ballina Shire Council
SUB 002	Bryan Douglas
SUB 003	Michael Hogan, Save Alstonville Aquifer
SUB 004	David Huett, Save Alstonville Aquifer
SUB 005	Australian Beverages Council
SUB 006	NSW Irrigators Council
SUB 007	Save Alstonville Aquifer
SUB 008	Duncan Dey
SUB 009	CONFIDENTIAL
SUB 010	Australian Beverages Council
SUB 011	CONFIDENTIAL
SUB 012	CONFIDENTIAL
SUB 013	CONFIDENTIAL
SUB 014	CONFIDENTIAL

APPENDIX 3: EXCERPTS FROM INITIAL REPORT – EXTRACTION LIMITS AND THE WATER SHARING PLAN

The following are extracts from the Initial Report providing background information about the North Coast Fractured and Porous Rock Groundwater Sources Water Sharing Plan; and how extraction limits are calculated and allocated. These sections are brought forward to provide context for the analysis undertaken by the Review. Note that some reference in the following text refer to Tables and Figures in the Initial Report.

Beginning of text from the Initial Report

The first Term of Reference entails an examination of extraction levels in the WSP and seeks advice on extraction levels for the bottled water industry and future monitoring. In working to address these, the consultation process proved to be a rich source of information, data and ideas from the community and other stakeholders. The issues identified in those fora (set out in Chapter 2 of the Initial Report) that relate to the volume of water and allocation processes and issues are the focus of this section.

The quantity of water that is available for the bottled water industry in the Northern Rivers region, as with other extractors for commercial purposes is established through the *Water Management Act 2000* and the WSP instruments.

Two fundamental principles for the WSP that are important for the framing of this Review are:

1. there are established priorities of allocation with environmental and ecological first, basic rights/stock and domestic second, and industrial and commercial extraction last
2. within the category of industrial and commercial, there is no distinction made between different ‘product categories’ or end uses – water involved in producing food, drink, minerals, manufactured products and services are all considered on a level playing field.

The following sections discuss in more detail the relevant WSP for groundwater in the region. Further information about the regulatory framework is in Appendix 4 (of the Initial Report) and the rules applying to the four groundwater sources relevant to the Review are at Appendix 5 (of the Initial Report).

WATER SHARING PLAN FOR NORTH COAST FRACTURED AND POROUS ROCK GROUNDWATER SOURCES

Under the *Water Management Act 2000*, WSPs have been developed for many groundwater and surface water systems in NSW to control and limit usage of water resources, ensure that Basic Landholder Rights (BLR) can be met and ensure that there is sufficient water reserved as environmental water to support dependent ecosystems and maintain aquifer health. Table 23 sets out the WSPs in the Northern Rivers region.

Table 23: Northern Rivers region groundwater and surface water sharing plans

Water Sharing Plan	Plan Status	Supporting Documentation	Cease Date
Brunswick Unregulated and Alluvial	Commenced July 2016	• Brunswick water source rules • Background document	July 2026
North Coast Coastal Sands Groundwater Sources	Commenced July 2016	• North Coast Coastal Sands Groundwater source rules • Background document	July 2026
North Coast Fractured and Porous Rock Groundwater Sources	Commenced July 2016	• North Coast Fractured and Porous Rock Groundwater source rules • Background document	July 2026
Richmond River Area Unregulated, Regulated and Alluvial	Commenced Dec 2010	• Richmond River are water source rules • Background document	July 2021
Tweed River Area Unregulated and Alluvial	Commenced Dec 2010	• Tweed River area water source rules • Background document	July 2021
Alstonville Plateau Groundwater Sources	Commenced 2004 - Repealed	• Replaced by Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources	June 2016

Source: DOI (2019)

The Review is focusing on four specific groundwater sources in the Northern Rivers region where there is current, proposed or potential historical groundwater extraction for bottled water (Table 24). If the Review is made aware of additional groundwater sources in the Northern Rivers region used by the industry, these will be added to the scope as the Review progresses.

Table 24: Groundwater sources and descriptions

Groundwater Source	Description
Alstonville Basalt Plateau Groundwater Source	A fractured rock aquifer system in which Tertiary basalt extends to a depth of up to 150 metres. Groundwater is contained in fractures in the basalt. The hydrology of the area is complex and the degree of connectivity (both vertical and horizontal) is not uniform. The groundwater in this source is used for town water supply and irrigated agriculture. Discharge at the surface provides baseflow to surface waters and is important to the environment
Clarence Moreton Basin Groundwater Source	A porous rock aquifer system, overlain by the Mount Warning complex (comprised of the North Coast Volcanics and the Alstonville Plateau groundwater sources). On the eastern extent it is overlain by alluvial and coastal sand deposits. Groundwater is both contained within the system, and moves through it, due to the primary porosity of the rock as well as the fractures present due to the folding and faulting of the rock formation. Low bore yields of 1L/s, rising to up to 10L/s in highly fractured fault systems. All surface units are recharged by direct rainfall recharge with subsequent vertical leakage. Generally used for stock and domestic purposes with some sporadic irrigation/commercial supplies.
New England Fold Belt Coast Groundwater Source	A fractured rock aquifer system, overlain by the Clarence Moreton Basin and North Coast Volcanics groundwater sources. On the eastern extent it is overlain by alluvial and coastal sand deposits. Groundwater is contained within, and moves through, fractures in the rock due to the folding and faulting of the rock formations. Low bore yields of 1L/s, rising to up to 10L/s in highly fractured fault systems. Recharge is typically by direct rainfall infiltration and, combined with the degree of mineral leaching that has occurred over time, has resulted in good quality water. Generally used for small scale irrigation, stock and domestic purposes.
North Coast Volcanics Groundwater Source	A fractured rock aquifer system comprised of the Lamington Volcanics, associated with the Mount Warning Complex. It is situated on top of the New England Fold Belt Coast and Clarence Morton Basin groundwater sources. Typically composed of basalt and rhyolite, the groundwater is contained within, and moves through, fractures formed as a result of the rock cooling as well as the vesicular structures of basalt flows. Moderate bore yields of 5L/s, rising to up to 10L/s in highly fractured fault systems. Recharge is typically by direct rainfall infiltration, resulting in excellent quality water. Used for stock, domestic and irrigation water supplies. Stream and spring flow is reliant on groundwater discharge during non-rainfall periods. As a result, groundwater-dependant ecosystems are common with the groundwater source.

Source: (DPI Water, 2016c, 2016d, 2016b, 2016a)

These sources are covered by the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources (DPI Water, 2016f) (WSP) released in September 2016.

The WSP covers 13 groundwater sources from Gosford to Tweed Heads, 10 of which had not previously been covered by a WSP. The total area covered by the WSP is approximately 76,000 km^2 (DPI Water, 2016f). The groundwater sources covered by this plan are defined either as porous or fractured rock aquifers, all with the following connectivity characteristics according to the WSP:

- low-moderate connection between surface and groundwater
- low impact on in-stream values
- years to decades travel time between groundwater and surface water (DPI Water, 2016f)

Prior to the commencement of the WSP, of the four groundwater sources in scope, only the Alstonville Plateau Groundwater Source was the subject of a WSP as noted in Table 24 above.

Prior to the finalisation of the WSP, report cards for each of the groundwater sources were issued in February 2016. For the Alstonville Basalt Plateau Groundwater Source, which had been subject to a prior plan, the proposed rule changes and technical specifications like calculation of recharge were compared against the original WSP for Alstonville.

One significant change was that the previous division of the Alstonville Plateau into six groundwater sources changed to the groundwater sources merged into one with two management zones - the Alstonville-Tuckean and the Bangalow-Wyrallah management zones. These were based on levels of extraction, particular intensity of extraction in the Alstonville-Tuckean area, and to prevent localised impacts.

Within the whole groundwater source, no water is being made available for new licences, as the source has been capped at the current entitlement. However, trading is allowed within the groundwater source, but not if the trade results in a net increase to the sum of share components in the Alstonville-Tuckean Management Zone. There are no restrictions to trades within each of the management zones or from the Alstonville-Tuckean into the Bangalow-Wyrallah zones.

The WSP is a regional water planning tool and a macro-scale instrument that considers a geographically large area to set guidelines and regulations to limit overuse or stress on an aquifer at a regional scale. The WSP does not specifically assess local scale risks, other than setting broad limits on the proximity of groundwater extractions to groundwater dependent ecosystems (GDEs), other groundwater users, aboriginal heritage sites and major water supply bores. These are summarised for the four groundwater systems in the rules in Appendix 3 (of the Initial Report). The issue of potential localised impacts from extraction will be further investigated by the Review over the coming months.

Under the WSP, priority is given to environmental water and basic landholder rights (BLR). The plan allocates an amount of water that is to be reserved for these priority uses, and prevents licensed extractions from accessing a portion of the estimated groundwater source. Licensed extractions for all other uses are secondary to BLR and environmental water. Some additional priority is given to groundwater extracted for local and major utilities that are typically licensed to extract reasonably large amounts for water security and to licensed stock and domestic bores.

Under the *Water Management Act 2000*, granting of commercial water licences (e.g. groundwater extractions that are not for BLR or utilities) is independent of their intended use. This allows ready trade and aims to promote efficient use of resources, as well as allowing new industries to develop and water to be allocated to the highest value use (DPI Water, 2016f). Under the *Water Management Act 2000* and the WSP, extraction for bottled water is treated the same as any other commercial extraction, including commercial irrigation and horticulture. Further information about the WSPs, including audit and review processes are contained in Appendix 4 (of the Initial Report).

The following sections review the purpose and methods used in the WSP that governs groundwater licenses for the areas relevant to this review.

EXTRACTION LIMITS

A major output of the WSP is the LTAAEL for each of the 13 groundwater sources. The LTAAEL determines the maximum average volume of water that can be extracted from one source in a given year. To prevent the overuse of groundwater resources, the water sharing plans generally enforce the LTAAEL to be a portion of the average recharge of the aquifer (i.e. versus water that is already stored in the aquifer). To quantify an appropriate LTAAEL, average recharge must be defined.

Groundwater sources in the WSP are described as '*less highly-connected groundwater sources*' (DPI Water, 2016f), so the estimates of aquifer recharge only consider direct rainfall. While some surface water – groundwater connectivity may exist, no surface water contribution to recharge is considered in these calculations. Under that assumption, the LTAAEL for fractured rock aquifers is determined by the following simplified procedure (DPI Water, 2015):

1. estimation of the annual average rainfall (discussed in Section 3.2.1)
2. estimation of the recharge as a fixed percentage of rainfall (discussed in Section 3.2.2)
3. determination of areas of high environmental value and non-high environmental value
4. determination of current and future water requirements (the latter increased by 10 percent to ensure a conservative estimate)
5. determination of the UEL, which is equal to the recharge in the non-high environmental value area multiplied by a sustainability index (described in Section 3.2.3)
6. determination of LTAAEL as the UEL or a lower value based on estimates of existing and future extractions.

The current total water access rights, including an estimate of BLR (which does not require a licence for extraction), was calculated for each of the groundwater sources as part of the WSP in 2016. Where the total water access rights are less than the 80 percent of the LTAAEL, water can be made available as new licence allocations by state government agencies via a controlled allocation process.

When the WSP was first released in 2016, the Alstonville Basalt Plateau Groundwater Source was the only source subject to the Review where licence allocations were at the LTAAEL, whereas (the other three sources subject of this Review were less than 60 percent allocated). There is a provision for the LTAAEL of fractured rock aquifers to be increased to a maximum of the UEL if demand for water increases beyond the predicted amount.

Within the area covered by the WSP, licences entitle their holders to a certain 'share' of the water resource. Under ordinary circumstances, one share is equal to an entitlement of 1ML/y. However, at the Minister's discretion, the allocation of water per share can be reduced to minimise environmental or socio-economic impacts, such as during a drought or in response to a growth in use of local water utility or BLR use.

The following sections review the process for water allocation determination in the WSP.

Average Annual Rainfall

Annual rainfall is variable over the relatively large area covered by the WSP. Rainfall data used by the WSP was sourced from the BOM gridded rainfall data (approximately 5 km^2 grid) from 1901 – 2011. More information on the rainfall data can be found on BOM (2015).

This rainfall model uses algorithms to estimate a weighted average rainfall in each grid based on the observations at the nearest BOM stations (see Section 1.2). This accounts for the spatial variability of rainfall throughout large catchments and is based on the best available data.

Recharge Rates

The WSP simplifies the aquifer recharge to the relationship shown in Equation 1. The systems considered in the WSP are considered to be '*less highly-connected groundwater sources*' (DPI Water, 2016f), which means there is little recharge through creek beds, and therefore, only recharge through rainfall was considered.

Calculating recharge through this relationship assumes that the aquifer is homogenous, which is a simplification of the complex geology that occurs in porous and fractured rock aquifers. It also assumes that the recharge is generated over the entire surface area of the groundwater source that is not overlain by another defined groundwater source (i.e. the outcropping area).

$$\textbf{Average Recharge (ML/yr) = Average Rainfall (mm/yr) x Area (km}^{2}\textbf{) x Recharge Rate (\%)/100}$$

Equation 1: Average recharge

While rainfall and area are measurable (although the area over which the source is recharged is sometimes less clear, which is discussed further below, the recharge rate is more difficult to define. The transmissivity of different aquifers can vary significantly depending on the geology, and different recharge rates were applied by the WSP for each of the groundwater sources. DPI Water (2015) provides some guidance on the recharge rates applied for different groundwater source types (Table 25).

Table 25: Recharge rates recommended by DPI Water (2015)

Hydrogeological Type	Recharge Rate	Comment
Coastal Porous Rock	1 – 6%	Based on the findings of Coastal Porous Rock Rainfall Recharge Study
Inland Porous Rock	6%	
Fractured Rock (excl. North Coast Volcanics)	4%	
North Coast Volcanics	8%	Source is unclear

Table 26 shows the recharge rates adopted in the WSP for the groundwater sources relevant to this report. DPI Water (2016f) and DPI Water (2015) acknowledge that regional estimates of recharge of large aquifers is not an exact science, and they state they that due to this uncertainty have taken a precautionary approach. DPIE Water has advised that the precautionary approach was based on using zero percent recharge estimates for high value area, no allowance for recharge from anything other than direct rainfall, and sustainability indexes to ensure that use is significantly less than recharge (DOI Water, 2019).

Table 26: Rainfall recharge rates adopted in the Water Sharing Plan

Groundwater Source	Rainfall Recharge Rate adopted	Based on
Clarence Moreton Basin	6%	There is little direct data and very little demand for groundwater, therefore the NSW default 6 percent was recommended, based on the Coastal Porous Rock Rainfall Recharge Study (DPI Water, 2016f)
North Coast Volcanics	8%	DPI Water (2016f)
New England Fold Belt Coast	4%	DPI Water (2016f)
Alstonville Basalt Plateau	8%	Based on preceding WSP

Sustainability Index

The sustainability index (SI) is a qualitative risk based approach used in water sharing plans to account for the relative social, economic and environmental risks of extracting groundwater from a particular water source.

The environmental risk considers the prevalence of high priority groundwater dependent ecosystems and the risk to the groundwater source itself. It considers water quality, ecology and aquifer integrity. Environmental risk is rated as high (e.g. permanent and significant change), moderate (temporary change) or low (no change anticipated) and is a simple relative measure. If there are any mitigation actions (e.g. groundwater modelling or distance rules from sensitive areas), these may be considered to lower the environmental risk.

Socio-economic risk considers the financial and social dependence of local communities on a groundwater resource. For example, the socio-economic risk considers whether there is any readily available alternative to groundwater extraction, the contribution of groundwater dependent industry on the local economy (including employment rates) and the dependence of the local communities on groundwater resources for drinking water supplies. As per the environmental risk, the socio-economic risk is assigned a relative rating (high, moderate or low).

Following these assessments, the environmental (known as the 'aquifer risk') risk and the socio-economic risk are input into the matrix shown in Table 27 to define the final sustainability index. For example, if the aquifer risk is classified as 'High' and the socio-economic risk is 'Medium', the sustainability index would be 25 percent as illustrated in Table 27.

Table 27: Sustainability index matrix, with an example calculation of a high aquifer, medium socio-economic risk sustainability index of 25%

Aquifer Risk	High	5%	25%	50%
	Medium	25%	50%	60%
	Low	50%	60%	70%
		High	**Medium**	**Low**
		Socio-Economic Risk		

Source: (DPI Water, 2016f)

The sustainability index is used to define the upper extraction limit (UEL – the maximum allowable extraction from the groundwater source) as per Equation 2 below. The sustainability index is the portion of estimated recharge that can be assigned to the UEL.

A lower sustainability index indicates less water is to be available for extraction (i.e. more water is assigned as environmental water). All the catchments are split into two areas – high conservation areas (e.g. National Parks) and the remaining areas. For all WSP groundwater sources, the sustainability index over high conservation areas is, by default, 0 percent. This means that recharge over these areas is preserved for environmental use. The sustainability index calculated in Table 27 only relates to the remaining areas.

UEL (ML/yr) = Recharge over non- high environmental areas (ML/yr) x SI(%)

Equation 2: UEL

Table 28 summarises the sustainability indexes for the four groundwater sources considered in this report, including the assigned socio-economic and environmental risk. Environmental risk of the North Coast Volcanics is high due to the prevalence of springs, rainforests and groundwater dependent soils. The socio-economic risk in the Clarence Moreton Basin is largely due to the predicted (at the time) reliance of the coal seam gas industry on groundwater resources, as well as the dependence of the smaller industries on groundwater. No socio-economic or environmental risk was provided for the Alstonville Basalt Plateau in the WSP, as there were limited changes to the allowable extraction from the previous Water Sharing Plan for the Alstonville Plateau Groundwater Source.

Table 28: Sustainability index for relevant groundwater sources

Groundwater Source	Socio-Economic Risk	Environmental Risk	Sustainability Index
New England Fold Belt Coast	Low	Moderate	25%
Clarence Moreton Basin	Moderate	Low	60%
North Coast Volcanics	Moderate	High	25%
Alstonville Basalt Plateau	-	-	~20%*

This is not presented in the current WSP but is based on the preceding legislation Water Sharing Plan for the Alstonville Plateau Groundwater Source

Estimates of LTAAEL

The LTAAEL is calculated differently depending on whether the groundwater source is defined as a porous or fractured rock aquifer. For fractured rock aquifers (New England Fold Belt Coast, North Coast Volcanics and the Alstonville Plateau), the UEL is calculated as per Equation 2, as a direct relationship between the recharge and sustainability index. However, in an acknowledgement of the uncertainties surrounding the recharge estimates for fractured rock, the upper extraction limit is compared to the current and estimated future requirements for water (including a 10 percent buffer on the future requirements). The future estimated requirements were calculated considering the following (DPI Water, 2015):

- growth in BLR as a result of increasing populations. BLR was assumed to grow in proportion with population. Population forecasts were based on Department of Planning estimates
- increase in requirements for dewatering, based on dewatering in the previous decade increasing proportionally with population growth
- growth in town water supply requirements, sourced from future water strategies and consultation with the relevant councils;
- growth in agricultural, which was determined by the North Coast Interagency Regional Panel based on local knowledge and present agricultural requirements
- growth in mining requirements, based on industry statistics reviewed by the North Coast Interagency Regional Panel.

Once the future estimated requirement for groundwater was calculated, the following rules are applied to determine the LTAAEL:

1. if the future estimated requirement for groundwater (+10 percent) < 10 percent of UEL, LTAAEL = 10 percent of UEL
2. if the future estimated requirement for groundwater (+10 percent) > UEL, LTAAEL = UEL
3. otherwise, LTAAEL = future requirement for groundwater (+10 percent).

In cases where the LTAAEL<UEL, the LTAAEL can be increased during the life of the WSP if the entitlement reaches 80 percent of the LTAAEL. This would require a review of the LTAAEL (of one particular groundwater source) by the North Coast Interagency Region Panel or some other similar interagency panel (DPI Water, 2016e). DPI Water (2016f) notes that the future requirement estimates were 'generous' implying that it was considered unlikely that there would be an increase in LTAAEL in the life of the plan.

For the New England Fold Belt Coast and the North Coast Volcanics, the LTAAEL is substantially smaller than (< 25 percent of) the UEL (Table 29). This provides a suitable buffer to account for the uncertainty related to the recharge rates for these areas, and results in what is likely a conservative allocation of groundwater resources. For the Alstonville Plateau, where the LTAAEL is based on the preceding WSP, the LTAAEL is relatively high compared to the average annual recharge.

Table 29: LTAAEL in fractured rock aquifers as reported in February 2019 (Initial Report)

Groundwater Source	Average Recharge over non-high environmental areas (ML/yr)	Estimate Future Requirement (+10) (ML/yr)	UEL (ML/yr)	10% of UEL (ML/yr)	LTAAEL (ML/yr)
New England Fold Belt Coast	1,500,000	60,000	375,000	37,500	60,000
North Coast Volcanics	220,000	13,000	55,000	5,500	13,000
Alstonville Plateau*	50,000	-	-	-	8,895

Source: DPI 2016
Based on the preceding legislation Water Sharing Plan for the Alstonville Plateau Groundwater Source, no future requirement or UEL was presented

For porous rock aquifers (Clarence Moreton Basin), the WSP states a higher degree of confidence in the recharge rates due to the results of the Coastal Porous Rock Rainfall Recharge Study. Further investigation is needed to determine the basis for this higher degree of confidence.

Table 30: LTAAEL for porous rock aquifers as reported in February 2019 (Initial Report)

Groundwater Source	Average Recharge over non-high environmental areas (ML/yr)	Current Requirement (ML/yr)	LTAAEL (ML/yr)
Clarence Moreton Basin	500,000	4,562	300,000

Source: DPI Water (2016f)

LTAAEL values in the porous rock aquifers were calculated as per Equation 2, where the LTAAEL is equal to the UEL. Unlike fractured rock aquifers, no reduction is made in the LTAAEL to account for cases with low current and estimated future requirements for groundwater extractions.

As a result, the LTAAEL for the Clarence Moreton Basin, shown in Table 30, is large compared to the current water extraction. While this is an indicator that the groundwater source is unlikely to be currently under stress, there is no trigger for review of the LTAAEL if there is a large growth in extraction (as would be required for the New England Fold Belt Coast or the North Coast Volcanics). However, the whole WSP is reviewed after a period of ten years, so any significant growth in these porous rock aquifers could be reviewed at this time.

Environmental Water

The WSP requires an assignment of a portion of the annual average recharge to be classed as environmental water. As mentioned previously, 100 percent of recharge over high conservation areas, such as National Parks, is preserved for environmental water. The total volume of water assigned as RRE is defined by the relationship in Equation 3.

$$\text{RRE (ML/yr)} = \text{Average Recharge (ML/yr)} - \text{LTAAEL}$$

Equation 3: Recharge Reserved for the Environment (RRE)

Table 31 shows the RRE for the four groundwater sources of interest. The allotment of total estimated recharge is illustrated graphically in Figure 24.

With the exception of the Clarence Moreton Basin, the RRE is in excess of 80 percent of the estimated recharge. RRE is typically higher in fractured rock aquifers due to the more conservative approach used to obtain a value of LTAAEL.

