Otago Regional Council

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MEMORANDUM

To: **Sam Walton – Policy Analyst, Freshwater and Land**

From: **Sam Yeo – Groundwater Science**

Date: **09/10/2023**

Re: **Options for management of fractured rock aquifers**

Name	Role	Date Completed
Amir Levy	Reviewer (internal)	10/10/2023
Brydon Hughes	Reviewer (external – Land and Water People)	XX/12/2023

1 Introduction

The National Policy Statement for Freshwater Management 2020 (NPS-FM) requires Otago Regional Council to set environmental levels for groundwater, and to identify take limits as rules in the proposed Land and Water Regional Plan (pLWRP)[1].Further to this, the National Planning Standards 2019 prescribe the following definitions for which the pLWRP must apply:

- Aquifer: means a permeable geological formation, group of formations, or part of a formation, beneath the ground, capable of receiving, storing, transmitting, and yielding water.
- Groundwater: means water occupying openings, cavities, or spaces in soils or rocks beneath the surface of the ground.

In addition to Otago's more common unconfined and semi-confined aquifers hosted in permeable sediments such as gravels and sands, the region also has the potential for hosting variably yielding, fractured rock aquifers. These are predominately located in the Otago Schist (Clutha/Mata-au FMU, North Otago FMU, Taieri FMU, Dunedin and Coast

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[1] Clause 3.19, National Policy Statement for Freshwater Management 2020

FMU) , the Murihiku Terrane fractured rock in the Catlins FMU, the Dunedin volcanics, and potentially in the Otekaike Limestone in the North Otago FMU. The pLWRP requires an assessment of options for managing these fractured rock aquifers in a manner that gives effect to national policy direction. Therefore, to improve this management, the provisions in Environment Southland's (ES) regional plan were also reviewed.

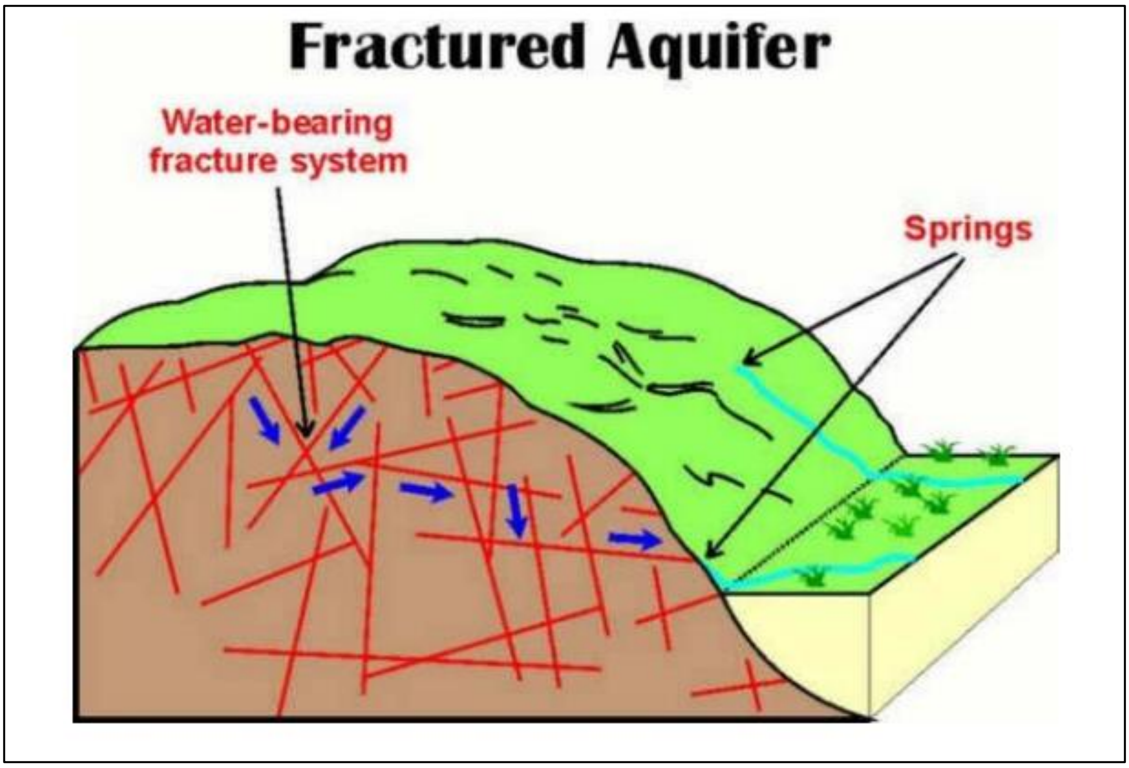
This memo provides:

- Background and definitions
- A brief explanation on ES' approach to the management of fractured rock aquifers. This is based on a recommending report from Liquid Earth (2011) which provided recommendations on how to manage fractured rock aquifers in Southland
- A description of fractured rock aquifers in Otago
- Options for possible groundwater management and allocation of Otago's fractured rock aquifers, with the pros and cons of each option.

2 Background information and definitions

The key properties of aquifers are saturation of the aquifer material and their capability to transmit and yield water, usually via bores or wells. The majority of Otago's aquifers are found in horizons of permeable sediments such as sands and gravels. However, much of the region is also underlain by fractured rocks (Otago Schist, Murihiku Terrane meta-sediments, and volcanics) that can also potentially form aquifers.

Fractured rock aquifers store and transmit water through discontinuities such as fractures or joints in the rock mass. Conversely, the intact part of the rock often has very low permeability (Figure 1). Water availability depends on the fractures' number, aperture size, infill-type, and degree of interconnectedness. Therefore, the long-term yield from a



bore located within a fractured rock aquifer depends on the localised extent and interconnectedness of discontinuities in the rock mass itself (i.e. the fractures) rather than the nature of the materials surrounding the bore (i.e. in contrast to sand/gravel aquifers).

Figure 1 Schematic of fractured rock aquifer and groundwater flow through discontinuities

Fractured rock aquifers also have recharge characteristics that are different from sediment-hosted unconfined and confined aquifers. Many fractured rock aquifers that daylight at or near the surface are weathered, where minerals within the rock have altered to clays. This can form a hydraulic barrier that limits recharge from the surface. Fractured rock aquifers also tend to be found in rolling or hilly topography, where surface water runoff is higher than in flat-lying basins. The size and “openness” of fractures can decrease with depth due to increased overburden pressures related to the weight of the overlying rock mass. Additionally, if the fracture network has any infill such as clays, this will inhibit water flow through the fracture network. Due to these differences, fractured rock aquifers require a different management approach to sediment-hosted aquifers.

3 ES Policy framework for Aquifers

- The ES water plan defines four aquifer types: riparian, lowland, confined and fractured rock
- Groundwater is allocated within management zones. Each zone is classified according to the aquifer type described above.

3.1 ES policy provisions to manage fractured rock aquifers as of 2010.

Because of the heterogeneity of fractured rock aquifers, ES was unable to assign overall allocation limits for each fractured rock aquifer in the region, even though these aquifers are classified as a distinct aquifer type in the ES Plan. However, the unique characteristics of these aquifers, i.e., the limits that fracture interconnectedness has on overall reliable yield through the whole aquifer and the typically low hydraulic conductivity, effectively limit the environmental impacts of groundwater takes, e.g., well interference and stream depletion. Therefore, effects due to pumping in these fractured rock aquifers are very localised to that specific area.

3.2 Recommendation for fractured rock aquifer management from Liquid Earth (2011)

Liquid Earth proposed a simple methodology for establishing activity status for groundwater takes from fractured rocks (i.e., permitted, discretionary) based on a simple estimate of local aquifer recharge, using the recharge on the relevant landholding. The activity status is based on percentage of recharge that is consumptive. E.g., activity is discretionary if 25-50% of the estimated recharge on the land holding is allocated.

4 Otago’s fractured rock aquifers

The main fractured rock aquifers in Otago are likely to be found in the Otago Schist, Murihiku Terrane in the Catlins FMU and the Dunedin/North Otago volcanics.