Table 31: Recharge amount reserved for the environment as reported in February 2019 (Initial Report)

Groundwater Source	Total Estimated Recharge[1] (ML/yr)	LTAAEL (ML/yr)	RRE (ML/yr)[1,2]	RRE as a percentage of estimated recharge[1]
New England Fold Belt Coast	1,980,000	60,000	1,920,000	97%
Alstonville Plateau	50,079	8,895	41,184	82%
Clarence Moreton Basin	576,000	300,000	276,000	48%
North Coast Volcanics	310,000	13,000	297,000	96%

Source: (DPI Water, 2016f)

1. All numbers presented in this table are over the whole groundwater source and include recharge and environmental water from high-conservation areas and less environmentally sensitive areas combined, which may differ from numbers expressed in the WSP
2. Table 15 in WSP Background document refers to these values as planned environmental water 'PEW'

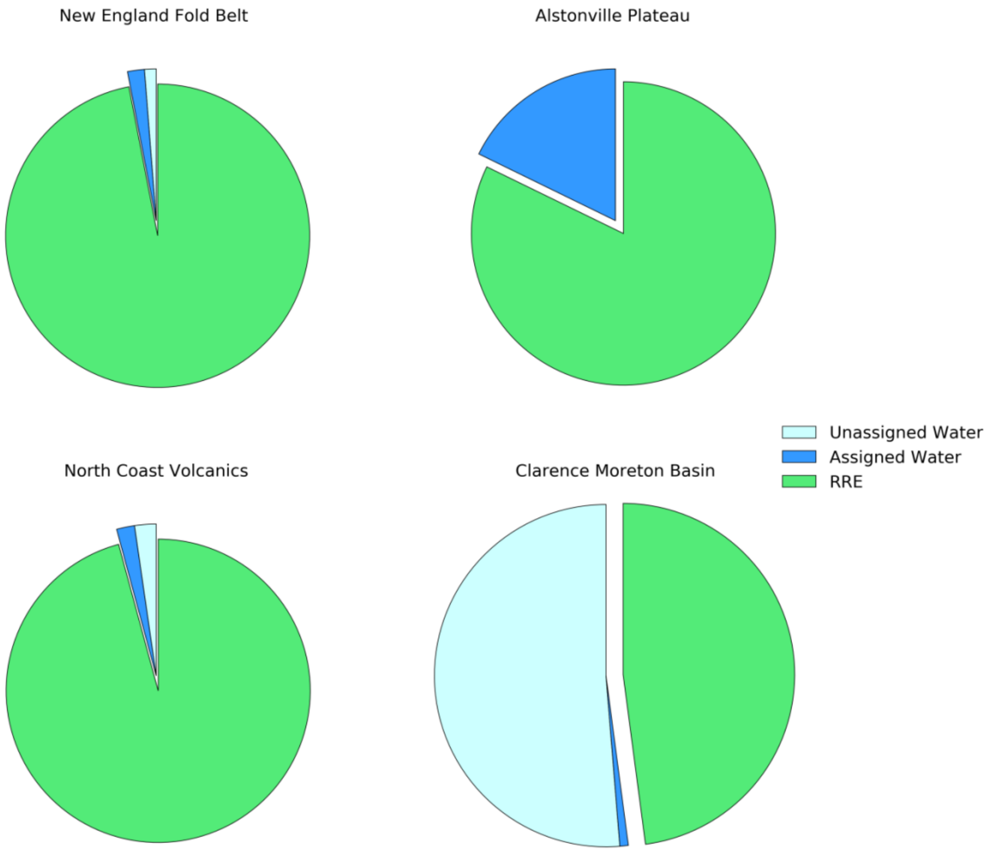


Figure 24: Allotment of estimated recharge to Recharge Amount Reserved for the Environment (total volumes differ between aquifers) as reported in February 2019 (Initial Report)

APPENDIX 4: BASEFLOW FILTERING TECHNIQUE

Baseflow was filtered from the total daily flow time series using a recursive digital filter (Arnold et al., 1995; Arnold & Allen, 1999). It corresponds to an adaptation of digital filter methods used in signal analysis, and assumes that low frequency baseflow could be distinguish from high frequency flows. The filter equation is:

$$q_t = \beta q_{t-1} + \frac{1+\beta}{s}(Q_t - Q_{t-1}) \qquad \text{Equation 1}$$

Where, q_t is the filtered surface runoff (quick response) at day number t, Q is the original streamflow, and β is the filter parameter. The filter can be applied to the stream flow data, in both forward and reverse directions, as many times as desired. The number of times determines the degree of smoothing of the baseflow hydrograph. In general, each pass will result in less baseflow as a percentage of total flow. For this review, the filter parameter β was set to 0.925, as determined by Nathan and McMahon (1990) and Arnold et al. (1995) to provide realistic results.

Baseflow, b_t, was then calculated via:

$$b_t = Q_t - q_t \qquad \text{Equation 2}$$

Although the technique has no physical basis, it is objective and reproducible and has been successfully compared with graphical (manual) methods of baseflow separation (Arnold et al., 1995; Mau & Winter, 1997) and with measured field estimates (Arnold & Allen, 1999). For this study the filter was passed three times; forward, backwards and forward for smoothing the baseflow hydrograph based on the dataset length.

Baseflow filtering results

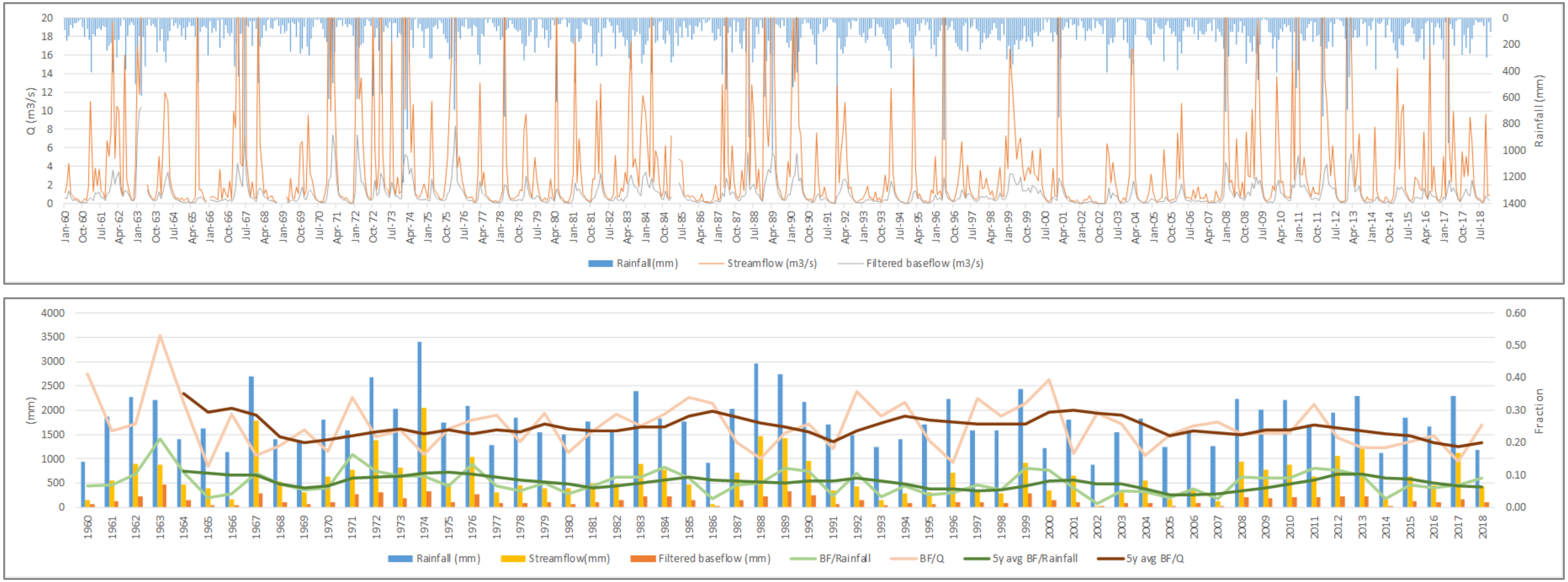


Figure 25: Baseflow filtering results - monitoring point 201001: Oxley River at Eungella

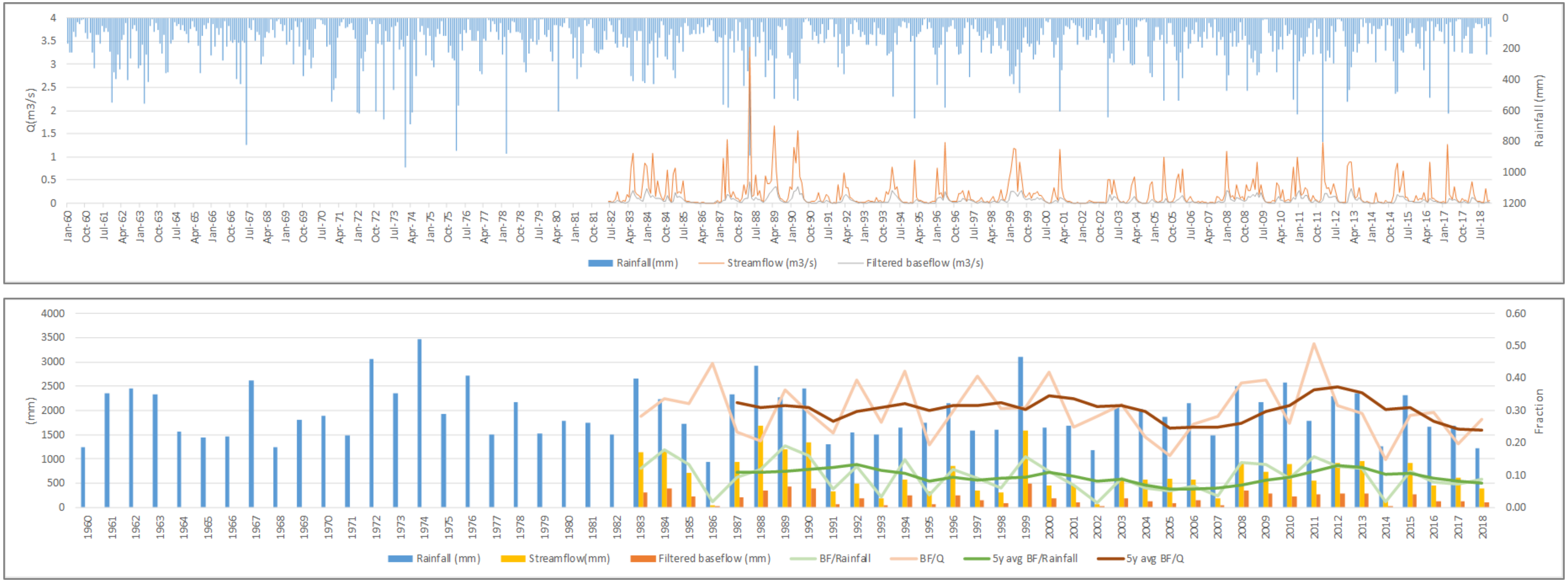


Figure 26: Baseflow filtering results monitoring point 201005: Rous River at Boat Harbour No. 3

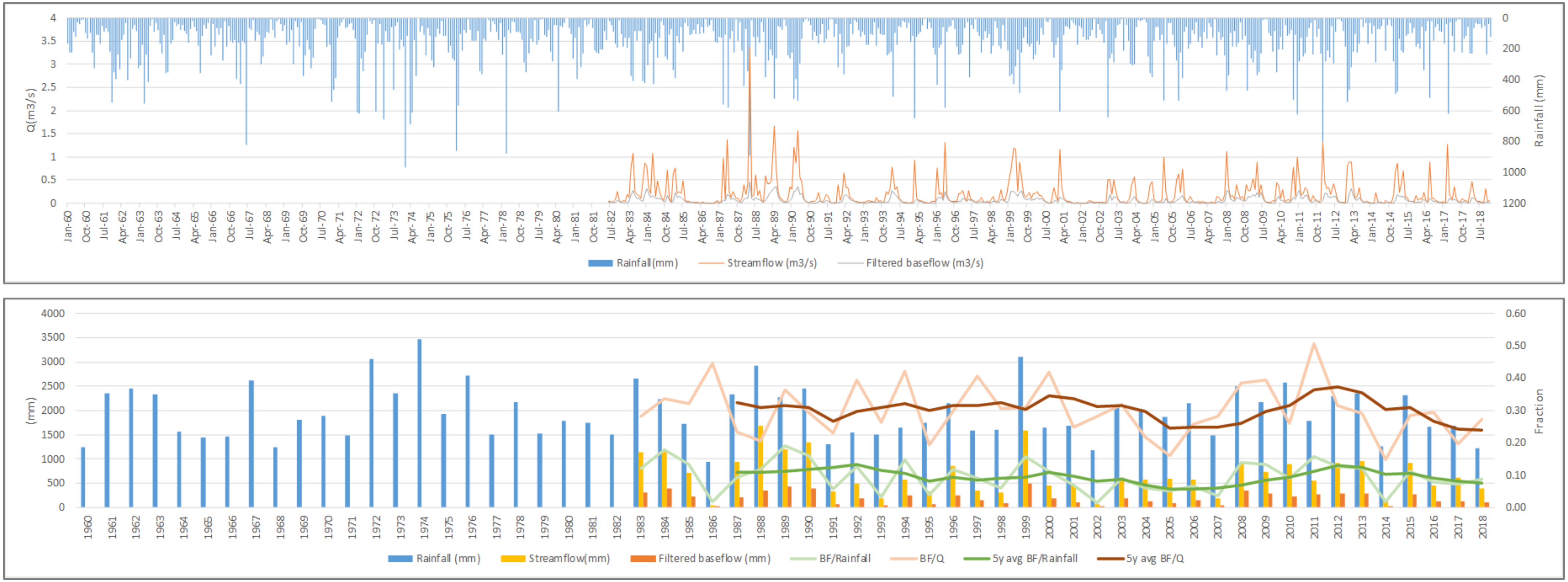


Figure 27: Baseflow filtering results monitoring point 201012: Cobaki creek at Cobaki

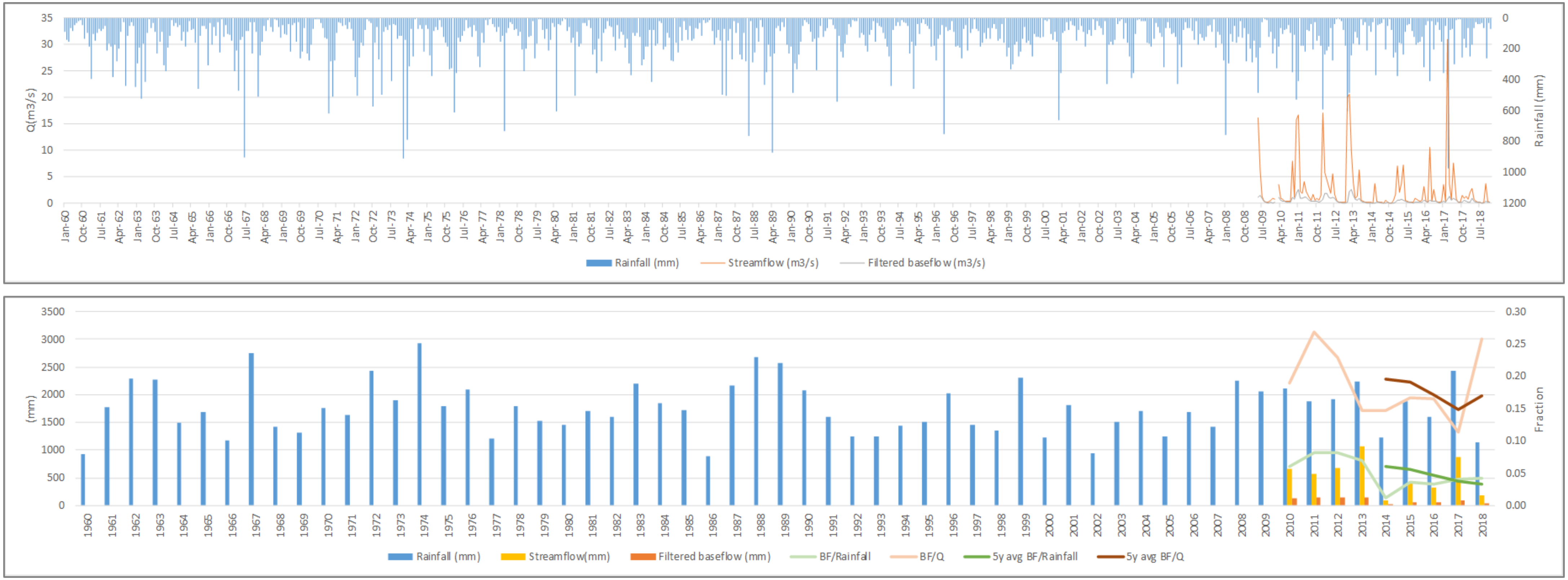


Figure 28: Baseflow filtering results - monitoring point 201015: Tweed River D/S Palmers Road Crossing

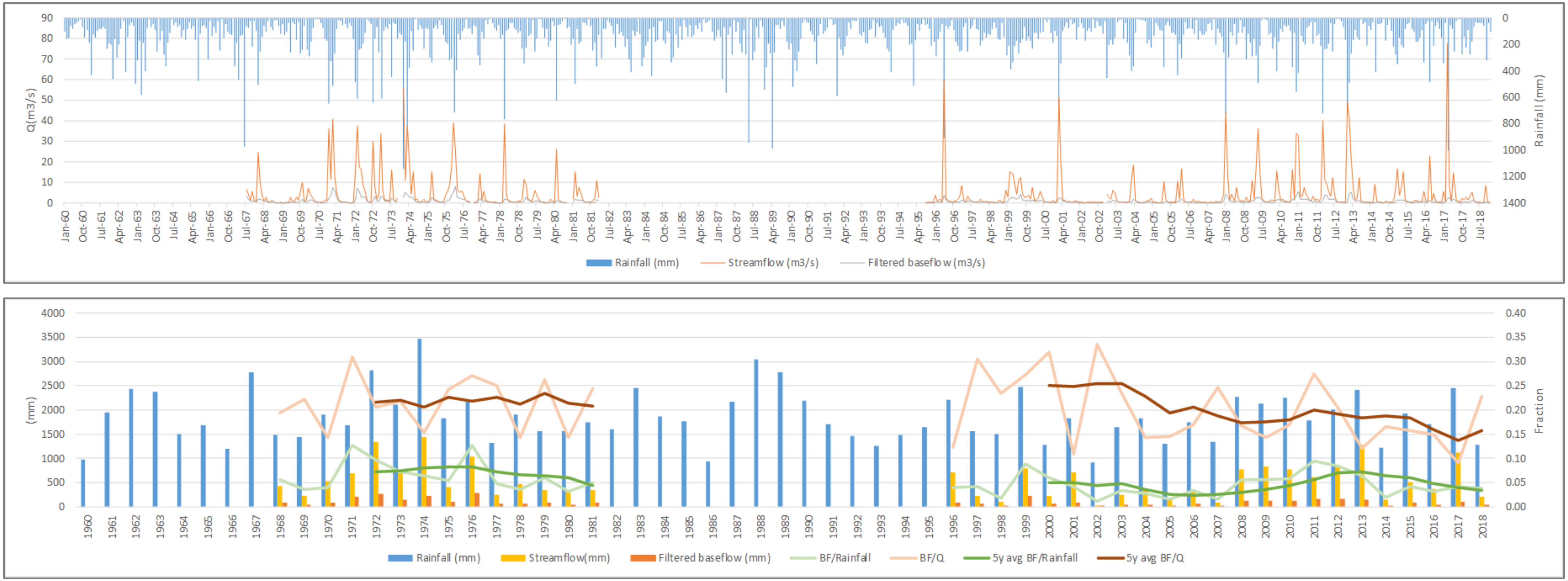


Figure 29: Baseflow filtering results - monitoring point 201900: Tweed River at Uki

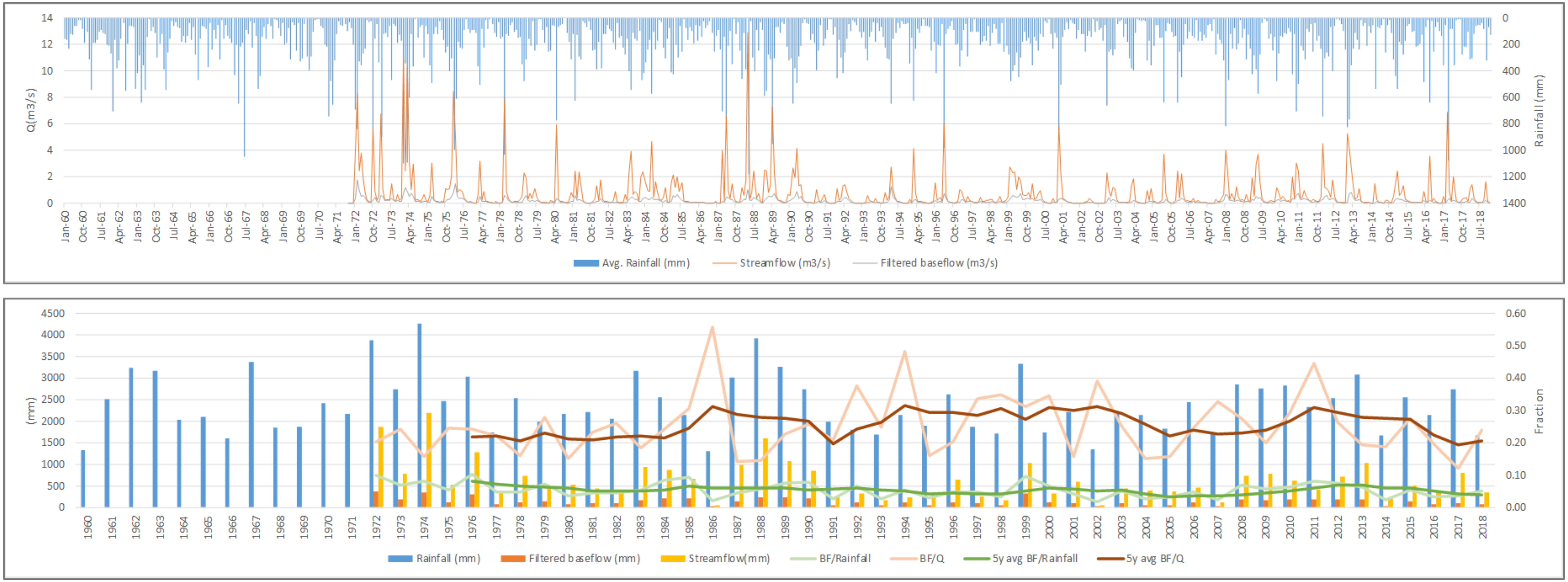


Figure 30: Baseflow filtering results - monitoring point 202001: Brunswick river at Durrumbul (sherrys crossing)

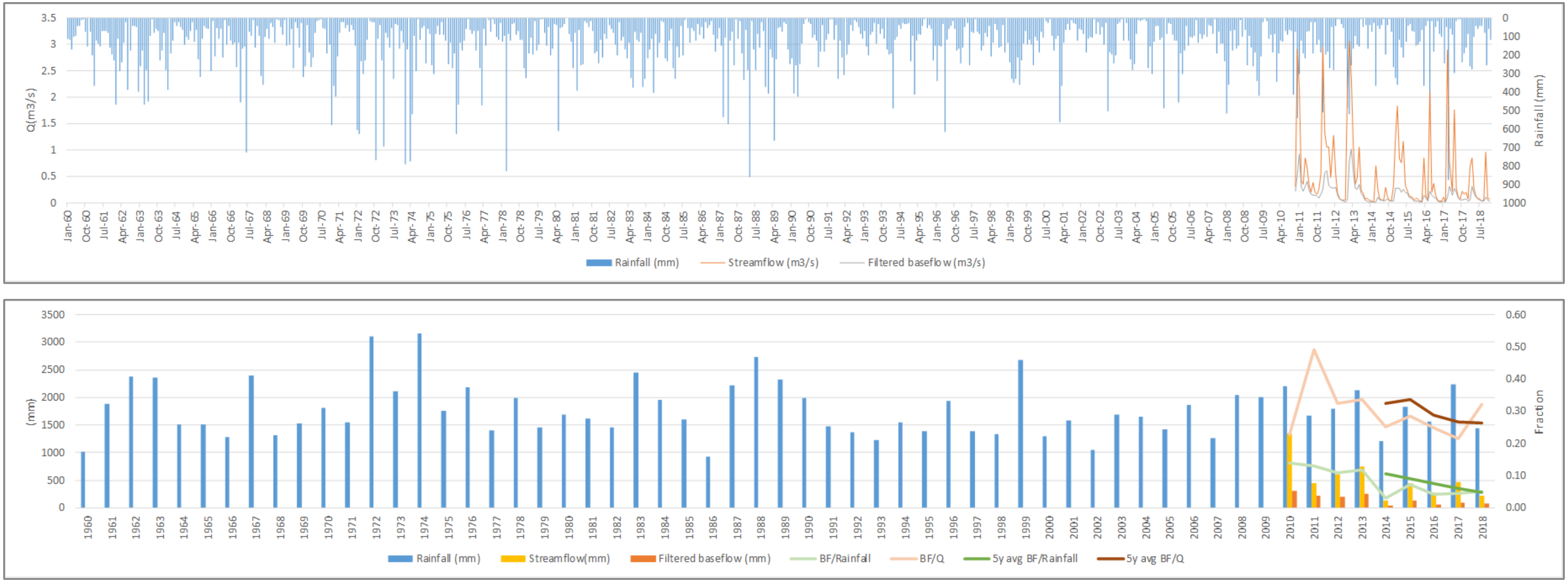


Figure 31: Baseflow filtering results - monitoring point 202002: Burringbar creek at Burringbar

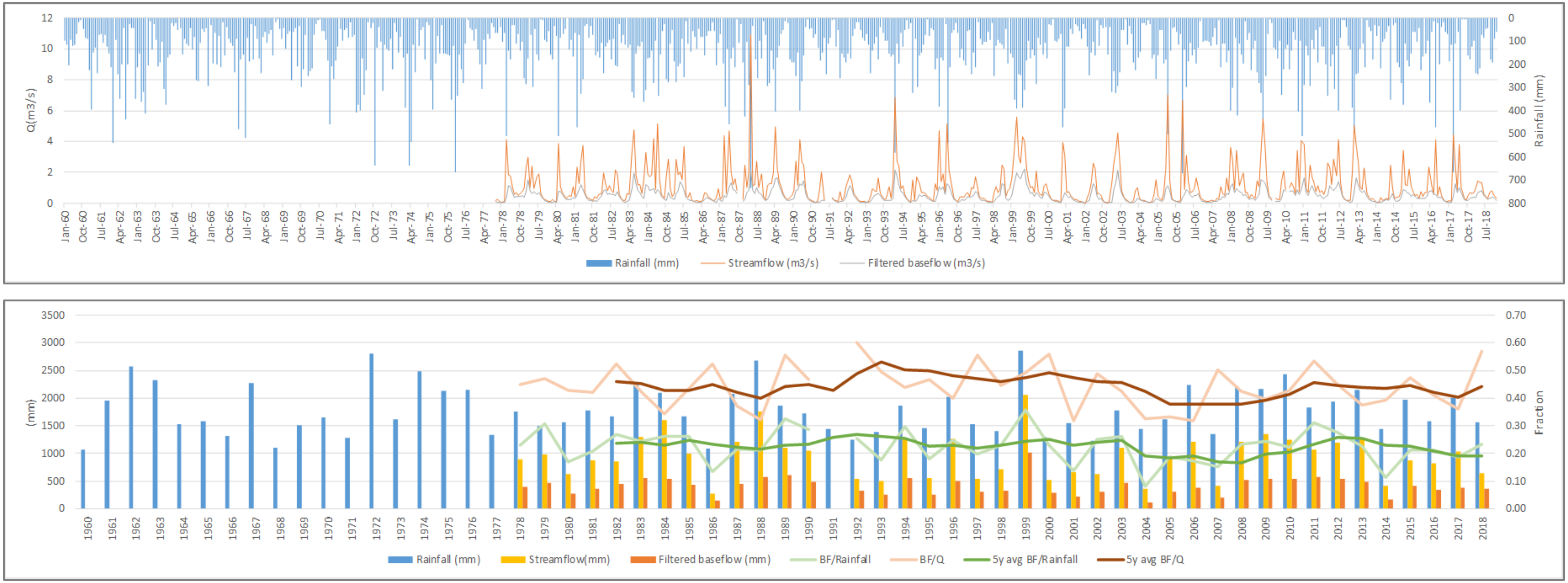


Figure 32: Baseflow filtering results - monitoring point 203012: Byron Creek at Binna Burra

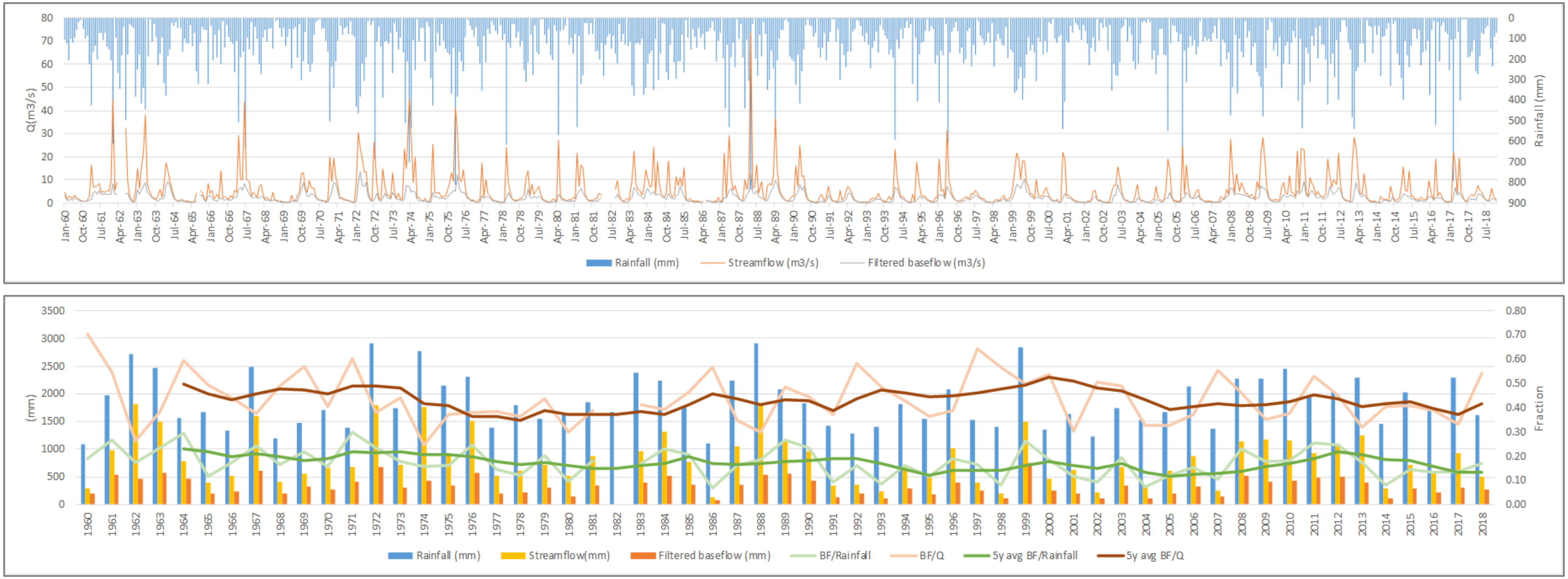


Figure 33: Baseflow filtering results - monitoring point 203014: Wilsons River at Eltham

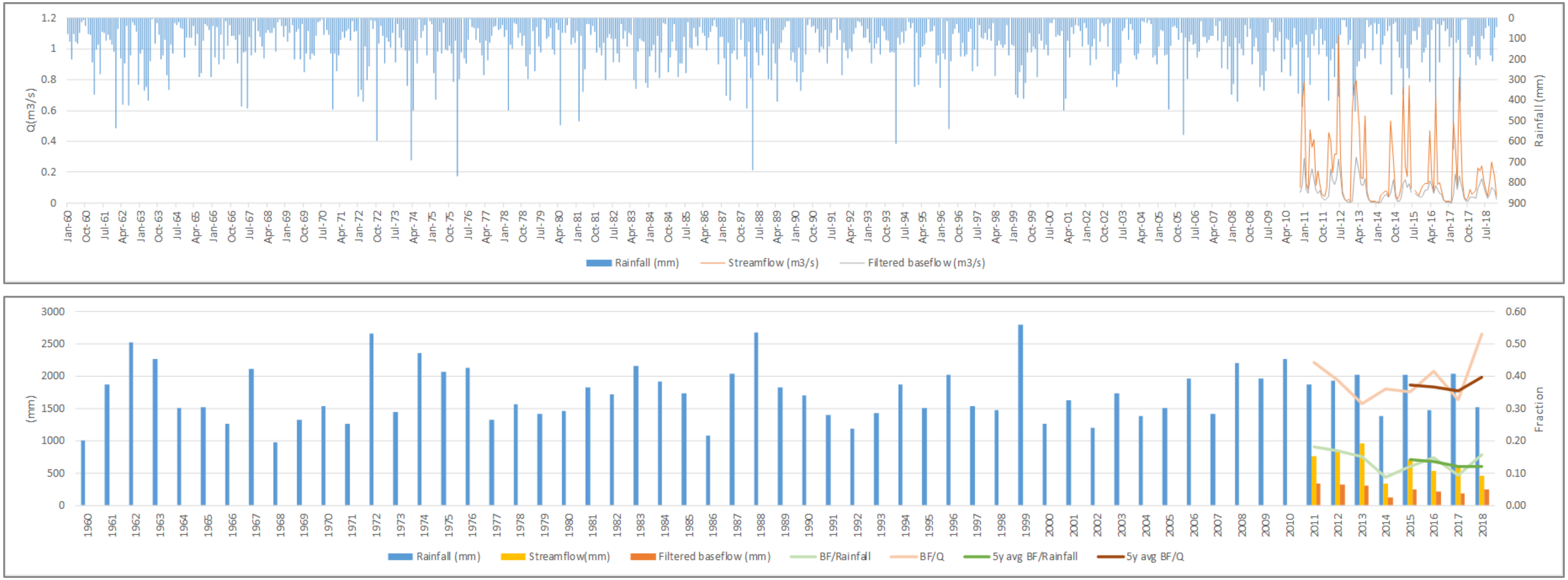


Figure 34: Baseflow filtering results - monitoring point 203057: Houghlahans Creek at upstream Teven

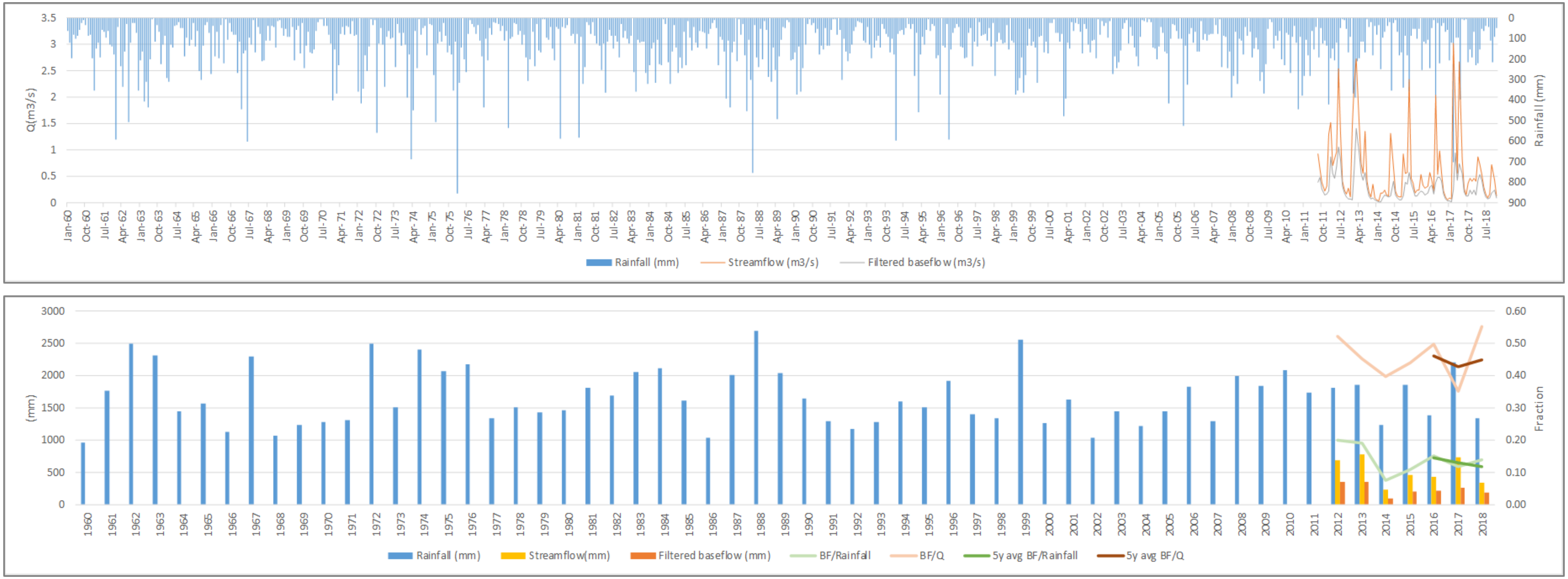


Figure 35: Baseflow filtering results - monitoring point 203059: Maron Creek at Graham road

APPENDIX 5: MODELLING OF ALSTONVILLE PIEZOMETRIC DATA

Professor Louise Ryan

This appendix describes the GAM analysis for each of the Bore, Hole and Pipe combinations listed in Table 12. As discussed in the main report, the Review used a statistical technique called the Generalized Additive Model or GAM to explore how water levels varied over time, and also to assess the extent to which rainfall and seasonal effects could explain the observed levels.

We developed GAM models that predict piezometer level (in metres below measuring point) as a function of time, rainfall and season. The Review explored a range of options for how to best incorporate rainfall into the model. It found that ‘lagged rainfall’ averages, where rainfall is reported for each day as the average rainfall over the previous x days (where x was allowed to range from 10 days up to 240 days) provided a better explanation of variability in the piezometers than daily rainfall.

For each piezometer, the Review team re-ran the GAM models to identify the most appropriate lag time (x). The Review then explored the extent to which each component contributes to the variability of each piezometer. To ensure that the significant tests were appropriately adjusted for autocorrelation induced by the time-series nature of the data, a technique called the block bootstrap (Kunsch, 1989) was used, which has been implemented using the *boot* package in the statistical programming environment, R (Canty & Ripley, 2019). This analysis is an alternative to using the Seasonal Kendall Trend test which is popular in hydrogeology.

Although the primary focus in this section of the Report lies in the period from 2009 onwards, we included data from 2006 onwards in these analyses in order to boost statistical power to detect effects. These figures were computed by running models leaving out each factor and comparing the deviance explained by that model to the deviance explained by the model with all three factors in included. Statistical significance was assessed through use of a likelihood ratio test, using the block bootstrap to adjust for autocorrelation. Numbers that are statistically significantly different from 0 at $p<0.05$ are indicated by an asterix. A higher percentage indicates that the water levels in that piezometer are more highly correlated to that particular variable.

This appendix shows the results of fitting the GAM models to each of the bores. The results are summarised in the Table given in the main body of the Report. Note that no data were available after 2006 for the following bores:

- GW036701 hole 1 pipe 4
- GW036702 hole 1 pipe 4
- GW081004 hole 1 pipe 1

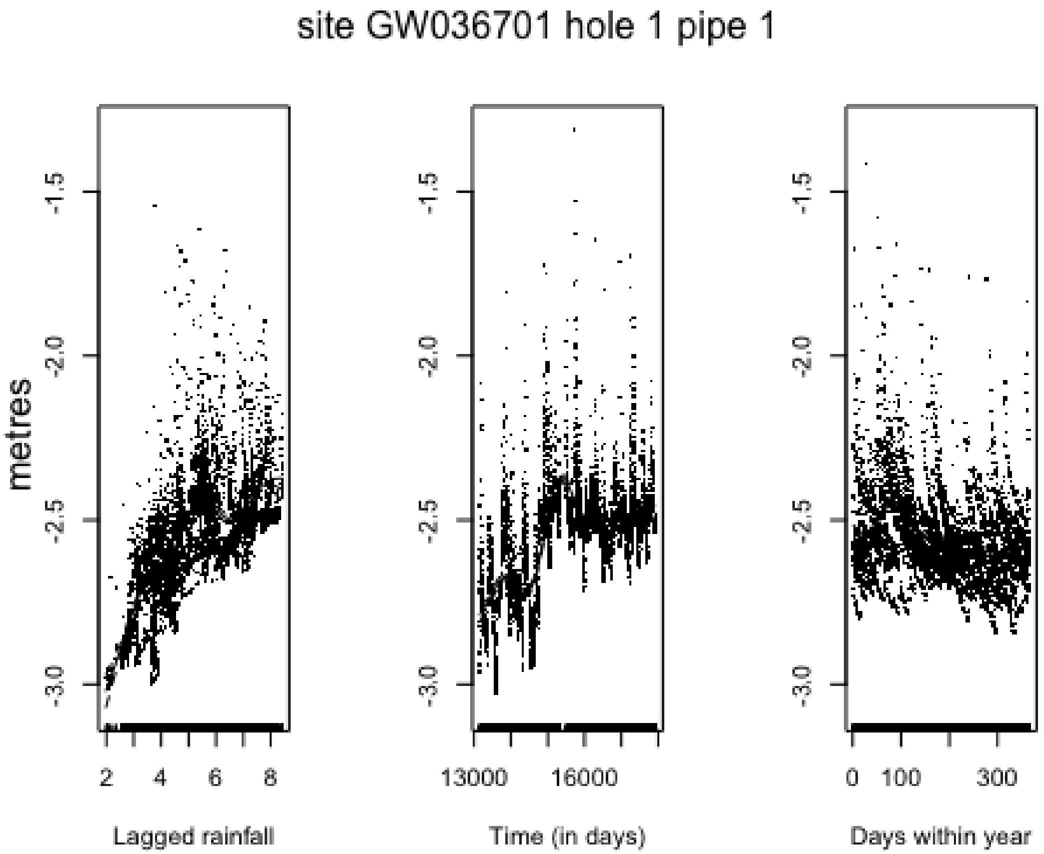
Analysis for site GW036701 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 240 days. Adding rain into the model explained an additional 32.61 percent of variability compared with a model that included just time and season. This effect was statistically significant (p<.001).

Adding season into the model explained an additional 11.11 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.128).

Adding time into the model explained an additional 41.26 percent of variability compared to a model with just rain and season. This effect was statistically significant (p<.001).

There were statistically significant non-linearities in the time effect (p= 0.018).



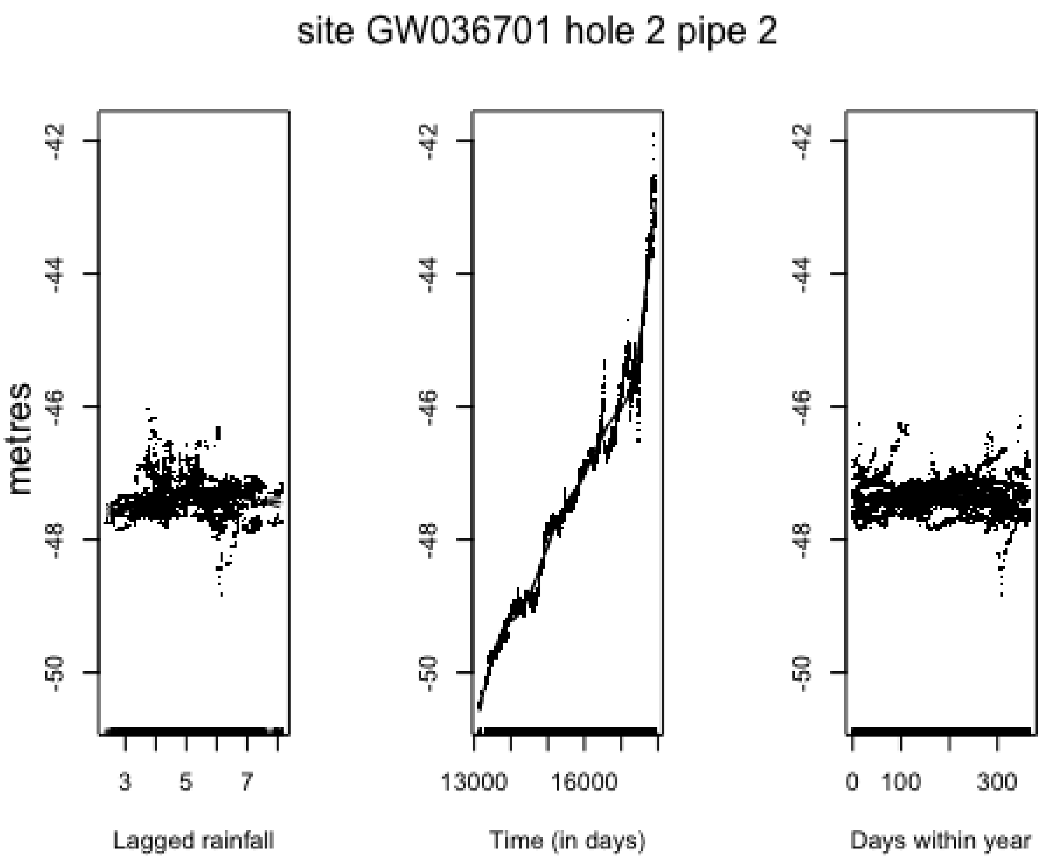
Analysis for site GW036701 hole 2 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 280 days. Adding rain into the model explained an additional 7.6 percent of variability compared with a model that included just time and season. But this increase was not statistically significant (p= 0.217).