For the majority of the region, the main source of potential groundwater within fractures is the Otago Schist. There are only ~27 bores in Otago that draw water out of the schist, over half of which abstract groundwater under the permitted activity category. The bore depths range from 5.4m – 168m. Observation of pump test data from these schist bores show they are relatively low yielding, with large drawdown at low pump rates, often on the order of >20 metres.

The Catlins FMU area has a moderate number of takes within the basement/Tertiary lithologies, predominately for stock water or domestic purposes. Generally, within the lower elevation basins/valleys the bore depth is generally ~25-40m where it is expected that the fracture density and ideal joint intersections for secondary permeability are found.

The Speights brewery is the main (only?) user of groundwater from the Dunedin Volcanics, which requires treatment before use. Groundwater in the volcanics flows along relatively persistent joint sets, seeping out of joints where they daylight at the surface. Jointing in volcanics is generally relatively consistent, caused by cooling of the basalt during emplacement. There is little need for this groundwater resource for Dunedin city.

5 Options for consideration in Otago/recommendations

Several potential options for managing groundwater takes from fractured rock aquifers above permitted activity volumes are given below:

1) **Due to the self-limiting characteristics of fractured rock aquifers one option would be to leave the status quo and not impose an allocation regime for fractured rock aquifers.**

    a) **Pros**

Straightforward and means there are no onerous, time-consuming analyses on a likely complicated system paid for by applicants wanting to receive a water allocation from groundwater outside of a mapped aquifer, often in isolated, high-country areas. It is also less time consuming in terms of consenting as there will be no review required of the methodology used by the applicant for determining recharge/mean annual recharge.

    b) **Cons**

The NPS-FM requirement is to set allocation limits to groundwater. Additionally, there are areas that are already under pressure for water usage such as the Wakatipu Basin. If we do not set an allocation limit regime, we will have little oversight on water usage or adverse environmental effects from over abstraction.

2) **Adopt the proposed allocation regime as recommended by Liquid Earth, where applicants determine recharge to their specific landholding and ORC then allocates a certain portion of the Mean Annual Recharge (MAR) for that landholding.**

a) Pros

Provided the plan is not too prescriptive in terms of methods used to calculate recharge, it gives flexibility to applicants to determine recharge using a method that is appropriate to the area. It is relatively straightforward thereafter in terms of allocation as they are then given up to 50% of the calculated MAR volume to their landholding. Matters to consider when determining MAR could be in line with Schedule 4D in the current RPW. However, there are many aspects in Schedule 4D that will not be appropriate for steep, hilly hard rock terrain with high run-off and recharge refusal.

b) Cons

There are many different methods for determining recharge and it may be time-consuming for consenting purposes to review these methods and determine how appropriate they are. It will be nuanced for many areas and the difficulty with fractured rock aquifers is that usual methods of recharge calculations are not necessarily appropriate for these as there will be high topological factors in many areas and high rates of recharge refusal.

Additionally, it is unknown in some areas whether 50% of the calculated MAR would be considered a conservative approach. For mapped aquifer basins where a default 50% MAR is obtained from Land Surface Recharge (LSR) models in the current plan, GW Science has recommended this is decreased to 35% MAR as a more conservative approach to GW management. This is particularly important in areas where we do not have good knowledge of the aquifer extent and properties, which is certainly the case for fractured rock GW zones.

3) Use a more prescriptive method of determining allocation per landholding by way of the Radius of Influence calculation (R (m))

$$R = b \times \sqrt{\frac{K}{2 \times N}}$$

Where (units).

b = saturated thickness (m)

K = hydraulic conductivity (m/T)

N = recharge (m/T)

The radius of influence determines the maximum distance from a pumping well where drawdown can be measured [2] (Fig 2).