Adding season into the model explained an additional 3.26 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.462).

Adding time into the model explained an additional 97.91 percent of variability compared to a model with just rain and season. This effect was statistically significant (p<.001).

There was no statistically significant non-linearity in the time effect (p= 0.106).



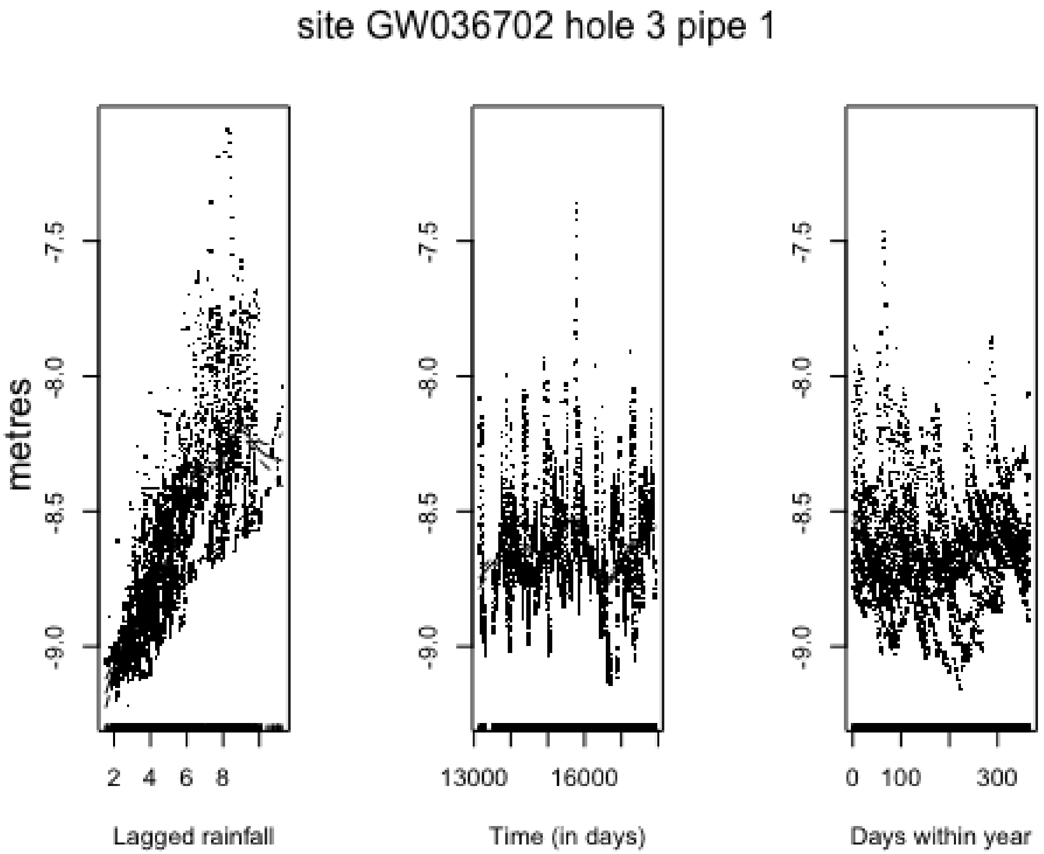
Analysis for site GW036702 hole 3 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 150 days. Adding rain into the model explained an additional 49.42 percent of variability compared with a model that included just time and season. This effect was statistically significant (p<.001).

Adding season into the model explained an additional 4.27 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.296).

Adding time into the model explained an additional 8.01 percent of variability compared to a model with just rain and season, but this effect was not statistically significant (p= 0.052).

There was no statistically significant non-linearity in the time effect (p= 0.058).



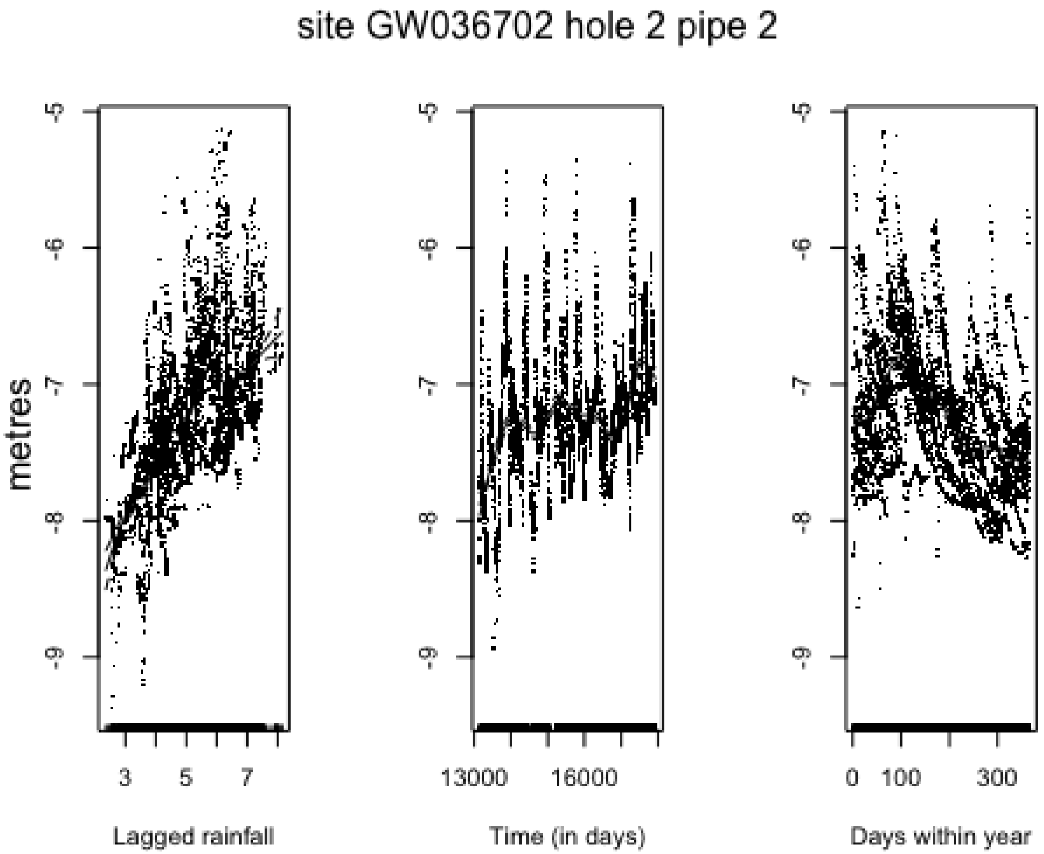
Analysis for site GW036702 hole 2 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 280 days. Adding rain into the model explained an additional 28.9 percent of variability compared with a model that included just time and season. This effect was statistically significant (p<.001).

Adding season into the model explained an additional 21.11 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.066).

Adding time into the model explained an additional 17.83 percent of variability compared to a model with just rain and season. This effect was statistically significant (p= 0.01).

There was no statistically significant non-linearity in the time effect (p= 0.193).

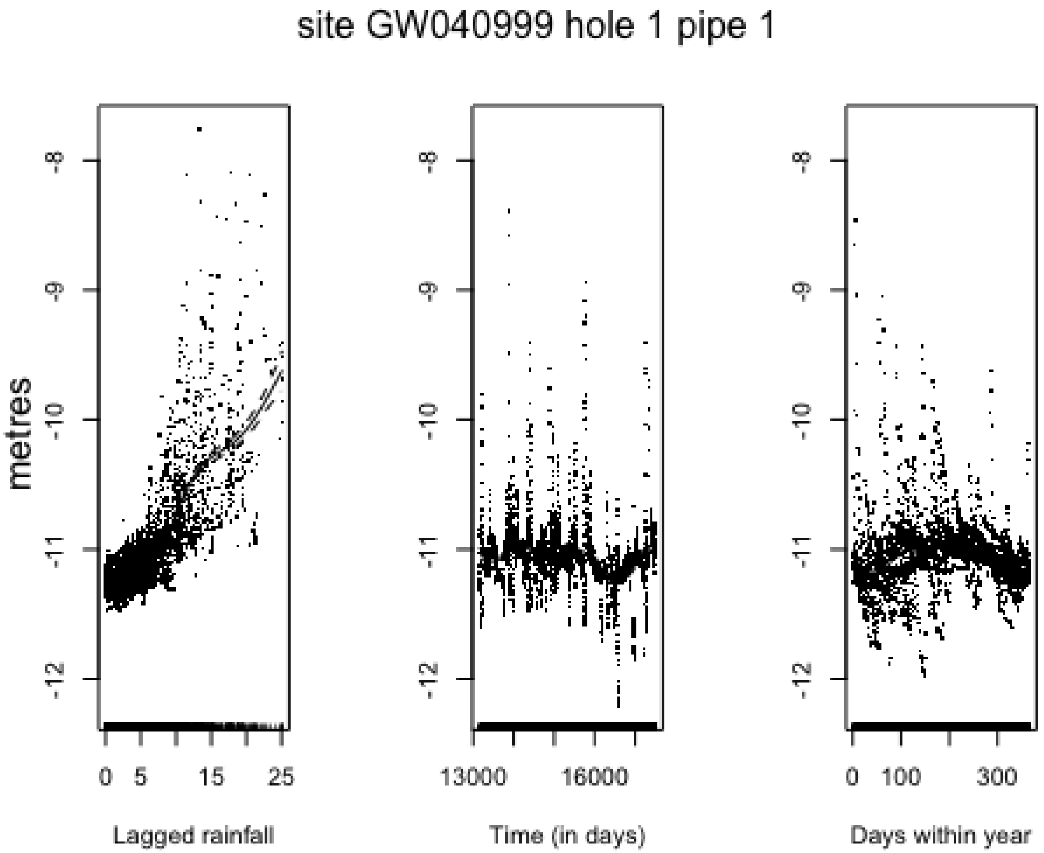


Analysis for site GW040999 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 30 days. Adding rain into the model explained an additional 57.37 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 8.34 percent of variability compared to a model with just rain and time. This effect was statistically significant ($p= 0.009$).

Adding time into the model explained an additional 10.62 percent of variability compared to a model with just rain and season. This effect was statistically significant ($p= 0.002$). There were statistically significant non-linearities in the time effect ($p= 0.007$).

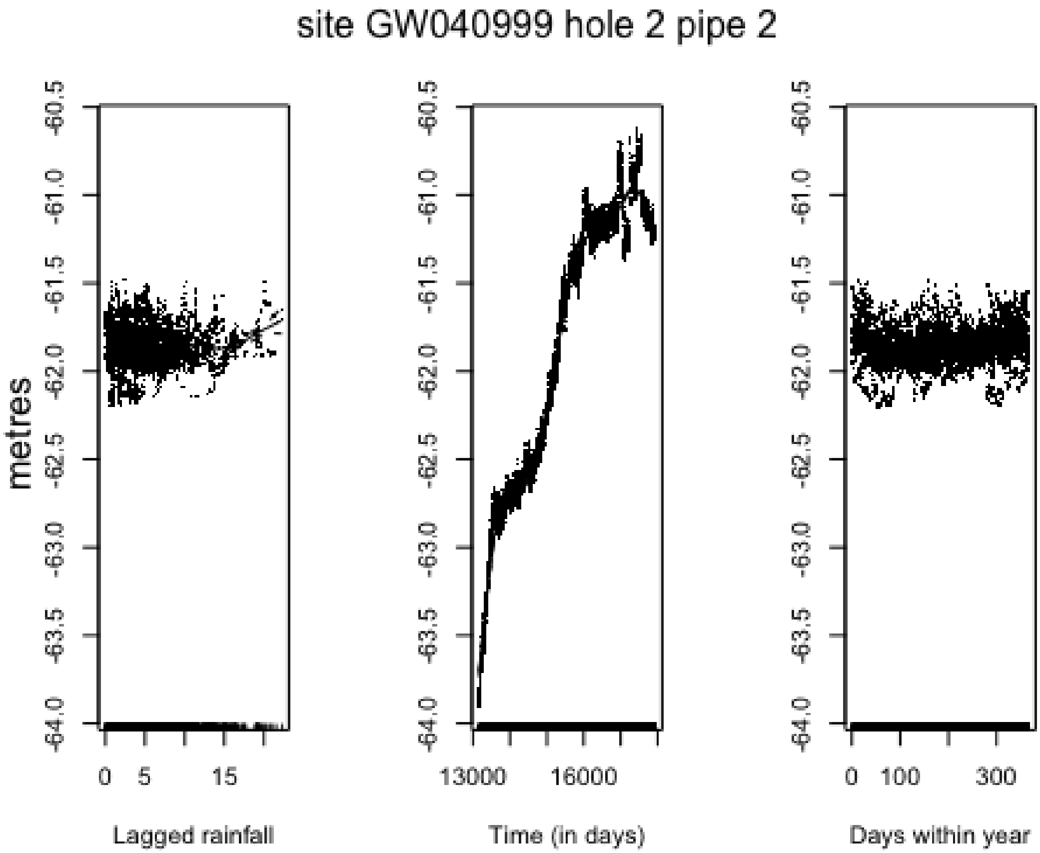


Analysis for site GW040999 hole 2 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 40 days. Adding rain into the model explained an additional 1.46 percent of variability compared with a model that included just time and season. but this increase was not statistically significant (p= 0.734).

Adding season into the model explained an additional 7.27 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.267).

Adding time into the model explained an additional 98.24 percent of variability compared to a model with just rain and season. This effect was statistically significant (p<.001). There were statistically significant non-linearities in the time effect (p= 0.016).



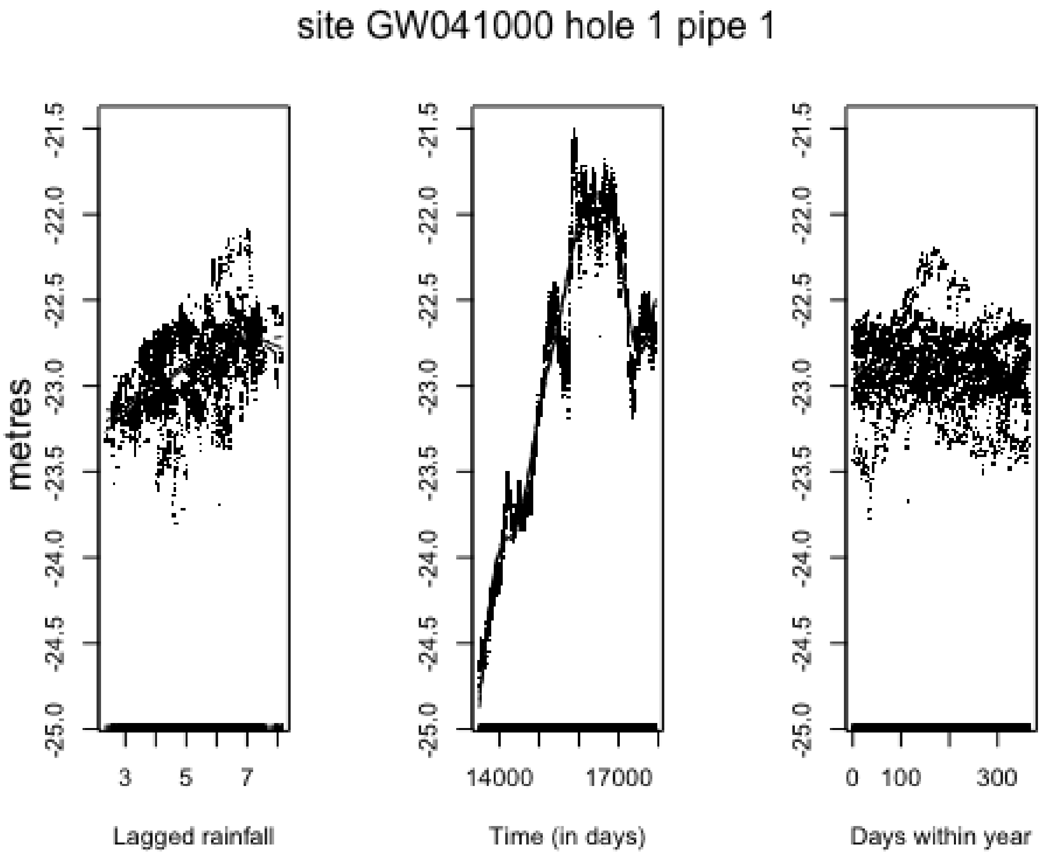
Analysis for site GW041000 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 280 days. Adding rain into the model explained an additional 16.59 percent of variability but this increase was not statistically significant (p= 0.14).

Adding season into the model explained an additional 2.3 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.743).

Adding time into the model explained an additional 93.79 percent of variability compared to a model with just rain and season. This effect was statistically significant (p<.001).

There were statistically significant non-linearities in the time effect (p<.001).



Analysis for site GW041000 hole 1 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 280 days. Adding rain into the model explained an additional 20.68 percent of variability but this increase was not statistically significant (p= 0.061).

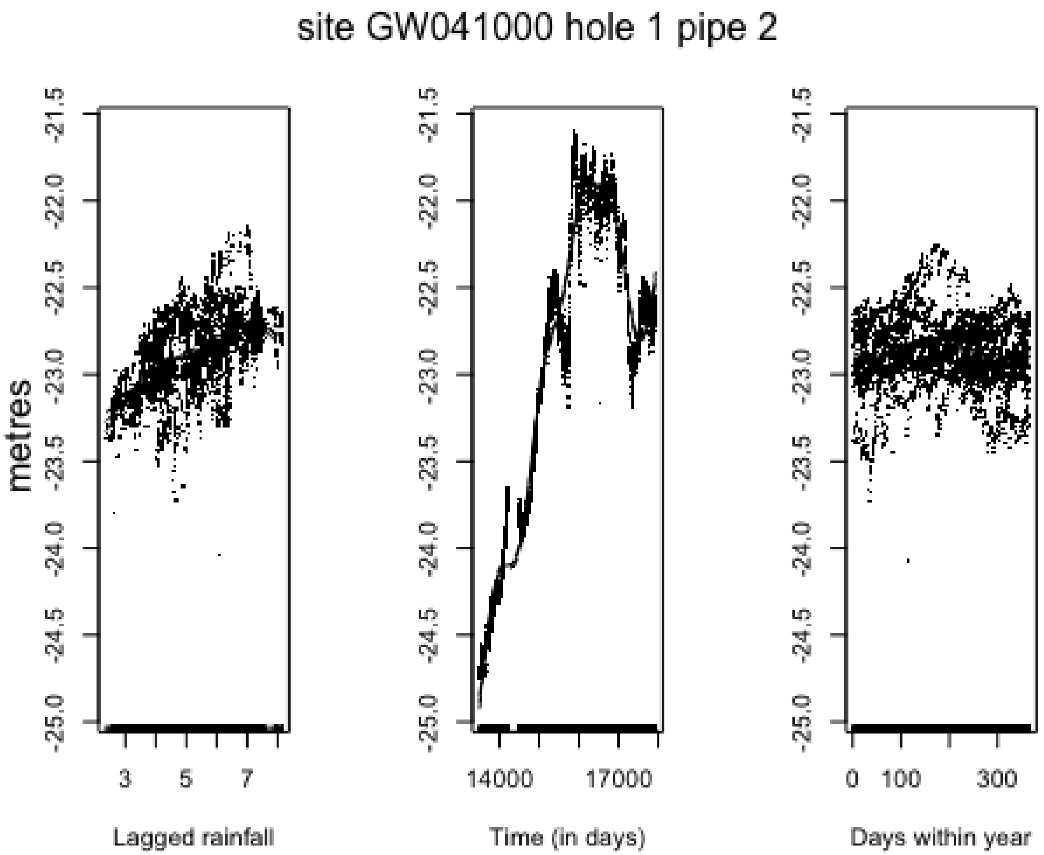
Adding season into the model explained an additional 3.03 percent of variability compared to a model with just rain and time.

However, this effect was not statistically significant (p= 0.576).

Adding time into the model explained an additional 95.01 percent of variability compared to a model with just rain and season.

This effect was statistically significant (p= 0.001).

There were statistically significant non-linearities in the time effect (p<.001).



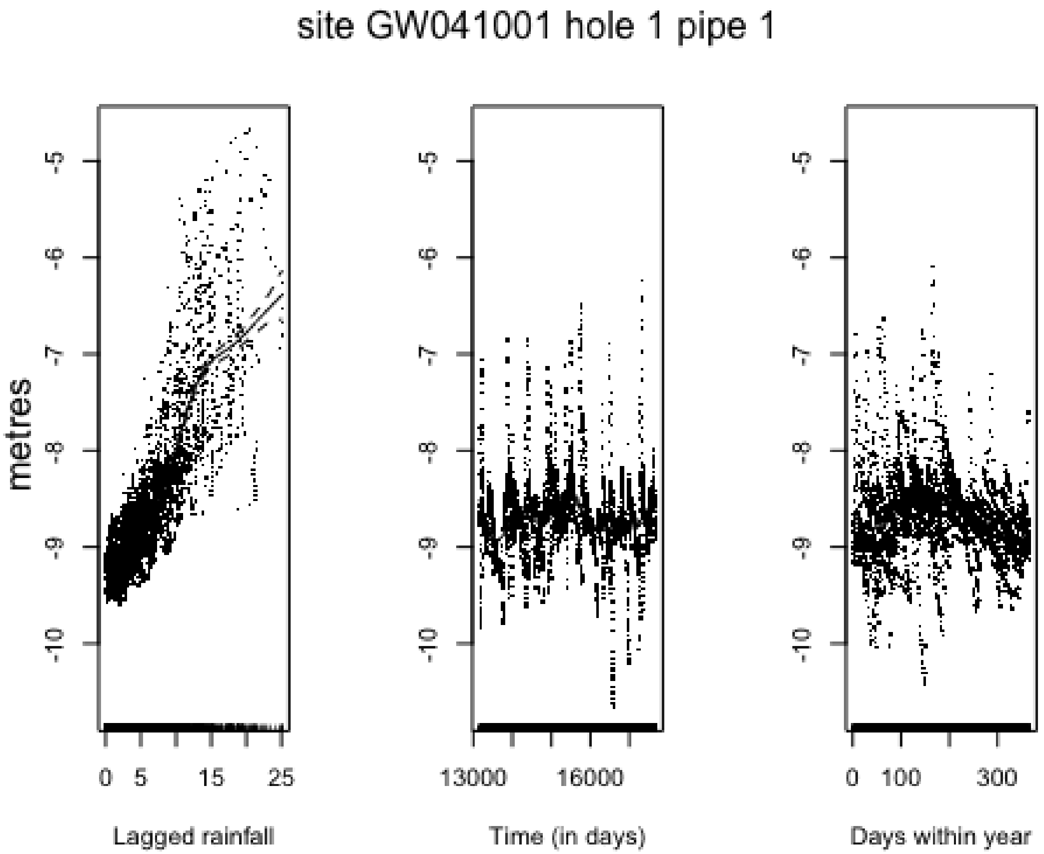
Analysis for site GW041001 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 30 days. Adding rain into the model explained an additional 68.44 percent of variability compared with a model that included just time and season. This effect was statistically significant (p<.001).