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[2] Gragoni, W. 1998. *Some consideration regarding the radius of influence of a pumping well.* Hydrology (3), 21-25

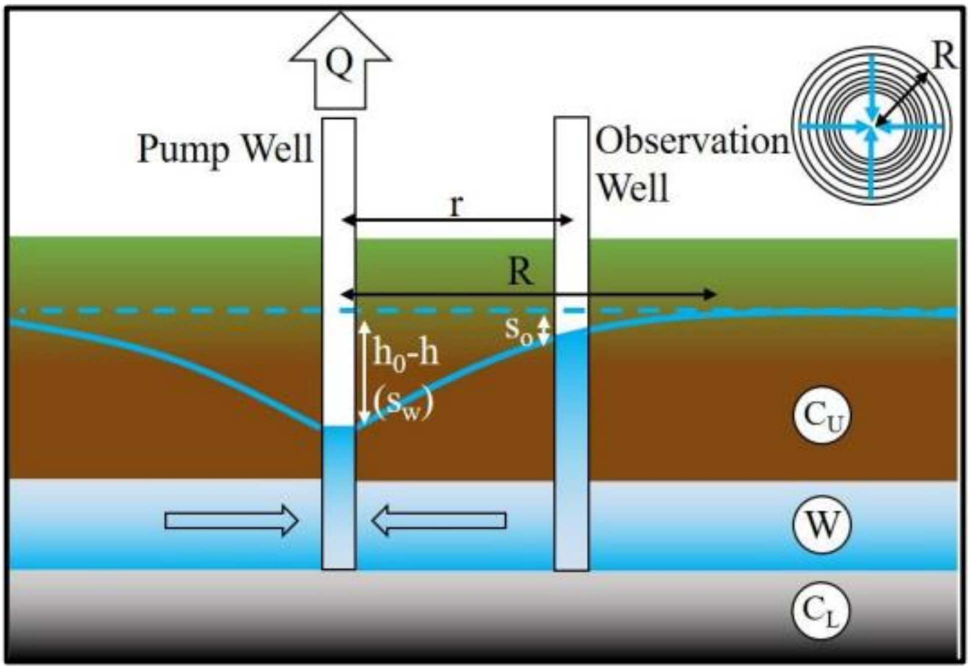

Figure 2.1 Schematic drawdown in a confined aquifer due to pumping (modified from Freeze & Cherry, 1979). Illustration of radial flow, seen from above, in upper right corner. Q = flow/pump rate, r = horizontal distance between pump well and observation well, R = Influence radius, C_U = upper confining layer, W = water-bearing layer, C_L = lower confining layer, $s_w = h_0 - h$ = drawdown in pump well, s_o = drawdown in observation well.

Figure 2 Schematic from Druid (2022)[3] showing R (radius of influence) or the edge of the cone of depression in a pumping well.

a) Pros

The ROI is a much more conservative method when compared to the above options. The outcome of this option is that the applicant would end up providing a conservatively calculated maximum allocation limit. Additionally, to calculate an allocation limit this would require an aquifer test to determine aquifer parameters such as hydraulic conductivity (K). This reduces uncertainties in terms of sustainability of the allocation as ROI generally calculates a conservative annual allocation. This calculation will also aid in the determination of where we may expect interference on neighbouring bores due to pumping.

b) Cons

The calculation of ROI assumes an unconfined aquifer in relatively flat to rolling topography. It is also based on the Theis equation where the aquifer is presumed to be isotropic, homogeneous, of infinite extent etc., most of which are not satisfied by fractured rock aquifers. Additionally, the hydraulic gradient has a significant effect on the radius of influence, which is not covered by the above equation, and will require additional bores and surveying to obtain (i.e. further costs and work for applicants). Much of the schist terrain encompasses steep-sided slopes and therefore there would have to be an up-gradient recharge component also. It is also potentially a time consuming and

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[3] Druid, S. (2022). *Comparing Groundwater Drawdown with Estimated Influence Radius – A case study of infrastructural projects in Sweden.* Degree Project at the Department of Earth Sciences ISSN 1650-6553 No. 583

expensive process (for the applicant) to determine all the parameters needed for the ROI calculation, including determining expected recharge (e.g., rainfall recharge).

This methodology requires a sound hydrogeological conceptual model, which may be difficult in many areas as the fractured rocks are very heterogeneous. A particular issue with the ROI calculation is the number of uncertainties and assumptions in the calculation. This includes the determination of recharge amounts and the saturated thickness of the “aquifer”, where the likely thickness used in the ROI calculation would only be to the base of the screen.

Furthermore, sustainable water yield is not always guaranteed in fractured rock groundwater systems. Hard rock groundwater systems generally have low specific yield and once available water compartments have been drained, the water yield may begin to decrease to the point the bore is no longer yielding what is expected/allocated. Therefore, the applicant may go through this lengthy and costly process of determining potential recharge to the area including development of a hydrogeological model, carrying out and analysing pump test data to then find over time that the yields to their bore are decreasing with use.

4) **Not set allocation limits but put the onus on the applicant demonstrate that the proposed allocation volumes are available through an extended aquifer test. For instance, if the bore is continuously pumped at the proposed maximum rate for 14 days and it can yield the volumes required, then the allocation will be granted.**

   a) **Pros**

This method would enable both the applicant and the council to get a good grasp of aquifer parameters in the area and, importantly, providing the applicant assurance of supply. An aquifer test would help determine the T and Sy values alongside the daily, monthly, and annual limits.

   b) **Cons**

This could potentially allow unlimited water use in some areas and may have adverse effects in terms of water quality by way of intensification. The risk is relatively low as it expected most of the time the fractured rock areas would be unable to provide this kind of water supply as over time any accessible compartments would be drained of water and generally the bore will go dry when pumped hard. This was observed in aquifer tests from bores in fractured rock that usually show high drawdown in response to pumping. However, there are always exceptions to this, and this is where the need lies in having an allocation provision.

In addition this methodology could also be expensive to the applicant if at the end of the test they have proved that the groundwater take is not sustainable.

5) **Allocation limit based on average annual rainfall per landholding**.

Rather than allocate a percentage of recharge to the aquifer, determine the average annual rainfall accumulation on a landholding and allocate 5% of that as a limit. The ORC

(2004)[4] paper estimates only 2.5-3.5% of average annual rainfall ultimately makes it to a fractured rock aquifer as recharge. The remaining 97% of rainfall forms run-off, percolation into streams or evaporation. This calculation is simple, and not costly for the applicant to determine. This calculation could then be combined with a longer aquifer test (e.g. 7-day constant discharge?), to demonstrate that the bore can yield the proposed volumes and rates. Water level recovery is the most important information from this aquifer test.

a) Pros

This method is very simple to calculate and not onerous on the applicant. It also provides a consistent calculation when reviewing the consents. It provides a straightforward and attractive option that meets the NPSFM requirements for a groundwater allocation regime in a complex groundwater system where recharge is very difficult to quantify.

The calculation is relatively conservative as it would be expected that in most cases the fracture network will draw from an area that is larger than the specific landholding. Therefore, if in any cases the 5% rainfall seems too generous, it should be made up for by the likely larger recharge area.

b) Cons

It is not always likely that the rainfall falling on the ground at each landholding actually makes it into the aquifer. There is a chance that the groundwater pumped from a well recharged the aquifer higher up in the catchment areas (or other areas not within the landholding), where the fractured rock (e.g., schist) daylights the surface allowing rainwater to seep into fractures. So, despite the assumptions and unknowns related to this simple calculation, we still think that 5% is suitably conservative. The takes subject to this allocation regime will also be subject to well interference assessments, pump tests and consideration given to stream depletion.

6) Additional considerations

Matters to be considered for takes above the PA threshold should include well interference, cumulative effects, and potential adverse effects to surface water bodies. Determining the impact of pumping from fractured rock aquifers on surface water can be very difficult to determine, hence a comment in the AEE should be required but not necessarily the full (proposed) stream depletion assessment (?).

6 Conclusion

Generally, wells within fractured rock aquifers are self-limiting as the specific yield is often low and, with the well likely to go dry at higher pumping rates, mitigating the effects on neighbouring wells or stream depletion.

Currently the demand for water resources from the Otago Schist and Catlins Mesozoic sequence is low. However potentially with river/surface water resources becoming

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[4] ORC. 2004. *South Otago Groundwater Investigation: Clydevale and Wairuna Basins*. Objective ID. A900175

tightened due to changes to minimum flow restrictions in some areas, exploring for groundwater in hard rock and drilling deeper holes may become more viable, hence this resource should be managed in the new LWRP.