Adding season into the model explained an additional 8.47 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.126).

Adding time into the model explained an additional 8.18 percent of variability compared to a model with just rain and season. This effect was statistically significant (p= 0.031).

There were statistically significant non-linearities in the time effect (p= 0.018).



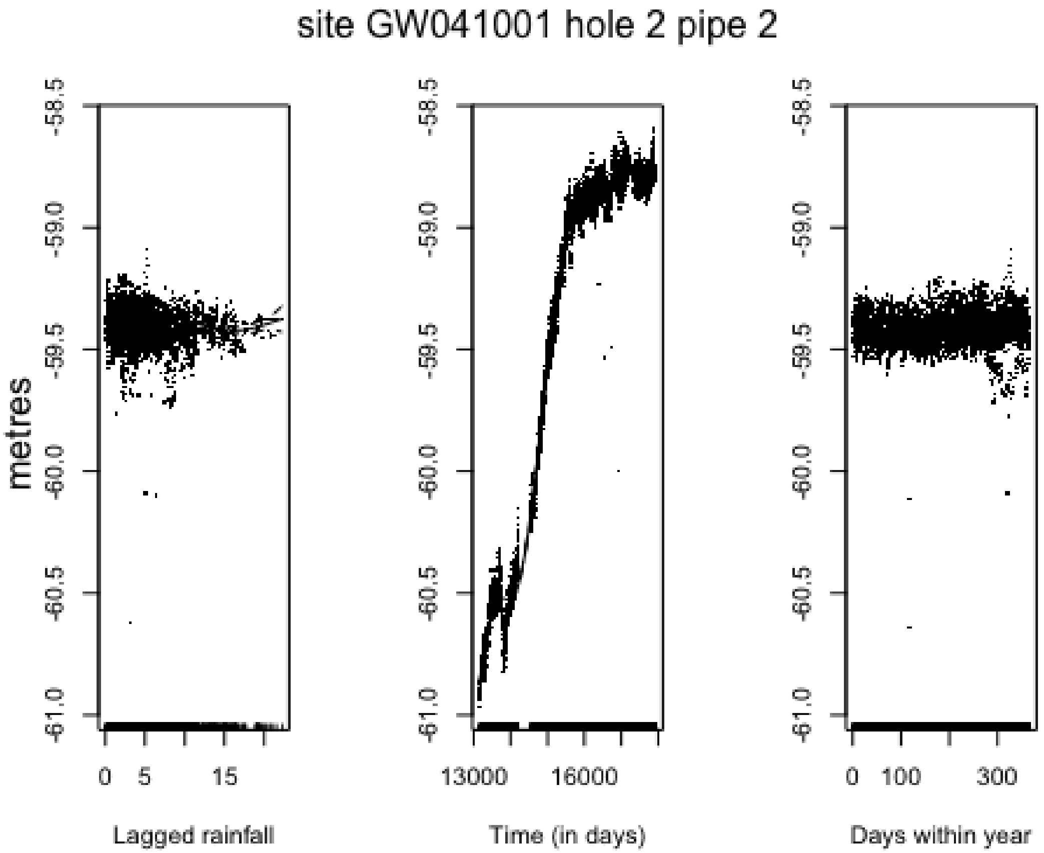
Analysis for site GW041001 hole 2 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 40 days. Adding rain into the model explained an additional 2.7 percent of variability but this increase was not statistically significant (p= 0.406).

Adding season into the model explained an additional 1.71 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.568).

Adding time into the model explained an additional 99.02 percent of variability compared to a model with just rain and season. This effect was statistically significant (p<.001).

There were statistically significant non-linearities in the time effect (p<.001).



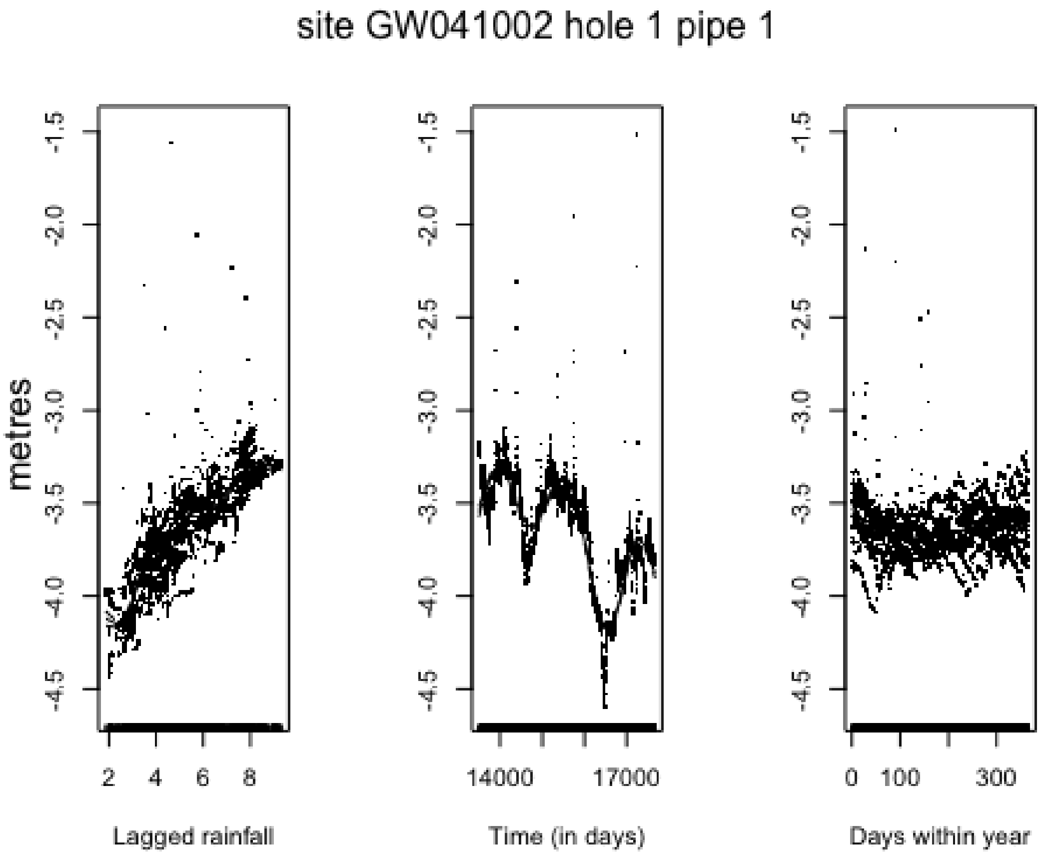
Analysis for site GW041002 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 200 days. Adding rain into the model explained an additional 61.02 percent of variability compared with a model that included just time and season. This effect was statistically significant (p= 0.001).

Adding season into the model explained an additional 4.54 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.151).

Adding time into the model explained an additional 75.22 percent of variability compared to a model with just rain and season. This effect was statistically significant (p= 0.005).

There were statistically significant non-linearities in the time effect (p= 0.016).



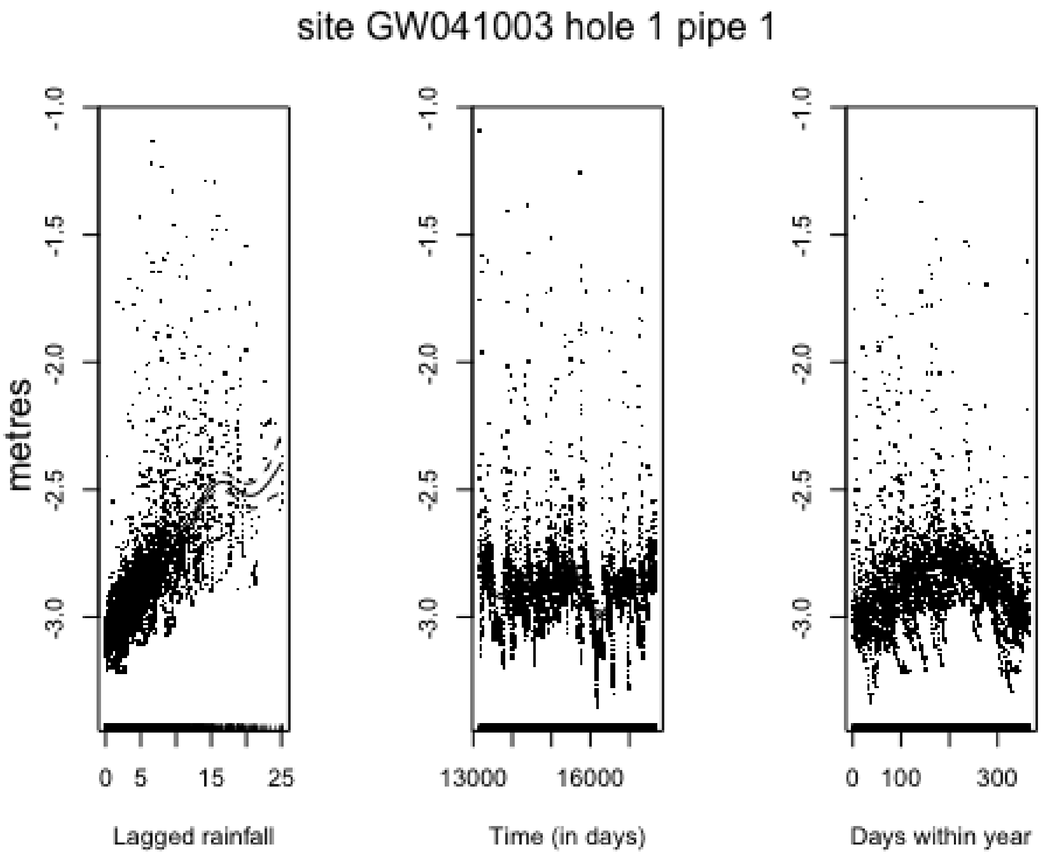
Analysis for site GW041003 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 30 days. Adding rain into the model explained an additional 38.81 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 10.76 percent of variability compared to a model with just rain and time. This effect was statistically significant ($p= 0.001$).

Adding time into the model explained an additional 7.78 percent of variability compared to a model with just rain and season, but this effect was not statistically significant ($p= 0.259$).

There was no statistically significant non-linearity in the time effect ($p= 0.228$).



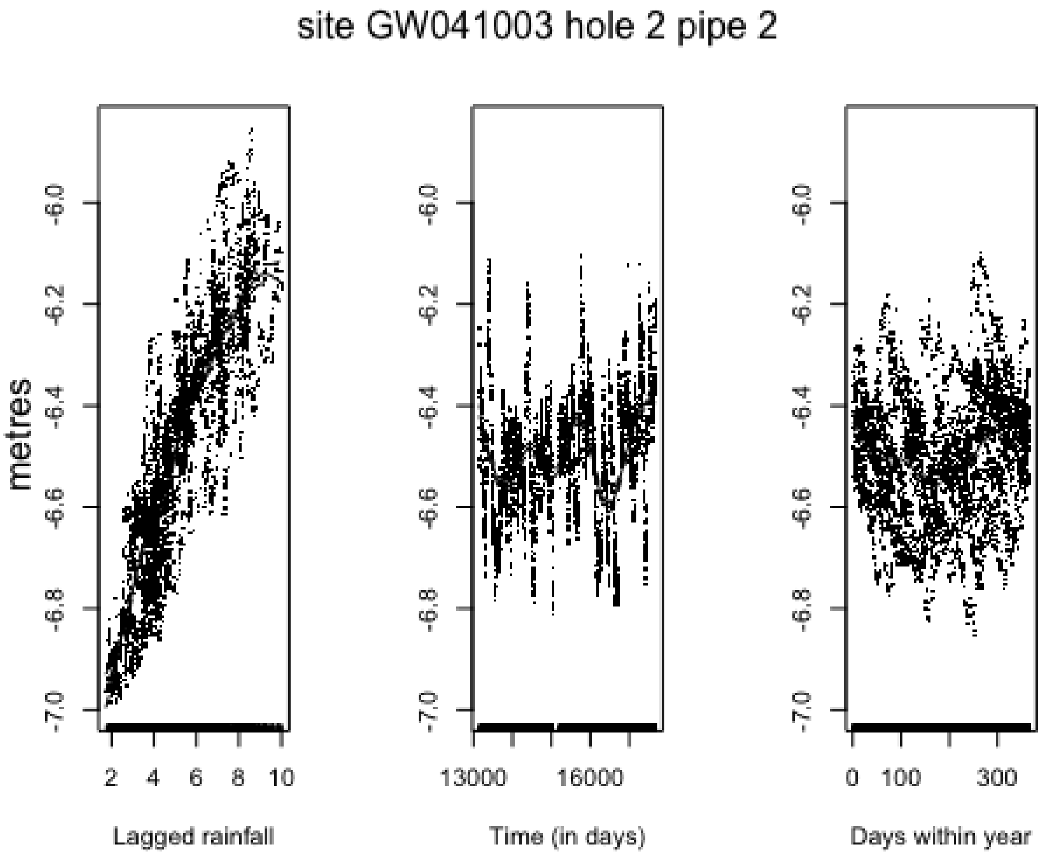
Analysis for site GW041003 hole 2 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 180 days. Adding rain into the model explained an additional 63.43 percent of variability compared with a model that included just time and season. This effect was statistically significant (p= 0.001).

Adding season into the model explained an additional 5.04 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.383).

Adding time into the model explained an additional 18.75 percent of variability compared to a model with just rain and season. This effect was statistically significant (p= 0.014).

There were statistically significant non-linearities in the time effect (p= 0.023).



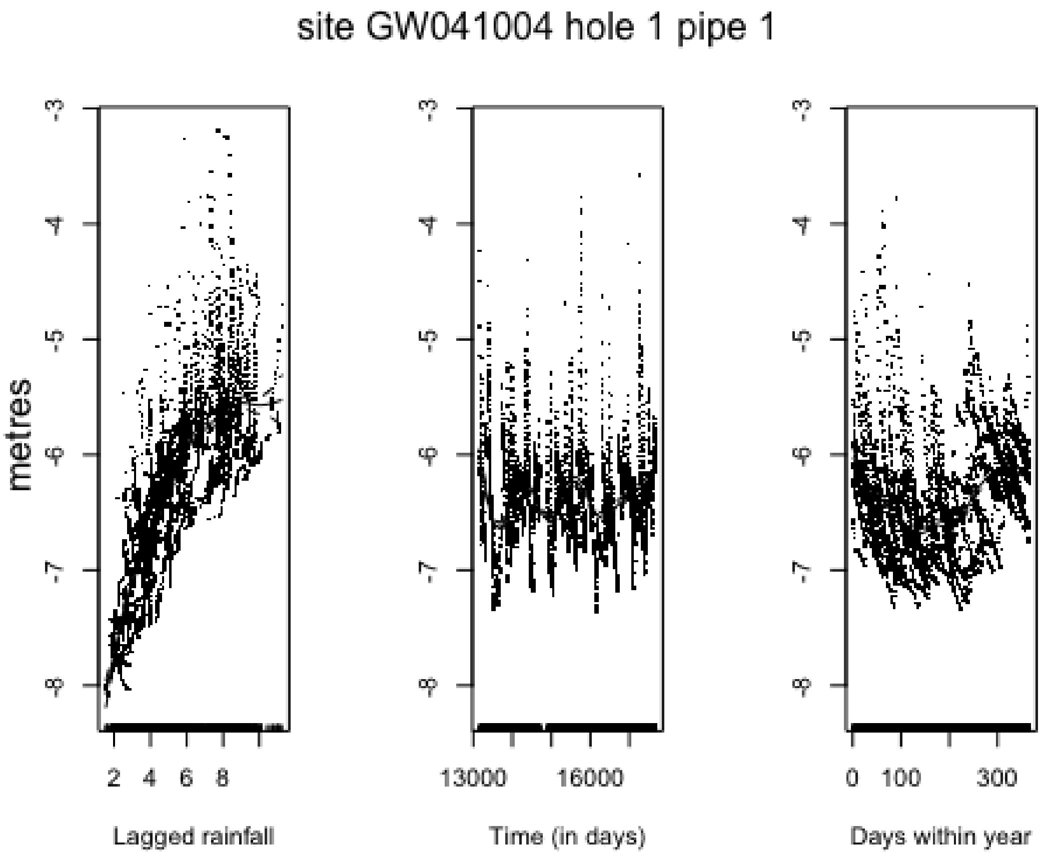
Analysis for site GW041004 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 150 days. Adding rain into the model explained an additional 50.21 percent of variability compared with a model that included just time and season. This effect was statistically significant (p= 0.001).

Adding season into the model explained an additional 11.22 percent of variability compared to a model with just rain and time. This effect was statistically significant (p= 0.049).

Adding time into the model explained an additional 7.78 percent of variability compared to a model with just rain and season, but this effect was not statistically significant (p= 0.093).

There was no statistically significant non-linearity in the time effect (p= 0.07).



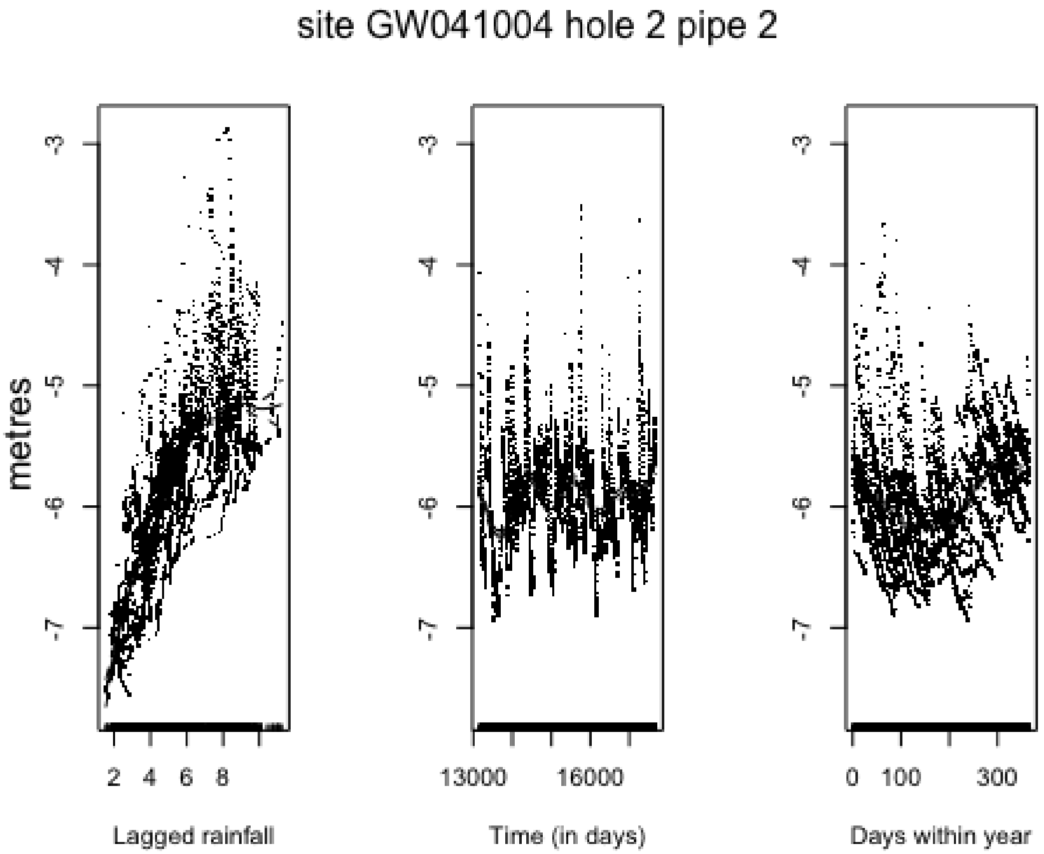
Analysis for site GW041004 hole 2 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 150 days. Adding rain into the model explained an additional 50.63 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 11.08 percent of variability compared to a model with just rain and time. This effect was statistically significant ($p= 0.039$).

Adding time into the model explained an additional 8.17 percent of variability compared to a model with just rain and season but this effect was not statistically significant ($p= 0.191$).

There was no statistically significant non-linearity in the time effect ($p= 0.178$).



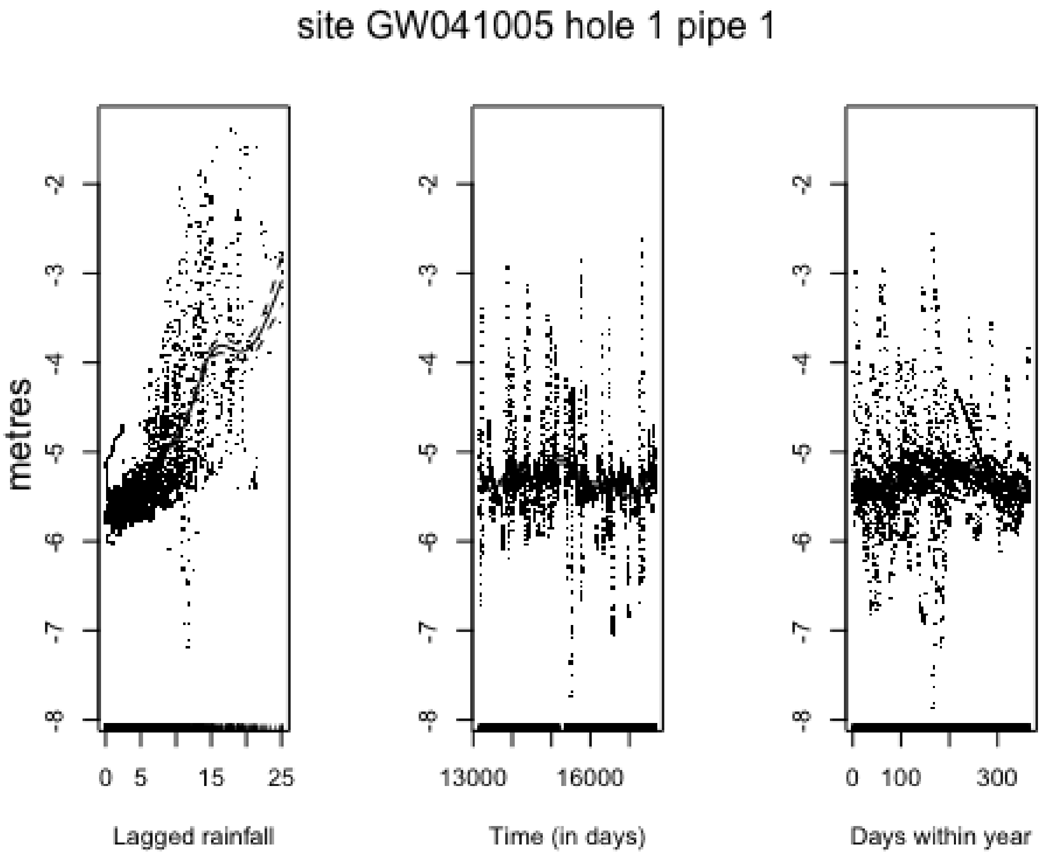
Analysis for site GW041005 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 30 days. Adding rain into the model explained an additional 53.08 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 2.76 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant ($p= 0.169$).