7 Appendix 1: Maps

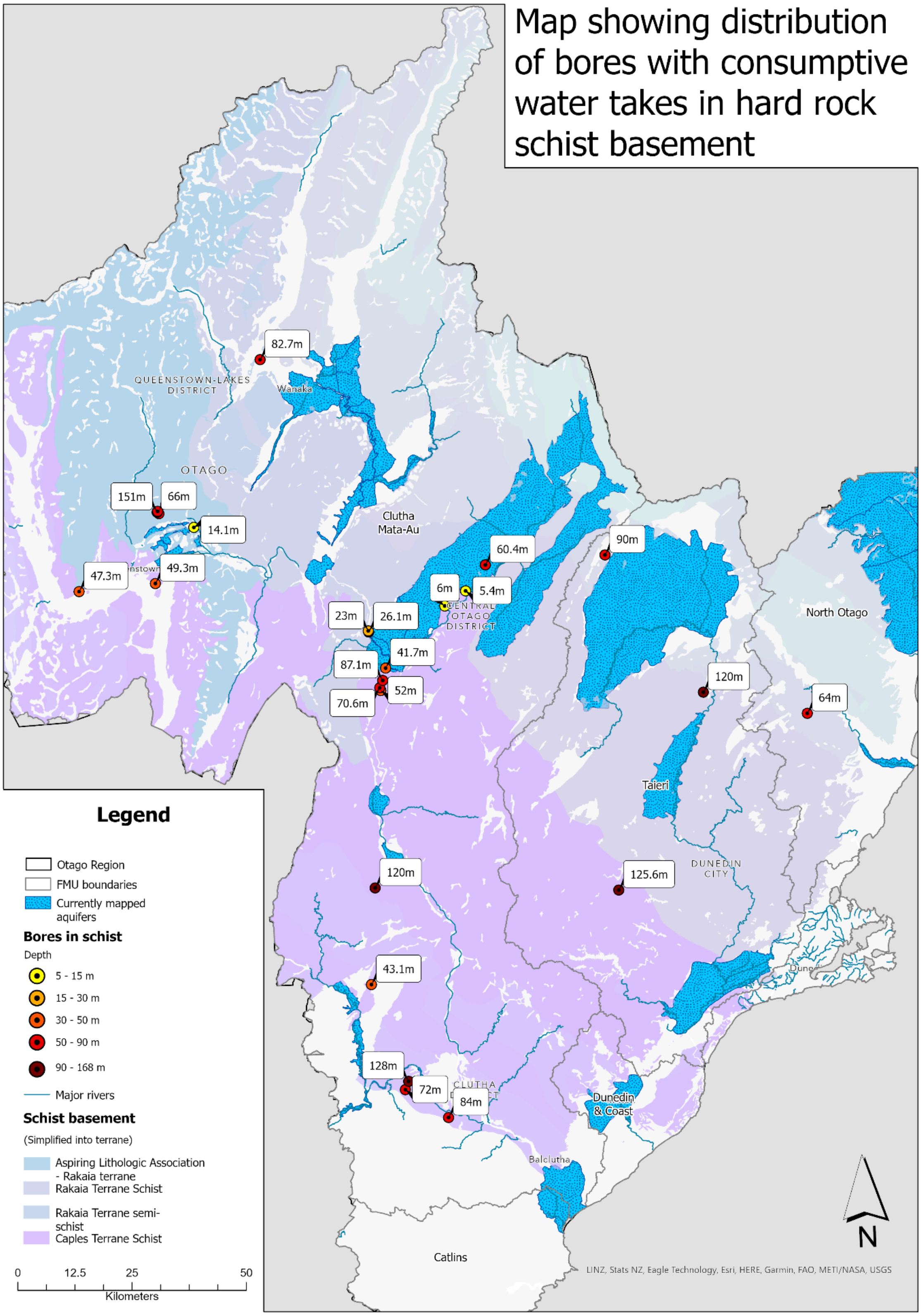

Figure 3 Figure showing the location of all known wells in the Otago Schist. The Otago Schist lithology is shown in the purple colours. The blue areas denote current aquifer boundaries both operative and recommended