Adding time into the model explained an additional 5.17 percent of variability compared to a model with just rain and season. This effect was statistically significant ($p= 0.044$).

There were statistically significant non-linearities in the time effect ($p= 0.028$).



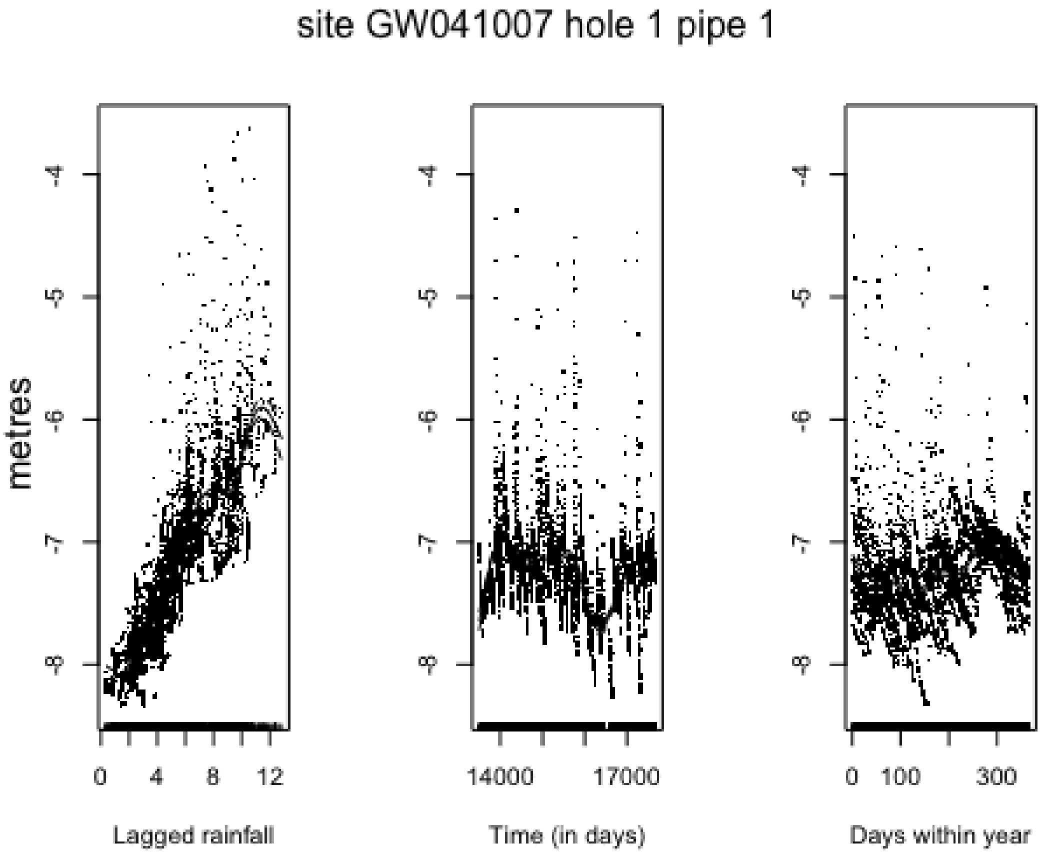
Analysis for site GW041007 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 100 days. Adding rain into the model explained an additional 54.98 percent of variability compared with a model that included just time and season. This effect was statistically significant (p<.001).

Adding season into the model explained an additional 7.11 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.078).

Adding time into the model explained an additional 18.85 percent of variability compared to a model with just rain and season but this effect was not statistically significant (p= 0.056).

There were statistically significant non-linearities in the time effect (p= 0.008).



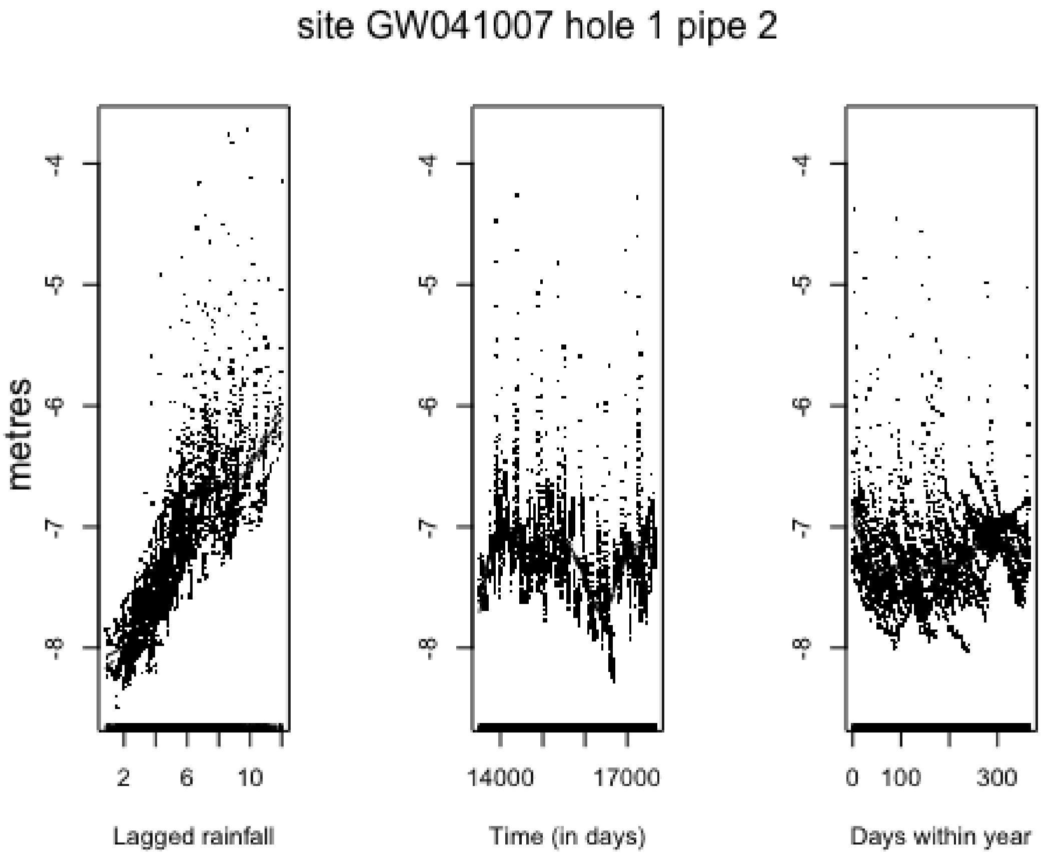
Analysis for site GW041007 hole 1 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 120 days. Adding rain into the model explained an additional 50.81 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 6.99 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant ($p= 0.062$).

Adding time into the model explained an additional 22.23 percent of variability compared to a model with just rain and season. This effect was statistically significant ($p= 0.007$).

There were statistically significant non-linearities in the time effect ($p= 0.003$).



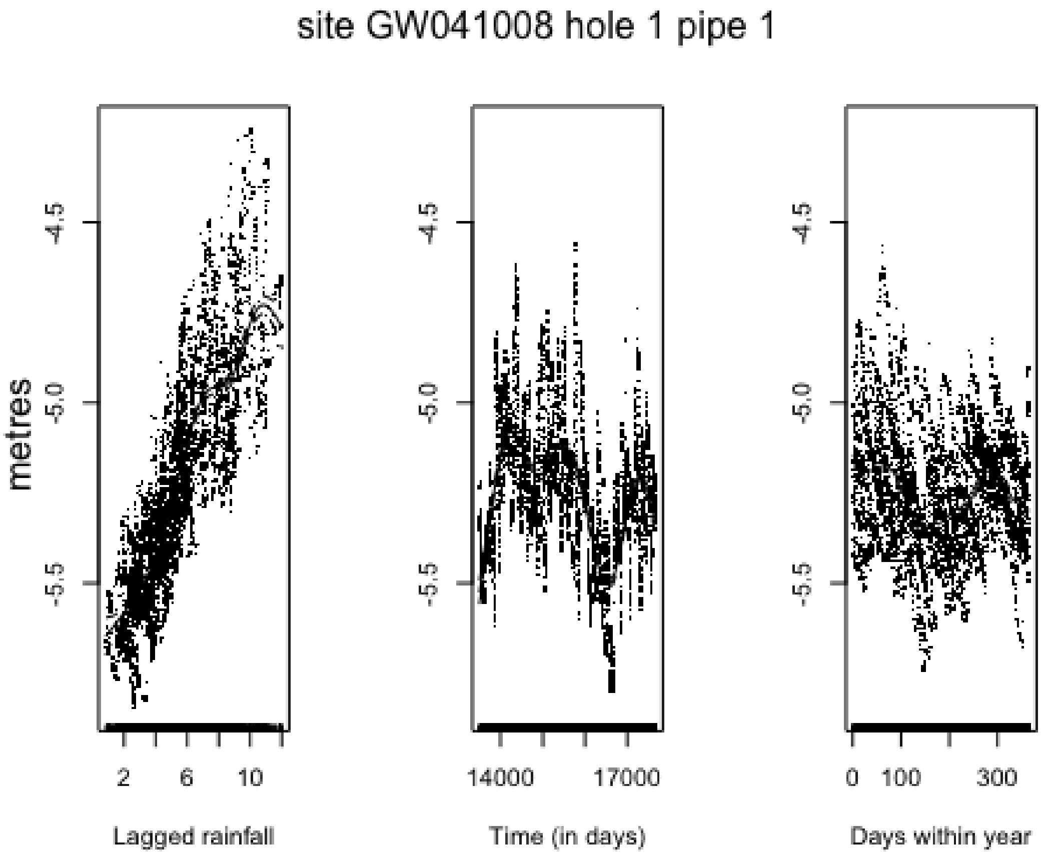
Analysis for site GW041008 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 120 days. Adding rain into the model explained an additional 56.38 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 10.49 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant ($p= 0.087$).

Adding time into the model explained an additional 36.79 percent of variability compared to a model with just rain and season. This effect was statistically significant ($p= 0.007$).

There were statistically significant non-linearities in the time effect ($p= 0.01$).



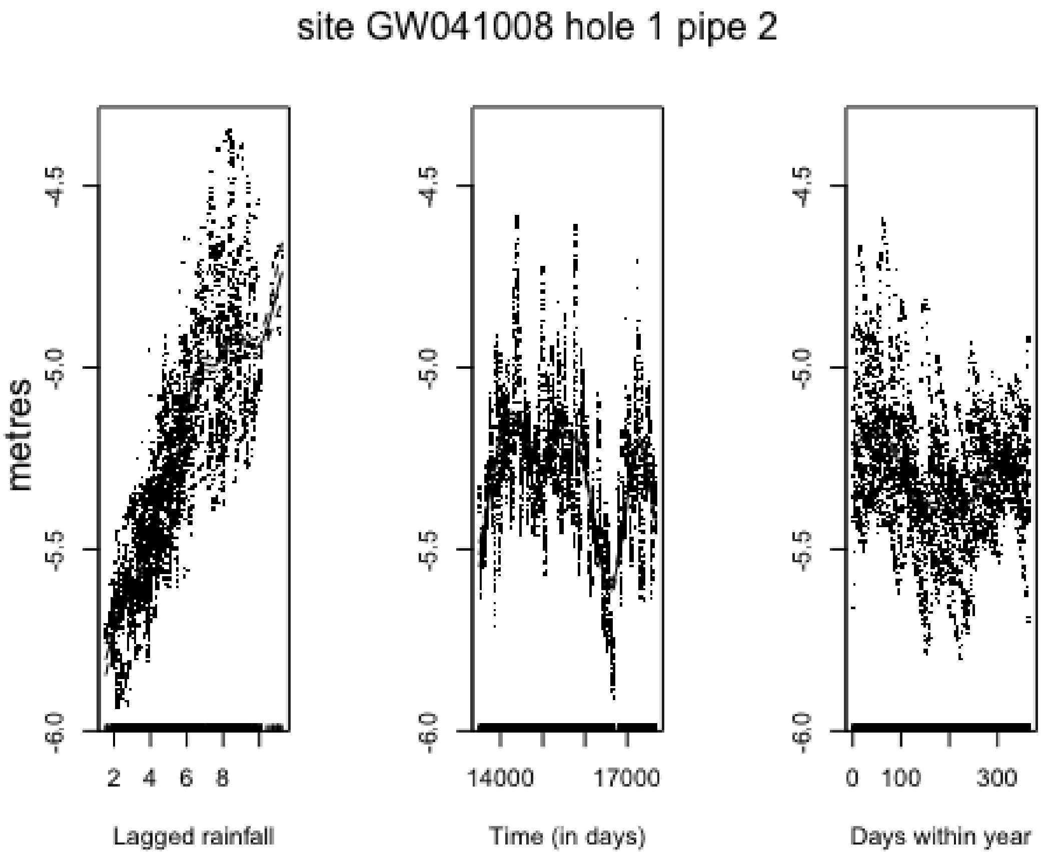
Analysis for site GW041008 hole 1 pipe 2 data from 2006 only

The highest percent variation explained was given by lagging rain over 150 days. Adding rain into the model explained an additional 57.62 percent of variability compared with a model that included just time and season. This effect was statistically significant (p<.001).

Adding season into the model explained an additional 15.87 percent of variability compared to a model with just rain and time. This effect was statistically significant (p= 0.004).

Adding time into the model explained an additional 36.41 percent of variability compared to a model with just rain and season. This effect was statistically significant (p= 0.017).

There were statistically significant non-linearities in the time effect (p= 0.006).



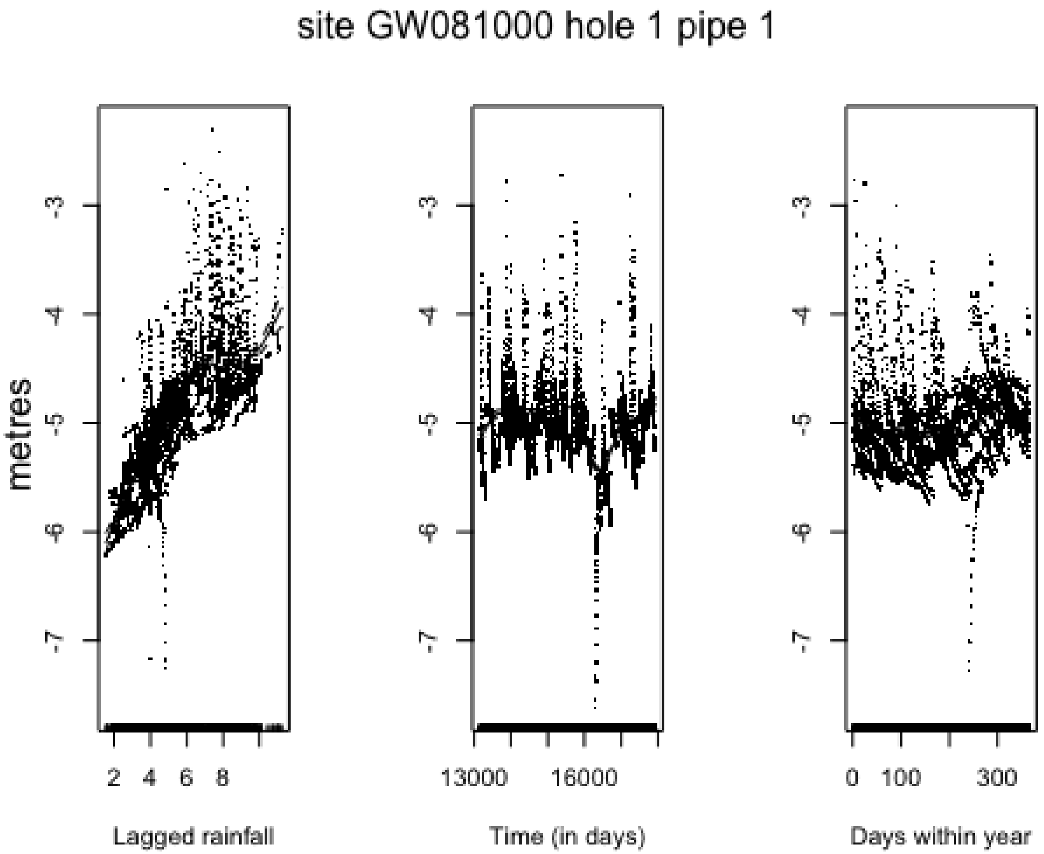
Analysis for site GW081000 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 150 days. Adding rain into the model explained an additional 46.88 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 3.58 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant ($p= 0.202$).

Adding time into the model explained an additional 15.33 percent of variability compared to a model with just rain and season but this effect was not statistically significant ($p= 0.072$).

There was no statistically significant non-linearity in the time effect ($p= 0.07$).



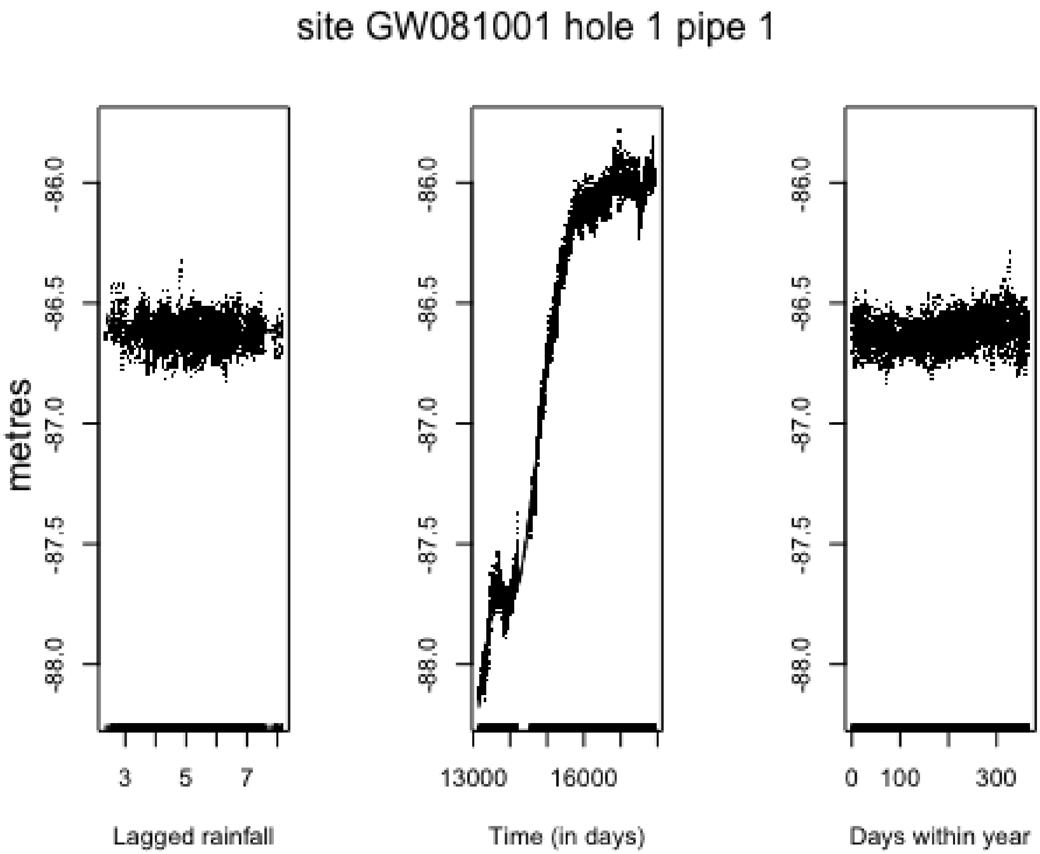
Analysis for site GW081001 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 280 days. Adding rain into the model explained an additional 2.46 percent of variability but this increase was not statistically significant (p= 0.421).

Adding season into the model explained an additional 10.95 percent of variability compared to a model with just rain and time. This effect was statistically significant (p= 0.044).

Adding time into the model explained an additional 99.35 percent of variability compared to a model with just rain and season. This effect was statistically significant (p<.001).

There were statistically significant non-linearities in the time effect (p<.001).



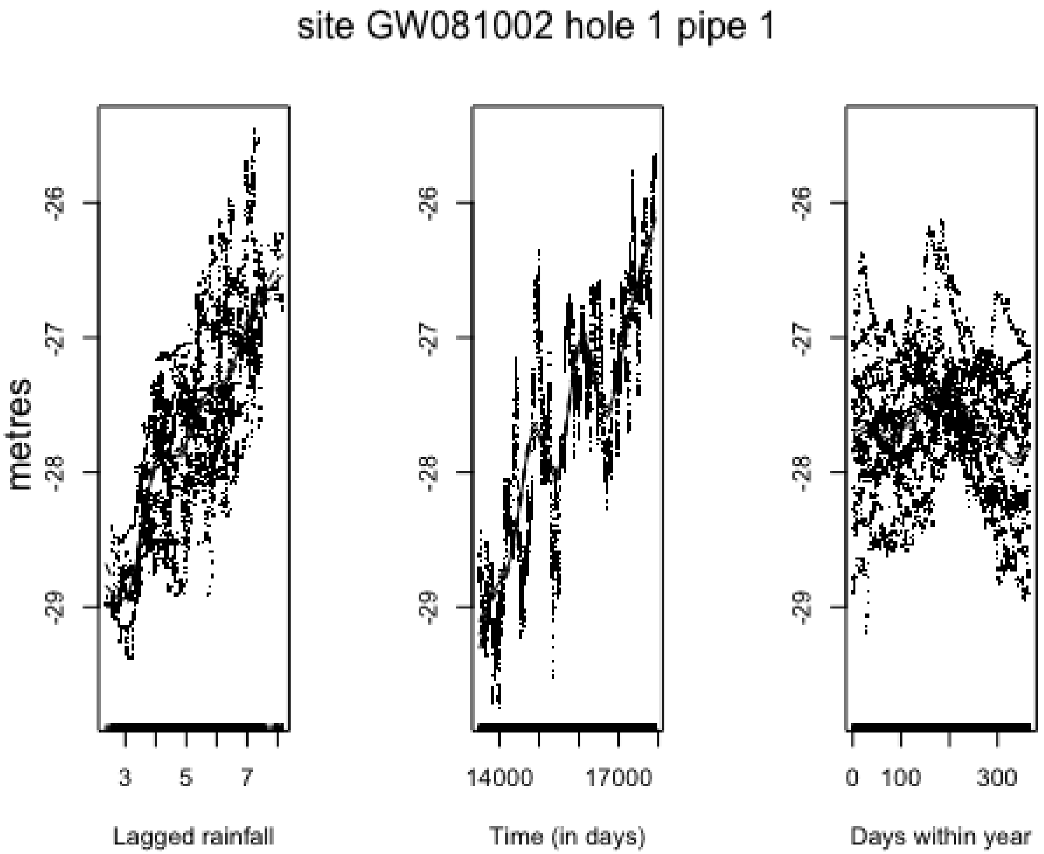
Analysis for site GW081002 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 280 days. Adding rain into the model explained an additional 44.91 percent of variability compared with a model that included just time and season. This effect was statistically significant (p= 0.001).

Adding season into the model explained an additional 7.05 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.462).

Adding time into the model explained an additional 71.2 percent of variability compared to a model with just rain and season. This effect was statistically significant (p<.001).