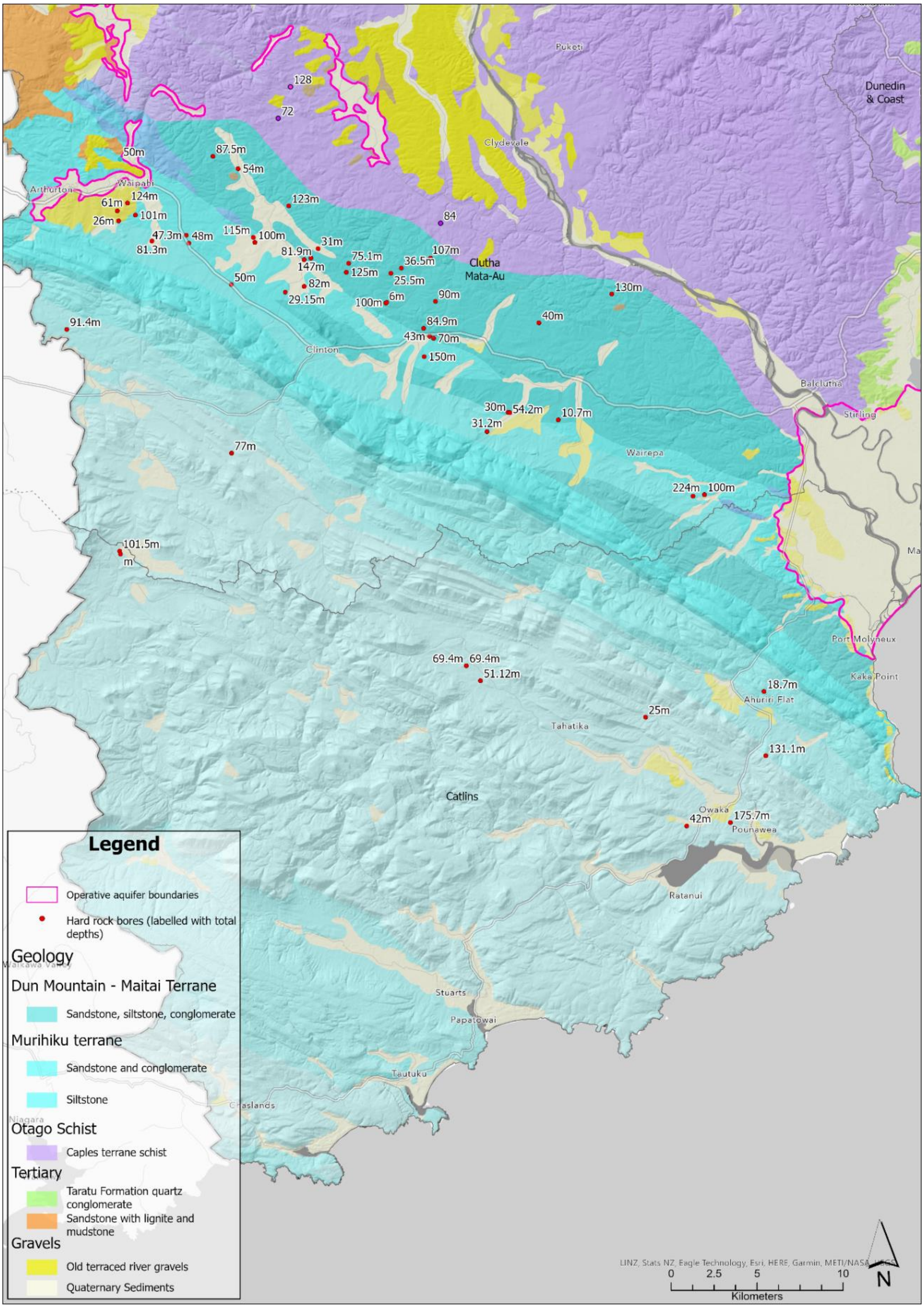

Figure 4 Figure shows the current bores and corresponding depths within the Catlins Mesozoic sequence. The Mesozoic sequences is denoted by the blue colours. There are much higher densities of bores in the upper, northern section of the Catlins area, predominately found within valley floors.