There was no statistically significant non-linearity in the time effect (p= 0.277).



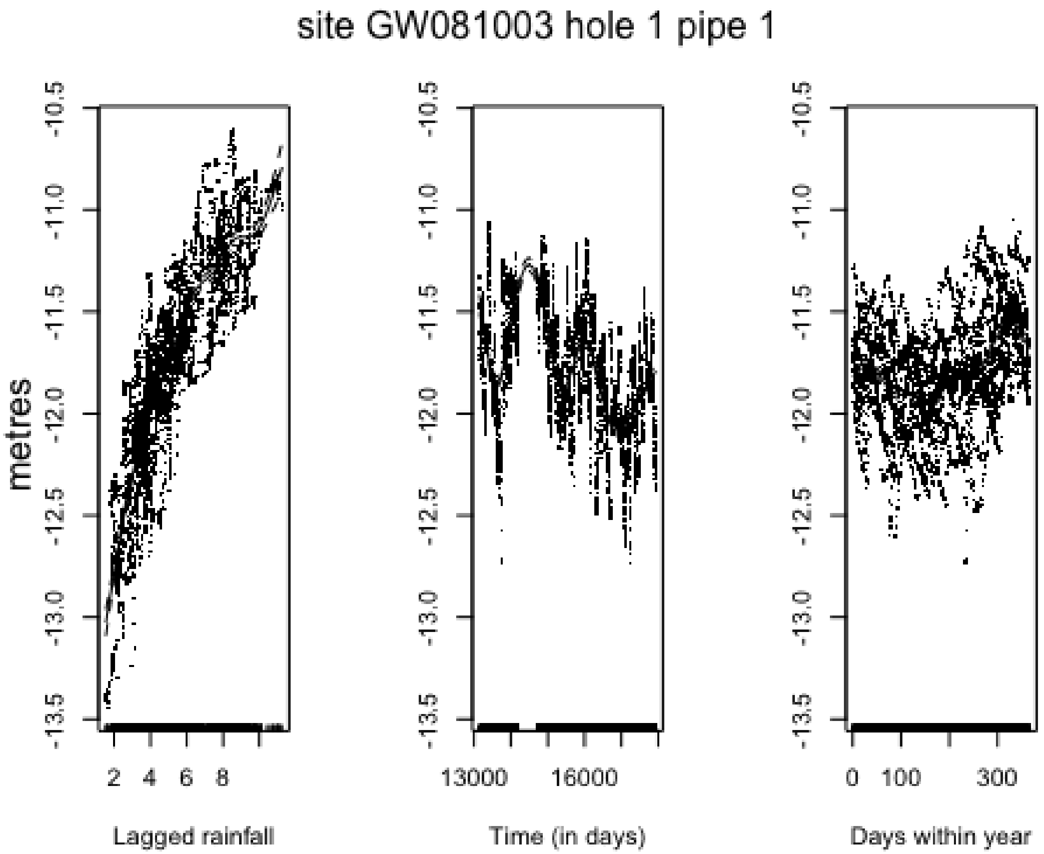
Analysis for site GW081003 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 150 days. Adding rain into the model explained an additional 66.13 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 13.57 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant ($p= 0.129$).

Adding time into the model explained an additional 35.11 percent of variability compared to a model with just rain and season. This effect was statistically significant ($p= 0.004$).

There were statistically significant non-linearities in the time effect ($p= 0.009$).



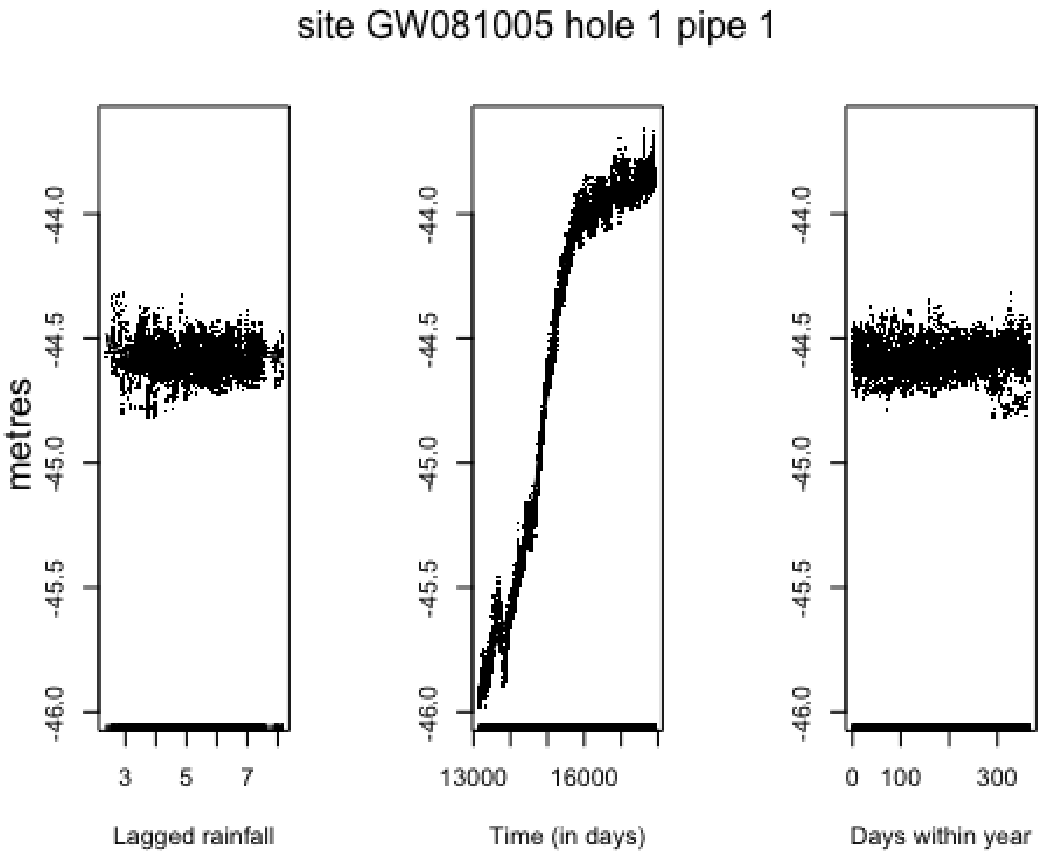
Analysis for site GW081005 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 280 days. Adding rain into the model explained an additional 1.77 percent of variability but this increase was not statistically significant (p= 0.48).

Adding season into the model explained an additional 0.83 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant (p= 0.585).

Adding time into the model explained an additional 99.23 percent of variability compared to a model with just rain and season. This effect was statistically significant (p<.001).

There were statistically significant non-linearities in the time effect (p<.001).



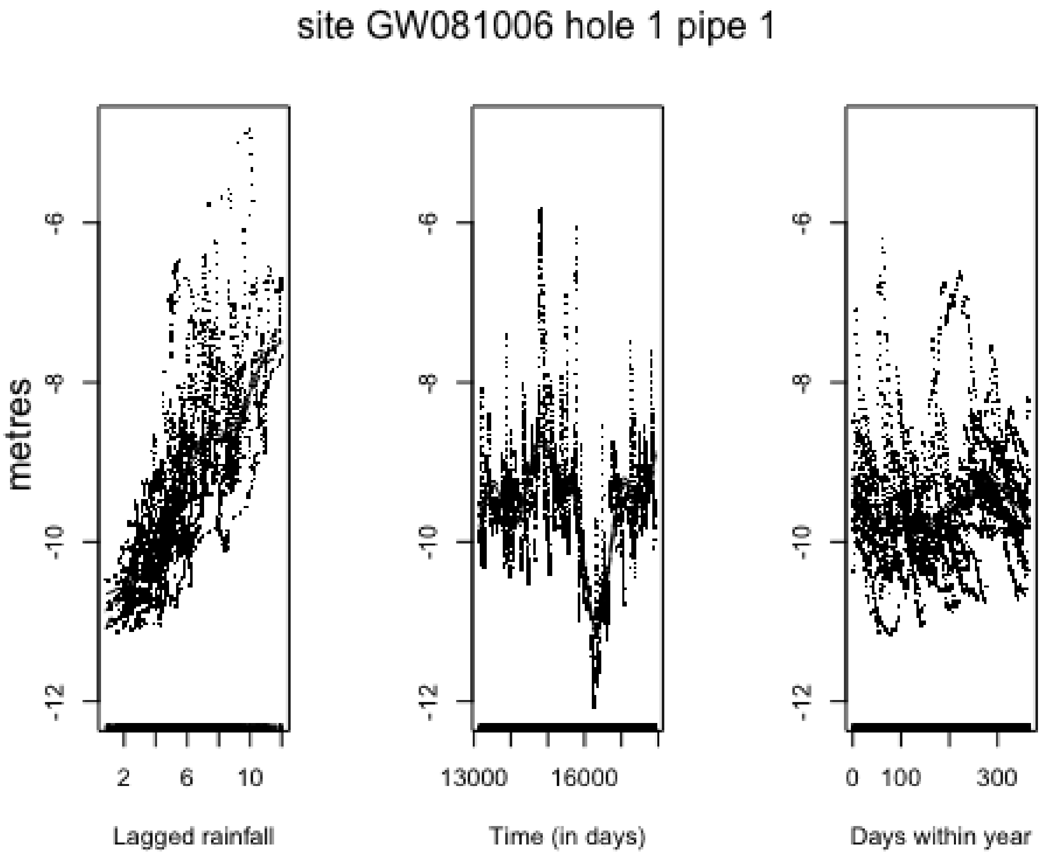
Analysis for site GW081006 hole 1 pipe 1 data from 2006 only

The highest percent variation explained was given by lagging rain over 120 days. Adding rain into the model explained an additional 43.52 percent of variability compared with a model that included just time and season. This effect was statistically significant ($p<.001$).

Adding season into the model explained an additional 5.02 percent of variability compared to a model with just rain and time. However, this effect was not statistically significant ($p= 0.264$).

Adding time into the model explained an additional 42.1 percent of variability compared to a model with just rain and season. This effect was statistically significant ($p= 0.023$).

There were statistically significant non-linearities in the time effect ($p= 0.019$).



APPENDIX 6: CASE STUDY - LUMLEY PARK AND CONVERY'S LANE, ALSTONVILLE

This case study provides one of the few examples for the region and illustrates the complexities of evaluating and ascertaining potential connections between the deeper groundwater system, the shallower aquifers and impacts on local assets. However, it is not provided to specifically examine connectivity and drawdown effects.

Rous County Council has TWS bores at Lumley Park and Convery's Lane that draw from the deeper aquifer in the Alstonville Basalt Plateau Groundwater system (Table 32). These bores have allocations that provide town water supply at around ten times or higher than most licences for bottled water extraction. These bores are also in close proximity to the DPIE Water monitoring bores.

Table 32: Details for TWS bores, the allocation, depth of the bore, and nearby DPIE groundwater monitoring piezometers

TWS Bore Name	TWS bore allocation (ML/y)	TWS depth (m below measuring point)	DPIE monitoring bore	Depth of monitoring piezometer (screen interval)	Monitoring bore year installed
Convery's Lane	253	111	GW036702	17-21m	1987
			GW036702	150-168m	1987
Lumley Park	530 (max historical extraction 192)	82	GW081005	60-71 m	1999
			GW081006	7.5-12 m	1999
			GW41001 -1	Shallow*	2005-06
			GW41001 -2	Deep*	2005-06

*the exact depth was not available

In 2006 a comparison was made of the Convery's Lane TWS bore pumping data with the deeper groundwater levels at the nearby DPIE Water monitoring bore GW036702 around one km away. At the time, investigations found that the pressure heads in the deeper groundwater system dropped significantly when the Convery's Lane TWS bore was pumping, indicating that pumping was not sustainable. Once these pumps ceased it took several years for pressure heads to recover (Green, 2006) (Figure 36). In 2003, Rous County Council ceased using the Convery's Lane bore due to its effect on the deeper groundwater levels (Rous Water, 2014). Further investigation would be required to ascertain the hydrogeologic relationship between the deep level pumping, the shallow water levels and rainfall.

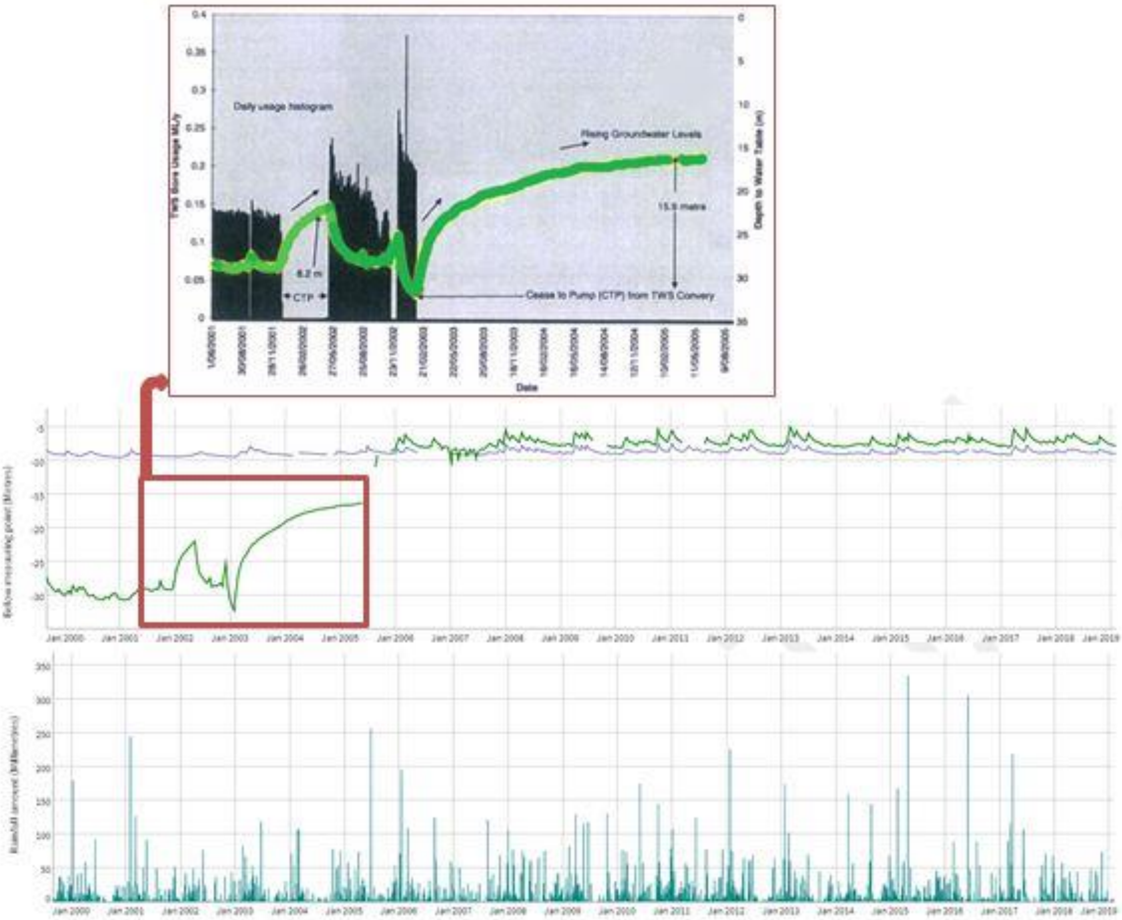


Figure 36: Convery's Lane TWS bore usage (ML/y) with GW036702 (deeper and shallow) levels and rainfall data.

The Convery's Lane usage shows gaps in extraction in 2001-2002 and from 2003. The bore usage is shown in subset graph in black columns. Figure modified from (Parsons Brinckerhoff, 2011).The nearby bores shows a response from the deeper monitoring bore (depth to groundwater shown as below measuring point in green), while the monitoring bore GW036702.3.1 (shallow) may be associated with rainfall (nearby Bureau of Meteorology rainfall stations, shown in blue columns). Data source: WaterNSW and BoM

In the case of the TWS bore at Lumley Park, in contrast to that at Convery's Lane, investigations of the groundwater pressure heads at the nearest DPIE Water monitoring bore around one km away (GW081005 (deeper) and GW081006 (shallow)) in 2006 indicated that drawdown during pumping at this site had limited influence on groundwater levels (Parsons Brinckerhoff, 2011). This may indicate a confined or partially confined aquifer and help to ensure that a remnant subtropical rainforest (Scientific Committee, 2019) is not impacted by the TWS. This rainforest is likely a GDE that contains highly diverse vegetation, invertebrates and fauna including a small melaleuca swamp community with platypus (Moore, 2014). However, it has been estimated that this rainforest most likely relies on the shallow groundwater zone during dry periods and contains at least one spring feeding into Maguires Creek (Green, 2006; Parsons Brinckerhoff, 2011).

Previous analysis indicated that groundwater pressure heads within the TWS bore at Lumley Park, or in close proximity to it, were likely to be temporarily lowered during the period it was operational (2002-2006) (Parsons Brinckerhoff, 2011). However, the deeper groundwater levels at the monitoring bore in proximity remained around 45 m below ground level (Parsons Brinckerhoff, 2011) (Figure 37). The TWS bore was used again for a period in between late August and late December 2007, but has not been operational since (Rous County Council, 2019a, 2019b).

Additional monitoring piezometers were installed in 2005-2006 (GW041001_1 and _2) near the TWS bore at Lumley Park (~10-20 m away) and Lumley Cutting (~50-100 m away). The deeper levels during this period were generally stable, with the four dips potentially attributed to measurement error, periods when the data from the logger was being downloaded or the logger was down (Figure 37 and Figure 38). Small rises in the shallow levels seem to follow the significant rainfall events. It was previously reported that groundwater levels in the shallow aquifer are rapidly recharged with rainfall events (Green, 2006), which can be seen in Figure 38.

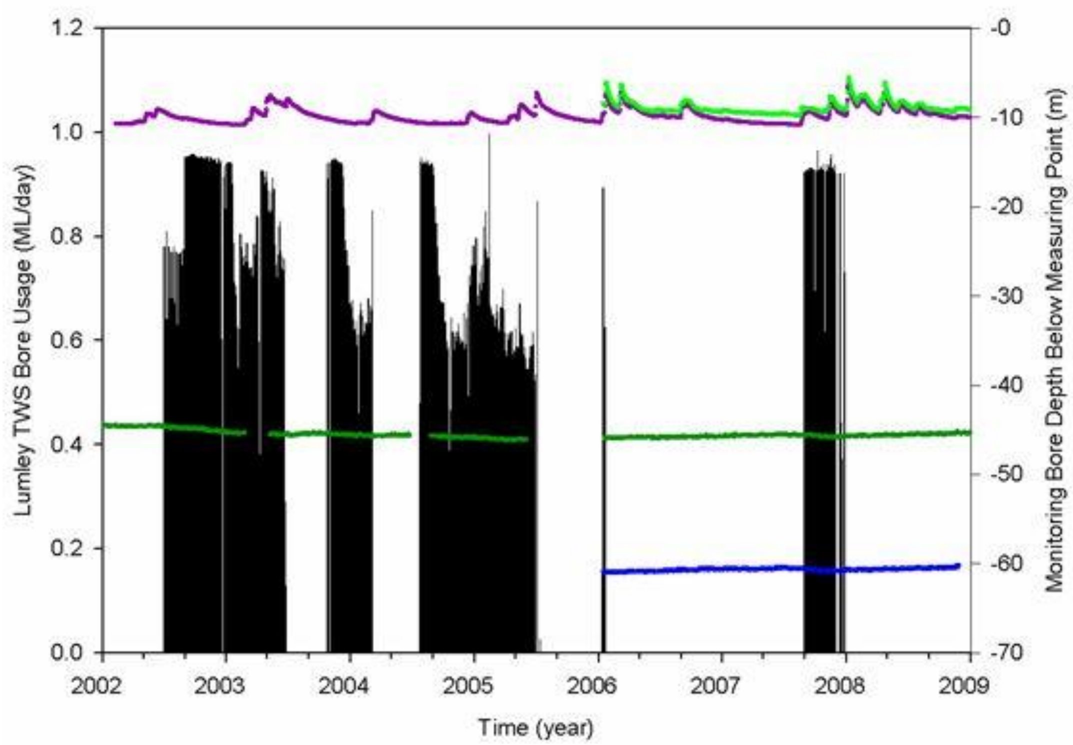


Figure 37: Lumley Park TWS bore usage (black columns) and water level and/or pressure observed at DPIE monitoring bores GW081006 (shallow) and GW081005 (deeper) from 2002 to 2009.

Source: Rous County Council (2019a) and WaterNSW data register (WaterNSW, 2019)

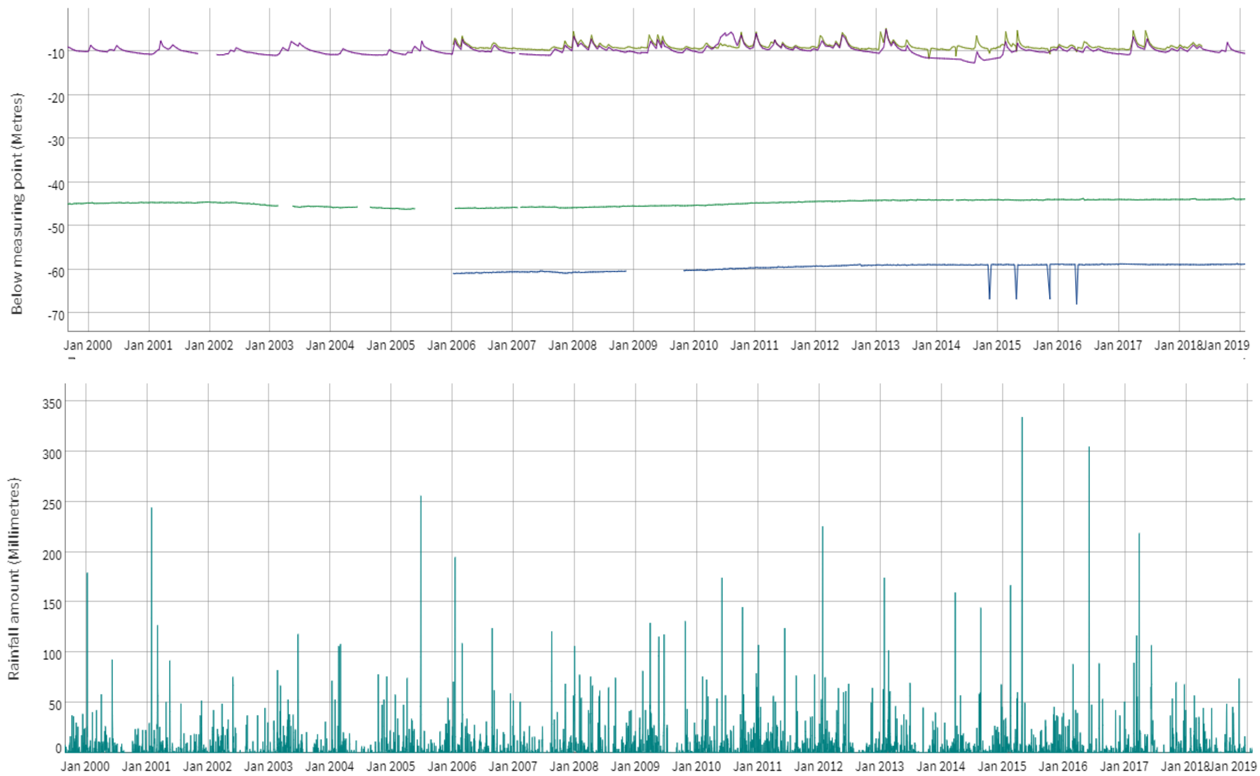


Figure 38: Groundwater levels from DPIE monitoring bores near Lumley Park plotted with rainfall
Groundwater levels from DPIE monitoring bores near Lumley Park: GW081006 (shallow, purple line) and GW081005 (deeper, green line) and two more recent monitoring bores GW041001.1.1 (shallow, light green line) and GW041001.2.2 (deeper, light blue line, note the four dips are most likely associated with logger servicing); and the rainfall amount (nearby Bureau of Meteorology rainfall stations, shown in blue columns). Data source: WaterNSW and BoM

At Lumley Park, the monitored levels did not appear to support an immediate link between extraction and the deeper and shallow levels nearby; whereas at Convery's Lane there appeared to be a link between extraction and drawdown from the deeper aquifer. This example highlights the complexity of the spatial and temporal variation across the fractured rock aquifers despite monitoring of the deeper and shallow aquifers over extended periods. However, these investigations also highlight the value of properly conducted investigations, which include field investigations, conceptual model development, and bore testing.

As these cases do not include monitoring of the local GDEs, it is difficult to draw conclusions about environmental impacts. Further monitoring at Lumley Park (Parsons Brinckerhoff, 2011) and an assessment of the interaction with the GDE could determine if the pumping rate may cause unacceptable drawdown (Moore, 2014). Monitoring suggestions, highlighted in reports prepared for Rous, included monthly data collection of groundwater levels and parameters including: EC, pH, temperature and redox potential, as well as annual monitoring for major ions, metals, and nutrients to detect any potential changes in groundwater quality (Parsons Brinckerhoff, 2011).

APPENDIX 7: SETBACK RULES FROM THE WSP

Table 33: Minimum distance rules to minimise interference between bores in fractured rock groundwater sources (Alstonville Basalt Plateau, New England Fold Belt Coast, and North Coast Volcanics)

Other bore/asset type	Minimum distances
An existing bore that is not used for basic rights	200m (bores < 20ML/yr) 400m (bores > 20ML/yr)
An existing bore that is used for basic rights	200m
The boundary of the property (unless consent gained from neighbour)	100m
A local or major water utility bore	500m
A bore used by the Department for monitoring purposes	400m
Exceptions – the above restrictions do not apply if either: • The bore is used solely for basic rights; • The bore is a replacement bore; • The bore is used for monitoring, environmental management or remedial works; or • The location of the bore would result in no more than minimal impact on existing extractions within the water source.	

Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 cl 40

Table 34: Minimum distance rules to minimise interference between bores in porous rock groundwater sources (Clarence Morton Basin)

Other bore/asset type	Minimum distances
An existing bore that is not used for basic rights	400m
An existing bore that is used for basic rights	100m
The boundary of the property (unless consent gained from neighbour)	50m
A local or major water utility bore	1000m
A bore used by the Department for monitoring purposes	200m
Exceptions – the above restrictions do not apply if either: • The bore is used solely for basic rights; • The bore is a replacement bore; • The bore is used for monitoring, environmental management or remedial works; or • The location of the bore would result in no more than minimal impact on existing extractions within the water source.	

Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 cl 40

Table 35: Minimum distance rules to minimise contamination

Contamination source	Minimum distances
The plume associated with a contamination source	Any distance from the plume that is insufficient to protect the groundwater source; or 250-500m if no drawdown will not occur within 250 m of plume; or or 250m
Exceptions – the above restrictions do not apply if either: • The distance is adequate to protect the groundwater source, its dependent ecosystems and public health and safety; or • The bore is used for monitoring, environmental management or remedial works.	

Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 cl 41

Table 36: Minimum distance rules to minimise impacts on GDEs and environmentally sensitive areas

GDE or environmentally sensitive area	Minimum distances
A high-priority GDE	100m (for bores used for basic rights)
A high-priority GDE or the outside perimeter of a National Park estate	200m (for bores not used for basic rights)
A high-priority karst environment GDE	500m (for bores not used for basic rights)
A river or stream (1st, 2nd or 3rd order)	40m (for bores not used for basic rights)
An escarpment	100m (for bores not used for basic rights)
Exceptions – the above restrictions do not apply if either: • The water supply works (bores) are used for monitoring, environmental management purposes or remedial work; • A hydrogeological study demonstrates no drawdown of the groundwater at the outside edge of the GDE; or • No more than minimal impact will occur to any groundwater dependent vegetation in the nearby National Park estate.	

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Table 37: Minimum distance rules to minimise impacts on groundwater-dependent culturally significant sites

Site	Minimum distances
A groundwater-dependent culturally significant site	100m (for bores used for basic rights)
A groundwater-dependent culturally significant site	200m (for bores not used for basic rights)
Exceptions – the above restrictions do not apply if either: • The bore is used for monitoring, environmental management or remedial works; or • The location of the bore at a lesser distance would result in no greater impact on the groundwater source and its groundwater dependent culturally significant sites.	

Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 cl 43

APPENDIX 8: DECISION MAKING AND UNCERTAINTY

As part of Term of Reference 1, the Review was requested to provide advice on the sustainability of the extraction limits in the relevant Water Sharing Plan (WSP) for groundwater sources in the Northern Rivers.

While in common use, the term ‘sustainability’ is complex and underpinned by principles that require interpretation and consideration of multiple, changing and sometimes competing factors. The *Protection of the Environment Administration Act 1991* considers the sustainability to be informed by integration of social, economic and environmental considerations in decision-making processes. For the purposes of this report, ‘groundwater sustainability’ relates to managing the current (environmental and anthropogenic) use of the resource to provide for ensure long-term water security.

Regulatory instruments provide a framework and strategies to help achieve this long-term security, including adaptive management, risk assessment of proposed developments and approval conditions for licences and development applications. However, within these frameworks, judgements still need to be made. Salient questions in exercising judgement include for example, how much risk is acceptable, to whom, under what circumstances, with what information and what consequences and the degree of confidence in the assumptions made, what tools can be drawn on to reduce uncertainty in a way that is cost effective and proportional to the level of risk.

The Review recognises the community concern about water allocations and use, and the desire for greater certainty and more definitive information about sustainability to inform decision making at a regional, local and individual scale. Yet all decisions entail some degree of uncertainty, and all decisions are made in the context of imperfect knowledge.

At an individual- and community-level we are faced on a daily basis with the challenge of making decisions that balance risks and potential benefits of actions. These range from the routine to significant, may be implicit or explicit and are dynamic in light of changing knowledge – with advances and evolutions in science often shifting the balance. All are influenced by the actions and/or opinions of others, communal decisions made more complex by diverse stakeholder priorities and values.

In undertaking its work, the Review considered risk and uncertainty and how these have been managed by decision-makers and proponents from a scientific perspective based on currently available knowledge. This Section sets out how these concepts were approached by the Review and informed consideration of sustainability and impacts under the Terms of Reference.

TYPES OF UNCERTAINTY

Much has been written, both for academic and popular science audiences, on the topic of decision making under uncertainty. Some issues are well recognised – for example the need to account for sample variability, computational uncertainty or establishing appropriate margins of error. However, increasing recognition is being given to the importance and best means of communicating uncertainty to diverse audiences and recognition of the emotional side of decision making under uncertainty. Some offer practical guidance for individuals.

The prestigious US National Academy of Sciences (NAS) convened an expert panel several years ago to develop guidelines around environmental decision making under uncertainty (Institute of Medicine, 2013). The report had a strong focus around human health risks associated with environmental exposures. Notwithstanding this focus, the report offers many useful principles that can help in contexts where a regulatory body is faced with the challenge of making a complex decision.

One of the first steps in any uncertainty analysis should be a clear articulation of the various sources of, and nature of, the uncertainties involved and it is useful to distinguish between the different types of uncertainty.

Statistical variability, sometimes referred to as aleatory uncertainty, refers to natural variation in the physical environment and in human behaviour and biology. In the context of this Review, there will be statistical variability associated with daily rainfall levels or with how much water is actually extracted by an individual licensee within the maximum amount allowed.

This kind of variability is inherent to the system and cannot be reduced by collecting further data, though the latter may be extremely useful in helping decision makers to understand further this kind of uncertainty. This first type of uncertainty is, at least in broad principle, easy to accommodate through statistical modelling.

Model uncertainty refers to the fact that in virtually every area of enquiry, there will be uncertainties associated with the conceptual understanding of the relevant science that describes the context of interest. A useful definition of scientific modelling that recognises both its values and limitations is

“The generation of a physical, conceptual, or mathematical representation of a real phenomenon that is difficult to observe directly. Scientific models are used to explain and predict the behaviour of real objects or systems and are used in a variety of scientific disciplines, ranging from physics and chemistry to ecology and the Earth sciences. Although a central component of modern science, scientific models at best are approximations of the objects and systems that they represent—they are not exact replicas. Thus, scientists constantly are working to improve and refine models” (Rogers, 2011).

It is useful to subdivide model uncertainty into uncertainty associated with the broad nature of the model itself as well as uncertainty associated with particular parameters or inputs needed to characterise a particular model.

In some contexts, there can be substantial scientific debate about the appropriate conceptual model for a situation at hand. In the Review, an example of this uncertainty is in the appropriate method to calculate the recharge rate of groundwater. As will be seen later in Section 4.3.1, there are two approaches that can be used to model the recharge rate of groundwater, being Chloride Mass Balance and the baseflow filtering approach. The choice of which model to use may be based on a conceptual understanding of the mode of recharge (local or widespread, rainfall to groundwater versus rainfall to surface water to groundwater), previous experience, availability of data and tools.

Even in settings where scientists agree in broad terms over the appropriate conceptual modelling framework, there will often be uncertainty over the particular inputs needed to precisely define that model. This is referred to as parameter uncertainty.

Parameter uncertainty can generally be reduced through additional data collection, though this may involve time consuming and costly effort. In the context of this Review, it is likely that hydrogeologists would agree in broad terms about how one should go about constructing a model to characterise the aquifers in the Northern Rivers region. However, there might be variations in opinions regarding precise approaches.

The greatest source of uncertainty in this context arises from limitations in the availability of data to inform the right inputs to these models and to help define the needed model parameters. This would include data from geological surveys designed to help characterise the nature and structure of the aquifers and to elucidate their recharge behaviours.

There is a fourth kind of uncertainty referring to settings where there may be fundamental disagreements about the nature of the processes driving the situation of interest or where it is impossible to collect all the data needed to properly inform the system due to cost and time considerations. The term deep uncertainty is sometimes used to describe this kind of uncertainty. This kind of uncertainty classically arises in settings where decisions may have long-term consequences, but where it is not possible to accurately predict the future with full accuracy.

The process of decision making under uncertainty naturally follows several phases. The first phase involves problem formulation and scoping, creating an inventory or even a taxonomy of the uncertainties associated with a particular decision making context. This would involve listing out the various sources of statistical variation and heterogeneity. As part of the process in identifying and listing these sources, it is important to assess whether a particular source of heterogeneity might have impact on the decision and hence need to be incorporated specifically, or whether it is simply a source of heterogeneity that can be noted and then set aside and not considered further. In the hydrogeological context for example, it is typical to recognise that while there will always be a lot of small-scale fluctuations in the structure of a porous aquifer, it is not necessary to capture these precisely and only a general, larger-scale description of the aquifer characteristics may be needed.

As part of the first scoping phase of a decision, it is very important to assess whether some of the sources of uncertainty could be reduced relatively easily and in an acceptable timeframe through additional data collection or even research. It will also be critical to identify any sources of deep uncertainty and also to decide on the broader strategies that will be used to incorporate the identified uncertainties into the decision making process and ongoing risk management. Applying appropriate strategies to account for and manage those uncertainties correspond to the second and third phases of decision making under uncertainty, the focus of the following section.

APPROACHES TO INCORPORATING AND MANAGING UNCERTAINTY

A variety of modern-day tools are available to help with the incorporation of uncertainty considerations into decision making. Indeed, the science of Decision Theory goes back to the work of probability theorists such as Pascal and Bernoulli in the 17th and 18th centuries who discovered identified that people do not always react completely rationally and predictably when it comes to making decisions under uncertainty. These early developments were largely done in the context of gambling games where the choices and associated losses or gains were fairly simple.

The concept of Utility was developed to measure the value that people place on certain outcomes happening and then the decision making could be framed in terms of choosing the action with the highest expected utility. Alternatively, strategies such as minimax (choosing the option that minimizes the worst outcome) can be used in settings where it is difficult to assign probabilities to the relevant scenarios. Polasky et al. (2011) discuss these ideas in the context of environmental impact assessment. However, they make the point that these fairly simple classical decision theory tools work well only in settings where existing information is extensive and where the probabilities, risks and benefits associated with various decisions are well delineated. In most complex real world settings, more sophisticated tools are needed.

Modern decision science has evolved considerably in order to have relevance in and applicability in complex real-world settings. For example, there have been extensions to so-called multi-attribute utility analysis for settings involving multiple different outcomes. Cost-benefit analysis is an example. Extensions to the setting of multiple decision makers led to the field of game theory which has found wide application and interest from economists.

Tools such as probabilistic risk assessment were proposed in the late 80s and 90s as a means of incorporating uncertainty into the modelling process.

While probabilistic risk assessment cannot remove uncertainty, it provides a means of enabling decision makers to gain a clearer understanding of the impact of various sources of uncertainty on the outcomes of interest. Probabilistic risk assessment typically uses Monte

Carlo simulation and Bayesian methods to add extra layers to the modelling process. It works very well in terms of addressing the second type of uncertainty, model and parameter uncertainty. An example would be in areas of water quality and risk assessment, some stakeholders may have concerns that variation in the amount of water drunk by individuals each day might affect the estimated dose-response of contaminants and hence impact on the decision making process. By extending classic dose-response modelling to incorporate this variability, it is possible to explicitly assess the impact of this variability. Probabilistic Risk Assessment has also been adopted by the US Nuclear Regulatory Commission.

In very complex settings, the number of scenarios needing to be considered can easily balloon out to an unmanageable level. Some new computational tools have been recently developed to handle this. For example, MIT researchers utilise Bayesian networks to efficiently evaluate and compare thousands of decision options in the context of robotics and autonomous vehicle management (Kochenderfer et al., 2015; Hodgett & Siraj, 2019) describe a computational tool that builds uncertainty into a complex decision framework via a series of triangular distributions.

Bayesian modelling approaches can also be used in settings where there are uncertainties about the model to be used. In data-rich settings, statistical methods can be used to guide the choice between different models or even to build a “meta-model” that includes multiple models as special cases. In complex settings such as groundwater modelling, model specification requires the input of experts with deep knowledge of the subject. Once a model has been specified, there will still be a need to use a combination of data and informed by expert knowledge to estimate model parameters. (Peterson & Western, 2014) used this kind of approach in the context of groundwater modelling.

Rojas (2010) refer to this as a multi-model approach and discuss how this kind of approach can be used to consider the impact of various future scenarios. However, this kind of approach can be difficult to apply in practice. While it naturally allows for a wide range of opinions about the right conceptual model, it still requires that there be enough data available to help quantify the different sources of uncertainty. These approaches can also be computationally very complex when the individual models in the multi-model all require the running of a time consuming hydrogeological model. This can also make such models very expensive to develop. Asher et al. (2015) discuss a more computationally feasible approach based on surrogate models that approximate a complex hydrogeological model with an empirical model that captures the relationship between various model inputs and expected outcomes.

However, the greatest challenge in complex real-world settings is not so much running the models, but delineating all the different elements involved in the decision making and characterising the probabilities and uncertainties associated with these events. In settings that are data-poor or subject to deep uncertainties, the more mathematical tools described above become less relevant since it becomes almost impossible to attach realistic probabilities to the various settings being considered. While the ideal is of course to reduce uncertainty in order to create more reliable predictive models of environmental systems, this step can be time consuming, expensive and potentially unfeasible in the timeframe needed for decision making. Polasky et al. (2011) In such cases other more pragmatic solutions may be taken such as adaptive management, with monitoring and feedback steps to maintain an up-to-date view on the trajectory of an issue so that changes can be made, including potentially decisions to cease activity, informed by new information.

Adaptive management is a precautionary measure in certain cases where there is uncertainty, defined as a “procedure for implementing management while learning about which management actions are most effective at achieving specified objectives.” (OEH, 2018). It is an “iterative based approach involving explicit testing of the achievement of defined goals” (Preston, 2017).

The *Water Management Act 2000* provides that "the principles of adaptive management should be applied, which should be responsive to monitoring and improvements in understanding of ecological water requirements." The NSW Land and Environment Court of NSW has held that an adaptive management approach might involve monitoring management impacts, research, periodic evaluation of outcomes and learning reviewing and adjusting in light of these and establishing effective compliance systems.

Scenario planning provides an appealing method to facilitate thinking and planning about potentially complex future events and outcomes. Scenario planning is less quantitative than traditional decision theory approaches, relying instead on a set of detailed stories that reflect possible changing conditions over time. An advantage of the scenario approach is that it allows the incorporation of complex interplays between social, economic and physical factors such as climate. However, this flexibility and capacity also leads to the main weakness of the approach, namely the difficulty in quantifying the relative likelihoods of the various scenarios. Also important is to prepare responses to potential scenarios with action 'trigger' points, thereby avoiding both the risk of automatically defaulting to a 'middle' option or over-investing to manage theoretical extremes unless required.

A threshold approach to decision making involves identifying critical boundaries that might have major implications if crossed. Setting emissions caps in the context of planning related to climate change is an example of a threshold approach to environmental management.

Resilience thinking refers to the idea of organizing decisions so that they can adapt or transform to a new mode of operation should the old mode become unworkable. Adaptive monitoring in those settings, emphasizing the importance of having access to good quality data that can be used to monitor the context of interest and potentially being used to trigger alerts should problems arise. In the context of aquifer management, having access to reliable data from monitoring bores can play a critical role in terms of assessing the long-term viability of the system and activities.

Polasky et al. (2011) also argue that most situations can benefit from the use of multiple tools and stress the importance of thinking of decision-making as a dynamic process that can responsively adapt in the face of change and of new information. Fletcher, Lickley, and Strzepak (2019) discuss similar ideas in the context of water resource planning. This is consistent with statutory and policy approaches described earlier. In the context of the Review, this kind of adaptive planning and decision making would require that reliable data be available to inform on the state of the various aquifers. Section 3.4 discusses how the data from the network of 29 functional monitoring bores in the Alstonville Plateau region can potentially be monitored in a real-time manner and how such analyses can either provide reassurance that the system is in good health or perhaps trigger a warning that some change might be needed.

Communicating uncertainty

Once the various sources of uncertainty have been identified and a strategy developed for decision making in that context, the next step involves ensuring that issues of uncertainty are communicated to various stakeholders and other audiences. There has been significant research undertaken into the effectiveness of visual and descriptive versus numerical representations of the uncertainty in risk. Professor David (Spiegelhalter, 2017) has written for both the scientific community and the general public about the importance of using clear language and graphical displays to help audiences understand the nature and sources of uncertainty and magnitude of consequences. An overriding principle is that information needs to be presented in a clear and digestible way. Greater attention is also needed to evidence about how visual representations including infographics are processed and understood by different reading audiences (Spiegelhalter, Pearson, & Short, 2011).

APPLICATION OF PRINCIPLES AND CONCEPTS BY THE REVIEW

The Review has examined the potential impacts and consequences of groundwater extraction for bottling purposes having regard to the statutory context in which water resources are allocated and managed and approaches of decision makers at regional and local levels to understand and manage risk and uncertainty.

In so doing, the Review has analysed the assumptions underpinning the relevant WSP, including the strategies deployed and level of conservatism applied to assumptions to manage uncertainty. The Review undertook further analyses and gave consideration to comparable and alternate approaches to managing uncertainty.

The Review was cognoscente of the complexity of the groundwater system, including potential groundwater and surface water interactions in confined and unconfined aquifers and implications this has for any extraction. The Review accepted the assumption that drawing groundwater from a bore will have some impact on the water balance, both spatially and temporally, and may have potential consequences for other water assets in the vicinity, including the environment and other groundwater users. These consequences can be related to changes in both water quantity and quality that may not emerge in the short term. At the same time, an effect on a system may be a measurable effect but may not have significant consequences or be of lesser significance relative to other factors at play.

Insofar as possible the Review has sought to provide pragmatic and feasible suggestions to improving knowledge and understanding. While not directly in its Terms of Reference, it has also made observations about communication and data arrangements as they relate to the management of water resources and transparency and confidence in decisions made.

ACRONYMS

Table 38: Acronyms

Acronym	Complete Term
ACT	Australian Capital Territory
ADR	Australian Design Rules
AIP	Aquifer Interference Policy
APCO	Australian Packaging Covenant Organisation
ATC	Automatic Tube Counts
AWD	Available water determination
AWRA-L	Australian Water Resource Assessment Landscape model
BLRs	Basic Landholder Rights
BOM	Bureau of Meteorology
CCA	Coca-Cola Amatil
DPE	Department of Planning and Environment (now DPIE)
DPI Water	Department of Primary Industries Water
DPIE	Department of Planning, Industry and Environment
EGS	Environmental goods and services
EPA	Environmental Protection Authority
ESD	Ecologically sustainable development
GAM	Generalized Additive Model
GDE's	Groundwater dependent ecosystems
GMP	Good Manufacturing Practice
HDPE	High density polyethylene
HVNL	Heavy Vehicle National Law
HVSS	Heavy Vehicle Safety Stations
KM	Kilometres
LEP	Local Environment Plan
LGA	Local Government Area
LTAAEL	Long Term Average Annual Extraction Limit
ML	Mega Litres
ML/y	Mega Litres per year
mm/yr	millimetres per year
MRFs	Materials Recycling Facilities
NAS	National Academy of Science
NRAR	Natural Resources Access Regulator (NRAR)
NRC	Natural Resources Commission
NSW	New South Wales
NTC	National Transport Commission
NWI	National Water Initiative

OCSE	Office of the Chief Scientist & Engineer
PCT	Plant Community Type
PET	Polyethylene terephthalate
PEW	Planned Environmental Water
RCP	Road Contribution Plan
REA	Representative Elementary Area
REV	Representative Elementary Volume
RMS	Roads and Maritime Services
RRE	Recharge amount reserved for the environment
SEED	Sharing and Enabling Environmental Data
SI	Sustainability Index
SILO	Scientific Information for Land Owners
SSDs	State significant Developments
SSIs	State Significant Infrastructure
TAD	Total Available Drawdown
TOR	Terms of Reference
UEL	Upper Extraction Limit
UNSW	University of New South Wales
WAL	Water Access Licences
WSP	Water Sharing Plans